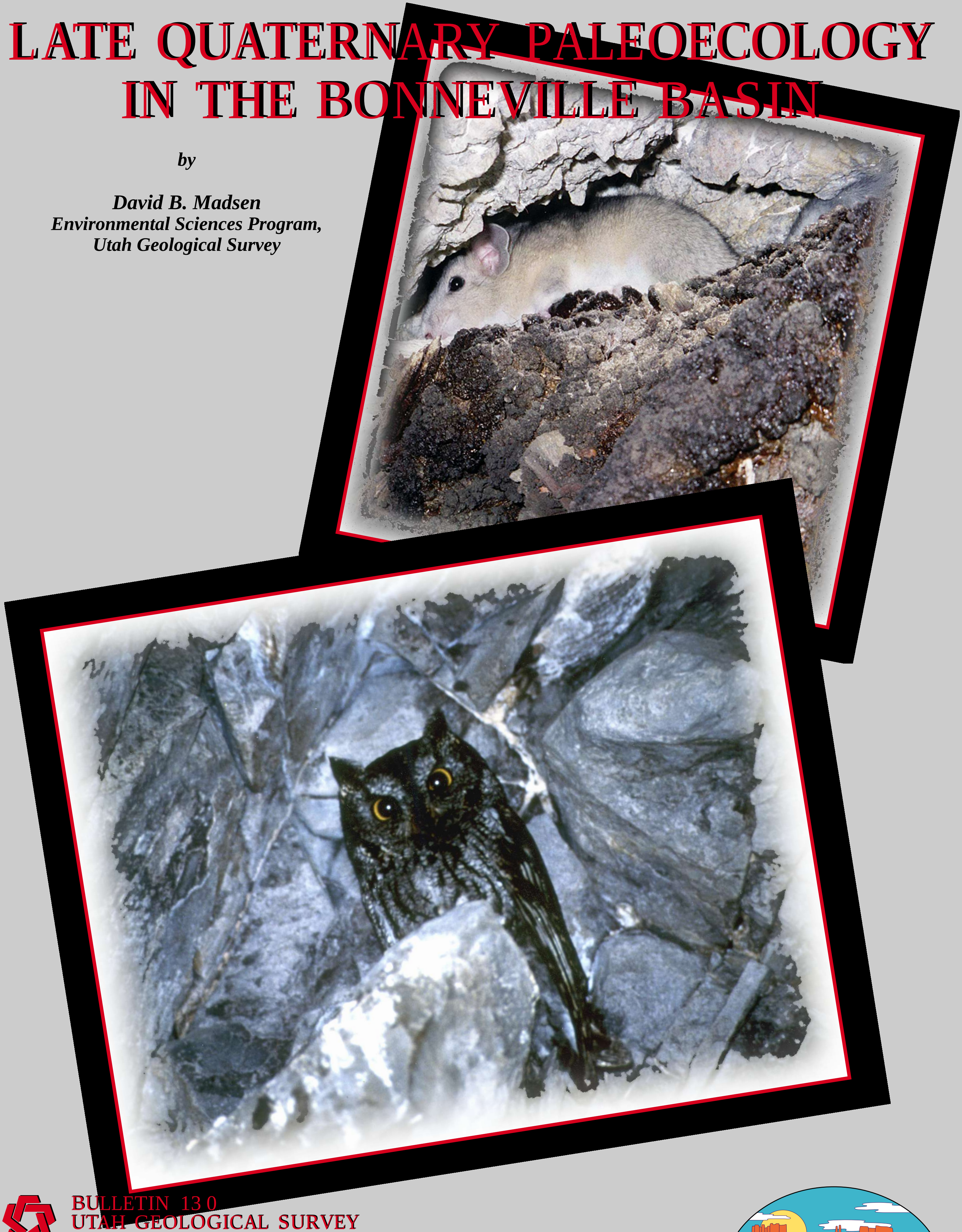
LATE QUATERNARY PALEOECOLOGY IN THE BONNEVILLE BASIN

by

David B. Madsen
Environmental Sciences Program,
Utah Geological Survey



BULLETIN 130
UTAH GEOLOGICAL SURVEY
a division of
Department of Natural Resources
2000

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Madsen

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Utah Geological Survey Bulletin 130

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David B. Madsen
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Cover photographs (Monsen Shaver and David Rhode)

Bushy-tailed woodrat (*Neotoma cinerea*) atop an indurated fossil midden
in a Bonneville basin midden locality

Western screech owl (*Otus kennicotti*) on a perch in Homestead Cave

ISBN 1-55791-648-9

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Acknowledgments

Major funding for this project was provided by the U.S. Department of Defense Legacy Program and the Environmental Directorate, Hill Air Force Base. Additional financial and institutional support was provided by the Utah Geological Survey, Utah Historical Society, Antelope Island State Park, Bureau of Land Management, University of Arizona, University of Washington, and Desert Research Institute. It is almost impossible to thank everyone involved in a project of this size, but I would like to specifically acknowledge the assistance of Marcus Blood, Vicky Clarke, David Gillette, Bryan Hockett, Peter Hovingh, Mike Hylland, Carl Limone, Mike Lowe, John Martin, Jack Oviatt, John Porcher, Suzanne Sarver, Evelyn Seelinger, Lawson Smith, Tim Smith, Robert Thompson, Dennis Weder, and Gabrielle Woodbury. I would also like to thank the Center for Disease Control, the people who filled the ice machine at the Oasis Cafe, and the forces responsible for creating the Deep Creek Range. Acknowledgments associated with specific topics are provided at the end of appropriate chapters.

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CHAPTER ONE

Introduction

BACKGROUND AND PURPOSE

The work reported here is part of an extended study of paleoenvironmental change and human adaptation in the deserts of western Utah. This research, involving both archaeological excavations and the recovery of strictly paleoecological materials, is loosely grouped under the rubric of "The Silver Island Expedition," since much of the work has been conducted in the vicinity of the Silver Island Mountains along the western margin of the Great Salt Lake Desert (Madsen, unpublished data). The paleoecological aspects of the project, presented primarily in this volume, have two separate but related purposes. First, understanding both the diversity and similarity of human adaptation through space and time is only possible within the context of the larger biotic communities of which people are a part. Since the more than 12,000-year history of people in the deserts of the eastern Great Basin (figure 1) spans a prolonged period of profound environmental change, understanding the nature of that change is critical to understanding human behavior and adaptation in the region. For that reason, much of the archaeological research conducted under the umbrella of the Silver Island Expedition and funded by the National Science Foundation, the U.S. Bureau of Land Management, the Utah Division of Water Resources, and the U.S. Department of Defense has had a significant paleoecological component geared towards clarifying the environmental context within which people act.

Second, modern ecosystems are a part of a continuum of change in terms of both composition and distribution, and understanding the nature and trajectory of that change is critical to those charged with the responsibility of managing these ecosystems in an appropriate fashion. Resource managers are managing change, not stasis, and an adequate explanation of how and why that change occurs is a necessary component of any management strategy. For that reason, much of the paleoecological research conducted as part of the Silver Island Expedition, and funded by land management agencies, has been oriented toward the definition of a detailed environmental record and the impact that human-populations have had in shaping that record.

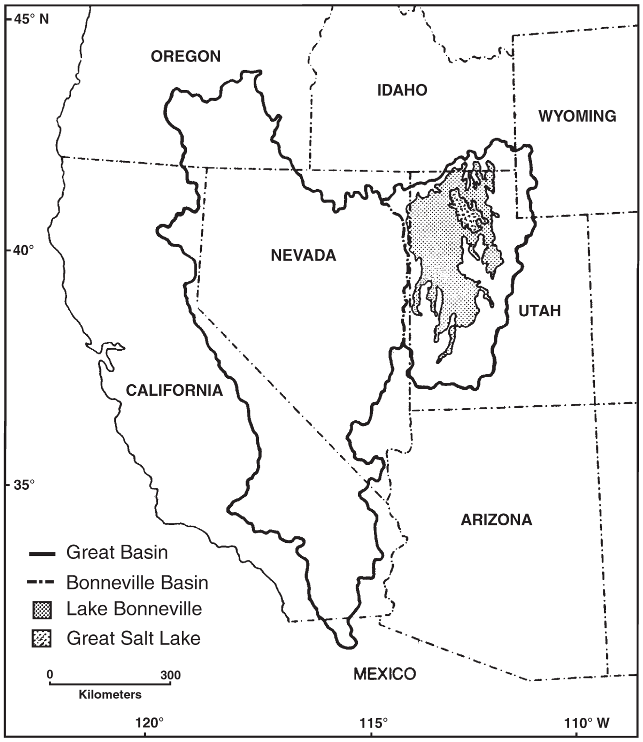

Figure 1. *Map of the western United States showing the location of the Great Basin and the Bonneville basin along its eastern margin.*

To some extent, this second research focus is a product of problems encountered as work on the archaeological aspects of the expedition progressed. That is, it became increasingly clear that the origin of biotic components at many archaeological sites, particularly cave sites, could not be readily identified, and that our inability to distinguish human from non-human floral and faunal accumulations in Great Basin caves and rockshelters created a taphonomic problem that was not easily resolved. This is a problem well known to archaeologists and paleontologists worldwide (see Binford, 1984; Stiner, 1995) and, while a variety of techniques have been developed to help distinguish cultural from non-cultural deposits (see Lyman, 1994), it still remains impossible to confidently disentangle materials transported into a cave by people and those deposited by other animals. In short, such a depositional mixture is problematic when viewed archaeologically, but this "problem" can be turned to an advantage by examining the combined deposits biogeographically, and by using the stratigraphy created by human occupation to help interpret changing environmental conditions. Viewed in this way, it has become clear that the dry stratified caves of the Bonneville basin can provide extraordinary sources of data for interdisciplinary paleoecology programs focusing on changes in small mammal populations and corresponding vegetational changes during the late Quaternary.

Initial work in the general area (Jennings, 1957; Aikens and Madsen, 1986; Grayson, 1988) has suggested that many of the limestone caves modified by Pleistocene Lake Bonneville were occupied by raptors and other carnivores immediately after the lake receded 14-15 ka. Although people began to occupy many of these same caves by 10 ka, the intermittent cultural use associated with most of these sites was not usually sufficient to dislodge the raptors and other carnivores (Marti, 1986; Andrews, 1990). Such intermittent use did, however, produce a highly stratified depositional record which allows change through time to be readily identified. For example, at Danger Cave, near Wendover, Utah on the western margin of the Bonneville basin, 108 identifiable depositional units spanning the last 13 ka have been identified (Madsen and Rhode, 1990).

These dry caves share two additional features that make them particularly useful as paleoecological laboratories. First, since they are dry, they are also home to woodrats, whose fossilized packrat nests provide clues to surrounding vegetation spanning the last 50 ka or longer (Betancourt and others, 1990). Combined with floral remains brought to the

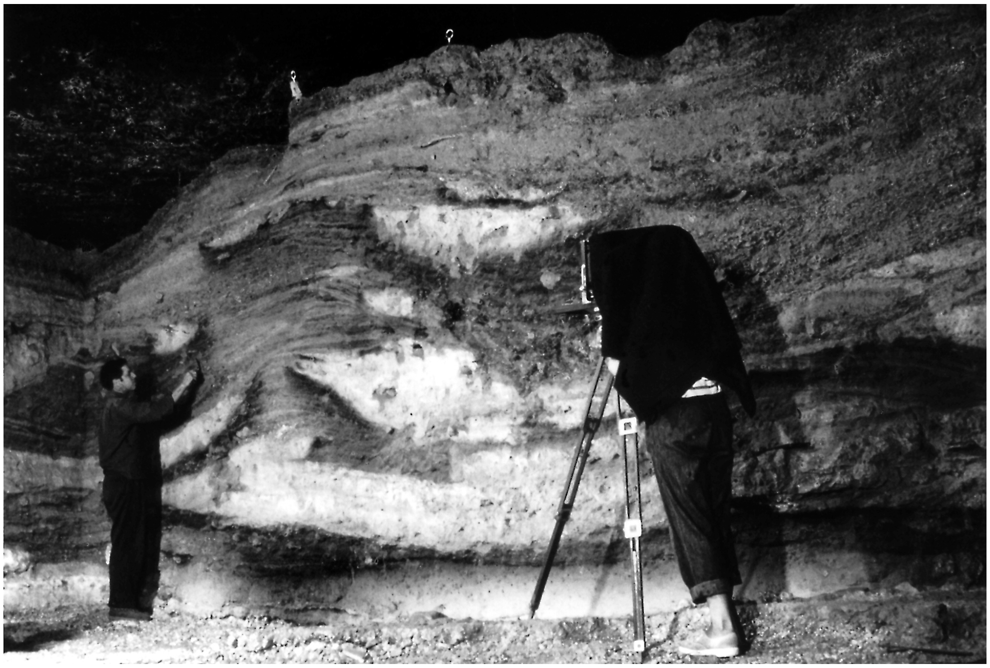

Figure 2. *View of stratified deposits at Danger Cave. Photo courtesy University of Utah, Department of Anthropology, Archaeology Center.*

caves by later human occupants, the plant record produced by these fossil nests provides the necessary background against which the small mammal record can be examined. Second, many of the western Utah mountain ranges in which these cave and fossil middens are found are completely isolated within the vast expanse of the flat salt desert. As a result, faunal records from these ranges provide a test of biogeographical theories of change in isolated animal populations (see Brown, 1971; Grayson, 1987, in press). Examination of such theories is important in understanding rates of extinction and in developing ways to deal with endangered species problems.

Small mammal remains and plant macrofossil records provide extraordinarily useful proxy data for paleoclimatic change because they can often be identified to the species level (thereby allowing the identification of specific temperature and precipitation requirements, as in Thompson and others, 1999) and because they can be recovered in samples large enough to offset factors of chance in the discovery process. Other paleoenvironmental records, such as pollen sequences (see Madsen and Currey, 1979; Spencer and others, 1984), lake level fluctuations (see Currey, 1990), and megafaunal remains (see Nelson and Madsen, 1980), are available for the area but are too generalized to allow the reconstruction of historic native habitats and the changes those habitats have undergone. Moreover, with the exception of isostatic rebound associated with the disappearance of Lake Bonneville, tectonic and geomorphic change has been limited, and any changes in floral and faunal records can be attributed directly to climatic events.

ECOSYSTEMS AND ENVIRONMENTAL CHANGE

One of the principal differences between many ecological studies of modern biological communities and paleoenvironmental studies, which often span tens of thousands of years, is the contrasting views about the validity of the ecosystem concept these synchronic and diachronic studies produce. This concept is essentially that the plants, animals (including people), and the physical setting of a particular region are formed into groups of interrelated species which, together with specific physical variables, affect and are affected by each other in such a way that they constitute a "system" that is essentially greater than the sum of its parts and which changes or develops as a whole independent of its constituent parts (Odum, 1953). This is most often a functional, static view of a current biome, but even when the elements of time and change are included, this "system" is essentially fixed. Ecosystems may be conceived and studied in various sizes, but "as long as the major components are present and operate together to achieve some sort of functional stability the entity may be considered an ecosystem" (Odum, 1953, p. 11). In this view each ecosystem responds as a whole to changing climatic conditions: pygmy woodland communities move up or downslope on western mountains together in response to long-term heating and cooling cycles, and hardwood forests move north and south through eastern North America in response to glacial advances and retreats.

This ecosystem concept was initially developed by biologists in the 1930s and has come to dominate environmental planning and land management. Yet many modern biologists are beginning to abandon the functional (as opposed to descriptive) aspects of the ecosystem concept just as it has been fully incorporated into environmental management policy (see Diamond and Case, 1986; Johnson and Mayeux, 1992; Tausch and others, 1993; Wigand and Rhode, in press). Much of this change is due to the work of paleoecologists whose studies of paleoenvironments over the course of the last 20 to 30 years have repeatedly shown that ecosystems do not exist except as conceptual constructs imposed by the ecologists who describe them (see Grayson, 1993, p. 142-143). That is not to say that many species are not interdependent nor that particular physical variables do not affect a number of plant and animal species simultaneously. Clearly, many species are interrelated, and a change in the density and/or distribution of one will affect the density and/or distribution of another. What is becoming equally clear, however, is that the composition of biological communities is not fixed and that recent, historically known communities are simply one point in a continually changing mosaic of plants and animals.

"Systems" do not change as a whole, but rather individual plant and animal species react independently to the changing physical and biological environments around them. Communities do not move up and down the mountain in response to changing climatic conditions; individual plants and animals do. Some respond quickly to such changes, some respond more slowly, and some do not respond at all. Individual components of a community die out, and others are added, and the "system" is composed of whatever happens to be present at the moment it is described. As Tausch and others (1993, p. 444) suggest:

> The ecosystem idea represents a paradigm used to synthesize principles of ecological science into a set of concepts or models to interpret the highly complex, nonlinear causal networks or developmental pathways of energy, matter, and information flows. These models of ecosystem dynamics have been largely based on assumptions of equilibrium conditions. Equilibrium conditions, however, are an artifact of the temporal and spatial scales of the observations on which they are based. From approximately 100,000 to 1.6 million years of available vegetation change data, it is apparent that today's communities are composed of species that arrived at different times, from different sources, and that had to cope with different biotic interactions. Past vegetation changes generally coincide with climate variations that records of temperature and lake level fluctuations indicate have been occurring for about 2 million years. Each combination of species, environment, and topography is in some way unique in both space and time. There is no "natural vegetation" in the common usage or interpretation of the term based on equilibrium conditions.

Examples of these changing community mosaics, virtually all derived from paleoenvironmental studies with long-term chronological components, are becoming increasingly numerous. For example, in the eastern United States and the upper Midwest, where deciduous and mixed conifer-deciduous forests now occur, a large number of pollen studies together provide the basis for mapping differential forest composition through time (see Davis, 1983; Webb and others, 1983). The changes are most pronounced during a 4000 to 5000-year transitional period at the close of the last ice age but occur throughout the period spanning the last full-glacial episode to the present. If plant communities (and the animals they support) functioned as "systems," one would expect that they would respond as a whole to changing climatic conditions. They do not. Rather, species such as oak, hickory, hemlock, pine and spruce have reacted differentially and "individualistically" to changing climatic conditions, with several major tree species taking nearly 10,000 years to reach their modern distributional configurations (figure 3). In the Midwest, this individualistic response to changing conditions resulted in the development of forest communities which seem "...anomalous in comparison with present-day forests" and which are difficult to interpret because of the "lack of modern analogues" (Webb and others, 1983, p. 159-160).

In the Great Basin, plant macrofossil studies with chronologies spanning the last 30 ka suggest that the composition of plant communities has also changed dramatically. This paleoenvironmental research is focused both on studies of fossil packrat middens (see Thompson and Mead, 1982; Spaulding, 1985; Rhode and Madsen, 1995) and on the examination of macrofossils from dry, stratified caves (see Madsen and Rhode, 1990). Together these studies indicate that not only have communities moved north and south and up and downslope in response to changing climatic conditions, but that the composition of these communities has changed dramatically. In the southern Great Basin, for example, plant communities on valley bottoms and mountain slopes were very different during both the last glacio-pluvial period and during a subsequent long transitional period compared to today's conditions, and they have no modern analog. In the Sheep Range, Joshua trees, limber pines, junipers, yucca and shadscale all co-occurred, a combination found rarely if at all in current communities (Spaulding, 1985, 1990).

These dramatic differences do not represent a simple massive but singular shift from ice-age to recent climates, but rather are a product of a continuing adjustment of individual species to changing conditions. The modern pygmy woodland forest of pinyon and juniper found over much of the western United States is a comparatively recent phenomenon. Not only has the particular species of juniper in the community changed (see Thompson, 1990), but pinyon pine, now such a dominant part of the community is an almost completely new addition. Prior to 10 ka pinyon was restricted to the Southwest and the extreme southern Great Basin. With the shift to post-glacial climatic conditions, pinyon began to migrate northward and did not reach its modern distributional configuration until about 3 ka (Thompson, 1990; Madsen and Rhode, 1990; Rhode and Madsen, 1998). Modern studies of the pinyon-juniper woodland suggest a substantial change in its distribution during the last century and a half, and it remains an open question as to how much of this change is due to continuing adjustments to climate or to massive modern human intervention such as grazing and logging (see Everett, 1987). This migration pattern suggests that the "ecosystem" at any one time was substantially different from the "ecosystem" at any other time, and that "natural" or "climax" communities do not exist except as short-term phenomena.

This is a critical concept for resource management, and Davis' account of Holocene vegetational change in the eastern United States is instructive:

> .... species of trees moved northward individualistically. Forest communities have represented fortuitous combinations of species during the Holocene. Many modern communities are very young; they include dominant species that have grown locally for only a few thousand years.... Evolutionary processes that may have adapted co-occurring species to one another have had very little time in which to take effect...extensive

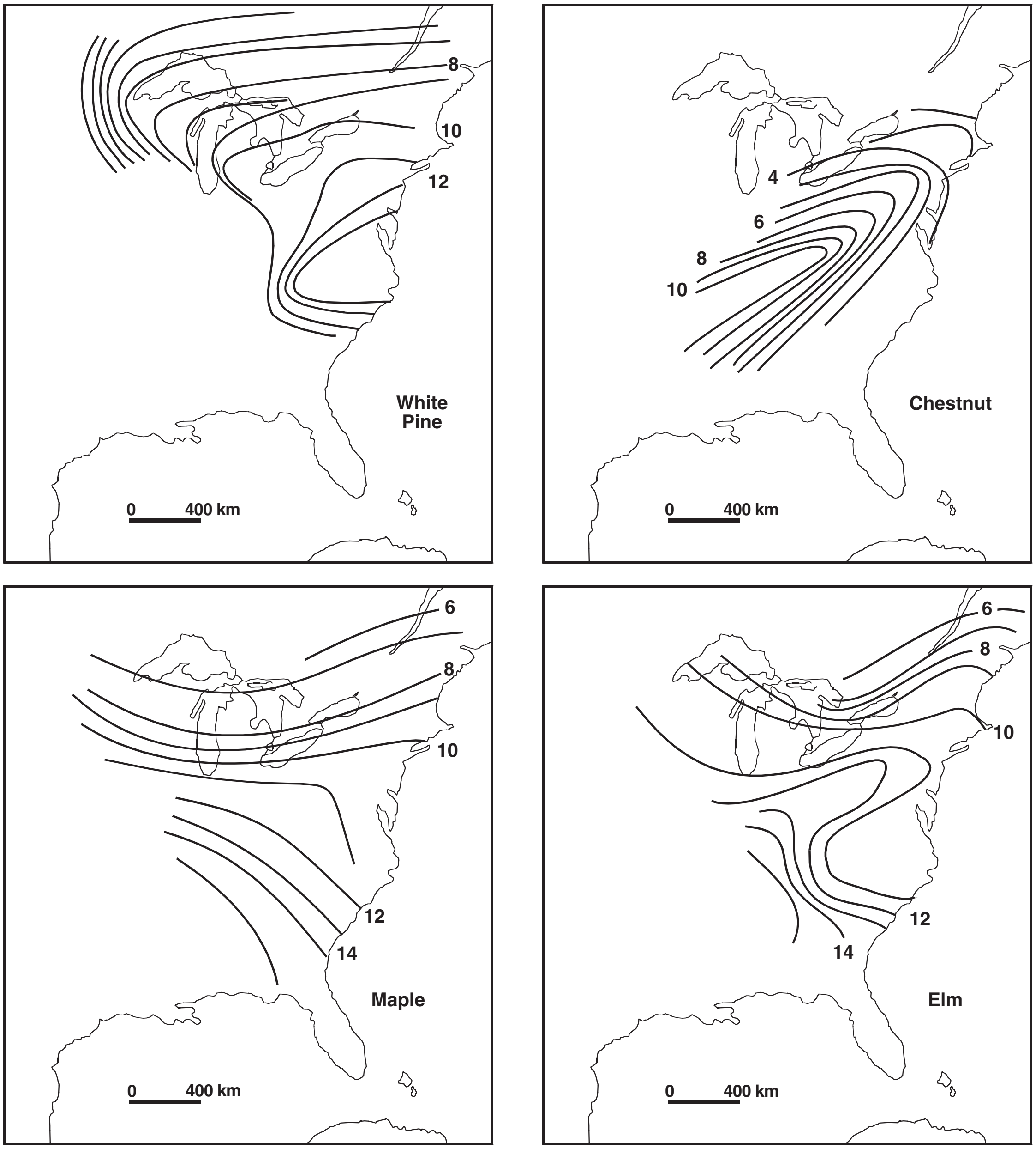

Figure 3. Schematic diagram of the Holocene migration of four tree species in the eastern United States (from Davis, 1983, p. 174). Lines represent the northernmost distribution of the species for a particular time (in thousands of years).

> contractions and expansions of species ranges occurred during each glacial-interglacial cycle, that is 16 to 18 times during the Quaternary. Chance differences in climate and geography from one interglacial to another, and loss or gain of biotypes through time, have resulted in different geographic distributions and thus different communities during each interglacial (Davis, 1983, p.173).

In short, change, not stasis, is the keystone of all environmental systems, and "ecosystems" are continually being modified in terms of both composition and distribution. As a result, the problem in environmental resource planning lies in determining the type of change that is appropriate rather than in attempting to maintain the status quo.

The paleoenvironmental changes described above take place on the order of thousands of years; geologically speaking, in the blink of an eye. To repeat Davis (with added emphasis): "many modern communities are *very young*, [they have] *grown locally for only a few thousand years*"; and, in terms of environmental change, a few thousand years really is very recent. In human terms, however, a few thousand years is well over a hundred generations long, and that time span is an order of magnitude longer than the period of time elapsed since the beginning of the Industrial Revolution. Ecological change does occur - one species replaces another, the composition of ecosystems change, and whole biomes replace one another. These changes occur at a pace that is virtually unrecognizable to the average person, however, leading to the idea that ecosystems are stable "things."

This is a problem that Magnuson (1990) refers to as the "invisible present," and its solution requires a long-term perspective available only through the acquisition of paleoecological information (see Schoonmaker and Foster, 1991). One of our major purposes here is to provide such a long-term perspective by better defining late Quaternary paleoenvironmental change in the Bonneville basin.

This view of ecosystems - as organizing constructs imposed on continuously changing biotic communities - must, however, be tempered by the time-scales used to explore that change. Throughout much of the Quaternary, for example, the pace of change has been such that the diversity of plants and animals has, for the most part, not been significantly reduced. With each slight change in climate, one species may eventually displace another geographically, but it is extremely rare that whole classes of plants and animals cease to exist. The pace of change is such that while the composition of a particular environmental landscape may change, the array of plants and animals within it more rarely (or more slowly) does. This paradox, between the stability of communities as a whole and the variability of the particular species within them, is very apparent in interpretations drawn from previous paleoecological work in the Bonneville basin.

PREVIOUS WORK

What is known of the late Quaternary paleoenvironmental history of the Bonneville basin has been drawn, for the most part, from studies of Lake Bonneville shoreline geomorphology (see Currey, 1990) and from the geochemistry of deep-water lacustrine depositional sequences (see Eardley and others, 1973; Oviatt and others, 1999). With a few important exceptions, studies of past biotic communities are limited to a few generalized pollen records. Most of these are, in turn, limited in time to the Holocene, and long-term records spanning the Quaternary are rare. For western North America as a whole, vegetational communities appear to have been relatively stable since the Pliocene (Axelrod and Bailey, 1969; Axelrod, 1976; Wolfe, 1981). More recently reported, long-term pollen records from in or near the Bonneville basin confirm this early assessment (see Davis, 1997; Thompson, 1992b; Thompson and others, 1995). Deep cores from the Great Salt Lake suggest that "vegetation indistinguishable from modern types of the western U.S.A. has existed in the Great Salt Lake basin for the last 4 million years" (Davis and Moutoux, 1998). To some extent, however, this apparent stability may be a product of the generalized nature of pollen records (particularly from lakes at the end of large drainage basins) and the limited number of taxa that can be identified to the species level. After about 900 ka there is a change to steppe-like vegetation characterized by an increase in pine and sagebrush pollen which is associated with the onset of pluvial oscillations in the basin.

Biotic conditions in the Great Salt Lake basin are better known for the Lake Bonneville pluvial cycle spanning 30-12 ka, but still remain rather generalized in comparison to Holocene records (Wigand and Rhode, in press). Pollen in a short core from Great Salt Lake provides a somewhat more detailed record, particularly in terms of chronology, and species-level data are available from fossil woodrat middens along the southern edge of the Bonneville basin. Isolated finds of Pleistocene megafauna in Bonneville and Provo-level shoreline deposits provide some estimate of large herbivore communities and associated predators. The most comprehensive pollen record comes from a 5-meter core collected from Great Salt Lake (Spencer and others, 1984), although less detailed late Pleistocene pollen records are also available for the lake (see Martin and Mehringer, 1965; Mehringer, 1977, 1985). Absolute and relative percent pollen counts from the core, redated by Thompson and others (1990), show an almost total dominance of coniferous pollen (figure 4). Sagebrush (*Artemisia* spp.) is also well represented in the absolute pollen count, and it is probable that the relatively dense forest cover suggested by the conifer pollen was restricted to the higher and more massive Wasatch Range and Uinta Mountains east of the lake, with more open cold-steppe vegetation found at least at lower elevations in the central and western basin. This period of extensive conif-

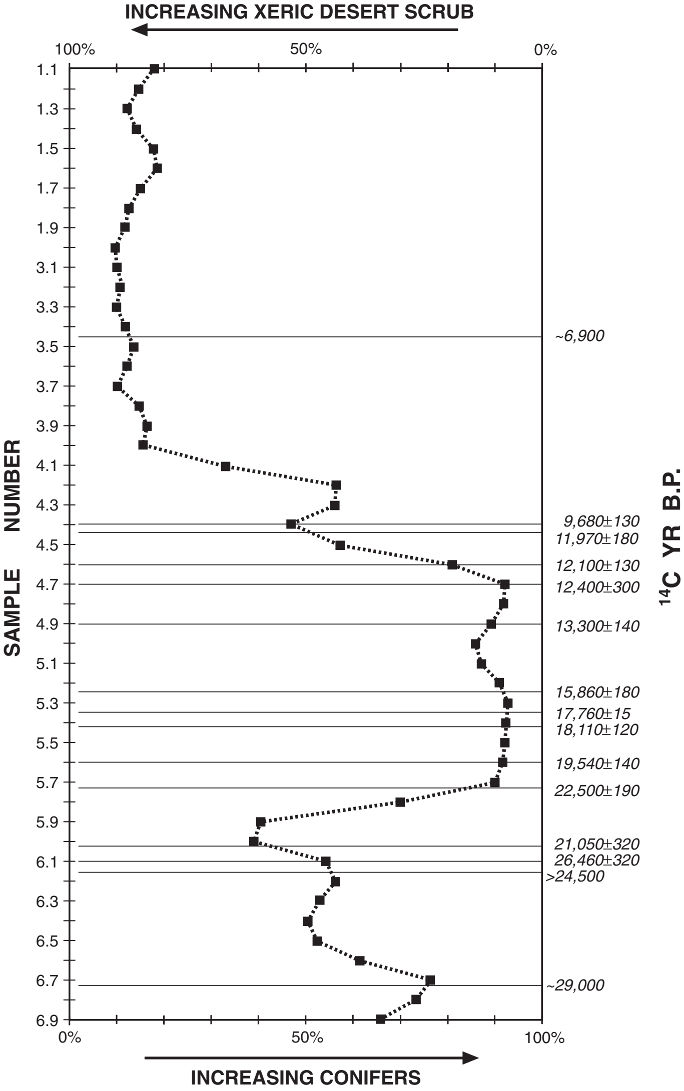

Figure 4. *Relative proportion of conifers (C =* Abies+Picea+Pinus+Pseudotsuga*) to xeric desert scrub (D = Chenopodiacae-*Amaranthus+*Sar*cobatus+*Ambrosia-type Compositae) during the last 30,000 years. Curve (C/C+D) is smoothed by a weighted three-level moving average. The curve is derived from absolute pollen counts of samples from a 5-meter-long core of latest Great Salt Lake basin deposits (Madsen and Kay, 1982; Spencer and others, 1984). Temporal controls are from Thompson and others (1990).*

erous forest lasts from ~22 to ~12 ka and extends several thousand years before and after the lake approached its maximum elevation. Between ~12 and ~8 ka conifer pollen is gradually replaced by pollen of a xeric desert scrub community including greasewood (*Sarcobatus* spp.) and shadscale (*Atriplex* spp.). The dominance of these playa margin communities probably reflects both the exposure of valley floor habitats and a reduction in the contribution, via stream flow, of pollen from the eastern mountains.

Plant macrofossils from fossil woodrat nests collected in the Confusion, Wah Wah, and Snake ranges along the southwestern margin of the Bonneville basin are available for at least the latter part of this period (Wells, 1983; Thompson, 1984, 1990). In the Snake Range, a limited number of pluvial-age middens is dominated by spruce (*Picea* spp.), prostrate juniper (*Juniperus communis*) and mesic shrubs such as buffaloberry (*Shepherdia* sp.) (Thompson, 1984). Limber pine (*Pinus flexilis*) and Douglas fir (*Pseudotsuga menziesii*) apparently began to expand through the region during the late pluvial, sometime after ~14 ka. Limber pine, prostrate juniper, mountain mahogany (*Cercocarpus* spp.) and a variety of mesic shrubs remain at depressed elevations (although often in cold-air drainages) throughout an early Holocene transitional period that lasted until about 7.5 ka.

A limited array of large mammals is known from deposits of the last lake cycle in the vicinity of Great Salt Lake (Nelson and Madsen, 1980, 1987; Heaton, 1990; Jefferson and others, 1994). By far the most common specimens are those representing mountain sheep (*Ovis canadensis*), musk ox (*Bootherium/Symbos* spp.) and mammoth (*Mammuthus columbi*). Together these three species constitute more than 90% of the large herbivore specimens known from around the lake (table I). Camel (*Camelops* sp.), horse (*Equus* sp.), American bison (*Bison* sp.) and mastodont (*Mammut* sp.) are present in limited quantities. Peccary (*Platygonus compressus*) and ground sloth (*Megalonyx jeffersonii*) are represented by single individuals. Large predators are missing from the Lake Bonneville sequence for the most part, although a single gray wolf (*Canis lupus*) has been identified, and omnivores such as the giant short-faced bear (*Arctodus simus*) and black bear (*Ursus americanus*) are present.

Table I

Large vertebrates (>30 kg) of Lake Bonneville age (~20-10 ka) in the Great Salt Lake basin. Number of individuals is shown in parentheses.

Bootherium spp. [Musk ox] (34+)
Ovis canadensis [Mountain sheep] (24+)
Mammuthus columbi [Columbian mammoth] (21+)
Camelops hesternus [Yesterday's camel] (5)
Equus sp. [Horse] (5)
Bison bison cf. *antiquus* [American bison] (3)
Arctodus simus [Short-faced bear] (2)
Mammut americanum [American mastodont] (2)
Vulpes vulpes [Red fox] (2)
Canis lupus [Gray wolf] (1)
Megalonyx jeffersonii [Jefferson's ground sloth] (1)
Navahoceros cf. *fricki* [Mountain deer] (1)
Odocoilus hemionus [Mule dear] (1)
Platygonus compressus [Flat-headed peccary] (1)
Ursus americanus [Black bear] (1)

Biotic conditions during the Holocene are known primarily from a variety of pollen sequences at montane situations on the Great Salt Lake basin margins (see Mehringer and others, 1971; Madsen and Currey, 1979; Davis, 1984), from pollen sequences at valley floor marsh and lake settings (see Bright, 1966; Mehringer, 1977, 1985; Thompson, 1992a), and from faunal and plant macrofossil records at lake margin cave sites (see Harper and Alder, 1970, 1972; Grayson, 1988; Madsen and Rhode, 1990). Together these records suggest that until ~8 ka conditions were slightly cooler and possibly more mesic than at present (figure 5), and that the lower montane and foothill zone now covered with pinyon/juniper woodlands was largely an open, brushy steppe. By ~10 ka limber pine woodlands had disappeared from these zones, but single-leaf pinyon (*Pinus monophylla*) and Utah juniper (*Juniperus osteosperma*) were largely absent until 7-8 ka (Mehringer, 1986; Thompson, 1990; Madsen and Rhode, 1990; Rhode and Madsen, 1998). By 7 ka, the composition and distribution of modern biotic communities was basically established, although changes in the proportions and ecotone elevations continued to occur. At lower

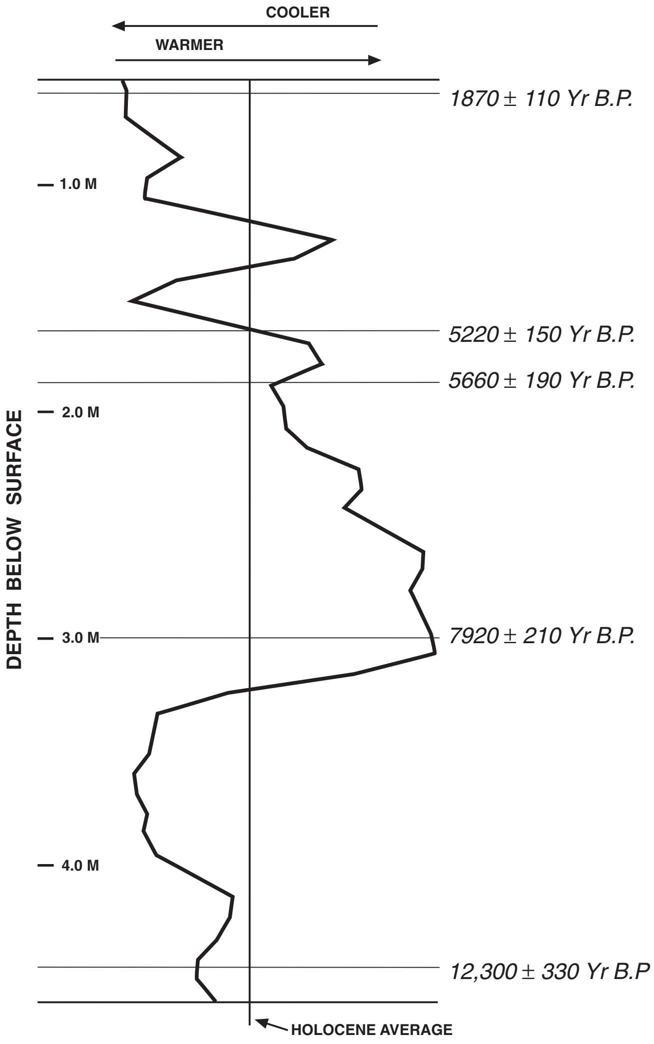

Figure 5. *Estimate of Holocene temperature change in the Great Salt Lake basin based on changes in the relative proportion of conifer pollen to all other pollen at Snowbird Bog, Little Cottonwood Canyon, Wasatch Range, Utah. The curve is smoothed by a weighted three-level moving average. Modified from Madsen and Currey (1979).*

elevations shadscale began to dominate more thoroughly as sagebrush communities moved higher up on foothill slopes (Thompson, 1990). At higher elevations tree lines moved upslope above modern elevations during the mid-Holocene (Bright, 1966; LaMarche and Mooney,1972) and downslope below modern elevations in the late Holocene (Bright, 1966; Madsen, 1984), possibly corresponding to neoglacial events in the Rocky Mountains. The relative proportion of conifers within these forest communities has also changed substantially during the late Holocene (see Madsen and Currey, 1979).

RESEARCH STRATEGY

The central component of our initial research strategy was to examine a variety of locations in the western margin of the Great Salt Lake basin, select a suitable dry cave site in one of these isolated ranges, and collect a 1-square-meter sample column from the deposits. Our intention was to describe the stratigraphy of the selected cave and photograph and map it in detail. Individual stratigraphic units were to be removed in total, bagged, and taken to the laboratory for sorting, detailed examination, and dating by a variety of means. We planned to obtain multiple dates on individual depositional units in order to maximize chronological control. We intended to retrieve several kinds of data from this column. First, and most importantly, we expected to retrieve a large collection of small bones (including mammals, birds and reptiles) derived from raptor pellets. Raptors provide a relatively comprehensive sample of small vertebrates from a very local area (see Marti, 1986), and bones from stratified raptor deposits can provide a relatively detailed proxy record of changing environmental conditions. Second, we expected to retrieve cultural materials, particularly in the upper strata, related to the occupation of the area by hunter-gatherers who visited these caves intermittently (see Aikens and Madsen, 1986). This would allow us to relate change in local flora and fauna to cultural change in the area. Third, we hoped to obtain a vegetational record from the column that could supplement the faunal record. We hoped to employ both plant macrofossils and pollen in defining this floral record and to use that information to assist in reconstruction of plant biogeography and climatic change.

Another major component of our research strategy was to search out, collect, date and identify the components of fossil woodrat middens from the western Great Salt Lake basin. Fossil packrat middens are composed of plant fragments, fecal pellets, pebble-sized rocks, bone and other debris. This indurated mass of material is often encased in crystallized urine (termed "amberat") which makes it resistant to destruction and erosion and preserves it for thousands of years (Betancourt and others, 1990). Middens in excess of 50,000 years old have been reported. Woodrats (*Neotoma* spp.) collect 40-80% of all plants (depending on the number of middens examined) within a 15-ha area around their nests (Dial and Czaplewski, 1990), and the vegetation in the middens, while biased towards woody species (Frase and Sera, 1993), represents a relatively complete record of very local vegetation. These midden records are essentially point samples in both space and time and, consequently, a large library of such records is required in order to identify regional environmental change. We expected to collect and date 30 to 50 middens from the study area to offset this disadvantage. On the other hand, the singular advantage midden records have over pollen records (the other principal source of long-term vegetational data) is that individual species can be identified and specific climatic constraints can be defined (see Thompson

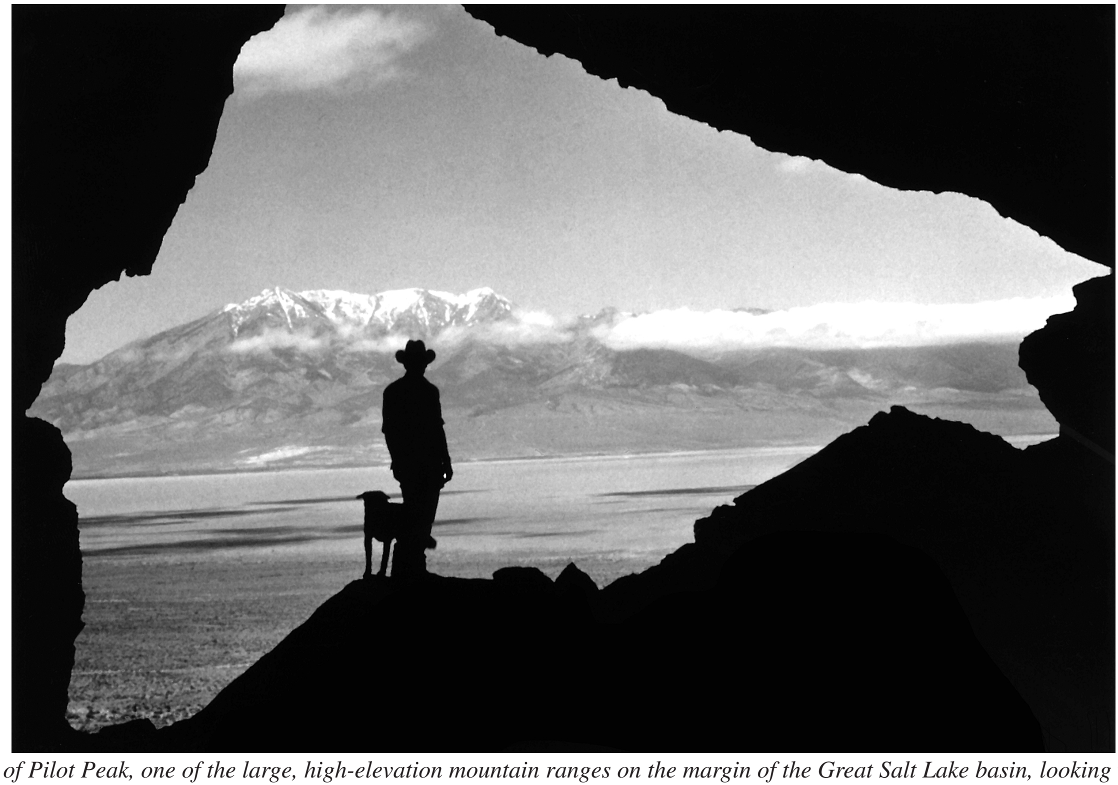

Figure 6. *View of Pilot Peak, one of the large, high-elevation mountain ranges on the margin of the Great Salt Lake basin, looking west from a cave in the Silver Island Mountains, one of the small, low-elevation ranges in the basin interior.*

and others, 1999).

Woodrat middens have not previously been reported from the Great Salt Lake basin; the nearest record is from Granite Creek Canyon on the eastern flank of the Deep Creek Range (Thompson, 1990). Extant midden records from the southern Bonneville basin are primarily from the higher and more massive mountain ranges on the basin margins and may be biased in terms of the overall distribution of plant communities. We hoped to eliminate this bias by structuring our search to include smaller, low-elevation interior mountain ranges such as Granite Peak and the Silver Island Mountains, and larger, high-elevation ranges such as the Stansbury Mountains, Pilot Range, and Deep Creek Range (figure 6). Middens from such diverse settings should allow us to detect differential migration into the region of recent additions to local communities such as pinyon and ephedra.

In addition to these two major components, we expected to conduct a number of ancillary studies to help interpret the faunal and floral record. First, we planned to trap and identify small mammal populations in the vicinity of the selected cave to provide a modern standard against which to evaluate late Quaternary change in the faunal assemblage. Similar plant records and collections were to be made in the vicinity of each fossil midden that was collected. Second, we intended to examine other geomorphological features near the cave, such as the banks of dry stream beds, in an effort to identify Pleistocene megafauna which may be present. Third, we hoped to explore a variety of geochemical sequences through the length of the sample column, such as strontium ratios (see Quade and others, 1997) and hydrogen isotope ratios (see Friedman and Gleason, 1980). Finally, a variety of additional biotic components ranging from gastropods to fecal pellets could occur in the sample column. We planned to investigate these components in detail if they occurred consistently enough and in high enough frequency to act as sources of climatic proxy data.

CHAPTER TWO

Setting

GEOLOGY OF THE GREAT SALT LAKE BASIN

The Great Salt Lake basin is the northernmost of three major hydrological subbasins in the Bonneville basin, which is the easternmost major drainage basin in the Great Basin. The Great Basin can be defined in a variety of ways, and there are a number of competing hydrographic, physiographic and floristic definitions (see Grayson, 1993). The Bonneville basin is part of the Basin and Range Province (see Hunt, 1967) and like the Great Basin itself can be defined both hydrologically (see Gilbert, 1890) and physiographically. The fault-block mountains which characterize the province (Gilbert, 1928) began forming during the late Tertiary ~15 million years ago (Miller, 1991). Ongoing crustal extension has created a series of north-south-trending fault-block mountains separated by long, narrow graben and half-graben valleys filled with Tertiary strata and Quaternary alluvium (Atwater, 1970; Zoback and others, 1981; Miller, 1991). In the Great Salt Lake basin, the Raft River Mountains, Pilot Range and Deep Creek Range (which reach ~3600 m) constrain the basin on the northwest and west, while the larger and more massive Wasatch Range bounds it on the east and forms the eastern margin of the Great Basin as well (figure 7). Major fault-block mountains within the Great Salt Lake basin include the Oquirrh, Stansbury, Promontory, Grouse Creek and Cedar Mountains. The Lakeside, Silver Island, Terrace/Hogup, Newfoundland, Fish Springs, Simpson and Dugway ranges are smaller in both area and elevation, and a host of even smaller ranges is scattered throughout the basin.

In the eastern part of the Great Salt Lake basin, many of these smaller mountain ranges consist primarily of Mississippian, Pennsylvanian and Permian strata (Doelling, 1980; Hintze, 1988). In the west, most bedrock outcrops are Cambrian through Devonian carbonate rocks, although older quartzite and younger limestone formations occur as well. Igneous intrusive rocks are present in a number of locations; a major granite intrusive is present in the Deep Creek Range. Tertiary volcanics are scattered along the western margin of the Great Salt Lake basin and a major source of obsidian occurs on Topaz Mountain on the southern edge of the Great Salt Lake Desert.

In the northern Lakeside Mountains in the vicinity of Homestead Cave, the major exposures are Mississippian through Permian limestones, although a fault-block wedge of Cambrian through Devonian strata occurs in the Salley Mountain area (Doelling, 1964, 1980; Hintze, 1988). These major exposures include the Cambrian Nounan and St. Charles Formations; the Ordovician Garden City, Swan Peak and Fish Haven Formations; the Silurian Laketown Dolomite; and the Devonian Water Canyon, Simonson and Guilmette Formations. The largest exposures, by far, are Mississippian limestones which form parallel, north-northeast-trending, cliff-forming ridges. These are comprised almost entirely of Great Blue Limestone, although small exposures of the Madison Limestone, Deseret Limestone and Humbug Formation occur as well. The Great Blue Limestone is characterized by ubiquitous horn corals, crinoids and brachiopods.

Homestead Knoll (renamed from Gosiute Mountain in 1970) is part of the Gosiute syncline and contains the only Pennsylvanian-age rock exposed in the northern Lakeside Mountains. These are units 1 and 2 of the Oquirrh Formation (Doelling, 1964). Unit 2 consists of a resistant silty and sandy limestone and buff, calcareous sandstone which forms cliffs approaching 100 m in height. Chert is very common within the formation. Underlying unit 1 is unit 2 in which Homestead Cave is formed. It is a very thick to thick-bedded gray limestone. Fossils are not well identified, but are primarily crinoids and brachiopods. Bedding is almost vertical in the vicinity of Homestead Cave, and strikes 31° east.

QUATERNARY FEATURES

Geomorphology below elevations of 1700 m in the Great Salt Lake basin is primarily the result of the late Quaternary rise and fall of Lake Bonneville during Isotope Stage 2. Although closed-basin lakes have occupied the basin for at least the last two million years (Morrison, 1991; Machette and others, 1992), geomorphological features produced by these lakes are generally limited to valley floor lacustrine deposits. With rare exceptions (see Morrison, 1965; Scott and Shroba, 1985; Oviatt, 1988a), the alluvial and shoreline features are primarily associated with the Bonneville lake cycle and were formed in the last 30,000 years (figure 8). Eardley and others (1973) recognized 28 cycles of lake formation and desiccation in cores from Great Salt Lake spanning the last 8-900,000 years. Later work (Scott and others, 1983; McCoy, 1987; Oviatt and others, 1987; Machette and others, 1992) suggests that two major lake cycles, the Little Valley (~130-160 ka) and Cutler Dam (~60-75 ka), may correspond to Isotope Stages 6 and 4, respectively. Oviatt and others (1999) reexamined the Burmester core and identified only 4 (as opposed to 28) deep-lake cycles apparently correlating with marine oxygen Istotope Stages 2, 6, 12, and 16.

The age of the Cutler Dam lake cycle is poorly controlled since it exceeds the radiocarbon-datable time-scale (all ages within the radiocarbon time-scale are in radiocarbon years unless otherwise noted). Oviatt and others (1987) provide a limiting radiocarbon age estimate of >36,000 years. McCalpin (1986) obtained thermoluminescence age estimates of 76 and 82 ka for the probably contemporaneous Hansel Valley lake cycle (see also McCalpin and others, 1992). In the Salt Lake Valley, Keaton and others (1987) reported amino acid racemization age estimates of 45-80 ka for the Cutler Dam cycle, but suggest that it had ended by about 58 ka. Taking these age estimates together, Machette and others (1992) suggested an age of 60-75 ka for this penultimate lake cycle in the Bonneville basin. These dates should be considered tentative, however.

Sometime before about 35 ka, the Bear River was diverted from the Snake River drainage system into the Bonneville basin by lava flows in southern Idaho (Bright, 1967).

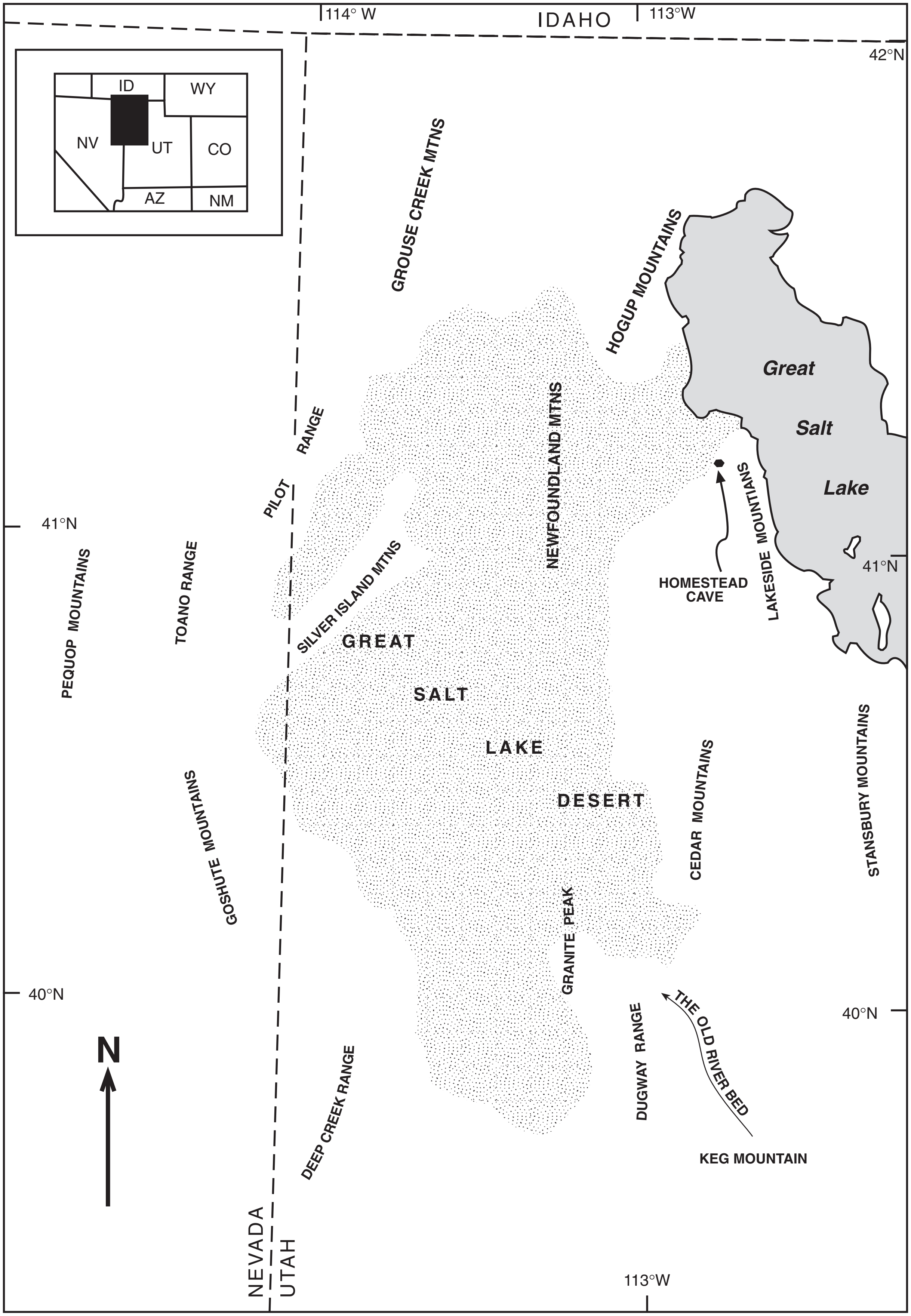

Figure 7. Major geomorphic features in the western part of the Great Salt Lake basin.

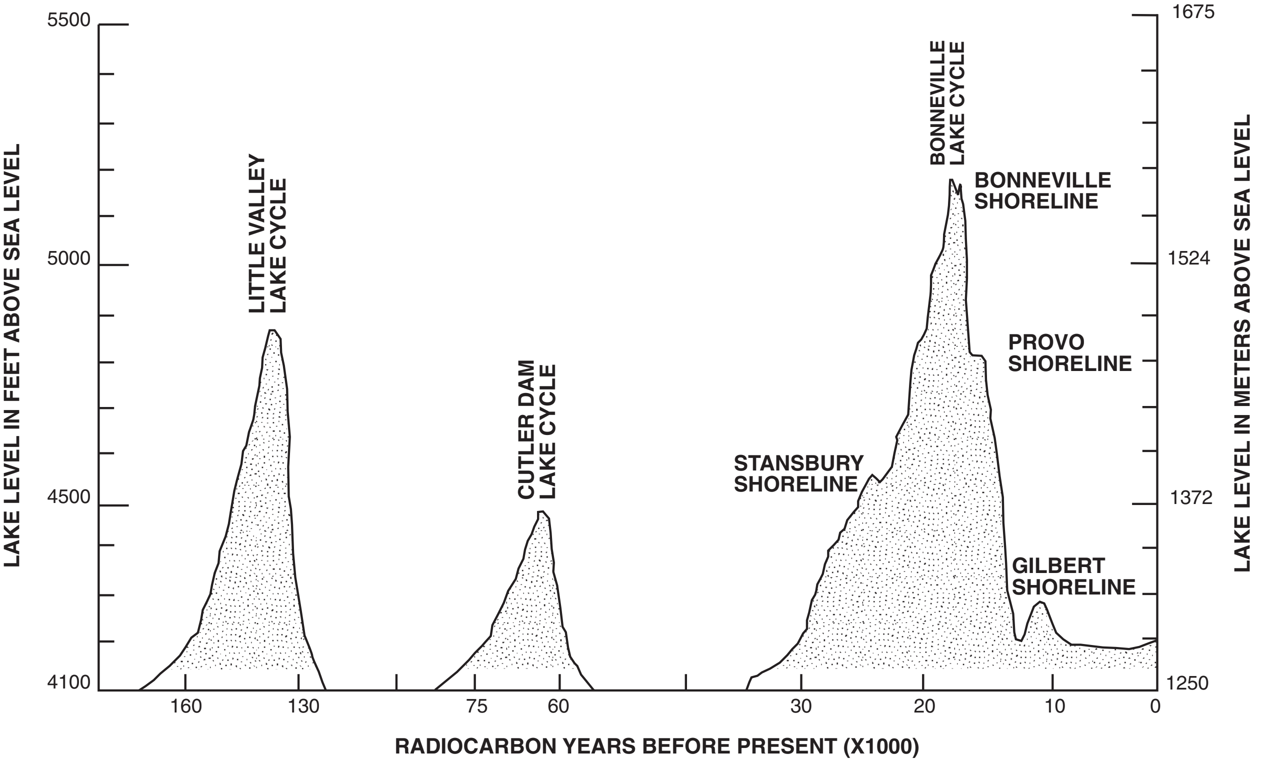

Figure 8. *Schematic diagram of probable lake levels in the Great Salt Lake basin during the last 200 ka. Modified from Machette and others (1992, p. 9, figure 2); note breaks in temporal scale.*

Bouchard and others (1998) suggested that this likely occurred ~50 ka. The Bear River currently contributes a third to half of all surface runoff to modern Great Salt Lake, and its addition to the Bonneville basin drainage system significantly altered the nature of subsequent lake-level fluctuations. The transgressive phase of the Lake Bonneville cycle probably began about 30 ka (Oviatt and others, 1992), and consisted of a 10,000 to 15,000-year period of oscillating, but generally rising lake cycles peaking at the Bonneville level about 15.3-15.0 ka. This general trend was interrupted by a climatically controlled stillstand which formed the Stansbury shoreline complex, and a ~45 m lake-level regression (Currey and Oviatt, 1985; Oviatt and others, 1992). The oldest shoreline features are poorly dated but were probably formed sometime about 22 ka. The subsequent Stansbury regression is dated to sometime between 22-20 ka by Oviatt and others (1992).

The Stansbury shoreline complex on the northern Lakeside Mountains has not been studied in detail but occurs at an elevation of ~1360-1405 m. At the top of this shoreline complex, the Lakeside Mountains are connected to the Cedar Mountains to the south by a low tombolo. After the Stansbury oscillation, the range became an increasingly smaller island as the lake rose to its highest levels. Lake levels did not again fall below this elevation until after ~12.5 ka, so the Lakeside Mountains remained in biotic isolation for approximately 9000 years.

The continued rise of Lake Bonneville over the course of the next 6000 years was probably interrupted by a number of minor climatically induced oscillations, but these are poorly represented in shoreline features (but see Oviatt, 1997). These inferred stillstands may be associated with threshold elevations between subbasins of the Bonneville basin, and are the result of the lake being maintained at a relatively stable elevation as these drier subbasins were filled (Currey and Burr, 1988). Two of the more prominent of these stillstands may be represented by beaches carved as the lake filled the Tule Valley subbasin about 19.5 ka and the Cedar Valley subbasin shortly after about 18 ka (Currey and Oviatt, 1985). Sack (1999) suggests that a transgressive-phase oscillation near the elevation of the regressive-phase Provo shoreline may have occurred during this period.

About 15 ka, the lake reached the Zenda threshold in southern Idaho and began to overflow into the Snake/Columbia river drainage (Oviatt and others, 1992). The formation of Bonneville-level shoreline features at this threshold elevation may have been interrupted by the climatically controlled Keg Mountain oscillation (Currey and Oviatt, 1985; Oviatt and others, 1992), but overflow resumed until catastrophic downcutting at Red Rock Pass about 14.5 ka lowered the level of the lake 108 m in less than a year (Currey and Oviatt, 1985; Jarrett and Malde, 1987; Oviatt and others, 1992), and possibly in less than two months at the maximum estimated flow rate (O'Conner, 1993). This threshold-controlled Provo-level lake elevation was maintained until after about 14.0 ka when the lake began to enter a regressive phase that continued, with some major interruptions, for the next 7000 years (Currey, 1990; Oviatt and others, 1992).

In the northern Lakeside Mountains, the Bonneville and Provo shorelines and related deposits are at elevations of ~1625 m and ~1501 m, respectively (Currey, 1982). The top of the single ridge connecting Homestead Knoll to the rest of the Lakeside Mountains is ~20 m below the Provo shoreline. Since the transgressive shoreline associated with the Tule Valley threshold is only about 11 m below the Provo level

(Currey and Oviatt, 1985), it appears that Homestead Knoll became separated from the rest of Lakeside Island sometime shortly before 19.5 ka and remained separated for at least 4500 years. At the highest levels of Lake Bonneville, Homestead Knoll was almost completely covered by lake waters and Lakeside Island was reduced to a small 1 x 5 km outcrop on what is now known as Salley Mountain. This island probably was exposed bedrock with poorly developed soils and limited vegetation.

The post-Provo chronology of the Lake Bonneville regressive phase is poorly known, and the rapidity and extent of lake-level decline is a matter of debate (Rhode and Madsen, 1995; Light, 1996). Regressive shorelines are poorly marked, probably because they are more often erosional rather than depositional features. Numerous sequential post-Provo shoreline features mark the northwest-facing slopes of large interior island/mountain ranges, such as Stansbury and Antelope Islands, where large fetch distances allowed wave action to more effectively erode unconsolidated materials. The northwest margin of the Lakeside Mountains is no exception and is marked by an array of minor beaches. Because these shorelines were occupied relatively briefly, they are difficult to correlate across differentially rebounded areas of the Great Salt Lake basin and remain unnamed and unmapped.

Sometime between 13 and 11 ka Lake Bonneville levels fell to elevations approaching those of modern Great Salt Lake (all ages discussed here are radiocarbon years unless otherwise noted). Data from adjacent lake basins (see Currey, Oviatt and Czarnomski, 1984) and from the Old River Bed connecting the Sevier and Great Salt Lake basins (Oviatt, 1987, 1988b) suggest that this did not occur until sometime after ~12 ka. Because the floor of the basin was not completely rebounded, however, it is likely that the surface area was much greater and the lake probably extended well out into what is now the Great Salt Lake Desert. After 11 ka the lake may have increased in size once again and between 10.9-10.3 ka formed the Gilbert shoreline complex (Currey, 1990; Oviatt and others, 1992; but see Zachary and Oviatt, 1999). This transitional Pleistocene/Holocene lake cycle may be related to the Younger Dryas climatic event evident throughout the Northern Hemisphere (Benson and others, 1992). In the northern Lakeside Mountains, the Gilbert shoreline (Currey, 1982) occurs at an elevation of ~1311 m, about 27 m above the modern playa floor of 1284 m. Immediately below Homestead Cave, the lake at this Holocene high level formed a shallow embayment (figure 9). During the Gilbert cycle, a small, possibly ephemeral, stream draining most of the western margin of the northern Lakeside Mountains emptied into this bay.

The early Holocene history of Great Salt Lake is poorly controlled by shoreline data. These are poorly dated and precise elevations are unknown (Murchison, 1989a; Currey, 1990; Benson and others, 1992). Core data from the lake (Spencer and others, 1984; Thompson and others, 1990) are also difficult to interpret for this period. Sometime after ~10 ka, the lake apparently retreated to levels below 1287 m and fluctuated within a 10 m range below this point throughout the remainder of the Holocene. Environmental data from locations around the Bonneville basin indicating slightly cooler than average early Holocene temperatures (see Madsen and Currey, 1979; Madsen, 1985a; Thompson and others, 1990) suggest the lake may have fluctuated at the higher end of this envelope until after about 8 ka. During this period, the lake may have stabilized at an elevation of 1289-1292 m long enough to form a poorly recognized beach (Currey,

Figure 9. *View of Gilbert-level embayment below Homestead Cave.*

Atwood, and Mabey 1984; Murchison, 1989a). At this elevation, the lake would have flooded much of the Great Salt Lake Desert, but since the central part of the basin in the vicinity of the Lakeside Mountains continued to rebound well into the early Holocene and the Eardley threshold did not exist (Currey, 1980), it is likely that lake waters extended around the Lakeside Mountains and inundated the playa between Homestead Knoll and the Newfoundland Mountains to the west even during lowstands.

Desiccation polygons below the current level of Great Salt Lake suggest that the lake reached its late Quaternary low sometime during the middle Holocene (Currey, 1980). However, the creation of these polygons is not controlled chronologically, and it has also been suggested that they formed during the pre-Gilbert low phase (see Currey, 1990). Current interpretations, outlined above, favor the mid-Holocene scenario. During the late Holocene, the lake transgressed to a highstand of 1287 m and flooded the Great Salt Lake Desert to the Utah/Nevada border (figure 10). Core data (see McKenzie and Eberlie, 1987; Mehringer, 1985) suggest this occurred between about 2 to 3 ka and may be related to the Neoglacial interval (Currey, 1990). Lake-level fluctuations over the last 2000 years have been within the 1277-1284 m range of the historical record for the most part. A single high-lake cycle overtopped the Eardley threshold by less than a meter during the "Little Ice Age" ~250 years ago (Currey, 1980).

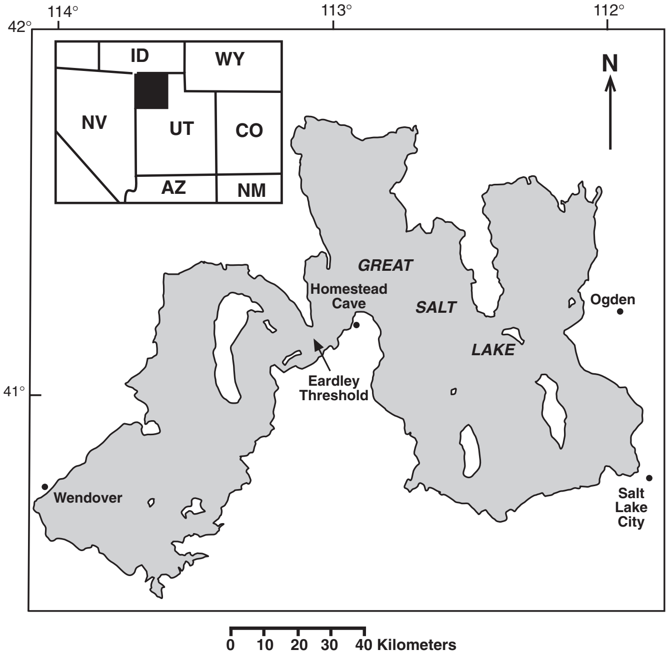

Figure 10. Maximum extent of Great Salt Lake during the Holocene highstand. Modified from Currey (1990, p. 209, figure 19).

NEOTECTONICS

The reconstruction of lake-level history and associated paleoenvironmental changes is complicated by both crustal deformation caused by the weight of lake waters and ongoing extension related to the formation of the Great Basin. Isostatic deformation of the basin floor was first identified by G. K. Gilbert (1890), who recognized that differences in elevations of the same shoreline were a product of the load removed as the lake regressed. Gilbert also recognized that these differential elevations formed a dome and that with a planar water surface the center of the basin must necessarily have been depressed. He determined that the area of highest rebound (measured by him to be as great as 55 m) was located just west of Great Salt Lake. While this interpretation was questioned by Eardley and others (1957) and Heylmun (1960), subsequent work has confirmed it in all but the details of elevational measurements.

Crittenden (1963) mapped the Bonneville shoreline and estimated that a maximum of 64 m of deflection had occurred. While this work, in turn, has been revised, Crittenden's map of shoreline elevations remains one of the best visual representations of the inverse basin shape of Bonneville shorelines. Crittenden also produced mathematical models of the rate of deflection and rebound, and while these are in error due to the poor chronological controls available at the time, they do suggest that isostatic adjustment continued to occur well into the early Holocene. The definitive work on Bonneville basin neotectonics has been done by Currey (1982, 1988), and detailed shoreline elevation maps for the Bonneville, Provo, Gilbert and late prehistoric levels are now available. These data have been incorporated into more up-to-date models of isostatic warping (figure 11). Shoreline data suggest that the greatest amount of deflection was 74 m, 59 m and 18 m for the Bonneville, Provo and Gilbert shorelines, respectively (figure 12).

The rate of both isostatic subsidence and rebound appears to be essentially logarithmic but asymmetrical in form (Bills and May, 1987; Bills and others, 1994). Using revised chronological estimates for these mapped shoreline events, Currey and Burr (1988) estimated a maximum subsidence rate of 7.3 cm/yr just prior to the possible Keg Mountain oscillation and a maximum rebound rate of 5.2 cm/yr

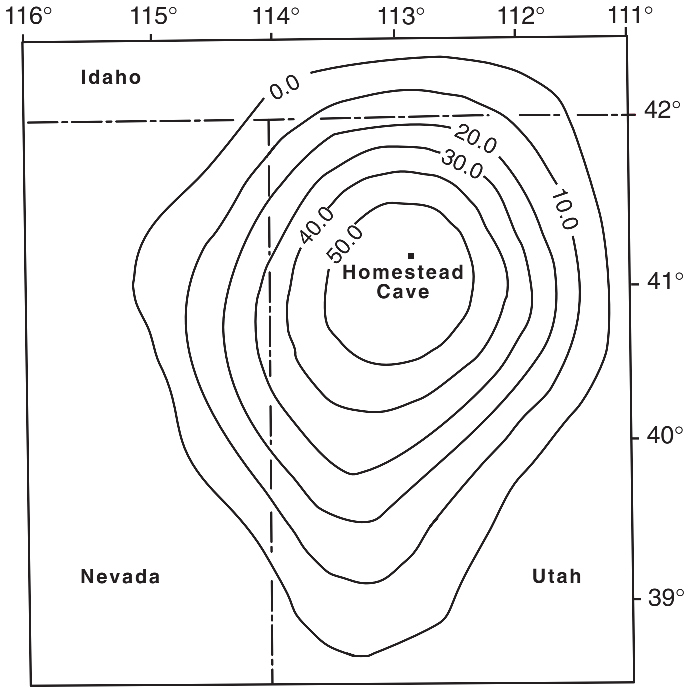

Figure 11. Schematic map showing relative amounts of Bonneville shoreline rebound elevation in the Homestead Cave area. Modified from Bills and others (1994). Contour elevations are in meters.

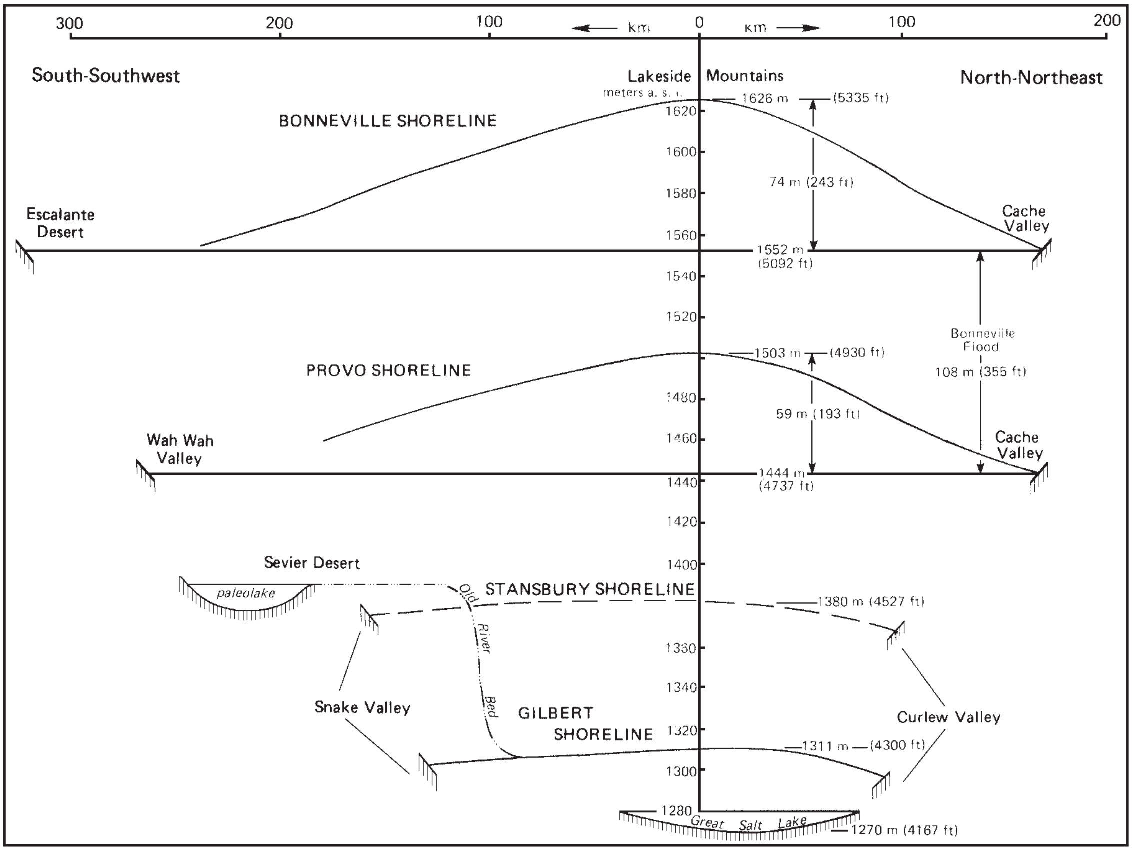

Figure 12. *Schematic diagram of isostatic deflection of major Lake Bonneville shorelines. Modified from Currey (1990, p. 203, figure 13).*

just after the Bonneville flood. Not only is the rebound rate slower than the subsidence rate initially, it also appears to be more prolonged. For example, the amount of deflection across the basin floor of the regressive Gilbert shoreline is more than twice that at the transgressive Stansbury shoreline (Currey, 1990), despite being much less than half its volume (they are equally removed in time from the ~15 ka highstand of Lake Bonneville). Assuming dates of 14 and 10.5 ka for the Provo and Gilbert lake levels, the rate of isostatic rebound slowed to ~1.2 cm/yr during the post-Provo regression. The rebound rate during the early Holocene is unknown, due to the lack of shoreline data, but it is probable that much of the remaining 10 to 15 m of differential rebound was prolonged well into the early Holocene (Bills and May, 1987). At least some of this rebound may have occurred after the formation of a mid-Holocene playa on the floor of Great Salt Lake (Currey, 1980).

These "limnotectonic" changes can be distinguished from "seismotectonic" events related to extension and basin and range formation, which also affect basin morphology in the Bonneville basin. The Wasatch fault zone along the eastern margin of the basin is one of the most tectonically active normal faults in North America, with major earthquake events occurring every 125-300 (Hecker, 1993) to 400 (Machette and others, 1992) years throughout the Holocene. Faults close to the Wasatch fault zone (that is, within the basin itself) have been subjected to less frequent seismic events of similar magnitude throughout the Pleistocene and Holocene. In the Bonneville basin, the frequency of these events may be related to crustal loading associated with lake cycles; the numbers and/or severity of seismotectonic events during and immediately following deep-water periods are significantly higher than those during low-water intervals (Currey, 1988; Hecker, 1993). Machette and others (1992) suggest that these lake-related events are more often associated with the unloading of lake waters during regression rather than with transgressive or deep-water situations. Bills and others (1994), in turn, suggested that lateral displacement of up to 12 m across the Bonneville basin (E-W), caused by isostatic deformation during high lake levels, would counteract extensional tectonics and limit faulting to periods after lake loads were reduced.

While the Wasatch fault is the longest and most tectonically active fault zone in the Bonneville basin, smaller faults within the basin, in particular those associated with the Great Salt Lake graben, may have had a greater impact on the shape of the basin floor. The long, narrow Great Salt Lake half graben is located west of the Promontory/Antelope Island mountains and forms the deepest part of the basin floor. The East Great Salt Lake and East Lakeside Mountains fault zones form the eastern and western margins of this half graben. Movement along the East Great Salt Lake fault zone has been estimated at an average slip rate of 0.4-0.7 mm/yr during the Quaternary (Hecker, 1993), suggesting that the graben may have been downthrown as much as 7 meters or more in the last 10 ka. Recent seismic examination of faults along the eastern margin of the half graben suggests that Holocene movement may be as much as 12 m (Dinter and Pechmann, 1999).

Regardless, Holocene movement of up to several meters is evident along these fault zones, and, when combined with changes in the basin-floor morphology caused by isostatic rebound, suggests that the shape of the basin floor and the lake surface configuration may have been significantly different than at present during much of the early to mid-Holocene. The difference in elevation between the Eardley threshold (the slightly elevated area west of the Lakeside Mountains separating Great Salt Lake and the Great Salt Lake Desert) and deepest part of the Great Salt Lake basin along the eastern margin of the half graben is only 11 to 13 m, much less than the 18 m of maximum post-Gilbert rebound. Even with no active faulting, 5 to 7 m of rebound would have had to occur in the early Holocene before the area along the northwest margin of the Lakeside Mountains below Homestead Cave ceased to be the deepest area of the lake. If 5 m of downthrow and 4 to 5 m of rebound are products of the mid- to late Holocene, then it is probable that the basin floor had a much flatter shape during the early Holocene and that the Great Salt Lake "Playa" actually extended well out into the Great Salt Lake Desert.

In sum, the restriction of Great Salt Lake waters into a narrow and relatively deep trough along the western margin of the Promontory/Antelope Island mountains is a product of Holocene limnotectonic and seismotectonic events. Prior to the creation of this trough, the lake may have been centered much farther west, almost directly below Homestead Cave. During the early to mid-Holocene a lake with a similar volume to that of the modern lake would have been shallower with a significantly larger surface area. As a result, climatic interpretations for the late Pleistocene/early Holocene, based on the modern configuration of Great Salt Lake, may have to be reconsidered.

MODERN CLIMATIC CONDITIONS

Current weather systems in the northern Bonneville basin are primarily a product of its interior continental location, the generalized west-to-east flow of air related to the position of the jet stream, and the orographic effects caused by marked differences in altitude (Stevens and Brough, 1987). Also important, but less critical, is the limited vegetative cover on most of the valley floors and western mountains which contributes to a high albedo, and a large water surface which contributes to "lake effect" storms that enhance precipitation along the eastern rim of the basin. Together these factors produce a relatively unique dichotomous regional climatic regime with cool, dry valley bottoms characterized by limited precipitation and cold, wet mountains with very high precipitation patterns. Currey (1991) has termed this half arid, half humid climate a "hemiarid (as opposed to "semiarid") environment, and differences can be quite marked. For example, annual precipitation averages ~13 cm in the Great Salt Lake Desert and ~155 cm in the Wasatch Range.

Most precipitation in the basin is a product of central-northern Pacific storm systems, although minor amounts are contributed by storms originating in the Gulf of California and Gulf of Mexico. These storms generally track the position of the jet stream and changes in its average location through time are a major characteristic of late Quaternary climatic models (see Kutzbach and Guetter, 1986; COHMAP members, 1988). Such changes are also considered to be the principal cause of lake-level fluctuations (see Benson and Thompson, 1987). The limited contribution of the southern monsoons produces a relatively even year-round precipitation regime, with slightly higher amounts in the spring months of March-May and relatively smaller amounts in the late summer months of July-September. Monthly average precipitation amounts at four weather stations on an approximate west-to-east transect through the center of the Great Salt Lake basin are shown in table II. Average yearly precipitation in the vicinity of Homestead Cave is ~22.5 cm, and is spread relatively evenly throughout the year. The record is short, however, and this figure may not be representative. Snow cover during the winter months is limited, and snowfall averages only ~20 cm per year.

This precipitation regime is complicated by a west-to-east difference in rain and snowfall patterns caused by lake-effect enhanced storms (Dunn, 1983; Carpenter, 1985). As storm fronts move across Great Salt Lake, differences in sur-

Table II

Monthly average precipitation (cm) and temperatures (°C) at four stations along a west-to-east transect through the Great Salt Lake basin

Precipitation

Locality	**Jan**	**Feb**	**March**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Wendover	0.61	0.33	0.48	1.42	2.48	1.80	0.79	2.11	2.00	2.06	1.73	1.47
Tooele	2.72	3.40	5.90	6.32	4.85	2.82	2.33	2.39	3.60	4.60	4.30	3.76
Salt Lake	2.82	3.12	4.85	5.38	4.57	2.36	2.06	2.18	3.25	3.66	3.28	3.57
Brighton	12.50	12.10	13.54	11.35	7.54	4.47	4.30	4.88	6.55	8.74	12.45	12.50

Temperature

Locality	**Jan**	**Feb**	**March**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Wendover	-2.9	0.9	5.6	10.3	16.0	21.6	26.5	24.8	18.6	11.1	3.6	-2.4
Tooele	-1.8	1.0	4.8	9.3	14.5	19.8	24.4	23.1	17.6	11.0	4.1	-1.2
Salt Lake	-2.3	1.2	5.4	9.8	14.8	20.6	25.5	24.2	18.4	11.7	4.8	-1.3
Brighton	-7.2	-6.1	-4.1	-0.2	4.7	10.0	14.5	13.6	8.8	3.5	-2.8	-6.8

face and air temperatures, together with the addition of moisture from evaporation, result in higher levels of precipitation along the mountains east of the lake. This lake-effect enhancement is particularly great during fall and spring months and results in a much larger snow pack on the mountains of the Wasatch Front. As the lake increases in size, the contribution of lake-effect storms is correspondingly greater (and correspondingly more widespread) and, at the Bonneville and Provo levels of the lake, lake-effect storms may have contributed 30% or more of total precipitation in the hydrographic basin, with most of that falling in drainages to the east of the lake (Hostetler and others, 1994).

Seasonal temperature variation in the Great Salt Lake basin is characteristic of middle latitudes, but is complicated by its basin and range morphology. The difference between winter (January) and summer (August) average daily maximum temperatures is ~ 49.5°C on valley floors and ~37.1°C in subalpine locations along the eastern rim. Average monthly temperatures at stations along a west-to-east transect generally reflect elevational differences (table II), but this is complicated by temperature inversions during winter months when daily maximums are often higher in upland locations. These inversions are more pronounced in the eastern portion of the basin and this difference may be related to west-to-east differences in plant communities. In particular, the distribution of single-leaf pinyon may be limited by the presence of long periods of cold stress associated with winter temperature inversions (Beeson, 1974; West and others, 1978). Average monthly minimum and maximum temperatures in the vicinity of Homestead Cave are shown in figure 13. The distribution of many plant and animal species in the Homestead Cave vicinity is controlled primarily by summer temperatures; the modern average summer high temperature for the month of August is 32.9°C, but, again, the record is relatively short.

BIOTIC LANDSCAPE FEATURES

Particular local modern combinations of flora and fauna are a product of unique and varied environmental histories, and specific components have varied throughout the late Pleistocene and Holocene (Tausch and others, 1993), often in concert with changing lake levels. These specific changes, however, have occurred within a relatively stable framework, and vegetation broadly similar to the present has existed in the Great Salt Lake basin throughout the Pleistocene and late Pliocene (Davis and Moutoux, 1998). That is, the vegetational zonation characteristic of modern plant communities, ranging from halophytic playa-margin plants on the valley floors to the Arctic-like plants of the highest alpine zones, has been present for at least the last four million years, but specific components of these zones, such as pinyon in the lower woodland plant community, have changed through both time and space.

Modern plant communities in the Bonneville basin vary significantly from west to east across the basin and represent a transition from Great Basin to Rocky Mountain floristic types. This generic difference between Great Basin and Colorado Plateau plant communities is exacerbated in the Great Salt Lake region by differences in scale and in precipitation patterns. In the Great Basin (and particularly in the Bonneville basin), upper slope plant communities are found on small, relatively low-elevation mountain ranges that are separated from one another by large intervening valley floor tracts in places consisting of barren playas. This island-like morphology has tended to limit species diversity, since individual species on these small islands are more susceptible to extirpation and the isolation of individual mountain ranges inhibits recolonization. This principle of island biogeography has been applied primarily to animal species (see Brown, 1971; Grayson, 1993), but can be applied to plant commun-

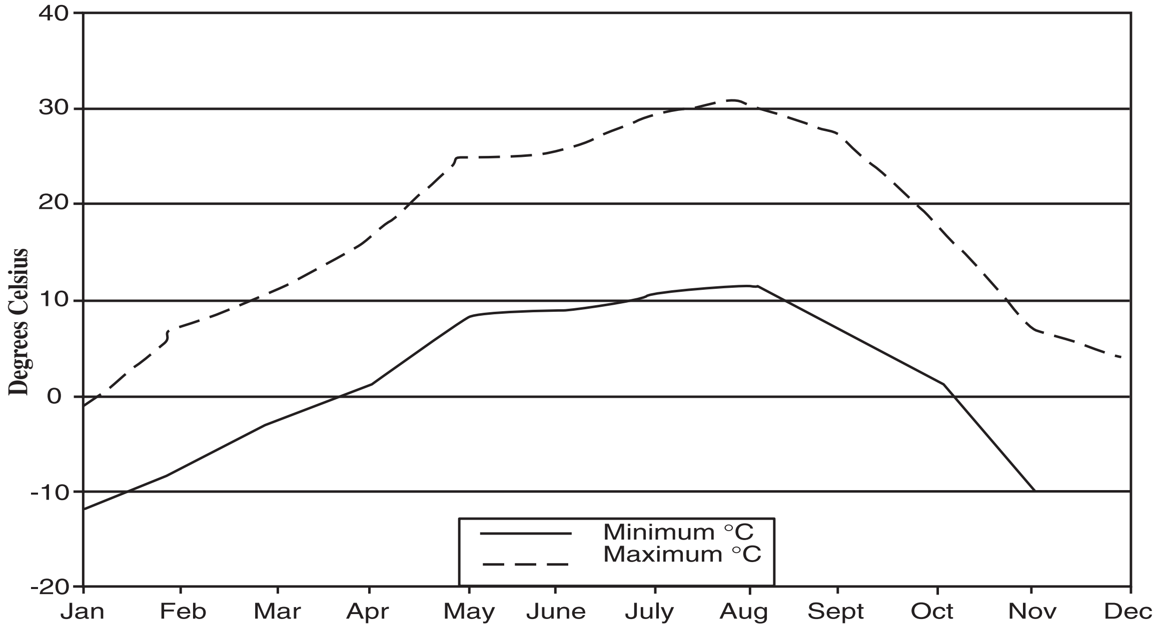

Figure 13. *Monthly average temperatures (minimum and maximum) at Lakeside Station, Utah (National Climatic Data Center, 1997).*

ities as well (although it is not as pronounced since seeds of many plants are more easily dispersed). The mountains along the eastern margin of the Great Basin, however, are much more massive, reach higher elevations, and are connected to much of the Rocky Mountains to the north, south and east at elevations well above valley floors. As a result, the diversity of species is greater and their distribution is more even. "Lake-effect" precipitation differences may also be a locally important factor explaining vegetational differences between the western and eastern basin margins, particularly in the southern portion of the basin southeast of Great Salt Lake and Utah Lake (Stevens and Brough, 1987). As a result of both factors, there is a west-to-east transition across the Great Salt Lake basin from relatively xeric to more mesic plant communities.

These west-to-east differences are more pronounced at elevations above the valley floors and plant communities below foothill locations are relatively similar. Along playa margins halophytic plant types such as pickleweed (*Allenrolfea* spp.), samphire (*Salicornia* spp.) and seepweed (*Suaeda* spp.) predominate but give way to communities dominated by shadscale/greasewood (*Sarcobatus* spp.) and saltbush in other valley floor areas. In lower foothill localities, communities of sagebrush, horsebrush (*Tetradymia* spp.) and rabbitbrush (*Chrysothamnus* spp.) are most common and include an array of grasses such as bluegrass (*Poa* spp.), wheatgrass (*Agropyron* spp.) and wild rye (*Elymus* spp.) whose distribution varies widely with exposure and soil moisture.

Above these valley floor and lower foothill locations, west-to-east vegetational differences become more pronounced in the Great Salt Lake basin. In the western mountain ranges pinyon/juniper woodlands are dominant at elevations of ~1600 to 2300 m, but the distribution of the community varies significantly with the size and substrate of individual ranges and is often limited on smaller and more isolated interior basin mountains. Utah juniper dominates these woodlands in the lower portion of this woodland zone, while pinyon pine dominates in the upper portion and juniper is replaced by mountain mahogany (*Cercocarpus ledifolius*). Sagebrush/grass communities are found throughout this woodland zone, where conditions of exposure, soil moisture and soil type permit. In the eastern mountains pinyon is absent from this woodland zone; Utah juniper is present, but scrub oak (*Quercus gambelii*) and maple (*Acer grandidentatum*) are dominant.

Subalpine forest communities above ~2300 m also differ in a similar west-to-east pattern, although these differences are more in proportion than kind. On the interior western ranges, more xeric conifers such as Douglas fir, white fir (*Abies concolor*) and limber pine tend to dominate, with more mesic species such as subalpine fir (*Abies lasiocarpa*) and Engelmann spruce (*Picea engelmannii*) restricted to north-facing slopes and stream drainages. Quaking aspen (*Populus tremuloides*) is also common, as is a variety of brushy plants such as snowberry (*Symphoricarpos* spp.), current (*Ribes* spp.), buffaloberry and prostrate juniper. A similar array of conifers and brushy understory plants is found in the mountains of the Wasatch Front, but spruce and subalpine fir are more common, and Douglas fir and limber pine are more reduced.

These zonal patterns are complicated in both the interior and eastern margin ranges by cold-air drainage along stream courses, where many species nominally found only at higher elevations reach well down into and often through lower woodland communities. In the Deep Creek Range, for example, limber pine, subalpine fir and Rocky Mountain juniper are found at elevations as low as 1800 m in Granite Creek Canyon. They co-occur with shadscale on well-drained gravel terraces several meters above stream level. In the interior and western Great Salt Lake basin, alpine plant communities are limited to small areas in the Pilot and the Deep Creek Ranges, and the Stansbury Mountains. The larger and higher mountains to the east have correspondingly larger alpine zones. Moist meadows are dominated by avens (*Geum* spp.) and a variety of small asters.

The diversity of plant species in the northern Lakeside Mountains is quite limited, in keeping with other small isolated interior basin ranges. Biotic communities around Homestead Cave are discussed in more detail in later chapters, but briefly, only nine species of grass, six species of forbs, nine species of desert shrubs, and a single tree species were identified during line transect surveys of three study plots in the Lakeside/Grassy Mountains (Workman and others, 1992). An additional 19 species were observed outside the transects (table III). This number is undoubtedly too low, as a result of the limitations of the kind of study conducted, but it also reflects the depauperate nature of local vegetational communities. Workman and others (1992, p. 79-80) provide this generalized description:

> The plant communities...are similar to those found in areas often categorized as the Northern Desert Shrub Biome. The large areas of mud flats, devoid of vegetation, are usually found with expansive adjacent areas where pickleweed occurs in scattered hummocks. Greasewood and Nuttall's saltbush occasionally grow on the mounds of pickleweed. The greasewood/shadscale community occurs at slightly higher elevations than pickleweed and in less saline soils. In some areas greasewood grows in almost pure stands. Usually it is interspersed with shadscale, Nuttall's saltbush and spiny horsebrush. The shadscale community is widespread and occurs in conjunction with different species in different areas. There are large areas where it occurs with gray molly as the only other species present. In areas of high elevation, it occurs with cheat grass, an annual, invading disturbed areas. At the bases of the mountains and on dry hillsides, shadscale occurs with mixed brush species, including budsage, winterfat, sagebrush, horsebrush and ephedra. Perennial grasses including bullgrass and Indian ricegrass are common among the shrubs. A juniper-mixed brush community occurs at higher elevations in the Lakeside Mountains. Various shrubs are present along with juniper, big sagebrush, big rabbitbrush, winterfat, and shadscale. Perennial grasses growing in these mountains include bluegrass, wild rye, galleta, and Sandberg bluegrass.

Table III

Plant species in three line transect surveys of
the Lakeside/Grassy Mountains area
(from Workman and others, 1992)

Grasses
Bromus tectorum
Elymus salinus
E. ambiguus
Hilaria jamesii
Hordeum jubatum
Oryzopsis hymenoides
Poa sandbergii
Stipa comata
Sporobolus cryptandrus

Forbs
Cirsium sp.
Halogeton glomeratus
Haplopappus sp.
Lactuca seriola
Phlox hoodii
Salsola kali

Trees
Juniperus osteosperma

Shrubs
Artemisia tridentata
Atriplex confertifolia
Ceratoides lanata
Chrysothamnus viscidiflorus
Ephedra nevadensis
Gutierrezia sarothrae
Sarcobatus vermiculatus
Tetradymia canescens
T. spinosa

Other species observed but not recorded within transect areas:

Agropyron cristatum, A. elongatum, A. smithii, Astragalus mollissimus, Bassia hyssopifolia, Chrysothamnus nauseosus, Cleome serrulata, Elymus cinereus, Eriogonum sp., *Grindelia squarrosa, Helianthus annuus, Kochia americana, Lepidium perfoliatum, Mentzelia laevicaulis, Tragopogon dubius, Rhus trilobata, Sitanion hystrix, Sphaeralcea* sp., *Suaeda torreyana.*

FAUNAL ACCUMULATIONS AND ANIMAL FORAGING BEHAVIOR IN THE LAKESIDE MOUNTAINS

(by Dave N. Schmitt)

Great Basin caves and rockshelters offer havens for a variety of bone collectors, carnivores and raptors. Modern observations and excavated materials in the Homestead Knoll caves and vicinity identified the presence of numerous collectors and predators, including woodrats (*Neotoma* sp.), coyotes (*Canis latrans*), golden eagles (*Aquila chrysaetos*) and owls (see *Tyto alba*). Woodrats habitually collect sticks, feces and bones from areas adjacent to their residences for use in house construction (see Stones and Hayward, 1968; Wells, 1976). Because woodrat nests are often located in wall crevices or on interior ledges, they are capable of introducing bones to sheltered contexts. A large woodrat house currently is situated near the entrance of Cathedral Cave, and an active, bone-rich house occupies a crevice in the rear wall of Homestead Cave. While the excavated fauna offer no direct evidence of *Neotoma* bone accumulations, it is probable that some of the bones were introduced by woodrats. *Neotoma* bones occur throughout the Homestead Cave deposits (see Grayson, chapter seven), suggesting that woodrats often were locally abundant and occupied the cave throughout most of the Holocene.

Terrestrial and avian predators customarily pursue small animals (especially rodents and leporids) and deposit prey remains in feces or pellets, or as transported carcasses or body segments (see Andrews and Evans, 1983; Andrews, 1990; Hockett, 1991, 1995; Schmitt and Juell, 1994). Coyote prey accumulations largely consist of materials deposited in scatological droppings. Undigested tissue and other frail organics will slowly disaggregate and decay, resulting in concentrations of partially digested bone and bone fragments. Excavated deposits from Homestead Cave contained a few carnivore (probably coyote) scat fragments. Scats were observed in the woodrat house at the rear of the cave, and a number of the recovered leporid bones exhibit polish, pitting and/or rounding of fracture surfaces characteristic of bones deposited in coyote scats (Schmitt and Juell, 1994). Cathedral Cave also contains small mammal remains that appear to have been partially digested by coyotes, and scats were observed scattered about the cave's entrance during 1994 and 1995 field investigations. Evidence for golden eagles is also present on Homestead Knoll, including a paired nest site located immediately northeast of Cathedral Cave ("Cathedral Roost;" see Schmitt, 1995). As at Cathedral Roost, golden eagles characteristically nest outside caves on craggy outcrops or cliff ledges (see Smith and Murphy, 1982), but their presence may result in the accumulation of prey remains in sheltered contexts (see Elston and Budy, 1990). Although eagle prey remains are usually dominated by complete jackrabbit (*Lepus* sp.) hind limbs (Hockett, 1995; Schmitt, 1995), eagles also may cast pellets containing partially digested bone (Hockett, 1996).

Modern observations, in concert with the wealth of recovered small animal remains, suggest that most of the Homestead and Cathedral cave faunas were deposited by owls. On numerous occasions we encountered screech owls (*Otus asio*) roosting in Homestead Cave, and we flushed a barn owl (*Tyto alba*) from Cathedral Cave during the summer of 1994. Owls typically roost on interior ledges where they regurgitate pellets consisting of indigestible fur, feather and bone (Dodson and Wexlar, 1979; Andrews, 1990; Kusmer, 1990; Mayhew, 1977). Large flows or cones of pellets can form under roosts that are subject to long-term habitation, ultimately resulting in pellet concentrations comprised of tens-of-thousands of small animal bones. Consolidated cones of droppings, pellet matter and bone are situated below perches in both of the Homestead Knoll caves (figure 14), clearly indicating that the caves have had extensive use as roosting sites. Both loci currently remain active; we collected fresh pellets from the surface of the cones during 1994 and 1995 field investigations. Blocks of what could be termed organic breccia containing abundant microvertebrate remains also occur in both of the caves (see also Brain, 1981), representing disaggregated portions of similar, ancient cones.

Humans are additional and often significant bone accumulators. The butchered remains of large and small mammals have been recovered from numerous Great Basin caves and rock shelters (Thomas and Mayer, 1983; Grayson, 1988; Hockett, 1994; Schmitt and Lupo, 1995), usually in association with large and diverse artifact assemblages, hearths and other cultural features. The recovery of artifacts from Homestead Cave indicates that prehistoric peoples visited the site, but the scarcity of material culture and cultural features (Shaver, chapter six) and lack of burned or butchered bone suggest that human occupation was infrequent, brief, and occurred only during the later part of the record. As a result, it appears that few (if any) bones were accumulated by human activities.

Although we are confident that the majority of the bones at Homestead and Cathedral Caves were accumulated by non-human agents, especially nocturnal raptors, it is necessary to investigate animal foraging behavior before inferring Holocene zoogeography and environmental change based on the recovered faunas. Specifically, we are concerned with the home (that is, foraging) range of local avian predators. For example, if the foraging range of a raptor nesting in a valley foothill encompasses distant, high-elevation contexts, boreal taxa may be dispatched and subsequently deposited in a low-elevation setting. Table IV presents the maximum home range for a variety of mammalian and avian taxa. Included are raptors that presently occur or are likely to occur in the Lakeside Mountains, and taxa whose skeletal remains were identified in the Homestead Cave faunas. These data indicate that golden eagles maintain the most extensive foraging range, but note that this maximum range is relatively restricted (figure 15) and only encompasses neighboring valleys and low ridges in elevations ranging from 1285-1660 m. It is possible, however, that some of the Homestead Knoll faunas were procured from extraneous contexts. Golden eagles commonly have different nesting sites and may alternate residences (Ryser, 1985, p. 240), and transient coyotes have annual home ranges commonly exceeding 100 km^2 (Gese and others, 1988) and are capable of traveling over 6 km in a 24-hour period (Litvaitis and Shaw, 1980). As a result of such movements, the remains of prey consumed elsewhere could have been deposited in the Homestead Knoll Caves. Additionally, both a predator and its prey may converge on the outer extent of their foraging radii, thereby extending the confines of our proposed maximum foraging range. We acknowledge these potential processes, but they do not affect our interpretations of regional biogeography and environmental change. The Lakeside Mountains represent an isolated feature and local elevational gradients are minimal. Even if we extend our maximum predator foraging radius to 15 km, all captured prey would represent species available in the immediate vicinity of Homestead Knoll. Consequently, the recovered faunal remains, especially the large and diverse assemblage from Homestead Cave, offer an unprecedented data set for inferring regional change in late Quaternary paleoecology. Predators and collectors extracted an extensive sample of fish and waterfowl from Great Salt Lake and mammalian fauna from local valleys, drainages, low ridges and mountain foothills characteristic of most Bonneville basin habitats.

Figure 14. *View of raptor pellet and debris cones on the floor of Homestead Cave.*

Table IV

Maximum home range of selected mammals, birds, and birds of prey from Homestead Cave and vicinity

Common Name (Species)	Max. Home Range (radius)	Reference
Black-tailed jackrabbit (*Lepus californicus*)	2.39 km*	Smith (1990)
Badger (*Taxidea taxus*)	2.10 km	Lindzey (1978)
Desert woodrat (*Neotoma lepida*)	126 m	Stones and Hayward (1968)
Common flicker (*Colaptes auratus*)	400 m	Lawrence (1967)
Sharp-tailed grouse (*Tympanuchus phasianellus*)	2.02 km*	Saab and Marks (1992)
Sage Grouse (*Centrocercus urophasianus*)	2.10 km	Ellis and others (1989)
Golden eagle (*Aguila chrysaetos*)	5.32 km	Smith (1971)
Ferruginous hawk (*Buteo regalis*)	4.02 km	Smith (1971)
Red-tailed hawk (*Buteo jamaicensis*)	5.15 km	Anderson and Rongstad (1989)
Marsh hawk (*Circus cyaneus*)	3.22 km	Smith (1971)
Great horned owl (*Bubo virginianus*)	4.35 km	Smith (1971)
Long-eared owl (*Asio otus*)	1.08 km	Craighead and Craighead (1969)
Short-eared owl (*Asio flammeus*)	2.34 km	Smith (1971)

*Interpolated from maximum home range reported as km^2.

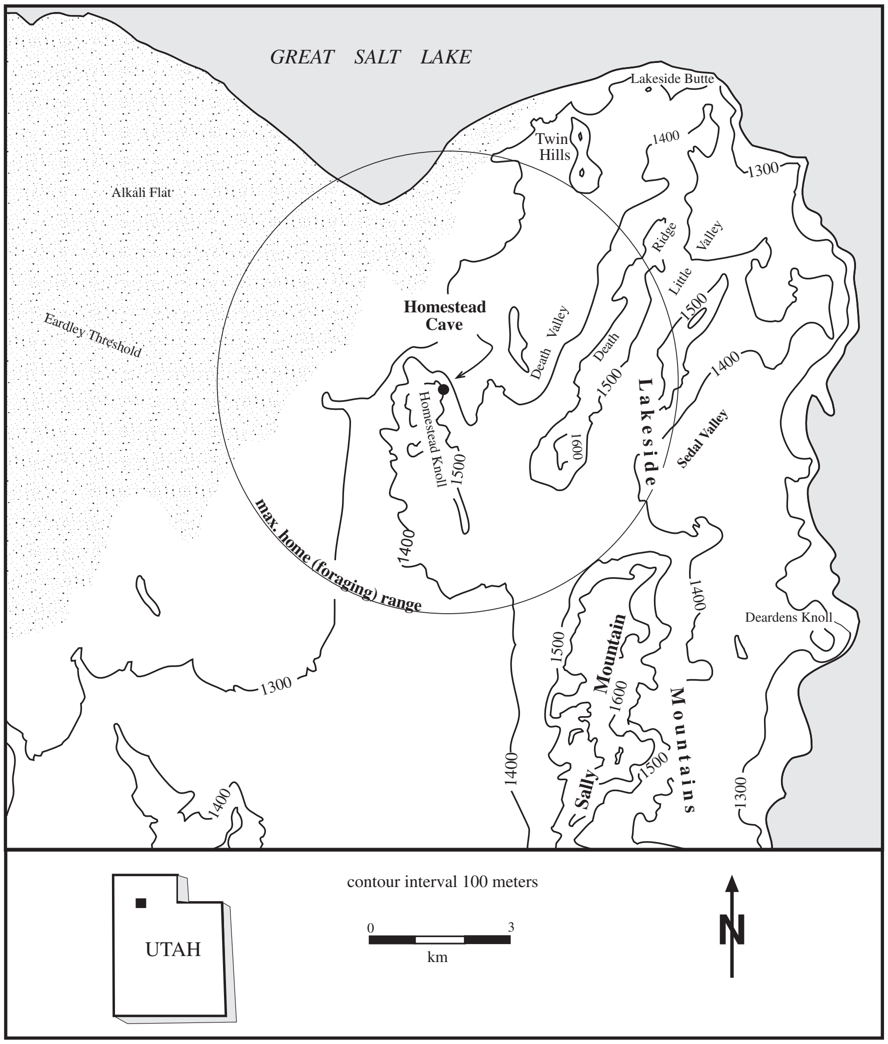

Figure 15. Maximum raptor home range (golden eagle, Table IV) centered on Homestead Cave; Cathedral Cave is on the tip of Homestead Knoll approximately 1 km northwest of Homestead Cave.

STRONTIUM RATIOS AND LAKE BONNEVILLE CHRONOSTRATIGRAPHY

(by Jay Quade)

The waters of Lake Bonneville precipitated abundant calcium carbonate ($CaCO_3$) in the form of shoreline tufas, deep lake marls, and associated shells of mollusks and ostracodes. These carbonates contain trace amounts (100-1000 ppm) of strontium (Sr) which freely substitutes for calcium (Ca) (both are Group II elements) in the structure of $CaCO_3$, forming both the minerals aragonite and calcite, and in $Ca_{10}(PO_4)_6(OH)_2$, forming biogenic phosphates. Thus there is abundant Sr available in a variety of mineral phases associated with the lake, and now preserved within Homestead Cave.

Strontium has four stable isotopes, the two forms of which, ^{87}Sr and ^{86}Sr, have been used as tracers in many geological studies. These isotopes are ideal tracers because they are stable and conservative in the sense that the $^{87}Sr/^{86}Sr$ ratio does not change during phase transformations. For example, the $^{87}Sr/^{86}Sr$ ratio of lake Sr will be identical to the ratio of tufas or mollusks, or fish skeletons formed in the presence of that lake water. The change from one physical state to the next does not discriminate for or against ^{87}Sr or ^{86}Sr. Thus, changes through time in the $^{87}Sr/^{86}Sr$ ratio of lake waters will be recorded in any carbonate or phosphate phase in the lake, assuming, of course, that they have not been altered since burial.

The Sr-isotope system will only be of use if the $^{87}Sr/^{86}Sr$ ratio of the lake varied in the past, preferably in step with datable lake-history events. This study will be able to show that there have been such variations, but to understand these changes, the controls on Sr chemistry in Lake Bonneville must be reviewed. At high lake stages during the last glacial maximum, the $^{87}Sr/^{86}Sr$ ratio of Lake Bonneville would have been determined by the $^{87}Sr/^{86}Sr$ ratio of rivers flowing into the basin, weighted by their Sr concentration and relative discharge. The Bear River carries the largest discharge of any river flowing into the basin today, and it was probably the largest in the past. Other important rivers are the Weber, Jordan, Ogden, Sevier and Beaver. The formula describing these relationships would be:

$$^{87}Sr/^{86}Sr\text{ (full lake)} = {}^{87}Sr/^{86}Sr_{\text{Bear River}}\,F_{\text{Bear River}}$$

and so forth, for all rivers, where: F = fraction of total Sr

As long as all the same rivers flowed into the basin, the $^{87}Sr/^{86}Sr$ should not have changed. The solution to this equation requires a knowledge of Sr concentrations in rivers, which I obtained with the help of D. Bouchard (a former student at Utah State University) for all the major modern rivers. A preliminary model of these values appears in Bouchard (1997).

Changes in the $^{87}Sr/^{86}Sr$ ratio of the lake would come as the lake dropped in the late stages of the last glacial period. These changes could come about in at least two ways. As collapse of the lake below basin thresholds isolated local bodies of water, the $^{87}Sr/^{86}Sr$ ratio of the now isolated lakes shifted in the direction of the $^{87}Sr/^{86}Sr$ ratio of the local constituent rivers (figure 16). Alternatively, changes in river composition, as new reaches of river were exposed by the dropping lake, could have changed their input $^{87}Sr/^{86}Sr$ ratios. These compositional changes should be reflected in any Sr-bearing phase of the lake. The $^{87}Sr/^{86}Sr$ ratio of lake minerals then becomes an indicator of the lake level at the time of mineral formation.

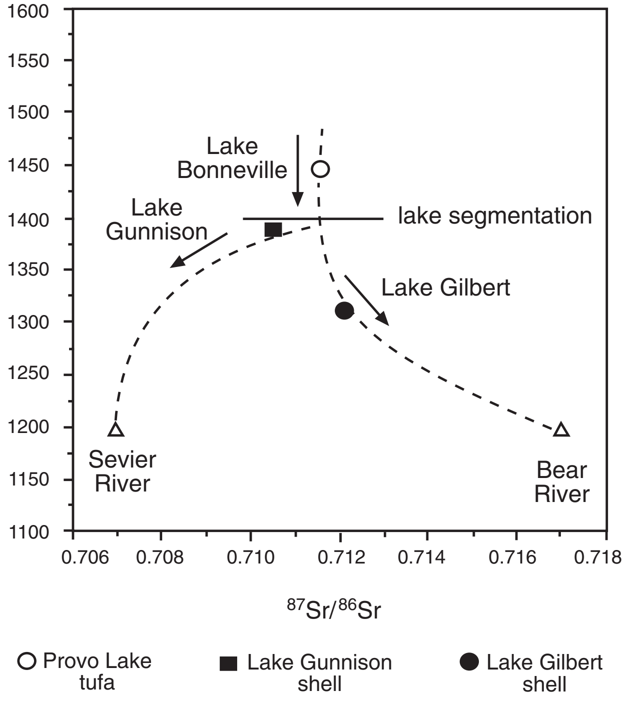

Figure 16. *Evolution of the $^{87}Sr/^{86}Sr$ ratio of lake water with lake-level change. As the lake segmented into Lake Gunnison and Lake Gilbert, their ratios evolved in the direction of the ratios of local rivers. The rates of change in $^{87}Sr/^{86}Sr$ ratios of segmented lake waters would be non-linear and asymmetrical because the Sr concentrations of input rivers differ.*

Several conditions must be met for the Sr system to be useful in deducing lake level. If basin segmentation alone (explanation [1] above) is the cause of changes in $^{87}Sr/^{86}Sr$ ratios with lake elevation, then the $^{87}Sr/^{86}Sr$ ratio of inflowing rivers must be sufficiently distinct in the separate basins that, when basin isolation occurs, it leads to changes in the $^{87}Sr/^{86}Sr$ ratio of the involved lakes. Fortunately, the main rivers feeding the Bonneville system are quite distinct isotopically, fulfilling this condition (table V; Jones and Faure, 1972). The Bear River displays one of the highest $^{87}Sr/^{86}Sr$ ratios (0.7140-0.7219) in the system, and it supplies most of the discharge to the northern, now Great Salt Lake basin. Other important rivers in the north include the Weber (0.71002-0.71290), the Ogden (0.741529) and the Jordan (0.72060). The Sevier and Beaver Rivers (0.7070-0.7078) have much lower $^{87}Sr/^{86}Sr$ ratios than the northern rivers, and they supply virtually all the moisture to the southern, Sevier Lake basin (table V). The lake water should display some $^{87}Sr/^{86}Sr$ ratio intermediate between the Bear and the Sevier/Beaver Rivers when all the major basins are connected at high-lake stage. With lake segmentation, the southern lake (Gunnison) should have $^{87}Sr/^{86}Sr$ ratios like that of the Sevier/Beaver Rivers, and Great Salt Lake should be close to that of the Bear.

A second condition is that the lake be well mixed with respect to Sr. Many factors can effect mixing, but the key consideration is the residence of time of Sr compared to the mixing time within the lake. I took an empirical approach to this issue by sampling tufas from a single former lake elevation, the Provo shoreline at 1444 m, from all over the basin. Results for Provo tufas fall within a relatively narrow range of 0.7113-0.7119 (table V), demonstrating substantial but not complete mixing of the lake waters prior to tufa formation. The pattern of $^{87}Sr/^{86}Sr$ ratios is systematic and predictable. The highest values come from the north, where Bear River water dominated, and the lowest values come from the south, nearest the outlet to the Sevier River. As we will show later, the degree of mixing was sufficient to distinguish very low from intermediate and high lake levels.

I have analyzed tufas and lacustrine gastropods of many ages and elevations in order to construct a $^{87}Sr/^{86}Sr$ versus elevation curve for Lake Bonneville near its highstand, and for Lake Gilbert and Lake Gunnison when the lake level dropped and the lake segmented after 12.5 ka (figure 16). This curve will undergo some refinement as more samples from different elevations are analyzed, but the main elements of the curve are clear, and they make good sense in light of what is known about modern river composition.

The lake waters should have stayed within a narrow range of composition of $^{87}Sr/^{86}Sr$ as long as lake levels stayed above the Old River Bed threshold, which Oviatt (1988b) estimates to have been 1390 m. Support so far for this prediction comes from the narrow range of $^{87}Sr/^{86}Sr$ values defined by Provo-level tufas and from white marl considered to be equivalent in age to the high Bonneville shoreline. The lake level is thought to have begun to drop rapidly shortly after 14.0 ka. The lake must have remained hydrologically well integrated until at least 12.5 ka because fish vertebrae from two dated Great Salt Lake basin packrat middens (Rhode and Madsen, 1995) yielded $^{87}Sr/^{86}Sr$ ratios of

Table V

Summary of Sr isotopic analyses

sample #	**shoreline**	**location**	**material**	**$^{87}Sr/^{86}Sr$**
Bonneville basin				
Old River Bed	Bonneville	Old River Bed	white marl	0.711814
High	Bonneville	High Crossing (Sevier R.)	white marl	0.711306
DK93-06	Bonneville	Cutler Dam	shell	0.711835
DK93-28B	Provo/Bonn.	Cache Valley	shell	0.711750
Stansbury A	Provo	Stansbury Mountains	tufa	0.711770
Stansbury B	Provo	Stansbury Mountains	tufa	0.711711
Stansbury C	Provo	Stansbury Mountains	tufa	0.711795
Th-5B	Provo	Tabernacle Hill	tufa	0.711587
Homestead (A)	Provo	Homestead Cave	tufa	0.711737
Table Provo	Provo	Table Mountain	tufa	0.711526
Promontory	Provo	Promontory Mountains	tufa	0.711864
Smelter	Provo	Smelter Butte	tufa	0.711831
Pot	Provo	Pot Mountain	tufa	0.711490
Tule	Provo	Tule Valley	tufa	0.711584
Newfoundland	Provo	Newfoundland Mtns.	tufa	0.711945
Jukebox 1	post-Provo	Jukebox Cave	tufa	0.711594
BVSR-3	Gilbert	Promontory Mountains	tufa	0.712034
BVSR-3D	Gilbert	Promontory Mountains	tufa	0.712015
BVSR-3E	Gilbert	Promontory Mountains	tufa	0.711936
BLM-1	Gunnison	Sevier Lake basin	*Anodonta*	0.710486
Raven Cave 1a	12,550±50	midden	fish vertebrae	0.711415
Triple Barrel 1	13,470±100	midden	fish vertebrae	0.711482
River/lake waters				
Bear		Bear River *	water	0.72190
Bear		Bear River	water	0.713976
Jordan		Jordan River	water	0.72060
Weber		Weber River *	water	0.71290
Weber		Weber River	water	0.710017
Ogden		Ogden River	water	0.741529
Sevier		Sevier River	water	0.707026
Beaver		Beaver River	water	0.707845
GSL		Great Salt Lake*	water	0.7174
West		Western desert*	water	0.7135

* from Jones and Faure (1972)

0.71141 (table V: Raven Cave 1a, 12,550 ± 50 yr B.P.) and 0.71148 (Triple Barrel 1, 13,470 ± 100 yr B.P.). The lake segmented below 1390 m at the Old River Bed, but the ^{87}Sr/^{86}Sr values of the new, smaller lakes would depend on whether the lakes were totally isolated from each other or if one lake flowed into the other. Oviatt (1988b) has presented evidence that the late-glacial lake in the Sevier Lake basin (Gunnison) was the one that overflowed into the northern basin across the Old River Bed, and this proposition is testable using Sr isotopes. Overflow northwards would have continued to produce ^{87}Sr/^{86}Sr ratios in the northern basin representing a mixture of Bear River and Sevier River sources. However, it is plausible that the ^{87}Sr/^{86}Sr value of the northern lake might begin to evolve in the direction of the Bear River, particularly where mixing across the lake became less complete as the lake grew shallower. In contrast, the ^{87}Sr/^{86}Sr ratio of the southern basin should show a much sharper shift toward the composition of the Sevier/Beaver Rivers, if Sr acquired while the lakes were still integrated was rapidly cycled out and replaced by lower ratios from the Sevier/Beaver Rivers. This process would have been all the more rapid because the Sr concentration in the Sevier and Beaver Rivers is higher than other rivers in the system.

The few samples I have from lower elevations would seem to confirm this scenario (figure 16). Tufa from the Gilbert shoreline (1311 m) on the tip of the Promontory Mountains shows slightly, but consistently, higher ^{87}Sr/^{86}Sr ratios (table V: 0.71194-0.71203) than local higher elevation tufas (0.71171-0.71186). This is the expected direction of the isotopic shift toward Bear River composition if the southern rivers were contributing less or if circulation and mixing was less complete at low lake levels. *Anodonta* shell from the high shoreline of Lake Gunnison returned values of 0.710486 (table V). These low values are consistent with the low ^{87}Sr/^{86}Sr ratios of the Sevier/Beaver River, but they still appear to show the influence of the northern rivers. This would only be consistent with northward overflow of Lake Gunnison if the shells formed very shortly after lake segmentation.

The preliminary modeling by Bouchard (1997) offers a another explanation for the fall in ^{87}Sr/^{86}Sr ratios as the lake dropped. The key assumption in their model is that the Sr concentrations in rivers have not changed through time, despite major changes in discharge. The model suggests that the fluxes of Sr from the southern rivers (Beaver and Sevier) are so small that subtraction of their inflow to the northern Bonneville system would have little impact on lake ^{87}Sr/^{86}Sr ratios. In effect, the flux of Sr from the modern Bear and Ogden are so large that they dominate the ^{87}Sr/^{86}Sr ratio of the lake. But Bouchard (1997) suggests that the ^{87}Sr/^{86}Sr ratio of the Bear River itself may have increased as lake level dropped, thus producing the observed increase in ^{87}Sr/^{86}Sr ratios in the lake. Apparently, the addition of spring water with very high ^{87}Sr/^{86}Sr ratios to the lower reaches of the Bear River dramatically raises the ratio of the river just before it enters the present lake. The proportion of the spring inflow (with high ^{87}Sr/^{86}Sr ratios) to runoff (with low ^{87}Sr/^{86}Sr ratios) from the rest of the Bear River watershed may have been changed dramatically in the last glacial period. If correct, this could have produced the increase in ^{87}Sr/^{86}Sr ratios as the lake dropped, and not lake segmentation. The correct explanation awaits a far more detailed documentation of the system.

Whatever the details of the mass-balance calculations, an elevation versus ^{87}Sr/^{86}Sr curve (figure 17) can be generated on the present results that shows sufficient differences in ^{87}Sr/^{86}Sr values to distinguish high and intermediate lake levels from low lake levels in both the southern and northern basins. I will use these relationships in the section dealing with strontium ratios in Homestead Cave to reconstruct the probable elevations of the lake from which Homestead tufas, shells and fish bone were formed (see Quade, chapter four).

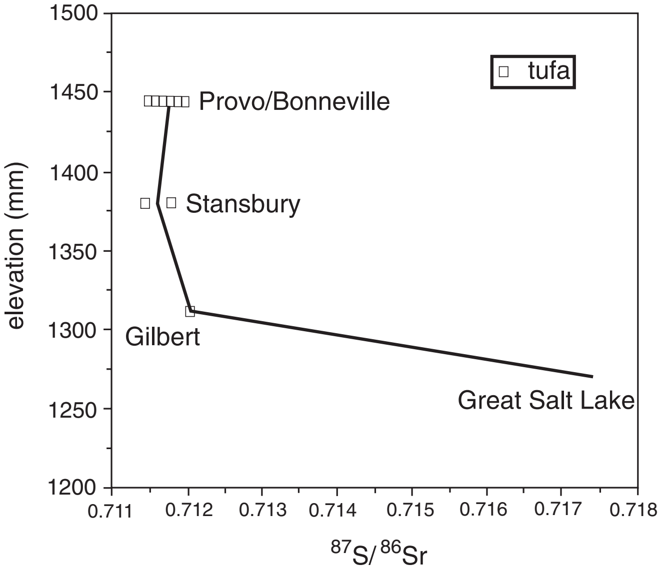

Figure 17. *Change in the ^{87}Sr/^{86}Sr ratio of lake waters with change in lake elevation in the northern (Great Salt Lake) basin.*

CHAPTER THREE

Excavation and Laboratory Procedures

SITE SELECTION AND GOALS

One of two primary project goals in the study of paleoenvironmental change in the Bonneville basin was the identification and excavation of a cave site where faunal remains accumulated by raptors and other predators could be found in stratified deposits spanning the Holocene and at least the very latest Pleistocene. To this end, we conducted a thorough examination of extant archaeological and geological data on file at a variety of federal and state land-management agencies. Based on the results of these file searches, we selected three areas for field examination and possible testing: (1) the western margin of the basin in the vicinity of Wendover, Utah where a number of deeply stratified cave sites have been identified and reported (see Jennings,1957; Madsen and Rhode, 1990), (2) the southern margin of the basin in the vicinity of the Old River Bed where both Pleistocene megafauna and early peoples would likely have exploited riverine resources, and (3) the northern end of the Lakeside Mountains where Great Salt Lake occasionally overflows and spills into the Great Salt Lake Desert. Potential sampling localities were identified at caves in each of these areas.

Caves in the Wendover area were ultimately rejected for paleoecological purposes because of intense prehistoric human occupation and very complex depositional sequences. In the Old River Bed area, a cave at the south end of a small fault-block mountain known as Camels Back Ridge was tested for its paleoecological potential in 1993. Although the site proved to have a number of very interesting archaeological features, the depositional sequence spanned only the last 8000 years and, thus, did not meet project goals. Results of these test excavations at Camels Back Cave are reported elsewhere (Schmitt and others,1994; Schmitt and others, 1998). A series of known cave sites was examined in the northern Lakeside Mountains, but all proved to be unsuitable for our purposes. In the process of examining these sites, however, we encountered a previously unreported cave site on Homestead Knoll with surface indications of extended use by raptors (figure 18) and limited evidence of disruption by intense human occupation. Test excavations at the Homestead Knoll cave revealed well-stratified deposits extending back to the era of Lake Bonneville. As a result, the site was selected as the focus of project faunal studies since it appeared to satisfy all primary project goals. Based on these initial results, full-scale sampling was conducted during a number of study episodes spanning 1993-1995.

The general goal of excavations at Homestead Cave was to isolate, identify and remove a stratified column of deposits containing a sample of small faunal elements sufficiently large enough to be representative of local biotic communities through time. To meet this general goal, more specific goals were developed to minimize interpretive problems with the recovered faunal sequence. First, past experience with the excavation and interpretation of numerous Great Basin caves suggests that a principal cause of out-of-order radiocarbon age estimates and inverted archaeological sequences at many sites (for example, Hogup Cave [Aikens,1970]) is the attempt to remove materials in the maximum possible stratigraphic detail. While it seems counter-intuitive that coarser rather than finer stratigraphic excavations may produce more accurate and consistent results, the use of this seemingly upside-down approach is sometimes warranted because of the diverse morphology of many Great Basin cave deposits. Commonly, coarse-grained layers of roof spall and loosely aggregated vegetation are overlain by fine-grained deposits of eolian materials and plant chaff, and materials in these upper layers sift down into and often completely through lower layers. When an attempt is made to excavate such depositional units separately, spurious results are often obtained. At Homestead Cave we hoped to circumvent this problem by imposing an "excavatable" stratigraphy on the

Figure 18. Aerial view of Homestead Cave looking southwest.

natural depositional sequence and remove many strata in sets with readily separable upper and lower surfaces.

Second, these numerous coarse and fine-grained layers are often morphologically indistinguishable from one another, and their horizontal distribution is undulating, sporadic, and disturbed by both human and animal intervention. Without extensive vertical exposures for control, it is extremely easy to inadvertently shift from one stratigraphic layer to a similar higher or lower one in the process of excavation. We hoped to limit problems of this kind by isolating our sample column on at least two and possibly three sides so as to trace each excavation unit completely through the sample block. As a related measure, our intent was to ignore all materials encountered in the process of isolating the column to preclude any possible cross-strata mixing. That is, material recovered from outside the column would not be included in our analyses and interpretation to insure that only material with maximum controls was considered.

Third, detailed chronological control is critical to the adequate interpretation of floral and faunal data from cave sites as representative of changing local biotic communities. In combination with the excavation problems just noted, however, the use of only limited numbers of radiometric dates applied to a very complex and detailed depositional sequence, as is commonly the case in Great Basin cave sites, makes the assessment of the age of undated intervening strata tentative at best. Even when individual strata are directly dated, problems of bioturbation can cause individual dates to be out of place and in error in relation to other materials from that depositional unit. At Homestead Cave, we hoped to circumvent these common problems of chronology by obtaining multiple radiocarbon samples directly from every stratigraphic unit identified in the sample column.

In sum, our excavation goals were relatively simple: (1) to isolate a representative column spanning the entire depositional sequence, (2) to insure that it was large enough in terms of volume to contain a representative sample of local biota – to this end we ultimately selected a 1 x 1 m column, (3) to insure that excavated depositional units were cleanly and clearly separated by isolating and mapping the column in detail, and (4) to insure that the chronological placement of each identified stratum was made as correctly as possible.

SITE DESCRIPTION AND ORIENTATION

Homestead Cave lies on the western margin of the northern Lakeside Mountains in a northwest-trending ridge/spur known as Homestead Knoll. The Lakeside Mountains consist of a long (~50 km), narrow (4-6 km) fault-block range of primarily limestone bedrock material with central peaks reaching to ~2000 m above sea level (asl) on the southern end and ~1750 m on the northern end. The Homestead Knoll spur itself is ~4 km north-south by ~2 km east-west and is separated from the main body of the Lakeside Mountains by a low pass reaching 1450 m asl. The knoll is 1625 m asl at its crest. The surface of the limestone bedrock and the associated unconsolidated colluvial sediments has been heavily modified by the wave action of Lake Bonneville. Homestead Knoll is essentially a flat-topped seamount or guyot formed during the highest stand of the lake (figure 19, A). At the Provo level, ~1500 m, the knoll was deeply incised by wave action, forming a ~30 m wide shelf that extends completely around the knoll and grades into a tombolo on both the northwestern and southeastern margins (figure 19, B). Bedrock features at this elevation are heavily draped by a thick tufa coat, with the tufa extending 5 to 20 m downslope from the wave-cut shelf.

Below the Provo level, between rocky cliff-forming outcrops, Homestead Knoll is veneered with coarse beach gravels deposited during both the transgressive and regressive phases of the last lake cycle. These are deepest in shallow bays, where they have been incised and exposed by historical erosion channels (figure 19, C). Homestead Cave (figure 19, D) is in a rocky ridge ~30 m below the elevation of the most prominent of these beaches (~1435 m asl). Below this elevation the eastern margin of Homestead Knoll is connected to the rest of the northern Lakeside Mountains. Slopes become much more gentle, forming a shallow alluvium-filled valley between Homestead Knoll and Death Ridge, the main crest of the Lakeside Mountains. A short (3-4 km long) system of stream channels drains the east slope of Homestead Knoll and the west slope of the central Lakeside Mountains. These channels currently contain running water only during major rainstorms. During the later regressive phases of the Lake Bonneville cycle, waters in this valley formed a series of shallow embayments. The most recent of these embayments is at the Gilbert level (figure 19, F). The highest Holocene beach was formed across this embayment, creating a lagoonal marsh. Midway between Homestead Cave and the Gilbert beach is a broad shelf formed by a series of transgressive Stansbury beaches (figure 19, E).

This landscape is characterized by a limited number of vegetational communities. The saline playa of the Great Salt Lake Desert forms a broad arc around the western margin of Homestead Knoll and is ringed with a narrow band of halophytic plants such as pickleweed and samphire. These give way rapidly to a saltbush/greasewood community covering the Holocene beaches and interior embayments below the Gilbert level. Sagebrush, horsebrush and rabbitbrush provide a sparse cover on the rockier slopes. The gentler colluvial slopes and valley bottoms are dominated by annual grasses, most of which are introduced species. Trees and shrubs are virtually nonexistent, with only a few small, isolated Utah junipers found along stream drainages on the valley floor. A few currants (*Ribes cereum*) and other more mesic brush species occur at the base of rocky ridges and cliffs where precipitation runoff is frequent and where shade reduces evaporation. One of these moister localities is found at the mouth of Homestead Cave, where wax currant and a small stand of wild rye (*Elymus* sp.) are found below the dripline.

Homestead Cave faces north-northeast and overlooks the playa of the Eardley threshold. The orientation of the long axis of the cave is 31° east of true north. The waters of Great Salt Lake are readily visible and the lake margin varies from to 2 to 6 km away as the lake surface rises and falls episodically (figure 20). The floor of the cave at the center of the cave mouth (marked by a permanent metal datum stake) is at an elevation of 1406.3 m asl. This elevation was measured with a laser theodolite from a section corner marked by the United States Geological Survey, and the elevation is thus within the margin of error of the original survey. The cave is contained within a small limestone ridge that extends north

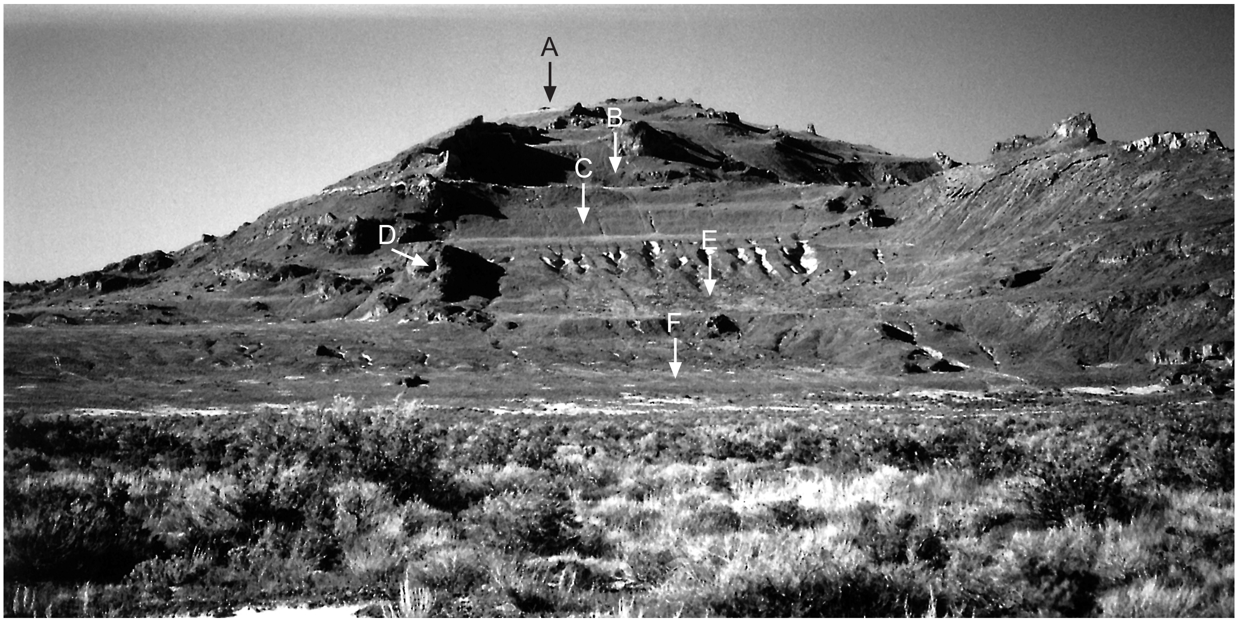

Figure 19. *View of the north slope of Homestead Knoll looking south from the top of the highest Holocene beach of Great Salt Lake showing (A) the Bonneville beach, (B) the Provo beach, (C) erosion channels in a post-Provo regressive beach, (D) Homestead Cave, (E) the Stansbury beach complex and (F) the Gilbert beach.*

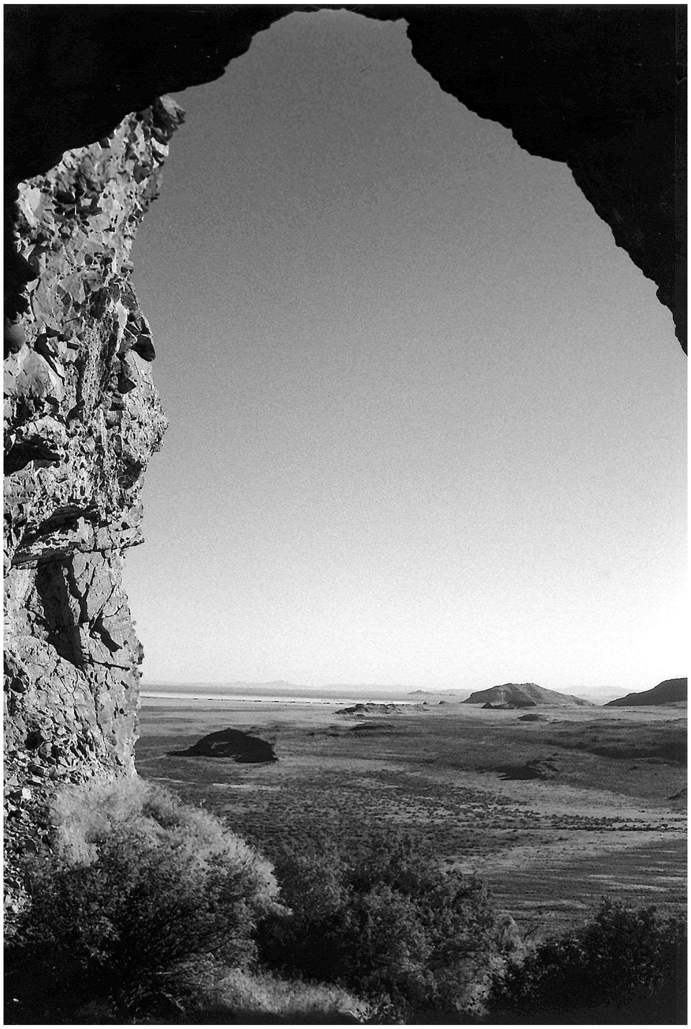

Figure 20. *View looking north from Homestead Cave towards Great Salt Lake. The Eardley threshold and the playa of the Great Salt Lake Desert are visible in the upper left.*

~300 m from the main body of Homestead Knoll. The ridge top, some 20 to 30 m above the cave floor, is relatively flat and has been modified by wave action. The bedding planes of the basal limestone are almost vertical along this ridge. Construction of the cave must have occurred during the transgressive phase of the Bonneville lake cycle or even earlier, since the cave is coated by a layer of tufa deposited under water as the lake regressed. Spalling during the Holocene has expanded the size of the cave marginally. The vertical limestone bedrock extends north of the cave to the west, shading the area immediately in front of the cave and forming a relatively more mesic microhabitat (figure 21).

The cave itself is 17 m deep from the center of the dripline to the rear wall and tapers from 4.5 m wide along the floor at the mouth to 1 m wide at the rear (figure 22). The height of the cave from floor to ceiling along the center axis varies from 5 to 6 m. The floor of the cave slopes gently from the back to the front, dropping 0.5 m across a 20 m distance, but dips sharply from the east to west cave wall (figure 23). The limestone bedrock around the mouth of the cave is almost completely coated with a layer of tufa 20 cm thick. However, most of this tufa coating has spalled off bedrock surfaces within the cave. The cave floor is covered primarily by small- to medium-sized rock spall less than 2 cm in diameter. Larger pieces up to 0.5 m in diameter occur along the western cave wall at the base of the interior east-west slope. A small relic-hunter’s pit was dug into the west-central part of the cave, but the deposits were otherwise undisturbed when initially recorded. A surface scatter of human bone at the cave mouth probably originated in this hole. The surface rock spall is held in a matrix of organic material derived from both raptor deposits and woodrat nests. A large, modern, woodrat midden chokes the extreme rear of the cave. Part of the midden has been burned historically, probably within the last several decades. Owls currently occupy roosts on ledges along the upper rear cave walls. White fecal drapes below a number of associated perches festoon the east cave wall. Debris cones composed primari-

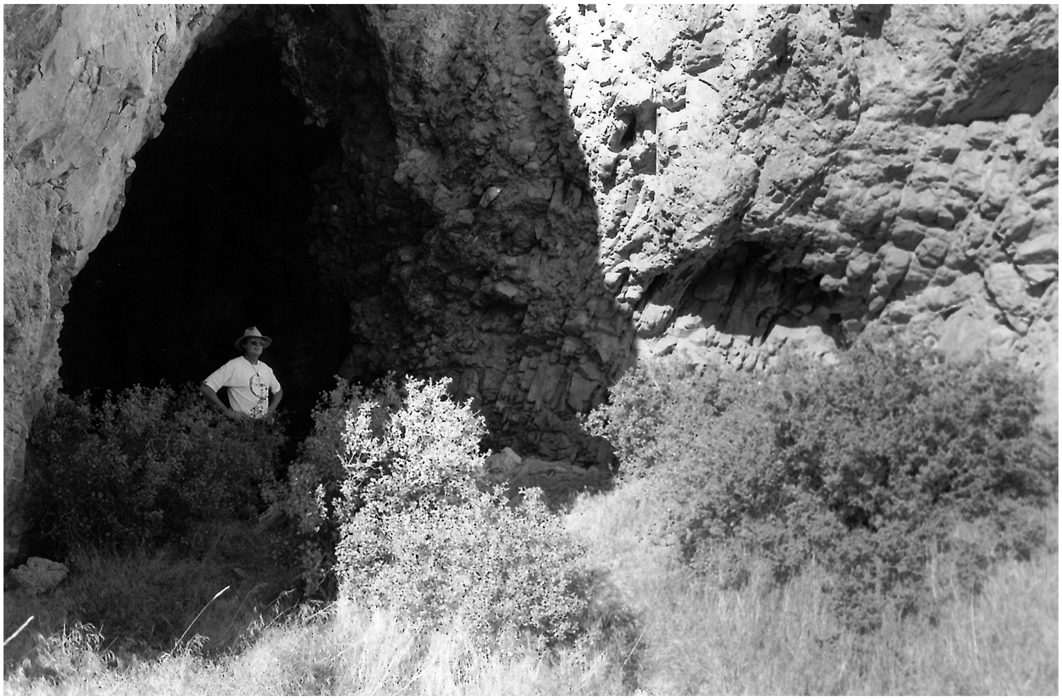

__Figure 21.__ View of the mesic microhabitat in the mouth of Homestead Cave.

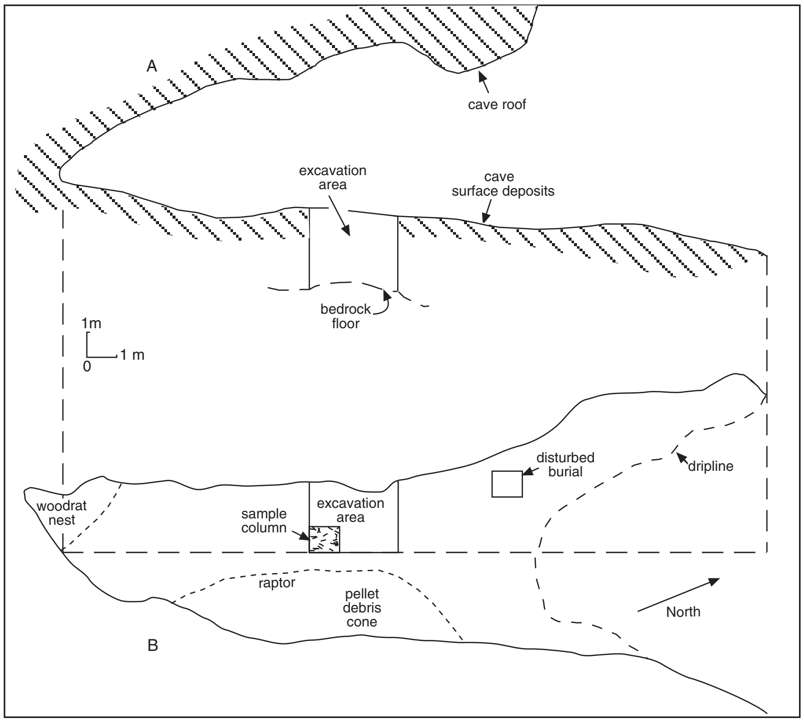

__Figure 22.__ Profile (A) and plan (B) schematic of Homestead Cave.

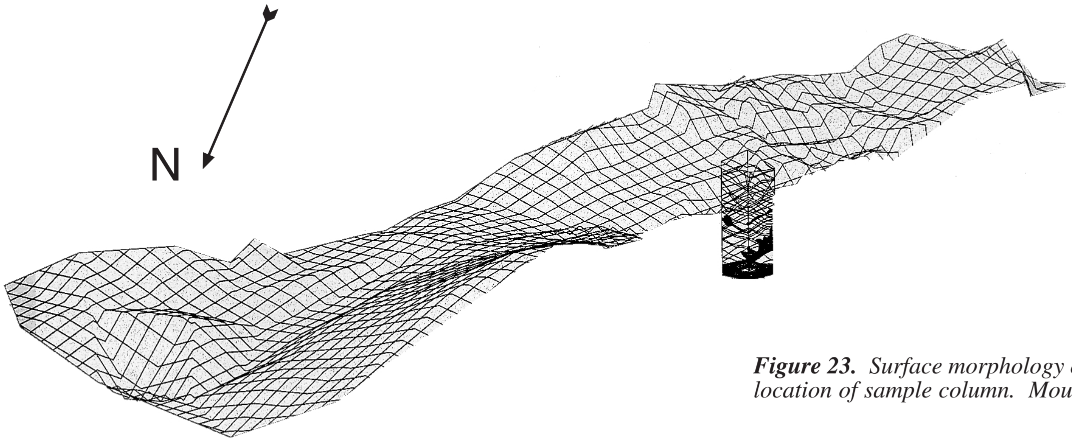

__Figure 23.__ Surface morphology of the Homestead Cave floor showing location of sample column. Mouth of cave is to the left.

ly of whole and partially disarticulated raptor pellets occur below these perches (figure 14). Small animal skeletal elements originating from these pellets cover most of the cave floor.

INITIAL EXPLORATION

Homestead Cave was unrecorded prior to our first visit in 1993 despite recent archaeological work in the area (see Arkush, 1991, 1994; Arkush and Workman, 1993b). While the project goals are almost entirely paleoecological in scope, a surface inventory revealed the presence of a limited cultural deposition, and initial work at the site consisted of recording site parameters for inclusion in federal and state archaeological site files. The Smithsonian trinomial identification number issued by the State Historic Preservation Office for the cave is 42Bo763. Cultural materials were limited to a few pieces of twine in the backdirt from a looter's pit. There were no surface indications of cultural deposition.

Test excavations were initiated on May 24, 1993 by mapping the cave and imposing a metric grid system on the site to provide horizontal controls. The grid system (figure 24) is oriented along the long north-south axis of the cave and is centered on an imaginary datum point outside and west of the cave mouth. All horizontal measurements represent points south and east of this imaginary datum (see 117.45 m south, 98.6 m east is a point just inside the cave mouth along the west wall). A permanent reference point is marked by a steel stake at point 112S 100E. The 100E line which runs north-south through this point is oriented 31° east of true north. Excavations were geared towards the removal of deposits from a series of 1 x 1 meter squares. Fill within each of these squares is designated vertically by stratigraphic unit, and horizontally by the grid point on the northwest corner of each square. More precise measurements were recorded for individual items where appropriate.

Our test excavations were initially limited to the clearing of spoil dirt from the looter's pit along the west-central portion of the cave, and to cleaning and profiling the pit walls. After spoil from the hole was cleared away, slightly more than one meter of the upper cave deposits was exposed. Careful evaluation and mapping of the pit profiles revealed the presence of large quantities of small animal bone in a well-stratified context and the absence of significant cultural disturbance of the depositional sequence. Based on these results, Homestead Cave was selected for the extraction of a sample column.

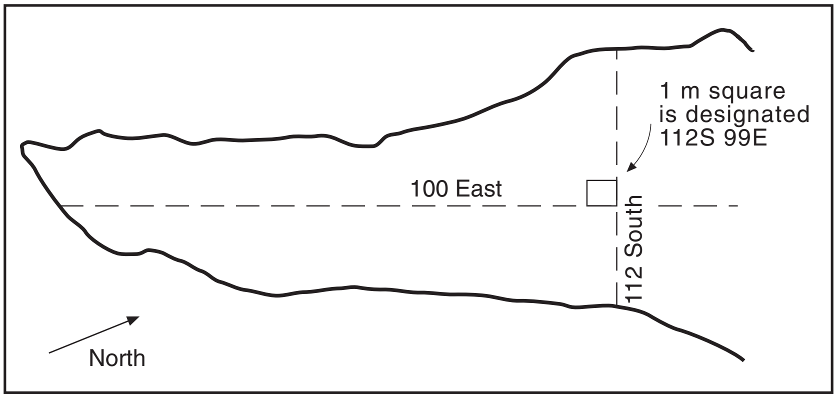

Figure 24. *Schematic of horizontal control system at Homestead Cave.*

ISOLATION AND EXCAVATION OF SAMPLE COLUMN

The excavation of a stratified faunal sample from Homestead Cave was initiated by squaring up the walls of the looter's pit to conform to the horizontal control system and by extending the resulting excavation area down into underlying undisturbed materials. Due to problems with rockfall and slumping, this excavation area was eventually extended to a 3.0 m x 2.5 m area along the center of the western wall (figure 22). A column one m^2 in the southeast corner of this excavation area, immediately below and downslope from the largest raptor perch and associated pellet cone, was selected for isolation and sampling. All material from outside this column was screened through 6.3 mm mesh screen to recover any possible cultural items in the deposits. In some instances, samples of the fill from various stratigraphic units were screened through 3.1 mm mesh screen to evaluate the nature of the faunal remains they contained.

The deposits from around the sample column were excavated in relatively coarse stratigraphic units due to the exploratory nature of this initial work and to the texture of the deposits themselves. Very thin depositional layers are often difficult to recognize during exploratory operations when excavations come directly down on top of them. As a result, materials from these thinner depositional layers usually become mixed into thicker overlying strata, and it becomes pointless to try to separate them. Once vertical exposures are available, excavation in much greater detail is possible. This normal excavation problem was exacerbated at Homestead Cave by the coarse rockfall along the western wall of the cave. The east-to-west slope of the modern surface appears to have been present throughout the depositional history of the site, and larger spall, up to 0.5 m in diameter, consistently accumulated at the toe of this slope. Individual depositional layers were difficult to trace both laterally and vertically through this rockfall area. The presence of this coarse spall in the sidewalls of the excavation area also promoted ready slumping of the remaining deposits and it was necessary to install extensive bracing to prevent cave-ins. Working in and around this bracing markedly increased the difficulty of the excavations. The basal deposits also proved to be uniformly dark, almost black in color, due to their high organic and moisture components, and it was difficult to distinguish individual strata during exploratory operations at the bottom of the limited excavation area. Problems of these kinds were to be expected, however, and constituted the principal reason why we felt it necessary to isolate and describe the sample column in detail prior to excavating it. Upon completion of the exploratory phase, we were able to define a column which was isolated from major rockfall areas and in which the most detailed stratigraphy exposed in the excavation area could be described and mapped.

Deposition in a cave such as Homestead Cave is a product of both continuous and episodic events, some of which affect deposition across the entire floor of the cave and others of which are isolated in only a portion of the cave. The sediments range from thin, ephemeral deposits of limited distribution to thick, easily recognized strata that can be readily traced completely through the deposits. As a result, the way in which the stratigraphic sequence is defined at such a site is due largely to the goals of the project, and "stratigraphy" can vary significantly as these goals change. In our case, because our primary goal was the recovery of a sequence of dated faunas uncontaminated by extensive bioturbation, the definition of stratigraphy within the cave was based largely on our ability to map and excavate individual stratigraphic units. This led to the definition of three kinds of depositional units: (1) "excavatable" deposits having clearly defined upper and lower surfaces that could be easily mechanically separated in the excavation process; (2) "mappable" deposits that could be traced completely around the sample column but that could not be separately excavated because of textural problems between over-and-underlying deposits; and (3) "ephemeral" deposits that could be recognized and described, but which were too limited or discontinuous in extent to map throughout the column. Ultimately, we defined 29 mapped stratigraphic layers in the three-m-deep column. These were combined into 18 separately removed excavation units. Innumerable "micro" laminae were clearly evident within this more coarsely defined stratigraphy, and, by limiting analyses reported in subsequent chapters to these 18 excavation units, we do not mean to imply that materials within them were bioturbated. To the contrary, the microlaminae indicate such disturbances were very limited, and the 18 stratigraphic units are a by-product of our ability to confidently separate excavated materials completely across the column. Prior to excavation, this stratigraphic sequence on the north and west sides of the sample column was mapped and described in detail. The southern profile was mapped and described after the sample column was removed. An extensive photographic record was also made in both still and video camera formats.

The sample column was excavated and removed in two separate stages due to complications imposed by slumping of the loosely compacted and much drier upper deposits. The upper one-third of the column, containing the entire cultural sequence at the site, was defined and excavated prior to the exposure and isolation of the lower portion. Each excavation unit was removed by a single excavator (Madsen) using a small trowel and working from both exposed surfaces. For the sake of consistency, the same individual excavated the entire column. Disturbed fill from krotovina and small rockfall blocks was discarded. The few cultural features, including a small hearth, were mapped in place. Fill from these features was separately collected. No processing of these sample column deposits was done at the site. The fill from each excavation unit was simply double bagged in large plastic garbage bags and transported to the laboratory for processing and analyses. One hundred eleven bags were eventually carried down Homestead Knoll. Pollen samples were extracted from the remaining southern profile subsequent to the excavation of the sample column. A series of radiocarbon samples, comprising primarily individual woodrat fecal pellets, was also hand-picked from the profile for accelerator dating to supplement dates run on materials from the bulk samples (figure 25).

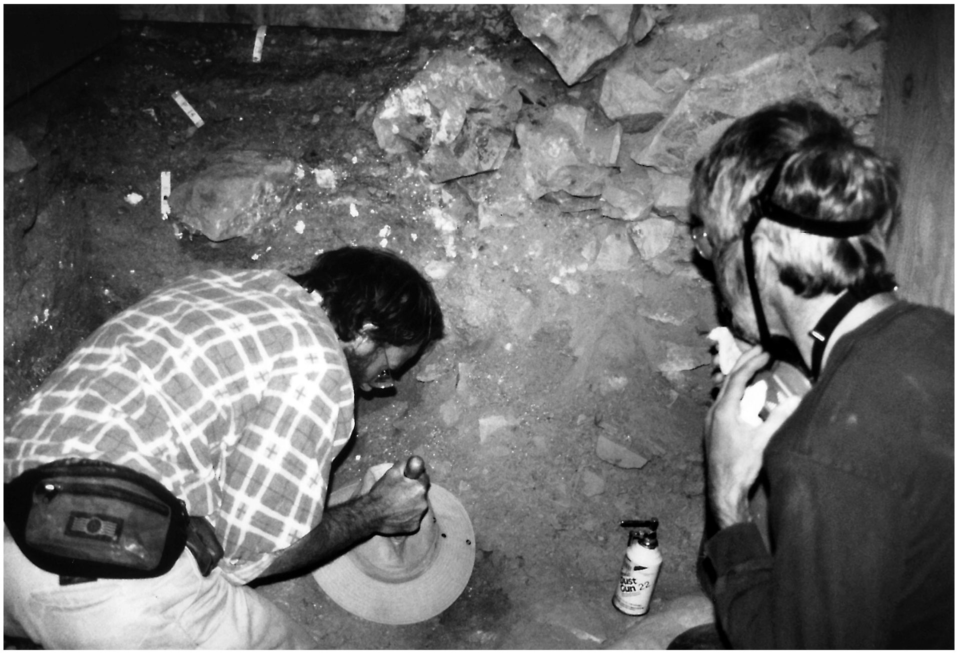

Figure 25. *Selecting individual fecal pellets directly from the profile face for radiocarbon dating.*

Stratum I was sampled in several different ways due to its complexity and evidence of a major depositional change within the unit (figure 26). Initially, Stratum I was collected as an entire unit in a manner similar to the rest of the column. Additional samples of the upper and lower one-half of the lowest excavation unit were separately removed from the profiles south and east of the sample column. This was done to provide better chronological controls after preliminary radiocarbon dating suggested that the deposition spanned several thousand years and the original bulk sample may have contained a mix of sequent faunas. Finally, ~2 liter samples were collected from the upper and lower 10 cm of Stratum I in the south profile where it was thickest (30 cm) and where a major stratigraphic break was most evident. This allowed a clean separation of different faunas in the top and bottom of Stratum I.

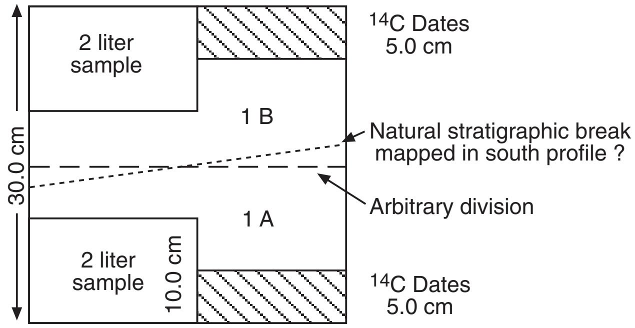

Figure 26. *Stratum I sampling scheme.*

LABORATORY ANALYSES AND SAMPLE PROCESSING

Materials from the sample column at Homestead Cave were processed at the laboratories of the three principal institutions involved in the project. Sample bags were initially returned to the Utah Geological Survey (UGS) where they were opened and allowed to dry to prevent moulding and to ease the sorting process. The sample was then passed through a set of graded screens commercially available in large sheets. These sizes, 19 mm, 6.3 mm, 3.1 mm, and residual materials, correspond to those most often used in the analyses of small mammal fauna in sites from western North America (see Grayson 1983, 1991). It is important to note, however, that these are the average measured mesh sizes, rather than those advertised, and there is some variation due to slight flaws in the weave. This is only important for the smallest screen size, since everything larger than 3.1 mm was completely sorted and analyzed. Analysis of the residual material which passed through the 3.1 mm mesh screen was limited to a 5-liter subsample, since little information on mammal faunas is added to that available from materials larger than that size (Grayson, 1984). Ostracodes and snail fragments were hand sorted from this subsample which was also scanned for any very small animal teeth that may have slipped through the larger mesh screen. Reptiles remain unanalyzed, as do many identifiable specimens, such as those from bats, which passed through the 3.1 mm mesh screen. Future analyses of these materials may substantially supplement the environmental record reported here.

Material larger than 4.5 mm in each sample was hand sorted into broad analytical categories at the UGS laboratory. These include limestone spall, tufa spall, bone, floral remains, fecal pellets, insect remains, gastropods and ostracodes. Materials in each of these categories were rebagged and sent to the relevant specialist for detailed analysis. Analytical procedures specific to each of these general categories are described where relevant in following chapters. The limited number of cultural items recovered from the sample column and from elsewhere in the site were individually sorted and were bagged and labeled following curation procedures outlined by the Utah Museum of Natural History. This was a long and tedious process since the number of items sorted averaged more than 16,500 per liter of fill (exclusive of rock) and the sample column contained more than 3,000 liters of fill.

Material caught in the 3.1 mm mesh screen was sent to the faunal laboratory at the Burke Museum, University of Washington, Seattle. There, all bone was removed by hand sorting and retained for analysis and identification. The remaining unsorted material from the 3.1 mm screen was sent to the laboratories of the Desert Research Institute, Reno, where the floral material was sorted and removed. The samples were then returned to the UGS laboratories where gastropods, ostracodes and insect remains were sorted out. This rather circuitous sorting process was engendered by the tedious, time-consuming nature of the task. For example, most of the identifiable faunal material from each sample was caught in the 3.1 mm mesh screen (see chapter seven) and hand-picking a sample of this size proved to be an arduous task.

The weight and volume of each sample was recorded to provide a measure by which samples could be compared in a standardized fashion (table VI). Each sample was weighed after it was allowed to dry, so as to minimize variation introduced by the position of the sample in the upper and drier or lower and wetter portions of the column. Volumes were estimated during the screening process at the laboratories but are suspect because of the introduction of differential compaction during the excavation, bagging and transport process. The volume estimates listed here are derived from the mapped profiles by multiplying the average area of each excavation unit by the one-meter dimension of the sample column and are probably much more reliable. Since there is considerable variation in the size of the 18 excavation units, weight or volume is used where appropriate in the following analyses to provide estimates of changing proportions of various taxa through time.

Table VI

Weight and volume of excavation units in the Homestead Cave sample column

Stratum	Weight (kg)	Volume (m^3)
XVIII	20.7	.025
XVII	198.3	.290
XVI	100.0	.057
XV	199.8	.288
XIV	88.5	.158
XIII	179.0	.306
XII	147.3	.180
XI	99.3	.115
X	55.7	.044
IX	114.6	.120
VIII	38.2	.075
VII	65.1	.062
VI	105.0	.216
V	9.53	.045
IV	143.0	.205
III	16.5	.108
II	52.5	.176
I	90.7	.150
Ib	5.97	.010
Ia	11.9	.019

CHAPTER FOUR
Homestead Cave Sediments and Chronology

INTRODUCTION

The stratigraphic sequence at Homestead Cave (figure 27) was initially defined during the 1993 isolation of the sample column and was reconfirmed and slightly refined during a 1994 effort to obtain a more detailed radiocarbon record. Three sides of the sample column stratigraphy were mapped; the south profile (figure 28) shows the slight 1994 modifications. The descriptions of the deposits, below, are essentially those made in the field, but they have been modified where necessary based on laboratory analyses. Additional assessments of the spalling sequence in the cave and of the more critical depositional units in the column supplement these descriptions. With the exception of four radiocarbon age estimates from bulk samples analyzed for initial control purposes, all age estimates are derived from samples taken directly from mapped profiles.

Overall depth of the column varies slightly due to differences in both bedrock and surface morphology. Maximum depth is 2.82 m; minimum depth is 2.65 m. In the profiles of the sample column and excavation area, the strata in Homestead Cave appear to be generally undisturbed by bioturbation, and the few areas that were clearly burrowed or disrupted (primarily along the west wall of the cave) were avoided during sampling. What evidence there is for mixing (as in very small numbers of fish bones and gastropods in the upper strata) appears due to undetected (and unavoidable) rodent burrowing along the margin of large roof-fall blocks. Away from these blocks, microlaminae are undisturbed and not bioturbated. All radiocarbon samples were derived from these undisturbed microlaminae. Many layers show moderate to strong stratification of roof spall, bone and feces. Bone is not usually a descriptive feature in most sediment profiles, but it is a primary feature of the Homestead Cave sequence. The coherency of the ^{14}C results supports the notion that the cave deposits, where sampled, were laid down sequentially on the flanks of raptor pellet mounds, and that they are little disturbed by later bioturbation. Where multiple ^{14}C age estimates were obtained on individual fecal pellets from the same microstrata within major stratigraphic units, for example

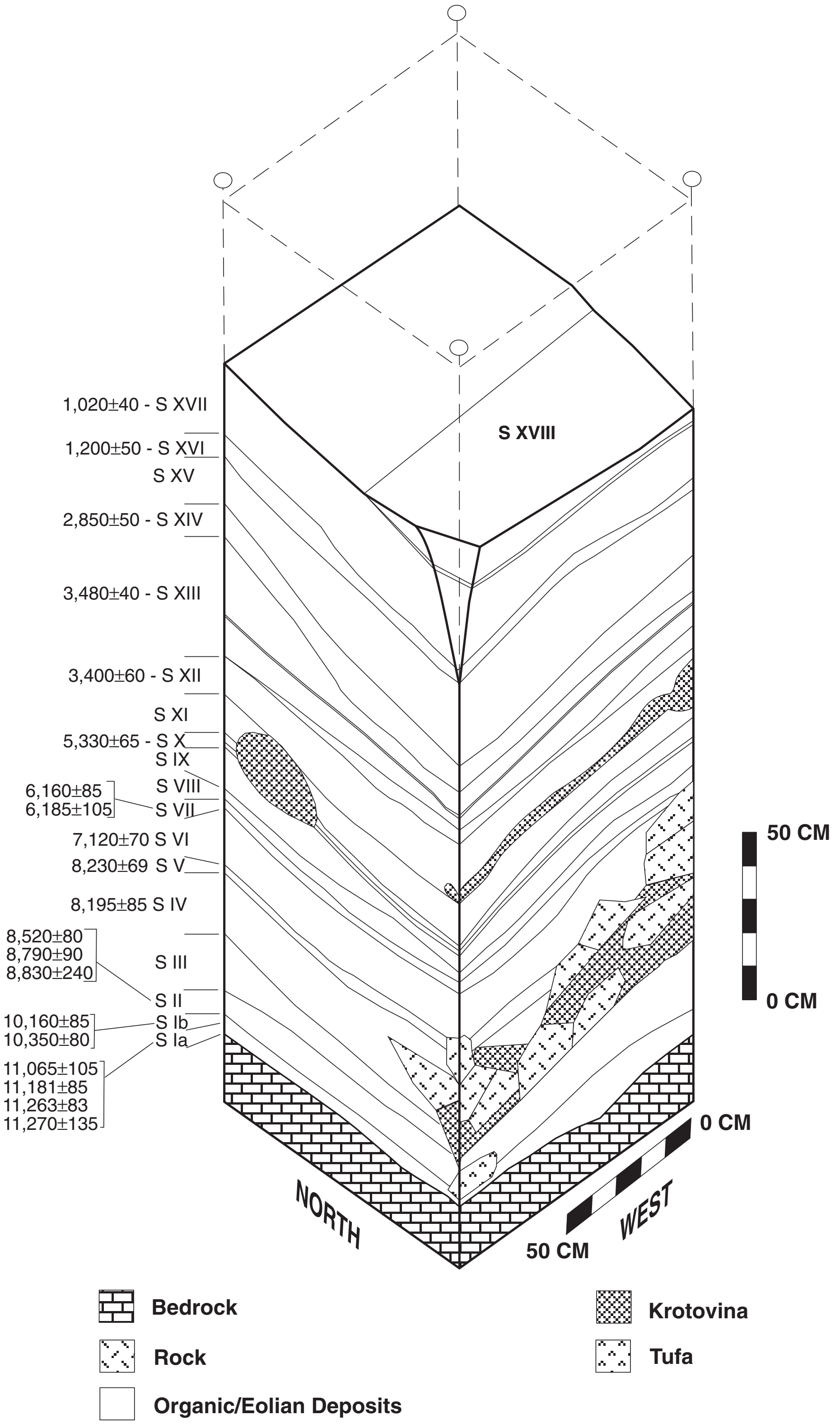

Figure 27. Three-dimensional view of Homestead Cave sample column stratigraphy showing the north and west profiles and radiocarbon age estimates.

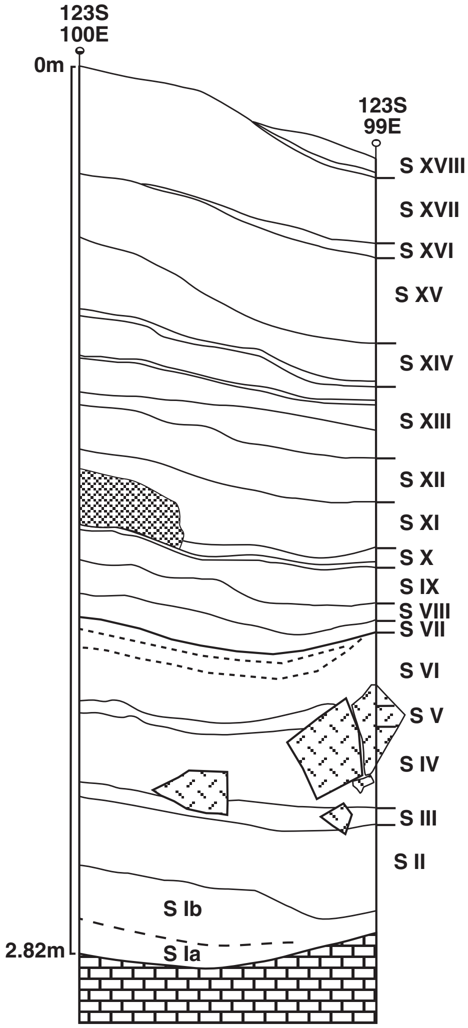

Figure 28. South face of the Homestead Cave sample column. Note the stratigraphic break within Stratum I not readily apparent in the other profiles.

Units Ia, Ib and VII, they are within, or close to within, one standard deviation of each other. This concordance of age estimates, if representative, shows that there is little mixing of feces of greatly different ages from the time they were dropped to when they were incorporated into layers. By analogy, the faunal remains from each stratigraphic unit should be the same age as the feces dated from that horizon.

STRATIGRAPHIC DESCRIPTIONS

(*with Jay Quade*)

The Middle Pennsylvanian limestone bedrock in the excavation area has been heavily rounded and polished by wave action during at least the last lake cycle. However, there is no evidence of lacustrine deposition of either fine-grained deep-water deposits or coarser shoreline beach materials. This may be a product of the cave morphology, as the bedrock surface tilts sharply downward from the back of the cave to the front (figure 29). Any remnant regressive-phase beach deposits may be limited to areas in the cave mouth. Tufa in the cave is a calcium carbonate deposit precipitated from supersaturated lake waters through biochemical action. The definitions and classifications of tufas vary widely (see Pedley, 1990; Viles and Goudie, 1990; Benson, 1994), and the Homestead Cave tufa is here described only as a microdetrital, algal tufa, taking a sheet form. The ~20 cm-thick tufa has exfoliated off interior cave surfaces, but remains on most exposures immediately outside the cave. Estimates of tufa deposition rates vary (Viles and Goudie, 1990), but suggest that the Homestead Cave tufa could have formed in a lake stillstand lasting less than 200 years. The tufa probably formed in the offshore, deeper water littoral zone and the lake surface may have been 5-15 m above the cave itself, about the level of the wave-cut ridge surface above the cave. The tufa has not been directly dated and the time of its deposition is unknown. Because of the relative speed of lake regression it has often been assumed that most Bonneville-cycle tufas from middle elevations are derived from transgressive-phase stillstands, but the presence of a tufa-coated gastropod and ostracode fauna in the cave suggests that it may be associated with a post-Provo lake.

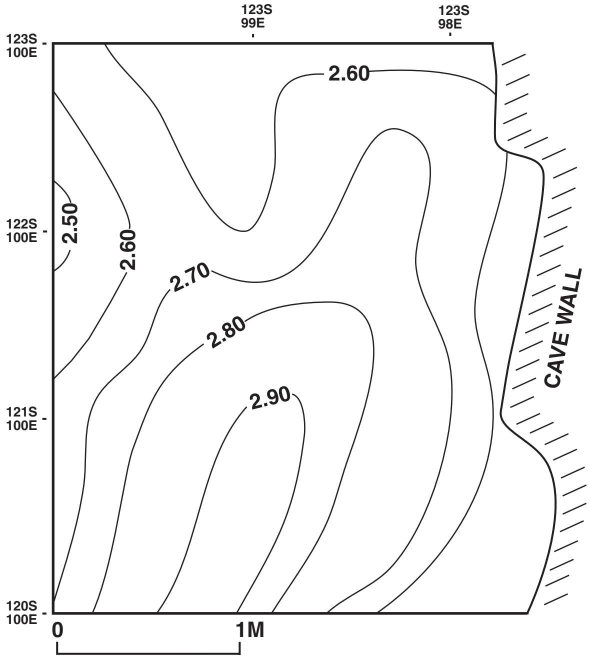

Figure 29. Bedrock surface morphology in the Homestead Cave excavation area. Note the relatively steep interior-to-exterior slope.

Stratum I

Stratum I is a moist, very dark reddish-brown (5YR3/4) silty loam directly overlying the floor of Homestead Cave. It is highly organic and exhibits a "greasy" texture. Internal microstratification is evident, characterized by discontinuous lenses of thin (<1 cm thick), light grayish-brown fine-grained sediments (figure 30). A major break in the Stratum I depositional sequence was noted during mapping of the south profile, but neither this major break nor the microlaminae could be traced continuously throughout the stratum and, as a result, they were not separately excavated. Stratum I varies

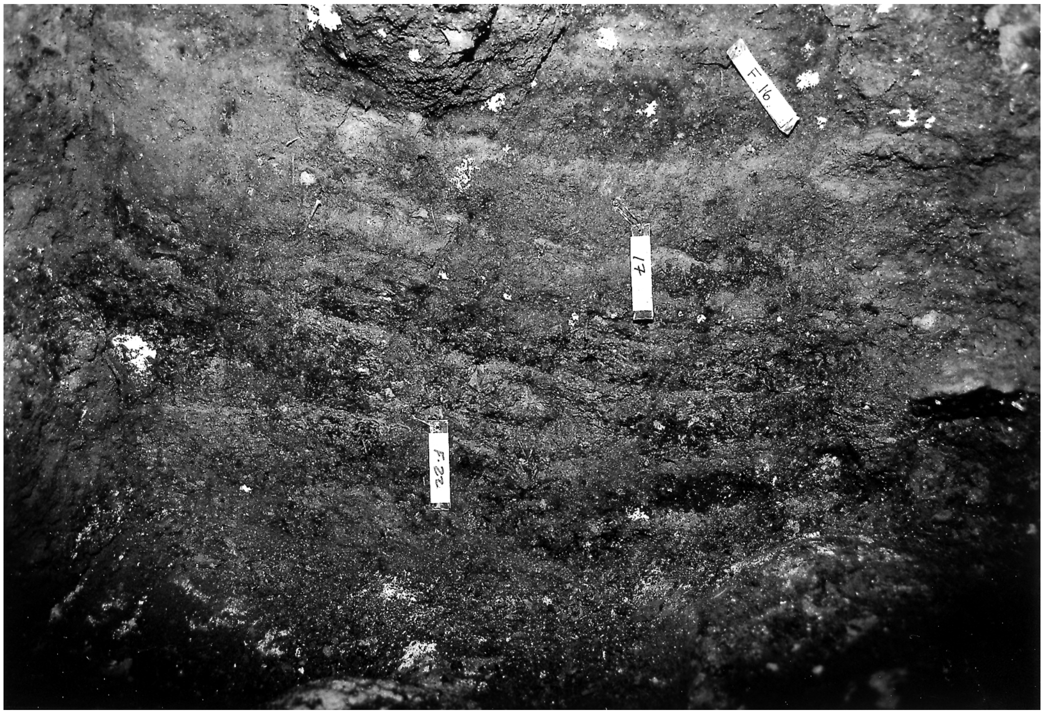

Figure 30. *Close-up view of microstratigraphy in Stratum I.*

in thickness due to the undulating nature of the underlying limestone bedrock, ranging from a maximum of 30.0 cm to a minimum of 6.0 cm thick around the circumference of the sample column. Within the column it averages 15 cm in thickness and has a total volume of 0.150 m^3. The weight of this collected sample is 90.7 kg. It consists primarily of degraded organic material and fine-grained sediments. These latter consist of both sands and aeolian materials. The water-modified sands are well mixed with other materials and appear to derive from down-slope colluviation of Provo and Bonneville-level lake sediments. Large blocks of exfoliated tufa up to 20 cm in diameter occur within the unit. Limestone eboulis is present, but represents a smaller proportion of total volume than in upper depositional units. Total rock (>3.1 mm) weighs 15.7 kg. Residual finer grained deposits (<3.1 mm) weigh 67.7 kg. Large numbers of small faunal elements are present. Plant macrofossils are limited to hackberry (*Celtis* sp.) endocarps found primarily in the upper half of the stratum. Fish elements do not occur in the upper one-third of the stratum and disappear sometime during the middle of the Stratum I depositional sequence. Protein from a marmot femur collected from the Stratum I bulk sample provides an age estimate of 10,910 ± 60 yr B.P. (Beta 72205).

Stratum Ia is the arbitrarily defined lower one-half of Stratum I in the east and south profiles adjacent to the sample column. Given the clear stratigraphic break evident in the south profile, samples from Ia and Ib may represent real depositional differences but are likely contaminated to some extent by the arbitrary nature of their excavation. Material is sticky and plastic, and the unit is weakly stratified to unstratified. A large (>50%?) proportion of the layer is composed of small (~1 cm long), crushed fecal remnants. The average thickness of Stratum Ia is 7.5 cm. Total sample weight is 11.9 kg. Total rock (>3.1 mm) weighs 0.12 kg. Residual finer-grained deposits (<3.1 mm) weigh 10.9 kg. Fecal pellets of *Neotoma* sp. from the lowest 5 cm of the unit, directly overlying bedrock, provide age estimates of 11,270 ± 135 yr B.P. (AA 14816), 11,263 ± 83 yr B.P. (AA 16809), 11,181 ± 85 yr B.P. (AA 16808) and 11,065 ± 105 yr B.P. (AA 14817).

Stratum Ib is the arbitrarily defined upper one-half of Stratum I. The matrix is sticky and plastic, and the unit is well stratified in places. Crushed fecal pellets appear to dominate this unit, as in Stratum Ia. The average thickness of Stratum Ib is 7.5 cm. Total sample weight is 5.97 kg. Total rock (>3.1 mm) weighs 0.37 kg. Residual finer-grained deposits (<3.1 mm) weigh 5.17 kg. Fecal pellets of *Neotoma* sp. taken directly from the upper 5 cm of the mapped deposits on the south column profile provide age estimates of 10,350 ± 80 yr B.P. (AA 11818) and 10,160 ± 85 yr B.P. (AA 11819).

Stratum II

Stratum II consists of a dark brown, highly organic silty loam characterized by large numbers of hackberry endocarps. It contains relatively few angular limestone spalls but does contain numerous tufa spalls up to 30 cm in diameter. The matrix is sticky, slightly plastic, loose, and largely unstratified. Large numbers of small faunal elements are present, as well as artiodactyl and woodrat fecal pellets. Color is generally dark brown (10YR3/4 to 10YR 4/4), but the stratum contains a significant eolian component in the upper portion of the unit and the color is brownish yellow (10YR6/6) in places. Stratum II ranges in thickness from a maximum of 30.0 cm to a minimum of 6.0 cm around the circumference of the sample column and averages 17.6 cm. Its total volume is 0.176 m^3. The weight of this collected sample is 52.5 kg. Residual finer-grained deposits (<3.1 mm) weigh 32.5 kg. The age of the Stratum II deposits is controlled by three radiocarbon age estimates. One, on hackberry endocarps collected from a bulk sample in the laboratory, provides an age estimate of 8830 ± 240 yr B.P. (Beta 63438). The remaining two are AMS age estimates on single hackberry endocarps of 8790 ± 90 yr B.P. (AA 14820) and 8520 ± 80 yr B.P. (AA 14821). Wang and others (1997) also obtained an experimental age estimate from endocarp carbonates of 7880 ± 50 yr B.P. (RA-CO416).

Stratum III

Stratum III is a thin, medium brown (10YR6/6) layer of mixed organic and eolian material. Its upper and lower surfaces are somewhat amorphous and can be distinguished only with difficulty. It contains limited amounts of spall, mostly smaller than 5 cm in diameter, but a large area of rockfall occurs along the western margin of the sample column and extends into the overlying Strata IV and V. Small faunal elements, hackberry endocarps and artiodactyl/woodrat fecal pellets are prevalent. Stratum III ranges in thickness from a maximum of 24.0 cm to a minimum of 3.0 cm around the circumference of the sample column and averages 10.8 cm. Its total volume is 0.108 m^3. The weight of this collected sample is 16.5 kg. Residual finer-grained deposits (<3.1 mm) weigh 5.4 kg. Stratum III is undated.

Stratum IV

Stratum IV consists of a thick, faintly stratified, highly organic, dark yellowish-brown (10YR5/6 to 5/8) silty loam. It is sticky, slightly plastic and loose. Eolian deposition is apparent, but there are no evident bedding planes (figure 31). It contains randomly oriented spall of mixed tufa and limestone and, with the exception of a few larger pieces up to 25 cm in diameter, most are small. It contains abundant hackberry seeds, lower proportions of artiodactyl and woodrat fecal pellets, and rare elements of other vegetation types. Stratum IV ranges in thickness from a maximum of 29.0 cm to a minimum of 3.0 cm around the circumference of the sample column and averages 20.5 cm. Its total volume is 0.205 m^3. The weight of this collected sample is 143.0 kg. Residual finer-grained deposits (<3.1 mm) weigh 80.9 kg. The age of Stratum IV is controlled by a single radiocarbon age estimate of 8195 ± 85 yr B.P. (AA 14823) run on a single artiodactyl fecal pellet.

Stratum V

Stratum V is a thin, light yellowish-brown (10YR6/5 to 7/3) silty loam containing higher proportions of eolian silts and reduced amounts of organic materials relative to other strata. Hackberry endocarps, small angular limestone spall, and small faunal elements are common. The upper and lower surfaces are irregular, and Stratum V can be distinguished from upper and lower deposits only with difficulty. Stratum V ranges from a maximum of 8.0 cm to a minimum of 3.0 cm thick around the circumference of the sample column and averages 4.5 cm. Its total volume is 0.045 m^3. Approximately half this sample was contaminated in the laboratory and was discarded. The weight of the remaining half sample is 9.5 kg. Residual finer-grained deposits (<3.1 mm) weigh 2.2 kg. The age of Stratum V is controlled by a single radiocarbon age estimate of 8230 ± 69 yr B.P. (AA 16810) run on a single artiodactyl fecal pellet. The two age estimates from Strata IV and V are statistically indistinguishable, suggesting they were laid down in rapid succession.

Figure 31. *View of the lower portion of the south face of the Homestead Cave sample column.*

Stratum VI

Stratum VI is a relatively thick, organic-rich deposit containing large amounts of small faunal elements. It is sticky, slightly plastic and loose. Some minimal internal stratification is evident, characterized mainly by color variation, but no bedding planes are apparent. Color ranges from light yellowish brown to very dark brown (10YR6/4 to 3/3). Artiodactyl and woodrat fecal pellets are common, but hackberry endocarps are rare. Angular limestone spall is significantly reduced and is generally of small size, although a few pieces reach 40 cm in diameter. Two depositional layers are mapped as Stratum VIa and VIb in the south profile, but Stratum VI was excavated as a unit and they are not treated separately for analytical purposes. Stratum VI ranges in thickness from a maximum of 28.0 cm to a minimum of 5.0 cm around the circumference of the sample column and averages 21.6 cm. Its total volume is 0.216 m^3. The weight of this collected sample is 105.0 kg. Residual finer-grained deposits

(<3.1 mm) weigh 64.4 kg. The age of Stratum VI is controlled by an AMS radiocarbon age estimate of 7120 ± 70 yr B.P. (AA 11426) run on a single artiodactyl fecal pellet.

Stratum VII

Stratum VII is a thin layer of light, very pale brown (10YR7/3)) eolian and/or colluvial silt containing reduced amounts of organic material. It is conspicuously stratified. The relative proportion of small spall is also reduced, although some fragments up to 15 cm in diameter are evident. There are abundant small, imbricated chips of roof spall, mostly in grain-to-grain contact. Stratum VII contains woodrat pellets and rare fragments of plants (no hackberry endocarps are evident). It ranges in thickness from a maximum of 11.0 cm to a minimum of 3.0 cm around the circumference of the sample column and averages 6.2 cm. Its total volume is 0.062 m^3. The weight of this collected sample is 65.1 kg. Residual finer-grained deposits (<3.1 mm) weigh 28.2 kg. The age of Stratum VII is controlled by two AMS radiocarbon age estimates of 6160 ± 85 yr B.P. (AA 14824) and 6185 ± 105 yr B.P. (AA 11825) run on single artiodactyl fecal pellets.

Stratum VIII

Stratum VIII is a dark to very dark brown (10YR3/3) highly organic silty loam containing relatively reduced amounts of small angular limestone spall. It is generally well stratified. The proportion of small faunal elements is very high, and in places the stratum appears to be almost pure bone. Krotovina are evident throughout the stratum and a rodent nest was identified and discarded prior to removing the stratum from the sample column. The proportion of eolian/colluvial silt appears to be reduced. Stratum VIII ranges in thickness from a maximum of 12.0 cm to a minimum of 4.0 cm around the circumference of the sample column and averages 7.5 cm. Its total volume is 0.075 m^3. The weight of this collected sample is 38.2 kg. Total rock (>3.1 mm) weighs 20.9 kg. Residual finer-grained deposits (<3.1 mm) weigh 14.5 kg. Stratum VIII is undated.

Stratum IX

Stratum IX is a thin, pale yellowish-brown (10YR 6/5 to 7/5) depositional layer containing reduced amounts of organic debris and small angular spall. The deposition is characterized by very abundant, well-stratified roof spall in grain-to-grain contact. It appears to be primarily of eolian origin, although some colluvial silt may be present. It appears to contain some microlaminae, but individual laminae cannot be mapped or excavated separately. Artiodactyl fecal pellets and small faunal elements are common. Some recent limited contamination from krotovina is suggested by the presence of a piece of electrical wire probably originating from a relic hunter's pit adjacent to the sample column. Stratum IX ranges in thickness from a maximum of 17.0 cm to a minimum of 5.0 cm around the circumference of the sample column and averages 12.0 cm. Its total volume is 0.120 m^3. The weight of this collected sample is 114.6 kg. Residual finer-grained deposits (<3.1 mm) weigh 3.05 kg. Stratum IX is undated.

Stratum X

Stratum X consists of two very thin depositional layers which could be readily mapped, but could not be separately excavated with confidence. Stratum Xa, the lower of the two, is a very thin light gray, almost white (10YR8/2) eolian deposit containing very reduced amounts of organic staining and relatively few small faunal elements. Some small angular spall is evident. It ranges in thickness from a maximum of 2.0 cm to a minimum of 1.0 cm around the circumference of the sample column and averages 1.5 cm. Stratum Xb, the upper of the two, is an organic-rich silty loam with a relatively high concentration of small faunal elements, some artiodactyl and woodrat fecal pellets, and reduced amounts of small angular spall. Rare elements of plant macrofossils occur. It is dark yellowish brown in color (10YR 4/4 to 5/6). Cultural material, limited to two pieces of twine, is rare and probably originates from this upper subunit. Stratum Xb ranges in thickness from a maximum of 7.0 cm to a minimum of 2.0 cm around the circumference of the sample column and averages 4.5 cm. The total volume of Stratum X is 0.058 m^3. The weight of this collected sample is 55.7 kg. Residual finer-grained deposits (<3.1 mm) weigh 22.6 kg. The age of Stratum Xb is controlled by a single radiocarbon age estimate of 5330 ± 65 yr B.P. (AA 14822) run on an individual artiodactyl fecal pellet.

Stratum XI

Stratum XI is a pale yellow (2.5Y8/4) eolian deposit containing a relatively high proportion of large to medium-sized angular spall. Much of this spall is highly eroded, and virtually every fragment is covered by a rind of partially decomposed limestone. Some of the finer-grained sediments may be of colluvial origin and/or of degraded bedrock. Stratum XI is generally well stratified but grades into a thick area of rockfall along the western margin of the cave. Small amounts of organic debris and small faunal elements are present but may be a product of bioturbation. Cultural remains are present but rare, consisting of an ignimbrite atlatl point fragment and a piece of twine. Stratum XI ranges in thickness from a maximum of 22.0 cm to a minimum of 4.0 cm around the circumference of the sample column and averages 11.5 cm. Its total volume is 0.115 m^3. The weight of this collected sample is 99.3 kg. Residual finer-grained deposits (<3.1 mm) weigh 26.9 kg. A large charred log identified as pine, on the surface of Stratum XI and apparently brought into the cave by humans (figure 32), provides an age estimate of 3400 ± 60 yr B.P. (Beta 63179).

Stratum XII

Stratum XII is a highly organic, light yellowish-brown (10YR6/4) deposit containing relatively lower portions of imbricated well-stratified spall in a silty matrix. The spall is generally less than 5 cm in diameter, although several specimens reach 15 cm in diameter. Artiodactyl and wood-rat fecal pellets are common and small faunal bones are preva-

Figure 32. View of large branch fragment probably imported into Homestead Cave by human occupants.

lent. Stratum XII is moist and plant macrofossils and items of cultural origin are rare; the latter items consist of several pieces of twine. The upper surface of this stratum is irregular and poorly defined due to large pieces of limestone spall which penetrate from the overlying Stratum XIII. Stratum XII ranges in thickness from a maximum of 25.0 cm to a minimum of 15.0 cm around the circumference of the sample column and averages 18.0 cm. Its total volume is 0.180 m^3. The weight of this collected sample is 147.3 kg. Residual finer-grained deposits (<3.1 mm) weigh 58.9 kg. The charred log at the base of the unit, noted above, may be associated with the deposition of Stratum XII.

Stratum XIII

Stratum XIII consists of four thin depositional layers, combined for excavation and sampling purposes because the irregular nature of their interfacing surfaces prevented their clean separation. Stratum XIIIa, the lowest of the four substrata, is a spall-rich layer packed in grain-to-grain contact. It contains the highest occurrence of a white powdery mineral (probably gypsum) in the entire sequence. The fine-grained sediments appear to contain both eolian and decomposed bedrock components. The light gray to very pale brown (10YR7/3) deposit contains little obvious organic material. Both its upper and lower surfaces are poorly defined due to high spall content. It ranges in thickness from a maximum of 12.0 cm to a minimum of 2.0 cm around the circumference of the sample column and averages 5.6 cm. Stratum XIIIb is a thin, organically stained yellowish-brown (10YR6/6) deposit containing numerous artiodactyl and woodrat fecal pellets. It is moist and contains few plant macrofossils. Stratum XIIIb ranges in thickness from a maximum of 16.0 cm to a minimum of 5.0 cm around the circumference of the sample column and averages 10.7 cm. Stratum XIIIc is a very thin (less than 1 cm thick) eolian deposit which serves to separate the highly organic substrata above and below it. It is light gray in color (2.5Y7/2) and contains no evident spall component. Stratum XIIId, the uppermost of the four combined depositional units, is an organically stained yellowish-brown (10YR6/6) deposit containing numerous artiodactyl and woodrat fecal pellets. It is relatively dry and contains numerous plant macrofossils. Overall spall is dispersed, and the unit is primarily matrix-supported silt with crude layering. It is flecked with charcoal throughout and contains a number of items of human origin, principally twine. Stratum XIIId ranges in thickness from a maximum of 31.0 cm to a minimum of 5.0 cm around the circumference of the sample column and averages 13.9 cm. The total volume of Stratum XIII is 0.305 m^3. The weight of this collected sample is 179.0 kg. Residual finer-grained deposits (<3.1 mm) weigh 66.5 kg. Stratum XIII is dated by a standard radiocarbon analysis run on 30 g of mixed artiodactyl pellets. The age estimate is 3480 ± 40 yr B.P. (Beta 101878).

Stratum XIV

Stratum XIV is a mixed depositional unit containing eolian sediments, numerous angular spalls in the 3-5 cm diameter range (with a few larger specimens), and some plant macrofossils. Stratum XIVa, a thin, 1-2 cm thick eolian deposit at the base of the stratum, extends throughout the sample column and serves to separate Stratum XIV from underlying deposits. It could not be individually excavated, however. Stratum XIVb is mottled in color, but predominantly light gray (2.5Y7/2). Although it is relatively dry, it contains proportionally few artiodactyl fecal pellets. It is charcoal flecked, and items of human origin include an obsidian atlatl point and a number of pieces of twine. Stratum XIV ranges in thickness from a maximum of 20.5 cm to a minimum of 10.0 cm around the circumference of the sample column and averages 15.8 cm. The total volume of Stratum XIV is 0.158 m^3. The weight of this collected sample is 88.5 kg. Residual finer-grained deposits (<3.1 mm) weigh 31.0 kg. The age of Stratum XIV is controlled by a single standard radiocarbon age estimate of 2850 ± 50 yr B.P. (Beta 103692) run on 30 g of mixed artiodactyl fecal pellets.

Stratum XV

Stratum XV is a faintly bedded depositional unit containing numerous plant macrofossils, abundant artiodactyl fecal pellets and a relatively small proportion of angular spall. It is charcoal flecked and is light yellowish brown in color (10YR6/4). It contains abundant silt, with weakly stratified, dispersed spall. Items of human origin include a chalcedony arrow point, hide knots, and fragments of twine. Stratum XV ranges in thickness from a maximum of 41.0 cm to a minimum of 20.0 cm around the circumference of the sample column and averages 28.8 cm. The total volume of Stratum XV is 0.288 m^3. The weight of this collected sample is 199.8 kg. Residual finer-grained deposits (<3.1 mm) weigh 96.0 kg. Stratum XV is undated.

Stratum XVI

Stratum XVI is a thin layer of mixed organic ash, plant macrofossils, spall and eolian sediments associated with a hearth on the surface of Stratum XV. It contains numerous small faunal elements but relatively few artiodactyl fecal pellets and is light brownish-gray in color (5YR6/2 to 7/2). The hearth is partially disturbed but appears to have been relatively circular, roughly 35 cm in diameter, and about 5 cm thick. It appears to be the result of a small fire laid directly on the underlying surface with no preparation. Ash from the hearth extends throughout Stratum XVI, thinning towards the limit of the excavation area. The unit is completely filled with matrix silt and contains abundant angular spall and plant fragments. Stratum XVI ranges in thickness from a maximum of 12.0 cm to a minimum of 1.0 cm around the circumference of the sample column and averages 5.7 cm. The total volume of Stratum XVI is 0.057 m^3. The weight of this collected sample is 100.0 kg. Residual finer-grained deposits (<3.1 mm) weigh 37.0 kg. Charcoal from the hearth in Stratum XVI provides an age estimate of 1200 ± 50 yr B.P. (Beta 66940).

Stratum XVII

Stratum XVII is a thick layer of mixed small angular spall, plant macrofossils, and large chunks (to 50 cm in diameter) of fused guano and raptor pellets with minor amounts of fine-grained eolian sediments (figure 33). It is mottled in color, but generally appears to be a pale brown (10YR6/3). Some charcoal flecks are present and heavy concentrations of artiodactyl fecal pellets occur in the relatively dry depositional layer. Items of human origin include a metate of local bedrock material and a single piece of twine. Stratum XVII ranges in thickness from a maximum of 36.0 cm to a minimum of 19.0 cm around the circumference of the sample column and averages 29.0 cm. The total volume of Stratum XVII is 0.290 m^3. The weight of this collected sample is 198.3 kg. Residual finer-grained deposits (<3.1 mm) weigh 63.6 kg. The age of Stratum XVII is controlled by a single standard radiocarbon age estimate of 1020 ± 40 yr B.P. (Beta 101877) run on 30 g of mixed artiodactyl fecal pellets.

Figure 33. *View of the upper portion of the Homestead Cave sample column.*

Stratum XVIII

Stratum XVIII consists of the two uppermost recognizable depositional units in the sample column and is found only in the western half of the sample column. The two layers were excavated as a unit due to the indistinct interface between them. Stratum XVIIIa, the lower of the two substrata, is a thin layer of ash and small spall containing no evident plant or animal macrofossils. It is 1-2 cm thick where it occurs. Stratum XVIIIb is the uppermost deposit and consists of mixed and disturbed sediments. It is essentially dry and contains chunks of compacted raptor pellets, spall, plant macrofossils and minor amounts of eolian material. It is 13.0 cm thick along the western margin of the sample column and wedges out toward the center. The total volume of Stratum

XVIII is 0.025 m^3. The weight of this collected sample is 20.7 kg. Residual finer-grained deposits (<3.1 mm) weigh 6.7 kg. Stratum XVIII is undated.

CHRONOLOGY

(*with Jay Quade*)

Chronology at Homestead Cave is controlled by 25 radiocarbon age estimates (table VII). Four of these were obtained for experimental and control purposes and are not directly related to the sample column. While these are reported here, interpretation is based only on the remaining 21 age estimates obtained on samples collected from column deposits. Of these, 13 were obtained from individual fecal pellets of either woodrats or artiodactyls taken directly from the southern mapped face of the sample column. Two were obtained on charcoal also taken directly from cultural features within the sample column. The remaining six were obtained in the laboratory from the bulk samples collected from the column for analyses. Two of the three age estimates for Stratum II were obtained from individual hackberry endocarps. Only six of the 18 age estimates from the sample column are conventional radiocarbon age estimates. The remaining 15 were run using an accelerator mass spectrometer, since this allowed us to date individual specimens and assess the degree of variation among stratigraphically related samples. Accelerator mass spectrometer dating also generally produces a significantly reduced error range.

Standard ^{14}C pretreatment procedures were followed for samples dated at the University of Arizona accelerator facility, except the use of a base was omitted. Most samples were weakly to moderately calcareous, which the 6N HCl treatment removed. Experimentation with the base treatment on one sample showed there was no humic fraction present. This is not surprising given the relatively closed and dry conditions of the cave. The base treatment was therefore not performed on the dated samples. Pretreatment for the Arizona accelerator samples was: (1) soak in 20 ml ~6N HCl in 50 ml polypropylene centrifuge tubes, set in ~80°C bath for one hour, (2) centrifuge, decant and wash five times in milli-Q distilled H_2O; pH>5 in resultant solution, and (3) dry overnight in covered centrifuge tubes, transfer to clean glass vials, take to acclerator facility for combustion, conversion to graphite and counting.

The 21 radiocarbon age estimates from the sample column listed in table VII have been converted to calendrical dates and adjusted to changes in atmospheric ^{14}C using a calibration program (version 3.03c) produced by Stuiver and others (1998) and conversion sequences cited therein. Where the slope in the radiocarbon curve has been markedly affected by changes in atmospheric ^{14}C, particularly for the period

Table VII
Radiocarbon age estimates from Homestead Cave

Stratum	^{14}C Age	Cal Age (yr B.P.)	Lab No. (cal B.P.)*	Material
XVII	1020±40	925-961	Beta 101877	30 g artiodactyl pellets
XVI	1200±50	1058-1216	Beta 66940	charcoal
XIV	2850±50	2873-3056	Beta 103692	30 g artiodactyl pellets
XIII	3480±40	3689-3328	Beta 101878	30 g artiodactyl pellets
XII	3400±60	3572-3695	Beta 63179	wood/charcoal
X	5330±65	5993-6266	AA 14822	1 artiodactyl pellet
VII	6160±85	6906-7208	AA 14824	1 artiodactyl pellet
VII	6185±105	6908-7248	AA 14825	1 artiodactyl pellet
VI	7120±70	7865-8003	AA 14826	1 artiodactyl pellet
V	8230±69	9033-9399	AA 16810	1 artiodactyl pellet
IV	8195±85	9097-9397	AA 14823	1 artiodactyl pellet
II	8520±80	9474-9547	AA 14821	1 hackberry seed
II	8790±90	9808-10,146	AA 14820	1 hackberry seed
II	8830±240	9544-10,221	Beta 63438	hackberry seeds
I-upper 5cm	10,160±85	11,706-12,105	AA 14819	1 rodent fecal pellet
I-upper 5cm	10,350±80	11,948-12,600	AA 14818	1 rodent fecal pellet
I-general	10,910±60	12,878-13,005	Beta 72205	bone collagen
I-lower 5cm	11,065±105	12,919-13,160	AA 14817	2 rodent fecal pellets
I-lower 5cm	11,181±85	13,018-13,187	AA 16808	1 rodent fecal pellet
I-lower 5cm	11,263±83	13,142-13,397	AA 16809	1 rodent fecal pellet
I-lower 5cm	11,270±135	13,039-13,431	AA 14816	1 rodent fecal pellet
			*(@ 1σ)	

Additional experimental dates; provenience unknown:

	6965±70	AA 14827	1 artiodactyl pellet
	7020±60	Beta 70838	bone collagen
	7880±50	RA-COH16	hackberry endocarp carbonate
	8270±60	Beta 70837	bone collagen

from 12,000 to 10,000 B.P., the uncertainty range of each age estimate expands substantially. For example, an age estimate of 10,350 ± 80 yr B.P. from Stratum Ib has a 95.4% probability of dating within a range of more than a thousand years (11,762 - 12,816 cal yr B.P.). While this complicates interpretation of the true age of the lower depositional units, age determinations within each unit remain internally consistent and there is clear chronological separation between most units. Because calibrations remain subject to change, where age estimates are discussed in the text, they are listed simply in terms of radiocarbon years before present (figure 34).

Multiple age estimates from a number of individual stratigraphic units also suggest that there has been little bioturbation or other mixing of deposits of differing ages, and that these radiocarbon age estimates are accurate proxies for the age of all the materials within each unit. For example, the four age estimates from Stratum Ia are statistically indistinguishable and fall within a maximum range (at 2 sigma) of 11,540 - 10,855 yr B.P. even when unaveraged. The consistency of the age estimates on these fecal pellets suggests that other materials in the unit, particularly the fish bones, were deposited at the same time and do not represent mixing from an earlier, undetected deposition. When averaged (weighted by sigma), the age estimates suggest an age of 11,201 ± 76 yr B.P. for Stratum Ia. The calibrated calendrical age is 13,155 cal B.P. with a 2 sigma range of 12,903 - 13,757 cal yr ago.

These radiocarbon determinations suggest several marked changes in deposition rates throughout the sedimentary sequence. While the long-term average deposition rate for Homestead Cave is 24.4 cm per 1000 years (20.8 cm/1000 ^{14}C yr), periods of rapid deposition are juxtaposed with periods of limited or no deposition. The average age estimates for Strata Ib and II are ~1500 ^{14}C yr apart (~2400 cal yr), suggesting a depositional hiatus between the two units and/or relatively slow deposition during the period when Stratum II was laid down. Sedimentation rates then changed dramatically, and Strata II through V were deposited in a period of ~500 ^{14}C yr or less. Sedimentation rates for the deposition of Strata VI-X then return to approximately the long-term average for the cave sequence. A second marked reduction

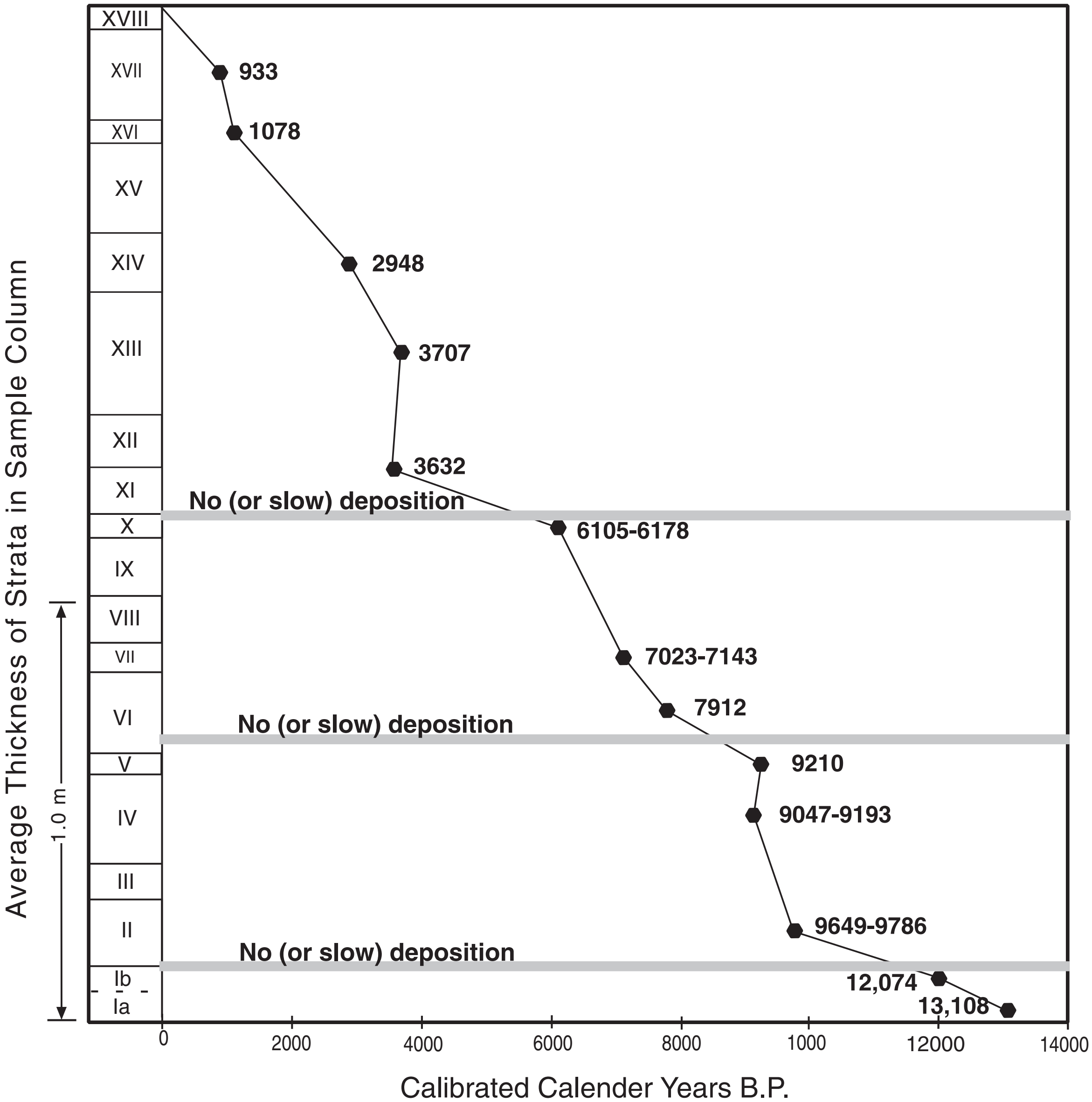

Figure 34. *Schematic diagram of deposition rates at Homestead Cave.*

in sedimentation rates occurs during the deposition of Stratum XI, with this relatively thin unit being laid down over a period of ~2500 ^{14}C yr. Strata XII-XIV were laid down relatively rapidly, within a period of a ~500 ^{14}C yr. The upper portion of the column is not well dated, but the sedimentation rates again appear to approach the long-term average.

EBOULIS

Spall is a common component of every stratigraphic unit, although there is significant variation in material type, size and proportion of total sediment throughout its vertical distribution. The data available on the Homestead Cave eboulis, however, is a by-product of extraction techniques used to retrieve faunal and floral elements from the deposits, and a detailed study of the Homestead Cave eboulis has not been attempted. In particular, two aspects of sample recovery and processing hinder interpretation. First, and perhaps most importantly, our primary goal was to identify change in the composition and relative proportions of biotic communities through time, and every effort was made during the excavation phase to insure there was as little intersample contamination as possible. To this end, where separate depositional units could not be cleanly and clearly separated, they were combined and excavated as a unit. As a result, detailed analysis and interpretation of the rate and size of spalling, colluvial deposition and wind-borne materials are problematic.

Second, to speed the sorting process, materials from the sample column were passed through screen sizes most appropriate to the analyses of small mammal fauna. These correspond roughly to the -4.0, -2.5, and -1.5 screen sizes in the metric phi scale most often used for grain size analysis (Boggs, 1987). No attempt was made to retrieve faunal materials smaller than 3.1 mm. As a result, it is not possible to attempt to duplicate the kind of sediment analysis carried out at a number of other stratified cave deposits in the Bonneville basin (see Swanson and Muto, 1975; Duncan, 1991). It is possible, however, to compare changes in coarse-grained materials through time with that defined at other Bonneville basin caves. This larger sediment fraction is derived almost exclusively from bedrock sources within the cave itself and relates directly to weathering of the roof and wall surfaces. Bedding planes in the bedrock outcrop at Homestead Knoll are almost vertical and are oriented parallel to the long axis of the cave. This orientation promoted relatively rapid weathering once the cave was exposed through wave action and the tufa had exfoliated from the cave roof and walls.

The distribution of coarse-grained sediments changes significantly through the depositional sequence, and the cave strata essentially form two separate sets. Eboulis in the lowest strata at Homestead Cave, Strata I-VI, constitutes a relatively small proportion of the total sediment from each unit (table VIII). In Strata VII-XVIII, on the other hand, the proportion of organic materials and finer-grained eolian and colluvial sediments is reduced, and coarse limestone spall averages 30-40% of each stratigraphic unit by weight (figure 35). Two alternate causes may explain this distribution.

The first is a climatic explanation and rests on the assumption that changes in the rate of eboulis production in cave sediments are due to change in temperature and moisture regimes, principally in the frequency of freeze/thaw episodes (see Fryxell, 1964; Tankard and Schweitzer, 1976; Laville and others, 1980; Birkeland, 1984). If this assumption is valid, the Homestead Cave sequence suggests a grad-

Table VIII
Sediment composition of the Homestead Cave deposits

Stratum	Spall(>3mm)	Organic Remains*	Residual Sediments	Total Weight/Volume
XVIII	12.0 kg	2.0 kg	6.7 kg	20.7 kg / 0.025m^3
XVII	95.7	39.0	63.6	198.3 / 0.290
XVI	47.0	16.0	37.0	100.0 / 0.057
XV	78.4	25.4	96.0	199.8 / 0.288
VIV	49.3	5.2	31.0	88.5 / 0.158
XIII	108.5	4.0	66.5	179.0 / 0.306
XII	74.5	13.9	58.9	147.3 / 0.180
XI	65.5	11.6	26.9	99.3 / 0.115
X	28.2	4.9	22.6	55.7 / 0.044
IX	60.8	10.8	43.0	114.6 / 0.120
VIII	20.9	2.8	14.5	38.2 / 0.075
VII	30.4	6.5	28.2	65.1 / 0.062
VI	28.0	12.6	64.4	105.0 / 0.216
V	4.9	2.4	2.2	9.5 / 0.045
IV	42.5	19.6	80.9	143.0 / 0.205
III	4.5	6.6	5.4	16.5 / 0.108
II	12.7	7.6	32.5	52.5 / 0.176
I	15.7	7.3	67.7	90.7 / 0.150
Ib	0.37	0.4	5.17	5.97 / 0.010
Ia	0.12	0.7	10.9	11.9 / 0.019

(*) Seeds, fecal pellets, bones, etc.

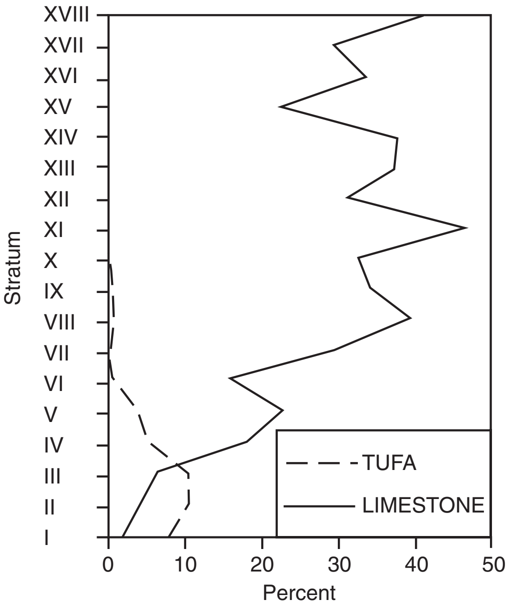

Figure 35. *Percentage by weight of large limestone and tufa spall (>1.9 cm) in the Homestead Cave sample column.*

ual increase in freeze/thaw episodes from Stratum I through Stratum VIII, with variation around a rather stable mean thereafter. This increase in the number of freeze/thaw episodes can, in turn, be explained in one of two ways. Average winter temperatures may have gradually increased during the Pleistocene/Holocene transition and the early Holocene such that normal variation around that mean resulted in increasingly frequent freeze/thaw episodes as warming continued. Alternatively, average temperature may have remained the same, with amplitude and frequency of temperature changes gradually increasing.

Regardless, such a climatic explanation is at best tentative, despite the close match with general reconstructions of Great Basin climate change, and with the specific paleoenvironmental conditions suggested by the Homestead Cave flora and fauna. The assumption that spalling rates are related to cryoclastic processes has been widely challenged (see Farrand, 1985), and a variety of other chemical and mechanical mechanisms for eboulis production have been suggested. For example, the growth of calcium carbonate crystals along bedding planes is just one of many equally viable explanations for spall production. In short, the increase in the spall component of the Homestead Cave deposits from ~11.5 to 7 ka may be related to warming winter temperatures and an increase in the number of freeze/thaw episodes, but that relationship can be verified only with great difficulty.

A much more likely and reasonable explanation for the change in coarse-grained sediments is a mechanical one. A thick coating of tufa initially protected all the limestone bedrock surfaces from the effects of weathering after receding lake waters exposed Homestead Cave. Limestone bedrock spall could not be produced and added to the cave floor deposits until after this tufa coating had been eliminated. The proportion of tufa and limestone eboulis in Homestead Cave deposits is inversely related (figure 35), with limestone spall increasing significantly only after tufa ceases to be an important component of the sediments in each stratum. Even when tufa and limestone spall are combined, however, the proportion of total coarse-grained spall to all sediment is low in the early Homestead Cave deposits, and the rate of spalling clearly increased through the Holocene. Since the tufa initially coated the cave walls and roof, this suggests that the tufa weathered at a slower rate than the limestone bedrock beneath it. This is probably due to a number of factors related to the different internal chemistry and structure of the tufa and limestone. Tufa is essentially a cement (Pedley, 1990; Viles and Goudie, 1990) and lacks the fractures and bedding planes that characterize the limestone of the Oquirrh Formation. As a result, it is less susceptible to weathering, particularly to freeze/thaw episodes, and most mechanical weathering occurs along the tufa/limestone interface. In short, the most likely explanation for the difference between the earlier and later portions of the Homestead Cave record is a mechanical one, with the tufa coating of the cave surface slowing eboulis production during the early portion of the depositional sequence.

The problem with assigning a strictly climatic interpretation to the Homestead Cave spall sequence is shown clearly by comparing the frequency curves for rockfall in four Bonneville basin caves of comparable age. The excavation techniques and sediment analyses employed at Homestead, Danger, Hogup and Floating Island Caves are sufficiently similar that it is possible to compare change in the proportion of coarse-grained sediments to all other sediments through time (figure 36). The ages for basal deposits in these caves are ~11.5 ka, ~10.5 ka, ~8.5 ka and ~7.5 ka, respectively. In the three caves with deposits older than 7.5 ka, patterns of spall deposition are markedly different. At Homestead Cave the proportion of eboulis to other materials gradually increases; at Hogup Cave the proportion of rockfall drops sharply in the earliest part of the record; and at Danger Cave the proportion of coarse-grained sediments varies markedly in the 10.0 to 7.5 ka period. Given this site-to-site variation, it is difficult to derive an acceptable climatic interpretation that would explain these differences.

After ~7.5 ka, on the other hand, the patterns of spall production are very similar at all four caves, suggesting some interdependence in the mechanism(s) responsible for eboulis at the sites. The most obvious mechanism is climate, although what particular aspect of climate (precipitation, temperature, storm frequency) may be responsible cannot presently be discerned. It is possible that the earlier site-to-site differences may be explained by different, but temporary, morphological features (for example, presence/absence of an extensive tufa coating, length of exposure after the post-Provo regression) which were only resolved after several thousands of years of weathering, and that changes in spall-to-finer sediment ratios are indeed a valid, albeit crude, proxy for Holocene climates in the Bonneville basin. If so, the generalized pattern of spalling shared by the four sites is instructive.

After 7.5 ka the proportion of eboulis in the deposits at the four caves drops sharply, and within 500 to 1000 years thereafter the proportion of spall to all other sediment types is at a Holocene low. From this low point until ~5 ka, the ratio of eboulis increases rapidly. From ~5 ka to the present the long-term trend is toward a gradual increase in eboulis as a percentage of all sediments, although there is considerable variation around this trend at all sites. Differences in excavation strategies at the four sites and in the refinement of

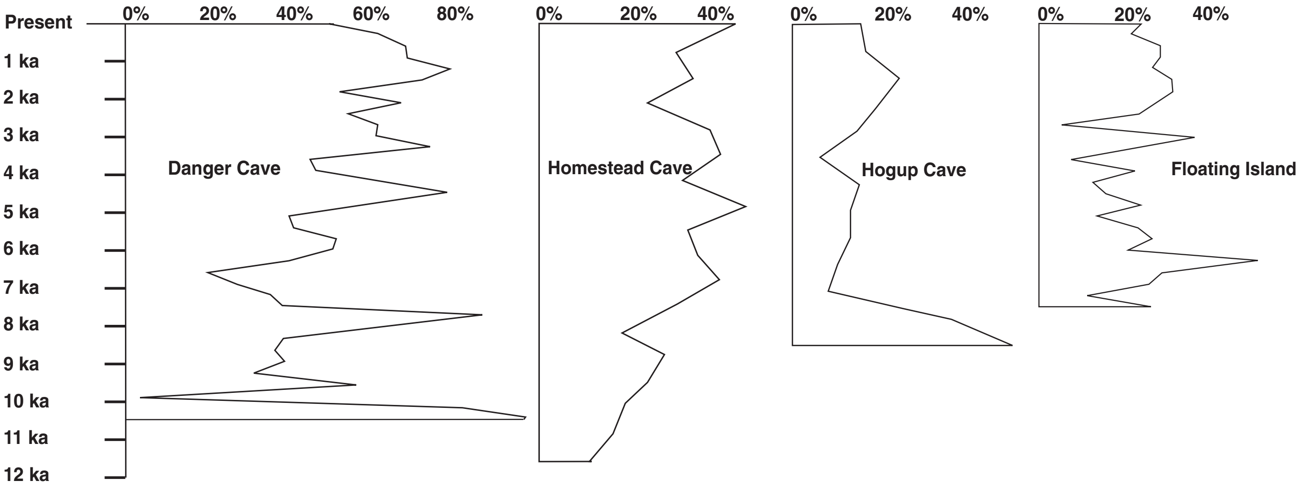

Figure 36. *Changing amounts of large spall (>3.1 mm as a percent of total weight/strata) at four Bonneville basin cave sites.*

stratigraphic definitions prevent determination of the validity of any correlation among these sequences.

NON-EBOULIS DEPOSITS

Organic remains, including bone, fecal pellet fragments, ostracodes, snails and dispersed organics are the most common component of the >3.1 mm deposits, but sand-to-granule-sized fragments of limestone are common as well, making up 10-20% by volume of the finer-grained sediments. In Stratum I the limestone fragments in the subsample of the fine sediments are subrounded to angular. This rounding indicates that the sand was transported by water (most likely) or wind (less likely). In the cave, the most likely transport mechanism at this lowest depositional level would have been waves in Lake Bonneville. The sediments may have originated from beach deposits at the mouth of the cave or from shoreline deposits washed down from the ridge above the cave opening. The unit also contains some sand-sized lumps of what appear to be carbonate mud that may be reworked lake sediment, and many sand-sized lumps of iron oxides, which may also have been reworked from lake sediments. Small, curved selenite crystals, which probably grew in the cave deposits, are common. Together, snails, ostracodes, lumps of carbonate mud, oxide lumps and subrounded sand make up 40-50% of the finer grained sediments in Stratum I and are most likely all derived from reworked lake beds.

Wind-borne deposits are common throughout the depositional sequence. Thin stringers of eolian materials, primarily gypsum derived from the playa to the north and west of the cave, occur within virtually every stratum in the sample column. Some eolian deposits, such as Strata Xa, XIIIc, and XIVb, are 1-2 cm thick and can be traced and mapped throughout the column profiles. Others are more discontinuous and appear as small, thin lenses within larger spall/organic deposits. These visually recognizable eolian deposits contain virtually no bone, fecal pellets or eboulis, and appear to have been deposited during short-duration windstorms. Less easily recognized eolian materials most likely comprise a significant component of the fine-grained deposits in every stratum, but detailed analyses of geological samples has not been attempted.

Organic remains constitute a major component of all stratigraphic units, in some cases comprising 80-90% of a depositional unit. These organic materials include plant macrofossils (primarily hackberry seed endocarps in the lowest stratigraphic units and twigs in the uppermost units), whole and broken rodent and artiodactyl fecal pellets, and small mammal, bird and reptile bones. Less recognizable, more dispersed organic remains form a matrix in the lower stratigraphic units in which the other depositional materials such as spall and bone are held. Much of this is probably derived from the disintegration of compacted blocks of raptor fecal/pellet cones which have been displaced downslope from below raptor roosts in the back of the cave. In the upper, drier deposits, where these blocks remain intact, they comprise as much as half of each stratum by volume (figure 37).

STRONTIUM RATIOS AND THE ORIGIN OF EARLY HOMESTEAD CAVE BIOTA

(*by Jay Quade*)

The $^{87}Sr/^{86}Sr$ ratio of carbonates and phosphates from in and around Homestead Cave provide some important clues to their origin. The Sr-bearing phases analyzed in this study include: (1) tufa from the Provo shoreline above the cave entrance, (1) fish vertebrae from Stratum I, the basal stratigraphic unit in the cave, and (3) fossil mollusks from throughout the stratigraphic column.

Stratum I contains abundant fossil fish remains, as described in chapter nine. Vertebrae from Stratum I were examined representing *Catostomus*, *Oncorhynchus*, and *Gila atraria*. Analysis from single vertebrae was possible because of the high Sr concentrations. The $^{87}Sr/^{86}Sr$ ratios on the six analyzed vertebrae fall in a narrow 0.71256 - 0.71285 range (table IX; figure 38). These ratios are markedly higher than any we obtained on Provo-level tufas, including a result of 0.71174 on the Provo-level tufa above the cave entrance. $^{87}Sr/^{86}Sr$ ratios on mollusks from all stratigraphic levels

Figure 37. *View of organic pellet block from Stratum XVII in the Homestead Cave sample column.*

range from 0.71174 - 0.71191, ratios markedly lower than those on fish, but in line with the range of ratios displayed by Provo-level tufas (figure 38).

The ^{87}Sr/^{86}Sr ratios of the fish vertebrae are unusual in not matching the ratios for any known lake in the basin, modern or ancient. The ^{87}Sr/^{86}Sr ratios from the Gilbert shoreline tufas at 0.71194-0.71203 provide the closest match, although the ratios are measurably lower than for the fish. Probable variation in the ^{87}Sr/^{86}Sr ratio of the Gilbert-level lake needs more characterization, but a low-elevation lake near the Gilbert shoreline is the best candidate for the origin of the Homestead fish in Stratum I. This hypothetical lake would have had a ^{87}Sr/^{86}Sr ratio (0.7127) lying on a mixing line between the modern Great Salt Lake (0.7174) and the Provo-level lake (0.7114 - 0.7119). Since only the latest glacial stages of the lake display the high ^{87}Sr/^{86}Sr ratios, I therefore conclude that the fish from Stratum I lived in a low-elevation lake most similar to Lake Gilbert, which implies that the lake had sufficiently low salinity to allow such fish to survive. If the ^{14}C dates on lower Stratum I represent the ages of the fish remains, as they probably do, then it is possible to conclude that a non-saline, low-elevation lake was present within the foraging radius (<5 km; see chapter two) of the Homestead raptors at or shortly before 11.2 - 11.3 ka.

The ^{87}Sr/^{86}Sr ratios of fossil mollusks from Homestead Cave overlap the range of ratios displayed by the Provo-level lake, but are lower than the ratios of Lake Gilbert (0.7120), modern Great Salt Lake (0.7167 - 0.7178), and the brines of the Great Salt Lake Desert (0.7125 - 0.7139) (Jones and Faure, 1972). The most plausible explanation is that the mollusks were once a part of the tufa coating the ceiling and were gradually spalled into the cave deposits. Tufa once encrusted much of the cave ceiling, and spalled tufa is common in the Homestead deposits. It would have had a ^{87}Sr/^{86}Sr ratio similar to that of the Provo-level tufas. Mollusks are commonly associated with (often encrusted by) some tufas in shoreline deposits. Moreover, all the analyzed specimens were coated by creamy, secondary carbonate. The carbonate

Table IX
Summary of Sr isotopic analyses at Homestead Cave

Sample #	**Stratum**	**Material**	**^{87}Sr/^{86}Sr**
Homestead fishA	I (F22)	fish vertebrae	0.712775
Homestead fishB	I (F22)	fish vertebrae	0.712638
Homestead fishC	I (F22)	fish vertebrae	0.712564
Homestead fishD	I (F10/13)	fish *Catostomus*	0.712685
Homestead fishE	I (F10/13)	fish *Oncorhynchus*	0.712852
Homestead fishF	I (F10/13)	fish *Gila atraria*	0.712469
Amnicola	I (F22)	shell	0.711740
F30 Lymnaid	XII (F30)	shell	0.711820
F6 FS 33	XVII (F6)	shell	0.711747
F17FS62	II (F17)	shell	0.711918

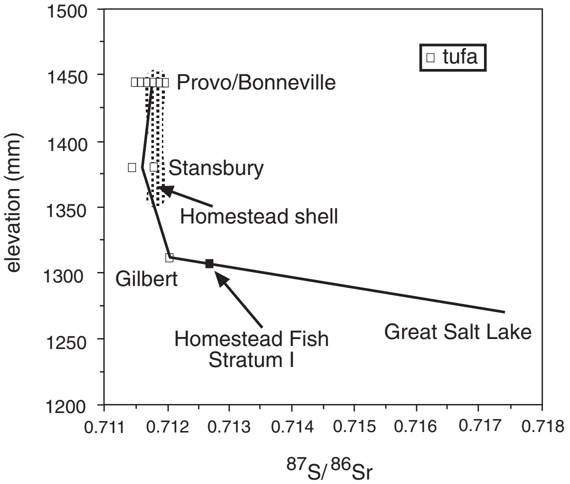

Figure 38. *Change in the ^{87}Sr/^{86}Sr ratio of lake waters with change in lake elevation in the northern (Great Salt Lake) basin. The ^{87}Sr/^{86}Sr ratio of fossil aquatic shell (shaded) from the cave overlaps that of the integrated lake, implying that the shell came from a lake filled to well above the Gilbert shoreline level. In contrast, the ^{87}Sr/^{86}Sr ratio of fossil fish from Homestead Stratum I falls on a mixing line between a high lake and modern Great Salt Lake. This shows that the fish probably came from a low-elevation, possibly sub-Gilbert shoreline lake.*

may be a tufa coating acquired in the cave, or in a beach deposit above the cave, with subsequent reworking into the cave deposits. All this evidence strongly implies that the analyzed mollusks are older than the deposits themselves, an observation that may extend to some of the carbonate-encrusted ostracodes also found in the cave (see Hunt, chapter five).

This explanation is consistent with the scattered presence of mollusks in most of the stratigraphic column but inconsistent with their marked abundance in Stratum I. I analyzed only one valve from Stratum I and more analyses from this horizon are warranted. If the mollusks are contemporary with the stratum, as their numbers would seem to imply they are, then high (>0.7120) $^{87}Sr/^{86}Sr$ ratios consistent with the ratios from Stratum I fish should be obtained from them.

CHAPTER FIVE

Homestead Cave Flora and Non-Vertebrate Fauna

by
Jeffrey M. Hunt, David Rhode, and David B. Madsen

PLANT REMAINS

Scattered among the masses of animal bones, fecal pellets and other faunal remains preserved in the sediments of Homestead Cave was a somewhat smaller number of identifiable plant fragments. These plant materials are distributed throughout the cave strata in two basic patterns, reflecting preservation within the cave environment. Hackberry endocarps (*Celtis reticulata*) are found in great quantities in lower strata of the cave. These bony endocarps (the hard coating that surrounds the seed) are composed of aragonite and opal (Wang and others, 1997), and they survived millennia of potential decay through oxidation, moisture and exposure, just as the millions of animal bones had done. Hackberry endocarps are dated mainly to the early Holocene strata within the site. The second pattern of distribution is exhibited by all other plant macrofossils, mostly bits of wood and twigs, which are far more susceptible to decomposition and degradation through time. These materials were recovered from the uppermost strata of the cave and are comparatively recent in age.

Hackberry

Hackberry (*Celtis reticulata*) is a large bush or small tree, bearing thin-fleshed drupes containing a single bony nutlet. It is not known to occur in the vicinity of Homestead Cave today (Workman and others, 1992), but is reported from the Lakeside Mountains (Albee and others, 1988) and is common in the nearby Stansbury, Oquirrh and Promontory Mountains. It will grow at low elevations in relatively mesic settings and appears to prefer rock outcrops, possibly for greater access to reliable sources of water trapped in and around fractures (DeBolt and McCune, 1995).

Abundant hackberry endocarps were recovered from 6.3 mm and 3.1 mm sediment fractions in the lower strata of Homestead Cave (table X). Hackberry endocarps, whole and fragmentary, could be retrieved from most sediment fractions. In some strata, however, the number of hackberry endocarps and endocarp fragments encountered per unit volume of sediment was so great, and the endocarps were commonly so small, that manually sorting the entire stratum was simply not feasible. Flotation experiments were attempted, but these also failed because the specific gravity of endocarps is very similar to bone and not very different from sand and gravel, thus, they were not easily separated. For these strata, estimates of the total number of hackberry remains were made by manually sorting a small sample of the sediment fraction, determining the number of remains per unit weight of sediment, and then multiplying by the total weight of sediment to get an estimated count for the sediment fraction.

Figure 39 depicts the abundance of hackberry endocarps and endocarp fragments per unit volume of each stratum. The inset graph shows the distribution on a linear scale which illustrates the overwhelming abundance of hackberry endocarps found in Strata II-V, and the paucity of remains found through the rest of the stratigraphic column. The hundreds of thousands of endocarps present in Strata II-V comprise a sort of ‘hackberry hash’ in which the calcareous endocarps are a dominant part of the depositional matrix. By comparison, the scattered occurrences of hackberry endocarps found in Stratum VI and upwards are but trace quantities. To better reveal the distribution of hackberry remains in these other strata, the main graph shows the distribution of endocarps on a logarithmic (base 10) scale; units on the abscissa reflect orders of magnitude of change.

How these hackberry remnants were brought into Homestead Cave is a matter of some question. Several taphonomic vectors are probably responsible; those responsible for the bulk of the endocarps in Strata II-V are probably not the same as the vectors that deposited the scattered endocarps in higher strata. The sheer bulk of the hackberry deposits in Strata II-IV suggests a local source. The likeliest agents for deposition of the endocarps in Strata II-V are rodents, such as *Neotoma*, that collected the berries from bushes growing on rock outcrops surrounding the cave site. Hackberry fruits are a valuable food source for a variety of birds and mammals, including woodrats (Martin and others,

Table X
Hackberry nutlet counts by stratum, Homestead Cave

Stratum XVIII	—
Stratum XVII	7 whole
Stratum XV	2 whole, 17 fragments
Stratum XV	6 whole, 1 fragment
Stratum XIV	—
Stratum XIII	2 whole
Stratum XII	1 fragment
Stratum XI	3 whole
Stratum X	—
Stratum IX	2 whole, 7 fragments
Stratum VIII	28 whole, 31 fragments
Stratum VII	5 whole, 22 fragments
Stratum VI	*EST 1800 whole, 650 fragments
Stratum V	EST 2300 whole, 1900 fragments
Stratum IV	EST 45,000 whole, 244,000 fragments
Stratum III	EST 26,000 whole, 62,000 fragments
Stratum II	EST 14,000 whole, 67,000 fragments
Stratum Ib	134 whole, 509 fragments
Stratum Ia	16 whole, 118 fragments

*EST = estimated

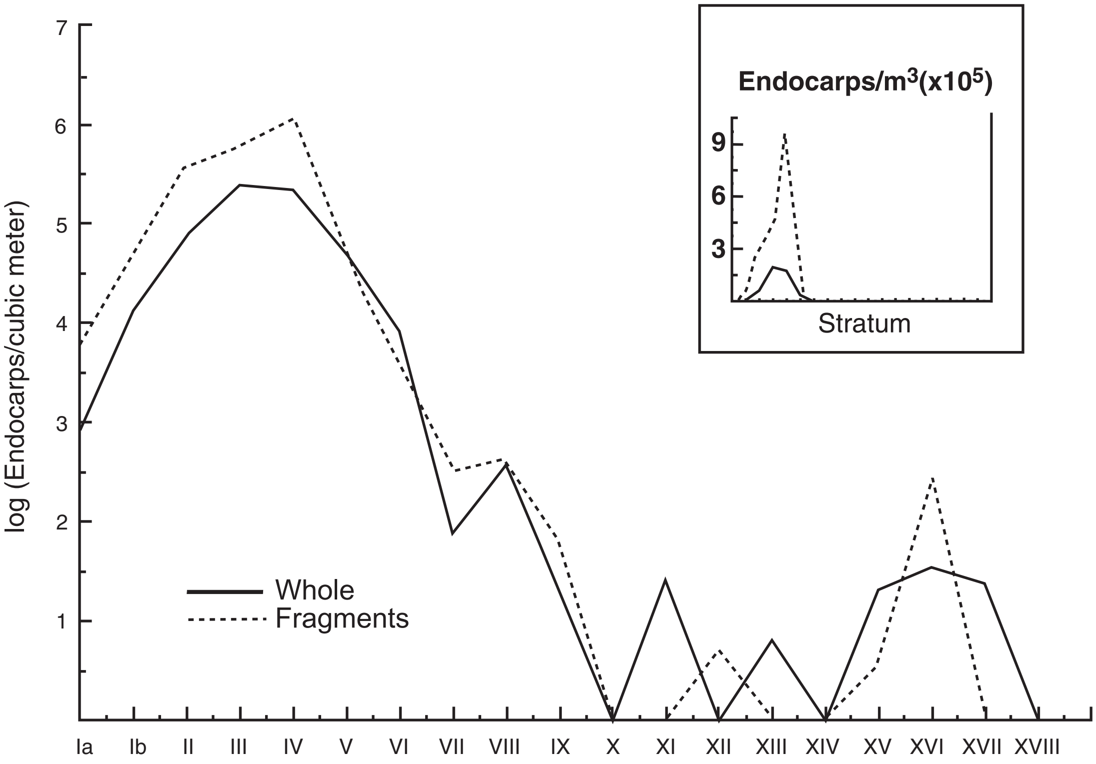

Figure 39. *Distribution of hackberry endocarps in strata from Homestead Cave. Note that main graph is logarithmic scale, inset is graphed on linear scale.*

1951); hackberry endocarps are abundant in a woodrat midden located near Homestead Cave, dating to approximately 8100 - 6700 yr B.P. (see chapter twelve; Wang and others, 1997). *Neotoma* bones derived from Homestead Knoll area are common throughout the early strata and especially abundant in Stratum IV (see chapter seven). However, the abundance of woodrat fecal pellets (which may be a measure of woodrat nesting frequency within the cave itself) declines substantially after Stratum I, to negligible amounts by Stratum III (table XIII). Woodrats were apparently extirpated from the cave, but not from the surrounding area, after the deposition of Stratum III (see below, this chapter). If *Neotoma* was responsible for bringing in the fruits, one might expect much greater evidence that it lived in the cave while the vast bulk of the endocarps were deposited. It is noted, however, that 3.1 mm screened sediment from Stratum III, containing enormous quantities of hackberry endocarps, also contained numerous *Neotoma* fecal pellets.

A second likely depositional vector is birds (or small mammals) that fed on the berries, in turn were eaten by raptors, and then both bones and bony endocarps were deposited in the raptors' ejecta. Livingston (chapter eight) proposes an avian "berry guild," including waxwings, robins, flickers and other woodpeckers, finches and other passerines, with "a marked taste for berries," that reflects the presence of riparian areas and thickets in the vicinity of Homestead Cave. She notes that "it is entirely possible that at least some of the numerous hackberry seeds in the Homestead Cave matrix were introduced as part of the [raptor] cast pellets containing the bones of these birds." However, Livingston reports that "berry guild" bird remains appear to be most abundant after the deposition of the 'hackberry hash' in Strata II-IV, and "continue to be well represented throughout the stratigraphic column [above Stratum VI]." While deposition of endocarps associated with remains of 'berry-guild' birds in raptor pellets seems likely to account for scattered occurrences of hackberry endocarps in the upper strata, such deposition seems much less likely to account for the vast bulk of the endocarp remains in Strata II-IV.

A third potential taphonomic vector is coyote or fox, both of which eat the fruit and which aid in dispersal of the shrub (Welsh and others, 1987, p. 612). Casual observation of the hackberry remains revealed little evidence either of digestion or of being enclosed in castings or feces, but more detailed and systematic analysis is necessary to assess these possibilities. It should be noted that if raptors or canids were responsible for significant hackberry deposition, then the endocarps may not necessarily reflect the existence of hackberry plants growing in the immediate vicinity of the cave site (in contrast to the local collecting habits of *Neotoma* and other small rodents). Instead, hackberry could have grown in other environments within the much larger region encompassed by the foraging ranges of owls roosting in the cave (see chapter two).

By whatever means the endocarps arrived in the cave, it is clear that they were deposited in greatest abundance in Strata II-IV (~9-~8 ka), declined to much lower levels from Strata VI-VIII (~8-~6 ka), declined to negligible amounts in Strata IX-XIV (~6-~2 ka), possibly slightly increased in abundance in Strata XV-XVII (~1.2 ka), and dropped back to nothing by XVIII, the latest stratum. The great abundance of hackberry in the lower strata of the Homestead record probably indicates that the shrub grew in the immediate vicinity of Homestead Cave, reflecting increased effective moisture in the area prior to 8 ka. This increased moisture could have been a function of higher local water tables during the early

Holocene or a function of cooler and moister climatic conditions than at present. The substantial decline in endocarp abundance after 8 ka documents a shift to a climate with significantly less effective moisture. The subsequent continuing drop to negligible quantities by ~6 ka probably reflects local extirpation of hackberry, resulting from increased drought and/or a decline of the available local water table. The few hackberry endocarps found in the strata younger than 6 ka could reflect small populations persisting in favorable habitats in the Lakeside Mountains, but they could also reflect stratigraphic disturbance and transport of a few nutlets through the stratigraphic column by burrowing animals. Radiocarbon dating of endocarps from the upper strata would answer this question. If the former is true, the slight increase in nutlet abundance around 1.2 ka might signal a period of greater effective moisture. If so, that period was short-lived, as the number of endocarps diminished in later strata and hackberry does not occur in the vicinity of Homestead Cave today.

Certain elements of the small mammal record from Homestead Cave are generally consistent with the foregoing account (see chapter seven), though there are differences as well. Ratios of abundance of kangaroo rats (*Dipodomys*) show a relative increase in the more xeric-adapted *D. microps* over *D. ordii* beginning in Stratum II and accelerating in Stratum IV to reach a peak by Stratum VII. Ratios of abundance of species of pocket mice (*Peromyscus parvus* and *P. longimembris*) and woodrats (*Neotoma cinerea* and *N. lepida*) show very similar patterns. By comparison, hackberry abundance also increases beginning in Stratum II, but remains extremely abundant through Stratum IV, after which it declines. In Stratum XVII, both upland species of pocket mouse (*P. parvus*) and woodrat (*N. cinerea*) reappear in the faunal record after long absences. This is intriguingly close in time to the slight increase in hackberry endocarp abundance in late Holocene strata (XV-XVI), again indicating a period of increased effective moisture and perhaps local reestablishment of populations of these animals as well as hackberry ~1.2 ka.

Recent studies (see Jahren, 1996) suggest that ratios of stable isotopes of hydrogen and oxygen in hackberry endocarps can provide a paleotemperature signal and might distinguish between use of ground water and seasonal precipitation. In particular, Jahren has reported on the success of using ^{18}O ratios in endocarps to estimate average maximum growing-season temperatures. Preliminary results from Homestead Cave (Jahren, 1998, personal communication) suggest long-term secular variation in growing-season temperature (that is, between-strata variation), as well as significant variation within, on shorter time scales (that is, within-strata variation). Further analysis of hackberry endocarps from Homestead Cave may yield a more direct climate proxy than is presently available.

Other Plant Materials

In contrast to the abundant, well-preserved hackberry endocarps, other plant materials are limited in quantity and identifiability. Table XI provides a list of plant materials identified to genus or species by stratum. Identification proceeded by comparison with modern reference specimens of wood, leaves and seeds, with the aid of a 10-70X reflected light dissecting microscope.

Several features are of interest. First, the distribution of identifiable plant materials is strongly constrained by factors of preservation: identifiable wood, twigs and other items are found only in the upper strata (XII-XVIII), roughly the last 3500 ^{14}C yr of deposition within the cave. Fragments of wood and twigs occurred in lower strata, but these were typically in very poor condition and were not identifiable by the technique described above. Second, the bulk of the materials found within the upper strata are entirely consistent with vegetation growing in the vicinity of the cave site today, including sagebrush (*Artemisia sp.*), shadscale (*Atriplex confertifolia*), greasewood (*Sarcobatus vermiculatus*), hopsage (*Grayia spinosa*), horsebrush (*Tetradymia* sp.), currant (*Ribes* sp.) and wild rye (*Elymus cinereus*). It appears that modern vegetation communities were largely in place by at least 3.5 ka. Two significant taxa do not appear to be represented in the wood or leaf fragments: hackberry (suggesting that it was not growing locally at this time) and ephedra (*Ephedra* sp.), which may have expanded into the area during the late Holocene (see chapter twelve).

A third feature of interest is the presence of some remains attributable to plants not found in the vicinity today. A chokecherry (*Prunus* sp.) pit was found in Stratum III, in association with abundant hackberry endocarps. Livingston (chapter eight) notes that the abundance of bones of woodpeckers and passerine birds suggests riparian woods and thickets in the vicinity of Homestead Cave. This chokecherry pit is also consistent with greater amounts of mesophilic, fruit-bearing bushes and trees in the area. The lack of any other such seeds higher up in the stratigraphic column is not consistent with the suggestion that patchy riparian woodlands and thickets persisted in the area after the early Holocene.

A single needle from the mesic, high-montane conifer white fir (*Abies concolor*), found in Stratum IX, is decidedly anomalous, but the same stratum also contains pine wood and charcoal, including a large branch fragment identified as pine (see figure 32). These items were probably brought into the cave site by humans, either from distant mountains or, more likely, from a driftwood source on the shores of Great Salt Lake near Homestead Cave. Seeds of the Utah juniper (*Juniperus osteosperma*) appear in small quantities in two of the latest strata (XV and XVII), probably reflecting the expansion of Utah juniper into the Lakeside Mountains during the late Holocene. An occurrence of pinyon pine (*Pinus monophylla*) in Stratum XVII (two seed fragments) is also anomalous, the nearest pinyon pine presently growing over 80-100 km away, in the Stansbury, Oquirrh and Pilot mountains. Possibly the pinyon expanded into the Lakeside Mountains during the slightly more mesic late Holocene interval represented by Stratum XVII, but more likely the seed was brought in via long distance transport, again most likely by humans.

OSTRACODES

Ostracodes have been identified in samples from Strata Ia and Ib where they are most common. Above Stratum I, ostracodes appear rarely in five-liter subsamples of the fine-grained deposits (>3.1 mm) collected from the strata and

Table XI
Plant remains identified to genus from Homestead Cave strata

Stratum XVIII:	*Artemisia* sect. tridentatae	wood
	Atriplex sp.	wood
	Sarcobatus vermiculatus	wood
	Ribes sp.	leaf fragments
	Atriplex confertifolia	leaf
	Grayia spinosa	2 fruits
	Elymus cinereus	2 seeds
Stratum XVII:	*Artemisia* sect. tridentatae	wood
	Atriplex sp.	wood
	Sarcobatus vermiculatus	wood
	Ribes sp.	wood, leaf fragments
	Tetradymia glabrata	twigs
	Tetradymia spinosa	twigs
	Pinus cf. *monophylla*	1 seed
	Grayia spinosa	2 fruits
	Lomatium sp.	1 seed
	Elymus cf. *cinereus*	2 seeds
	Bromus sp.	1 spikelet
	cf. *Allium* sp.	bulb sheath
Stratum XVI:	*Artemisia* sect. tridentatae	wood
	Atriplex sp.	wood
	Sarcobatus vermiculatus	wood
	Ribes sp.	wood, leaf fragments
	Tetradymia glabrata	twigs
	Tetradymia spinosa	twigs
	Oenothera caespitosa	fruits
	Grayia spinosa	2 fruits
	Lomatium sp.	1 seed
Stratum XV:	*Artemisia* sect. tridentatae	wood, charcoal
	Atriplex sp.	wood, charcoal
	Ribes sp.	wood, leaf fragments
	Sarcobatus vermiculatus	wood
	Tetradymia spinosa	twigs
	Chrysothamnus sp.	flowers
	Oenothera caespitosa	fruits
	Grayia spinosa	fruit
	Lomatium sp.	1 seed
	Juniperus osteosperma	2 seeds
Stratum XIV:	*Artemisia* sect. tridentatae	bark, wood
	Artemisia tridentata	leaves
	Ribes sp.	leaf fragments
	Sarcobatus vermiculatus	wood
	Tetradymia spinosa	twigs
	Atriplex sp.	twigs
	Grayia spinosa	fruits
	Elymus cf. *cinereus*	1 seed
	cf. *Sitanion hystrix*	flowering parts
Stratum XIII:	*Artemisia* sect. tridentatae	bark, wood, charcoal
	Artemisia tridentata	leaves
	Ribes sp.	leaf fragments
	Tetradymia sp.	twig
Stratum XII:	*Artemisia* sect. tridentatae	bark, wood
	Sarcobatus vermiculatus	twig
	Ribes sp.	leaf fragments
Stratum XI:	*Artemisia* sect. tridentatae	wood
	Pinus sp.	wood
Stratum X:	*Artemisia* sect. tridentatae	charcoal, wood
	Atriplex sp.	wood
Stratum IX:	*Artemisia* sect. tridentatae	bark
	Pinus sp.	charcoal
	Abies cf. *concolor*	1 needle

Table XI *(continued)*

	Lomatium sp.	1 seed
	Elymus sp.	1 seed
	Bromus cf. *tectorum*	3 spikelets (modern)
Stratum VIII:	*Artemisia* sect. tridentatae	bark, charcoal
	Bromus cf. *tectorum*	3 seeds (modern)
	Bromus sp.	1 seed (modern)
Stratum VII:	*Bromus rubens*	5 spikelets (modern)
Stratum VI:	*Artemisia* sect. *tridentatae*	charcoal, wood
Stratum III:	*Prunus* sp.	1 seed
	Atriplex sp.	1 piece bark
Stratum II:	*Atriplex/Sarcobatus*	1 twig
Stratum Ib:	cf. *Tetradymia* sp.	1 twig
	Juniperus osteosperma	2 seeds

appear either to be redeposited by wind action or to be part of limited colluviation of fine-grained materials from the ridge above the cave. Many of the specimens in these samples, particularly those from Stratum Ib and above, are heavily coated with carbonate. In other samples from the Bonneville basin, this sort of carbonate coating occurs in sediments just above the Bonneville flood markers or in cores associated with the complete collapse of the lake. In the latter case, these are normally associated with numerous limnocytherids and brine shrimp pellets/eggs which do not occur in the Homestead Cave samples. In addition, two candonid species that are most common after the Bonneville flood and during the evaporative collapse of the lake are not found in the samples from the cave.

In Stratum Ia, the lowest depositional unit at the site, the primary ostracode taxon is *Candona adunca*, a species that is relatively well known from the Bonneville lake cycle. In cores from the lake, *C. adunca* enters the transgressing Lake Bonneville ~19 ka and dies out as the lake is evaporatively regressing from the Provo shoreline (Thompson and others, 1990). However, other taxa common to the *C. adunca* ecozone in deep-water Bonneville sediments are rare in the samples from Stratum Ia. In particular, the limnocytherids common to the sequence are less common in these samples than they are in the cores from the lake. Based on other information from the Bonneville basin, the ostracode assemblage in Stratum Ia most closely resembles that from a lake dating to ~14 ka or later. These may well be related to the redeposited water-laid sands in this lowest stratigraphic unit; if so, they suggest that these lake sediments are also redeposited from shoreline deposits higher up on Homestead Knoll rather than from beach sediments deposited directly in the mouth of Homestead Cave.

In addition to *C. adunca*, the ostracode *Cytherissa lacustris* also occurs in the samples from Stratum Ib. Other taxa are also present including taxa found in the marshes and wetlands surrounding the lake today and in the past. Many of these specimens look like others recovered from the digestive tracts of fish and it seems possible that many of these may have been introduced to the cave deposits inside of fish brought into the cave by scavengers and raptors. Stratum Ib may thus contain both redeposited materials from higher beaches and material deposited by biological vectors from a lower elevation lake.

GASTROPODS

Identifiable shells of 390 freshwater gastropods, three land snails, and three bivalve mollusk shell fragments were recovered from the sample column. The snails are primarily of the families Lymnaeidae and Hydrobiidae, with lesser numbers of the families Helicidae, Physidae, Planorbidae and Valvatidae; the bivalve is probably *Anodonta* (table XII). Gastropods of all these taxa are known to occur in fluvial and lacustrine deposits of the Bonneville basin, many of them dating to the late Pliocene/early Pleistocene (Chamberlin and Jones, 1929; Eardley and Gvosdetsky, 1960; Roscoe, 1961, 1963; Taylor and Bright, 1987; Oviatt, 1989). These have been noted in the shoreline deposits of Lake Bonneville from the time of the early scientific expeditions in the Great Basin, beginning with Henry Engelmann in 1859. Specimens collected by G.K. Gilbert and R. Ellsworth Call were identified and first published by Call (1884), and later by Gilbert (1890, p. 209, 297). Gastropods occur throughout the column but are overwhelmingly concentrated in Stratum I (figure 40).

Shells of the family Lymnaeidae are the most abundant taxa in the deposits (n=226 plus a large number of frag-

Table XII
Mollusks from Homestead Cave

Genera	**Habitat**
LYMNAEIDAE	
Fossaria sp. (n=11)	Ponds, mud flats
Stagnicola bonnevillensis (n=226)	Lakes, rivers
PLANORBIDAE	
Carnifex (n=3)	Ponds
Helisoma (n=3)	Silty substrates, ponds
Gyraulus (n=1)	Lakes, streams, springs
Planorbid sp. (n=1)	Ponds
HYDROBIIDAE	
Pyrgulopsis (*Amnicola*) (n=137)	Springs, streams
Fluminicola (n=2)	Streams
PHYSIDAE	
Physa (n=1)	Streams, ponds, wetlands
VALVATIDAE	
Valvata (n=2)	Ponds, streams, springs
HELICIDAE	
Vallonia (n=3)	Land, damp locales
ANODONTIDAE	
Anodonta (fragments)	Rocky/sandy substrates, rivers, lakes, springs

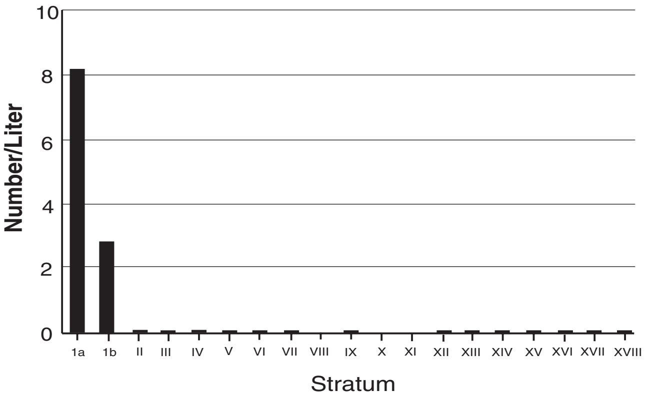

Figure 40. *Distribution of snails in Homestead Cave. Only minimal numbers (<0.1/liter) occur above Stratum Ib.*

ments). Lymnaeids are pulmonates, gill-breathing snails that feed on algae, epiphytons and decaying vegetation in generally shallow waters (McMahon, 1983). Lymnaeids are commonly associated with various forms of emergent vegetation such as bladderwort (*Utricularia*), duckweed (*Lemna* sp.) and bulrush (*Scirpus* sp.) (Collias and Collias, 1963). Identified lymnaeid taxa include the genus *Fossaria*, and a large number of *Stagnicola bonnevillensis* Call. The latter species had a generalized distribution throughout the Bonneville basin, becoming extinct sometime after 13 ka (but see Clarke, 1991). Taylor and Bright (1987) considered it a lake, and possibly a large river species, based on the geological contexts in which it has been found on Lake Bonneville shorelines and its near relation to species found to the north and northeast along the Snake River drainage. *Fossaria* is known to inhabit ponds and mud flats.

Three taxa of the family Planorbidae, *Helisoma*, *Gyraulus* and *Carnifex*, were found in small numbers. All are detritivores burrowing into silty substrates of quiet to stagnant freshwater (McMahon, 1983). When mature they live on and burrow into silty substrates (Harman, 1972). Among the Prosobranch snails, Hydrobiidae were the second most common specimens in the sample column. These include *Amnicola* (=*Pyrgulopsis*) (n=137) and *Fluminicola* (n=2). Chamberlin and Jones (1929) recorded *Amnicola* at Utah Lake, but Taylor and Bright (1987) suggest that it is now extinct in the Great Basin. Shells of this genus closely resemble those of the genus *Pyrgulopsis*, and the *Amnicolids* of earlier studies (see Chamberlin and Jones, 1929) may be *Pyrgulopsis* based on present forms. *Pyrgulopsis* is known to inhabit springs and flowing water, while *Fluminicola* is described as living on rocks in swift streams. A single specimen of the lake and pond snail taxon *Physa* was recovered. Three specimens of *Vallonia*, family Helicidae, were also recovered. These terrestrial snails frequent moist areas beneath rocks and rotting vegetation.

The relatively limited molluscan fauna recovered from the sample column is a mixture of both nearshore/fluvial/ terrestrial and deep-water fauna. This can best be explained by the geography of the Bonneville basin and the location of Homestead Knoll in the basin. During the final deep lake cycle in the eastern Great Basin, the waters of Lake Bonneville did not create a unified faunal system throughout its extent (Taylor and Bright, 1987), possibly due to the relatively short life of the lake and the continually changing shoreline conditions as the lake level rapidly rose and fell. Nor was it particularly favorable for nearshore aquatic fauna. Hovingh (1993) suggests that since most of the shorelines of Lake Bonneville were quite steep, they were subjected to direct impact of wave action and did not provide favorable habitat for most nearshore aquatic fauna; it not only forced them to higher elevations out of the harsh lake waters and into streams and springs, but also restricted their geographic spread throughout the lake. These physical conditions governing the lake likely account in large part for the restricted taxa in the sample. Homestead Knoll, located near the center of the lake basin far from the more varied habitats offered by mainland marshes and rivers, was alternately a peninsula and island and for a period may have been completely submerged. These conditions would not have favored development of a diverse fauna. Passive dispersal by floating or attachment to birds (see Roscoe, 1955), though less likely, cannot be ruled out as factors affecting the nature of the sample.

Strontium analysis (see Quade, chapter four, table IX) suggests that the lymneaids originate from the period of deep lake conditions when the northern and southern arms of the lake were connected. This could have been anytime following the Stansbury level, approximately 20 ka, when transgressing lake waters first reached the level of the cave, down to the time of the post-Provo regression. This is also reflected by the predominant taxa in the sample, lymnaeids and hydrobiids. These have been associated predominantly with the deep-water phase of the lake that prevailed since the Stansbury level (Oviatt and others, 1990). Deposition of the shells in the cave seems to have occurred in two ways. A comparison of the numbers of shells with the volume of tufa per stratum (see figure 35) suggests that many shells could have been incorporated within the precipitating carbonate that coated the walls of the cave. A few shells are heavily coated with carbonate, ranging from a smooth veneer on both interior and exterior, to heavy encrustation that obscured the fine details of the shell; a few are embedded within small pieces of tufa spall. But this is not the case with the majority of shells, and most of the specimens in the sample column likely originated in older shoreline deposits at and above the level of the cave.

FECAL PELLETS

Dried fecal remains are common throughout the Homestead Cave deposits. The presence of feces is a proxy indication of the animal itself, but it also offers potential information on the animal's immediate diet, health and physiology, and changing habitat conditions in the area in which it lives. Most work concerning fecal analysis of non-humans has been conducted for wildlife management of modern game populations. Fecal pellets of animals living in cave sites have not been widely studied for paleoecological purposes, although there are a number of studies of dung from Pleistocene megafauna such as mammoths (Mead, Agenbroad, and others, 1986), ground sloth (Martin and others, 1961; Hansen, 1980) and Harrington's goat (Mead, O'Rourke, and Foppe 1986). Studies of carnivore and raptor pellets for taphonomic purposes are common (see Andrews, 1990; Schmitt and Juell, 1994; Stiner, 1995). Fecal pellets recovered from the sample column at Homestead Cave consist primarily of modern artiodactyl and woodrat (*Neotoma* sp.) pellets, with smaller numbers of lagomorph, and possible microtine rodent and carnivore dung boli. Quantities of avian feces were also recovered, in addition to substantial numbers of raptor pellets.

Here we review the fecal pellet record recovered from the sample column and provide a discussion of the analysis. Because of the nature of the depositional record at Homestead Cave, skeletal remains of small rodents, birds and reptiles are abundant in the deposits of the sample column, but larger mammals (like ungulates and carnivores) are, with the exception of a few teeth, essentially absent. The fecal pellets of these larger animals represent the only record of their activity in the area through time, and pellets of smaller animals are valuable as a potential means of differentiation to species level based on pellet size and morphology. In the case of *Neotoma*, the bone record from the cave deposits is very good and can serve as a check on the identification of pellets. Despite their great age and generally friable condition, the pellets still preserve the morphological features of fresh remains remarkably well. Decomposition of feces begins in the intestinal tract of the animal, through both digestive processes and the activity of microorganisms that are ingested with the plant food (Lodha, 1974). The process continues following deposition owing, in part, to the moisture retained within the fecal mass. The generally good preservation of pellets, particularly in the upper strata, is likely due to the arid conditions within the cave and possibly to rapid burial which terminated decomposition at an early stage. Degradation by coprophagous insects appears to be minimal.

All fecal pellets discussed in this analysis were taken from 12.6 mm and 6.3 mm screened material and separated into broad categories such as ungulates, rodents, lagmorphs (virtually all pellets in the 3.1 mm and residual categories are broken and too fragmented for useful analyses). Subsequent separations were made based on size, color, weight and presence of gross vegetation. The dimensions of pellets were recorded, especially diameter, as this is considered more diagnostic of animal size (Halfpenny, 1986). Samples from Strata Ia and Ib were screened through 600 micron mesh screens in an effort to pick out smaller faunal remains. Use of this finer-gauge screen for these samples may have increased the number of broken and partial pellets. The pellets were either in a dry state when the strata were excavated or dried prior to the processing of bulk samples in the laboratory. There is considerable variation in the number of pellets from one stratigraphic unit to another, and we have attempted to assess whether this variation represents a change in deposition/preservation or only differences in thickness of the strata by standardizing raw counts into numbers of pellets per unit volume (table XIII).

Various characteristics of animal feces have been used by other investigators for identification of both the animal and the diet of the animal at the time of defecation, including gross size and morphology, pellet contents, pH and other biogenically produced chemical features. Most studies of feces in game animals have attempted to quantify behavioral aspects useful in wildlife management, in particular population, habitat use and diet (Putman, 1984). The use of fecal pellet size and morphology to identify the producing animal has a long tradition and is generally considered sufficient for tracking animals via fresh scat (see Murie, 1974; Halfpenny, 1986). Broad features such as size and presence of vegetation or animal tissue distinguish carnivores, herbivores and rodents. Within these broad classes, many animals produce feces that closely resemble one another and which can overlap in size. This is particularly the case with species of *Neotoma* and with ungulate taxa. Within these taxa, pellet size is determined primarily by diameter, which is limited by the size of the anus (Halfpenny, 1986, p. 142). Length is a more variable element. Nevertheless, diet, season and animal size are important variables and studies have shown that identifications based on visual characteristics alone will be in

Table XIII
Total number of fecal pellets and number of pellets/liter in the Homestead Cave sample column

Strata	**Artiodactyl**	***Neotoma***	**Lagomorph**	**Microtine**	**Carnivore**
XVIII	61(2.4/L)	43(1.7/L)	53(2.1/L)	4(0.2/L)	0
XVII	4300(14.8/L)	230(0.8/L)	860(3.0/L)	219(0.8/L)	1
XVI	935(16.4/L)	131(2.3/L)	206(3.6/L)	60(1.1/L)	2
XV	2500(8.7/L)	352(1.2/L)	235(0.8/L)	97(0.3/L)	0
XIV	500(3.2/L)	74(0.5/L)	53(0.3/L)	16(0.1/L)	2
XIII	7300(23.9/L)	110(0.4/L)	17(0.1/L)	12(——)	1
XII	2450(13.6/L)	8(——)	0(——)	13(0.1/L)	0
XI	140(1.2/L)	0(——)	0(——)	0(——)	0
X	657(14.9/L)	0(——)	0(——)	1(——)	0
IX	450(3.8/L)	0(——)	0(——)	3(——)	0
VIII	78(1.0/L)	0(——)	0(——)	0(——)	0
VII	542(8.7/L)	0(——)	0(——)	0(——)	0
VI	737(3.4/L)	0(——)	0(——)	0(——)	0
V	175(3.9/L)	2(——)	0(——)	0(——)	0
IV	117(0.6/L)	1(——)	0(——)	4(——)	0
III	21(0.2/L)	19(0.2/L)	0(——)	3(——)	0
II	50(0.3/L)	420(2.4/L)	0(——)	4(——)	0
Ib	9(0.9/L)	6018(601/L)	0(——)	0(——)	0
Ia	23(1.2/L)	3730(196/L)	0(——)	0(——)	0

error at least part of the time (Johnson and MacCracken, 1978; Halfpenny, 1986, p. 136-137).

Artiodactyla

Artiodactyl fecal pellets are common throughout the entire Homestead Cave depositional sequence (figure 41). Unfortunately, it is almost impossible to distinguish which ungulate species these pellets represent. A variety of studies have attempted to differentiate ungulate pellets and assign them to taxa. Typically this has been done by measuring pH (Howard and DeLorenzo, 1974; Johnson and MacCracken, 1978; Hansen, 1978; Peek and Keay, 1979). Other studies have looked at differences in bile acids and steroids (Major and others, 1980), used electrophoresis (Scribner and Warren, 1984), and analyzed blood residue (Williams, 1990; Newman and others, 1993; compare to Eisele, 1994). Analysis for dietary content, phytoliths, pollen and microorganisms has also been sought as a means of differentiation by taxa. The pH of mule deer shows a wide variability, with means ranging from 5.90 to as high as 9.12. The pH of desert bighorn also has a wide range, from 6.31 to 7.36. The pH values of antelope fall within the upper end of this range, at a mean of 8.6. Hansen (1978) noted that "fecal pH values of any herbivore may vary from area to area and from date to date," and that the pH value for a given species "may behave independently of those of other herbivores on the same range." In a study of fecal pH of three deer species in Marin County, California, Elliott and Longhurst (1984) found that differences were not great enough to enable a distinction to be made. MacCracken (1980) measured changes in the pH of pellets of mule deer, elk, mountain goat and mountain sheep as they aged over a 32-day period. The animals were all fed the same diet to minimize variation due to diet. Among air-dried pellets, the mean pH initially increased at or around day 2, possibly in association with loss of moisture or due to the activity of decomposing microorganisms. With increasing age, an overall decrease in pH occurred among pellets of all four species, and did so uniformly. MacCracken (1980) concluded that the uniformity in the change of pellet pH over time severely limited its use in making distinctions between species.

All of these attempts at identification on a species level have been problematic. The pellets produced by antelope, mule deer and mountain sheep have certain broadly distinct morphological features, but they also overlap to a considerable degree. This is to be expected in animals not only of the same family, but which share the same range and to some extent the same diet. This is a major problem in interpreting the Homestead Cave artiodactyl fecal pellets. Deer and antelope occur in the Lakeside Mountains today and mountain sheep were present prehistorically (Schmitt and Manion, unpublished data). Both mountain sheep and mountain goats are known to occupy cave/rockshelter sites during winter months or during periods of inclement weather (see Geist, 1971, p. 298; Chapman and Feldhamer, 1982, p. 1014), and intermittent use by white-tailed deer (but not mule deer) has

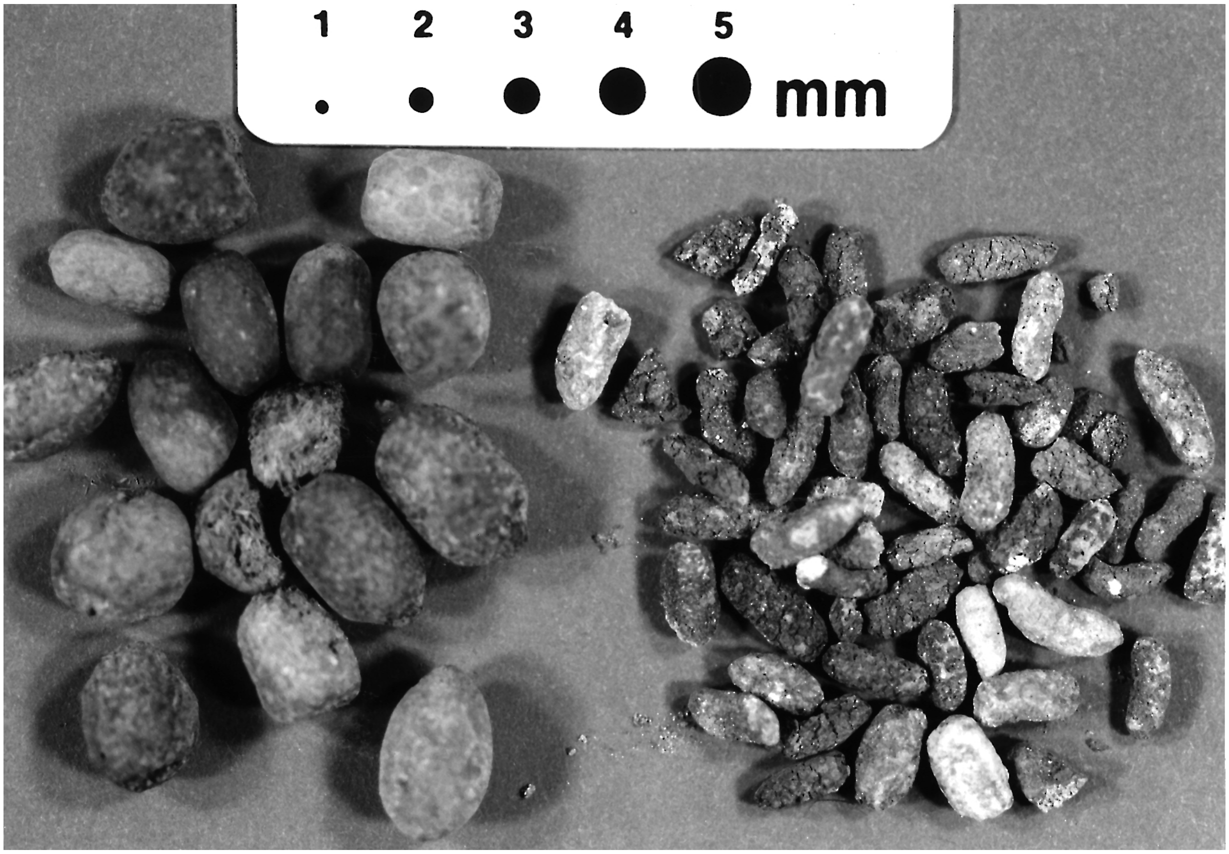

Figure 41. *Ungulate fecal pellets from Stratum XVII (left) and* Neotoma *pellets from Stratum Ib (right).*

been reported (Krausman, 1979). We personally observed antelope in Bonneville basin caves during the earlier stages of this project. In short, the ungulate fecal pellets at Homestead Cave are most probably that of antelope, deer or mountain sheep, but these are impossible to distinguish in large numbers with current technology (see Mead, O'Rourke, and Foppe, 1986). Late Pleistocene/early Holocene fecal pellets identified as those of mountain sheep at other Bonneville basin caves (see Jennings, 1957) may be sheep, but could also easily be those of other artiodactyls.

The deposition of ungulate pellets in the cave can be explained by two aspects of ungulate behavior: shelter from extremes of weather, and defecation habits. During both summer and winter, deer thermoregulate by behavioral adjustments. In winter, deer are faced with two situations: the maintenance of a quality diet in order to retain fat, and protection from wind chill. Dasmann (1981), studying whitetail deer in Pennsylvania, found that given an adequate diet, deer will continue to gain weight when temperatures are above 4.4°C. At temperatures below 4.4°C they begin to lose weight, and below -1°C they lose weight rapidly regardless of dietary quality. Sargeant and others (1994) found that mule deer in arid eastern Washington had little trouble coping with low temperatures given an adequate diet, but found heat stress to be a greater concern for these animals. In both studies, convective loss of heat was of greater importance at low temperatures. Wind chill is a significant factor in the lowering of winter temperatures, and protection from wind was found to be a means of reducing loss of body fat through convective heat loss, and of survival on a less than optimum diet. A study of domestic sheep in Scotland (Munro, 1962) found these animals invariably seeking shelter when wind speeds exceeded 39 km following a drop in temperature below freezing. These same animals also seek shade on hot days with clear skies in order to minimize radiative heat loading. Whether or not wild species behave in the same fashion is unclear. The defecation habits of both mule deer (Linsdale and Tomich, 1953) and mountain sheep (Geist, 1971) are similar. Both have the habit of defecating after rising from a rest, resulting in bedding sites littered with droppings.

Ungulate fecal pellets are most common in the upper portion of the Homestead Cave depositional sequence (table XIII, figure 42), but are comparatively rare in the early Holocene deposits of Strata I-IV, where their density is only one pellet per liter or less (figure 42). After ~8 ka, the number of ungulate fecal pellets per liter of sediments begins to increase, and by the middle Holocene pellet densities reach ~15/liter in Stratum X. There is substantial variability in pellet density in the upper portion of the sample column, with densities reaching as high as 24/liter in Stratum XIII. The overall distribution suggests that the greatest change occurred about 8 ka and corresponds to other paleoecological data from the cave indicating that a shift to essentially modern habitats occurred about this time. During the Holocene a clear pattern of cyclical variation appears related, perhaps, to millennial-scale changes in vegetation around the cave (see chapter thirteen). If modern conditions are a suitable guide, then the ungulate fecal pellets in Stratum V and above are most likely from antelope, with deer a more remote possibility.

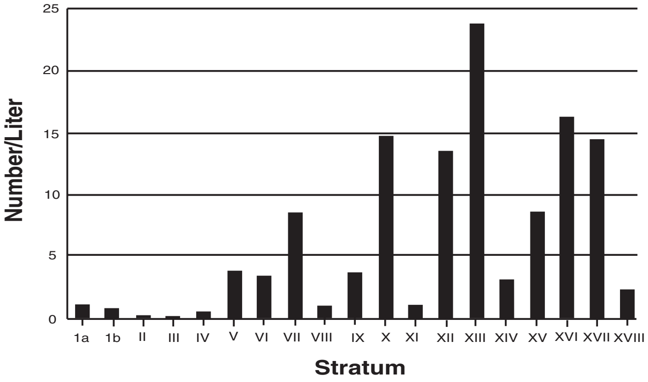

Figure 42. *Density variation (number/liter) in the distribution of artiodactyl fecal pellets in the Homestead Cave sample column.*

Neotoma

Woodrat fecal pellets have a remarkably different distribution through the Homestead Cave sample column (table XIII, figure 43). While the fecal remains of woodrats have not been studied in the same detail as those of ungulates, anecdotal information and a few preliminary studies (see Smith, 1991; Smith and others, 1995; Smith and Betancourt, 1998) suggest that size and morphology may be useful in distinguishing woodrat species. Faunal remains at Homestead Cave include a substantial number of both *Neotoma cinerea* (bushy-tailed woodrat) and *N. lepida* (desert woodrat) skeletal elements, but no other species. Modern trapping within the cave and in its immediate vicinity suggests that both species continue to be present to the exclusion of all other *Neotoma* taxa (Grayson and others, 1996). The woodrat fecal pellets in the cave thus undoubtedly come from one of these species. The bushy-tailed woodrat is substantially larger than *N. lepida*, with adult males ranging from 175 to 440 g compared to an average of 122 g for adult male desert woodrats (Finley, 1958; Lee, 1963). The expectation is that the fecal pellets of bushy-tailed woodrats are correspondingly larger than those of desert woodrats. Great Basin paleoecologists who use fossilized woodrat nests as a source of plant macrofossil data use this expected size difference with some success in selecting middens for analysis. In desert settings, fossil middens with larger than average fecal pellets are often collected for analysis with the expectation that they

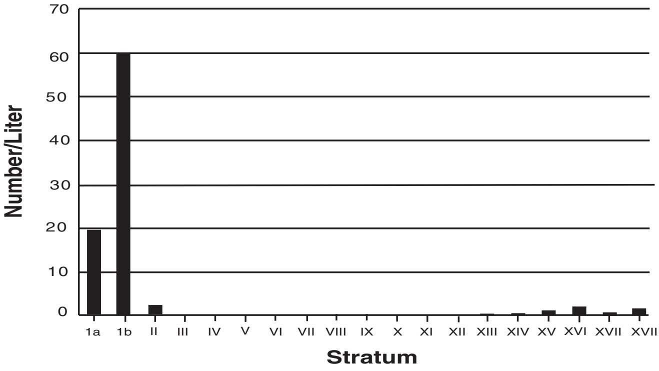

Figure 43. *Density variation (number/liter) in the distribution of* Neotoma *fecal pellets in the Homestead Cave sample column. Note that the ratios in Strata Ia and Ib have been reduced by a factor of 10.*

were deposited by the more boreal *N. cinerea* and therefore were deposited during earlier, cooler periods.

Actual size measurements of woodrat fecal pellets have been taken for a number of species by Smith and others (1995). While pellet sizes vary with the sex and age of individual woodrats and with variations in diet, there is a consistent and statistically valid difference in average size between some *Neotoma* species, particularly between *N. cinerea* and *N. lepida*. We have attempted to test this size relationship by measuring a sample of woodrat fecal pellets from the Homestead Cave sample column. Given that both bushy-tailed and desert woodrats are currently found at the cave and that both are represented in the depositional sequence by skeletal remains, our expectation was that there would be a bimodal distribution in the pellet size. We selected a sample of *Neotoma* pellets from each stratigraphic unit where they were present using a sediment sample splitter, and measured pellet maximum width as a proxy measure for overall volume following Smith and others (1995). Where the total sample size was less than 150 for a particular stratigraphic unit, we measured the entire collection.

The results are somewhat different than expected (figure 44). *Neotoma* fecal pellets are common in 10 of the 18 strata from Homestead Cave. There is no evidence of more than a single group in any of these 10 strata. There are a number of possible interpretations of these results. The most obvious is that there is no statistical difference in the size of fecal pellets between bushy-tailed and desert woodrats living in close proximity in the same environmental setting, with a corollary being that the overlap in pellet size between males, females and juveniles in the two species precludes the identification of subsets that can be readily distinguished. This seems unlikely in view of extant experimental data (Smith and others, 1995). The second possibility is that different species are represented in each stratigraphic unit, but that only one occurs locally within the cave at any one time. We tested this possibility by comparing pellet sizes between strata but found no statistical difference from one stratum to another. A third possibility is that the cave was initially occupied by bushy-tailed woodrats, with desert woodrats moving in sometime during the Holocene. However, there is no significant change in either the average fecal pellet size or the range of variation from one depositional unit to another which one might expect with the addition of the much smaller desert woodrat to the sample mix. This suggests that either one or both species are represented throughout. Final-

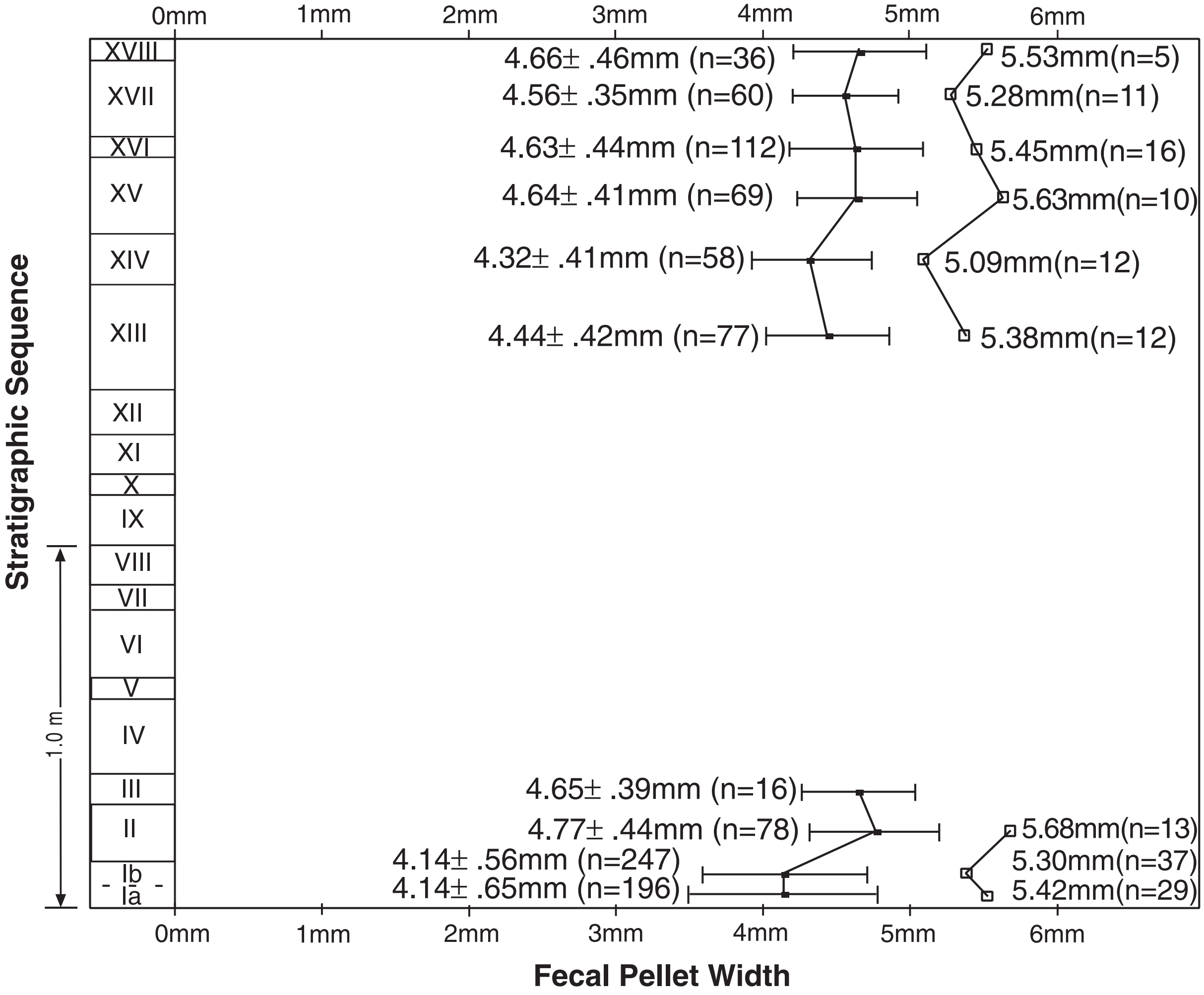

Figure 44. *Variation in average fecal pellet width (left) and average width of the largest 15% of the measured sample (right). Note that sample size varies from that shown in table XIII. This is due to the use of a sample splitter where the sample size was larger than 150, and to the elimination of broken pellets from each sample.*

ly, it is possible a single species, most likely *N. cinerea*, was the sole contributor of fecal pellets to the Homestead Cave throughout its depositional history and that the *N. lepida* skeletal remains are entirely a product of raptor foraging well beyond the cave.

The highest numbers of woodrat fecal pellets occur in Strata Ia and Ib where they are found in concentrations of 196/liter and 601/liter, respectively. These high numbers may be the result of differential processing, since these samples were sorted without screening, while those from later depositional units were shaken through a series of graded screens. The presence of thousands of ungulate and *Neotoma* fecal pellets in the screened samples, however, suggests that these concentrations represent a real phenomenon. These woodrat pellets have dark brown cuticles covering lighter interiors. In Stratum Ib the *Neotoma* pellets are unusually flattened and appear to have been smashed while they were moist. This situation does not occur with *Neotoma* pellets in the succeeding levels. In Strata II and III, the *Neotoma* pellets are firm and hard, light tan in color with only a few pellets showing any distinct cuticle. The others are pitted and eroded. Texture is consistent with those in Stratum I. The total number of woodrat pellets declines dramatically through Stratum II and Stratum III. Only a single woodrat pellet was found in Stratum IV and only two were recovered from Stratum V. All three are most likely present as a product of relatively limited bioturbation. No *Neotoma* fecal pellets are present in Strata VI-XI. *Neotoma* pellets reappear in low numbers in Stratum XII (0.04/L) and are present in all depositional units thereafter. In Stratum XIII, pellets increase in numbers to 110, are moderately well preserved, and fine-grained to medium-grained vegetation is visible for the first time. In Stratum XIV, pellets are moderately well preserved with fine-grained vegetation present. *Neotoma* pellet numbers reach their highest Holocene density (1.22/L) in Stratum XV, with medium to coarse-grained vegetation present in most. They are light tan to dark brown. The darker pellets are coated or indurated and are noticeably harder than the lighter-colored pellets. In Stratum XVI, pellets are light brown to dark brown with vegetation present in most, much of it medium to coarse textured. In Stratum XVII, darker colored pellets are better preserved and appear to be indurated; lighter colored pellets are less well preserved. Medium to coarse vegetation is present in most pellets. Stratum XVIII pellets are similar to those in Stratum XVII.

There are two striking features of the woodrat fecal pellet distribution in the Homestead Cave sample column: the high concentrations in the earliest stratigraphic units and their absence through the central part of the depositional sequence. Other floral and faunal data from the cave suggest a relatively cool-mesic habitat, well suited to *Neotoma cinerea*, was present in the vicinity of Homestead Cave during the deposition of Strata Ia and Ib. The high numbers of fecal pellets suggest that local forage was abundant during this period and that a number of dens may have been present within the cave and in the ridges along the cave mouth. After ~10 ka, the numbers of woodrat pellets decreases markedly, and by 8500 yr B.P. woodrats were completely extirpated from the cave. Woodrats do not reappear in the fecal pellet record until 3.4 ka or probably even later.

This absence for 5000 to 6000 years or more is perplexing given that skeletal remains of *N. lepida* occur throughout the record (Grayson, chapter seven), and that fossil middens dating to this period have been found in a number of similar environmental settings across the Bonneville basin (Rhode, chapter twelve). The lack of change in pellet size suggests the possibility that only a single species may be represented and that this sequence is the result of bushy-tailed woodrats being locally extirpated and then subsequently recolonizing the cave. To examine this possibility, we selected a subset of the largest 15% of the measured specimens from each stratum following a similar procedure used by Smith and others (1995). The specimens average greater than 5.0 mm in width for all units. If the correlation between fecal pellet width and body mass suggested by Smith and others (1995) is valid, widths of >5.0 mm indicate body weights of 275-450 g for

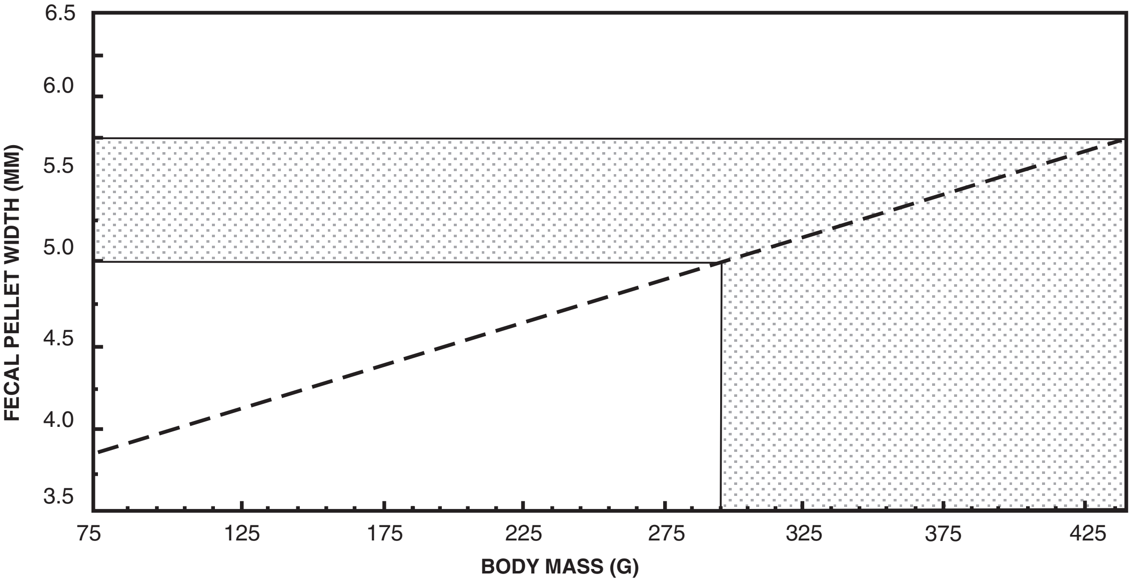

Figure 45. *Linear relationship between fecal pellet width and body mass for three species of woodrats (*N. albigula, cinerea, *and* lepida*) modified from Smith and others (1995, p. 2012, Figure 1.C). Fecal pellet size "can be used to estimate adult body mass with a prediction error of only 21%." The size range of the largest 15% from all strata suggests adult body weights of up to 450 g.*

the individuals who produced them (figure 45). These weights are much too large to have come from *N. lepida* and suggest that *N. cinerea* was a major contributor of fecal pellets to the Homestead Cave deposits in both the earlier and later periods. In short, despite the presence of desert woodrats at the mouth of the cave at present (Grayson and others, 1996) and the occurence of *N. lepida* faunal material in the deposits for at least the last 9000 years, it seems likely that desert woodrats were restricted to the warmer and more xeric environments outside the cave and, at best, made only minimal contributions to the Homestead Cave fecal record.

Grayson and others (1996) note the unusual occurrence of *N. cinerea* currently living at Homestead Cave and suggest its presence is most likely due to a previously unknown ability to expand rapidly from higher elevations during short-term climatic oscillations. An alternative possibility is that a small population managed to survive throughout the Holocene within the relatively mesic confines of Homestead Cave. The fecal pellet distribution supports the former possibility and suggests that this recolonization may have occurred during the relatively cool Neoglacial period when Great Salt Lake reached its Holocene high (Currey, 1990) and when vegetational communities in the eastern Great Basin may have been depressed as much as 100 m (Madsen, 1984; Wigand and Rhode, in press). Bushy-tailed woodrats are sensitive to high temperatures and prefer deep crevices or caves in cliffs which are of "...importance as buffers against high temperatures; [since] *N. cinerea* may suffer heat stress at temperatures above 34°C" (Vaughan, 1990, p. 20). Homestead Cave currently provides such a refuge, and bushy-tailed woodrats could have been reintroduced during the Neoglacial 2000 - 4000 years ago and have survived there since that time.

Other Fecal Remains

Fecal pellets of lagomorphs, microtine rodents and carnivores also occur at Homestead Cave in minor amounts (table XIII). With the exception of Strata XV-XVII, fecal pellets from microtines are either absent from the sample column or occur in very small numbers. In these three strata, however, microtine fecal pellets rival those of woodrats in frequency, suggesting that local breeding populations may be using the cave floor and the mesic habitat at the cave mouth. Below these relatively recent depositions, microtine pellets are rare enough to suggest they may be a product of prey items brought into the cave by raptors. Fecal pellets of lagomorphs are common in the upper third of the sample column, but may also be a product of raptor foraging, since neither jackrabbits (*Lepus* spp.) nor cottontails (*Sylvilagus* spp.) are known to frequent cave settings. Cottontails prefer dense sagebrush with abundant escape routes, while jackrabbits prefer open ground. Both taxa nest in burrows or under protective cover (Chapman and Feldhamer, 1982).

Hare and rabbit pellets first appear in Stratum XIII (after 3.4 ka) with 17 well-preserved pellets. Numbers quickly increase, reaching a maximum of 860 pellets in Stratum XVII. Beginning in Stratum XV, a few (n=4) small, hard, blackish pellets are found. These increase to 59 in Stratum XVII, comprising ~7% of the total pellets for this stratum. These blackish pellets may be what are known as "green pellets," rich in nutrients and reingested by the rabbit. These pellets form in the lower intestines of the rabbit and are generally excreted at night or early morning (Steigers and others, 1982). Their presence in the cave deposits suggests that these animals were caught by a raptor during night hunting and were scattered onto the cave floor as the animal was dismembered. The lack of rabbit fecal pellets in the lower Homestead Cave deposits may be a product of differential preservation, since both cottontail and jackrabbit skeletal elements are found throughout the depositional sequence.

Six fecal samples (table XIII) appear to derive from small carnivores, possibly coyotes. They are distinguished by the presence of partially digested bone (that is, pitted and polished). Acid-etched, small mammal bone imbedded in hunks of matted hair is characteristic of coyote scat (Schmitt and Juell, 1994).

Summary

Fecal material from Homestead Cave is primarily that of ungulates followed by *Neotoma* pellets, with smaller numbers of lagomorph pellets and a few possible carnivore pellets. Overall, ungulate pellets occur in small numbers in the lower strata of the sample column, increase rapidly in the middle strata, and vary thereafter. In general, preservation of the pellets is very good, although many pellets in the lower strata are friable and erode easily when handled or disturbed. These pellets may derive from deer, antelope or mountain sheep, but given local habitat conditions and known behavior patterns, were most likely deposited by antelope in strata deposited after ~8 ka. Prior to that time mountain sheep are a very viable alternative. *Neotoma* fecal pellets show a unique distribution, suggesting that no woodrats occupied Homestead Cave between ~8.5 and ~3 ka. Size measurements show no bimodal distribution in size categories, suggesting either that size alone does not provide good proxy data for species identification, or that Homestead Cave was occupied by only a single species. *N. cinerea* apparently lived within the cave during both the early and later periods. Hare and rabbit pellets are present in the upper portion of the sample column, but may well have been brought to the cave by raptors and carnivores.

CHAPTER SIX

Archaeological Materials from Homestead Cave

by

Monson W. Shaver III

INTRODUCTION

In choosing a cave site suitable for the investigation of paleoenvironmental change in the Bonneville basin, we assumed that people would be among the many biological vectors contributing to a complex ecological record embedded in the deposits. Based on previous work (see Aikens and Madsen, 1986; Madsen, unpublished data), it was clear that virtually every cave of any size in the basin was occupied to some extent by prehistoric peoples. However, we hoped to reduce interpretive difficulties by investigating a site where human occupation was limited, since human activity in a cave often creates a complex stratigraphy which is difficult to identify. The complexity increases in difficulty with repeated floor sweepings, movement of fill to level floor surfaces, digging of pits or storage cists, the use of fires on deposits consisting of combustible materials, and the general day-to-day activity of recurring use. As a result, there is often a direct correlation between the frequency of occupation and length of stay at a site and the complexity of the depositional record it contains. Within the Bonneville basin, it is apparent that heavy aboriginal use of a cave location appears to be generally dependent on access to water primarily, and to food resources secondarily. Distance to water therefore became one of the criteria we employed in selecting a site for this project.

Homestead Cave (42Bo763) was chosen for investigation primarily because of its prominent raptor roosts and related pellet cones on the cave floor, but also because of the lack of cultural remains on the cave surface. Open surface water is unavailable in the northern Lakeside Mountains and, as a result, human occupation appears to have been sporadic and relatively recent (Madsen and Kirkman, 1988; Madsen and Schmitt, 1998). The limited subsistence resources available in the Homestead Knoll area made an extensive archaeological record in the cave deposits unlikely, and suggested the possibility that any modest human deposition would aid rather than hinder interpretation of the paleoecological record by providing datable materials from infrequent fire hearths. Fortunately, this initial assessment proved to be accurate and only a very few cultural remains were recovered during the excavation process. These archaeological materials are reported here, primarily in a descriptive fashion. More detailed conceptual discussions of human occupation in the western Bonneville basin are available in Aikens (1970), Madsen (1980), Aikens and Madsen (1986) and Madsen (unpublished data).

THE ARCHAEOLOGY OF THE LAKESIDE MOUNTAINS

The Homestead Cave region on the northern end of the Lakeside Mountains has a history of human occupation limited to the last 5000 ^{14}C yr (Madsen and Kirkman,1988; Madsen and Schmitt 1998). Previous study of the area is limited to four surveys and the excavation at Lakeside Cave (42Bo385). Site inventories are reported by Arkush (1991, 1994), Arkush, and others (1992), and Arkush and Workman (1993a, 1993b). Individual sites have also been identified during projects conducted by the State of Utah and the U.S. Bureau of Land Management and have been recorded in the site files of the Utah State Historic Preservation Office. Those surveys identified 28 aboriginal sites on the northern half of the Lakeside Mountains (figure 46). Five are open camps and limited-activity lithic scatters, two are chalcedony quarry source/lithic scatters, and the remaining 21 sites are caves or rockshelters.

The archaeology of Homestead Cave is most readily understood in the context of previously excavated cave sites in the Bonneville basin. There are two sites, Lakeside and Hogup Caves (42Bo36), which the aboriginal visitors to Homestead Cave most likely also used. The other prominent comparative cave assemblages for the eastern Great Basin are Danger Cave (42To13), Floating Island Cave (42To106), and Camels Back Cave (42To392). Lakeside Cave, located 6 km due north of Homestead Cave, is the geographically closest known site containing a human occupation record. Hogup Cave is approximately 36 km northwest of Homestead Cave along the southeastern margin of the Hogup/Terrace Mountains. In the Silver Island Mountains, along the western boundaries of the Great Salt Lake Desert and less likely to have human association with Homestead Cave, are Floating Island and Danger Caves, some 59 and 91 km farther to the west, respectively. These sites have helped define a chronology and aboriginal history of the eastern Great Basin (Aikens and Madsen, 1986) and provide a backdrop for comparison to the archaeological record of Homestead Cave.

The environmental context of Lakeside Cave is most similar to Homestead Cave in that no sources of water or abundant food resources were available to early visitors of the area. The excavations at Lakeside Cave document 5000 ^{14}C yr of intermittent seasonal use of the site by small mobile bands. Grasshopper remains (*Melanoplus sanguinipes*) mixed with the oolitic sands from mid- to late Holocene beaches indicate that insects were a major seasonal component of the aboriginal diet and were probably collected from the surface of adjacent beaches. "Human fecal deposits are associated with all strata where grasshopper parts occur and contain oolitic sand and hopper parts as their principal components" (Madsen and Kirkman, 1988). Madsen and Kirkman (1988) also report ethnohistoric accounts of insect use and document windrows of dried and salted hoppers that accumulate in the thousands along today's Great Salt Lake beaches. "Grasshopper procurement appears to have been one of the primary subsistence activities at the site. The season of occupation appears to have been earlier than at Hogup Cave, most probably during late summer" (Madsen, unpublished data).

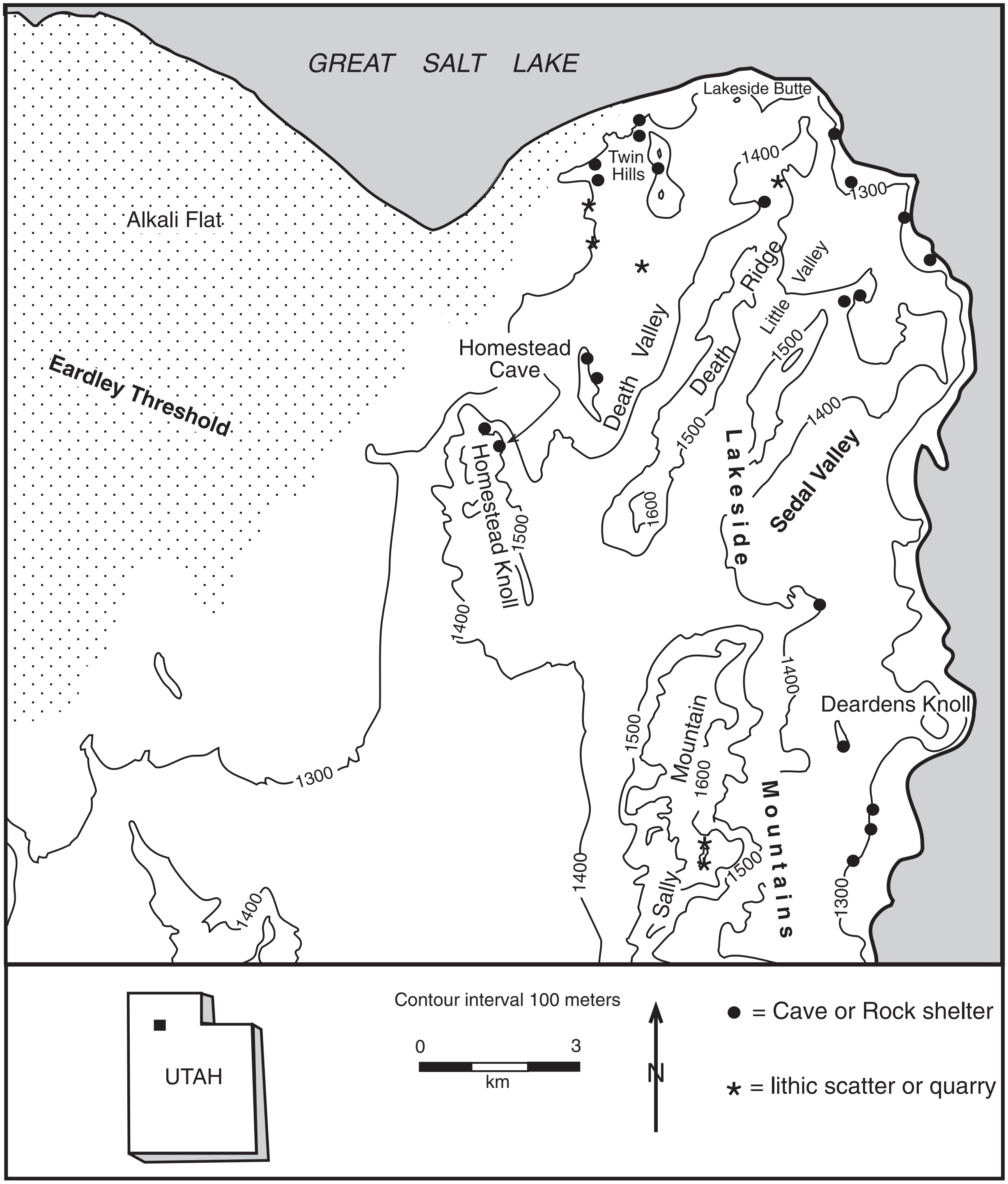

***Figure 46.** Location of known archaeological sites in the northern Lakeside Mountains.*

To the northwest, Hogup Cave is separated from Homestead and Lakeside Caves by 36 km of the mud and playa salts of the Great Salt Lake Desert and at times during the mid- to late Holocene has been isolated from the south by the rising waters of the lake itself. Several artifacts in the Lakeside Cave deposits, such as thin slab metates originally from bedrock sources in the Terrace and Raft River Mountains, suggest that visitors may have originated from around the Hogup area and points farther north. Detailed textile analysis (Andrews and others, 1988) also suggests that both sites were occupied by the same set of people and that the textiles "....may in fact reflect the work of the same but forever anonymous hands." According to Madsen (unpublished data), the two sites may also have been linked ethnographically and during periods of low lake level:

> ...the closest area of interaction appears to have been the Lakeside/Terrace Mountains area where Steward (1938) records a winter village of Gosiute near a spring (probably Craner Springs) on the Lakeside Mountains and a winter village of

> Northern Shoshone at Locomotive Springs at the north end of the Terrace Range. While the villages themselves were at least 80 km apart, Steward also reports that intervening areas were extensively used for antelope hunts and occasional contact and social interaction undoubtedly occurred. Some interaction also appears to have occurred on the western margin of the lake/desert in the area of the Pilot Range, but the population density was quite low and the only significant number of people between the Deep Creek Mountains on the south and Grouse Creek on the north were far to the west of the salt flat margin in the vicinity of Wells, Nevada (Steward, 1938, p. 173).

The environmental and archaeological patterns at Hogup Cave differ greatly from both Lakeside and Homestead Caves, however, despite the possible use by the same set of people. The Hogup Cave location overlooks Crescent Springs, and its inhabitants, both human and nonhuman, had immediate access to marsh flora and fauna. This proximity to water and food resources changes the nature and abundance of the archaeological record found in Hogup Cave. The site was excavated by the University of Utah under the direction of Melvin Aikens in the late 1960s. The analyzed remains reflect an adaptive desert culture that centers on the pickleweed seed (*Allenrolfea occidentalis*) as a seasonal staple and diversified small and large game hunting (Aikens, 1970). "Pickleweed constituted a major and dependable resource, available annually in late summer. It probably was the magnet which drew people regularly to the site and was a dependable staple that allowed them to remain in the area for a considerable period at each visit, hunting and foraging for other desirable, but less dependable or not as easily available, floral and faunal resources" (Aikens, 1970, p. 189). Analysis of the recovered materials suggests occupation spanning most of the Holocene, with ^{14}C age estimates ranging from 8350 ± 160 to 480 ± 80 yr B.P.

In stark comparison to the immediate access to subsistence resources at Hogup Cave, water and food resources are very limited at Homestead Cave. Identifiable water sources consist of seasonal washes or ceiling seeps noted on the interior of Cathedral Cave, on the north side of Homestead Knoll (see chapter ten), and Lakeside Cave. Today the closest consistent source of water, at the head of Craner Canyon on the northeastern slopes of the Lakeside Mountains, is 32 km to the southeast of Homestead Cave. This distance to water creates an ephemeral archaeological record that reflects brief visits at extended intervals, rather than the recurring seasonal use that creates the archaeological abundance found in more attractive sites such as Hogup Cave.

CULTURAL FEATURES AND STRATIGRAPHY

Cultural materials were recovered from the upper one-half of the 1 x 1 meter sample column. Those remains are very sparse, consisting of 41 small fragments of cordage, two projectile points, a point fragment, two obsidian flakes, two pieces of ground stone and a small fragment of a leather knot. Human occupation of the cave appears to have been limited, as little of the detritus resulting from daily living, such as resharpening flakes, broken ground stone, or fire-cracked rock, was identified during laboratory sorting of the bulk samples. Dispersed charcoal from cooking fires is, with the exception of that associated with the single hearth identified on the surface of Stratum XV, also rare in the bulk samples. At best, the human contribution to the depositional sequence was modest, and virtually all of the floral and faunal remains in the cave were left there by non-human animal vectors. The earliest cultural materials, consisting of two cordage fragments, first appear in Stratum X, which dates to ~5330 yr B.P. These may be out of place, however, as the initial occupation at nearby Lakeside Cave was somewhat later. Stratum X is heavily disturbed by rodent burrows, and nearly all of the cultural items appear in the Homestead Cave sequence only after ~3400 yr B.P. in Stratum XII and above.

Only three prehistoric cultural features were identified during the excavation and sampling process. These include a surface scatter of human bone, a charred log or large root fragment and a hearth. In addition, a rock or talus-ringed depression found on the surface of the cave deposits may be of human origin. The human skeletal remains were recovered from a surface scatter on the west side of the cave mouth. The scatter was about 1 m in diameter and appears to have been redeposited from a relic hunter's hole dug along the west wall of the cave. It was initially impossible to identify the remains as prehistoric due to the absence of a skull and associated diagnostic features. The highly weathered condition of the bones also suggested they had been exposed for some time. After these surface remains were removed and exploratory excavations were initiated, a vertebrae, a second left metacarpal, and partially ground tooth were found in the spoil dirt from the looter's pit, suggesting the surface remains originated from subsurface deposits and were probably prehistoric. This assessment was confirmed by the forensic examination.

Twenty-six of the identifiable cordage fragments were recovered from Strata XIII thru XV, and it is likely the burial is associated with the deposition of these three strata bracketed to a period from ~3400 - 1240 yr B.P. Given the limited array of cultural materials and the location of the sample column immediately adjacent to the pothole from which the burial originated, it seems possible the cordage fragments are the result of rodents having disturbed the body and the clothes in which it was buried.

The single major cultural feature consists of a concentration of ash and charcoal on the surface of Stratum XV that appears to be the remnant of a badly disturbed hearth (figure 47). A krotovina extends vertically downward below the ash. The hearth remnant is triangular, approximately 15.0 cm on a side, and is centered at 122.8S and 98.95E. It is a maximum of 5.0 cm. thick and contains burned large mammal bone fragments. Stratum XVI, in which the hearth occurs, is quite ashy and the hearth cannot be clearly distinguished from the fill of the stratum as a whole. If measured by the area of dispersed charcoal the hearth extends into 122S 99E approximately 20.0 cm. (figure 48). A log fragment or branch of pine on the surface of Stratum XI is 11.0 cm in diameter at its thickest and extends at least 0.5 m in length. It has no evident human modification and is identified as culturally deposited simply because there is no other plausible explanation for its presence in the cave. Another possible cultural feature is a rock/talus ringed depression in the rear

Figure 47. *View of hearth on the surface of Stratum XV.*

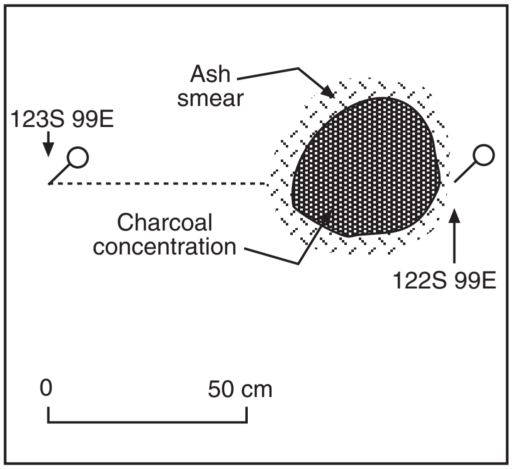

Figure 48. *Plan map of hearth on the surface of Stratum XV.*

western quadrant of the cave. It is roughly semicircular with a diameter of ~3.0 m. It is formed by limestone spall from the center and the rear of the cave and may simply be a product of convergence between the two main talus areas in the site. The depression is approximately 50.0 cm deep. No artifacts were identified within the rock ring.

ARTIFACTS

Cordage

The terminology for the structural types of cordage described here follows that employed by Emery (1966), Shaw (1972), Hurley (1979), and Andrews and others (1988). The basketry and cordage assemblage from Lakeside Cave analyzed by Andrews and others (1988), is the geographically closest assemblage of cordage materials to occur in proximity to Homestead Cave. The limestone outcrop in which Lakeside Cave is located, ~5 km to the north-northeast, can be seen from Homestead Cave. The Lakeside Cave cordage analysis reveals that the cordage construction techniques used at the site closely resemble the Hogup Cave cordage assemblage recovered by Aikens in the late 1960s. Later excavations at Floating Island, located in the Silver Island Mountains, recovered and identified a distinct set of construction techniques and found the construction style similar to those recovered from Danger Cave. Thus, two separate populations using different cordage construction techniques have been identified, one population using the Hogup-Lakeside Caves and a separate population depositing cordage remains in the Danger-Floating Island Caves.

Only a few pieces of cordage were recovered during the actual excavations at Homestead Cave. Most of the cordage assemblage was separated by hand in the laboratory from the bulk 1 x 1 meter column samples after screening through 12.6 mm, 6.3 mm and 3.1 mm mesh screen size (table XIV). Many of the samples consist of a mass of fragments which have been counted as one unidentifiable piece of cordage.

One small (1.5 mm) unidentifiable fragmentary piece of cordage was recovered from the uppermost Stratum XVIII. One piece of cordage was recovered from Stratum XVII and dates to ~1,020 yr B.P. It is 47 mm long and is constructed in a Z-twist, S-spun, 2-ply fashion. Stratum XVI, which dates to ~1240 yr B.P., contained one piece of cordage, measuring 42 mm and constructed in a Z-twist, S-spun, 2-ply fashion. Stratum XV contained the largest quantity of cordage recovered from the entire column. Of 15 total pieces, seven are S-twist, Z-spun, 2-ply, the longest of which is 102 mm and the shortest 18 mm. One is tapered from a broad to a narrow diameter and another contains an overhand

Table XIV
Artifacts from Homestead Cave

Stratum	Ground Stone	Tools & Chipped stone	Cordage	Other
XVIII			1*	
XVII	Metate	Bifacial thinning flake	1z/s	
XVI			1z/s	
XV		Bear River side-notched point	7s/z, 5z/s, 3*	Leather knot
XIV		Elko Series point	5s/z, 1z/s, 2*	
XIII			7s/z, 1z/s, 2*	
XII		Bifacial thinning flake	1s/z, 2*	
XI	Mano	Projectile point tang fragment		
X			2s/z	

*Unidentifiable fragmentary cordage

knot at one end. Five specimens are constructed in a Z-twist, S-spun, 2-ply fashion; two of these have overhand knots at one end. These five pieces of cordage are 24 to 210 mm in length, with 210 mm being the longest recovered specimen in the assemblage. The remaining three pieces consist of S-spun fragments which are too poorly preserved for categorization.

Stratum XIV contained eight pieces of cordage (figure 49a,b). Five are constructed in an S-twist, Z-spun fashion, with one individual piece being the only 3-ply cordage construction found in the collection; the other four are 2-ply. These five pieces range from 110 mm to 38 mm in length. Only one piece of cordage found in Stratum XIV is constructed in a Z-twist, S-spun, 2-ply fashion; it measured 59 mm in length. The remaining two specimens are too fragmentary for precise description. Ten pieces of cordage were recovered from Stratum XIII. Seven are constructed in an S-twist, Z-spun, 2-ply fashion and one in a Z-twist, S-spun, 2-ply fashion. The remaining two consist of fragments, one of which could only be defined as a Z-spun knot. Maximum length in this group is 148 mm, with the shortest being 8 mm. Two overhand knots occur in the S-spun, Z-twist group. Stratum XII, dated to ~3400 yr B.P., contained three samples of cordage, only one of which could be defined as S-twist, Z-spun, 2-ply construction. The remaining two pieces are so indurated it is impossible to identify more than a twist in an S-twist direction. None of these samples exceed 10 mm. The lowest stratum in the sample column to contain cordage is Stratum X, dating to ~5330 yr B.P. It contained two indurated pieces of cordage constructed in an S-twist, Z-spun, 2-ply fashion.

A small leather knot (figure 49c) was recovered from Stratum XV, dating to shortly before ~1240 yr B.P. The knot consists of three small individual curved fragments of indurated leather, forming a small inseparable clump. Measuring 12.2 mm x 8.4 mm x 5.0 mm, it contains no features indicating its function.

Chipped and Ground Stone Artifacts

The recovered assemblage of Homestead Cave chipped stone consists of only two obsidian thinning flakes and three specimens of finished tools. The two bifacial thinning flakes, debris associated with either the manufacturing or resharpening/repair of tools, suggest occupation was limited to extremely short-term visits. Four of the five specimens (the two obsidian flakes, a small side-notched chalcedony arrow point and a bifacially flaked ignimbrite tang fragment) were recovered during the lab screening of the bulk column samples. The fifth specimen, a complete obsidian Elko Series projectile point, was identified in the north profile face of the sample column during excavation. The two diagnostic projectile points are stratigraphically and temporally in sequence with the arrow point in Stratum XV, directly above the Elko Series point in Stratum XIV. Both of these deposits are bracketed above and below by radiocarbon age estimates of 1240 ± 50 yr B.P. and 3400 ± 60 yr B.P. The arrow point (figure 49e) measures 20 mm long by 10 mm wide, and is 2.1 mm thick. Material type is a white/brown chalcedony. This small, symmetrically triangular point is lacking its diagnostic basal stem, but it most closely resembles the Bear River side-notched point series defined by Holmer and Weder (1980). Chronologically, it falls just within, and geographically well within, the boundaries described for this point type.

The Elko series projectile point (figure 49d) was produced from obsidian and measures 36.45 mm in length by 21.5 mm at its widest by 6.15 mm in thickness. The shoulder-notched stem contracts slightly to a termination without basal notching. This projectile point was recovered from the side wall of the sample column during excavation and its location is tightly provenienced to the middle of Stratum XIV, dated to 2850 ± 50 yr B.P. The morphology of this point falls within the Large Contracting Stem point series or the Elko projectile point series. Large contracting stem points have been reclassified by Thomas (1981) as Gatecliff Contracting Stem. According to Holmer (1986, p. 105):

> Wherever they occur their temporal placement is remarkably consistent - always between 2500 B.C. to A.D. 500. Of interest is that they do not occur everywhere in the Intermountain West but seem to be limited to approximately the southern half. They are common at Hidden Cave, constituting 27% of the total Archaic points, at Gatecliff Shelter 7%, at O'Malley Shelter 36%, at Sudden Shelter 13%, and at Cowboy Cave 38%. Only a few were recovered from Danger Cave (2%) and none from the study sites north of that.

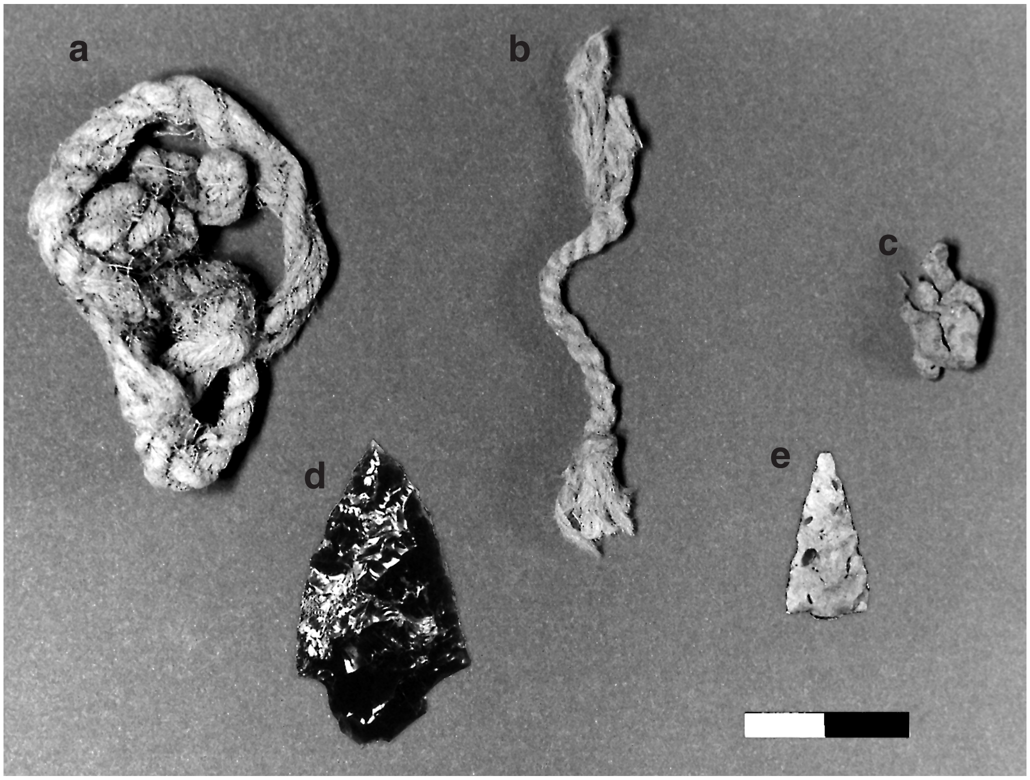

Figure 49. *View of selected artifacts from Homestead Cave: cordage (a,b), and leather knot (c), Elko Series point (d), Bear River side-notched point (e). Scale equals 2 cm.*

A histogram constructed by Holmer estimates the ages of each stratum for Danger Cave, Hogup Cave, Sudden Shelter and Cowboy Cave. By plotting the number of Elko Series points per 500 ^{14}C yr period within a 7000 ^{14}C yr occurrence in the eastern region, it is possible to see that Elko Series points are dominant between 3 and 5 ka (Holmer, 1986, p.102).

A small bifacially flaked tang, possibly originating from a projectile point, was recovered from Stratum XI dating to shortly before ~3.4 ka. It is produced on a dark piece of ignimbrite and measures 6.4 mm x 9.95 mm x 3.3 mm. Its size and chronological placement suggest that it may have come from an Elko Series point.

Two specimens represent the total ground stone assemblage recovered from Homestead Cave. The first is a metate from Stratum XVII and postdates ~1240 B.P. Typologically it falls well within the Class III metates defined by Madsen (unpublished data) for the Bonneville basin. Class III metates are expediently prepared and manufactured on locally available rock types. This type of ground-stone metate is usually identified and categorized within the Bonneville basin by its lack of preparation and light use. When found in relatively large proportions, they are thought to indicate higher frequencies of short-term occupation. The metate was made on a piece of limestone spall similar to many unmodified pieces in the cave fill. It is 21.0 mm thick by 100.3 mm long. The working surface measures 40.5 mm in width. Surface wear is flat, medium to heavy ground, with no edge preparation evident. It has wear on a single side, with calcium carbonate deposits adhering to one end and on the side opposite the ground surface. The ground surface is pitted and appears to have striations.

A one-handed mano, manufactured on a rounded beach cobble, was recovered from Stratum XI. It is an ovoid-shaped piece of limestone with one battered end and a unifacially ground surface. The end opposite the battering has begun to deflate away. Its dimensions are 150.05 mm x 89.3 mm x 48.0 mm. The ground working surface measures 101.0 mm x 62.0 mm.

ECOFACTS

Plant macrofossils identified in the sample column that are most likely related to human activity consist of a single needle from the mesic, high-montane conifer white fir (*Abies concolor*), pine charcoal from Stratum IX, a pine log from Stratum XII and two fragments of pinyon pine seed hulls (*Pinus monophylla*) from Stratum XVII (Rhode, chapter five). The presence of these plant macrofossils have no ready explanation. Great Salt Lake beaches are commonly strewn with driftwood of many types, and it may be this pine detritus was used as a source of fuel for campfires in the depauperate environment of Homestead Knoll. Alternatively, it may be a transported branch of pine used as a ready source of pine pitch for waterproofing or as a fastening agent with basketry, ceramics or projectile points. Neither explanation is entirely satisfactory.

Pine nuts are known to be of critical importance to prehistoric populations inhabiting the northern Great Basin (Simms, 1985; Madsen, 1986). The remains of pine nuts are common in Bonneville basin cave sites, and they have been reported at Lakeside Cave (Madsen, unpublished data), Hogup Cave (Aikens, 1970) and Danger Cave (Madsen and Rhode, 1990). They were reportedly in use at Danger Cave by 7 ka following the early to mid-Holocene migration of single leaf pinyon (*Pinus monophylla*) into the northeastern Great Basin (Madsen and Rhode, 1990; Rhode and Madsen, 1998). The nearest known location for pinyon growing today is over 80-100 km away in the Stansbury, Oquirrh and Pilot ranges. It also occurs in dense concentration more than 100 km to the north in the Raft River Mountains. While pine nuts can be readily transported as a food source (Jones and Madsen, 1989; Metcalfe and Barlow, 1992), these distances are outside the economically viable limit for logistical foraging from the cave, and it is most likely they result from the one-way transport of pine nuts through a series of stops. Alternatively, it may be they derive from a now extirpated refugium of pinyon in the higher elevations of the Lakeside Mountains.

HUMAN SKELETAL REMAINS

During the initial survey of Homestead Cave, human skeletal remains in extremely poor and fragmentary condition were discovered on the surface outside the dripline of the cave. This material appears to have been derived from a shallow looters pit in the rear of the cave and was redeposited at the cave mouth. The skeletal material was determined to be that of an active middle-aged adult, most likely a female, about 166 cm tall (McCullough, 1994). Some moderate arthritic development was apparent and all the bones show obvious ridging resulting from muscular-related stress. No apparent injuries were noted on the skeletal material. The woman was most probably indigenous American, but ethnic affiliation could not be determined in the absence of DNA testing.

SUMMARY

The limited array of cultural materials at Homestead Cave suggests that visits by people were infrequent and short term. The lack of chipped stone detritus, dispersed charcoal, burned bone and broken finished slab metates indicates limited occupation. Only a few finished tools were recovered and only a single hearth was identified throughout the entire excavation area. What infrequent visits did take place probably occurred during the late Archaic to early Fremont period from ~5 to 1 ka. Most likely, these visits took place in conjunction with the seasonal occupation of Lakeside Cave or other similar nearby sites, and may have been limited to day trips. There is no evidence suggesting the purpose of these visits. The extremely sparse contribution of humans to the faunal and floral record at the cave allows the direct comparison of the later depositions with those laid down prior to the appearance of people in the northern Lakeside Mountains.

CHAPTER SEVEN

The Homestead Cave Mammals

by
Donald K. Grayson

ANALYTICAL QUESTIONS

The initial testing of Homestead Cave revealed the presence of a rich, stratified small mammal fauna that reached back into the latest Pleistocene and that held the potential of providing important insights into two interrelated aspects of arid western history.

The first of these involves the nature of past climates in the northern Great Basin in general, and in the northern Bonneville basin in particular. Climatic modelers using the National Center for Atmospheric Research Community Climate Model (NCAR CCM) have recently suggested that the early Holocene in the northern Great Basin was not only relatively moist, as has long been suggested by a wide variety of proxy paleoclimatic indicators, but that it was warm as well (see Thompson and others, 1993). An impressive body of empirical data, however, has seemed to contradict this conclusion. These data include an early Holocene small mammal record that strongly implies that this period of time was moist and cool, not moist and warm (see discussion and references in Grayson, 1998). Although compelling to some with an empirical bent, these data have been largely ignored by those whose prime focus has been on the models themselves. This is the case even though the modelers are not slow to call on mammal data when it happens to match model-derived expectations. One of the main reasons for analyzing the Homestead Cave mammalian fauna was provided by this climatic issue, since this fauna clearly spanned the late Pleistocene/early Holocene transition, was embedded in well-stratified deposits, held the promise of being precisely dated, and was of unparalled size for the Great Basin.

While the first set of issues I wished to address involved the nature of past climates in the northern Great Basin, the second involved a series of particular issues relating to the biogeographic history of Great Basin small mammals. Some of these issues relate to the intriguing and fruitful model of Great Basin small mammal history presented a number of years ago by J. H. Brown (Brown, 1971, 1978; Brown and Gibson, 1983; McDonald and Brown, 1992; Brown and Lomolino, 1998). Brown (1971, 1978) examined the modern distributions of a series of Great Basin mammals which today are primarily found on Great Basin mountains and not in the valleys that separate those mountains. These mammals, which Brown termed "boreal" but which I will refer to as "montane," include such species as yellow-bellied marmots (*Marmota flaviventris*), pikas (*Ochotona princeps*), golden-mantled ground squirrels (*Spermophilus lateralis*), Nuttall's cottontails (*Sylvilagus nuttallii*), white-tailed jackrabbits (*Lepus townsendii*) and bushy-tailed woodrats (*Neotoma cinerea*). Brown based his analysis on a series of arguments drawn from equilibrium island biogeographic theory, including the fact that the relationship between the number of montane species on Great Basin mountains and the area of those mountains was marked by a slope characteristic of isolated faunas. Brown concluded that the montane mammals included in his analysis reached Great Basin mountain islands during the Pleistocene, that they became fully isolated on those mountains when the Pleistocene came to an end, and that since then there have been differential extinctions of, but no new colonizations by, these species.

Paleontological investigations of the implications of Brown's model initially provided extremely strong support for it, including evidence that montane mammals had once occupied Great Basin mountains and valleys where they no longer occur (Grayson, 1977, 1981, 1983, 1987, 1988). At the same time, these studies suggested that the history of Great Basin montane mammals was far more complex than Brown's model suggested. It became clear that different species, and different populations of the same species, became extinct at different times in different places in both mountain and lowland contexts (Grayson, 1993). It also became clear that the earliest losses had occurred in the south, the latest in the north, and that smaller, lower ranges likely lost their montane mammals earlier than had larger, higher ones. Some of these conclusions have more recently been echoed by Lomolino and Davis (1997) on other grounds.

As these paleontological studies were occurring, more detailed observations were being made of the modern distributions of the montane mammals involved. Those observations clearly showed that the list of mammal occurrences by mountain range that was available to Brown was quite incomplete and that the mammalian distribution pattern he had described reflected in part the search patterns of mammalogists (Grayson and Livingston, 1993). It also became clear that at least some of these mammals could cross valley bottoms under current conditions in some places (Grayson and Livingston, 1993), a phenomenon well-described for the Southwest (see Davis and Dunford, 1987). More recently, and based on far more rigorous and expansive surveys, Lawlor (1998) has shown that this pattern is a general one: many of the montane species once thought absent from these ranges are, in fact, present. Lawlor's detailed analysis of these data shows that the effect of all these species additions is to dramatically reduce the slope of the curve for the relationship between numbers of species and mountain area. Lawlor (1998) convincingly argues that both colonization and extinction have shaped these faunas, an argument I have made as well (Grayson and others, 1996; see also Lomolino and Davis, 1997). That is, we now know that the montane mammals central to Brown's analysis are far more widespread than was once thought, and that the mountains themselves are, for at least some mammals in some places, less isolated than was once thought. These discoveries have significant implications for the management of Great Basin small mammal habitats, as I discuss below.

The Homestead Cave mammalian fauna was clearly relevant to addressing these issues. It promised, and has delivered, a remarkably precise record of small mammal arrivals and departures in the Homestead Knoll area over the last 11,300 years. Some of these comings and goings are not surprising. Some, however, are. Indeed, what I had at one time thought quite unlikely to be accomplished - the detection of both the local extinction of, and the subsequent recolonization by, a small "montane" mammal - has been made possible by the precision and size of the Homestead Cave mammalian fauna (Grayson, 1993).

As much as I was intrigued by these issues, I was also intrigued by another. Climatic modelers have actually suggested that the early Holocene was not only warm, but that it was warmer than the middle Holocene (see Thompson and others, 1993). These arguments notwithstanding, an extremely broad set of paleoclimatic indicators show that the middle Holocene in the Great Basin was, in general, both warm and dry. Consistent with this view, derived largely from lake level and paleovegetational histories, is the fact that a wide variety of small mammals characteristic of cool and moist habitats decline in abundance, or become locally extinct, in the Great Basin between about 8 and 7 ka (see the review in Grayson, 1993).

No concomitant change in small mammal distributions or abundance has been detected in Great Basin mammalian faunas as the middle Holocene ended between about 5 and 4 ka (Grayson, 1993). One implication of this asymmetry is as clear as it is obvious: the end of the early Holocene was, from at least the standpoint of mammals, far more dramatic than was the end of the middle Holocene. Nonetheless, the well-accepted view of the middle Holocene as generally much hotter and drier than what came before and after suggests that there had to have been a detectable mammalian response. In 1993, I argued that the fact that "we have yet to detect this response in any convincing way very probably reflects the fact that the mammal sequences now available from the Great Basin for the period from about 5.5 to 3.5 ka are not sensitive enough to tell us what the changes in mammalian distribution and abundance were at this time" (Grayson, 1993, p. 221). The Homestead Cave fauna promised to, and did, address this issue as well.

ANALYTICAL CHOICES

The mammalian faunal sample retrieved from Homestead Cave is of almost overwhelming size. Although, as I will discuss, I did not identify all specimens from all units, I have identified 183,798 mammal bones and teeth to at least the genus level from the 6.3 mm and 3.1 mm sample fractions (see chapter three). This represents the most substantial late Pleistocene and Holocene mammal sequence ever identified from the Great Basin. The magnitude of the laboratory work required by the size of the Homestead Cave mammalian fauna meant that not all of it could be identified, a situation exacerbated by unexpected funding limitations. There were several possible solutions to this problem, and different members of the Homestead Cave analytic team met the challenge in different ways. Broughton (chapter nine) emphasized the analysis of the fishes from the deepest deposits of the site. Livingston (chapter eight) examined the birds from all strata, but emphasized the analysis of material from the 6.3 mm sample.

I chose a different approach. I identified every specimen I could identify to at least the genus level from both the 6.3 mm and 3.1 mm screen samples. This decision was made because one of the prime strengths of the Homestead Cave mammal sample is its size. Analyses could finally be done that would likely avoid the kind of quantitative problems, including the detection of rare taxa, that often attend the analysis of fossil and subfossil mammal sequences in the Great Basin and elsewhere. I also decided to begin at the bottom of the sequence and work upwards. When funding to analyze the uppermost units in the site became available, attention shifted to those units. Accordingly, the mammal sequence now available for Homestead Cave is strongest for the earliest and latest stratigraphic units represented. This process resulted in the identification of the mammals from both the 6.3 mm and 3.1 mm sample fractions for 14 of the 18 stratigraphic units, with a substantial gap in the late Holocene record (table XV). In addition, the kangaroo rats (*Dipodomys* spp.) have been identified from a single stratum (X) that is otherwise unanalyzed. Little has been done with the remaining assemblages from the remaining strata, and these are not discussed here.

It is also essential to realize what "identified" means in this context. For the same reasons that led to the exclusion of certain strata from the analysis (essentially those that were not reached as I worked my way up or down the column), certain taxa were excluded from detailed study in order to expedite analysis of the remaining material. No attempt was made to identify the sample of bats present in the fauna, and deer mice (*Peromyscus* spp.) were identified only to the genus level. Homestead Cave also provided a small assemblage of shrews in the collection; these are being analyzed separately and will be reported elsewhere.

TAPHONOMIC ISSUES

As discussed elsewhere in this volume, the Homestead Cave fauna accumulated largely as a result of the use of the cave by owls (see chapters two, eight and nine). The deposits contain numerous owl pellets, both fragmentary and whole, and many isolated mammal bones and teeth, regardless of their age, have remains of these pellets adhering to them. As a result of this mode of accumulation, almost all of the mammal specimens from the site are from small species, and these species are represented by nearly all parts of the skeleton.

Both artiodactyls and large carnivores are accordingly rare in these deposits, and the specimens of these taxa that are present primarily represent small elements from the distal regions of the skeleton (tables XVI and XVII). Coyotes (*Canis latrans*), wolves (*Canis lupus*), bobcats (*Lynx rufus*) and bears (*Ursus americanus*) are represented by a total of only 24 identified specimens, of which 19 are phalanges. Artiodactyls are represented by only 22 specimens, of which 16 are carpals, phalanges, or fibulae. In contrast, the smaller carnivores tend to be represented not simply by greater numbers of specimens, but by a far wider variety of skeletal elements, as table XVIII, which presents data for *Mustela frenata*, shows. These differences in skeletal representation suggest that the mechanisms that introduced the larger and smaller mammals into Homestead Cave were not identical. In particular, many of the small elements of larger carnivores and artiodactyls may have been introduced into the site by woodrats (*Neotoma* spp.).

Homestead Cave saw only limited human occupation (chapters three, four, and six), and there is no suggestion that any aspect of the vertebrate record in this site can be attributed to human activities. There is also very little evidence that larger mammalian carnivores were responsible for introducing significant numbers of specimens into Homestead Cave or altering specimens that had been introduced in other ways. The evidence that does exist for carnivore involvement is limited to three gnawed artiodactyl phalanges, one each from strata IV, VII, and IX.

There is some suggestion from the ground squirrel component of the Homestead Cave fauna that accumulation mechanisms did change during the history of the site. Both *Ammospermophilus leucurus* and *Spermophilus mollis* (= *S. townsendii*) increase steadily in representation in the fauna through time (figure 50). Both of these species are diurnal, and it is possible that the increase in ground squirrel representation reflects an increase in the use of the cave by a diurnal avian predator, of which the short-eared owl (*Asio flammeus*) is perhaps the most likely candidate. Even though this is the case, there is no trend toward increasing representation of diurnal avian raptors in the Homestead Cave fauna, as Livingston (chapter eight) notes. There is also no relationship between the relative abundance of ground squirrels in the mammalian fauna and of *Asio* sp. in the avian fauna here. It is unlikely that this rise reflects changing seasonal use of the cave by predators, since both species rise in concert, even though *S. mollis* is today active only during a restricted part of the year while *A. leucurus* is active year-round (Rickart, 1982, 1987; Belk and Smith, 1991).

It may well be that the changing ratios of A. *leucurus* to S. *mollis* through time at Homestead Cave are of biogeographic and paleoclimatic significance. However, the changing relative abundance of ground squirrels across strata at Homestead Cave is significantly correlated with the ratio of *Ammospermophilus leucurus* to *Spermophilus mollis* within those strata (figure 51). Since this may simply reflect alterations in the ways in which the Homestead Cave fauna accumulated, these species are not further analyzed here.

DESCRIPTIVE SUMMARY AND IDENTIFICATIONS

The numbers of identified specimens per taxon by Homestead Cave stratum are presented in table XV (unless otherwise indicated, taxonomic nomenclature follows Wilson and Reeder, 1993). These are the basic data used in the analyses presented below.

I do not present standard counts of identified skeletal parts by taxon and stratum of the sort presented for taphonomic purposes in tables XVI through XVIII. It is not practical to do so, given the size of the collection and both the number of taxa and number of strata involved. The relevant data have been archived in electronic form at the Utah Geological Survey and are thus readily available. With few exceptions, all species-level identifications are based on skulls, mandibles and teeth. The exceptions involve the carnivores, artiodactyls, leporids, marmots (*Marmota flaviventris*) and muskrats (*Ondatra zibethicus*), for which both cranial and postcranial elements were identified. Specimens identified as *Neotoma* cf. *cinerea* and *Neotoma* cf. *lepida* also include both cranial and postcranial elements; these were assigned primarily on the basis of size. The criteria used for the more challenging identifications are in general the same as those described by Grayson (1983, 1985, 1988). A few taxa, however, require more detailed comment.

Mustela erminea

Skeletal remains of *Mustela frenata* and *M. erminea* can be difficult to distinguish from one another in the absence of complete skulls (Guilday, 1969; Heaton, 1985). Skeletally, the two species are quite similar to one another, and female *M. frenata* overlap male *M. erminea* in size. Nonetheless, I have assigned four postcranial specimens from Stratum I to *M. erminea*. These include a complete left tibia (maximum length = 2.56 cm), a complete left humerus (maximum length = 2.00 cm), a partial right scapula (height at glenoid = 0.29 cm) and a partial right maxilla retaining P^3, P^4 and M^1 (P^3-M^1 alveolar length = 0.53 cm). All are smaller than the corresponding elements of *M. frenata* in the substantial comparative series available to me and are indistinguishable from those of *M. erminea*.

Thomomys talpoides

The two specimens assigned to *T. talpoides* are nearly complete skulls from Stratum I, identified using the criteria discussed by Thaeler (1980). All later strata contain only *T. bottae*, identified either on the basis of their distinctive cranial morphology, or on the basis of the morphology of P^4.

Dipodomys microps and *D. ordii*

Kangaroo rats (*Dipodomys* spp.) are by far the most abundant mammal in the faunal assemblage: 59.1% of the identified specimens (104,764/177,197, excluding Stratum X, for which only kangaroo rats were identified) pertain to this genus. A total of 8393 specimens were identified to the species level, as either *D. microps* (8060) or *D. ordii* (333). These identifications were based almost entirely on two criteria: differences in the morphology of the lower incisors, and differences in the morphology of the masseteric ridge of the mandible. The morphology of the lower incisors of these species is discussed below (see Selected Faunal Histories), and here I note simply that these distinctive morphologies are also registered on the ventral surface of the incisive housing of the mandible (broad and flattened in *D. microps*, narrow and rounded in *D. ordii*). The anterior extension of the masseteric ridge of the mandible is far less rugose and is situated more ventrally in *D. microps* than in *D. ordii*. The anterior end of this ridge also tends to curve lingually to a point beneath the anterior face of P^4 in *D. ordii*, while the anterior termination of the masseteric ridge in *D. microps* tends to occur on the buccal wall of the mandible. These differences presumably reflect the very different dietary adaptations of these animals (Kenagy, 1972, 1973). There are other distinct differences in the morphology of the anterior end of the mandible that distinguish these species, but specimens that are sufficiently complete to show these differences are also

Table XV
Homestead Cave mammals
Numbers of identified specimens (NISP) per taxon[1]

	Stratum																	
Taxon	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**	**XI**	**XII**	**—**	**—**	**—**	**XVI**	**XVII**	**XVIII**
Carnivores																		
Canidae																		
Canis latrans				1	1	6			3		3							
Canis lupus											1							
Vulpes velox				5		7	5	2	3			7					1	
Vulpes vulpes					1													
Felidae																		
Lynx rufus				1		5	1		1									
Mustelidae																		
Mustela sp.	2	1																
Mustela erminea	4																	
Mustela frenata	21	6		10	2	2	3	1	8		6	9				4	5	1
Mustela vison									1									
Spilogale putorius				10	3	7	6	3	19		3	11				2	3	
Taxidea taxus				1		2		1	1		3	6				1		
Ursidae																		
Ursus americanus				1														
Artiodactyls																		
Cervidae																		
Odocoileus cf. *hemionus*				1		1	2		1									
Antilocapridae																		
Antilocapra americana	1		1		1	1	1	1	1		1						2	1
Bovidae																		
Ovis canadensis				3					1		2							
Rodents																		
Sciuridae																		
Ammospermophilus sp.								3	8									
Ammospermophilus cf. *leucurus*				5	2	10	11	4	6		18	6				7	6	
Ammospermophilus leucurus	2	6	5	110	19	123	56	37	88		41	117				26	41	1
Tamias sp.	2																	
Tamias minimus	2																	
Marmota cf. *flaviventris*	30	4		7		1	2											
Marmota flaviventris	13	4		8		3		1	1									
Spermophilus sp.		1	2	3			10	23	32									
Spermophilus cf. *mollis*			1	8	1	39	18		89		183	306				52	119	10
Spermophilus mollis	5	4	4	38	17	148	76	54	227		205	523				231	556	35

Taxon	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	—	—	—	XVI	XVII	XVIII
Geomyidae																		
Thomomys sp.	107	404	238	2952	506	2492	1153	665	1573		520	1144				393	1008	48
Thomomys bottae		30	18	215	35	129	86	44	141		42	79				57	87	4
Thomomys talpoides	2																	
Heteromyidae																		
Chaetodipus formosus	2	2	1	3		1						6				2	14	
Dipodomys sp.	310	1212	964	12,629	2713	14,016	9086	5286	14,378	6070	6343	15,518				4084	9692	671
Dipodomys microps	7	83	75	1033	245	1094	775	451	1075	526	467	1201				276	704	48
Dipodomys ordii	43	34	17	50	7	63	7	5	24	5	10	34				11	22	1
Microdipodops sp.	1	7																
Microdipodops megacephalus	6	10																
Perognathus longimembris		4	8	77	7	37	21	12	22		3	12				18	36	2
Perognathus parvus	121	86	9	12	1	4	1									2	6	
Muridae																		
Lemmiscus curtatus	552	121	8	2	2		3		2		1					3	9	
Microtus sp.	247	197	44	53	3	16	2	1	4		4	1				2	1	
Neotoma sp.	50	150	59	258	43	182	147	53	180		57	56				26	50	48
Neotoma cf. *cinerea*	2310	1274	250	196		3	3	4									7	
Neotoma cinerea	267	234	56	46	1	2	1	1	1								2	
Neotoma cf. *lepida*	37	224	277	4281	786	2873	1340	807	2454		1257	2322				660	1810	118
Neotoma lepida	4	56	68	883	144	572	287	178	522		225	287				90	394	11
Ondatra zibethicus				1		3			2								1	
Onchyomys sp.	7	4					1	1	3		1						5	
Onychomys leucogaster	8	4	1	5		2	1	1	4		1	5				5	10	
Peromyscus sp.	1550	1124	205	531	52	178	88	52	147		49	187				61	205	17
Pitymys sp.	1																	
Reithrodontomys sp.	4	39	4	36	5	9	2	1	6			13					8	
Reithrodontomys cf. *megalotis*				4														
Reithrodontomys megalotis	54	52	18	94	7	31	5	5	10		3	12				33	88	1
Lagomorpha																		
Leporidae																		
Brachylagus idahoensis	192	32	3	4	1	4	1	1			1							
Lepus sp.	2243	577	91	680	202	806	422	407	618		420	642				138	355	14
Lepus californicus		2																
Lepus townsendii	18	2																
Sylvilagus sp.	2020	1832	450	2332	295	1443	278	181	424		221	349				109	294	15
Sylvilagus cf. *audubonii*	2	13	6	13	2	8		1	5		2	6				2	6	
Sylvilagus cf. *nuttallii*	28	20	1	13	5	7	4	2	3		3	1				1	1	1
COLUMN TOTALS	10,275	7855	2884	26,615	5109	24,330	13,905	8289	22,088	6601	10,096	22,860				6296	15,548	1047
TOTAL																		**183,798**

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[1] Mammalian fauna from strata XIII-XV were not analyzed, and only the kangaroo rats (*Dipodomys* sp.) were analyzed from Stratum X.

Table XVI
Skeletal representation of larger carnivores within Homestead Cave

Taxon	Stratum	Elements Represented
Canis latrans	XI	1 distal radius, 2 phalanges
	IX	3 phalanges
	VI	1 tooth (M_2), 1 metacarpal, 1 metatarsal, 3 phalanges
	V	1 phalanx
	IV	1 phalanx
Canis lupus	XI	1 phalanx
Lynx rufus	IX	1 phalanx
	VII	1 phalanx
	VI	5 phalanges
	IV	1 tooth (P_4)
Taxidea taxus	XVI	1 metatarsal
	XII	1 tooth (P_4), 1 scapula, 1 metacarpal, 2 carpals, 1 distal tibia
	XI	1 proximal humerus, 1 metacarpal, 1 tarsal
	IX	1 phalanx
	VIII	1 premaxilla
	VI	1 distal metapodial, 1 phalanx
	IV	1 tarsal
Ursus americanus	IV	1 phalanx

Table XVII
Skeletal representation of artiodactyls within Homestead Cave

Taxon	Stratum	Elements Represented
Antilocapra americana	XVIII	1 phalanx
	XVII	1 tooth (P_3), 1 carpal
	XI	1 phalanx
	IX	1 phalanx
	VIII	1 carpal
	VII	1 phalanx
	VI	1 phalanx
	V	1 phalanx
	III	1 tooth (P_2)
	I	1 tooth (molar fragment)
Odocoileus cf. *hemionus*	IX	1 distal radius
	VII	1 tooth (P_2), 1 fibula
	VI	1 carpal
	IV	1 carpal
Ovis canadensis	XI	1 carpal, 1 fibula
	IX	1 carpal
	IV	1 tooth (molar fragment), 1 carpal,1 phalanx

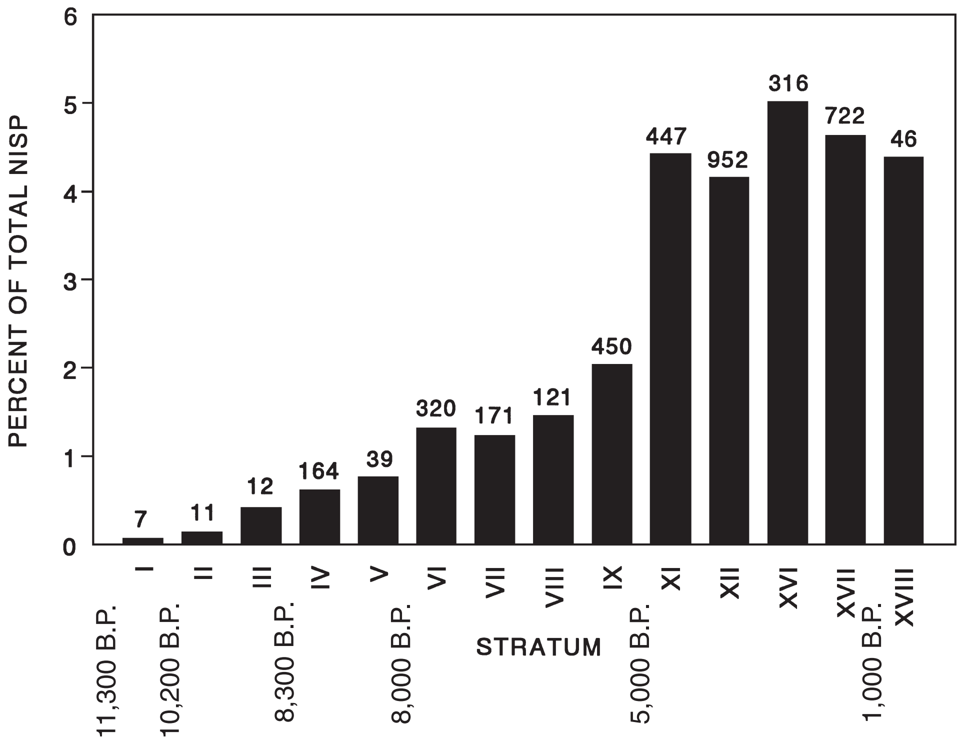

***Figure 50.** Increasing relative abundances of ground squirrels (*Ammospermophilus *and* Spermophilus*) through time at Homestead Cave. The numbers above the bars provide the total number of specimens identified as either* Ammospermophilus *or* Spermophilus*. All ages in this and subsequent figures are in ^{14}C yr.*

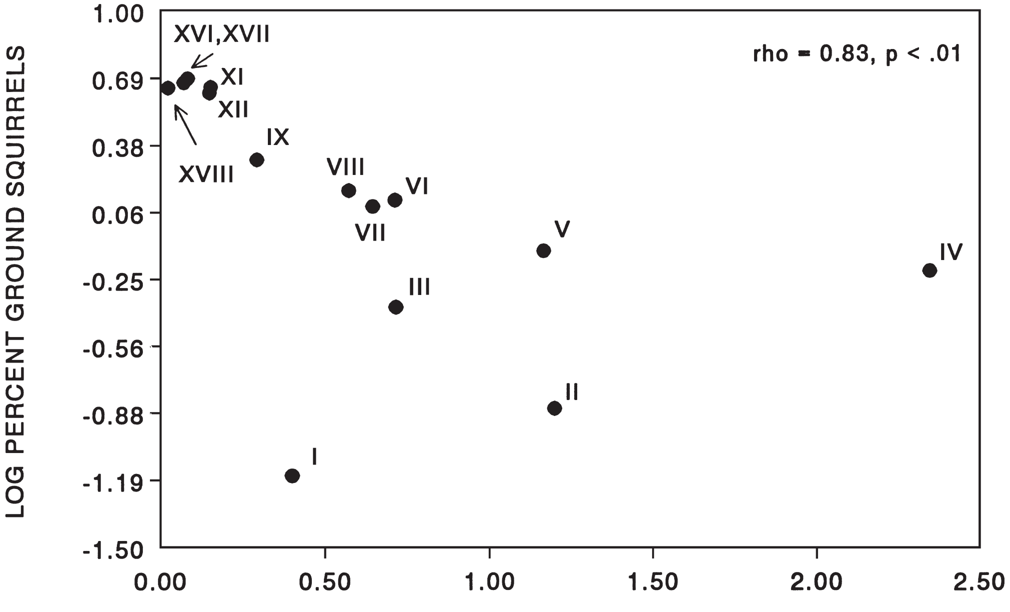

Figure 51. *Relationship between ground squirrel relative abundance and the ratio of* Ammospermophilus *and* Spermophilus *at Homestead Cave.*

Table XVIII
Skeletal representation of *Mustela frenata* within Homestead Cave

Stratum	Elements Represented
XVIII	1 tarsal
XVII	2 scapulae, 1 tibia, 2 tarsals
XVI	1 innominate, 1 femur, 1 tibia, 1 tarsal
XII	4 skull fragments (1 maxilla, 3 occipitals), 1 scapula, 2 ulnae, 1 innominate, 1 femur
XI	1 mandible, 1 tooth (M1), 2 innominates, 2 tibiae
IX	4 mandibles, 1 humerus, 1 femur, 1 tibia, 1 tarsal
VIII	1 scapula
VII	1 mandible, 1 ulna, 1 innominate
VI	1 mandible, 1 tibia
V	1 mandible, 1 tooth (P_4)
IV	1 skull fragment (occipital), 2 mandibles, 2 teeth (M^1, M_l), 1 scapula, 1 innominate, 1 femur, 2 tibiae
II	1 skull fragment (bulla), 1 scapula, 1 humerus, 1 ulna, 2 tarsals
I	2 teeth (P^4, M_l), 4 mandibles, 1 scapula, 4 humeri, 1 radius, 5 ulnae, 2 innominates, 2 tibiae

sufficiently complete to be diagnosed using the criteria I have just described.

Lemmiscus (=*Lagurus*) *curtatus* and *Microtus* sp.

The identification of arvicolines in general, and of *Lemmiscus* and *Microtus* in particular, was based entirely on nearly complete skulls, and on M^3 and M^1. I also relied on the location of the mandibular foramen to distinguish between mandibles of *Lemmiscus* and *Microtus* (Grayson, 1983). The dental criteria employed are thoroughly discussed by Barnosky and Rasmussen (1988) and Repenning (1992). No attempt was made to identify species of *Microtus*.

Neotoma cinerea and *N. lepida*

My identifications of *Neotoma cinerea* and *Neotoma lepida* specimens were based on maxillary and mandibular alveolar lengths, on occlusal lengths of M^1 and M_1, M_2, and M_3, and on the morphology of M^1. T-tests between the measurements of paleontological specimens and those taken from modern comparative series were used to assign the Homestead Cave specimens to species. This procedure has been discussed in detail elsewhere (Grayson, 1983, 1985, 1988); these earlier publications also provide the measurements of the modern comparative material used in this approach.

This method assigns specimens to species on the basis of size for all but one element. As a result, the measurements themselves provide the means by which specimens were identified. The one exception is provided by M^1, which can be identified on the basis of the depth of the anterointernal reentrant angle (shallow in *N. lepida*, deep in *N. cinerea*: see Hall 1981). Smith (1991) has shown that, compared to *N. lepida*, *N. cinerea* incorporates a higher component of fibrous plant material into its diet, and it is possible that the greater complexity of the M^1 of *N. cinerea* has evolved to provide more enamel surface for the processing of fibrous material.

Since M^1 can be identified independently of measurements, the accuracy of occlusal lengths in identifying the Homestead Cave *N. lepida* and *N. cinerea* can be assessed by comparing measurement-based and morphology-based as-

Table XIX
Summary statistics for occlusal lengths of *Neotoma* first upper molars identified morphologically

	Neotoma lepida				*Neotoma cinerea*			
Stratum	Range	Mean	SD	N	Range	Mean	SD	N
XVIII	2.84-3.01	2.927	0.085	3				
XVII	2.69-3.37	3.031	0.139	100	2.99-3.24	3.153	0.142	3
XVI	2.64-3.34	3.080	0.152	26	3.11-3.16	3.135	0.035	2
XII	2.70-3.31	2.992	0.129	121				
XI	2.60-3.33	3.007	0.135	60				
IX	2.62-3.44	3.026	0.141	156				
VIII	2.80-3.43	3.059	0.130	50				
VII	2.78-3.62	3.051	0.149	97				
VI	2.68-3.39	3.019	0.125	158				
V	2.58-3.36	3.023	0.134	51	3.21			1
IV	2.58-3.36	3.003	0.146	269	3.34-3.83	3.478	0.200	5
III	2.70-3.22	2.945	0.121	22	3.08-3.61	3.363	0.181	8
II	2.64-3.46	2.853	0.202	15	3.19-3.81	3.485	0.163	28
I	3.13-3.29	3.210	0.113	2	3.01-3.88	3.457	0.179	34
TOTAL				1130				81

signments. Table XIX presents the occlusal lengths of all measurable *Neotoma* M^{1}s that were identified as either *Neotoma cinerea* (81) or *Neotoma lepida* (1130) on the basis of morphology alone (an additional 77 measurable specimens have anterointernal reentrant angles that do not allow unambiguous assignment and are not included in this table). Only 12 of these 1211 specimens have occlusal lengths inconsistent with the taxonomic affiliation indicated by their morphology (table XX), a failure rate (of either morphology or occlusal length) of about 1% (12/1211 = 0.0099). Occlusal lengths thus seem to provide an accurate means of distinguishing between these two species.

Those M^{1}s whose occlusal lengths and morphology provided conflicting identifications have been assigned to *Neotoma* sp. First upper molars that fall within the area of statistical overlap between *N. cinerea* and *N. lepida* have been assigned to species on the basis of their morphology. Summary statistics that result from these assignments are provided in table XXI. Other measurable *Neotoma* maxillae, mandibles and teeth that could not be assigned to species on the basis of alveolar or occlusal lengths have been assigned to *Neotoma* sp.

Table XX

***Neotoma* first upper molars differentially classified by occlusal length and morphology**

		Identification	
Specimen*	Occlusal Length	Occlusal (mm)	Morphology Length
6-288	2.99	*N. lepida*	*N. cinerea*
22-109	3.01	*N. lepida*	*N. cinerea*
16-009	3.08	*N. lepida*	*N. cinerea*
30-69	3.11	*N. lepida*	*N. cinerea*
30-115	3.16	*N. lepida*	*N. cinerea*
17-98	3.19	*N. lepida*	*N. cinerea*
17-100	3.20	*N. lepida*	*N. cinerea*
20-35	3.43	*N. cinerea*	*N. lepida*
11-148	3.44	*N. cinerea*	*N. lepida*
17-298	3.46	*N. cinerea*	*N. lepida*
12-260	3.50	*N. cinerea*	*N. lepida*
12-93	3.62	*N. cinerea*	*N. lepida*

**The first number of the specimen number provides the Feature, and thus the Stratum, for the specimen in question; for example, 6-33 comes from F 6, or Stratum XVII (see chapters three and four).*

The Stratum I *Neotoma* sp. Skull

In addition to these *Neotoma* specimens, there is a single partial *Neotoma* skull (Homestead Cave *Neotoma* 6.3 mm fraction specimen 22-2) from Stratum I that shows a combination of characteristics that I have not observed in any species of *Neotoma* (figure 52). The general morphology and size of this skull are consistent with *Neotoma cinerea*, including the absence of a sphenopalatine fissure. Unlike most skulls of *Neotoma cinerea* that I have seen, however, this specimen is marked by a palate with an anterior border that extends well anterior to the anterior border of M^1, to a point midway between the anterior and posterior borders of the maxillary branch of the zygomatic arch. This condition is not, in itself, unknown in *Neotoma cinerea* (see Smith, 1997, figure 2 for a similar palatal extension). However, the Homestead Cave specimen also has a maxillary alveolar length (0.85 cm) that is both significantly smaller than that of *Neotoma cinerea* ($t = -3.99$, $p < 0.01$), but well within the range of that of *N. lepida* ($t = +0.84$, $p > 0.10$). The ratio of palate length (1.11 cm) to alveolar length shown by this specimen is distinctly different from that of *N. cinerea* (figure 53). No other specimen of *N. cinerea* in the Homestead Cave collection shows this combination of characteristics. It could well be that this specimen represents an aberrant *N. cinerea*, which it otherwise resembles strongly.

Pitymys sp.?

A single arvicoline right M$_1$ (figure 54) is marked by the

Table XXI
Summary statistics for occlusal lengths of *Neotoma* first upper molars assigned to *Neotoma lepida* and *Neotoma cinerea* using both morphology and occlusal length

	Neotoma lepida				*Neotoma cinerea*			
Stratum	Range	Mean	SD	N	Range	Mean	SD	N
XVIII	2.84-3.01	2.927	0.085	3				
XVII	2.69-3.37	3.026	0.138	114	3.23-3.24	3.235	.007	2
XVI	2.64-3.34	3.066	0.150	29				
XII	2.70-3.31	2.988	0.130	127				
XI	2.60-3.33	3.001	0.135	64				
IX	2.62-3.34	3.025	0.137	158				
VIII	2.80-3.30	3.047	0.121	51				
VII	2.78-3.38	3.036	0.128	103				
VI	2.68-3.39	3.017	0.123	174				
V	2.58-3.36	3.023	0.134	51	3.21			1
IV	2.58-3.36	3.000	0.146	276	3.34-3.83	3.510	.195	6
III	2.70-3.22	2.945	0.121	22	3.21-3.61	3.406	.141	8
II	2.64-3.03	2.806	0.109	16	3.27-3.81	3.518	.150	29
I	3.13-3.29	3.210	0.113	2	3.26-3.88	3.473	.161	34
TOTAL				1190				80

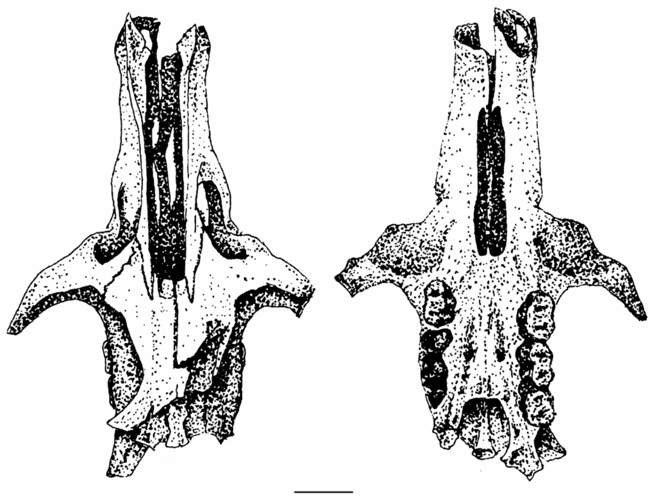

Figure 52. Stratum I Neotoma *sp. skull (Homestead specimen 22-2, 6.3 mm sample). Scale bar = 5 mm.*

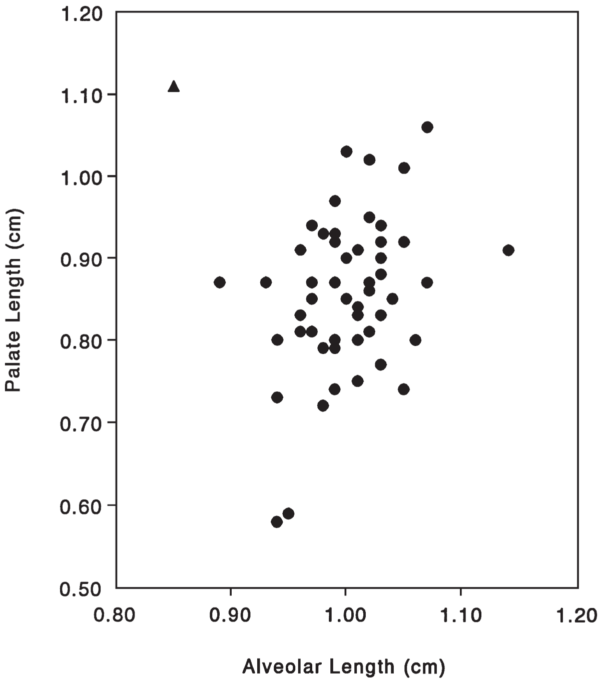

Figure 53. Relationship between palate and alveolar lengths in Homestead Cave Neotoma *specimen 22-2 (triangle) and a series of 52 modern* Neotoma cinerea *specimens from western North America (dots).*

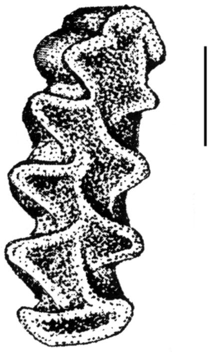

Figure 54. Stratum I lower first molar tentatively identified as Pitymys *sp. Scale bar = 1 mm.*

presence of fully confluent primary wings separated from both triangle 3 and the secondary wings by deep buccal and lingual reentrant angles (see Barnosky and Rasmussen, 1988, and Repenning, 1992 for terminology and a discussion of arvicoline dentition). Buccal reentrant angle 4 and lingual reentrant angle 5 are shallow; Repenning's dimension A-A′ is large. This complex of characters strongly suggests that this specimen is of *Pitymys* (this taxon is often treated as a subgenus of *Microtus*; Wilson and Reeder, 1993 place all *Pitymys* within *Microtus*). Geographically, the closest member of this genus is the prairie vole, *Pitymys ochrogaster*, which today occurs no closer than the eastern front of the Rocky Mountains (Stalling, 1990). The genus has not been reported from any ^{14}C-dated fauna west of the Rocky Mountains (Graham and Lundelius, 1994), and, as Repenning (1992, p. 73) has observed, "appears always to have had an eastern distribution within the eastern region of the United States."

There are three possible explanations of this specimen in the late Pleistocene deposits of Homestead Cave. First, there is some slim possibility that it was transported here from east of the Rocky Mountains by a wayward owl. Second, it is possible that *Pitymys* existed in the Homestead Knoll area during the late Pleistocene. Third, given the great variability of arvicoline teeth and given that there is only one specimen in the Homestead Cave fauna that shows this morphology, it is possible that this specimen pertains to some other member of the subfamily. Here, I simply report the presence of this specimen and provide an illustration of it (figure 54).

Lepus californicus and *L. townsendii*

Skeletal elements of the various species of *Lepus* are notoriously difficult to identify accurately. Indeed, of 7637 *Lepus* specimens from Homestead Cave, I have identified only 22 to the species level. These 22 specimens, all from Strata I and II, are crania that retain the supraorbital process and associated frontals, and all were identified on the basis of the morphology of this region of the skull (see Orr, 1940). The 20 specimens of *Lepus townsendii* identified in this way are quite large, and are thus consistent with *L. townsendii* in size as well. Purdue (1980), however, has appropriately criticized the use of size as a means of identifying *L. townsendii* from late Pleistocene and early Holocene contexts, and size played no role in my assignment of these specimens.

Sylvilagus audubonii and *S. nuttallii*

I identified only two skeletal elements of *Sylvilagus* to the species level: the supraoccipital shield, generally pointed in *S. nuttallii* and truncated in *S. audubonii* (Hoffmeister, 1986, p. 130), and the P^3, following the criteria outlined by Dalquest and others (1989). All but 25 of the 156 specimens identified in this fashion are lower third premolars (table XXII).

The degree of crenulation shown by the enamel that forms the anterior wall of the posterobuccal reentrant of the lower third premolar of *Sylvilagus* is quite variable, as Dalquest and others (1989) have observed (see also Ruedas, 1998). In *S. nuttallii* this enamel tends to be uncrenulated (42 of 44 specimens examined by them), while the equivalent enamel in *S. audubonii* tends to be moderately to strongly crenulated (42 of 50 specimens examined by them). As Dalquest and others (1989) discuss, these differences allow statements to be made concerning the probable species affiliation of isolated specimens. My own observations of a large series of *S. audubonii* and *S. nuttallii* specimens in the Utah Museum of Natural History provided results that mirror their conclusions.

In making assessments using these criteria, I assigned lower third premolars to *S. audubonii* if they were heavily crenulated, and to *S. nuttallii* if they lacked crenulation; those intermediate in this regard were identified as *Sylvilagus* sp. The results of this process are shown in figures 55 (*S. nuttallii*) and 56 (*S. audubonii*). Given their habitat preferences – *S. nuttallii* in cooler, moister settings, *S. audubonii* in warmer, drier ones – my strong expectation was that the former would be the abundant cottontail during the early Holocene, the latter during the middle and late Holocene. While this expectation is to some extent met by the faunas of Strata I and II, which are dominated by *S. nuttallii*, there is little evident trend in these graphs after that time. It is possible that both cottontails have been present in this area during much of the Holocene. However, it is also possible that the probabilistic nature of these identifications coupled with the relatively small sample involved has provided me with results that are relatively meaningless. I do not consider them further here.

Table XXII
***Sylvilagus* supraoccipital shields identified to the species level from Homestead Cave**

Stratum	Taxon	N
XVI	*S. nuttallii*	1
XII	*S. nuttallii*	1
VII	*S. nuttallii*	1
VI	*S. nuttallii*	1
V	*S. audubonii*	1
	S. nuttallii	1
IV	*S. audubonii*	2
	S. nuttallii	2
III	*S. audubonii*	1
II	*S. audubonii*	2
	S. nuttallii	6
I	*S. nuttallii*	6

PALEOCLIMATIC IMPLICATIONS OF THE HOMESTEAD CAVE MAMMALIAN FAUNA

The paleoclimatic implications of the Homestead Cave mammalian fauna are best derived from analysis of the histories of a group of environmentally sensitive taxa that are well represented in the fauna. I first discuss these histories and then discuss their broader implications.

Selected Faunal Histories: 1. Kangaroo Rats

I begin with the local histories of two species of kangaroo rats, the chisel-toothed kangaroo rat (*Dipodomys microps*) and Ord's kangaroo rat (*D. ordii*). The aptly named chisel-toothed kangaroo rat is characterized by the fact that the anterior faces and tips of the lower incisors of this rodent are flattened, or chisel-shaped. In this, they are distinctly different from the rounded and pointed, or awl-shaped, lower incisors of Ord's kangaroo rats. Some years ago, Kenagy (1972, 1973; see also Garrison and Best, 1990) demonstrated that *D. microps* uses these incisors to shave off the hypersaline external surfaces of *Atriplex* leaves, then consumes the palatable inner portions of those leaves. In contrast, *Dipodomys ordii* is primarily a granivore and is often found associated with habitats in which sagebrush is common (Hayssen, 1991). Indeed, in his analysis of the spatial relationships within the rodent community of Warm Springs Valley, west-central Nevada, O'Farrell (1980) found little spatial overlap between these two species, with *D. microps* restricted to habitats dominated by shadscale. This is not to say that

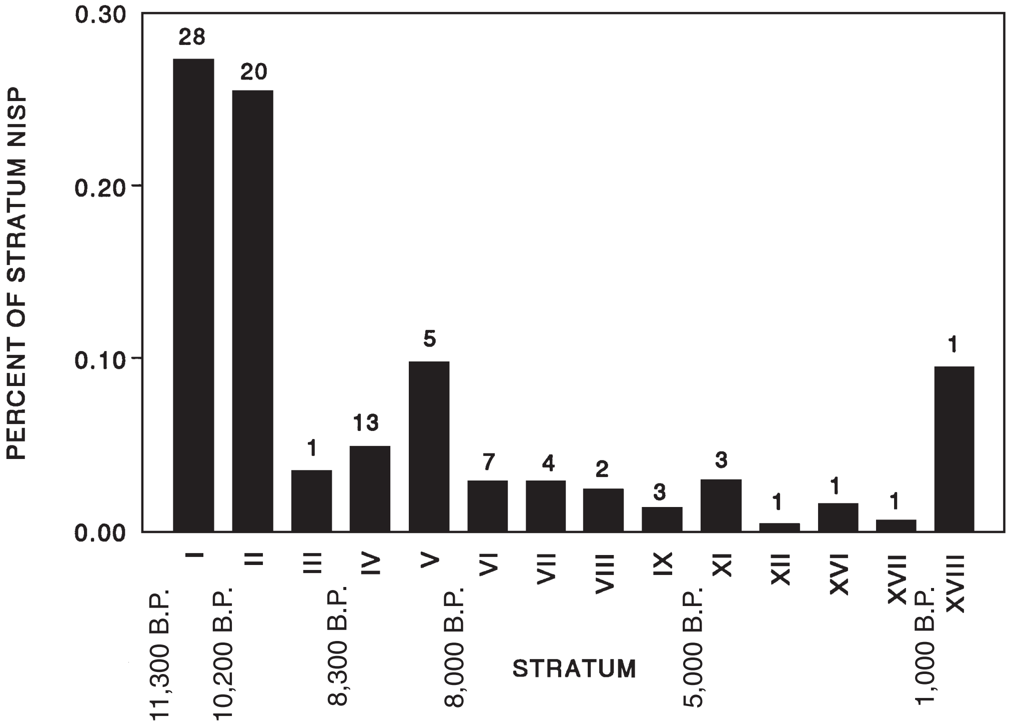

Figure 55. Changing proportions of Nuttall's cottontails at Homestead Cave. The numbers above the bars provide the total number of specimens identified as S. nuttallii.

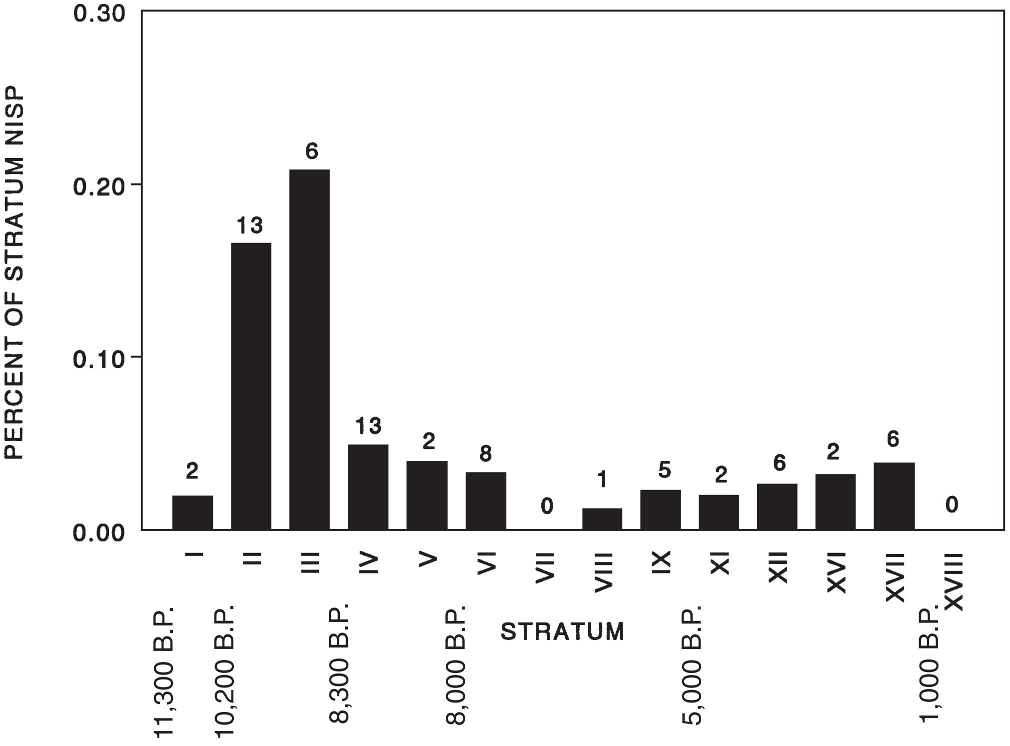

Figure 56. Changing proportions of Audubon's cottontails at Homestead Cave. The numbers above the bars provide the total number of specimens identified as S. audubonii.

D. microps cannot exist in habitats that lack *Atriplex*, or that *D. ordii* cannot exist in habitats in which *Atriplex* is common. It is, however, to say that when both taxa are present, *D. microps* will tend strongly to be found in *Atriplex* habitats, and *D. ordii* in habitats marked by other plant associations, including those dominated by *Artemisia*.

Figure 57 provides the ratio of *D. microps* to both *D. microps* and *D. ordii* through time at Homestead Cave, and shows that the late Pleistocene and early Holocene faunas of this area were marked by abundances of *D. ordii* that have not been seen here since. Figure 58 presents the same data in terms of the ratio of *D. microps* to *D. ordii* and shows that the middle Holocene, particularly between about 7 and 5 ka, had elevated proportions of *D. microps* compared to what came before and after. This history strongly suggests the progressive replacement of sagebrush by shadscale vegetation during the early Holocene in the Homestead Knoll area, as well as a middle Holocene peak in xericity here.

It is also possible to take a broader view of the history of *Dipodomys* in the Homestead Knoll area. While *D. ordii* and *D. microps* may have different environmental implications, they are both kangaroo rats, and kangaroo rats in general are extremely well-adapted to arid habitats (French, 1993). As a result, changing relative abundances of kangaroo rats through time in the Homestead Cave fauna should provide a clear indication of local desertification. Indeed, as figure 59 shows, kangaroo rats provided a relatively small proportion of the late Pleistocene fauna at Homestead Cave. During the early Holocene, kangaroo rats became increasingly abundant; soon after 8.3 ka (Stratum IV), they began to comprise over half of the identified mammal fauna. By about 6.2 ka (Stratum VII), they began to contribute more than two-thirds of the specimens of each stratum and, in the analyzed units, never fall beneath this fraction.

Given that the increasing relative abundance of *D. microps* appears to track decreasing abundance of big sage, and that increasing abundance of kangaroo rats in general indicate increasing aridity, I also observe that the proportion of each stratum's fauna that is contributed by kangaroo rats is very tightly correlated with the proportion of that stratum's kangaroo rat fauna that is contributed by *D. microps* (figure 60).

Selected Faunal Histories: 2. Pygmy Rabbits

It might be argued that environmental changes other than a replacement of sagebrush by shadscale vegetation might have driven the changing abundances of *D. ordii* documented by the Homestead Cave fauna. After all, *D. ordii* does not require *Atriplex* in its diet. However, the history of pygmy rabbits (*Brachylagus idahoensis*) at Homestead Cave would seem to make sense in no other way.

Pygmy rabbits are heavily dependent on dense stands of big sagebrush (*Artemisia tridentata*), both for food (pygmy rabbit winter diets may be composed of almost nothing else) and as locations for their burrows (Green and Flinders, 1980; Wiess and Verts, 1984; Dobler and Dixon, 1990; Katzner and Parker, 1997). Today, pygmy rabbits are found in the sagebrush valleys of the northern two-thirds of the Great Basin and on the immediately adjacent Columbia Plateau, albeit in declining numbers. There is also an isolated, and endangered, set of populations in eastern Washington. The latest Quaternary history of these mammals is reasonably well known. In the late Pleistocene, they were found as far south as central New Mexico (Harris, 1985), as well as outside their modern distribution in eastern Washington (Lyman, 1991). Within the Great Basin and adjacent Columbia Plateau, they are known to have undergone two separate declines in abundance, one at about 10 ka, and a second at the onset of, or during, the middle Holocene (Grayson, 1993). Both of these declines appear to be associated with declines in abundance of *Artemisia tridentata* (see the review in Grayson, 1993).

The record for pygmy rabbits at Homestead Cave is clear (figure 61). These animals were common in the Homestead Knoll area during the late Pleistocene and were clearly present during the early Holocene, but declined rapidly and had become locally extinct, or nearly so, by 8.3 ka. There is no secure evidence to suggest that pygmy rabbits have been in the Homestead Knoll area during the past 7000 years or so. Given the tight association between pygmy rabbits and dense stands of tall sage, it again appears extremely likely that *Artemisia tridentata* began a substantial decline in this area after about 10 ka, and that soon after 8.3 ka, there were insufficient stands of big sage to support populations of these animals. This record is fully consistent with other paleontological pygmy rabbit data, and is also fully consistent with the local history for *Dipodomys ordii* provided by Homestead Cave.

Selected Faunal Histories: 3. Voles

Most species of *Microtus* occupy grassy habitats and live in cool environments. Indeed, these animals show poor ability to thermoregulate at high temperatures, and no species of *Microtus* is restricted in distribution to arid areas. Within the modern Great Basin, even *Microtus longicaudus*, which is least tied to moist habitats, is more common in cooler, moister settings than in warmer, drier ones (Getz, 1985; Rose and Birney, 1985; Wunder, 1985).

Microtus is common in the late Pleistocene and early Holocene deposits of Homestead Cave (figure 62). Its numbers dwindled dramatically after 8.3 ka, and it has clearly been uncommon in this area for the last 7000 years. Much the same is true for *Lemmiscus curtatus* (figure 63). Sage voles are, as the name suggests, often associated with habitats dominated by stands of tall sagebrush, usually big sage (*Artemisia tridentata*), and grasses, though they can also be found in communities in which the dominant shrub is rabbitbrush (*Chrysothamnus* spp.) as well as in habitats dominated by grasses alone. Within these habitat parameters, there is also some suggestion that sage vole numbers are highest in settings marked by relatively warm winters coupled with cool and moist summers (Hall, 1946; Maser, 1974; Carroll and Genoways, 1980). These animals seem to be able to meet their moisture requirements through the ingestion of green vegetation, and surface moisture is clearly less critical for them than it is for most species of *Microtus*.

In short, *Lemmiscus curtatus* is most abundant in habitats dominated by *Artemisia tridentata* and grasses in contexts marked by relatively cool summers. These modern habitat preferences likely account for the strong similarity between the Homestead Cave histories of this animal and

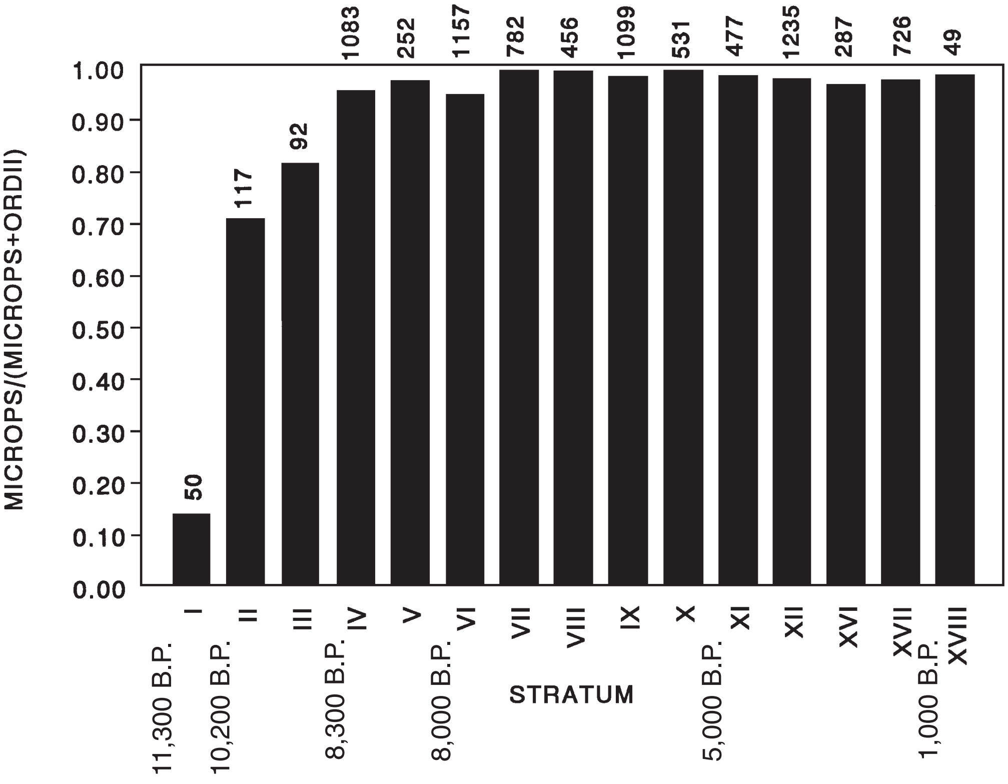

Figure 57. Changing proportions of the kangaroo rat fauna contributed by D. microps *at Homestead Cave. The numbers above the bars provide the total number of* Dipodomys *specimens identified as either* D. microps *or* D. ordii. *This figure includes Stratum X, for which only the kangaroo rats were identified.*

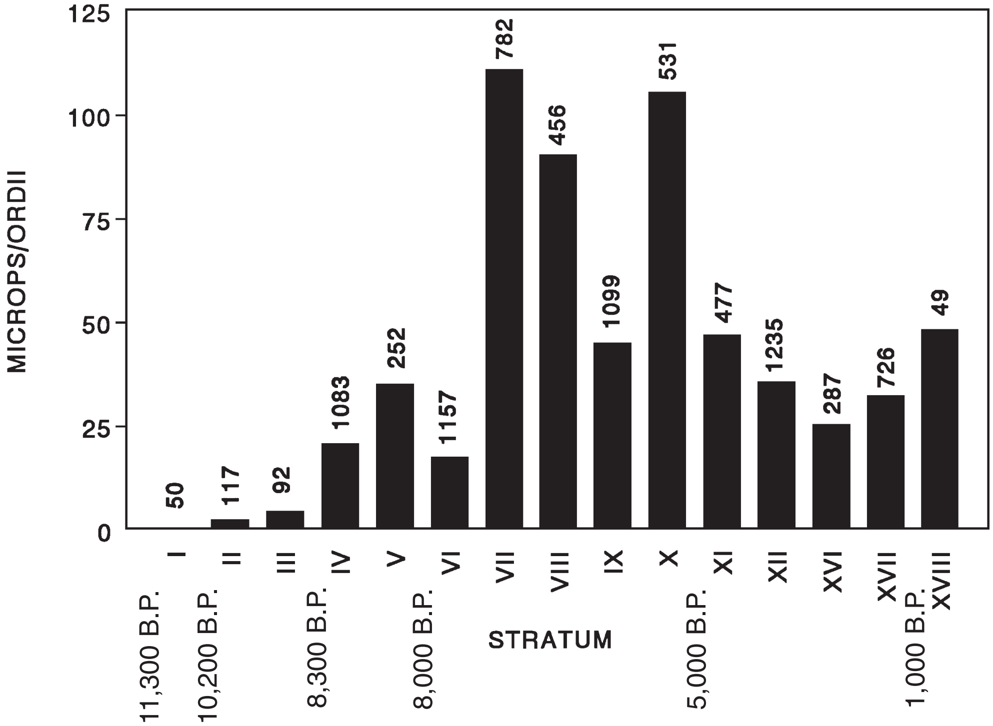

Figure 58. Changing proportions of D. microps *to* D. ordii *at Homestead Cave. The numbers above the bars provide the total number of* Dipodomys *specimens identified as either* D. microps *or* D. ordii. *This figure includes Stratum X, for which only the kangaroo rats were identified.*

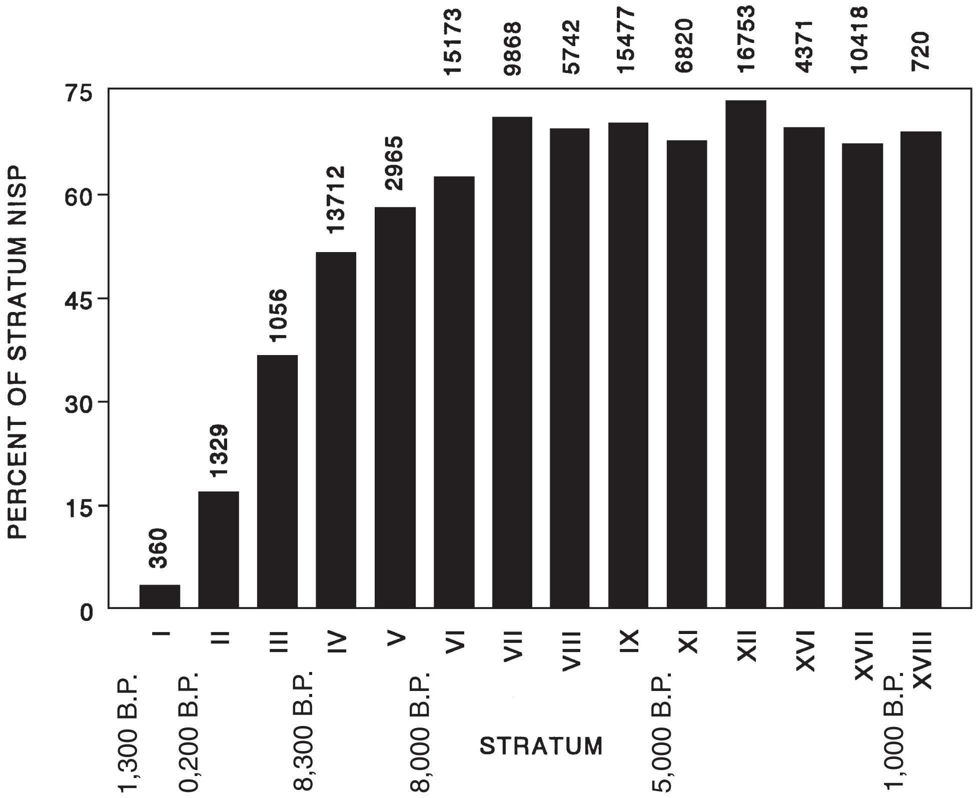

Figure 59. *Changing relative abundances of* Dipodomys *compared to all identified mammals at Homestead Cave. The numbers above the bars provide the total number of specimens identified as* Dipodomys. *Stratum X is not included in this graph.*

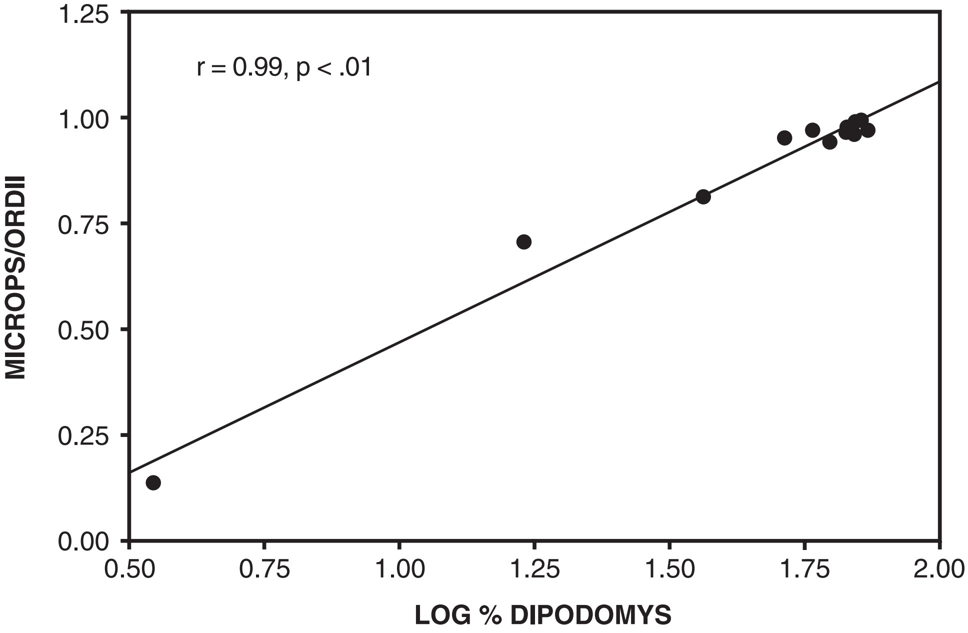

Figure 60. *Relationship between the relative abundances of* Dipodomys *and the proportion of the kangaroo rat fauna contributed by* D. microps *at Homestead Cave.*

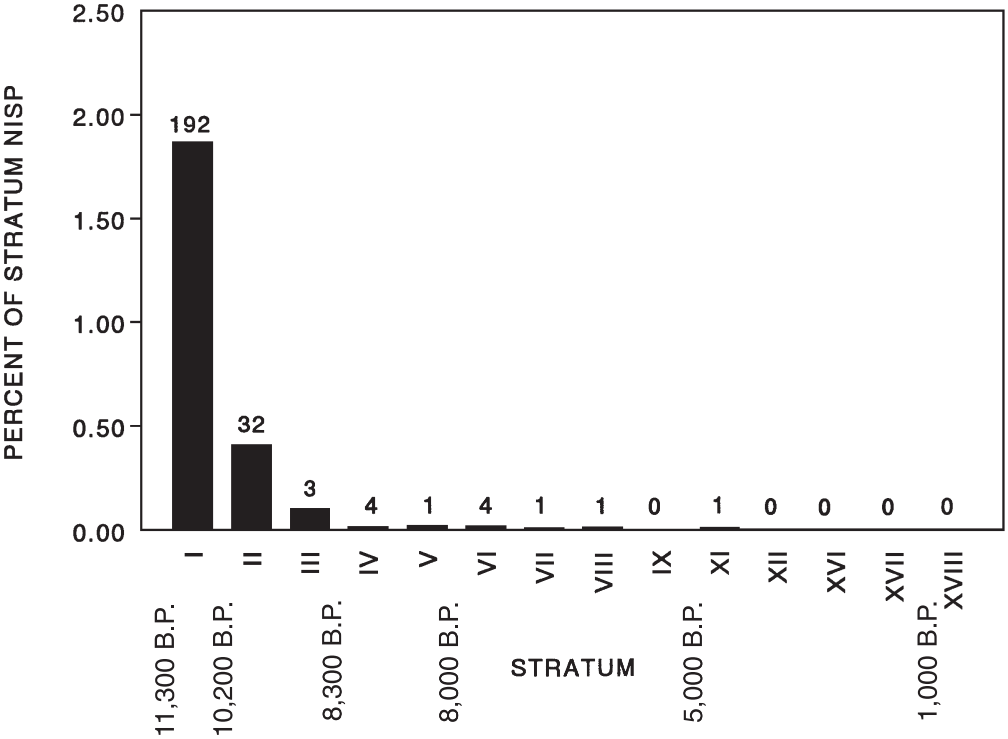

Figure 61. *Changing relative abundances of pygmy rabbits at Homestead Cave. The numbers above the bars provide the total number of identified* Brachylagus idahoensis *specimens.*

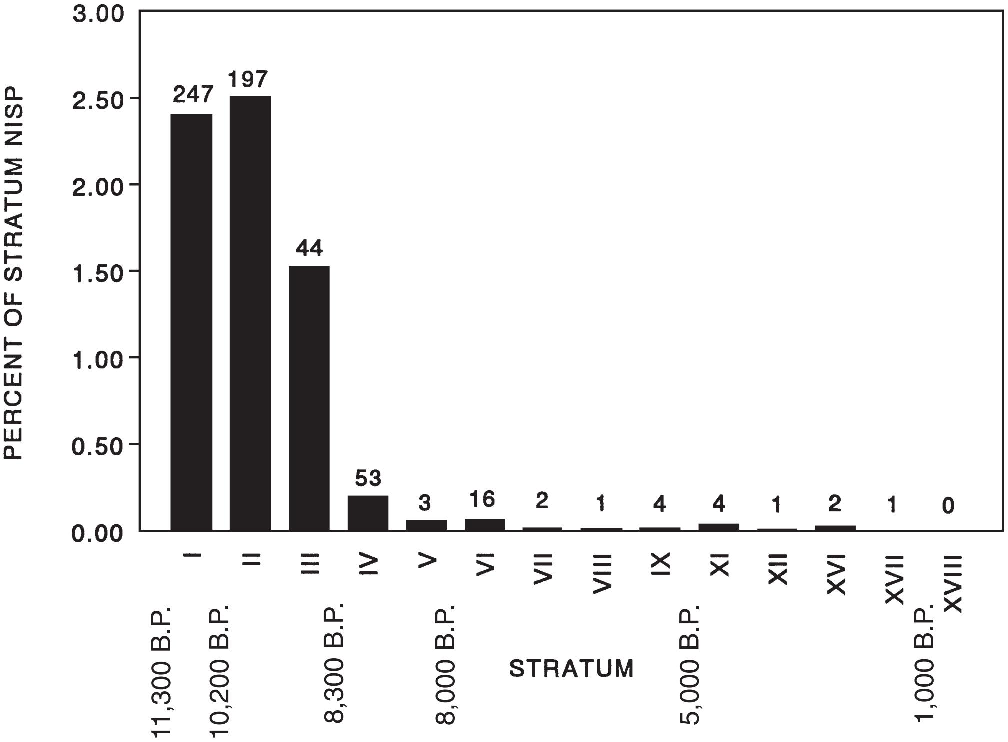

Figure 62. *Relative abundances of* Microtus *sp. at Homestead Cave. The numbers above the bars provide the total number of specimens identified as* Microtus *sp.*

that of *Brachylagus idahoensis* (compare figures 61 and 63). Both were most abundant during the latest Pleistocene in the Homestead Knoll area, both continued to be present during the early Holocene, and both saw their numbers fall dramatically in this area as the early Holocene came to an end at about 8.3 ka

Selected Faunal Histories: 4. Pocket Mice

Figure 64 shows the conjoined histories of two of the three species of pocket mice represented in the Homestead Cave fauna: the little pocket mouse, *Perognathus longimembris*, and the Great Basin pocket mouse, *P. parvus* (the long-tailed pocket mouse, *Chaetodipus formosus*, is the third species). *Perognathus longimembris* is common in the valleys and on the lower mountain slopes of the Great Basin and often co-occurs with *P. parvus*. The latter, however, ranges into altitudes far higher than those tolerated by the little pocket mouse. Hall (1946), for instance, noted that the highest elevation from which *P. longimembris* had then been taken in Nevada was 1981 m, but that *P. parvus* routinely occupies higher elevation habitats, for instance, at 3048 m on Mt. Grant in central Nevada. *Perognathus parvus* is also found well into British Columbia, but the little pocket mouse exists no farther north than southeastern Oregon (Hall, 1981).

Given what I have already said about the faunal sequence at Homestead Cave, it is perhaps no surprise that *P. parvus* is the abundant pocket mouse in the late Pleistocene deposits of Homestead Cave, and that *P. longimembris* is not present in the fauna at this time. The little pocket mouse first appears in Stratum II, sometime after 10 ka. In comparison with *P. longimembris*, *P. parvus* remains fairly common through the early Holocene. However, it becomes rare during the early centuries of the middle Holocene, appears to have become locally extinct between about 6 and 2 ka, and does not reappear until late prehistoric times.

Selected Faunal Histories: 5. Woodrats

Neotoma lepida is the woodrat found in the lower elevations of much of the Great Basin, while *N. cinerea* tends to occupy the mountains and the more northerly high valleys of the region. In addition, *Neotoma cinerea* ranges as far north as the Northwest Territories, while *N. lepida* extends no further north than central Oregon (Hall, 1981). Today, as I discuss below, both species are found on Homestead Knoll (Grayson and others, 1996).

Neotoma cinerea was the dominant woodrat in the Homestead Knoll area during the late Pleistocene and remained common through much of the early Holocene (figure 65). After about 8300 yr B.P., it underwent a dramatic decline and *Neotoma lepida* became, and has remained, the numerically dominant woodrat in the Homestead Knoll area. Indeed, the Homestead Cave faunal record strongly suggests that bushy-tailed woodrats had become locally extinct by no later than 5 ka, and perhaps significantly before that, only to recolonize the area prior to 1 ka (see below).

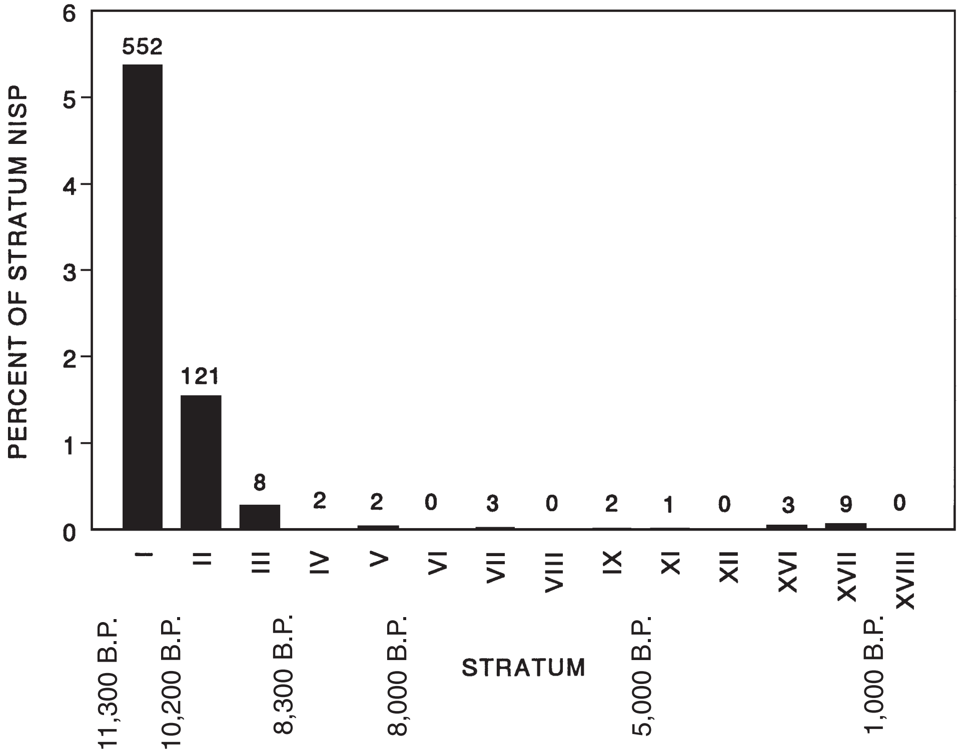

Figure 63. *Relative abundance of* Lemmiscus curtatus *at Homestead Cave. The numbers above the bars provide the total number of specimens identified as* Lemmiscus curtatus.

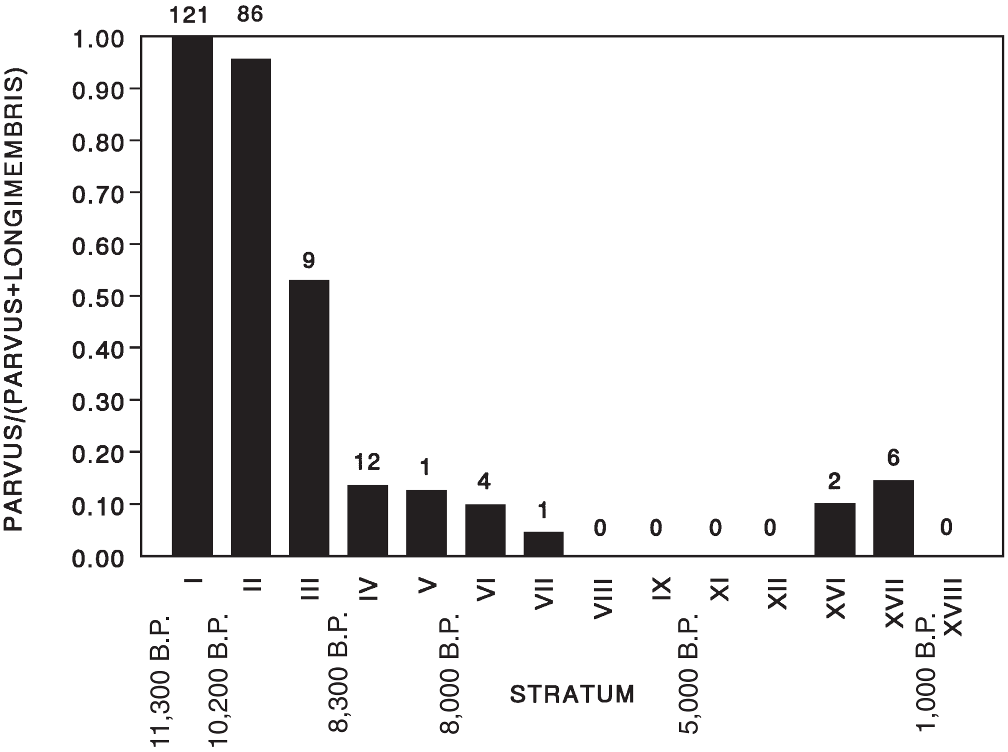

Figure 64. *Ratio of* Perognathus parvus *to* P. parvus *and* P. longimembris *at Homestead Cave. The numbers above the bars provide the total number of specimens identified as* P. parvus.

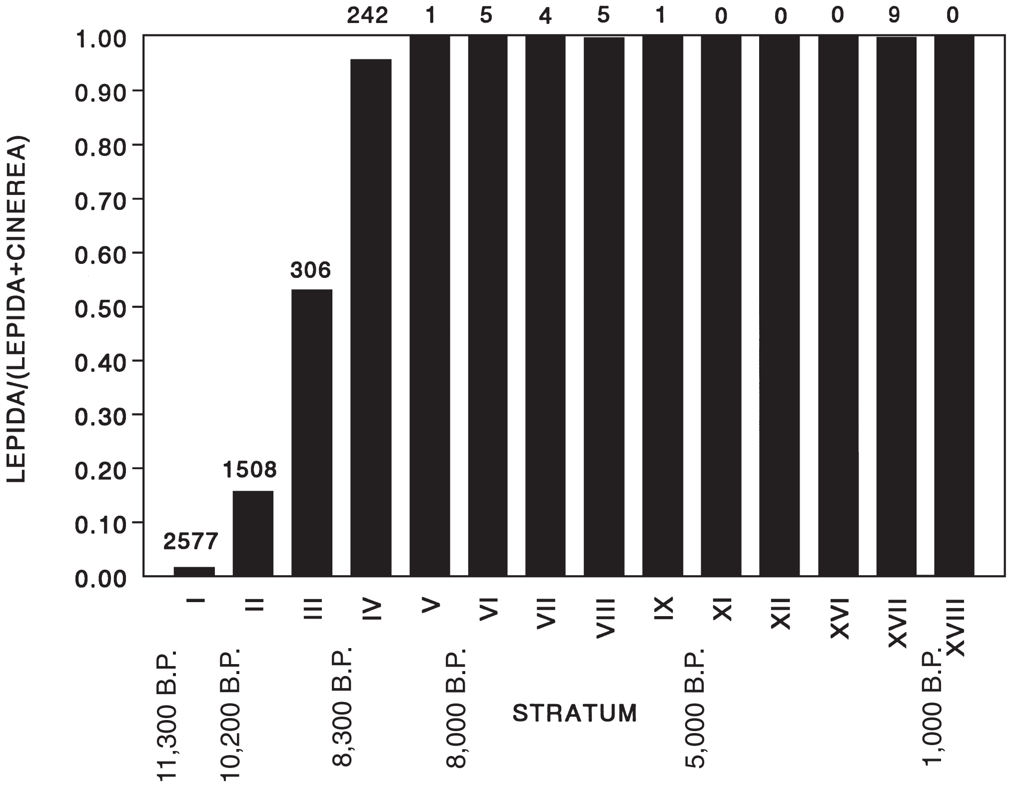

Figure 65. *Changing proportions of the woodrat fauna contributed by* N. lepida *at Homestead Cave. The numbers above the bars provide the total number of specimens identified as* Neotoma cinerea.

Selected Faunal Histories: 6. Harvest Mice

Western harvest mice are found in a wide variety of habitats but are most abundant in settings marked by dense grasses or other herbaceous vegetation (Webster and Jones, 1982). They can be found in arid contexts, but in Nevada they tend to be most abundant in grassy habitats near water (Hall, 1946) and may undergo significant population reductions in response to drought (Whitford, 1976).

The history of *Reithrodontomys* at Homestead Cave is summarized in figure 66 (the numbers plotted in this figure combine specimens identified as *Reithrodontomys* sp. with those identified as *R. megalotis*, the only species demonstrably present in the fauna). These animals were most abundant during the early Holocene, declined dramatically during the middle Holocene, and rebounded late in prehistoric times.

Selected Faunal Histories: 7. Pocket Gophers

There are two species of pocket gophers in Utah today: the northern pocket gopher, *Thomomys talpoides*, and Botta's pocket gopher, *T. bottae*. The northern pocket gopher is largely confined to the mountains and high valleys of the state (though it is has been reported from the Promontory peninsula: see Durrant, 1952), while *T. bottae* is the gopher of Utah's lower valleys. As far as we know, only *T. bottae* is known from the region immediately west of Great Salt Lake.

Gophers are also abundant in the Homestead Cave fauna. A total of 14,172 specimens have been identified from here, of which 969 have been identified to the species level. Although Stratum I at Homestead Cave provided only two gopher specimens that could be identified to species, both of these are *T. talpoides*. All identified gopher specimens from later strata represent *T. bottae*.

Selected Faunal Histories: 8. Marmots

Yellow-bellied marmots (*Marmota flaviventris*), mammals that also tend to be found only on Great Basin mountains though descending to much lower elevations to the north, are likewise present in the deeper strata of Homestead Cave (figure 67). Since the Homestead Cave fauna owes its accumulation largely to owls, and since adult marmots exceed the prey size routinely taken by these birds, it is not surprising that marmots were never abundant in the Homestead Cave deposits. As a result, it cannot be determined precisely when these animals became locally extinct, but they are reasonably common in latest Pleistocene Stratum I and appear to have been present in the area until roughly 8 ka. The fact that 66 specimens were present in the late Pleistocene and early Holocene Homestead Cave sample clearly documents the presence of local populations of these mammals during this time. Just as clearly, the complete absence of marmot specimens in these deposits during the past 5000 years shows that they had been extirpated from this area by the time the middle Holocene ended, and perhaps long before the end of this period.

THE HOMESTEAD CAVE MAMMAL SEQUENCE AND CLIMATIC MODELS

Recent climatic models suggest that the early Holocene in the Great Basin was both wetter and warmer than today, with increased summer insolation causing increased summer monsoonal precipitation (see Thompson and others, 1993; Mock and Bartlein, 1995). Mammalian data relevant to testing these models have long been available. However, as I have mentioned, these data have most often been ignored when the models have been tested against empirical data, although they have at times been given passing mention (Thompson and others, 1993) or have been selectively called upon when they support implications of the models (see Mock and Bartlein, 1995). Thus, it is important to stress that the early Holocene reconstructions provided by the models remain in conflict with a wide variety of mammalian paleontological data from the Great Basin, including that from Homestead Cave. The Homestead Cave mammals strongly suggest that between about 11.3 and 8.3 ka, the Homestead Knoll area was not only substantially wetter than the present but also substantially cooler.

As Bartlein and others (1995) have argued, uncalibrated radiocarbon ages are likely to give very misleading impressions of the relationship between events dated in this fashion and events expressed in calendar years. More to the point, then, is the fact that Homestead Cave Stratum II has three radiocarbon dates whose calibrated ages fall between about 10,000 and 9500 cal yr B.P. (see chapter four), and thus at about the time of the July Northern Hemisphere insolation maximum incorporated into the models. Even though this is the case, the fauna of this stratum is marked by taxa that do not suggest great warmth.

I have already described the data relevant to this conclusion. As we have seen, the early Holocene strata at Homestead Cave are marked by a wide variety of mammals whose modern habitat requirements and distributions strongly suggest that the Homestead Knoll area was relatively cool and moist at that time. The high relative abundance of arvicoline rodents (*Microtus* sp. and *Lemmiscus curtatus*), *Neotoma cinerea*, *Perognathus parvus* and the presence of *Marmota flaviventris* and *Brachylagus idahoensis* all imply a cool and moist climatic regime during the early Holocene, albeit less so than during the latest Pleistocene. Even the history of kangaroo rats within Homestead Cave is consistent with this view. These animals comprise a relatively small fraction of the Stratum II mammal assemblage, and within the Stratum II kangaroo rat fauna, *D. ordii* is 2.4 times more common than *D. microps*.

The implications of the early Holocene small mammal fauna from Homestead Cave are clear. During the time that Stratum II accumulated, the area surrounding this site was marked by fairly dense concentrations of *Artemisia*, presumably *A. tridentata*, with a significant grass understory. Vegetation and mammals alike existed in a climatic context that was both cool and moist, though not as cool and moist as during the period when Stratum I accumulated. This conclusion is in sharp disagreement with the implications of the climatic models for this time and area.

Homestead Cave is not alone in suggesting that the early Holocene, in at least the more northern parts of the Great Basin, was cool, not warm, and moist (see the discussions in Grayson, 1993, 1998). For instance, pikas (*Ochotona princeps*) are known from the lower elevations of the Fort Rock Basin of south-central Oregon between 11.2 and 7.2 ka, and it is difficult to see how these animals, so dependent on cool summer temperatures (see Smith, 1974), could have existed

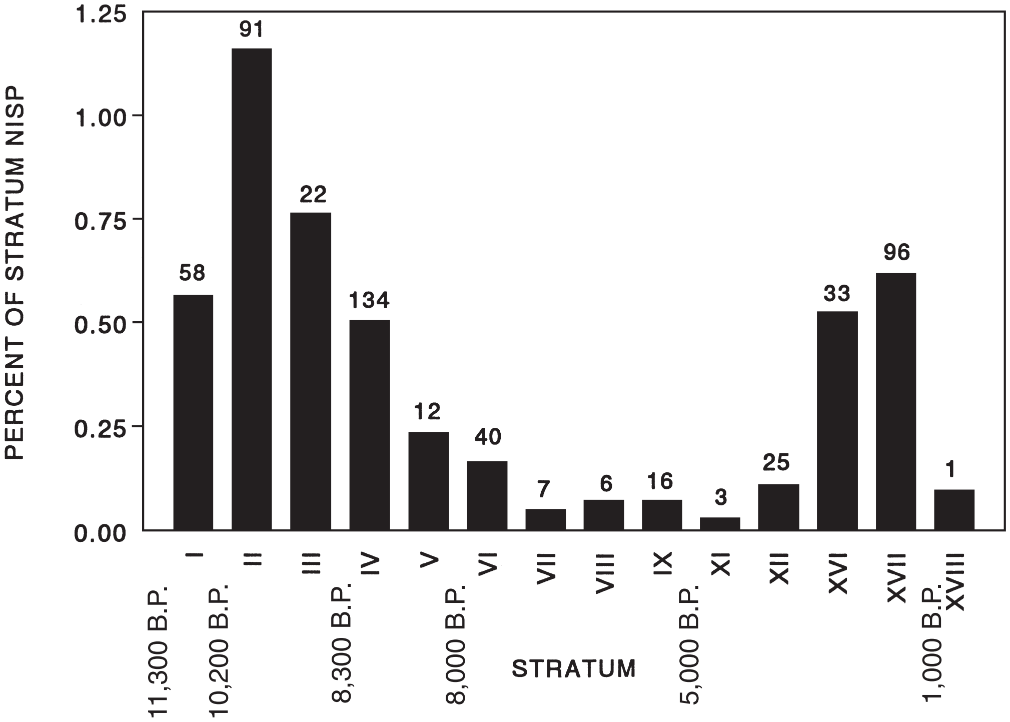

Figure 66. *Relative abundances of* Reithrodontomys *at Homestead Cave. The numbers above the bars provide the total number of specimens identified as* Reithrodontomys.

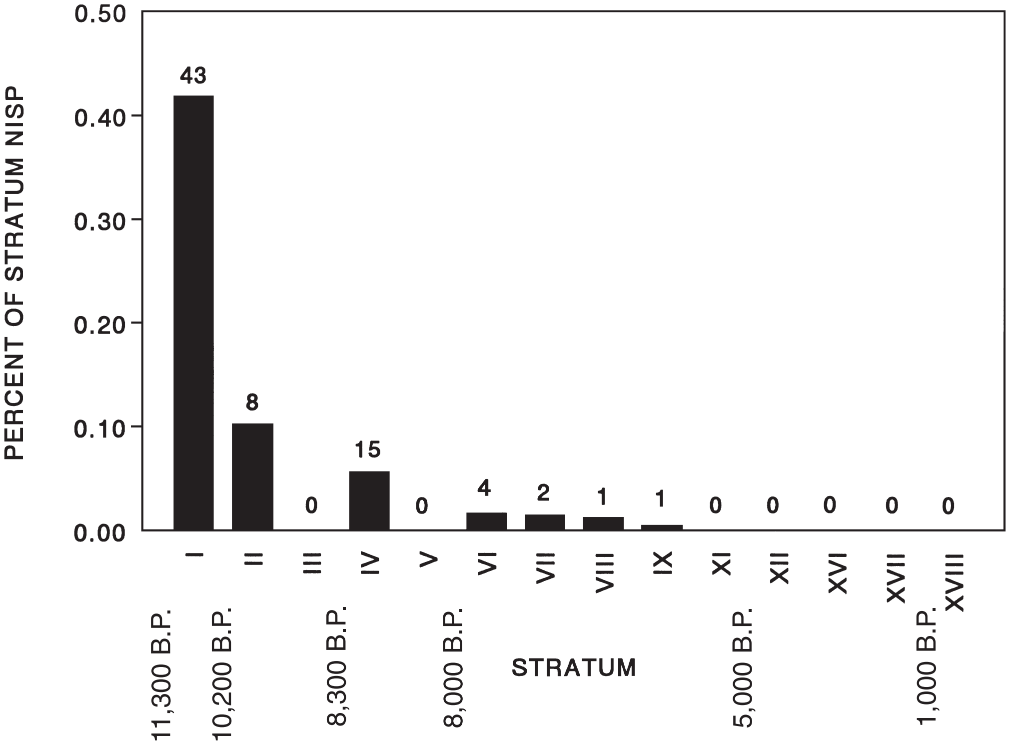

Figure 67. *Relative abundances of marmots at Homestead Cave. The numbers above the bars provide the total number of specimens identified as* Marmota flaviventris.

in such settings during an early Holocene that was warmer, albeit moister, than anything that has come since, including the middle Holocene. At Danger Cave some 100 km to the southwest, 95%, or 125, of the bushy-tailed woodrat specimens in the entire faunal assemblage were deposited between about 10.5 and 7.5 ka; the remaining six specimens were scattered across the subsequent 7,500 years of history registered in this site. Our knowledge of mammal history for the northern Great Basin is remarkably consistent in this regard (Grayson, 1993). That history implies a cool and moist early Holocene in this region as a whole, as does a substantial set of paleovegetational data that is at odds with those models (see Madsen and Currey, 1979; Wigand and Mehringer, 1985; Thompson, 1990, 1992a; Grayson, 1993; Rhode and Madsen, 1995).

This is not to say that the small mammal faunas of the early Holocene Great Basin are necessarily incompatible with warm and moist summers. It is always possible that mammals responded to non-analog environmental conditions in non-analog ways. Given the diversity of mammal species involved, however, this seems quite unlikely. In addition, the same kinds of qualitative assessments of paleoenvironmental, and in particular paleovegetational, data that have been used to assess the accuracy of the models (see Mock and Bartlein, 1995) lead to the conclusion that the mammalian data are strongly at odds with those models with respect to early Holocene temperature regimes in the Great Basin. It is also to say that we would be far better off in our attempts to understand both the models and arid western climatic history if these data were addressed rather than ignored.

MAMMALIAN RESPONSES TO MIDDLE HOLOCENE CLIMATES

The fact that the early Holocene mammalian fauna at Homestead Cave implies a climatic context that was cool and moist at that time is not novel. I have, however, also discussed the fact that previous analyses of Holocene mammalian faunas from the Great Basin have routinely detected major faunal changes as the early Holocene ended and the generally hot and dry middle Holocene began, but that it has been much more difficult to find concomitant change in small mammal distributions or abundance as the middle Holocene ended.

Homestead Cave also shows a broad range of responses to the end of the early Holocene. Arvicoline rodents declined in number dramatically; *Marmota flaviventris* and *Brachylagus idahoensis* became locally extinct; *Neotoma lepida* became the dominant woodrat, *Perognathus longimembris* the dominant pocket mouse, and *Dipodomys microps* the dominant kangaroo rat. These responses are in line with our knowledge of similar changes elsewhere in the Great Basin at this time (Grayson, 1993).

What is novel, however, is the evidence that this fauna provides concerning changes in mammal abundance during and after the middle Holocene. The abundance of *Reithrodontomys megalotis*, for instance, declined dramatically during the middle Holocene, then rebounded as this period ended. *Dipodomys microps* reached extremely high abundance, compared to those of *D. ordii*, between about 7 and 5 ka and then declined as the middle Holocene ended (figure 58). Consistent with the arguments made by others concerning the nature of the middle Holocene, the abundance of *D. microps* was not monolithically high during this period of time, but rose and fell much as the ratio of grasses to sagebrush rose and fell at Fish and Wildhorse Lakes on Steens Mountain, southeastern Oregon during the middle Holocene (Mehringer, 1985).

As the middle Holocene ended, not only did *D. ordii* increase in abundance relative to *D. microps* and *Reithrodontomys megalotis* return in number, but other mammals increased in abundance, or returned, as well. *Perognathus parvus* reappears in the record in Stratum XVI as does *Lemmiscus curtatus* (but note that Strata XIII, XIV, and XV, dating to between about 3.5 and 1.5 ka, remain unanalyzed).

Elsewhere the archaeological record strongly supports the proposition that Great Basin human populations fell dramatically during the hot and dry middle Holocene (Grayson, 1983), an argument first made in detail long ago (see Baumhoff and Heizer, 1965). The Homestead Cave fauna shows just how complex the biotic response to this event was. Some mammals that were lost as the middle Holocene began never returned (for instance, *Marmota flaviventris* and *Brachylagus idahoensis*). Others underwent substantial reductions in number but remained in the area throughout this period (for instance, *Dipodomys ordii* and *Reithrodontomys megalotis*), then increased in number as, from their perspective, climatic conditions ameliorated. Still others (for instance, *Perognathus parvus* and *Lemmiscus curtatus*) became locally extinct and then recolonized when conditions allowed.

Indeed, the post-middle Holocene recolonization of the Homestead Knoll area included *Neotoma cinerea*, a mammal that has been assumed by some to be isolated on Great Basin mountains today. It is to this issue that we now turn.

RECOLONIZATION AND SMALL MAMMAL BIOGEOGRAPHY

As I have observed elsewhere (Grayson, 1987, 1993), J. H. Brown's model of montane mammal biogeography in the Great Basin (Brown, 1971, 1978) makes three strong predictions about late Pleistocene and early Holocene small mammal history in the Great Basin. First, his model predicts that montane mammals currently isolated on Great Basin mountains must once have occupied the lowlands that intervene between these mountains, since those lowlands provided the corridors of access to the mountains. Second, montane mammals found on only some of these ranges must have been found on other ranges in the past, since the model maintains that the mountains were inhabited by a common pool of species and were reduced to their current numbers by subsequent extinctions. Finally, his model also requires that there have been no Holocene colonizations of these mountains since, in this view, the process driving the differential presence of montane species on massive Great Basin mountains has been extinction, not colonization.

Previous paleontological work has shown that Brown's model was insufficiently dynamic. In particular, it has appeared likely for some time that different mammals became isolated on different ranges at different times in different places, and that species-wise, rather than community-wise, analyses are critical if we are to understand the processes of colonization and extinction that have formed these faunas. This same work has, however, provided substantial support for the first two of the predictions made by the model (Grayson, 1993). Indeed, Homestead Cave provides exactly the same kind of support: *Mustela erminea* appears only in Stratum I and *Lepus townsendii* only in Strata I and II; *Marmota flaviventris* is gone by about 8 ka. While *Thomomys talpoides* is not on the list of montane mammals analyzed by Brown, it is also largely montane in distribution in the Great Basin and it, too, is present only in the late Pleistocene deposits of Homestead Cave.

Not only has previous work provided strong support for the first two of these predictions, but it has also shown that there were even montane mammals that have become extinct across all Great Basin mountain ranges during the Holocene (Grayson, 1981). At the same time, and as I have discussed earlier, it has now become clear that montane mammals are today far more widespread on Great Basin mountains than was once thought and that the pattern of this distribution is consistent with the argument that both extinctions and Holocene colonizations have been critical to forming that distribution (Grayson and Livingston, 1993; Lawlor, 1998).

It is thus particularly important that Homestead Cave has, for the first time, allowed a detailed assessment of the third of the paleontological predictions I outlined above, involving the demonstration of either the presence or absence of Holocene colonizations of Great Basin mountains. Indeed, one of the more remarkable discoveries made in conjunction with this project involves the discovery that *Neotoma cinerea*, one of the species that has been treated as a member of the montane mammal assemblage, is present in the Homestead Knoll area today. As part of an effort to document the nature of the local small mammal community in conjunction with the analysis of the small mammal assemblage from Homestead Cave, we trapped (and filmed and released) a bushy-tailed woodrat within Homestead Cave itself, and E. Rickart has uncovered a series of unpublished records for this species in other low-elevation settings in nearby parts of the northern Bonneville basin (Grayson and others, 1996). These discoveries led us to conclude that bushy-tailed woodrats can colonize low-elevation xeric settings. Indeed, we also concluded, as did Lawlor (1998) on very different grounds, that modern montane mammal distributions in the Great Basin have been determined by a complex pattern of colonizations and extinctions.

We now have a much clearer view of the history of this mammal in the Homestead Knoll area than was available when we addressed this issue in 1996. As has been noted, *Neotoma cinerea* had become locally extinct here by 5 ka, and perhaps well before then, only to reappear in the Homestead Cave fauna by 1 ka. Given that only nine specimens of this species are present in Stratum XVII (see table XXIII), it is possible that we are here seeing the effects of long-distance transport by a raptor (note that the sample available for Stratum XVIII, 1047 identified mammalian specimens, is so small that *Neotoma cinerea* is not likely to have been detected had it been present at this time). Nonetheless, given that bushy-tailed woodrats exist here today, there is no question that this species has recolonized the Homestead Cave area during late Holocene times. In addition, the reappearance of *Neotoma cinerea* in Stratum XVII is both preceeded and accompanied by increases in abundance of a number of other taxa suggestive of cooler and/or moister conditions. These include *Dipodomys ordii* (figure 58), *Lemmiscus curtatus* (figure 63), *Perognathus parvus* (figure 64) and *Reithrodontomys megalotis* (figure 66). Given that *Neotoma cinerea* reappears at the same time as other consistent changes occur in the nature of the local faunal community, it seems unlikely that this reappearance is to be attributed to a low-probability long-distance dispersal event.

Table XXIII
***Neotoma cinerea* and *Neotoma* cf. *cinerea* specimens present in Stratum XVII**

Identificaion	**Element**
Neotoma cinerea	Tooth: M^1
Neotoma cinerea	Tooth: M^1
Neotoma cf. *cinerea*	Skull: premaxilla
Neotoma cf. *cinerea*	Skull: premaxilla
Neotoma cf. *cinerea*	Skull: premaxilla
Neotoma cf. *cinerea*	Skull: maxilla
Neotoma cf. *cinerea*	Skull: occipital
Neotoma cf. *cinerea*	Skull: occipital
Neotoma cf. *cinerea*	Scapula

A wide variety of data are thus joining to suggest precisely how complex the biogeographic history of Great Basin “montane” mammals has been. While many of these complexities continue to elude us, recent studies make it quite clear that the degree of isolation of some montane mammals on Great Basin mountains is far less than has been thought, and that the distinctive small mammal faunas of Great Basin mountains have been shaped by both colonization and extinction.

The practical implications of these results are quite clear. On the one hand, they show that attempts to predict extinctions under conditions of global warming that require the assumption of isolation (McDonald and Brown, 1992) are problematic (see the discussion in Lawlor, 1998). On the other hand, they suggest that the creation of mountain-based wildlife reserves in the Great Basin must also include low-elevation dispersal corridors. Not only could such corridors prove critical for dispersal under climatic regimes different from those that now characterize the Great Basin, but they are also currently in use by at least some species in at least some places.

SPECIES RICHNESS RELATIONSHIPS

Precipitation in arid environments is positively correlated with net primary productivity (see Brown, 1975; Meserve and Glanz, 1978; Abramsky and Rosenzweig, 1984); both these variables are, in turn, correlated with mammal species richness (the number of mammal species present). This relationship, however, is not necessarily positive. With increasing precipitation in arid areas of low to moderate productivity, mammal richness increases linearly (Brown, 1973, 1975; Meserve and Glanz, 1978). As rainfall and productivity increase beyond this point, however, mammal richness has been shown to decline in some areas, producing a relationship that has been termed "unimodal" or "humped" (Abramsky and Rosenzweig, 1984; Abramsky and others, 1985; Owen, 1988, 1990; Rosenzweig, 1992, 1995; Wright and others, 1993). While the initial rise in this relationship is well understood, the cause or causes of the decline are not.

Brown (1973, 1975; Brown and Gibson, 1983) has shown that the relationship between rainfall and rodent species richness in sandy habitats in the Great Basin is positive and linear up to about 32 cm of annual precipitation (Brown, 1973). Rosenzweig (1992, 1995; Rosenzweig and Abramsky, 1993), on the other hand, has argued that Brown's data simply catch the initial, positive part of the full richness relationship. The clear implication is that, if we were to sample areas of higher precipitation within the Great Basin, the decline phase would become more evident (see also Abramsky and others, 1985, p. 368). Elsewhere (Grayson, 1988) I have referred to these two interpretations of the relationship between precipitation and small mammal species richness in the Great Basin as the "positive richness-response" (see Brown, 1975) and "unimodal richness-response" (see Rosenzweig and Abramsky, 1993) models.

Both climatic modelers and empiricists agree that the latest Pleistocene and early Holocene in the northern Great Basin saw higher levels of precipitation than have characterized this area since the end of the early Holocene. Given that temperatures during this time here were also cooler than in the middle and late Holocene (a point on which climatic modelers and empiricists do not agree), it follows that if the positive richness-response model applies to the Great Basin, small mammal richness should have been higher during the late Pleistocene and early Holocene than it has been since that time.

In an earlier examination of the Homestead Cave mammals (Grayson, 1998), I used regression analysis to take into account the fact that the greater the number of identified specimens (NISP) in a paleontological assemblage, the greater the number of taxa represented by those specimens (see Grayson, 1984). In that earlier study I found that the Homestead Cave faunal assemblages that accumulated between about 11.3 and 8.3 ka do contain greater numbers of small mammal taxa than those that accumulated after this time, as is predicted by the positive richness response model under conditions of increasing aridity. This result mirrors that obtained by Nowak and others (1994) concerning the vegetation of the western Lake Lahontan basin in far western Nevada. There, they observed, latest Pleistocene and early Holocene vegetation assemblages were far richer than those that followed.

Since a larger sample of identified small mammal specimens is now available from Homestead Cave, I have repeated this analysis, following the protocol discussed in Grayson (1998). Figure 68 presents the results. The lines in this figure, fit by least-squares regression, are given simply to indicate the fact that there are two separate relationships between NISP and the numbers of taxa. Whereas the lower, later relationship is highly significant ($r = 0.84$, $p < 0.001$), the upper, earlier relationship, drawn through three points, is not ($r = 0.94$, $p > 0.10$). As in the initial examination, the small mammal assemblages from Strata I - III are richer, at any given sample size, than are those from all later strata. Stratum XVI does fall well above the line that marks the later relationship, but this difference - 16 taxa present but 13.0 predicted - is not significant at $p = 0.05$ (standard deviation = 1.42).

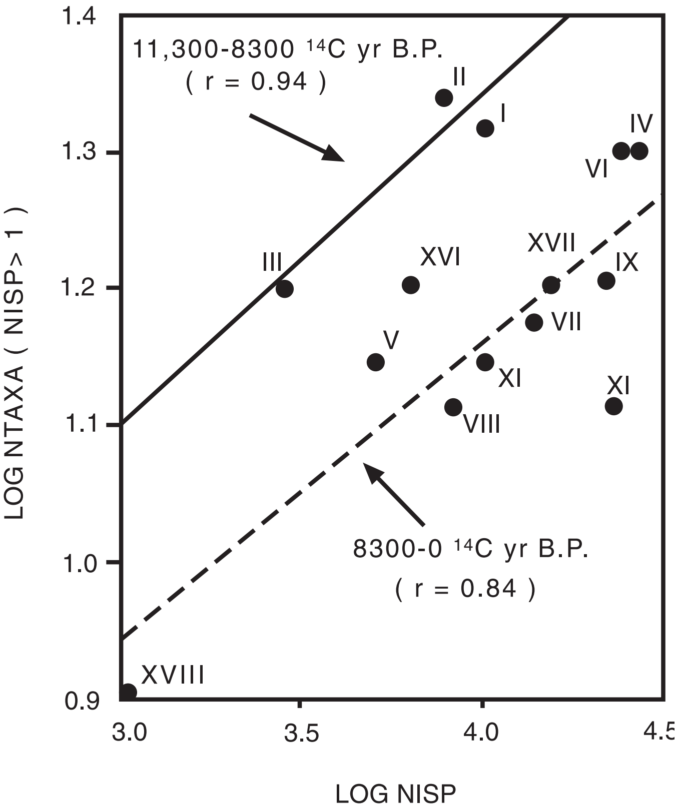

Figure 68. Relationship between the number of identified specimens (NISP) and taxonomic richness (NTAXA) at Homestead Cave.

Once again, I conclude that since small mammal richness in this area declined as moisture declined, it appears likely that the positive richness response model applies to all low elevation settings in the Great Basin. The "unimodal" small mammal species-response model does not appear to apply to the Great Basin and does not appear to have done so since at least the latest Pleistocene.

CONCLUSIONS

The Homestead Cave fauna documents environments that were clearly wetter between about 11.3 and 8.3 ka than any that have been seen in this area since. This conclusion is in agreement with conclusions drawn from a wide variety of other paleoenvironmental indicators. It is also in agreement with the conclusion drawn from the NCAR Community Climate Model (see Thompson and others, 1993). While this is the case, however, the Homestead Cave small mammal fauna also suggests that this period of time was cool, not warm, and thus stands in distinct contrast to the predictions of the NCAR CCM.

The Homestead Cave fauna is not alone in suggesting a moist and cool early Holocene in the northern Great Basin, as opposed to the moist and warm early Holocene called for by the models. Although at times recognized as a potential problem by at least some of the modelers (see Thompson and others, 1993), the differences between the climatic conditions called for by the models and those implied by the mammals are stark. The mammal histories have been replicated in so many places by so many taxa that it seems unlikely that the problem lies with them, as opposed to lying with the models themselves.

The Homestead Cave fauna also joins a growing body of data generated by both paleontologists and neoecologists to show that the history of "montane" mammals in the Great Basin has been far more complex than was once thought. Most significantly, it is now clear that the montane mammal faunas of Great Basin mountains have been formed by a combination of Holocene extinction and colonization events. Homestead Cave shows a number of those extinction events - of *Lepus townsendii*, *Mustela erminea*, and *Marmota flaviventris*. More importantly, since it has not been detected before, Homestead Cave also shows both the extinction and recolonization of the Homestead Knoll area by *Neotoma cinerea*, thus directly documenting what has earlier been inferred from the examination of modern distributions of small mammals in the Great Basin (Grayson and Livingston, 1993; Lawlor, 1998). Combined with neoecological analyses, this discovery has significant implications for the management of small mammal habitats in the Great Basin. Since some of these mammals can and do use lowland habitats and dispersal corridors today, those corridors must also become a focus of management concern.

Finally, and also of practical import, the Homestead Cave mammal fauna suggests that the linear-response model of small mammal richness, and not the "unimodal" model, applies to this region. Future decreases in precipitation can be expected to decrease small mammal richness here, future increases to increase it.

ACKNOWLEDGMENTS

I thank K. M. Bovy, J. M. Broughton, J. L. Kenagy, and R. S. Thompson for very helpful comments on all or parts of the manuscript; J. M Broughton, M. D. Cannon, M. Etnier, L. Nagaoka, and S. S. Hughes for critical assistance in the lab; R. W. Graham and A. D. Barnosky for examining the specimen reported here as *Pitymys* sp., E. Rickart for his time and help at the Utah Museum of Natural History, and the Zoology Division of the Burke Museum of Natural History and Culture for access to modern skeletal material.

CHAPTER EIGHT

The Homestead Cave Avifauna

by

Stephanie D. Livingston

INTRODUCTION

Much of what we know of the Holocene history of birds in the Great Basin came from bird bone assemblages from caves not far from Homestead Knoll. Those assemblages, excavated for archaeological purposes approximately half a century ago, have been carefully analyzed, the data synthesized, and published (Parmalee, 1970, 1980, 1988). But none of the assemblages described in the published literature are as large, cover the time span, are as finely stratified, or are as well dated as the bird assemblage from Homestead Cave. Further, most of the previously reported assemblages are from contexts where the accumulation processes of the bone materials included human activities which bias assemblage composition in favor of large-bodied gregarious birds that provide a food resource for people. Unlike those assemblages, the Homestead Cave bird bones were deposited primarily by raptors, an inference supported not only by owls roosting in the cave as it was being excavated, but more directly by the presence of complete and partially disaggregated pellets in the deposits and by pellet material adhering to the bones and embedded in foramina. Further, none of the specimens are burned or show other characteristics routinely interpreted as evidence of human activities influencing the accumulation process. Thus it is reasonable to assume that the specimens discussed in this chapter are from birds captured within the foraging radius of raptors using the site at the time they were deposited (see Schmitt, chapter two). The Homestead Cave avifauna provides a new, different, and more detailed glimpse at Holocene avian history as a result of these differences in time span and accumulation processes. That increase in detail allows more detailed inferences regarding past environments and climates.

The Homestead Cave avifaunal assemblage described here includes over 6,000 specimens representing at least 75 species in 26 families. These are the avian specimens identified to date from the total bone assemblage recovered in the 6.3 mm screens and the bulk samples from Stratum I. Identifications were made by comparison to a series of reference specimens of known species and provenience curated at the Desert Research Institute, Reno, Nevada, or borrowed from the Burke Museum of Natural History and Culture, Seattle, Washington. A few specimens from the 6.3 mm sample from each stratum remain to be identified, and a significant number of the specimens included here as "indeterminate passerines" will be identified in the future as time and access to appropriate reference specimens allow.

An attempt has been made to assure that none of the unidentified specimens are from species identified in other strata. However that effort is not complete for a number of taxa, particularly the small shorebirds and passerines. Some counts will change in the final analysis. Consequently, discussion of the assemblage at this time will focus on more inclusive taxonomic levels (genus, family, and even order) for many species, even though more precise identifications are available for numerous specimens in several strata. No attempt has been made to include vertebrae, phalanges of the feet, or skull elements posterior to the beak. A summary of the identified specimens from the 6.3 mm screen sample is presented in table XXIV.

Identification of the 3.1 mm screen sample has been started for several strata, but none are nearing completion. The specimens from the 3.1 mm assemblage identified to date include small elements of many of the same taxa already identified from the 6.3 mm sample, larger samples of the small, environmentally sensitive taxa such as shorebirds, woodpeckers and passerines, and even smaller taxa which were not identified in the 6.3 mm sample. Because analysis of the 3.1 mm sample has not progressed very far, it is discussed here only to demonstrate that further effort expended on the task will provide a more extensive list of taxa, and a more consistent record of occurrence for many taxa found in the 6.3 mm sample.

Although restricting the current discussion to the 6.3 mm sample eliminates some of the finest detail in the data for drawing inferences regarding Holocene environmental change, comparison of the Homestead Cave record to published avifaunas is enhanced. Because most published avifaunas were recovered in 6.3 mm or larger mesh, precluding the smaller screen sample from the discussion below eliminates the necessity of allowing that observed differences may be due strictly to differences in recovery techniques.

ASSEMBLAGE DESCRIPTION

Divers

Of the two orders of birds (Gaviiformes: the loons, and Podicipediformes: the grebes) highly adapted to diving and swimming underwater (Ryser, 1985, p. 59), no elements identifiable as the larger, shyer loons were found in the Homestead Cave avifauna. The large number of grebes, however, is particularly noteworthy. Grebes comprise approximately one-fourth of the total assemblage. They are the most abundant taxon in the deeper strata, above Stratum I.

There are four grebes commonly found in the Great Basin. Of those, I have found very few specimens that can securely be identified as Pied-billed Grebe (*Podilymbus podiceps*, NISP=5) or Western Grebe (*Aechmophorus occidentalis*, NISP=5). Most grebe specimens are referable to the genus *Podiceps*, of which both Eared (*P. nigricollis*) and Horned (*P. auritus*) species occur in the northeastern Great Basin. Both species are clearly represented in the Homestead Cave assemblage, but with a few exceptions, osteological differences between Eared and Horned Grebes are subtle. Thus, most elements remain identified only to the genus. Of the specimens that I could assign to species on he basis of morphological differences of selected elements, the majority

Table XXIV
Numbers of identified bird specimens

Taxon Stratum:	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII	XVIII	TOTAL
Podicipedidae																			
Podilymbus podiceps	2														3				5
Podiceps sp.	178	125	36	113	12	204	55	31	107	21	62	120	103	17	57	7	19	3	1270
Aechmophorus occidentalis	7					1	1												9
Phalacrocoracidae																			
Phalacrocorax auritus		2																	2
Anatidae	216	31	6	19	3	3	4	3			4		5	1		2	6		303
Branta sp.																		1	1
Anas sp.	47	25	7	33		5	6		7				16	2	9	7	10		174
Aythya sp.	104	16	2	4	1	1	1	1	1						1		3		135
Bucephala albeola	6	1																	7
Bucephala cf. *clangula*	1																		1
Bucephala clangula	2																		2
Oxyura jamaicensis				2															2
Accipitridae	2																		2
Circus cyanus	1			3		1		1	4			1	2		1				14
Accipiter sp.												1	1						2
Accipiter striatus	7			6			2	2		3	3	2			4				29
Buteo sp.	4					1			2					1					8
Falconidae																			
Falco sparverius	9	1	1	4					1		2	4		1	10	2	3		38
Falco columbarius	5	1		1		1													8
Falco cf. *mexicanus*	7			2															9
Phasianidae	15	5	1	2		1		1			1	1		3					30
Rallidae																			
Rallus limicola	2	3	2						2				1				4		14
Porzana carolina	3			4					2		1				5				15
Porphyra/Gallinula/Fulica	5	7		4		1	3			1	3		1	3	15	5	3		51
Recurvirostridae																			
Recurvirostra americana			1						1								2		4
Scolopacidae		1											2				4		7
sandpipers	7	16		5		2	5		1		1	3	5			1			46
Phalaropus sp.	9	13		5			2	2	7		1	2	2	3	11	1		2	60
Larida																			
Larus sp.	12	14	4	3								1	1		2		4		41
Columbidae			1										2						3
Zenaida macroura	1			1				1	2		1	1	1	1		2	3		14
Cuculidae																			
Coccyzus americanus												2					1		3
Tytonidae																			
Tyto alba			2						1										3
Strigidae	10	4						1						2	2				19
Otus sp.	2	2									2				2		11		19
Bubo virginianus		1									1								2
Glaucidium gnoma				2								1		1	1	4	2		11
Athene cunicularius						1	2				2								5
Asio sp.	52	13	1	8			2		7	2	3	9	1	3	4		1		106
Ageolius acadicus	2	2		6		2			3	1		5	8	2	4	2	9		46
Caprimulgidae																			
Chordeiles cf. *acutipennis*	5					2	2		1						2		3		15
Phalaenontilus nuttallii	9	2		6					8		1	1	4			3		1	35
Picidae								2				1							3
Melanerpes lewis									4		1								5
Sphyrivicus sp.	4	3		2	3	4	3	5	5		2	8	9		5			1	54
Picoides sp.			2														2		4
Colantes auratus	2	4	4	21	2	6	3	4	10	4	2	6	7	4	6		5		90
Alaudidae																			
Eremophila alpestris	11	33		9	6	35	33	32	88	44	35	190	129	36	58	41	55	5	840
Bombycillidae																			
Bombycilla sp.	2	5	1	36	15	47	5	22	13	2	13	47	4	8	14		1		235
indeterminate passerine	203	130	6	50	22	76	118	130	153	29	93	269	191	87	413	66	14	11	2061
STRATUM TOTAL	954	460	77	351	64	394	247	238	430	107	234	675	495	175	629	143	165	24	5862

are Eared Grebes with only an occasional Horned Grebe. Eared Grebes are common summer residents in the marshes of northern Utah, often occurring in large congregations (Behle and others, 1985, p. 4) in shallow water where they build their nests on floating vegetation (Ehrlich and others, 1988, p. 10). Horned Grebes are more solitary, but will occasionally be found in a large group of Eared Grebes. Both feed primarily on aquatic insects and larvae, crustaceans, mollusks and fish. At times up to 90% of Eared Grebe diets are brine shrimp (Ehrlich and others, 1988, p. 10). I have often observed them foraging in small, ephemeral ponds that form during wet years along roadsides in the Bonneville basin, suggesting that throughout the time period represented in the Homestead Cave sequence they may have readily returned to the Homestead Knoll area whenever even short, wet periods allowed formation of ponds in the area.

Specialized Fishers

Of the specialized fishers (pelicans, cormorants, mergansers), no specimens of the largest taxa (*Pelicanus* sp.) or the duck-sized mergansers (*Mergus* sp.) were found. Two specimens of Double-crested Cormorant (*Phalacrocorax auritus*) have been identified from Stratum II. Double-crested Cormorants are colonial birds that usually nest in trees near lakes, rivers or marshes. They feed primarily on schooling fish but take some other small vertebrates (Ehrlich and others, 1988, p. 26). They are uncommon, localized summer residents in northern Utah, though there is a report that they did nest along the Sevier River in historic times (Behle and others, 1985, p. 5). Adequate habitat for cormorants, such as trees for nesting, may have disappeared from the vicinity of Homestead Knoll early in the Holocene. More apparent is the loss early in the sequence of food resources for taxa specializing on fish (see Broughton, chapter nine).

Waterfowl

Geese and swans, the largest members of the family Anatidae, are most notable in the Homestead Cave avifaunal assemblage for their rarity or absence. No swans and only a single goose (*Branta* sp.) specimen have been identified. The absence of identifiable swans and geese in this assemblage probably says more about how the assemblage was accumulated in the cave than about local avifaunas in the past. No birds of the size of a goose or larger have been identified, which probably indicates the upper size limit of species preyed upon by the raptors that brought the birds into Homestead Cave.

Ducks can be identified to genus using standard comparative techniques, but recognition of species requires statistical analysis (Livingston, 1988) which has not yet been completed for this assemblage. Within each genus a rough assignment to size groups has been made, but all interpretation is strictly at the genus level at this time, and I venture no estimate of the number or identity of species represented.

Marshbirds

Marshbirds have toe, foot and leg adaptations for wading or for walking over muddy ground. Marsh taxa found in the Homestead Cave avifauna are all members of the family Rallidae: Virginia Rail (*Rallus limicola*), Sora (Porzana carolina), and the larger Purple Gallinules (*Porphyra martinica*), Common Moorhens (*Gallinula chloropus*) and American Coots (*Fulica americana*). Diets of most of these birds consist of snails and other invertebrates, seeds, algae and emergent vegetation. Although not abundant in any of the Homestead strata, the marshbirds, like the ducks, are most common in the lowest strata. They are clearly represented in the upper strata after a brief absence beginning with Stratum X.

The record for rails will be much clearer when the 3.1 mm assemblage has been analyzed. The small, slender body characteristic of most rails allows most elements to slide through a 6.3 mm screen. The fact that they occur at all in this sample attests to the care with which the sediments were sorted. Had the matrix contained more dirt and less bone and plant debris on which small bones could be trapped before they slipped through the screens, many of the small-bodied birds (including the shorebirds, woodpeckers and passerines as well as the rails) would not be represented in the assemblage reported here. The larger marsh taxa like Great Blue Herons and Sandhill Cranes are undoubtedly missing as a result of the same processes that excluded all large birds. Some of the unidentified specimens may be egrets and/or bitterns, but if present they are not abundant.

Shoreline Birds

The Order Charadriiformes includes three groups: shorebirds or waders; gulls, terns and jaegers; and alcids. These birds frequent shorelines or waters adjacent to shorelines, and may also occur in such places as marshes, wet meadows and tundra (Ryser, 1985, p. 170). Many of the shoreline birds are quite small, making their abundance in this sample subject to the screen-size bias described above for the smaller rails.

Phalaropes (*Phalaropus*) and sandpipers (*Tringa*, *Actitis*, *Calidris*) occur in the 6.3 mm sample in small numbers with some regularity. They are more abundant in the 3.1 mm samples that have been examined to date. The small size of these specimens, like those of the small rails dictates that all inferences drawn from the occurrence or abundance of these taxa must be considered extremely tentative and preliminary until analysis of the 3.1 mm sample is completed.

Gulls (*Larus* sp.) are the birds most people associate with the Bonneville basin, particularly Great Salt Lake, due to historical accounts of large numbers of California Gulls (*Larus californicus*) saving local crops from an invasion of grasshoppers in 1848 (see Madsen and Madsen, 1987). Gulls, especially the California Gull, are often common around large inland bodies of water. They are common around Great Salt Lake at present. Although gull specimens occur sporadically throughout the column, they are surprisingly rare or absent in strata above Stratum IV.

Raptors: Diurnal Predators (hawks and falcons)

At least seven species of diurnal raptors, representing both the Accipiteridae and the Falconidae, have been identified in the Homestead Cave avifauna. These are the birds most likely responsible for bringing the majority of the avian bird specimens into Homestead Cave, depositing them as cast pellets. Northern Harriers (*Circus cyaneus*) prey in open country; the Accipiters, or "bird hawks" (*Accipiter* sp.), are adapted to hunting in trees; the "buzzard hawks" (*Buteo* sp.) hunt both in the open and the woodlands. The falcons (*Falco* sp.), two of which used to be known by common names that reflect their preference for hunting birds ("pigeon hawk" and "sparrow hawk"), usually hunt in the open or along the edges of woodlands. Most of the diurnal raptors prey on birds. The Buteos in particular, and others to a lesser extent, do take a large number of lagomorphs and rodents as well.

Raptors: Nocturnal Predators (owls)

At least eight species of owls in two families occur sporadically throughout the Homestead Cave strata. These are all, to a greater or lesser extent, nocturnal hunters that are undoubtedly the primary source of the huge small mammal bone assemblage that made up the bulk of the matrix in the Homestead Cave column (chapter seven). Some, such as the Northern Pygmy Owl (*Glaucidium gnoma*), are mostly diurnal, hunting at dawn and dusk. Others, such as the Burrowing Owl (*Athene cunicularia*), will hunt at any time of the day or night. The less restricted members of a species are in terms of timing of the hunt, the more likely they are to capture avian as well as mammalian prey. Of all the species represented, only the Flammulated Owl (*Otus flammeolus*) shows a preference for true forests; the others are also residents of riparian and pinyon-juniper woodlands, cottonwoods, and even open deserts as long as adequate roosts are available. Homestead Cave and the other cracks, crevices, shelters and caves in the vicinity of Homestead Knoll provide such roosts. As with the diurnal raptors, owls deposit the remains of their prey under their roosts largely in the form of cast pellets.

Upland Game Birds

Members of the families Phasianidae (grouse and quail) and Columbidae (doves) are terrestrial, largely ground feeding and ground nesting birds. Their diets consist primarily of seeds and other vegetation. These families are often considered together by modern ornithologists because their terrestrial lifestyle, chunky bodies and vegetarian diets make them prime non-aquatic game counterparts of the waterfowl. These birds inhabit sagebrush and sage-grass habitats, and shrub-deciduous thickets near streams or springs. Although many live in very dry areas, most need daily access to water and tend to avoid shadscale shrub habitats.

The largest of the upland game birds, the grouse, occur primarily in the lowest four strata. I have not identified quail in the Homestead Cave avifauna. Doves occur in very low frequencies in the upper two thirds of the sequence.

Cuckoos

The only member of the family Cuculidae found in the Homestead Cave assemblage is the Yellow-billed Cuckoo (*Coccyzus americanus*). This slender bird is an inhabitant of riparian and open woodlands, especially those with dense undergrowth. Its diet consists of caterpillars, bird eggs, frogs, lizards and berries and fruit. Although cuckoo specimens are rare in the 6.3 mm assemblage described here, I have identified a number of cuckoo specimens in the 3.1 mm sample.

Goatsuckers

At least two members of this oddly named family occur in the Homestead Cave assemblage: the Common Nighthawk (*Chordeiles minor*) and the Common Poorwill (*Phalaenoptilus nuttallii*). These birds have cryptic plumages, nest on the ground, and perch lengthwise on limbs of trees, often in colonies. They feed on moths and other insects caught in flight. Although they may forage widely all day, they are most active during the evening hours, especially around water sources where insects are most abundant.

Woodpeckers

At least four, and possibly more, members of the family Picidae occur in the Homestead Cave avifauna. The Picidae are typically solitary and typically arboreal, perching vertically on tree trunks to feed on insects, fruits and nuts, and the sap of trees. Most nest in cavities excavated in trees (Van Tyne and Berger, 1959, p. 484). Northern Flickers (*Colaptes auratus*), however, are exceptional in being more terrestrial than other members of the family. They are inhabitants of open country or open woodlands, particularly deciduous woods. They eat more ants than any other North American bird, a diet they supplement with other insects and berries. It has been estimated that up to 40% of their diets can be berries when available (Bent, 1939, p. 277). Northern Flickers occur in almost all strata in Homestead Cave.

Lewis' Woodpecker (*Melanerpes lewis*) is also somewhat unusual for a woodpecker. It has been described as greatly resembling a crow in appearance and flight. Lewis's Woodpeckers also prefer more open country and scattered large trees, rather than dense forests. They are more frequently found in juniper than pines, and they like deciduous trees along streams in the lowlands and occasionally even solitary cottonwoods or willows near small springs in sage flats. Unlike other members of the Picidae, with the exception of the flickers, Lewis' Woodpeckers rarely sit vertically but perch across branches or even on wires. Their diet consists of acorns, various insects (particularly grasshoppers), and fruit and berries (Bent, 1939, pp. 230-233). Lewis' Woodpeckers are rare in the 6.3 mm sample, but have also been recognized in the 3.1 mm sample.

The genus Picoides includes both the Hairy and Downy Woodpeckers and is nominally represented in the 6.3 mm sample. These woodpeckers are more typical of the family in perching vertically and being obligate tree dwellers. The species most likely represented by the specimens identified to date is the Hairy Woodpecker (*P.* cf. *villosus*), an inhabitant of dry deciduous woods. Their diet consists of beetle larvae, ants, caterpillars and small berries and seeds.

Three species of sapsuckers (*Sphyrapicus*) form a complex that has been the subject of a significant taxonomic debate. It appears that when members of distinctively marked populations that are now recognized as members of separate species share a breeding range there is some interbreeding (Kaufman, 1990). However, because interbreeding is limited and not random, they are currently recognized as three legitimate species. Given that the birds themselves do not necessarily distinguish among each other, it is not surprising that I cannot readily distinguish them from their osteological remains. Homestead Knoll lies well outside the current range of all but the Red-naped Sapsucker (*S. nuchalis*), while the Red-breasted Sapsucker (*S. ruber*) inhabits the Pacific coastal region and the Yellow-bellied Sapsucker (*S. varius*) nests farther north and east. The Homestead Cave sapsucker elements compare well with *S. nuchalis* reference material. The species represented throughout the column is most likely *S. nuchalis*, but changes in range and recent speciation cannot be ruled out. Sapsuckers eat sap and cambium of a large number of tree species (both evergreen and deciduous), small beetles, spiders, grasshoppers, ants and larvae found under the loose bark of trees, and berries. They prefer aspen, cottonwood and willow and will inhabit thickets along the banks of small streams in sage-dominated areas some distance from large trees (Bent, 1939). In the 6.3 mm sample, sapsuckers occur with regularity in the early Holocene strata and at least sporadically in the late Holocene strata.

While the woodpecker record is not well defined in the materials analyzed to date, it is apparent that there are more woodpecker specimens in the 3.1 mm sample. The 6.3 mm screen was adequate to recover a reasonable record for the Northern Flickers, but skeletal elements of the more environmentally sensitive arboreal woodpeckers are sufficiently small enough to pass through to the smaller screen.

Perching Birds

The largest order of birds is the Passeriformes, birds with feet adapted to perching on branches and similar objects (Ryser, 1985, p. 335). To date I have identified specimens referrable to at least 10 families of Passeriformes (table XXV), but a number of those identifications are tentative due to lack of time or comparative material. Further, not all strata have been scrutinized with equal care for all taxa of passerines. Adding these caveats to the problem of many elements of the smaller species passing through the 6.3 mm screens makes the analysis of the passerines tentative at present. Consequently, I am restricting the present discussion to two taxa for which I believe the identifications are most secure and comparable across strata. I do note, however, that even at the ordinal level, the changing abundance of passerines relative to nonpasserines through the Homestead Cave sequence is informative. I will return to this issue shortly.

Table XXV
Passerines identified in the 6.3 mm screen sample from Homestead Cave

Tyrannidae	Tyrant Flycatchers
Tyrannus verticalis	Western Kingbird
Alaudidae	Larks
Eremophila alpestris	Horned Larks
Hirundinidae	Swallows
cf. *Stelgidopteryx serripennis*	Northern Rough-winged Swallow
Cyanocetta stelleri	Steller's Jay
Aphelocoma coerulescens	Scrub Ja
Pica pica	Black-billed Magpie
Troglodytidae	Wrens
Muscicapidae	Muscicapids
Myadestes townsendi	Townsend's Solitaire
Turdus migratorius	American Robin
Mimidae	Mockingbirds, Thrashers and Allies
Oreoscoptes montanus	Sage Thrasher
Bombycillidae	Waxwings
Bombycilla garrulus	Bohemian Waxwing
B. cf. *cedrorum*	Cedar Waxwing
Laniidae	Shrikes
Lanius ludoviciana	Loggerhead Shrike
Emberizidae	Emberizids
Piranga ludoviciana	Western Tanager
Pheuticus cf. *melanocephalus*	Grosbeak, Black-headed
Pipilo cf. *chlorurus*	Towhee, Green-tailed
Pipilo cf. *erythrophthalmus*	Towhee, Rufous-sided
Agelaius phoeniceus	Red-winged Blackbird
Sturnella neglecta	Western Meadowlark
Xanthocephalus xanthocephalus	Yellow-headed Blackbird
Fringillidae	Finches and Allies
Carpodacus mexicanus	House Finch
Carduelis tristis	American Goldfinch
Coccothraustes vespertinus	Evening Grosbeak

Having just noted that the passerines are adapted to perching on branches, the first species of passerine in the Homestead Cave avifauna that deserves special notice is the Horned Lark (*Eremophila alpestris*). Larks are highly gregarious inhabitants of open grass and shrub habitats with sparse vegetation. They spend much of their time on the ground foraging for seeds, or in low vegetation. Horned Larks are the only species of lark that occurs in North America, but they are widespread and abundant in dry, open areas.

The other abundant and easily recognized genus of passerine in the Homestead Cave assemblage is *Bombycilla*, which includes two species of waxwings: Bohemian Waxwings (*B. garrulus*) and Cedar Waxwings (*B. cedorum*). Waxwings are extremely gregarious and nomadic, traveling in flocks that may contain both species. They may even form mixed flocks with other less closely related species such as the American Robin (*Turdus migratorius*). The critical variable seems to be gluttony, focused on berries, fruit and insects.

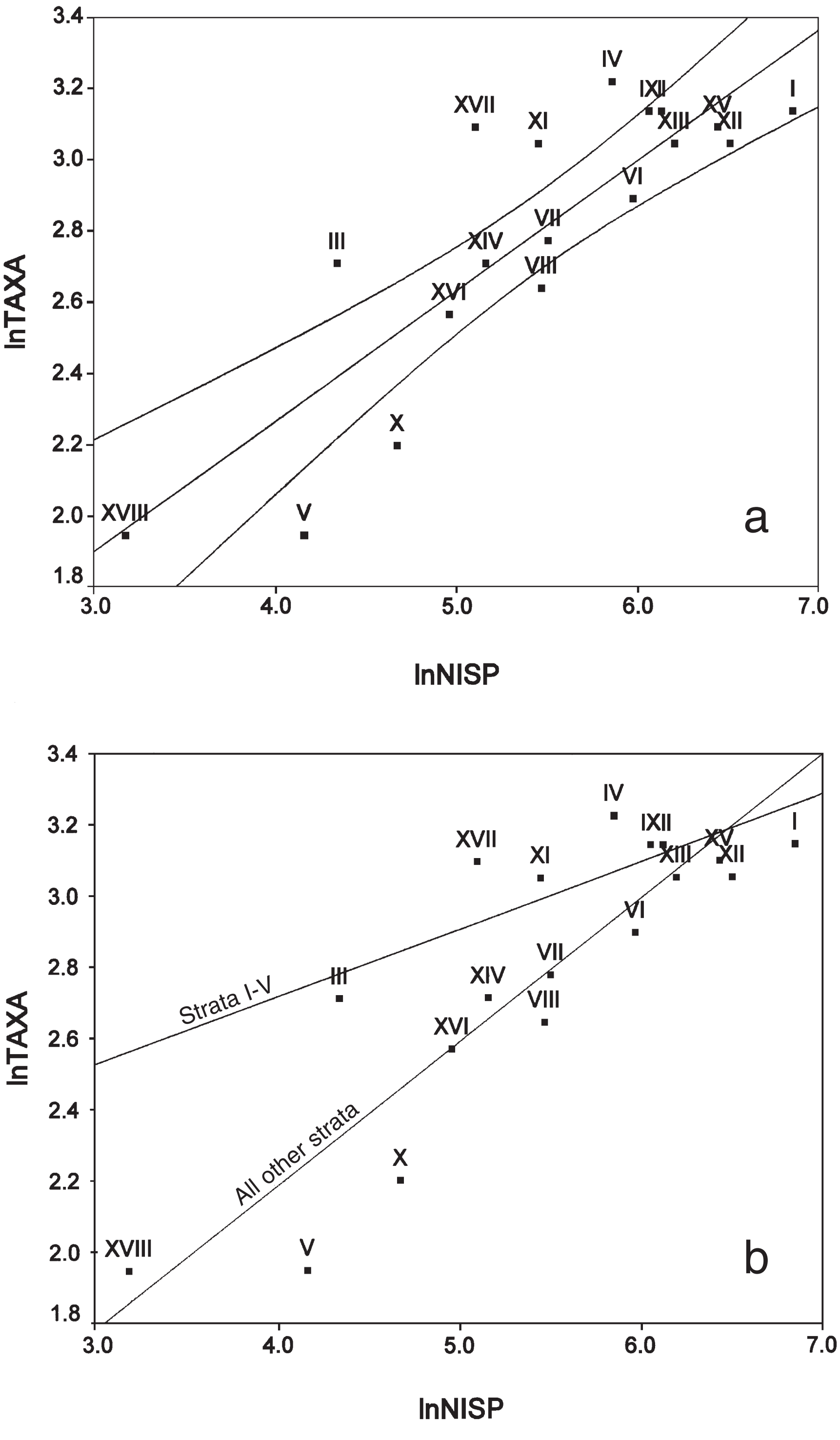

Figure 69. Relationship of the log number of avian taxa to the log sample size of avian assemblages for strata in the Homestead Cave column. Curved lines in (a) denote 95% confidence interval.

TAXONOMIC RICHNESS

Taxonomic richness, the number of different kinds of birds in an assemblage, is determined by many factors. The most obvious of those factors are the number of kinds of birds that were living in the collecting radius of the site, the feeding preferences of the agents of accumulation, and the size of the assemblage. The goal of assessing assemblage richness is to estimate the first of these: what birds were living in the vicinity of the site as a means of estimating the productivity and habitat complexity of the area at different points in time. To arrive at the most reasonable estimate of that diversity it is useful to first determine how much of the measured richness, or lack thereof, is attributable to other causes.

The effects of sample size are the most easily addressed. Regression of the log number of avian taxa on the log number of identified specimens yields a positive and significant correlation ($r^2 = 0.72$, $P<0.001$), illustrating the tight positive effect of sample size on the number of kinds of birds identified: the larger the sample, the more kinds of birds are included (figure 69a). The fit of the line describing the relationship can be improved slightly by eliminating the earliest strata from consideration as suggested by Grayson (1998). In chapter seven it was observed that the numbers of kinds of small mammals identified in the Homestead Cave assemblages are greater in the assemblages that accumulated prior to 8.3 ka (Strata I-III) than after. Further, the relationship between the number of taxa and sample size in the mammal-richer assemblages from Strata I-III is different than that in the later assemblages. If Strata I-III are eliminated from the avian analysis, the correlation between the number of taxa and sample size increases slightly ($r^2 = 0.76$, $P<0.001$). The increased correlation is due, in large part, to elimination of the outlier effect of Stratum III. Stratum III is a very small sample (N= 77), but it is relatively rich in avian taxa.

However, while Strata II and III both lie above the regression line, they have more taxa than predicted by regression, whereas Stratum I does not. Further, Strata I and II fall easily within the 95% confidence interval for number of taxa predicted by regression from sample size, but Stratum IV does not. Like Stratum III, Stratum IV lies well above the 95% confidence interval and I cannot justify removing I-III without removing IV as well. If Stratum IV is also removed, the correlation is slightly greater ($r^2 = 0.77$, $P<0.001$). Regression analysis further indicates that, as with the mammals, the relationship between log number of taxa and log NISP for the lower strata is different from the relationship described above (figure 69b), and the correlation between these two variables is insignificant for the lower strata ($P> 0.10$), regardless of whether Stratum IV is included with the lower strata or the upper strata. The lack of significant correlation may be due to the small number of cases considered or a difference in underlying variables that affect taxonomic representation under different environmental conditions. It appears that, for the avian fauna, the numbers of taxa in the assemblages from Strata I-IV are determined by different factors than those that determine the number of taxa in overlying assemblages.

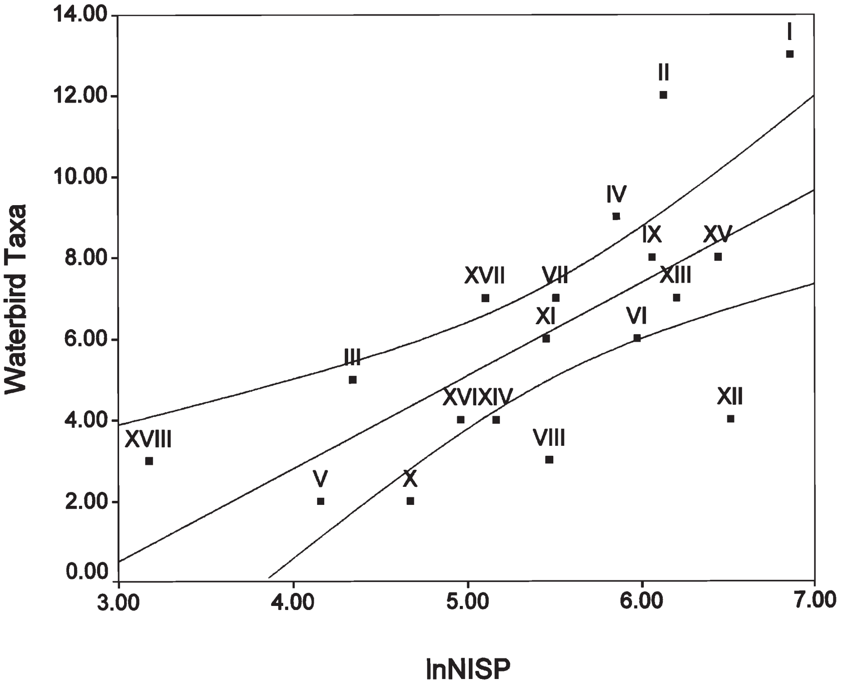

Figure 70. Relationship of the log number of waterbird taxa to the log sample size of avian assemblages for strata in the Homestead Cave column. Curved lines denote 95% confidence interval.

The residuals of the avian sample size-richness regressions provide greater insight into the differences between the assemblages from the various strata. Unlike the mammal assemblages, not all of the earliest assemblages are the most taxonomically rich, allowing for the effects of sample size. The earliest assemblage, Stratum I, includes the largest number of identified avian specimens to date but is not the richest of the strata in the regression. This difference is straightforward; with the exception of *Ondatra*, the mammals from Homestead Cave are terrestrial while the avian assemblage includes a variety of both terrestrial and water-dwelling taxa.

Regression of number of waterbird taxa on sample size reveals a significant correlation between the number of waterbird taxa and NISP across all strata in Homestead Cave ($r^2 = 0.49$, $P<0.001$, figure 70). At the time Stratum I was accumulating, Lake Bonneville was at the highest level it would stand during the accumulation of any of the avian assemblages considered here. The proximity of wetland environments to Homestead Cave during the accumulation of Strata I through IV is illustrated by the significant preponderance of waterbirds (all members of the families Podicipedidae, Anatidae, Rallidae, Recurvirostridae, Scolopacidae and Laridae) in the avian assemblage. Strata I, II, and IV assemblages include significantly more waterbird taxa than are predicted by regression on sample size.

A marked change in richness begins in Stratum V. Although the small size (N=64) of the Stratum V avian assemblage precludes identifying the nature of the change from that assemblage, the trend for assemblages to have below-predicted richness runs from Stratum V through Stratum X. Strata V, VIII and X are all below the 95% interval for species richness predicted by regression for the strata in Homestead Cave.

The abundance of waterbirds drops below the overall assemblage abundance of 36.7% waterbirds between strata IV and V. The only stratum above Stratum IV in which the relative abundance of waterbirds is over 37% is Stratum VI (% waterbirds = 55.0), where a large number of grebe specimens was identified. The decrease in waterbird taxa is most likely reflecting a shift in the environments available for raptor foraging, from lacustrine and shoreline dominated, to include more diverse terrestrial habitats.

ACCUMULATION BIAS IN THE HOMESTEAD CAVE AVIFAUNA

Accumulation bias does affect taxonomic richness in some assemblages. Homestead Cave is a clear case, at least in the early assemblages in which the wetland taxa identified beg the question of why other, larger taxa are missing. As noted above, the Homestead Cave avifauna was accumulated by raptors, both nocturnal and diurnal, that used the cave as a roost throughout the Holocene. Evidence of deposition as cast pellets remains on many specimens in the form of fur and feathers adhering to them and packed into every crevice and opening. Further, many others have puncture marks that undoubtedly were made by talons. Woodrats (*Neotoma* sp.) may have collected additional specimens from birds that died nearby and deposited them in the cave. There is even the possibility that coyotes or other mammalian carnivores carried an occasional bird into the cave or dropped it outside to be carried in by woodrats. However, non-raptor contributions appear to have been minimal in the case of the avian specimens. I have not observed gnaw marks on any bird bone specimens.

Raptor Prey

The influence of accumulation mechanism on the avifaunal assemblage is apparent in the upper size limit of birds that appear in the assemblage. Notably missing from this assemblage are loons, pelicans, swans, cranes and herons. These missing birds are all larger than the raptors, both diurnal and nocturnal, that appear to have been responsible for accumulating the bone assemblage.

Geese, cormorants, mergansers, gulls and corvids also are notably rare and sporadic in appearance in the Homestead Cave avifauna. The diets of cormorants and mergansers are almost exclusively fish, which disappeared from the Homestead Knoll area early in the record (see Broughton, chapter nine). It is possible, however, that these birds are rare in the Homestead Cave assemblage because they are large. The rarity of cormorants and absence of pelicans in Stratum I, when fish were abundant around Homestead Knoll, may be due to a common characteristic of the taxa that is also common to many of the large birds that are not represented: they are larger than the raptors that accumulated the Homestead Cave assemblage. If the local avifauna were being randomly sampled at any point in time, the large-bodied birds still might not be found due to sampling vagaries associated with rare taxa. But if they were they would most likely occur in the lowest strata because most large-bodied birds in desert environments live in wetland habitats. Consequently, the size-sorting effect of raptor accumulation bias is most likely dampening the patterns described above.

Gulls do occur in the deepest strata (I, II, III, and IV), but they are not particularly abundant. They are surprisingly rare or absent above Stratum IV. Like the ducks, they are completely absent in Strata X and XI. Gulls are generally not of a size that would preclude capture by raptors and their propensity for nesting on open ground should make them easy targets. However, gulls are known to be difficult prey. They are colonial and have been reported to "investigate" predators, clearly learning alarm and escape behavior (Kruuk, 1976). Thus, while an occasional gull may fall victim to predation, exploiting a colony is not a ready resource for predators such as large flocks of other birds might be. Like the gulls, the kites, shrikes and corvids may be rare or absent in the Homestead Cave avifauna more because they represented troublesome fare for raptorial midden accumulators than because they were rare or absent in the environment.

Which Raptors?

Because the faunal assemblage is largely the remains of detritus that accumulates under raptor roosts, it is reasonable to ask if some of the shifts in other taxa could be a reflection of change in raptors roosting in the cave. For instance, there is a pronounced shift in the abundance of passerines relative to all other taxa from the bottom of the sequence upwards (figure 71), with the exception of the very small sample from Stratum III. In Strata I through IV and below, less than 40% of the identified specimens are passerines. From Stratum V upward through the sequence, 40% or more are passerines. There is a slight increase in the relative abundance of diurnal raptors in Stratum VIII and Stratum XV (figure 72), but there is no clear correlation between the occurrence of any particular raptor and the occurrence or shift in abundance of other taxa at this time. This, however, is an issue that should be investigated further.

Another aspect of the raptors, made even more interesting by the small sample size, is the variety of raptorial birds represented. I have recognized three accipiters (Northern Harrier, Sharp-shinned Hawk and Red-tailed Hawk), two falcons (Kestrel and Prairie Falcon) and seven owls (Barn, Flammulated, Great Horned, Burrowing, Long-eared and Short-eared and Saw-whet). As I briefly outlined above, this combination of diurnal and nocturnal raptors includes species that prey in most, if not all, of the environments that would be expected to have occurred in the foraging radius of Homestead Cave throughout the time represented in the column.

Cade (1982), like others before him, has suggested that the huge, reversed sexual dimorphism in the bird-hunting raptors may be explained by the need to partition food resources. Larger females can take larger prey than their smaller mates, thus effectively increasing the size range of

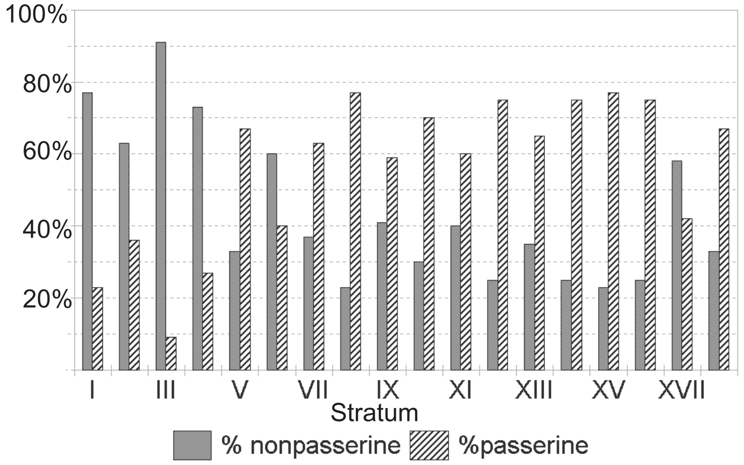

Figure 71. *Relative abundance of passerine and nonpasserine birds in the Homestead Cave column.*

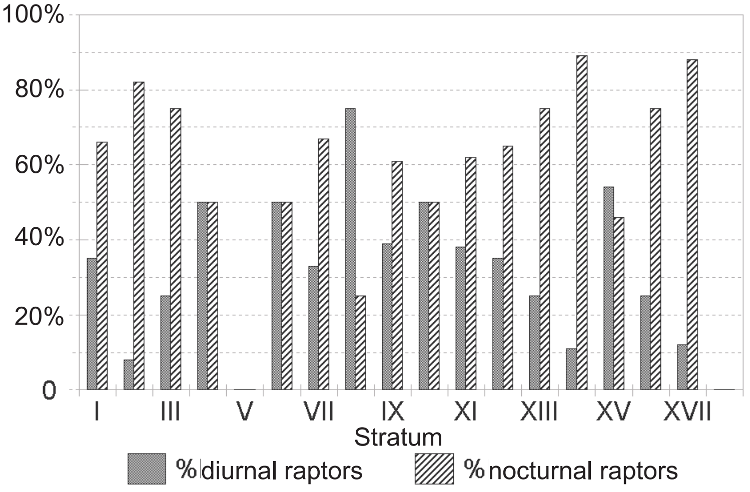

Figure 72. *Relative abundance of diurnal and nocturnal raptors in the Homestead Cave column.*

prey species. If this is true, sexual dimorphism may effectively double the effects of high predator species richness in contributing to the high prey species diversity in the Homestead Cave avifauna (but see Boal and Mannan, 1996 for a contrasting view).

ENVIRONMENTAL INDICATORS

Birds are often dismissed as sensitive indicators of past environments for some rather important reasons. First, and probably the most influential, is that they are usually rare in archaeological and paleontological deposits. Their aerial, arboreal, and/or aquatic lifestyles tend to make them less than prime candidates for preservation in archaeological and paleontological deposits except under exceptional circumstances. Likewise, their generally fragile skeletal structures do not lend themselves well to preservation. Consequently, unless preservation circumstances are unusual, bird assemblages from which environmental inferences can be made are not common.

A second factor leading to dismissal of birds as environmental proxy data is that they are difficult and time consuming to analyze. There are generally many different kinds of birds living in any environment, even in the Nearctic which is characterized as having avifaunas that are poor in variety compared with other areas of the world (Welty, 1982). The great diversity of birds means that it is essential to have large reference collections, laboratory space and time for analysis. The situation is further confounded by the propensity for avian taxa to exhibit a great deal of variability within species, frequently including extreme sexual dimorphism and age-related size differences and extensive overlap in osteological characters between closely related taxa.

And finally, the fact that birds fly and migrate long distances makes their occurrence somewhat difficult to interpret. That is, are they in a particular deposit because they were living in the area or because they died passing through dangerous and inhospitable territory? The flight issue is the most difficult of the three issues to address. The first problem is simply a matter of whether bird bones are present or not. The second can be addressed through additional effort in conducting the study (recovering more specimens or accessing more comparative material). But the flight issue is often an interpretive conundrum. If fortune allows the recovery of a bird assemblage and enough effort is expended to sort and identify the specimens, how does one interpret birds that might be present simply because they were strays or stragglers unfortunate enough to get caught in inhospitable territory?

Homestead Cave provided that unusual environmental circumstance in which the rare, bird-rich bone assemblage has been preserved. Although it has some accumulation biases as discussed above, the large and diverse assemblage provides an unusual, if not unique, opportunity to obtain data from an aspect of the environmental past that is generally invisible. All possible efforts are being made to deal with the problems of identification, including borrowing and preparing reference materials. At this time, however, caution must be used in drawing inferences because a number of identifications are not complete and a number need to be rechecked against a larger array of specimens. The sticky third problem may also be less an issue in this assemblage because of its size and diversity. In this analysis no single specimen or taxon must bear the weight of a critical inference. Instead, multiple specimens or taxa can be used to support inferences. While unfortunate strays and stragglers undoubtedly occur in this assemblage, inferences here are based on taxa represented by numerous specimens, regularly occurring taxa, and multiple species that provide similar indications, on the assumption that, by definition a stray or a straggler is an uncommon occurrence. If the birds are abundant and/or occur with some regularity, they probably were in the area for a reason.

Most Abundant Taxon

The three most common families of birds represented in the Homestead Cave avifaunal assemblage are Podicipedidae (grebes), Anatidae (ducks) and Alaudidae (larks) (figure 73). Grebes account for over 30% of the total assemblage and between 8 to 57% of the assemblages from individual strata. They are noticeably present in all strata, accounting for approximately 20% of the identified elements in all but Stratum XVI and Stratum XVII, where their frequency drops to less than 12%. They reach a peak of abundance in Stratum VI.

Although ducks account for only 15% of the total assemblage, they are the most abundant family of birds in Stratum I, making up almost 50% of the identified assemblage. Their frequency drops to between 17 and 21% in Strata II - IV, then to less than 10% in Stratum V. They remain rare or absent in overlying strata.

Horned Larks make up approximately 20% of the total assemblage. They are, however, relatively rare in Strata I through IV, making up less than 10% of the identified specimens. In Strata V and VI Horned Larks account for between 10 and 15% of the identified assemblages. From Stratum VII upward through the column, Horned Larks account for at least 20% of the identified assemblages, reaching peaks of over 40% in Strata X, XII - XIV, and XVI.

Habitats amenable to all three families apparently occurred in the vicinity of Homestead Cave throughout the sequence, with the possible exception of Strata X and XII when lake levels may have been too low to appeal to water-

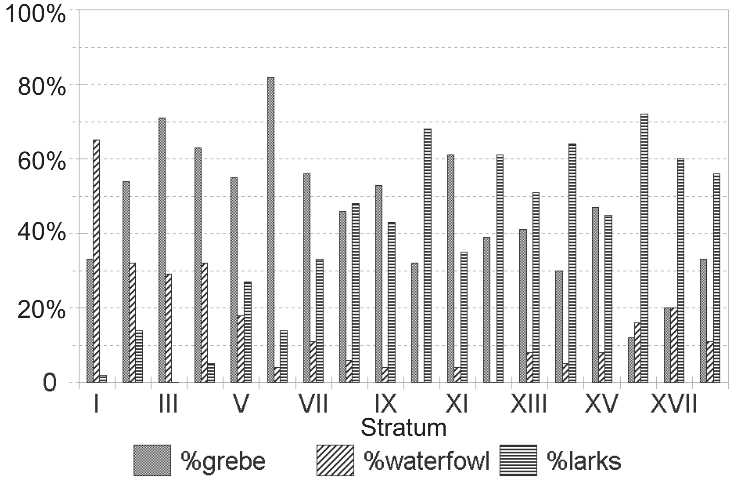

Figure 73. *Relative abundance of grebes, waterfowl and Horned Larks in the Homestead Cave column.*

fowl. The relative abundance of the three families suggest there was a radical drop in open water between Strata I and II, followed by a less radical but continuous loss of duck habitat through the lowest six strata. Duck habitat was apparently rare during the time the middle strata were being deposited. The slight, but noticeable, increase in ducks in the upper strata may indicate more lake-marsh habitat during the later Holocene.

The relative paucity of Horned Larks in the deepest four strata also suggest that dry, open grass-shrub habitats were less abundant around Homestead Knoll during the time the deepest strata were deposited than they were later in the sequence. Horned Larks are relatively abundant by Stratum V and continue to represent a significant proportion of the identified bird assemblage throughout the rest of the sequence.

Waterfowl

Ducks are commonly divided into two categories on the basis of feeding adaptation: the dabbling, or shallow water, species (all members of the genus *Anas*) and diving ducks (members of the genera *Aythya*, *Bucephala*, *Mergus* and *Oxyura*). The relative abundance of members of these two categories through time in the Homestead Cave deposits may provide a significant indicator of relative levels of Lake Bonneville as it receded from the area of Homestead Knoll.

Of the 321 duck specimens identified to at least genus, and consequently assignable to feeding adaptation category, slightly more than half (54%) are from shallow-water species. However, distribution across strata varies considerably (figure 74). The majority of the waterfowl are from Strata I through IV, and most of the diving ducks in the entire assemblage are from Stratum I. By Stratum V diving ducks are extremely rare. No ducks of either category have yet been identified from Strata X, XI and XIII. Above Stratum XII almost all ducks identified are shallow-water species.

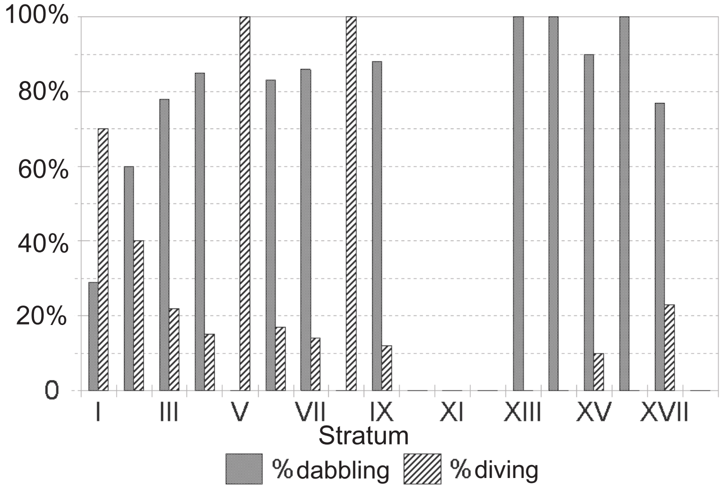

Figure 74. *Relative abundance of dabbling and diving ducks in the Homestead Cave column.*

Marshbirds and Shorebirds

Like the grebes, these taxa occur in at least small numbers throughout the Homestead Cave sequence. Their numbers are impossible to interpret at this time due to the fact that the only members of these groups that are large enough to be captured with regularity in the 6.3 mm screens are the large rails, and they do not occur in meaningful numbers. Analysis of the 3.1 mm sample will hopefully provide a large enough sample of the smaller taxa to provide an indication of the nature of nearby wetlands throughout the sequence.

The Terrestrial Taxa

Aside from the clear increase in abundance of Horned Larks between StrataVI and VII, there is an associated increase in other terrestrial species reflected in the overall increase in passerines (figure 71). That shift in abundance is not due entirely to the increase in Horned Larks, but is reflected in an increase in other species that inhabit open terrestrial habitats. The upland game birds and goatsuckers show remarkably similar histories (figure 75), except in Strata IV and IX where goatsuckers are considerably more abundant than upland game birds. Caution is recommended in interpreting these records due to the small sample sizes for these taxa.

There is also a marked relative increase in passerines other than Horned Larks beginning in Stratum VI (figure 76). Much of the increase in passerines other than Horned Larks reflects greater proportions of the arboreal taxa listed in table XXIV. Many of these species are birds of riparian habitats, especially lowland valley areas with thickets of deciduous trees such as willow, aspen and dense underbrush. However, some of these birds may have been brought in from the edges of juniper woodlands, and the possibility of occasional strays and stragglers caught off course in undesirable territory cannot be precluded.

Only small numbers of each species of passerine have been identified to date, unlike the case for waterfowl, grebes and Horned Larks. Yet, the probability that many of these birds represent unfortunate strays and stragglers is lessened by the similarities in their behavior, feeding strategies and dietary preferences, characteristics that are used to define guilds. The concept of a guild was proposed by Root (1967) as a means of defining competitors in trophic-level studies. Guilds are groups of species in a community that exploit the same set of resources in a similar manner, but the species are not necessarily closely related taxonomically. Members of guilds often differ in their precise food requirements, thus reducing the potential for competition among them when resources are limited. The taxonomic composition of a guild can change through the year as migrants are added or subtracted (Ehrlich and others, 1988, p. 493). In its strictest definition, it may be inappropriate to call a suite of taxa from a paleontological assemblage a guild due to the impossibility of assessing precisely the magnitude of dietary overlap for the various species (Jaksic, 1981; Jaksic and Medel, 1990). However, given that the frame of reference is the critical issue in defining a guild (Stiling, 1996, p. 334), the term is used here to identify a suite of taxa with similar dietary and habitat preferences.

The clearest suite of taxa in Homestead Cave that can be characterized as a guild includes a significant number of taxa that subsist on berries and fruits whenever they are available. The core of this group in the Homestead Cave avifauna is the waxwings. Although neither species of waxwing is current-

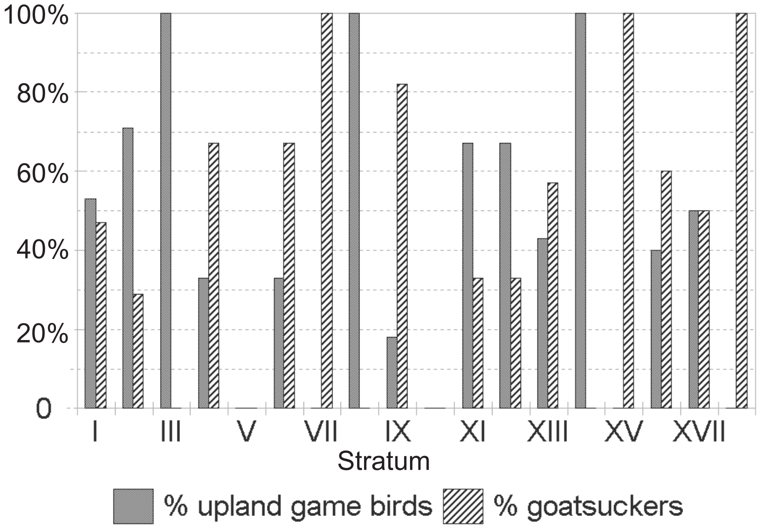

Figure 75. *Relative abundance of upland game birds and goatsuckers in the Homestead Cave column.*

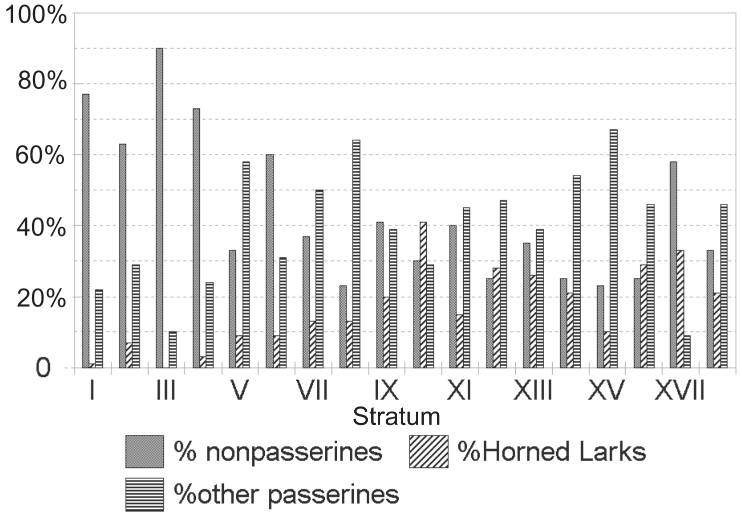

Figure 76. *Relative abundance of Horned Larks and other passerine and nonpasserine birds in the Homestead Cave column.*

Table XXVI
Potential members of the Homestead Cave berry guild

Picidae	Woodpeckers
Melanerpes lewis	Lewis' Woodpecker
Sphyripicus sp.	Sapsucker
Picoides sp.	Woodpecker
Colaptes auratus	Northern Flicker
Tyrannidae	Tyrant Flycatchers
Tyrannus verticalis	Western Kingbird
Muscicapidae	Muscicapids
Myadestes townsendi	Townsend's Solitaire
Turdus migratorius	American Robin
Mimidae	Mockingbirds, Thrashers and Allies
Oreoscoptes montanus	Sage Thrasher
Bombycillidae	Waxwings
Bombycilla garrulus	Bohemian Waxwing
B. cf. *cedrorum*	Cedar Waxwing
Emberizidae	Emberizids
Pipilo cf. *erythrophthalmus*	Towhee, Rufous-sided
Fringillidae	Finches and Allies
Carduelis tristis	American Goldfinch

ly abundant in the Great Basin on a regular basis, they appear in dramatic and apparently irregular migratory invasions known as irruptions. Irruptions usually occur when berries are available, but not necessarily on an annual basis (Ehrlich and others, 1988, p. 639). Migratory waxwing flocks feeding on locally abundant berry crops may be monospecific but are often mixes of both species of waxwings and may include other berry-feeding taxa such as American Robins (*Turdus migratorius*). Species found in the Homestead Cave avifauna with a marked taste for berries that could be considered as members of the Homestead Cave berry guild are listed in table XXVI.

A guild of berry-feasting birds very likely represented an abundant resource for raptors, at least seasonally when the hackberries were ripening near Homestead Knoll. Further, it is entirely possible that at least some of the numerous hackberry seeds in the Homestead Cave matrix were introduced as part of the cast pellets containing the bones of these birds.

CHANGES IN THE HOMESTEAD CAVE AVIFAUNA THROUGH TIME

A diverse suite of both diurnal and nocturnal raptors were clearly hunting in a mosaic of habitats and roosting in or near Homestead Cave throughout the time recorded in the avian assemblages recovered from the stratigraphic column. A synopsis of the changes noted between the 6.3 mm samples from each stratum, as detailed above, and environmental inferences drawn from those changes follows. The environmental inferences are made, however, recognizing that a number of specimens from the 6.3 mm sample remain to be identified and further recognizing that the 3.1 mm sample has only been analyzed to the point that it is clear that it contains many potentially environmentally sensitive taxa that could significantly change the inferences drawn here.

The Stratum I and II assemblages are dominated by waterbirds, having the greatest number of waterbird taxa and the greatest percentage of waterbird specimens of any strata, indicating the proximity of lacustrine habitats for raptorial foraging. The occurrence of a waterfowl-dominated assemblage in Stratum I reflects the most abundant open-water bird assemblage in the column, most likely accumulated from the receding waters of Lake Bonneville. After Stratum I, grebes remain abundant until sometime between Stratum IX and Stratum XI. The grebes suggest that water was not uncommon, though undoubtedly in smaller and more ephemeral bodies.

Beginning in Stratum II there is a decline in waterfowl relative to grebes and Horned Larks, suggestive of decreasing open-water habitats and an increasing diversity of habitats being sampled by the raptors. The decrease in deep-water taxa (diving ducks) may reflect recession of the lake away from Homestead Cave. Open-habitat terrestrial taxa such as Horned Larks increase, but upland game birds (grouse) and the berry guild (waxwings, woodpeckers, and others) indicate shrubby riparian woods are providing many of the birds deposited during Strata II - IV times.

In Strata V-VI there is a drop in avian taxonomic richness, reflecting the loss of diving ducks, shorebirds and other waterbirds. In Strata I - VI, there are more non-passerines than passerines. This relationship is reversed in Stratum VII and above, reflecting the loss of water-oriented taxa in favor of terrestrial birds, particularly the berry guild and Horned Larks, a trend that begins in Stratum V.

The berry guild, including the sapsuckers, continues to be well represented throughout the stratigraphic column. Although none of the berry-eating species require significant stands of trees, their continued presence indicates that at least patchy riparian woodlands, with deciduous species such as willow and/or cottonwood, continue to be important foraging habitats for raptors throughout all strata, with the possible exception of Strata X, XIV, XVII and XVIII, where sapsuckers have yet to be identified. Those strata that pose possible exceptions are all very small samples and may lack sapsuckers as a function of sample size.

In Strata VII - X, Horned Larks increase in abundance suggesting that dry, open habitats are the primary habitats available for foraging raptors. At least patches of ephemeral water are indicated by the continued presence of grebes and other waterbirds, as are patches of riparian woods. Waterbird taxonomic richness is very low in Strata VIII and X, supporting the inference that wetlands are uncommon during this period.

In Stratum XI there is a significant (greater than one standard error above the predicted value given the sample size) increase in taxonomic richness, suggesting an increased diversity of available habitats. This increase in number of taxa is due primarily to the increase in number of kinds of owls in the Stratum XI assemblage. From Stratum XI until the sequence ends, Horned Larks are the most abundant taxon, indicating much of the increase in habitat diversity may be changes in terrestrial habitats as opposed to recurrence of wetland habitats.

Strata XII-XIV are characterized by high Horned Lark abundance, and there are few waterbird taxa in Stratum XII. Waterfowl return in Stratum XIII and increase in relative abundance through the end of the sequence. However, unlike the relatively high abundance of waterfowl in the early strata, the waterfowl in the upper strata are almost all shallow-water ducks. The stable presence of Horned Larks and the berry guild indicate that foraging in open terrestrial and riparian woodlands continued during this interval, but ponds and streams may have been more abundant.

Stratum XV is characterized by an increase in grebes at the expense of Horned Larks, a trend reversed again in Stratum XVI along with an increase in waterfowl. Waterfowl and grebes then increase through the top two strata. The increase in waterbirds, particularly the waterfowl, suggests that wetland habitats (ponds and streams) were more common during the time the uppermost three strata were accumulating than during any period after the deposition of Stratum IV.

ACKNOWLEDGMENTS

I thank the project sponsors and participants for access to this important sequence of Holocene avian remains, their encouragement throughout, and discussion of the meaning of the Homestead Cave sequence. Some of my earliest efforts in analyzing this assemblage were supported by a grant from the Department of Energy for studying Great Basin Quaternary environments. The Burke Museum of Natural History and Culture, Seattle, Washington has been most generous in loaning me reference specimens without which identification of the birds would have been impossible. Bill Shaver and the Utah Fish and Game have been extremely cooperative in collecting reference specimens. I thank the project participants: Sievert Rowher, Carol Spaw, Chris Wood, and John Rozdilsky of the Burke Museum for assistance and helpful discussions of bird adaptations and habitats; and Annie and Grant Stitt for their help and support.

CHAPTER NINE

The Homestead Cave Ichthyofauna

by
Jack M. Broughton

INTRODUCTION

> Biological evidence on the climatic and hydrographic history of the intermountain region would be much richer, if we had more than the present dribble of paleontological data on the fishes (Hubbs and Miller, 1948, p. 25).

In this passage from their landmark synthesis of historical fish biogeography in the Great Basin, Hubbs and Miller lament the dearth of available fish fossil evidence and suggest that a far more detailed picture of past climates and hydrography would emerge were this situation to change. To Hubbs and Miller, the geographic distributions of fishes, both past and present, held the "least assailable" evidence of past hydrographic connections and climatic history of the Great Basin since "...fishes appear to occur only in habitats which they have been able to reach through surface water connections, by means of either active or passive migration. The dispersal of fishes is therefore closely linked with the history of water courses." The key assumption of this approach followed the earlier pioneering work of Jordan (1905) and was succinctly paraphrased by Smith, G. R. (in press): "fish are where they can swim and stop there."

In this approach, climatic inferences are derived primarily by documenting previous hydrographic connections from the geographic distributions of fishes and deducing the levels of ancient lake systems that would have allowed for such connections. A richer fossil fish record would enhance our understanding of historical fish biogeography and ultimately lead to a greater understanding of regional paleohydrography and climate change.

Inferences on the nature of past climates can be derived from fossil (or subfossil) fish assemblages in ways other than those based strictly on biogeography. Fluctuations in the size and depth of a lake can, of course, have dramatic effects on water chemistry and temperature and, in turn, profoundly influence the nature of its fish populations. In addition to controlling whether a lake can support fish at all, water temperature and salinity, for example, play critical roles in determining the species composition, growth characteristics, and the age and size structure of fish populations. As a result, high-resolution fossil fish sequences from Lake Bonneville could provide fine-scale details on lake-level oscillations to test and refine hypotheses based on other sources. And since there is perhaps a no more sensitive measure of regional climate than the size of closed-basin lakes, paleofish faunas can potentially provide one of the more direct proxies of climate change.

Utilizing this ichthyological source of information on past climates in the Bonneville basin has not, however, been possible due to what has continued to be an extremely sparse late Quaternary paleontological fish record in the region. While geological research of Lake Bonneville extends well back into the 19th century, knowledge of Lake Bonneville's fish fauna has been derived primarily from a single detailed analysis conducted by Smith and colleagues in the 1960s (Stokes and others, 1964; Smith and others, 1968). Smith's unique study of Quaternary fish biogeography in the Bonneville basin was based on the materials derived from two fossil fish localities in the northern Bonneville basin and provided our first glimpse of the fish fauna of Lake Bonneville. Smith identified eight species from these deposits and documented that the species composition of Lake Bonneville was very similar to that of the Recent fauna of Bear Lake, Utah-Idaho. This clearly confirmed the physiographic evidence that Bear Lake was tributary to Lake Bonneville during pluvial times. The analysis also revealed that the high degree of isolation and endemism among modern fishes of the Bonneville basin is recent in origin. The sites that produced the fish materials were, however, not well dated, nor were they internally stratified. Accordingly, no analysis of temporal variation in Lake Bonneville's fish fauna could be undertaken for any purpose.

The precisely dated ichthyofauna from Homestead Cave represents the largest, well-stratified, and richest Quaternary fish assemblage from the entire Bonneville basin and the only known terminal-Pleistocene fish fauna of the region. This fauna provides an unprecedented opportunity to examine the dynamics of Lake Bonneville's fish populations as it fluctuated toward the end of the Pleistocene and sheds light on both the nature and timing of fine-scale climatologically driven lake level oscillations and late Quaternary fish biogeography in the Bonneville basin. At last, we have far more than a dribble.

DEPOSITIONAL ORIGIN OF THE HOMESTEAD CAVE FISHES

The analyses of the Homestead fishes that follow depend in many ways on an understanding of their depositional origin. As previously emphasized (Grayson, chapter seven; Livingston, chapter eight), the mammals and birds from Homestead Cave were apparently accumulated by raptorial birds, especially owls. Owl pellet cones were observed on the floor of the cave when the excavation began, the deposits contain numerous owl pellets, and many of the bones themselves still have owl pellet material adhering to them. Although it is possible that the fish materials may have washed into the cave as the lake descended past its mouth during the post-Provo recession, the available evidence does not support this scenario. Instead, like the other vertebrates, the fish remains from Homestead Cave appear to have resulted from the use of the cave by owls.

A water-deposited origin for the Homestead fishes now appears unlikely for three reasons. First, evidence from the sediments of Stratum I (chapter three), where the fish remains are concentrated (see below), show no evidence of water-laid deposits. In fact, the cave appears to have been completely scoured out as the lake regressed past its mouth. Second, a diversity of small mammal and bird species dominates the vertebrate faunal assemblage in Stratum I of Homestead Cave; these materials are unlikely to have been deposited by water. Finally, the high strontium ratios (0.7125-0.7129) of the Homestead fishes indicate they originated from a low-elevation lake, and postdate the late Pleistocene lake-splitting event (see Quade, chapters two and five). The water-deposited hypothesis, on the other hand, calls for a higher elevation lake - one of roughly the elevation of the mouth of the cave - and fish strontium ratios low enough to indicate they occupied Lake Bonneville before the time of the lake-splitting event.

The analysis of the Homestead avifauna has documented the presence of nine raptor taxa in the lower strata (I-III) of the deposit (chapter eight; table XXIV). Of these taxa, only two routinely roost and nest in open caves: *Bubo virginianus*, Great Horned Owl and *Tyto alba*, Barn Owl, (figures 77, 78). Although the diet of these owls is comprised predominantly of small mammals, both species have been reported to utilize fish.

Reports of barn owls taking fish are extremely rare. The only reference of which I am aware was provided by Gallup (1949, p. 150). In Escondido, California, Gallup (1949, p. 150) noted that: "Barn owls are common birds in the region. I have seen as many as 30 on the beach at night feeding on grunion when these were running."

Accounts of Great Horned Owls taking fish are far more common. Although fish remains have been reported in small quantities from the pellets of Great Horned Owls in a variety of settings in western North America (Marti, 1974; Knight and Jackman, 1984; Marti and Kochert, 1996; Bogiatto, in prep.), the most detailed accounts come from eastern North America. For instance, in an analysis of 33 Great Horned Owl pellets collected in Wisconsin, Errington and others (1940, p. 806) indicate that fish were represented by at least 13 individuals comprising four different species. Similarly, a total of nine individual fish, also representing four species, were identified from a set of 21 Great Horned Owl pellets collected in Iowa (Errington and others, 1940, p. 850). Errington and others (1940, p. 806) indicate they "know little of the horned owl's technique in capturing fishes but have some reason to think that in winter it gets them mainly from concentrations about open springs or holes in the ice at the edge of lakes...It may be that the owls scavenge upon fishes stranded, washed ashore or left by other animals." Errington and others (1940) do not indicate what the reasons were for thinking this, but it is well known that Great Horned Owls are eager scavengers.

From an analysis of Great Horned Owl pellets from the Caney Creek roost in middle Tennessee, Klippel (personal communication 1998) indicates that fish remains comprise over 44% of the total vertebrate MNI (minimum number of individuals). The sample contains 33 individual fish, representing three families (Cyprinidae, Catostomidae and Centrarchidae) and 11 different species. Suckers, including *Hypentelium nigricans*, northern hog sucker, *Moxostoma duquesnei*, black redhorse, *Moxostoma* spp., redhorse, and unidentified catostomids, represent over 66% of the fish MNI. Klippel observed suckers spawning in the shallow water of Caney Creek near the roost that provided the pellets. While engaged in their spawning activities, adult fish became partially dewatered and would have made easy quarry for the owl (Klippel, personal communication 1998).

Figure 77. *Great Horned Owl (*Bubo virginianus*).*

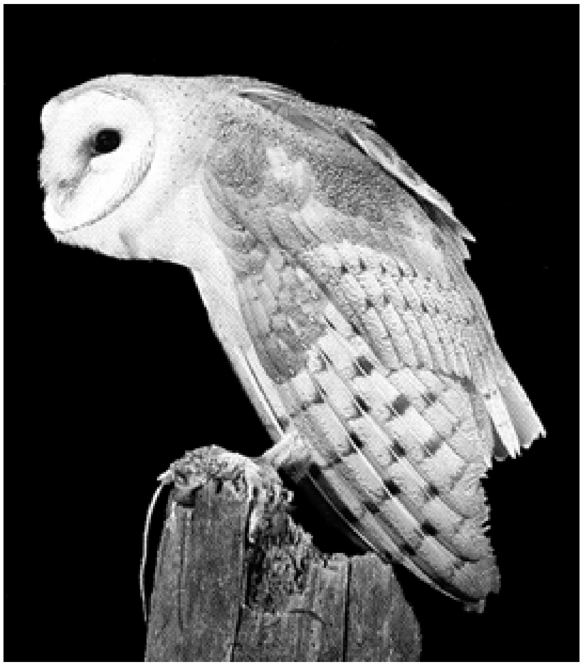

Figure 78. *Barn Owl (*Tyto alba*).*

Figures 77 and 78 are from Udvardy, M.D.F. (1977). Audubon Society Field Guide to North American Birds - Western region. New York, Knopf, distributed by Random House. All the fish figures are from Sigler and Sigler 1996, with one exception, figure 80, the picture of the bull trout. That figure is from Sternberg, D. (1987), Freshwater Gamefish of North America, Cy DeCosse, Incorporated, Minnetonka, Minnesota 553345. ISBN 0-86573-023-7. Distributed by Prentice Hall Press, a division of Simon and Schuster, Inc., NY, NY. ISBN 0-13-331125-2.

These limited data suggest that owls exploit fish resources only when the costs of taking them are substantially reduced, such as when fish are stranded (dead or alive) on shorelines or partially exposed in shallow streams (Gallup, 1949; Errington and others, 1940; Klippel, personal communication 1998). I am unaware of any accounts of these owls taking live fish from deep open water.

In addition, many of the fish specimens recovered from Homestead Cave represent very large individuals (>2.6 kg estimated live weight), which suggests they could not have been taken and carried out of deep water by owls but instead reflect fish parts that were scavenged by these birds. For example, many of the salmonine vertebrae (most probably represent *Oncorhynchus clarki*) exceed 9.0 mm in maximum width, suggesting live weights over 2.6 kg; some exceed 11.0 mm, suggesting weights over 6.2 kg (see Follett, 1980: 115, 1982: figure 3). The large size also eliminates the possibility that these fish entered the cave in the stomachs of fish-eating birds (for example, *Phalacrocorax auritus, Aechmophorus occidentalis*) who had fallen prey to owls.

The maximum distance from roost to foraging areas reported for the Barn Owl is 5.6 km (Marti, 1992); that distance for the Great Horned Owl is 4.35 km (Smith, 1971). Thus, aquatic habitats that supported, but at least periodically lost, fish populations must have existed within a radius of ~6 km or less from Homestead Cave during the periods of their deposition.

In sum, the fishes from Homestead Cave appear to have been accumulated by scavenging owls. An owl-based origin of the Homestead fishes suggests that local fish populations experienced substantial mortality (that is, die-offs) and/or were frequently exposed in very shallow water over the time the fauna accumulated. Strata in which the remains of Lake Bonneville fishes are abundant should thus signal recessional periods of the lake's history. By dating those strata, inferences on the chronology of lake-level fluctuations and climate change can be derived.

TAXONOMIC SUMMARY

The fish materials from Homestead Cave are heavily concentrated in the lowest stratum of the deposit, Stratum I. As I discuss in detail below, the extremely low representation of fish materials in the deposits above Stratum I appears to reflect the extinction of Lake Bonneville's fish fauna. All of the fish materials from the 6.3 mm and 3.1 mm sample fractions of Homestead Cave have been identified and are reported here.

Table XXVII provides a systematic list of the identified fish species in the Homestead Cave deposits; nomenclature follows Robins and others (1991). The total numbers of identified specimens per taxon by stratum are provided in table XXVIII. Table XXIX provides the numbers of identified specimens by provenience unit for Stratum I. The numbers of identified fish specimens by element and taxon for the Homestead Cave deposits are archived in electronic form at the Utah Geological Survey (see Broughton, 2000).

A total of 14,866 fish specimens have been identified from the Homestead Cave deposits (table XXVIII). The as-

Table XXVII
Sytematic list of the fishes identified at Homestead Cave

Osteichthyes	
Salmoniformes	Pikes, Smelts, Trouts and Allies
Salmonidae	Trouts, Chars, Whitefishes and Allies
Salmoninae	Trouts and Chars
cf. *Salvelinus confluentus*	Bull Trout
Oncorhynchus clarki	Cutthroat Trout
Coregoninae	Whitefishes
Prosopium spilonotus	Bonneville Whitefish
Prosopium abyssicola	Bear Lake Whitefish
Prosopium spilonotus/abyssicola	Bonneville or Bear Lake Whitefish
Prosopium gemmifer	Bonneville Cisco
Cypriniformes	Minnows and Suckers
Cyprinidae	Minnows
Gila atraria	Utah Chub
Richardsonius balteatus	Redside Shiner
Catostomidae	Suckers
Catostomus ardens	Utah Sucker
Catostomus discobolus	Bluehead Sucker
Scorpaeniformes	Scorpionfishes, Sculpins and Allies
Cottidae	Sculpins
Cottus bairdi	Mottled Sculpin
Cottus extensus	Bear Lake Sculpin
Cottus extensus/echinatus	Bear Lake or Utah Lake Sculpin

Table XXVIII

Numbers of identified fish specimens per taxon by stratum at Homestead Cave

TAXON	STRATUM																					
	I	Ia	Ib	I-II	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII	XVIII	Total
Salmoninae	701	258	23	-	21	2	6	1	2	1	-	1	-	-	2	1	1	-	1	-	1	1022
cf. *Salvelinus confluentus*	1	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Oncorhynchus cf. *clarki*	40	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	60
Oncorhynchus clarki	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
Prosopium sp.	945	5944	449	-	111	19	32	-	10	6	3	5	2	2	-	1	4	-	-	2	1	7536
Prosopium cf. *spilonotus*	79	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	84
Prosopium spilonotus	27	10	3	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	41
P. spilonotus/abyssicola	93	87	2	-	14	-	1	-	-	-	-	-	-	-	1	-	-	-	-	-	-	198
Prosopium abyssicola	2	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8
Prosopium gemmifer	225	499	37	-	15	1	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	778
Cypriniformes	1167	471	58	-	44	10	28	4	19	10	8	22	13	45	224	48	23	1	7	38	5	2245
Cyprinidae	34	35	3	-	3	3	5	-	1	1	-	1	-	2	14	4	2	-	-	12	-	120
Gila atraria	443	191	26	-	12	7	17	1	13	10	3	14	6	13	59	40	17	2	20	63	1	958
Richardsonius balteatus	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Catostomus sp.	900	299	24	-	19	4	20	2	7	6	7	5	2	3	25	6	9	2	1	2	-	1343
Catostomus ardens	134	22	7	-	2	-	4	-	1	1	-	1	-	-	5	1	1	-	-	-	-	179
Catostomus discobolus	-	-	-	-	-	-	-	-	1	-	-	3	1	-	-	-	-	-	-	-	-	5
Cottus sp.	53	178	9	-	13	5	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	259
Cottus cf. *bairdi*	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Cottus bairdi	2	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6
Cottus extensus/echinatus	3	9	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	14
Cottus extensus	-	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5
Total	4850	8045	641	1	257	51	114	8	54	36	21	52	24	65	330	101	57	5	29	117	8	14,866

Table XXIX

Numbers of identifed fish specimens per taxon by provenience unit for Stratum I at Homestead Cave

TAXON	**PROVENIENCE UNIT**										
	Stratum I				**Stratum Ia**				**Stratum Ib**		
	FS-47 (6.3 mm)	FS-63 (6.3 mm)	FS-63 (3.1 mm)	FS-64 (6.3 mm)	FS-93 (1.6 mm)	FS-94 (1.6 mm)	FS-75 (6.3 mm)	FS-75 (3.1mm)	FS-92 (1.6 mm)	FS-95 (1.6 mm)	Total
Salmoninae	210	203	276	12	207	25	13	13	1	22	982
cf. *Salvelinus confluentus*	-	1	-	-	-	-	-	-	-	-	1
Oncorhynchus cf. *clarki*	15	20	5	-	14	2	4	-	-	-	60
Oncorhynchus clarki	1	-	-	-	-	-	1	-	-	-	2
Prosopium sp.	103	72	768	2	4726	1008	6	204	48	401	7338
Prosopium cf. *spilonotus*	42	26	11	-	3	2	-	-	-	-	84
Prosopium spilonotus	3	9	14	1	5	1	-	4	-	3	40
P. spilonotus/abyssicola	8	6	79	-	59	14	3	11	-	2	182
Prosopium abyssicola	-	-	2	-	6	-	-	-	-	-	8
Prosopium gemmifer	1	4	220	-	349	100	-	50	3	34	761
Cypriniformes	229	161	772	5	317	50	16	88	9	49	1696
Cyprinidae	2	-	32	-	15	16	-	4	-	3	72
Gila atraria	150	68	221	4	140	29	5	17	3	23	660
Catostomus sp.	294	241	363	2	206	49	23	21	3	21	1223
Catostomus ardens	61	32	41	-	15	5	1	1	-	7	163
Cottus sp.	3	-	50	-	134	31	-	13	1	8	240
Cottus cf. *bairdi*	-	-	-	-	1	-	-	-	-	-	1
Cottus bairdi	-	-	2	-	2	2	-	-	-	-	6
Cottus extensus/echinatus	-	-	3	-	6	3	-	-	-	-	12
Cottus extensus	-	-	-	-	2	3	-	-	-	-	5
Total	1122	843	2859	26	6207	1340	72	426	68	573	13,536

semblage is represented by three orders (Salmoniformes, Cypriniformes and Scorpaeniformes), four families (Salmonidae, Cyprinidae, Catostomidae and Cottidae) and eleven species. The species represented include cf. *Salvelinus confluentus*, bull trout, *Oncorhynchus clarki*, cutthroat trout, *Prosopium spilonotus*, Bonneville whitefish, *Prosopium abyssicola*, Bear Lake whitefish, *Prosopium gemmifer*, Bonneville cisco, *Gila atraria*, Utah chub, *Richardsonius balteatus*, redside shiner, *Catostomus ardens*, Utah sucker, *Catostomus discobolus*, bluehead sucker, *Cottus bairdi*, mottled sculpin, and *Cottus extensus*, Bear Lake sculpin. As a group, the whitefish dominate the assemblage comprising 58.2% of the identified specimens. The percentage composition of the other major taxonomic groups are as follows: minnows and suckers, 32.6%, trout 7.4%, and sculpin, 1.9%.

In this section, I discuss the osteological criteria I used to identify the Homestead Cave fishes[1] and provide information on the modern and fossil geographic distributions, habitat requirements, and other data on the life histories of the represented species.

Salmoninae - Chars and Trouts

Salvelinus confluentus - Bull Trout, and *Oncorhynchus clarki* - Cutthroat Trout

Osteological notes: The single premaxilla fragment (figure 79, A, B) identified as cf. *Salvelinus confluentus* is similar to Recent material of this species and differs from that of *Oncorhynchus clarki*, the abundant and widely distributed salmonine of the Great Basin. The teeth of the premaxilla specimen project mesially, as in *S. confluentus*, rather than more directly ventral (that is, in the same plane as the main body of the bone) as in *O. clarki*. Also similar to *S. confluentus*, the mesial surface of the premaxilla exhibits a well-developed shelf or spine that extends from the anterior margin of the bone, just dorsal to the tooth row, to the posterior base of the ascending process (Norden, 1961, p. 753); *O. clarki* lacks this feature. Unfortunately, the dorsal margin of this specimen has been fragmented so that it cannot be determined whether or not it possessed the most diagnostic feature of *S. confluentus*, the well-developed ascending process (Norden, 1961, p. 753). Gerald R. Smith (1998, personnel communication) has examined this specimen and concurs with the identification as *S. confluentus*. However, because of the fragmentary condition of the single specimen I have included the prefixal cf.

The cranial elements of trout at Homestead Cave are heavily abraded and fragmentary, owing perhaps to the low mineral densities of the salmonine crania (Butler and Chatters, 1994). Accordingly, species-level identifications were not possible for many elements that are diagnostic when they are intact. The elements I identified as *O.* cf. *clarki* exhibited features that are similar to both *O. clarki* and *O. mykiss*, rainbow trout, but unlike those of *S. confluentus*. The designation as *O.* cf. *clarki* for these specimens is based on the known Quaternary distribution of these trout species in the Great Basin (see below).

I assigned the lingual plate specimens to *Oncorhynchus* on the basis of the pronounced medial-lateral ridge on the

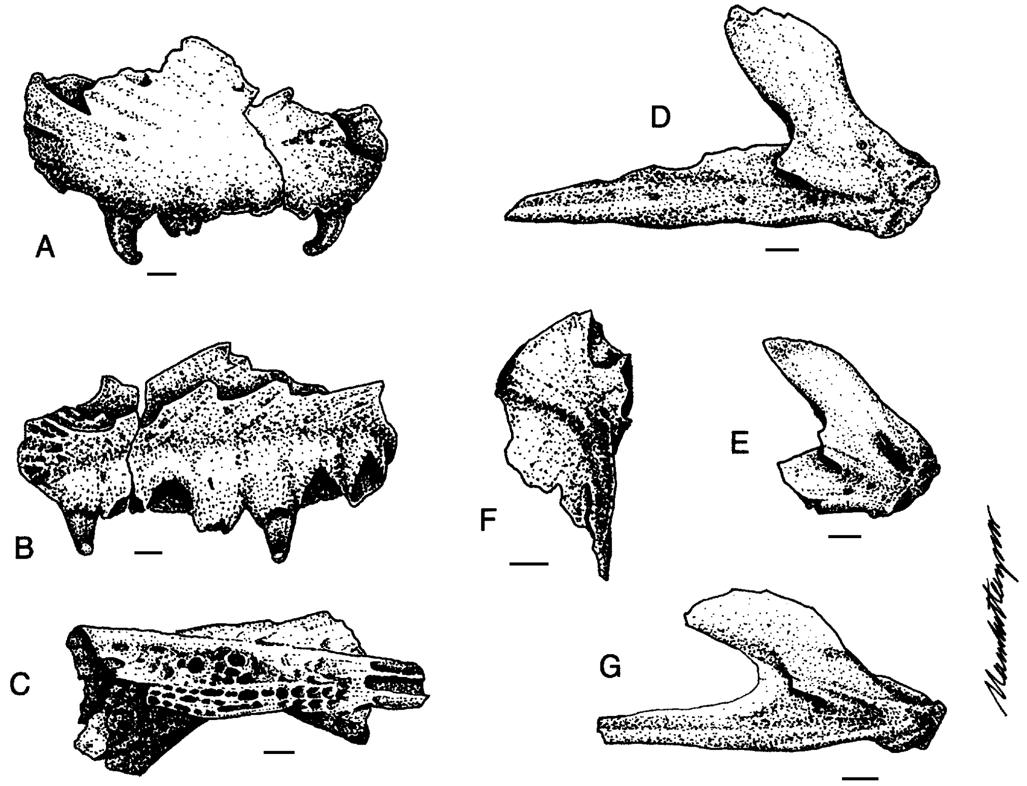

***Figure 79.** Selected diagnostic salmonid fish elements from Homestead Cave: (A) lateral view of right premaxilla of cf.* Salvelinus confluentus, *(B) mesial view of right premaxilla of cf.* Salvelinus confluentus *(same specimen as A), (C) basibranchial of* Oncorhynchus clarki, *(D) left dentary of* Prosopium spilonotus, *(E) left dentary of* Prosopium abyssicola, *(F) left hyomandibular of* Prosopium gemmifer, *(G) left dentary of* Prosopium gemmifer, *Scale: bar length = 1 mm.*

ventral-anterior surface of these elements; the corresponding surface in *S. confluentus* is smooth. The salmonine vomers were identified as *Oncorhynchus* since the specimens exhibited a long, zigzag row of substantial teeth on an elongated vomeral shaft (Stearley and Smith, 1993, p. 17). In *Salvelinus*, teeth occur in a patch on the head of the vomer and the posterior extension of teeth is not supported by the vomeral shaft but, instead, by a crest ventral to the shaft that is attached to the head of the vomer (Stearley and Smith, 1993, p. 17). The ceratohyal specimens are relatively deep for their length, as in *Oncorhynchus*; these elements are more slender (dorsal-ventrally compressed) in *S. confluentus* (Stearley and Smith, 1993, figure 17). The maxillae are referable to *Oncorhynchus* on the basis of the orientation of the premaxillary process. In *Oncorhynchus*, this feature is oriented dorsally less than 10° from the main axis of the maxilla. In *Salvelinus*, the premaxillary process is oriented greater than 10° from the main axis of the maxilla (Stearley and Smith, 1993). As in *Oncorhynchus*, the Homestead salmonine basioccipitals exhibit paired ventrolateral walls that form a deep V-shaped furrow along the ventral portion of the element. In *Salvelinus*, the ventrolateral walls are less elevated and are flattened ventrally to form a shelf for articulation with the posterior parasphenoid.

I used only a single diagnostic element, the basibranchial, to provide species level identifications of the Homestead trout. The two basibranchial specimens (figure 79C) were identified as *O. clarki* since they were toothed; the basibranchials are untoothed in *O. mykiss* (Norden, 1961; Stearley and Smith, 1993). The basibranchials lack a sharp-edged ventral keel as in *S. confluentus*.

Distribution and habitat: *Salvelinus confluentus* (figure 80) is a large piscivorous char that can attain lengths of over 1 m and weights of up to 18.3 kg (Cavender, 1978). Historically, *Salvelinus confluentus* was widely distributed in western North America from northern California to the south, north to Alaska, and east to Alberta (Cavender, 1978; Hass and McPhail, 1991). They have affinities for cold, clear lakes and streams that are fed by mountain glaciers and snowfields (Cavender, 1978).

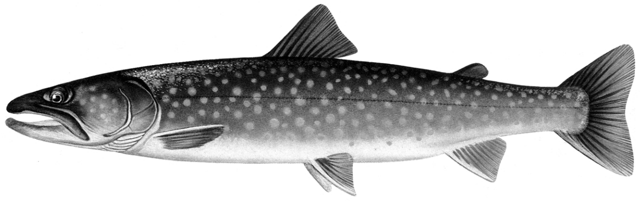

***Figure 80.** Bull trout (*Salvelinus confluentus*).*

No specimens, fossil or otherwise, have previously been collected for *Salvelinus* in the Great Basin. The nearest modern specimen record for *Salvelinus confluentus* is from the Jarbidge drainage, a tributary of the Snake River in northeastern Nevada (Miller and Morton, 1952; Cavender, 1978). The *Salvelinus* clade is known from Miocene deposits in both central Nevada and the Snake River Plain (referred to as *Hucho larsoni*; Smith, G. R., in press). A single historical account of char in the Bonneville basin was, however, provided in the early 19th century by John Kirk Townsend, a trained zoologist. Townsend was traveling as an assistant to the English botanist Thomas Nuttall on a scientific collecting expedition across the Rocky Mountains to the Columbia River. Encamped along the Bear River on July 6, 1834, about 19 km miles south (upstream) of Soda Springs, Idaho, Townsend (1978, p. 89) reported that: "Trout, grayling, and a kind of char are very abundant here - the first very large." Nuttall was familiar with fishes of the Great Lakes, which included grayling and char (Smith, G. R., in press), and since char are so easily distinguished from trout - char are dark with light spots, while trout are light with dark spots - there is little reason to dispute Townsend's record. Hubbs and Miller (1948, p. 76) have also reported a "glacial relict" population of *Salvelinus* from the Lost River system on the eastern Snake River Plain, located about 180 km north of where Townsend reported these fish.

O. clarki (figure 81), divided into six regional subspecies, is native to most of the major river drainages of montane western North America. *O. clarki* is the only native trout species of the Great Basin, with the exception of *O. mykiss gairdneri*, redband trout, of southeastern Oregon, which displays a composite of *O. mykiss* and *O. clarki* characters (Smith, G. R., in press). In the Bonneville basin, and most other locations within its range, *O. clarki* occurs in cold freshwater lakes, rivers and streams. However, certain populations outside of the Bonneville basin have adapted to higher-salinity conditions. Some stocks inhabiting coastal drainages are anadromous, spending summer months well out to sea. *O. clarki henshawi*, Lahontan cutthroat trout, have adapted to the moderately saline waters of Pyramid Lake (5300 ppm, [mg/l] TDS) and Walker Lake (10,300 ppm TDS). Populations inhabiting lakes spawn up inflow streams. *O. clarki* can reach substantial sizes; records for Nevada and Utah are 18.6 kg (41 lb) and 12.1 kg (26 lb, 12 oz), respectively (Sigler and Sigler, 1996).

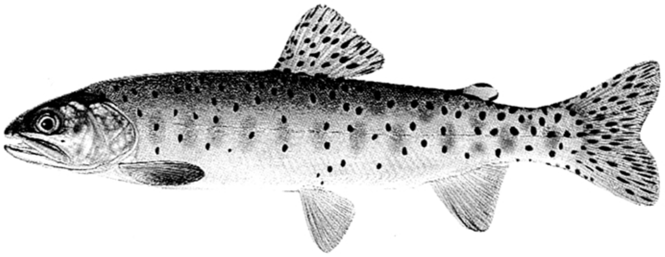

Figure 81. *Cutthroat trout (*Oncorhynchus clarki*).*

O. clarki is known from several other late Pleistocene deposits in the Bonneville basin. Smith and others (1968) described *O. clarki* specimens from the Black Rock Canyon locality of the northeastern Bonneville basin. *O. clarki* materials have also been derived from deposits of the Old River Bed, located between the northern and southern portions of Lake Bonneville (Oviatt, 1984, p. 59). Mead and others (1982, p. 7) report *O. clarki* specimens from the late Pleistocene deposits of Smith Creek Canyon in the Snake Valley of eastern Nevada.

Coregoninae—Whitefishes

P. spilonotus - Bonneville Whitefish*, P. abyssicola* - Bear Lake Whitefish*, and P. gemmifer* - Bonneville Cisco

Osteological notes: Four whitefish species are native to the Bonneville basin: *Prosopium williamsoni, P. spilonotus, P. abyssicola* and *P. gemmifer*. Both *P. abyssicola* and *P. gemmifer* are small whitefish. *P. gemmifer* rarely attains lengths over 216 mm (Sigler and Workman, 1978, p. 6). *P. abyssicola* rarely exceeds 254 mm in length (McConnell and others, 1957); the historical size record is 305 mm (Snyder, 1919). The other two whitefish that occur in the Bonneville basin, *P. williamsoni* and *P. spilonotus*, can reach much larger sizes: for both species, fish larger than 400 mm are not uncommon (McConnell and others, 1957; Sigler, 1951). Accordingly, I used the size of the Homestead whitefish specimens as an identification criteria for specimens that lacked other diagnostic characters.

I used the shape and orientation of the hyomandibular fossa of the opercle to separate *P. spilonotus* and *P. abyssicola* from *P. williamsoni*. In *P. williamsoni*, the medial margin of this fossa is squared-off; in *P. spilonotus* and *P. abyssicola* the medial margin of this feature is rounded. I found no criteria to separate the opercles of *P. abyssicola* and *P. spilonotus*. The hyomandibular fossa of the opercle in *P. gemmifer* is, however, distinct from all of the other whitefish. Specifically, the postero-dorsal margin of the hyomandibular fossa is more elevated, extending to or very near the dorsal margin of the opercle. The fossa thus appears to sit more directly atop the dorsal margin of the bone in *P. gemmifer* than in the other species of *Prosopium*.

I used the orientation of the coronoid process to identify the *Prosopium* dentaries. This feature varies systematically among the Bonneville basin whitefish along a gradient consistent with the phylogenetic relationships of these species (figure 79D, E, F; see Smith and Todd, 1993). Representing the ancestral condition, the coronoid process in *P. williamsoni* rises (dorsally) at a steep angle from the symphysis. The most derived condition is represented by *P. gemmifer* where the coronoid process is deflected posteriorly and rises at a very shallow angle from the symphysis. This condition is associated with the specialized elongation of the anterior portion of the cranium in *P. gemmifer* (see Smith and others, 1968, figure 3; Smith and Todd, 1993, figure 1). *P. spilonotus* and *P. abyssicola* represent the intermediate states of this feature. However, the orientation of the coronoid process in *P. spilonotus* is more similar to *P. williamsoni*, while this feature in *P. abyssicola* is more similar to *P. gemmifer*.

The articular-angular is distinctive in *P. gemmifer*. In *P. gemmifer*, the dorsal margin of the body of the articular-angular rises anteriorly at a very shallow angle from the quadrate articulating surface; this angle is much steeper in all of the other Bonneville basin whitefish. I used this feature, as well as size, to identify the *Prosopium* articular-angulars. The basioccipital in *P. gemmifer* is narrow relative to its length, compared to all of the other Bonneville basin whitefish. Among the reference material available to me, I found no criteria to securely separate the other *Prosopium* species using this element.

In *P. gemmifer*, the ceratohyal is more slender (dorsoventrally compressed) for its length compared to the other Bonneville basin *Prosopium*. I distinguished *P. spilonotus* from *P. williamsoni* by the relative length of the ceratohyal foramen: the foramen is longer, relative to the total length of the bone, in *P. spilonotus*. The relative length of the ceratohyal foramen is still longer in *P. abyssicola* compared to *P. spilonotus*.

The mesially deflected premaxillary process of the maxilla with a pointed condyle allows the secure identification of *P. gemmifer* with this element. I was unable to isolate characters that distinguished the remaining whitefish species using the maxilla. The quadrate is also quite distinct in *P. gemmifer*. Specifically, the latero-ventral margin of the articular process does not project laterally in *P. gemmifer* as it does in the other whitefish. In addition, a marked concavity is present in *P. gemmifer* on the latero-ventral margin of the quadrate just posterior to the articular process. I separated the two larger whitefish on the basis of the morphology of the quadrate as well. In *P. williamsoni*, a shallow concavity is present on the medial surface of the quadrate just dorsal to the articular process. *P. spilonotus* lacks this concavity.

The morphology of the hyomandibular allows secure separation of *P. gemmifer* (figure 79F) from the other Bonneville basin whitefish. In *P. gemmifer*, the postero-lateral ridge is less flared posteriorly than in the other *Prosopium.* In addition, the angle formed between the main axis of the ventral body of the hyomandibular and the margin formed between the opercular condyle and the dorsal condyle is less acute in *P. gemmifer* than in the other whitefish. I was unable to identify characters of the hyomandibular that would allow the consistent identification of *P. williamsoni*, *P. abyssicola* and *P. spilonotus* among the modern reference material of these taxa.

I used a variety of characters of the prootic to identify the Homestead whitefish. A pronounced concavity is evident on the postero-medial surface of *Prosopium* prootics. In *P. spilonotus* and *P. abyssicola*, the anterior and dorsal margins of this concavity are well defined and elevated; the corresponding margin in *P. gemmifer* is poorly defined and depressed. In *P. abyssicola* and *P. spilonotus*, the protuberance on the lateral aspect of the sphenotic condyle is situated more dorsally on the body of the prootic and projects less anteriorly than in *P. williamsoni*. In addition, the medial surface of the prootic is porous in *P. abyssicola* and *P. spilonotus*. The mesial surface of *P. williamsoni* is smooth.

I used the degree of porosity on the endocranial surface of the exoccipital to distinguish *P. abyssicola* and *P. spilonotus* as a group, from *P. williamsoni*. Specifically, the antero-lateral surface between the pterotic and epiotic condyles is porous in *P. abyssicola* and *P. spilonotus* but smooth in *P. williamsoni*. Since I identified no *P. williamsoni* from the Homestead material based on other diagnostic criteria, while *P. spilonotus* is well represented in the collection, I assigned all the *Prosopium* materials too large for *P. gemmifer* and *P. abyssicola* as *P.* cf. *spilonotus*.

Distribution and habitat: Of the four species of whitefish that occur in the Bonneville basin today, three are present in the Homestead Cave ichthyofauna: *P. spilonotus* (figure 82), *P. abyssicola* (figure 83) and *P. gemmifer* (figure 84). Each of these three species are presently endemic to Bear Lake. At an elevation of 1805 m, Bear Lake is a fresh, deep, cold and infertile (oligotrophic) body of water with over 50 percent of the lake registering a depth of more than 30.5 m; the maximum depth is 64 m (Sigler and Sigler, 1996, p. 13, p. 194). The fourth Bonneville basin whitefish, *P. williamsoni*, was not demonstrably present in the Homestead deposits. This species is widespread in western North America where it is most abundant in cold mountain rivers and streams. Some lake populations, however, do exist. *P. williamsoni* has been reported in Bear Lake (Kemmerer and others, 1923), but they have been extremely rare in that setting throughout historical times. McConnell and others (1957, p. 20) suggested that the few *P. williamsoni* reported in Bear Lake may have drifted in from the Bear River.

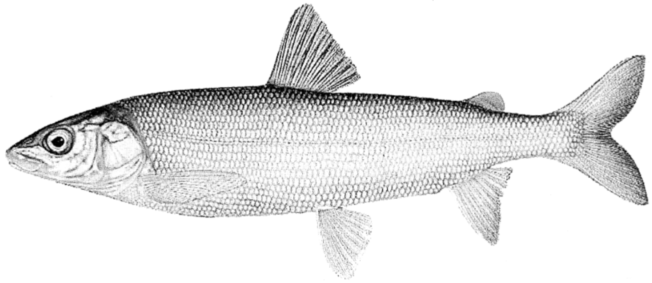

***Figure 82.** Bonneville whitefish (*Prosopium spilonotus*).*

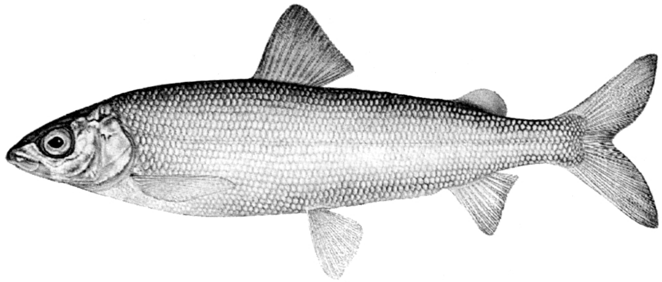

***Figure 83.** Bear Lake whitefish (*Prosopium abyssicola*).*

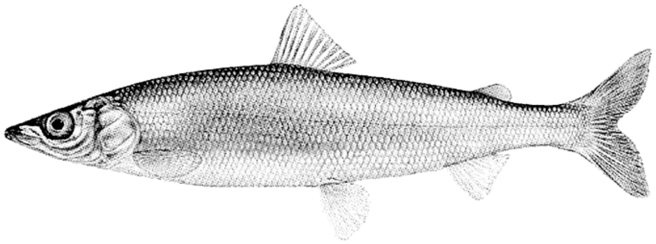

***Figure 84.** Bonneville cisco (*Prosopium gemmifer*).*

P. spilonotus is the large wide-ranging whitefish of Bear Lake. *P. spilonotus* usually occurs in waters between 12.2 to 30.5 m and deeper but moves into shallower water near the shore between mid-February to early March to spawn in water temperatures of about 7.2°C. The species is primarily insectivorous, with chironomid (midge) larvae and pupae forming the dominant component of their diet (McConnell and others, 1957, p. 53). Smith and others (1968) identified *Prosopium spilonotus* from the late Pleistocene Hot Springs and Black Rock Canyon localities, both of the northeastern Bonneville basin, on the basis of basioccipital specimens.

P. abyssicola is a dwarf, deep-water whitefish of Bear Lake. They rarely frequent inshore areas. Spawning takes place from late December to early February in depths ranging from 15 to 30 m when water temperatures drop between 2.2 to 3.9°C. A diet of ostracodes, copepods, midge larvae and aquatic oligocheates reflects a dependence on the deep, soft marl bottom of Bear Lake (Wurtzbaugh and others, 1989; McConnell and others, 1957). The Homestead Cave specimens of *P. abyssicola* represent the first records of this species for Lake Bonneville.

P. gemmifer, a small planktivorous species, is the most abundant fish species in modern Bear Lake; it is also the best represented fish in the Homestead Cave ichthyofauna. Although they normally occur in water temperatures lower than 14.4°C, they require temperatures between 0.5 and 5.6°C to spawn. *P. gemmifer* inhabits the deep offshore waters of Bear Lake for most of the year, but moves inshore (from 0.9 to 2.4 m) to shallow waters for a brief (~ 2 week) period in winter to spawn (Perry, 1943; Sigler and Workman, 1978). Because of their adaptation to deep and cold waters, attempts have been made to stock this fish in a number of cold high-elevation lakes in western North America (for example, Lake Tahoe, Nevada/California, and Twin Lakes, Colorado). Survival in these settings has not been documented (Sigler and Sigler, 1987, 1996). *P. gemmifer* has been identified from two other late Pleistocene Lake Bonneville deposits, both in the northeastern Bonneville basin (Smith and others, 1968).

Based on measurements of the hyomandibular, Smith and others (1968), documented significant differences between the populations of *P. gemmifer* that inhabited Lake Bonneville and those that occur in Bear Lake today. Those differences were interpreted as evidence for specialization of the jaw structure in *P. gemmifer* over the last ~11 ka (Smith and others, 1968). Alternatively, this pattern may reflect introgression of *P. gemmifer* with the other Bear Lake *Prosopium* during the Holocene. Ongoing analysis of the sample of *P. gemmifer* hyomandibulars from Homestead Cave will allow this issue to be examined in further detail.

Cyprinidae - Minnows

Gila atraria - Utah Chub, and *Richardsonius balteatus* - Redside Shiner

Osteological notes: Six cyprinid species are native to the Bonneville basin: *Gila atraria*, *Gila copei*, leatherside chub, *Iotichthyes phlegethontis*, least chub, *Rhinicthys cataractae*, longnose dace, *Rhinichthyes osculus*, speckled dace, and *Richardsonius balteatus*. With the exception of *Gila atraria*, these are very small fishes, rarely attaining lengths over 150 mm. *Gila atraria*, however, can reach lengths up to 559 mm, but typically range from 127 to 305 mm (Sigler and Sigler, 1996). Accordingly, I used size and robusticity of elements to identify *Gila atraria* from the Homestead materials for elements that lacked other diagnostic criteria.

Gila atraria can be easily separated from the other Bonneville basin cyprinids on the basis of the morphology of the pharyngeal teeth. The pharyngeal teeth of *Gila atraria*, in addition to having a unique tooth formula (2,5 - 4,2), are exceptionally robust, exhibit pronounced grinding surfaces and terminally hooked tips (figure 85A). With one exception, all of the identifiable pharyngeal specimens from Homestead Cave are *G. atraria*. A single pharyngeal specimen is referable to *Richardsonius balteatus* (figure 85B) on the basis of the delicate and slender body and teeth and the distinctively squared-off margin of the lateral surface of the bone.[2]

The cyprinid maxillae are referable to *Gila atraria* on the basis of (1) the steep anterior and posterior margins of the dorsal ramus, and (2) the wide breadth and flattened dorsal extremity of this process. The basioccipital of *Gila atraria* is also distinctive among the Bonneville basin minnows. Specifically, the postero-ventral platform of the basioccipital is relatively narrow for its length in *Gila atraria* and the lateral margins decurve ventrally to form a pronounced concavity.

Distribution and habitat: *Gila atraria* (figure 86) is native to the Bonneville basin, the Snake River above Shoshone Falls, and the lower Wood River system, Idaho. It is abundant in a diversity of environments: from deep, cold, high-mountain lakes, such as Bear Lake, to small, warm (up to 31°C), moderately saline springs (up to 2.5% NaCl [sodium chloride]) on the desert floor. Laboratory experiments also indicate that these fish can tolerate saline waters (Na, 213 meq/l; Westenfelder and others, 1988). During the spring, lake populations move from deep to shallow water (less than

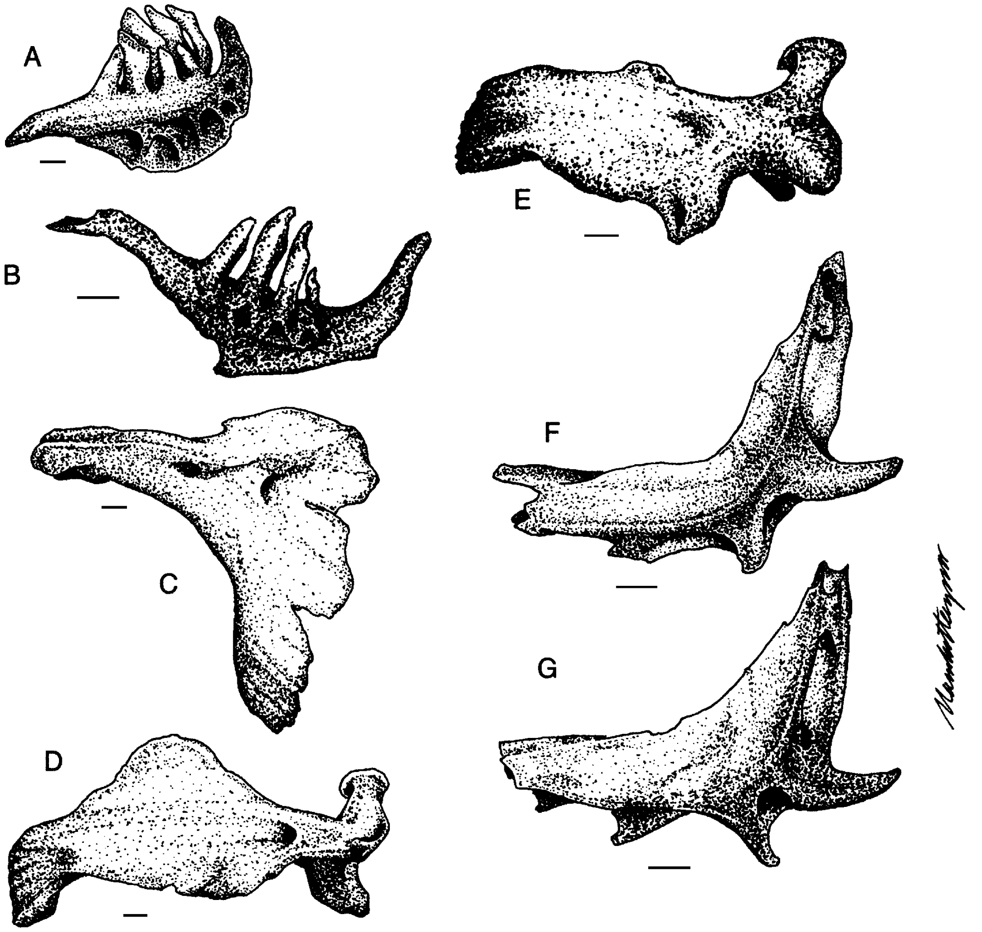

Figure 85. *Selected diagnostic cyprinid, catostomid, and cottid elements from Homestead Cave. (A) left pharyngeal of* Gila atraria, *(B) right pharyngeal of* Richardsonius balteatus, *(C) left dentary of* Catostomus ardens, *(D) right maxilla of* Catostomus ardens, *(E) right maxilla of* Catostomus discobolus, *(F) left preopercle of* Cottus bairdi, *(G) left preopercle of* Cottus extensus. *Scale: bar length = 1 mm.*

0.61 m) to spawn (Sigler and Sigler, 1987, 1996). *Gila atraria* is omnivorous, feeding on plant material, a variety of invertebrates, and occasionally even small fish. In desert spring settings, they will feed on green algae and their own eggs (Sigler and Sigler, 1996, p. 76).

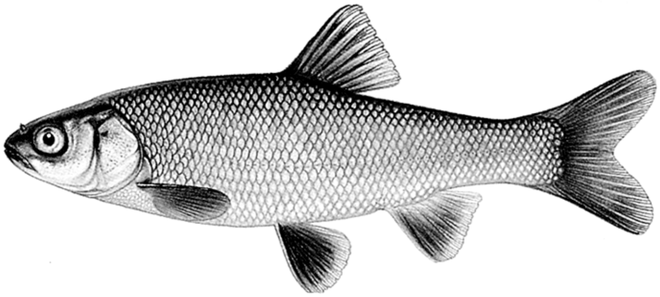

Figure 86. *Utah chub (*Gila atraria*).*

Gila atraria has been reported from three other late Pleistocene fossil localities in the Bonneville basin: Black Rock Canyon (Smith and others, 1968), Smith Creek Canyon (Mead and others, 1982) and the Public Shooting Grounds (Murchison, 1989a). Specimens of *Gila atraria* from the Public Shooting Grounds were derived from a matrix of transgressive lacustrine sands and silts rich in gastropod remains and were underlain by freshwater marsh deposits. *Lymnaea stagnalis* shell from the layer containing the chub materials provided a date of 10,990 ± 110 yr B.P. The *Gila atraria* specimens represented here may have been derived from freshwater marshes (Murchison, 1989a) or may have come from a lake setting.

Richardsonius balteatus (figure 87) is a small, short-lived minnow; most individuals are under 127 mm and attain ages of no more than 5 years. They are widely distributed west of the Rocky Mountains, east from the Bonneville and Snake systems, and west to the Columbia and Malheur-Harney Basins. They occur in a wide variety of habitats, from cold mountain lakes, such as Bear Lake, to warm (up to 24°C) ponds and springs. *Richardsonius balteatus* is omnivorous, feeding on a variety of aquatic and terrestrial insects, algae, mollusks, zooplankton, as well as their own eggs and fry (Sigler and Miller, 1963, pp. 76-78; Sigler and Sigler, 1996, pp. 119-122). The Homestead Cave specimen represents the first record of this species in Lake Bonneville.

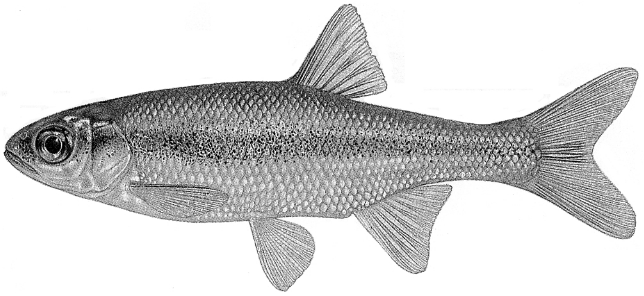

Figure 87. *Redside shiner (*Richardsonius balteatus*).*

Catostomidae—Suckers

Catostomus ardens - Utah Sucker, and
Catostomus discobolus - Bluehead Sucker

Osteological notes: Four sucker species are native to the Bonneville basin: *Chasmistes liorus*, June sucker, *Catostomus ardens*, *Catostomus discobolus* and *Catostomus platyrhynchus*. Both *Chasmistes liorus* and *Catostomus ardens* can reach substantial sizes (>600 mm in length), while *Catostomus discobolus* and *Catostomus platyrhynchus* (subgenus *Pantosteus*) are smaller fishes, reaching maximum lengths of 305 mm and 457 mm, respectively (Sigler and Sigler, 1996). Hence, I used size to rule out the latter two species for certain large-sized sucker specimens (see below) that lacked other diagnostic criteria.

The morphology of the dentary allows easy separation of the Bonneville basin catostomids. The angle and length of the gnathic ramus relative to the posterior body of the dentary is slightly obtuse and short in *Catostomus ardens* (figure 85C), but is more obtuse and longer in *Chasmistes liorus*. This gives *Chasmistes* a longer, more curved ramus than *Catostomus ardens*. In addition, the angle of the dentary symphysis is parallel to the gnathic ramus in *Catostomus ardens* but is subparallel in *Chasmistes liorus* (Miller and Smith, 1981, p. 37). In *Catostomus platyrhynchus* and *Catostomus discobolus*, the gnathic ramus is dramatically foreshortened and mesially deflected, as in all species of the subgenus *Pantosteus* (Smith, 1966, p. 14). In *C. discobolus* a substantial protuberance sits at the lateral-posterior margin of the gnathic ramus; this feature is far less developed in *C. platyrhynchus*. Two sucker dentaries from Homestead are assignable to *C. discobolus* based on these criteria; all the others are *C. ardens*.

The maxillae are sufficiently distinct among these species to allow secure identifications as well. The anterior constriction or neck of the maxilla is thicker in *Catostomus ardens* (figure 85D) compared to *Chasmistes liorus* (Miller and Smith, 1981, p. 36). A nearly semi-hemispherical ridge is present along the antero-ventral margin of the neck in *C. ardens*, whereas this feature is not well developed in *Chasmistes*. The antero-ventral (premaxillary) process projects at a right angle from the long axis of the maxilla posterior to the head in *C. ardens*. In *Chasmistes liorus*, this process projects anteriorly at an obtuse angle from the long axis of the bone and is more directly ventral to the head of the maxilla (Miller and Smith, 1981, p. 36). The ventral keel is also better developed in *C. ardens* compared to *C. liorus* (Miller and Smith, 1981, p. 36); both these species have well-developed dorsal keels. The maxillae of *C. discobolus* and *C. platyrhynchus* are robust, lack dorsal keels and are distinctively dissimilar to either *C. ardens* or *C. liorus* (Smith, 1966, p. 14). The posterior margin of the ventral keel slopes anteriorly more steeply in *C. platyrhynchus* compared to *C. discobolus*. Based on these criteria, both *C. ardens* and *C. discobolus* are represented at Homestead Cave (figure 85D, E).

Finally, the premaxillae of *Catostomus ardens* and *Chasmistes liorus* are distinctive. In *Chasmistes liorus*, the maximum medio-lateral length (horizontal limb) of the premaxilla is longer than the maximum ventro-dorsal (vertical limb) length. In *Catostomus ardens*, the maximum medio-lateral length of the premaxilla is considerably shorter than the maximum dorso-ventral length (see Miller and Smith, 1981, figure 10, A and B). In *C. discobolus* and *C. platyrhynchus* the relative lengths of the premaxillary limbs are near equal or the horizontal limb is longer. In addition, the dorsal extremity of the vertical limb exhibits an antero-medial protuberance and is anteriorly deflected; *C. ardens* lacks this feature.

Finally, the horizontal limbs of *C. discobolus* and *C. platyrhynchus* are more curved, producing a marked convexity of the anterior surface. All of the Homestead catostomid premaxillae are referable to *Catostomus ardens* based on these criteria. Since only *Catostomus* was demonstrably present in the diagnostic Homestead sucker elements, I assigned the remaining catostomid materials to *Catostomus* sp.

Distribution and habitat: *Catostomus ardens* (figure 88) is distributed widely in the Bonneville basin and upper Snake system above Shoshone Falls. *Catostomus ardens* thrives in a diversity of habitat types, from large deep, cold lakes, such as Bear Lake, to relatively small, warm (above 26.7°C) streams. For lake populations, spawning migrations may occur up inflow streams or in shallow inshore settings within the lake itself. *Catostomus ardens* populations that occupy large lakes, such as Bear lake, are benthic browsers, taking both plant and animal material along the bottom of the lake at all depths (McConnell, and others 1957, p. 47; Sigler and Sigler, 1987, 1996).

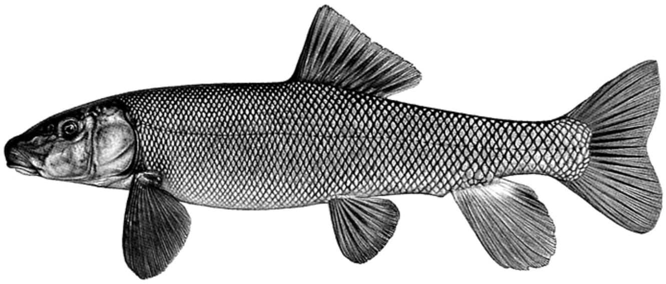

Figure 88. *Utah sucker (*Catostomus ardens*).*

Catostomus ardens is known from two other Lake Bonneville deposits: the Hot Springs locality (Smith and others, 1968) and the Old River Bed (Oviatt, 1984). Both of these samples are represented by single skeletal elements.

Catostomus discobolus (figure 89), the most specialized and derived species in the subgenus *Pantosteus* (Smith, 1966; Smith and Koehn, 1971), is found in the upper Colorado River drainage, the Weber and Bear River drainages in the Bonneville basin, and in the upper Snake drainage (Sigler and Miller, 1963, p. 99; Smith, G. R., in press). Suckers in the *Pantosteus* subgenus are river and stream fish and show a variety of morphological adaptations to fluvial environments (Smith, 1966; Powers, 1972). *Catostomus discobolus* occurs in a variety of fluvial environments, from small cool (20°C or less) creeks in the headwaters of the Weber River to the warm (up to 27.8°C) torrent of the main stem of the Colorado River (Smith, 1966, p. 94; Sigler and Miller, 1963, pp. 100-103; Sigler and Sigler, 1996, pp. 133-136). *Catostomus discobolus* feeds along the bottom using the chisel-like cartilaginous ridges of their jaws to scrape algae, aquatic insects and other invertebrates from rocks. No other *Pantosteus* fossils are known from the Great Basin.

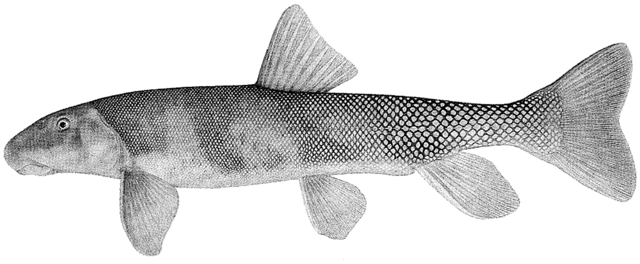

Figure 89. *Bluehead sucker (*Catostomus discobolus*).*

Cottidae—Sculpins

Cottus bairdi - Mottled Sculpin, and *Cottus extensus* Bear Lake Sculpin

Osteological notes: Four species of sculpin are known from the Bonneville basin: *Cottus beldingi*, Paiute sculpin, *C. bairdi*, *C. extensus* and *C. echinatus*, Utah Lake sculpin. *C. echinatus* is a Utah Lake endemic that is now extinct. As a result, osteological comparative material is extremely limited for this species. Features of the preopercle provide the most reliable osteological means of distinguishing these species (Bailey and Bond, 1963; Smith and others, 1968) and I relied on this element exclusively to identify the sculpin species represented in the Homestead fauna.[3]

The preopercle of *C. beldingi* is distinctive in possessing only a single, blunt, posteriorly directed preopercular spine. The preopercle of *C. bairdi* is also unique in exhibiting an anteriorly deflected second (from the dorsal) spine (figure 85F; see also Smith and others, 1968, figure 5B). The second spine in both *C. extensus* and *C. echinatus* is deflected posteriorly, allowing them, as a group, to be readily distinguished from *C. bairdi*. Securely distinguishing *C. extensus* from *C. echinatus* is more difficult owing to the strong osteological similarity of these species and the small number of recent *C. echinatus* reference specimens available for comparison. I used the orientation of the third (from the dorsal) spine to distinguish these species. In *C. echinatus*, the third spine projects more ventrally (less anteriorly) compared to *C. extensus* (figure 85G). I observed this feature on three *C. echinatus* specimens [UMMZ 156794, BYU 29212, and BYU 29213]. Gerald R. Smith (personal communication 1999) observed this feature on the four *C. echinatus* housed at the UMMZ. Using these criteria, *C. bairdi* and *C. extensus* are demonstrably represented in the Homestead ichthyofauna, but *C. beldingi* and *C. echinatus* are not.

Distribution and habitat: *Cottus bairdi* (figure 90) is widely distributed in the Bonneville and Columbia drainages and across much of northeastern North America as well. *C. bairdi* may reach a maximum length of ~150 mm; adults in the Logan River, Utah, range between 76 and 102 mm (Sigler and Sigler, 1996, p. 231). In the Bonneville and Columbia drainages, *C. bairdi* is found principally in clear, cold, well-oxygenated streams with rapid to moderate currents. They prefer summer water temperatures between 12.8 to 18.3°C and gravel or rocky substrates. Their diet consists primarily of aquatic insects (Wydoski and Whitney, 1979, p. 163; Sigler and Sigler, 1996, p. 231). In eastern North America, *C. bairdi* also inhabits cold streams but many populations are adapted to lacustrine settings as well. Most of the eastern lake populations of *C. bairdi* inhabit shallow-water shoreline settings (Hubbs and Lagler, 1964, p. 118; Becker, 1983, p. 970). However, deep-water lake populations, such as in Lake Erie, are known to occur for this species as well (Trautman, 1981, pp. 708-710; Keleher, 1952, cited in Scott and Crossman, 1973). *C. bairdi* has also been identified from the Hot Springs (four specimens) and Black Rock (two specimens) localities of Lake Bonneville (Smith and others, 1968).

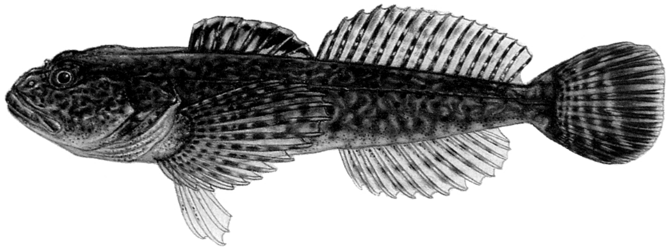

*Figure 90. Mottled sculpin (*Cottus bairdi*).*

Cottus extensus (figure 91) is presently endemic to Bear Lake, where they are the second most abundant fish in the lake. This is a very small fish with an average length of 76 mm. For most of the year, most *Cottus extensus* individuals occur in very cold, deep (15-53 m [50 to 175 ft]) water where they burrow into the soft marl bottom for cover; late winter and spring brings them to rocky nearshore settings to spawn. They feed primarily on ostracodes and cyclopoid copepods (McConnell and others, 1957; Dalton and others, 1965; Sigler and Sigler 1987, 1996). *Cottus extensus* has been identified from both the Hot Springs and Black Rock Canyon localities of Lake Bonneville (Smith and others, 1968).

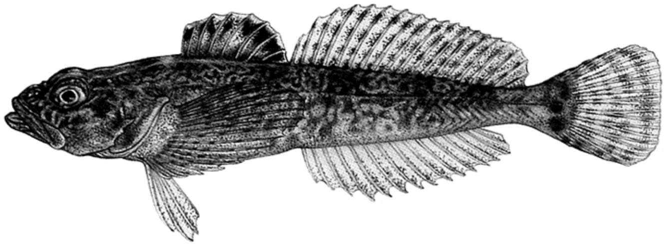

*Figure 91. Bear Lake sculpin (*Cottus extensus*).*

BIOGEOGRAPHIC IMPLICATIONS

In the 1960s, G.R. Smith described the fish materials from the Black Rock Canyon and Hot Springs sites, two late Pleistocene fossil localities in the Bonneville basin (Stokes and others, 1964; Smith and others, 1968). Those materials represented the first Lake Bonneville fish assemblages ever described and hence provided a wealth of information on the Quaternary biogeographic history of fishes in the Bonneville basin. Since that time, only a few isolated fish bones derived from the sediments of Lake Bonneville have been reported, and no new species have been identified among them (Oviatt, 1984; Mead and others, 1982). The Homestead Cave fauna is thus extremely unique in its potential to help explain issues of fish biogeography in the Bonneville basin.

Four fish species previously unknown to have inhabited Lake Bonneville are represented in the Homestead Cave ichthyofauna: *Salvelinus confluentus*, *Prosopium abyssicola*, *Catostomus discobolus* and *Richardsonius balteatus*. There are also several species that are noteworthy for their absence in the Homestead fauna: *Chasmistes liorus* and *Cottus echinatus*. Here, I discuss the biogeographic significance of the presence/absence of these taxa in the Homestead ichthyofauna.

From a biogeographic standpoint, one of the most important aspects of the Homestead fauna is the identification of a single *Salvelinus confluentus* specimen. Again, this represents the first specimen record for the genus *Salvelinus* in the Great Basin and supports Townsend's early historical period report of char in the Bear River – an account that has previously been considered "dubious" (see Hass and McPhail, 1991, p. 2204). The Bonneville system may have been colonized by *Salvelinus confluentus* from the Snake River system when Lake Bonneville overflowed into the Snake ~15 ka. Alternatively, *Salvelinus confluentus* could have reached Lake Bonneville sometime around 27 ka when the Bear River was diverted from the Snake River drainage system into the Bonneville basin by lava flows in southern Idaho (Bright, 1963, 1967; Smith, G. R., in press; but see Bouchard and others, 1998).

Today, *Salvelinus confluentus* is restricted to cold streams and lakes fed by mountain glaciers and snowfields and has declined dramatically in the southern portions of there range during historical times (Cavender, 1978; Hass and McPhail, 1991; Riemen and McIntyre, 1995). Petitions for listing under the U.S. Endangered Species Act have been issued (Reiman and others, 1997). For a species as large as *Salvelinus confluentus*, the presence of only a single specimen at Homestead Cave suggests that even by ~11.3 ka, they were uncommon in Lake Bonneville. Since the Homestead fishes were apparently derived from a low-elevation lake (~1300 m), it may be that by the time the Homestead fauna began to accumulate, water temperatures were already too warm and *Salvelinus confluentus* populations had already began to decline in Lake Bonneville. The indication that *Salvelinus confluentus* is a native species to cold waters of the Bonneville basin has implications for the modern management of this species in decline.

Homestead Cave has provided the first record of *Catostomus discobolus* in Lake Bonneville and the only fossil record of the subgenus *Pantosteus* in the Great Basin. *Catostomus discobolus* occurs almost exclusively in stream or river habitats; a single lake population has been reported for Lower Green River Lake, Wyoming (Sigler and Miller, 1963, p. 102). Today, two disjunct populations occur in swift, cool mountain streams of the Bonneville basin: one in the upper Weber River drainage and one in the Bear River drainage. This present distribution pattern led Smith (1966, p. 121) to suggest that the Weber River population must have colonized that system before the Bear and Weber Rivers were isolated by the desiccation of Lake Bonneville at the end of the Pleistocene. This argument requires that *Catostomus discobolus* had occupied Lake Bonneville, at least along its stretch of shoreline between the Bear River and Weber Rivers, but evidence of their presence in the lake has heretofore been lacking. The presence of *C. discobolus* at Homestead Cave indicates not only that they occurred in Lake Bonneville, but that they ranged widely across the lake. Since *C. discobolus* is a stream-adapted species, their presence also implies that populations of these fish had either adapted to some aspect of the lacustrine environments of Lake Bonneville and/or suitable fluvial environments ocurred near Homestead Cave in the past.

The distribution patterns of stream fishes in the Great Lakes region provide insight into how *C. discobolus* may have adapted to lacustrine environments of Lake Bonneville. High-energy wave action along the shorelines of the Great

Lakes creates substrate types and associated benthic algal and diatom communities that are analogous to those found in riffle sections of stream environments. As a result, fish species in northeastern North America that are primarily restricted to swift streams, or rivers with rock or gravel substrates, also occur in certain high-energy shoreline settings of the Great Lakes (Hubbs and Lagler, 1964). Wave-swept shorelines clearly characterized Lake Bonneville and may have provided suitable habitat for *C. discobolus* in those settings.

It is also possible that stream habitats may have existed near Homestead Cave in late Pleistocene times even though they do not occur there today. In this context, I note that avian taxa associated with riparian vegetation have been reported for the basal deposits of Homestead Cave (Livingston, chapter eight) and may reflect the presence of local fluvial habitats in the past. I also note that an ancient stream channel that would have drained much of the western margin of Lakeside Mountains is located ~0.5 km from the mouth of the cave (chapter two).

Prosopium abyssicola is the last of the four Bear Lake endemics to be identified in Lake Bonneville sediments. *Prosopium abyssicola*, *Prosopium spilonotus* and *Prosopium gemmifer* apparently evolved from a *Prosopium williamsoni* ancestor, the more widespread and morphologically least-derived western whitefish species. When and where the endemic Bonneville basin whitefish speciated has remained unknown, although the previous documentation of *Prosopium spilonotus* and *Prosopium gemmifer* in Lake Bonneville sediments has indicated that they have been around since the late Pleistocene. The documentation that *Prosopium abyssicola* also inhabited Lake Bonneville indicates they too evolved sometime before the late Pleistocene and eliminates the possibility that this species diverged more recently (that is, over the last ~11,000 years) in Bear Lake.

A single pharyngeal of *Richardsonius balteatus* was identified from the Homestead deposits. *Richardsonius balteatus* is abundant in a variety of lacustrine and fluvial habitats in the Bonneville basin. These are very small fish and their rarity in the sample may in part be a function of recovery bias. Analysis of the entire 1.6 mm fraction would shed light on this suggestion and may also indicate the presence of *Rhinichthyes osculus*, another widespread diminutive minnow of the Bonneville basin absent in the Homestead sample. The fact that *Richardsonius balteatus* specimens were previously unknown from Lake Bonneville fossil fish faunas but were present in sediments derived from Pliocene Lake Idaho has led to the suggestion that this species entered the Bonneville basin from the Snake system very recently (~12 ka; Sigler and Sigler, 1996, p. 24). Additional older Lake Bonneville fish fossils will be required to evaluate this suggestion, but it is certainly clear now that this species was part of the Lake Bonneville fauna.

The fact that *Cottus echinatus* was not demonstrably present in Homestead deposits is noteworthy. This species was endemic to Utah Lake in historical times but is now extinct. This sculpin has now failed to appear in the all of Lake Bonneville fish assemblages that have been studied. This fact, along with the close morphological similarity between *C. echinatus* and *C. extensus*, suggests that the former diverged from a relictual *C. extensus* population in Utah Lake over the last ~11,000 years (Rosenfeld, 1996, p. 32; Smith, G. R., in press).

Chasmistes liorus is noteworthy for its absence in the Homestead ichthyofauna as well. This species is also endemic to the shallow eutrophic waters of Utah Lake today. *Chasmistes liorus* is a large, planktivorous lake sucker; it spawns in June (hence its common name) up the Provo River. Miller and Smith (1981, p. 33) report a fragmentary coracoid and dentary referable to *Chasmistes* cf. *liorus* from the Black Rock Canyon locality. Hyomandibulars assigned to *Chasmistes* sp. were reported by Bright (1967) from late Pleistocene sediments in the Thatcher Basin (Miller and Smith, 1981, p. 33).

The absence of *C. liorus* in the abundant catostomid collection from Homestead deposits is thus intriguing. That absence may reflect a restricted spatial distribution of these fish in late Pleistocene Lake Bonneville. Perhaps they were restricted to warmer, shallower bays of Lake Bonneville near major input rivers.

FISH LIFE HISTORY ADAPTATION AND BODY SIZE CHANGE IN A REGRESSING LAKE BONNEVILLE

The demographic structure of vertebrate populations is determined by age-specific patterns in fertility and mortality. Variation in these parameters can not only mechanically alter the distribution and abundance of individuals across age classes in a population, but can provide the selective context for the emergence and persistence of different life history strategies as well (Gadgil and Bossert,1970; Stearns, 1992). It is well known, for example, that intraspecific variation in mortality and life expectancy among fishes is directly correlated with, among other variables, the age of initial reproduction and adult body size. The relationships between these variables and the fitness related trade-offs that underlie them, have been well explored through mathematical modeling (see Stearns and Crandall, 1981, 1984; Roff, 1984, 1992; Stearns and Koella, 1986; Charnov, 1993). In this section, I explore how change in the size of fish represented at Homestead Cave might inform on the nature of the extinction of Lake Bonneville's ichthyofauna.

In the context of intermountain fishes, Smith (1981) has developed a specific model linking intraspecific variation in life history strategies to local regimes of habitat stability, adult mortality and ultimately variation in adult body sizes:

> Many intermountain minnows, suckers, and trouts are selected locally for large size by increased adult survival and consequent late reproduction in large habitats. Annual fluctuations that reduce habitats seasonally, thus causing heavy mortality, lead to persistence of phenotypes that reproduce early at the expense of later growth...When adult mortality is low individuals leave more descendants by growing larger and producing more young over several seasons (Smith, 1981, p. 126, p. 162).

Smith has documented significant positive relationships between habitat size, as a measure of environmental stability, and maximum adult size in many western fish species, including some of the cypriniform taxa represented at Homestead Cave, namely, *Gila atraria* and *Catostomus discobolus*. In large stable rivers and lakes with limited adult mortality and high life expectancy, these species mature later, live longer and attain larger sizes. In smaller, less stable aquatic settings, where adult mortality is at least seasonally high, these fishes reproduce at younger ages and attain smaller maximum sizes. According to this model, the mortality rate is the critical variable affecting the selection of different life history phenotypes that ultimately constrain adult body size. This model has clear implications for change in the size structure of Lake Bonneville's fish populations as the lake regressed at the end of the Pleistocene.

The taxonomic composition of the Homestead fishes suggests that during the deposition of Stratum I, the lake was, at least periodically, a fresh, cold, oligotrophic body of water similar to modern high-elevation lakes that are fed by mountain glaciers and snowfields. If the Homestead Cave fish assemblage was derived from a process involving a series of die-offs that occurred either seasonally or over periods of many years during which lower lake levels exceeded the temperature or salinity tolerances of the fishes, then selection should have increasingly favored early maturing, smaller-sized fishes across this period of elevated mortality. If this was the case, it follows from Smith's model that the fish materials from Homestead Cave representing populations that resulted from later die-offs (that is, Stratum Ib) should be skewed to smaller size classes, compared to fish representing the initial die-offs (that is, Stratum Ia). If, on the other hand, the fish materials from Homestead Cave represent a single relatively instantaneous die-off event, no change in size structure should be evident across the divisions of Stratum I.

The sample of Cypriniformes vertebrae identified from Strata Ia and Ib was selected for analysis of change in fish size. Table XXX provides the summary statistics for the maximum diameters of cypriniform vertebral centra derived from these strata.[4]

Figure 92 shows the frequency distributions of the maximum diameters of cypriniform vertebral centra, as a measure of size, for Stratum Ia and Stratum Ib. The distributions are clearly distinct: the later deposits (Stratum Ib) are skewed to smaller-sized fishes, have a smaller maximum size, and exhibit a significantly smaller mean size than do those in Stratum Ia (Mann-Whitney $U = 8546.5$, $P < 0.05$).

It is also evident that neither of these distributions display ideal "catastrophic" profiles, that is, a decreasing number of individuals represented in progressively larger (older) size classes: both divisions of Stratum I are underrepresented by the smaller (< 2 mm) size classes. Catastrophic profiles are expected to result if individuals are sampled in direct proportion to their abundance in the living population and thus should be produced from death assemblages representing mass die-offs such as those represented at Homestead Cave. Since these materials were collected with 1.6 mm screen mesh, the underrepresentation of very small cypriniform vertebrae in both Ia and Ib is not likely due to recovery bias. Instead, very small individual fish may have consistently been outside the diet breadth of the owls that accumulated the fauna.

While the size change between Stratum Ia and Ib is consistent with Smith's model of life history adaptation, the same pattern would also be expected to result mechanically from a set of at least two catastrophic die-offs in which the population resulting from the second one had not occurred long enough in the lake to grow individuals of larger size classes. The smaller size of fishes in Stratum Ib, in this scenario, would thus represent a historical vestige derived from a previous period of substantial mortality. In either case, the data suggest that the Homestead Cave ichthyofauna represents multiple fish die-offs rather than a single die-off event.

Table XXX
Vertebral widths (mm) of the Homestead Cave Cypriniformes in Strata Ia and Ib

Stratum	N	$\bar{x}$	Range	s
Ia	365	4.40	1.26 - 9.20	1.46
Ib	56	4.02	1.74 - 7.62	1.38

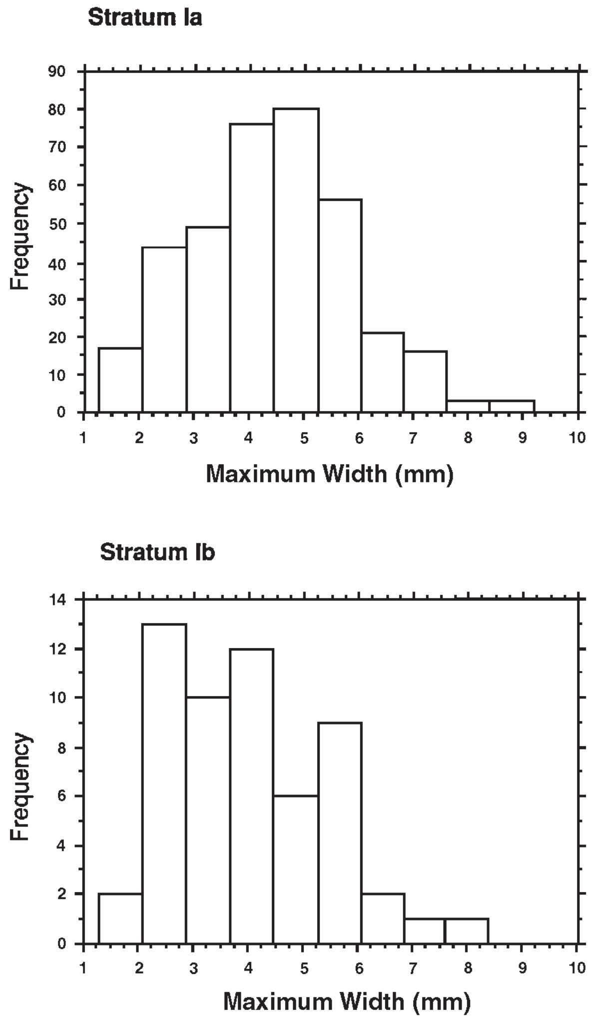

Figure 92. *Frequency distribution of the maximum diameters of cypriniform vertebral centra for Strata Ia and Ib at Homestead Cave.*

The data also do not allow a determination of the precise nature of fish mortality during the extinction process. It is unknown, for instance, whether Lake Bonneville ever completely lost its fish populations during any one of the initial die-offs; even during periods of mass mortality, remnant populations may have persisted in colder, less saline water, perhaps in deeper portions of the lake or in settings near major input rivers. The periodicity of the die-offs is also unknown: they may have occurred seasonally during low-level conditions or during low-level periods spanning many years or decades during which salinities or temperatures consistently exceeded the tolerances of the lake's fish populations. Determination of the seasonality of fish deaths through analyses of annulli formation on the Homestead fish elements could shed light on this issue. Such analyses could also potentially indicate changes in the age and size of initial reproduction of these fishes to more definitively test Smith's model of life history adaptation.

CHANGE IN TAXONOMIC ABUNDANCE IN RELATION TO SALINITY AND TEMPERATURE

Decreasing lake levels and associated increases in water temperature and salinity are the likely cause of the fish die-offs and ultimately the permanent loss of Lake Bonneville's fishes that occurred sometime within the deposition of Stratum Ib (see below). Comparisons of the relative abundance of fishes with different temperature and salinity tolerances between Stratum Ia and Stratum Ib might inform on the dynamics of the die-off(s) in relation to these variables. Although the precise temperature and salinity tolerances of most of these fishes are, unfortunately, not well known, broad categories of tolerance to these variables can be defined from what data are available.

Salinity

The fishes represented within Stratum I of Homestead Cave can be divided into two groups on the basis of their relative tolerance to salinity. Species intolerant of saline waters include *Prosopium gemmifer*, *Prosopium abyssicola*, *Prosopium spilonotus*, *Catostomus ardens*, *Cottus bairdi* and *Cottus extensus*. These species have never been known to occur in even moderately saline waters. By contrast, *O. clarki* is represented by anadromous stocks in coastal drainages where individuals spend considerable portions of their lives well out to sea (see Wydoski and Whitney, 1979, p. 41). *Gila atraria* presently inhabit springs in the Great Salt Lake Desert of widely varying salinity (freshwater to 2.5% NaCl). In addition, laboratory experiments conducted on these fish indicate they can readily tolerate waters with salt (Na) contents as high as 213 meq/L (Westenfelder and others, 1988).

Although most members of the large and diverse sculpin family (Cottidae) are benthic marine fishes, sculpins of the genus *Cottus* have invaded and adapted to inland freshwater lakes and streams. Both the cottids represented at Homestead Cave, *C. bairdi* and *C. extensus*, are found strictly in freshwater settings. Although it is possible these sculpin might be able to tolerate elevated salinities based on their evolutionary pedigree[5], their modern distributions clearly indicate they prefer freshwater environments. Thus, I consider them salinity-intolerant taxa in the analyses that follow.

Table XXXI shows the relative abundance in Strata Ia and Ib of the two groups of fishes that differ in their tolerance to salinity.[6] The salinity-intolerant taxa dominate both Strata Ia and Ib and, assuming both *C. extensus* and *C. bairdi* are represented by the *Cottus* sp. materials in Stratum Ib, no extinctions of species susceptible to high salinities are evident within the Stratum I fauna. There is, however, a significant decline in the relative abundance of salinity intolerant taxa across the two divisions of Stratum I ($X^2 = 4.31$, $P < 0.05$). That relationship remains significant if the sculpin, taxa whose tolerance to salinity remains in some question, are excluded from the analysis ($X^2 = 4.01$, $P < 0.05$). In sum, taxa intolerant of elevated salinities dominate both components of Stratum I, but they are significantly underrepresented in the upper portion of that deposit (Stratum Ib). At least upon initial inspection, a declining lake level and associated increase in salinity appear to be registered in the Homestead Cave ichthyofauna.

Temperature

The Homestead fishes can also be divided into two groups according to their relative sensitivity to high water temperatures. *Catostomus ardens* and *Gila atraria* are known to thrive in water temperatures over 26.7°C and 31.1°C, respectively. The other fishes represented at Homestead Cave are, as a group, much more sensitive to high water temperatures

O. clarki is most commonly found in cold water lakes and streams in western North America. Even though *O. clarki* occurs in Pyramid Lake, where surface water temperatures can reach as high as 23°C in the summer, the profundal water temperature of this lake remains a constant 6°C (Galat and others, 1981). Based on laboratory experiments, the upper lethal temperature for *O. clarki henshawi* is 23°C (Vigg and Koch, 1980). However, Behnke (1981, p. 101) reports an

Table XXXI
Numbers of identified specimens of salinity-tolerant and salinity-intolerant fish taxa from Strata Ia and Ib at Homestead Cave

	Stratum Ia	%	Stratum Ib	%
Salinity Tolerant				
Gila atraria	226	3.0	29	4.9
Salmoninae	279	3.7	23	3.9
Total	505	6.7	52	8.9
Salinity Intolerant				
Prosopium	6551	87.0	491	84.2
Catostomus	321	4.2	31	5.3
Cottus	197	2.6	9	1.5
Total	7069	93.0	531	91.1

unnamed subspecies of cutthroat trout in the headwaters of the Humboldt River, Nevada in waters up to 25.5°C. Optimum growth temperatures for trout are of course far lower (~16.5°C) than these lethal limits (Jobling, 1981).

Like virtually all members of the genus *Cottus*, both *C. bairdi* and *C. extensus* are found strictly in cool or cold water settings. There is no suggestion that these fish can tolerate warm water temperatures. The three *Prosopium* species represented at Homestead Cave are now endemic to Bear Lake where water temperatures do not exceed 14°C. In laboratory settings, *P. abyssicola*, *P. spilonotus*, and *P. gemmifer* develop debilitating abnormalities of the jaws when eggs are reared in temperatures over 5°C (Nielson, personal communication, 1998).

Table XXXII provides the abundance in Strata Ia and Ib of fishes that are sensitive to high water temperatures (*O. clarki*, *Cottus* and *Prosopium*) and those that are not (*Gila atraria* and *Catostomus ardens*). Although *O. clarki*, *Cottus* and *Prosopium* are present in both Strata Ia and Ib, there is a highly significant decline in their relative abundance across these stratigraphic divisions ($X^2 = 7.41$, $P << 0.01$). In other words, taxa that are intolerant of high water temperatures are underrepresented in Stratum Ib compared to Stratum Ia. Thus, an increase in water temperature also appears to be registered in the Homestead fish sequence.

Temperature Versus Salinity

Because the whitefish and sculpin species are sensitive to both high temperatures and salinities and because *Gila atraria* is tolerant of both of these conditions, change in the relative frequencies of these taxa cannot help us discriminate which of these variables had the greatest influence on Lake Bonneville's fish populations as the lake regressed during the late Pleistocene. As a result, it is possible that one or the other of these variables alone caused the mass mortality and extinctions of these fishes. Discriminating between the effects of temperature and salinity thus requires an analysis of change among taxa that are tolerant of one variable but not of the other. Of the major taxonomic groups represented at Homestead Cave, only *O. clarki* and *Catostomus ardens* meet this criteria. *O. clarki* is intolerant of high water temperatures but can readily adapt to increased salinity. *Catostomus ardens*, by contrast, can tolerate elevated water temperatures but is sensitive to increases in salinity. Change in the relative frequencies of *O. clarki* and *Catostomus ardens* across Strata Ia and Ib would allow us to estimate whether temperature or salinity provided the stronger limiting factor on fish rebounds or recolonizations across the period over which these materials accumulated.

Table XXXIII provides the numbers of identified salmonines (*O. clarki)* and *Catostomus (C. ardens)* for Strata Ia and Ib. *Catostomus ardens* are more abundant than *O. clarki* in both these sets of deposits and slightly more so in Stratum Ib (57%) compared to Stratum Ia (54%). That difference, however, is statistically insignificant ($X^2 = 0.30$, $P > 0.50$).

The analysis of change in fish size described above suggests that, as Lake Bonneville regressed episodically towards the end of the Pleistocene, its fish populations underwent a series of mass die-offs that were followed by brief rebounds or recolonizations. The analysis of change in relative abundance of species characterized by different salinity/temperature tolerances suggests that species tolerant of high salinites and/or temperatures were more successful at rebounding or reinvading the lake, although conditions were sufficiently fresh and cool to support the entire Bonneville fish fauna. It remains unclear, however, what the *relative* roles that temperature and salinity played in both limiting the success of these fish rebounds as the lake fluctuated and the ultimate extinction of the Lake Bonneville fish fauna.

Table XXXII

Numbers of identified specimens of temperature-tolerant and temperature-intolerant fish taxa from Strata Ia and Ib at Homestead Cave

	Stratum Ia	%	Stratum Ib	%
Temperature Tolerant				
Gila atraria	226	3.0	29	5.0
Catostomus	321	4.2	31	5.3
Total	547	7.2	60	10.3
Temperature Intolerant				
Prosopium	6551	86.5	491	84.2
Salmoninae	279	3.7	23	4.0
Cottus	197	2.6	9	1.5
Total	7027	92.8	523	89.7

Table XXXIII

Numbers of identified *Catostomus* and Salmonine specimens from Strata Ia and Ib at Homestead Cave

	Stratum Ia	Stratum Ib
Catostomus	321	31
Salmoninae	279	23

CHRONOLOGY OF LATE QUATERNARY LAKE-LEVEL FLUCTUATIONS IN THE BONNEVILE BASIN

It now seems clear that the Homestead Cave fish fauna resulted from a series of catastrophic die-offs associated with late Quaternary lake cycles in the Bonneville basin. Analysis of that fauna in relation to the detailed radiocarbon chronology provided by the Homestead deposits should thus shed light on our understanding of the timing of climatically controlled lake-level fluctuations in this region. To this end, I first examine the abundance of fish remains in the Homestead Cave deposits, relative to other vertebrates, to pinpoint the timing of the terminal Pleistocene extinction-recolonization cycles of Lake Bonneville's ichthyofauna. I then examine change in fish taxonomic composition across the Holocene sequence of deposits to inform on the chronology of fluctuations in Great Salt Lake. The results provide support for certain aspects of the lake-level chronologies based on core and shoreline data, but conflict with those chronologies in several important ways as well.

Lake Level Fluctuations of Terminal Pleistocene Lake Bonneville

Table XXXIV provides the numbers of identified mammal and fish specimens for each of the Homestead strata. Figure 93 shows the abundance of fish remains, relative to mammals, throughout the Homestead sequence. As noted above, fish remains are clearly concentrated in Stratum I of Homestead Cave. They account for over 26% of the assemblage in Stratum I but comprise, in most cases, far less than 1% of the fauna in the higher strata.

To further pinpoint the stratigraphic break in the Homestead deposits after which fish remains become rare, I examined the distribution of fish materials within Stratum I itself. In the bulk sediment sample taken from the lower 10 cm of Stratum Ia, fish comprise 23.5% (807 of 3,434 specimens) of the entire vertebrate faunal assemblage. By contrast, fish comprise only 0.02% (10 of 3,896 specimens) of the vertebrate materials from the upper 10 cm of Stratum Ib: a figure very similar to the relative abundance of fishes throughout the rest of the column. The difference in the frequencies of fish and non-fish vertebrate specimens across these divisions is astronomically significant ($X^2 = 955.34$, $P << 0.0001$). Fish remains are thus largely confined to Stratum Ia, and the lower microlaminae of Stratum Ib.

Fecal pellets of woodrats (*Neotoma* sp.) from the lowest 5 cm of Stratum Ia, directly overlying bedrock, date to 11,270 ± 135 yr B.P. (AA 14816), 11,263 ± 83 yr B.P. (AA 16809), 11,181 ± 85 yr B.P. (AA16808), and 11,065 ± 105 yr B.P. (AA 14817). Fecal pellets of woodrats taken directly from the upper 5 cm of Stratum Ib provided dates of 10,350 ± 80 yr B.P. (AA 11818) and 10,160 ± 85 yr B.P. (AA 11819). The die-offs of Lake Bonneville's fishes thus appear to have began shortly after ~11.3 ka[7] but were over sometime before ~10.4 ka.

Based on studies of shoreline features and sediment stratigraphy, it has been suggested that Lake Bonneville declined to elevations approaching those of the modern Great Salt Lake soon after 13 ka. Sometime after 12.2 ka, the lake rebounded again to form the Gilbert shoreline complex, peaking between 10.9 and 10.3 ka (Benson and others, 1992; Currey, 1990; Oviatt and others, 1992; Thompson and others, 1990). The plant macrofossil record, however, indicates that summer temperatures and evaporation rates were substantially depressed between ~13 and 11 ka, and suggests that a larger lake would have likely existed at this time (Rhode, chapter eleven).

Table XXXIV

Numbers of identified mammal and fish specimens by stratum at Homestead Cave

Stratum	Mammals	Fish	%Fish
XVIII	1047	8	0.08
XVII	15,548	117	0.08
XVI	6292	29	0.05
XV	—	5	—
XIV	—	57	—
XIII	—	101	—
XII	22,860	330	1.42
XI	10,096	65	0.06
X	6601	24	0.04
IX	22,088	52	0.02
VIII	8289	21	0.03
VII	13,905	36	0.03
VI	24,330	54	0.02
V	5109	8	0.02
IV	26,615	114	0.04
III	2884	51	1.73
II	7855	257	3.17
I*	10,275	3702	26.48
Total	183,798	5031	2.66

(*)Includes specimens from FS-63, the only provenience unit of Stratum I for which mammal materials were identified.

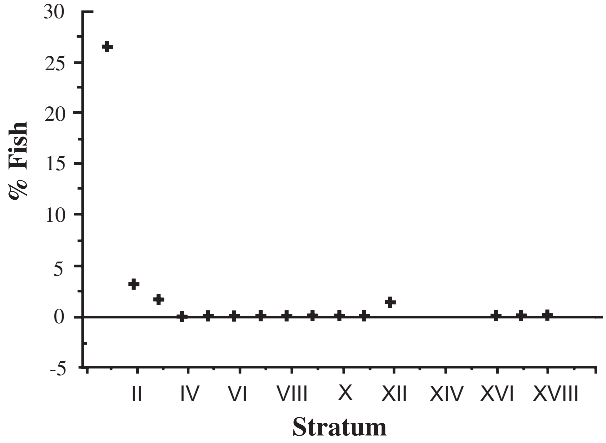

Figure 93. *Abundance of fish specimens, relative to mammals, across the Homestead strata.*

Cold-water lake fish are extremely abundant at the very base of Stratum I, a context that provided four radiocarbon dates with a weighted average of 11,201 ± 76 yr B.P. Thus, lake levels appear to have been sufficiently high (> ~1300 m based on the strontium isotope analysis; Quade, chapter two) to support the entire Lake Bonneville fish fauna from Provo times until ~11.2 ka. In the global climate scheme, this date corresponds with a brief, sharp, dry period, which Haynes (1991) has locally called the Clovis drought.

This was not, however, the end of fishes in Lake Bonneville and, subsequent to this first catastrophic die-off, at least one recolonization or rebound period occurred. The presence of this second, younger age-dominated, fish fauna can be interpreted in two ways. A Younger Dryas-age lake may have been too saline to contain fish and the fauna may simply represent a short period of lake-level fluctuation immediately following the initial die-off. Alternatively, there has been some suggestion that the lake may have supported fish populations during this period (Rosenfeld, 1991, p. 45, 1996; Grayson, 1993). Theoretical modeling and empirical analyses suggest that the uptake of salt by a growing lake from crustal efflorescences or from pore fluids found in lake basin sediments is a fairly slow process on the order of decades where it has been analyzed empirically (Lerman and Jones, 1973; Spencer and others, 1985). While it is not possible to estimate the rates of salinity uptake, it is possible a growing lake could have remained fresh for some time, closer to decades than centuries (B. Jones, personal communication, 1998), and may have supported the entire Lake Bonneville fish fauna, at least during the early to middle stages of its rise to the Glbert level.

Lake-Level Fluctuations of Great Salt Lake

As described above, Lake Bonneville was inhabited primarily by fishes now restricted to cold and freshwater habitats. However, the lake also supported populations of *Gila atraria*, a species that thrives in those settings, but is also abundant today in marshes and warmer, moderately saline, creeks and springs of the Great Salt Lake Desert. Based in part on the high degree of genetic similarity documented among now isolated populations of *Gila atraria* in the northern Bonneville basin, Rosenfeld (1991, p. 89) suggested that during wetter periods of the Holocene, Great Salt Lake may have become sufficiently diluted in places to support populations of the saline-tolerant *Gila atraria*. Even if *Gila atraria* could not have invaded Great Salt Lake during wetter cycles, the extent of local freshwater marshes, habitats these fish certainly would have inhabited, might be expected to vary positively with the extent of regional moisture and the elevation of the lake. Alternatively, if salinities of Great Salt Lake remained above the threshold of tolerance for *Gila atraria* even during its transgressions, an expanding lake may have drowned local freshwater marshes with highly saline water producing fish die-offs in these settings. In any case, *Gila atraria* frequencies should be linked to higher elevations of Great Salt Lake.[8]

Materials representing the Lake Bonneville fish fauna occur in very low frequencies above Stratum I in Homestead Cave and likely owe their presence in those contexts to limited mixing with that stratum. However, the *Gila atraria* materials in these upper strata may be derived not only from limited mixing with Stratum I but from Holocene-aged scavenging activities of owls as well. Insofar as substantial owl-based deposition of *Gila atraria* occurred in tandem with Holocene transgression-regression cycles of Great Salt Lake, then major peaks in the frequencies of *Gila atraria* within the Homestead deposits should signal those cycles.

Figure 94 shows the NISP values of *Gila atraria* across the Holocene-aged strata at Homestead Cave. The absolute abundances of *Gila atraria* exhibits two marked peaks: first within Stratum XII and second within Stratum XVII. While the absolute frequencies of any taxon can be expected to vary positively with the total sample of recovered bone, this factor does not appear to be the source of the two spikes in *Gila atraria* frequencies at Homestead Cave; the NISPs of *Gila atraria* are not significantly correlated with either the total mammal (r_s = -.284, P = .30) or the total bird NISPs (r_s = .41, P = .10) within the Homestead strata.

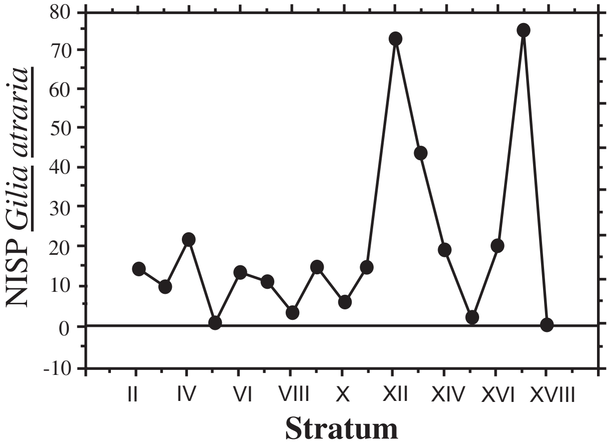

Figure 94. *NISP of* Gila atraria *through the Holocene deposits of Homestead Cave (Stratum I is not included).*

Several Holocene highstands of Great Salt Lake have been proposed. According to core and shoreline data, the most notable among them occurred between ~3 and 2 ka when the lake appears to have transgressed to a highstand of 1287 m and flooded the Great Salt Lake Desert (see chapter two; Murchison, 1989b; Currey, 1990; McKenzie and Eberlie, 1987; Mehringer, 1985). Although this transgression was clearly not high enough to allow the recolonization of the Lake Bonneville fish fauna, it may be recorded by the substantial increase in *Gila atraria* within Strata XII and XIII, contexts that provided radiocarbon dates of ~3400 and ~3480 yr B.P., respectively. The more dramatic increase in *Gila atraria* abundance occurs within Strata XVI and XVII, strata that provided radiocarbon dates of ~1200 B.P. and ~1020 B.P., respectively. Although a highstand of Great Salt Lake at this time has been documented from shoreline data, those data suggest it reached only to an elevation of ~1283 m and did not flood the Great Salt Lake Desert (Murchison, 1989a; Currey, 1990).

SUMMARY

1. The substantial fish fauna from Homestead Cave appears to have been accumulated by scavenging owls. The limited available evidence suggests that owls utilize fish resources only in very unusual circumstances, such as when fish are stranded on shorelines or exposed in very shallow water. North American owls are not known to take live fish from deep, open water but will readily scavenge stranded

fish carcasses. An owl-based accumulation thus suggests that the Homestead fishes were derived from die-offs of local fish populations.

2. The Homestead Cave fish assemblage is represented by 11 species of mostly cold- and freshwater-adapted species; four of these represent the first records for Lake Bonneville. The *Salvelinus confluentus* and *Catostomus discobolus* specimens provide the first fossil evidence for these species in the entire Great Basin; the *Salvelinus* premaxilla also represents the first specimen record of any kind for this genus in the Great Basin. These records provide a wealth of information on fish biogeography in the Bonneville basin; the *Salvelinus* specimen should have implications for fisheries management in the region.

3. A model of life history evolution of Great Basin minnows and suckers (Smith, 1981) suggests that these fish attain sexual maturity earlier and attain smaller adult body sizes in unstable environments characterized by high adult mortality. A significant decline in the mean and maximum size of minnows and suckers was documented across the Stratum I deposits. This pattern suggests that the fauna resulted from a process involving a series of fish die-offs.

4. Taxa intolerant of high water salinities and temperatures are significantly underrepresented in Stratum Ib compared to Stratum Ia, even though these taxa dominate both sets of deposits. A clear signal of decreasing water depth and increasing temperature and/or salinity is thus registered in the fauna. The data do not, however, allow us to tease apart the relative roles that temperature and salinity played in affecting fish die-offs and subsequent recolonizations of the lake's fish fauna.

5. The initial post-Provo die-off of the Lake Bonneville fish fauna occurred at ~11.2 ka, suggesting that climatically controlled lake levels were sufficiently high to support this fauna until that time. This result calls into question current models of lake-level history that posit a substantial regression beginning at 13 ka. The entire Bonneville fish fauna may have rebounded or recolonized the lake with the Gilbert transgression, but was permanently eliminated from the lake shortly before ~10.4 ka, toward the middle or the end of the Gilbert cycle. A late Holocene highstand of Great Salt Lake appears to have occurred around ~3.4 ka to judge from a substantial increase in *Gila atraria* within Stratum XII. This is roughly consistent with the proposed transgression of Great Salt Lake between ~3 and 2 ka based on core and shoreline data, albeit slightly earlier. An even more dramatic increase in *Gila atraria* occurs within Stratum XVII, deposits that date to ~1 ka, and suggests that a transgression-regression cycle of Great Salt Lake occurred at this time as well. Such an event has also been recorded in shoreline and core data.

ENDNOTES

[1] The identifications were based largely on comparisons with Recent fish specimens from the following collections: Division of Fishes, Museum of Zoology, University of Michigan; Department of Ichthyology, California Academy of Sciences; Division of Fishes, National Museum of Natural History; and The Utah Museum of Natural History.

[2] The single pharyngeal of *Richardsonius balteatus* was derived from deposits (F-17, FS-10-11) outside the column sample representing either Stratum I or II, but mostly likely Stratum I. Aside from this specimen, materials from this provenience unit have not been identified.

[3] Only nine specimens of *Cottus echinatus* were collected prior to its extinction in the 1930s: the holotype UMMZ 177376, UMMZ 156794 (two specimens), USNM 197681 (two specimens), USNM 30808, USNM 27414 (Bailey and Bond, 1963, p. 2) BYU 29212, and BYU 29213. All of these specimens are preserved whole in fluid, with the exception of UMMZ 156794: G. Smith cleared and stained a partial (Ridewood dissection) cranium of this specimen. I had access to the latter specimen, BYU 29212, and BYU 29213. Diagnostic features of the preopercle can be readily examined from fluid-preserved specimens.

[4] As a frame of reference, the mean vertebral widths of a modern 450 mm SL *Catostomus ardens* and a 202 mm SL *C. discobolus* are 8.76 and 2.84 mm, respectively.

[5] Several *Cottus* species (see *C. asper*, prickly sculpin, *C. gulosus*, riffle sculpin and *C. perplexus*, reticulate sculpin) that occupy coastal drainages in the Pacific Northwest are known to tolerate brackish waters (Wydoski and Whitney, 1979).

[6] In the analyses of temperature and salinity that follow, I assume the specimens identified as Salmoninae represent *O. clarki* since that species was the only member of this subfamily present in the materials of Strata Ia and Ib. Even if *Salvelinus confluentus* is represented in the salmonine material, this species has very similar temperature and salinity tolerances as *O. clarki*. Similarly, the materials identified as *Catostomus* sp. are assumed to represent *Catostomus ardens*. There is also no cost if this assumption is incorrect; the other *Catostomus* species represented at Homestead Cave, *C. discobolus*, has similar temperature and salinity tolerances to *C. ardens*.

[7] All of the following dates in this section refer to ^{14}C yr B.P.

[8] In this analysis, I assume the specimens identified as Cyprinidae represent *Gila atraria*, since *Gila atraria* represents well over 99% of the identified cyprinids at Homestead Cave.

ACKNOWLEDGMENTS

I thank Gerald Smith for his generous assistance on many aspects of this project, including the examination of the specimen reported here as cf. *Salvelinus confluentus*, discovering the *Richardsonius balteatus* specimen and providing reference specimens. I also thank Virginia Butler, Richard E. Broughton, Dominique Rampton, Shannen Robson and Andrew Ugan for helpful comments on the manuscript; Bryce Nielsen and Scott Tolentino for help in the collection of reference specimens at Bear Lake; Dominique Rampton for helpful assistance in the lab; Marlene Lambert-Tempest for figures 79 and 85; Monson Shaver III for his work on the Homestead fish posters; Walter Klippel for unpublished information on the Caney Creek owl roost; Dennis Shiozawa for help with the *C. echinatus* specimens at Brigham Young University; and the following museums for access to reference material: Division of Fishes, Museum of Zoology, University of Michigan; Department of Ichthyology, California Academy of Sciences; Division of Fishes, National Museum of Natural History; and The Utah Museum of Natural History.

CHAPTER TEN

Cathedral Cave Test Excavations

by

David B. Madsen, Dave N. Schmitt, and Monson W. Shaver III

INTRODUCTION

Cathedral Cave is ~850 m northwest of Homestead Cave on the western margin of Homestead Knoll (figure 95). The cave was initially investigated during exploratory operations in 1993, but was not selected for test excavation because of the difficulty of access and because Homestead Cave had more robust raptor deposits on its surface. However, as the Homestead Cave excavation progressed, it became apparent that the Cathedral Cave deposits should be explored because it seemed possible that the morphology of the cave might be conducive to the preservation of deposits older than those at Homestead Cave. Homestead Cave is relatively small and appears to have been cleaned out by wave action as Lake Bonneville regressed past the cave mouth. Cathedral Cave, on the other hand, is much larger and is fronted by a large calcium carbonate-cemented talus cone, which we thought may have protected older deposits inside the cave from wave action associated with the higher levels of Lake Bonneville. As a result, we conducted very limited test excavations at Cathedral Cave in the spring of 1995. These were designed only to determine the age of the basal deposits and the utility of the site for conducting the kind of paleoenvironmental research carried out at Homestead Cave.

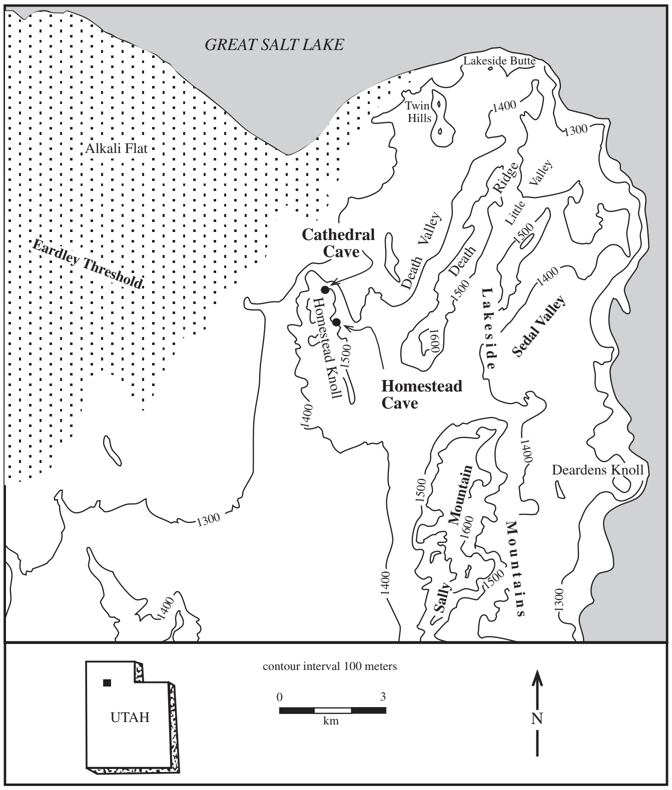

Figure 95. *Location of Cathedral Cave on Homestead Knoll, northwestern Lakeside Mountains.*

SITE SETTING AND DESCRIPTION

Cathedral Cave is a large limestone cavern directly overlooking the expansive playa of the Great Salt Lake Desert (figures 96, 97). The cave is a solution cavern created by groundwater moving through the Oquirrh Formation limestone which comprises the Homestead Knoll bedrock. The current morphology of the cave appears to predate the last highstand of Lake Bonneville, and it seems to have been largely unaffected by wave action associated with the regressive phase of the last lake cycle. It is possible, however, that the solution cavern was enlarged during the initial transgression of the lake to the Stansbury level some 20 to 24 ka. The cave is composed of a large antechamber, some 25 m wide by 20 m high, which tapers to less than 6 m by 10 m at a point 40 m from the mouth of the cave (figure 98). It continues beyond this point an unknown distance, and air currents within the cave suggest that it may eventually connect to the outside at another location. There are anecdotal reports that cold air escapes from the cave in crevices above and east of the cavern, but we have been unable to locate these other possible openings. The cave walls are almost vertical, while the roof and floor are almost flat.

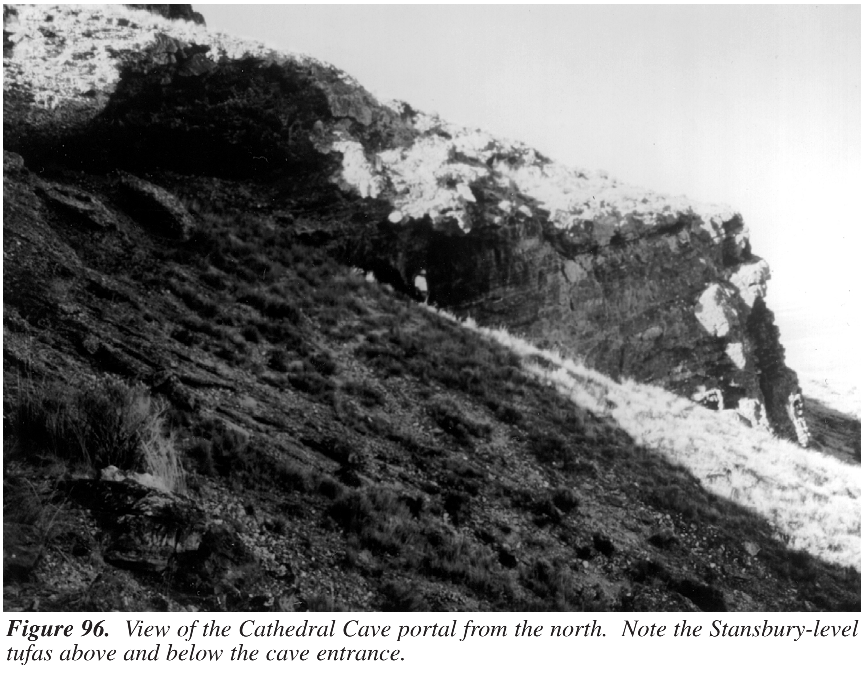

Figure 96. *View of the Cathedral Cave portal from the north. Note the Stansbury-level tufas above and below the cave entrance.*

Figure 97. View from Cathedral Cave looking northwest across the Eardley threshold and the playa of the Great Salt Lake Desert.

The cave opening is blocked by a large talus cone which extends completely across the cave mouth. This cone appears to be primarily coarse, angular limestone cobble and gravel colluvial material with only limited amounts of finer-grained materials. An extensive tufa-cemented breccia rings Homestead Knoll at an elevation of ~1402 m immediately above the cave, and large blocks of this tufa/breccia may form the core of the talus cone. The cone is more than 12 m high where it meets the top of the cave mouth. It completely blocks the north side of the cave opening, leaving only a narrow 2.5 m high by 7.25 m wide entryway on the south side. As a result, the main chamber of the cave has a high western window through which the afternoon sun sends shafts of light across the dim interior, creating the cathedral-like atmosphere which gives the cave its name. Anecdotal reports suggest that the north side of the cave mouth has been closed only within the last 5 to 10 years. Much of this closure may be due to the creation of a large woodrat midden which blocks the crevice, rather than to talus formation. The upper surface of the talus cone is heavily cemented by calcium carbonates which have formed a 2-5 cm thick shield on the upper one-half of the interior portion of the cone. Much of this appears to derive from moisture seeping through the limestone bedrock and dripping slowly onto the cone. In the spring, or after a series of particularly heavy storms, seepage is pervasive and rapid, and the interior of the cave is extremely humid. In many locations, calcium carbonate "straws" extend from the cave roof. During the winter and spring of 1994-1995, several of these straws grew 10 cm or more.

The axis of the cave is oriented 2.5 degrees west of true north, and when Lake Bonneville was at the level of the cave, northwest winds would have driven waves directly into the cave mouth across a fetch of more than 75 km. The elevation of the cave at the top of the depositional sequence inside the cave below the talus cone is 1383 m (all elevations were determined with a laser theodolite measuring from a marked United States Geological Survey section corner at the northwest corner of Section 6, T. 6 N., R. 9 W., Salt Lake Base Line and Meridian). In the northern Lakeside Mountains, this elevation is approximately in the middle of the Stansbury beach complex. The lowest well-defined Stansbury beach below the cave mouth is at an elevation of 1363 m, while the highest identifiable Stansbury beach is at ~1405 m above the cave.

The interior of the cave is almost completely coated 3.0-6.5 cm thick with a layer of tufa or travertine which extends along the cave walls

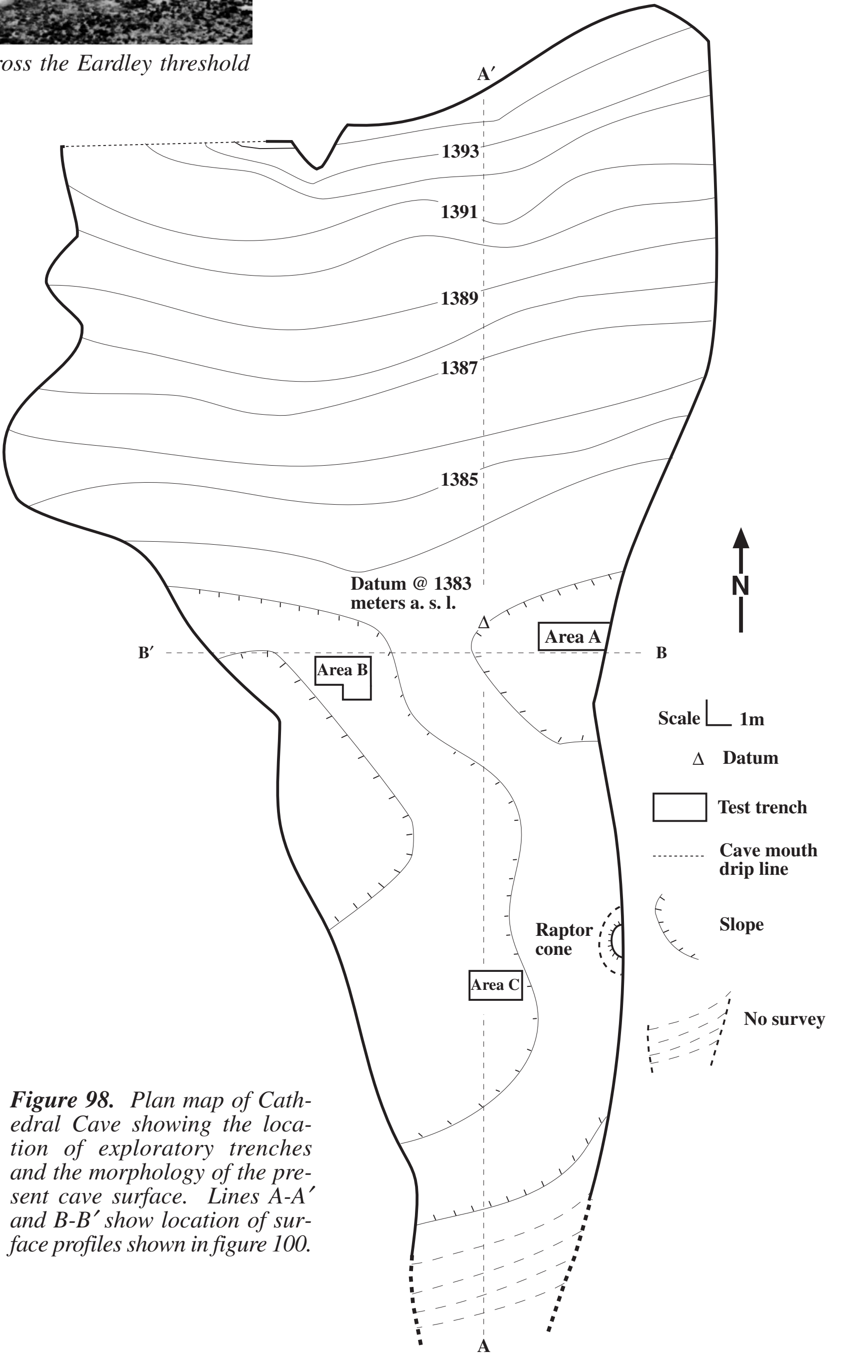

Figure 98. Plan map of Cathedral Cave showing the location of exploratory trenches and the morphology of the present cave surface. Lines A-A′ and B-B′ show location of surface profiles shown in figure 100.

and across most of the cave roof. It coats the cave as far back as we were able to observe, although it is somewhat thinner in the rear. The tufa coating has exfoliated off the cave roof in only a few areas and pea gravel-size limestone eboulis on the cave floor is limited to these locations. As a result, the surface of the interior cave deposits has a hummocky appearance, with eboulis mounds located directly below exposed limestone surfaces and valleys with limited deposition located below ceiling areas that are still coated with tufa (figure 99). These eboulis deposits are superimposed on lower materials that generally slope from back to front and from the north to south. This limited exfoliation of roof tufa has apparently occurred only in the mid- to late Holocene. The tufa on the cave walls merges with a travertine, which completely covers the cave floor and, as described below, underlies both the Holocene deposits and earlier deep-water deposits of Lake Bonneville. Thus, when tufa was forming (but see Interpretation and Implications, below), it coated all cave surfaces including the ceiling, walls and floor.

Modern raptor deposits are visible in three areas of the main cave chamber. The largest cone is found below a perch located just inside the cave mouth on the north edge of the present cave opening. A second small debris cone is ~5 m inside the cave along the southern wall. A third debris cone is ~30 m inside the cave mouth along the northern wall of the cave. The perch/nesting area associated with the latter debris cone appears to be currently active and we observed a pair of barn owls using the perch in 1994. We collected an array of recent owl pellets from the surface immediately below this perch for use in interpreting both the Homestead Cave and Cathedral Cave faunas. Woodrat middens occur at the mouth of the cave and in a crevice along the ceiling/wall juncture ~ 70 m inside the cave mouth on the northern wall. There is a limited amount of woodrat debris across the floor of the cave, extending all the way to the rear, but no definable nesting or midden areas other than those at the cave mouth.

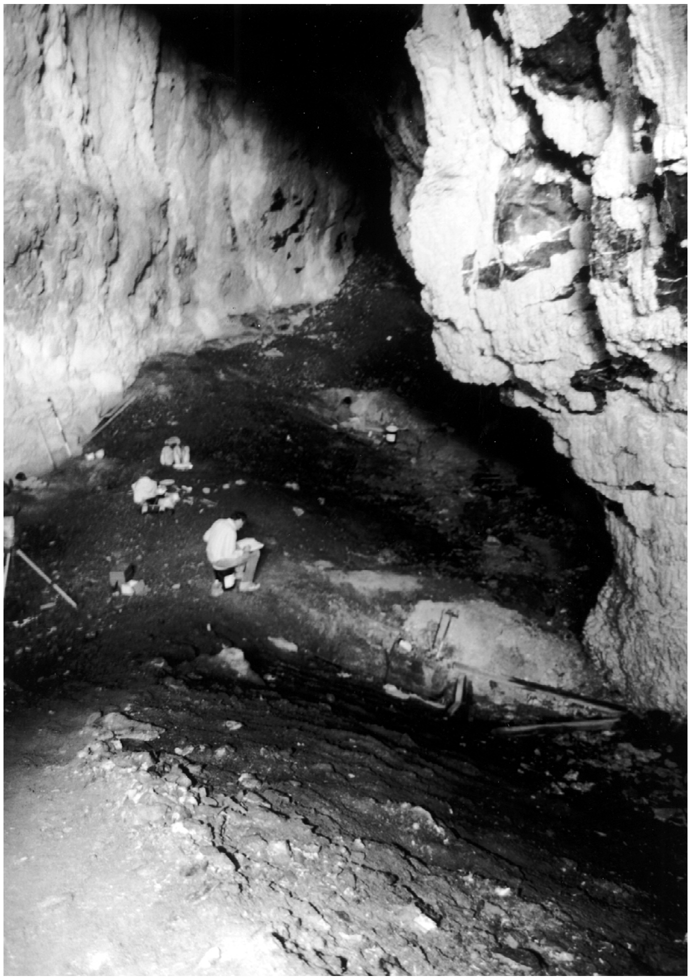

Figure 99. *View of the Cathedral Cave interior from the top of the talus slope at the cave mouth. Note the tufa coating on cave walls and the dark limestone spall on the floor.*

TEST EXCAVATIONS AND STRATIGRAPHY

Exploratory excavations were initiated in three areas within the main cave chamber. These were situated so as to explore areas we thought might have the deepest deposits containing the highest concentration of raptor materials, and to allow us to examine changes in cave stratigraphy along both the long and short axes of the cave (figure 100). Area A is a 1 x 2.5 m exploratory trench extending from the north wall of the cave towards the center of the cave deposits. Cave sediments were excavated only to the surface of the underlying travertine in this area. Deep-water lacustrine deposits and Holocene eboulis together range from less than 68 cm deep along the north wall of the cave to 165 cm deep at the cave axis. Area B is an L-shaped 2.5 m^2 exploratory excavation situated 6 m south and 1 m east of Area A so that the profiles of the two trenches provide a partial wall-to-wall cross section of the depositional sequence in the cave. Cave sediments are much thicker here than in the other two exploratory trenches, extending 1.65 m down to the top of extensive blocky limestone roof fall which appears to constitute the basal depositional layer. Because of this greater depth, the northeast corner of the excavation was selected as the location of a 0.5 x 1 m sample column (figure 101). Area C is a 1 x 2 m exploratory excavation located at the base of the innermost raptor debris cone. In this area maximum depth of the deposits to the top of the limestone roof fall is only 30 cm.

Fill from these exploratory trenches was passed through 6.3 mm mesh screen to examine the density of faunal material in each location and to search for any cultural materials which might be present. No culturally deposited materials were identified in any of the three excavation trenches, although burned branches occur on the surface as does a small hearth. These appear to be associated with historical visits to the cave. Once the stratigraphic sequence in Areas A and B was exposed, it was defined, mapped, described and photographed. The sequence in Area C was not mapped because of limited depth. After the deposits were described in detail, a 0.5 x 1 m sample column in Area B was excavated stratigraphically down to the top of the lacustrine deposits, and all fill was passed sequentially through 6.3 and 3.1 mm mesh screen. Faunal remains and fecal pellets were hand-sorted from this screened material. In some cases, the bulk samples which passed through the 3.1 mm mesh screen were bagged in total and returned to the laboratory for processing.

The lower lacustrine deposits were sampled somewhat differently. In order to maintain stratigraphic integrity for

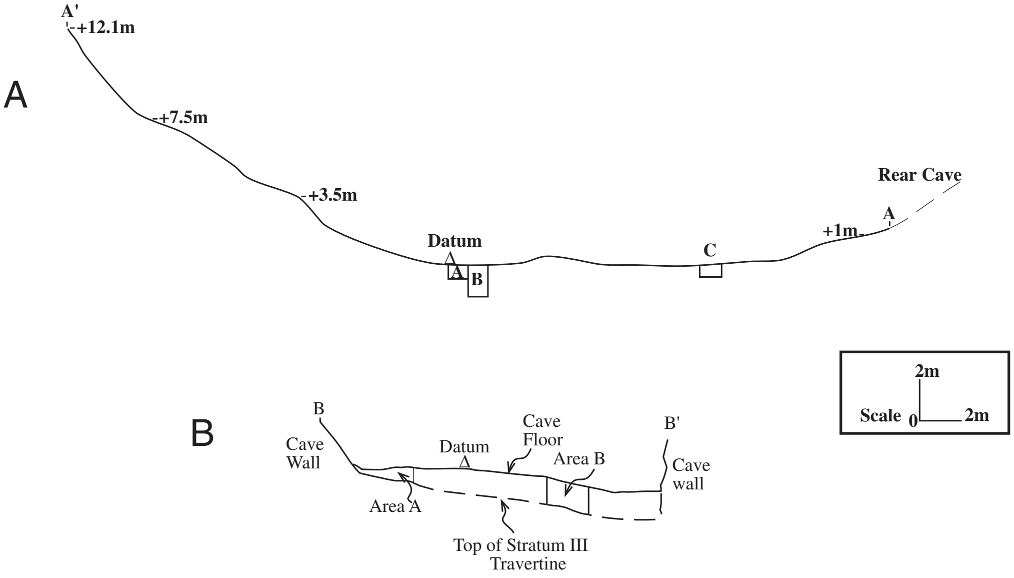

Figure 100. *Cross-section profile of the cave floor along the long axis of the cave (a); and cross-section profile across the cave through exploratory areas A and B showing both the modern surface and the top of the travertine deposits of Stratum III (b).*

detailed laboratory examination, two bulk samples of the upper deep-water deposits were collected from Area B by simply screwing coffee cans down through the thinly laminated lake clays and sealing them to prevent drying. Samples of the underlying layered travertine were collected from Areas B and C by breaking up the extremely hard calcium carbonate material with a sledge hammer, isolating large intact chunks, marking the vertical orientation, and bagging them for laboratory examination. The fine-grained lacustrine muds below the travertine were collected in large 45 liter bulk samples from Areas B and C in order to obtain a large representative sample of fish bone, snails and ostrocodes. The stratigraphic descriptions outlined below are derived from both the laboratory examination of these samples and detailed field descriptions of the Area A and B depositional sequence. The depositional sequence breaks readily into two discrete lacustrine and post-lacustrine sections, named here as Zone One and Zone Two (figure 101).

Zone One

The lower portion of the Cathedral Cave depositional sequence consists of lacustrine deposits which appear to be associated with the transgression and regression of Lake Bonneville past the cave portal (but see Interpretation and Implications, below). Together these deposits are less than a meter thick, but they represent 8-10,000 years of depositional history. These deposits are rather unusual, as virtually all other deep-water depositional sequences come either from the bottom of basins far removed from lake margins and sediment sources or from shoreline deposits. Depositional sequences from moderate depths at nearshore locations are rare.

Stratum I consists of large, angular limestone roof fall at the base of the deposits which could be penetrated in only a

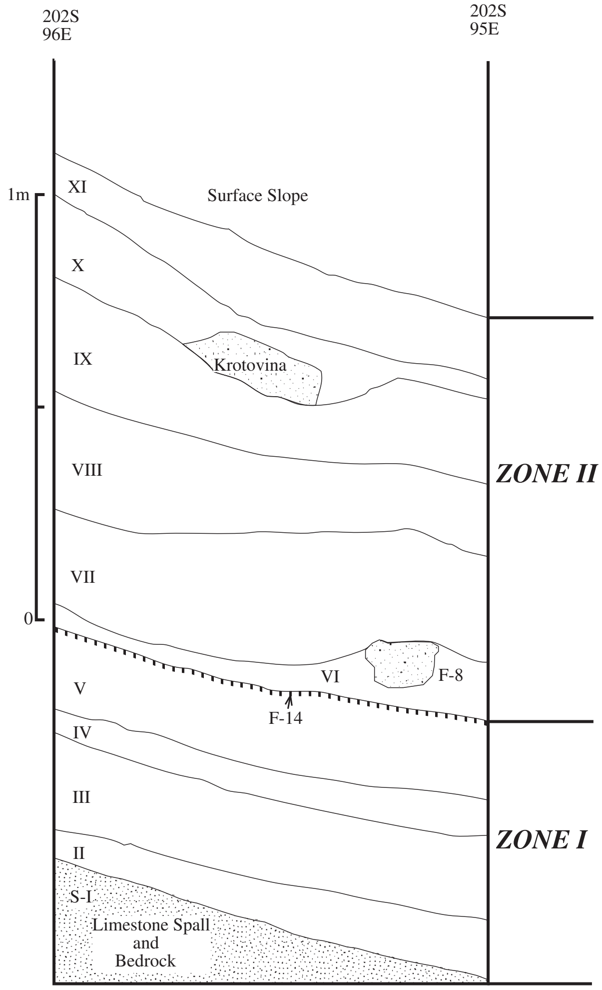

Figure 101. *Stratigraphic profile of the Cathedral Cave deposits on the west face of the sample column.*

few spots within the confines of the limited excavation areas, and we are unsure of the nature of bedrock materials. However, neither the roof fall nor the few exposed wall surfaces of the Oquirrh Formation limestone exhibit the kind of wave-polish modification found on bedrock surfaces of nearby Homestead Cave, and it may be that large talus at the cave mouth served as a breakwater, limiting wave action inside the cave. The vertical extent of the rockfall material is unknown at present. Some of these limestone blocks are thinly coated with an algal tufa unlike the travertines of Stratum III described below.

<u>Stratum II</u> is composed of laminated fine-grained lacustrine clays containing numerous ostracodes, gastropods and fish bones. Several layers at the base of the sequence are composed almost entirely of ostracodes, primarily *Candona caudata* and *Limnocythere staplini*. The gastropods are primarily *Amnicola* sp., although some *Limnaeid* sp. are also present. There are several thin, oxidized layers within the sequence. Stratum II is deposited in and around large roof fall on the bedrock floor (figure 101), and thus varies considerably in depth. Small lumps of tufa, possibly derived from the thin coat of tufa on this roof fall, occur sporadically within the laminated deposits. The uppermost portion of this stratum consists of a thin (>5 mm) white or light gray layer that has an abrupt lower boundary and contains broken and reworked ostracodes and carbonate lumps. Stratum II reaches a maximum of 15 cm thick in the Area C trench but may be thicker towards the mouth of the cave (figure 102). Desiccation cracks in Stratum II are filled in places by tufa associated with the deposition of Stratum III. Color (under florescent light) is reddish gray (5YR6/2).

Figure 102. *View of Stratum II profile in exploratory trench C. Note desiccation cracks.*

<u>Stratum III</u> consists of a set of interleaved and interbedded tufa/travertine deposits overlying the Stratum II muds. These generally conform to the cave floor topography and slope from north to south and east to west towards the cave mouth. In the area of the exploratory trenches near the base of the talus slope this gradient is low and the surface is almost flat. At least 25 individual layers are present, and many are separated by hollow spaces and/or fine-grained sediments which may have filled these spaces after deposition (figure 103). Together, the travertine layers reach a maximum of 23 cm thick. Layers of large calcium carbonate crystals have formed in these spaces in the lower portion of the sequence but are rare towards the top. These uppermost layers grade directly and continuously into the tufa coating on the cave walls and ceiling. There is no evidence of snails, ostracodes or fish remains. Color is varied due to the nature of the deposits, but is primarily white (5Y8/2) to pale yellow (5Y8/3).

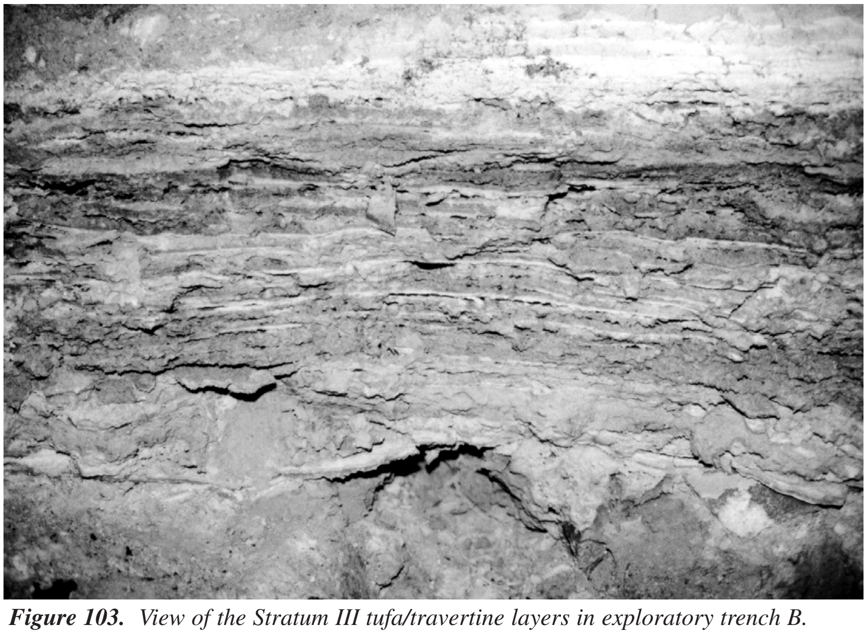

Figure 103. *View of the Stratum III tufa/travertine layers in exploratory trench B.*

The classification of tufas and travertines remains confused at best, and the relationship between particular forms and particular depositional environments is poorly defined (see Viles and Goudie, 1990; Pedley, 1990; Benson, 1994). However, in general, travertines are found primarily in shallow, flowing water situations, while tufas occur in pond or lake margin environments. The layered travertine deposits in Cathedral Cave therefore suggest very shallow-water conditions (<1 m) may have been present in the cave, with some increased flow of water seeping through the bedrock from sources in the rear of the solution cavern. The layering suggests the lake may have been fluctuating near this elevation, although it is possible the fine-grained silts and clays represent storm surges. If so, these travertine layers thus represent a time when Cathedral Cave was essentially a sea cave, with the lake covering the floor to depths of 1-5 m (depending on the slope) while the upper 10-15 m of the cave remained open.

Alternatively, Stratum III may have formed from massive ground-water discharge into the cave as the lake dropped below the cave mouth during an early oscillation in the regressive phase of the last major lake cycle. It is possible the travertines formed in sandy or pelletal layers between the two mud beds after they were deposited and are the result of rapid precipitation of aragonite at the boundary between the impermeable muds.

Stratum IV is composed of very finely laminated deep-water lacustrine deposits. Basal laminae are white, shifting to gray and brown at the top, with upper laminae appearing somewhat coarser than the lower. Color (under florescent light) grades from white (5Y8/2) at the base, to light gray (5Y7/2) in the middle to pale olive (5Y6/3) at the top. These lake marls contain numerous ostracodes, primarily *Candona caudata* and *C. eriensis*(?) at the base and *C. caudata*, *C. lacustris* and *Limnocythere ceriotuberosa* at the top. Occasional unidentified fish bone and snail shell fragments occur in the middle of the sequence. *Amnicola* sp. is the common gastropod in the upper portion of the sequence. Small flakes of limestone eboulis occur throughout the sequence. The deposits conform to the Stratum III surface and are thickest at the front west edge of the test exposures where they reach a maximum of 16 cm thick. Towards the rear of the cave in Area C, the Stratum IV marls are thin and appear to have been eroded away by wave action. There is a readily identified surface between the lower white marls and the darker layers of the upper section that may relate to the Bonneville flood. If so, this depositional change dates to ~14.5 ka (Oviatt and others, 1994). Pollen from the upper, darker laminae provided an age estimate of 15,310 ± 60 yr B.P. (WW1802), but this must be considered to be only a limiting date. That is, the true age is likely to be younger than this date (see below).

Stratum V is a layer of reworked marl containing numerous broken ostracodes and gastropods. Its surface is quite undulating and almost has the appearance of an eolian dune, although it appears to have been reworked by water. Due to these undulations, the thickness of this depositional unit varies from 27 cm to 4 cm within less than 50 cm horizontally. Stratum V rests directly on the laminated marls of Stratum IV, but there is no sharp break, and there is only a faint surface between the coarser upper materials of Stratum IV and the reworked marls of Stratum V. Some small limestone eboulis is present in very limited amounts, but there is no evident bone. Color (under florescent light) is light yellowish brown (2.5Y6/4). The deposits appear to be the result of wave action reworking the Stratum IV marls into a beach as Lake Bonneville regressed past the mouth of Cathedral Cave at the close of the Pleistocene. The upper surface of this reworked marl beach is uniformly marked by an oxidized/organic stain 2-3 cm thick which is found throughout the deposits. This oxidized surface appears to represent a relatively long depositional hiatus following the regression event, during which little or no material was introduced into the cave by any eolian, colluvial, or biotic vector.

Zone Two

The upper zone represents depositional events associated with the accumulation of materials in Cathedral Cave after Lake Bonneville permanently regressed below the cave portal. These upper deposits are relatively consistent and are very difficult to distinguish from one another in terms of either texture or color. They are composed almost entirely of sand- to pea gravel-sized limestone spall and limited amounts of organic debris and are a uniform very dark gray. These Zone Two strata are defined only in the Area B exploration trench and may be very difficult to follow horizontally across the cave deposits as a whole. We could not, for example, feel confident of our attempts to correlate these deposits in the Area A and B trenches even though they are less than two meters apart.

Stratum VI is composed of mixed limestone eboulis, tufa spall and reworked sand-sized fragments of marl, and represents the earliest post-lake deposition in the cave. It overlies the oxidized surface of Stratum V and fills in its deeper undulations. As a result, thickness varies from 5 to 32 cm, although the upper surface of the stratum is relatively uniform. It contains very minor amounts of bone, but no evident plant macrofossils. The limestone spall is generally small to medium in size, with some reaching 10 cm. The tufa spall is much larger and is composed of fragments up to 30 cm across. The reworked beach sand in the stratum appears to be derived both from bioturbation and from the large spall falling on and churning up the Stratum V surface. Because of these mixed deposits, the stratum is varied in color, but (under florescent lights) is primarily light brownish gray (10YR6/4).

Stratum VII is a dark layer of fine to medium limestone spall containing numerous fragments of wall and ceiling tufa and a variety of small bones. There are no apparent plant macrofossils. The dark appearance is due to sand-size limestone spall that may have disintegrated in place. Stratum VII is vaguely stratified, and its upper and lower surfaces are relatively uniform. Thickness ranges from 12-18 cm. It can be distinguished from the overlying Stratum VIII only with great difficulty and is separated on the basis of a layer of relatively coarser spall on the interface between the two units. Color is too dark to define adequately. A sample of bone from the stratum provides an age estimate of 3870 ± 50 yr B.P. (Beta 85683).

Stratum VIII is virtually identical to Stratum VII but can be distinguished by the presence of small amounts of plant macrofossils as well as the coarse eboulis unit mentioned above. A variety of small bone is also present. Like all the upper spall layers, it is characterized by very fine sand-sized limestone spall which gives it its color and texture. Medium spall to ~2 cm diameter is common. Its upper and lower surfaces are relatively uniform and the stratum varies from 20-25 cm thick throughout the exposure. Color is too dark to define adequately.

Stratum IX is also very similar to Strata VII and VIII but is readily distinguished from the overlying, more organic, Stratum X. It too is characterized by very fine sand-sized limestone spall, with some medium-sized spall reaching 2 centimeters. Several small microlaminae are evident in the profile, but these cannot be traced laterally beyond a few cm. Small bone and plant macrofossils are present. Color is also too dark to define adequately. Stratum IX is thickest towards the front of the cave below the talus cone and narrows sharply towards the rear. It varies in thickness from 35-10 cm in less than one meter horizontally.

Stratum X is a layer of mixed limestone spall and fibrous organic material. Much of this latter material is composed of large branches of sagebrush/rabbitbrush and other desert shrubs. In spots, this shredded fibrous material comprises the bulk of the unit. The lower surface of the stratum is marked by a thin eolian deposit that can be traced only intermittently across exposed profiles. The unit as a whole is very irregular, ranging in thickness from 3-30 cm, and in places is very difficult to recognize. In a few locations it forms the surface deposit. A sample of bone from the stratum provides an age estimate of 740 ± 40 yr B.P. (Beta 85682).

Stratum XI is the surface spall deposit and has characteristics very similar to Strata VII-IX. It contains sand- to pea gravel-sized limestone spall, with 2-3 cm diameter spalls being common. The unit contains some fibrous material derived from desert shrubs and some small bone. It varies in thickness from 15 to 0 cm in areas where the underlying Stratum X is exposed. Stratum XI is disturbed in spots by exploratory digging, and some of the back dirt from these holes covers both the Strata X and XI surfaces. Color is too dark to define adequately.

CHRONOLOGY

Temporal controls for the Cathedral Cave depositional sequence are provided directly by three radiocarbon dates, and indirectly by diagnostic microfauna, primarily ostracodes, which are well dated in other locations throughout the Bonneville basin (table XXXV). These faunal “events” occur in the Zone One lacustrine deposits and help provide some structure for the prolonged 10,000+ year history represented by these strata.

A general assessment of the age of the Stratum III travertines and that of the overlying Stratum IV lacustrine deposit is provided by a date on pollen from the Stratum IV muds. The calcium carbonate deposits on the floor and walls of the cave appear to be part of the same depositional event and were likely deposited during a lake-level oscillation during either the trangressive or regressive phases of the last lake cycle. Given the number of interpretive problems associated with such factors as diagenesis and redeposition in dating tufa (see Pazdur 1988; Pazdur and others, 1988), and that tufa dates have been particularly difficult to interpret in the Bonneville basin (see Oviatt and others, 1992), we sought to date pollen from the overlying lacustrine deposits to help us determine whether the travertines are associated with the transgressive or regressive phase of the last Lake Bonneville cycle. Although the ages of pollen in these deposits may differ by hundreds of years from the true age, the difference between the ages of a trangressive and regressive phase oscillation is on the order of thousands of years. A transgressive-phase oscillation most likely dates to the age of the Stansbury level at ~22-20,000 B.P., while a regressive-phase oscillation most likely postdates the age of the Provo level at ~14.5 ka. Moreover, pollen dates are most likely somewhat younger than their true age due to an unknown reservoir effect and to redeposition of older materials. This seems to be a common problem in western North American lakes (see Madsen and others, 2000). For example, pollen dates from samples in Great Salt Lake cores taken immediately above and below Mazama tephra are ~700 ^{14}C yr older than the well-established age of the ash.

Pollen from the base of the Stratum IV lacustrine clays dates to 15,310 ± 60 yr B.P. (WW 1802), suggesting that the age of all the Stratum IV deposits is younger, possibly as much as 1000 years younger, than 15.3 ka. Thus, it seems likely that the upper lacustrine deposits, and possibly the travertines below them, are associated with a post-Provo regressive phase, and that the Stratum II lacustrine deposits are associated with the highest Bonneville and Provo levels of the last lake cycle. Alternatively, the Stratum IV clays may be associated with the highest elevations of the lake. The upper dark gray, fine-grained sediments and the lower white marl of Stratum IV are separated by an abrupt boundary which contains an array of broken and reworked ostracodes, many of which are carbonate coated. This abrupt boundary may mark the Bonneville flood, during which lake levels were lowered catastrophically, and lacustrine sediments were redistributed and reworked on the lake bottom (Oviatt and others, 1994). Although the interior of Cathedral Cave was in a detrital rain shadow and well below wave base during this event, evidence from other lake floor locations suggests turbation of lake waters during this dramatic event was more than sufficient to wash these broken and reworked ostracodes into the cave. Similar boundary layers have been identified in a variety of Bonneville marl sequences and are confidently dated to ~14.5 ka.

Temporal controls for the Zone Two eboulis deposits are provided by two AMS dates on collagen extracted with alkali from artiodactyl bone fragments collected from Strata VII and X. Bulk collagen dates have often been shown to be in error (see Stafford, 1990) due to systematic differential amino acid degradation which produces dates younger than the actual age. When protein preservation is good, however, as in the case of bone samples from the Homestead Knoll caves, collagen dates can provide a relatively close approxi-

Table XXXV

Dated strata from Cathedral Cave

Stratum	**^{14}C Age**	**Lab No. (yr B.P.)**	**Material**	**Calibrated Calage Range (B.P. @ 2σ)**
IV	15,310 ± 60	WW 1802	pollen	17,765 - 18,889
VII	3870 ± 50	Beta 85683	collagen	4097 - 4,419
X	740 ± 40	Beta 85682	collagen	573 - 730

mation of the true age. At the very least, the dates provide limiting ages, in this case probably very closely limiting ages, for the deposition of these strata. The $^{13}C/^{12}C$ adjusted conventional age for Stratum VII is 3870 ± 50 yr B.P. (Beta 85683), and that for Stratum X is 740 ± 4 yr B.P. (Beta 85682). When converted to calendar ages using a calibration program produced by Stuiver and others (1998), these dates produce age ranges (at 2σ) of 4097-4419 cal yr B.P. and 573-730 cal yr B.P., respectively. The age range for the Stratum VII date is unusually large due to multiple intercepts of the calibration curve.

FAUNAL REMAINS

The limited excavations at Cathedral Cave recovered 770 skeletal specimens representing at least 14 species. The collection is dominated by the remains of small animals, many of which appear to have been deposited by avian and mammalian predators inhabiting the cave. The recovered faunal assemblage is surprisingly small, especially when considering site context and clear evidence of raptor habitation. Nevertheless, the bones provide supplementary data on Holocene zoogeography in the northern Bonneville basin.

Table XXXVI presents the number of identified specimens (NISP; see Grayson, 1984) by stratum from Area B. A few bones also were collected from excavations adjacent to the east wall in Area A from Strata XI (NISP=7) and VI (NISP=13). Both strata contained bird and hare (*Lepus* sp.) bones, and Stratum XI contained two large artiodactyl (bison/cow-sized) rib fragments. The following presents a summary of identified species and anatomical parts in the Area B assemblage. Discussions include modern records of various taxa in the Lakeside Mountains vicinity and, where pertinent, criteria used in species identification.

CLASS MAMMALIA-MAMMALS

Order Chiroptera - Bats

Material: 1 skull fragment, 1 mandible, 2 mandible fragments: 4 specimens.
Remarks: A variety of bats are found currently in the Lakeside Mountains and vicinity (see Durrant, 1952). Due to our lack of sufficient comparative skeletons, no attempt was made to identify the Cathedral Cave Chiroptera remains.

Order Lagomorpha - Rabbits, Hares and Pikas

Family Leporidae - Rabbits and Hares
Sylvilagus sp. - Rabbits

Material: 1 skull fragment, 1 isolated tooth, 1 distal femur, 1 distal tibia: 4 specimens.
Remarks: Hall (1981, pp. 303-309) reports both Nuttall's cottontail (*Sylvilagus nuttallii*) and Audubon's cottontail (*S. audubonii*) in the Cathedral Cave vicinity. The Cathedral Cave rabbit bones are larger than those of *B. idahoensis*, representing *S. nuttallii* and/or *S. audubonii*.

Lepus sp. - Hares

Material: 1 isolated tooth, 1 proximal humerus, 1 vertebra fragment, 1 innominate fragment, 1 calcaneus, 1 carpal/tarsal, 1 phalanx: 7 specimens.
Remarks: The black-tailed jackrabbit (*Lepus californicus*) is the only species of hare that resides in the Cathedral Cave area today (Durrant, 1952). However, *L. townsendii* (and probably *L. americanus*) occupied low-elevation settings in the region during the late Pleistocene and early Holocene (see Grayson, 1987; see also chapter seven). We observed a

Table XXXVI
Numbers of faunal specimens by stratigraphic unit at Cathedral Cave

Taxon	XI	X	IX	VIII	VII	VI	Total
Chiroptera	-	-	-	-	4	-	4
Sylvilagus sp.	4	-	-	-	-	-	4
Lepus sp.	1	-	2	2	2	-	7
Spermophilus sp.	4	-	4	2	-	-	10
Thomomys sp.	4	-	-	2	-	-	6
Thomomys bottae	2	-	-	-	-	-	2
Perognathus longimembris	-	-	-	1	-	-	1
Dipodomys sp.	7	2	5	5	13	1	33
Dipodomys microps	-	-	2	1	-	-	3
Peromyscus maniculatus	1	-	-	2	1	-	4
Neotoma sp.	5	2	1	3	7	-	18
Neotoma lepida	1	1	-	-	5	-	7
Artiodactyla	-	1	-	1	10	1	13
Reptilia	6	1	9	9	22	3	50
Aves	6	-	-	-	1	4	11
Large Mammal	3	14	3	-	1	-	21
Small Animal	95	14	47	123	228	39	546
Unidentified	-	2	-	1	6	1	10
Totals	139	37	73	152	300	49	750

few *L. californicus* while conducting field investigations in the Homestead Knoll vicinity and jackrabbit remains were abundant in the golden eagle prey assemblage collected immediately east of the cave at Cathedral Roost (Schmitt 1995).

Order Rodentia - Rodents

Family Sciuridae - Squirrels and Relatives

Spermophilus sp. - Ground Squirrels

Material: 1 skull fragment, 2 mandible fragments, 1 distal humerus, 1 innominate fragment, 1 femur, 1 distal femur, 1 tibia, 2 proximal tibiae: 10 specimens.
Remarks: A number of squirrels are to be expected in the northern Lakeside Mountains, including *Spermophilus mollis,* (Townsend's ground squirrel), *S. lateralis* (golden-mantled ground squirrel) and *Ammospermophilus leucurus* (white-tailed antelope squirrel) (Durrant, 1952).

Family Geomyidae - Pocket Gophers

Thomomys sp. - Smooth-toothed Pocket Gophers

Material: 2 skull fragments, 1 mandible fragment, 3 isolated teeth: 6 specimens.

Thomomys bottae - Botta's Pocket Gopher

Material: 2 skull fragments: 2 specimens.
Remarks: *Thomomys bottae* is the only species found in the Cathedral Cave vicinity today (Durrant, 1952). Our identification of two fragmentary skulls as *T. bottae* was based on rostrum characteristics reported by Thaeler (1980).

Family Heteromyidae - Pocket Mice, Kangaroo Mice, and Kangaroo Rats

Perognathus longimembris - Little Pocket Mouse

Material: 1 mandible fragment: 1 specimen.
Remarks: Although Durrant (1952, p. 238) reports the nearest record some 70 km north of Homestead Knoll near Kelton (elevation 1288 m), the presence of *Perognathus longimembris* in the Cathedral Cave fauna is not surprising. This diminutive taxon is known to inhabit low deserts and valley slopes throughout most of the Great Basin.

Dipodomys sp. - Kangaroo Rats

Material: 3 skull fragments, 2 mandible fragments, 8 isolated teeth, 3 humeri, 1 distal humerus, 3 ulnae, 3 innominate fragments, 1 proximal femur, 2 distal femora, 2 proximal tibiae, 5 distal tibiae: 33 specimens.

Dipodomys microps - Chisel-toothed Kangaroo Rat

Material: 1 mandible fragment, 2 isolated teeth: 3 specimens.
Remarks: Both the chisel-toothed kangaroo rat and Ord's kangaroo rat (*Dipodomys ordii*) are currently found in the Lakeside Mountains vicinity (Durrant, 1952; Hall, 1981). As its name suggests, the chisel-like cutting surface of *D. microps'* lower incisors are easily recognized and unique to the species (see Hall, 1946, p. 417, or Grayson, 1993, p. 24). *Dipodomys microps* remains were common in the sample of barn owl (T*yto alba*) pellets we collected from Cathedral Cave.

Family Muridae - Rats and Mice

Peromyscus maniculatus - Deer mouse

Material: 1 skull fragment, 3 mandible fragments: 4 specimens.
Remarks: Deer mice are found throughout North America and occur in a variety of Great Basin environmental contexts. A number of *Peromyscus maniculatus* were trapped during 1995 field investigations on Homestead Knoll (chapter seven), and their remains were identified in modern barn owl pellets collected from Cathedral Cave. Other species of mice that are known in southern Box Elder County include the canyon mouse (*P. crinitus*), northern grasshopper mouse (*Onychomys leucogaster*) and western harvest mouse (*Reithrodontomys megalotis*) (Durrant, 1952; Hall, 1981).

Neotoma sp. - Woodrats

Material: 1 skull fragment, 2 mandible fragments, 1 isolated tooth, 1 humerus, 3 distal humeri, 3 radii, 1 ulna, 2 innominate fragments, 1 proximal femur, 1 distal femur, 2 distal tibiae: 18 specimens.

Neotoma lepida - Desert Woodrat

Material: 1 skull fragment with M^1 and M^2, 1 mandible fragment with M_1, 5 isolated teeth: 7 specimens.
Remarks: Both *Neotoma lepida* and *N. cinerea* (the bushy-tailed woodrat) were trapped in Homestead Cave and vicinity during our 1995 field investigations (see Grayson and others, 1996 for the biogeographic significance of this low-elevation *N. cinerea* record). Our identification of Cathedral Cave *Neotoma* specimens employed morphological attributes and comparisons of molar occlusal lengths with modern *Neotoma* specimens reported by Grayson (1988, pp. 21-22, 53-55). The shallow reentrant angle of the anterior prism of M^1 retained in the single skull fragment (Stratum X) is characteristic of *N. lepida*; the maxillary alveolar length of this specimen (8.10 mm) also falls within the range of the species. Table XXXVII presents the occlusal lengths of isolated *Neotoma* molars recovered from the cave. Except for the single M_3 (Stratum VII), all of the occlusal lengths fall within the range of modern *N. lepida* and are smaller than those reported for *N. cinerea* (see Grayson, 1988, table 5). Since the size of the M_3 falls within the range of both *N. lepida* and *cinerea* and several of the larger specimens of woodrat pellets fall within the range of *N. cinerea* (see below), it is possible that bushy tailed woodrats also inhabited the cave.

Table XXXVII

Occlusal lengths (mm) of isolated *Neotoma* molars from Cathedral Cave

Stratum	Molar	Length	Species
X	M^1	3.04	*N. lepida*
VII	M_1	3.10	*N. lepida*
VII	M_1	2.89	*N. lepida*
VII	M_2	2.53	*N. lepida*
VII	M_2	2,55	*N. lepida*
VII	M_3	1.91	*Neotoma* sp.

Order Artiodactyla - Artiodactyls

Material: 1 thoracic vertebra fragment, 2 lumbar vertebra fragments, 9 rib fragments, 1 sacrum fragment: 13 specimens.

Remarks: All of the Area B ungulate remains are from small artiodactyls and represent deer (*Odocoileus hemionus*), pronghorn (*Antilocapra americana*) and/or bighorn sheep (*Ovis canadensis*); unfortunately, the fragmentary axial elements recovered from the cave could not confidently be identifed beneath taxonomic order. Ten specimens were found clustered in Stratum VII and likely represent bones from a single individual. Proximal rib fragments from Strata X and VII were submitted for ^{14}C assay and returned $^{13}C/^{12}C$ adjusted dates of 740 ± 40 and 3870 ± 50 yr B.P., respectively. Both specimens were destroyed by collagen extraction and subsequent radiocarbon analysis.

CLASS REPTILIA - REPTILES

Order Squamata - Lizards and Snakes

Material: 5 skull fragments, 2 mandible fragments, 42 vertebrae/vertebra fragments, 1 innominate fragment: 50 specimens.

Remarks: Reptile remains were recovered throughout the deposits excavated (table XXXVI). No attempt was made to identify the reptilian bones beneath taxonomic order.

Class Aves - Birds

Material: 2 proximal humeri, 1 distal humerus, 1 distal radius, 1 carpometacarpus, 2 vertebra fragments, 2 proximal femora, 2 distal tibiotarsi: 11 specimens.

Remarks: Morphological differences (notably bone size) indicate at least three species of bird are represented in the modest Cathedral Cave faunal assemblage.

The majority of the bones were recovered from late Holocene limestone and tufa spall accumulations (Strata VII-XI) and all identified specimens represent taxa that currently reside in the Cathedral Cave vicinity. Analysis of the faunas and the results of radiocarbon dating offer some information on when various animals inhabited the region but also provide data on how these materials accumulated. The cave contains abundant evidence for habitation by non-human predators and collectors, especially nocturnal raptors (see chapter two). Given this evidence, we surmised that most small animal specimens were deposited by avian predators. In an attempt to identify accumulative mechanisms in the cave we examined each bone for evidence of partial digestion, including corrosive pitting, rounding of fracture surfaces, extensive polish, and/or adhered matting or hair. Clear evidence of partial digestion was observed on animal remains recovered throughout the deposits, together representing approximately 40% of the small fauna (table XXXVIII). Although significant numbers of scat/pellet bones were identified, we are confident that a much greater proportion of the bones was deposited by raptors but passed undetected in our analyses; evidence of digestive attrition is often difficult to detect on small bone fragments (Schmitt and Juell, 1994) and many skeletal portions cast in owl pellets (especially those of *Tyto alba*) are complete and largely undamaged (Hoffman, 1988; Kusmer, 1990). Regardless, the varying frequencies of identified scat/pellet bones tend to reflect intermittent raptor habitation during the late Holocene.

OSTRACODES, FECAL PELLETS AND PLANT MACROFOSSILS

The primary purpose of our test excavations at Cathedral Cave was the recovery of the faunal sample described above. However, we also recovered a variety of other biological materials in association with a number of the geological samples. Most of these come from the Zone One sediments and are derived from deep-water Lake Bonneville deposits.

Ostracodes (*by Charles G. Oviatt*)

Ostracodes are microorganisms common in virtually all aquatic environments and, together with diatoms, form the primary organism record of the physical and chemical properties of lake waters. Ostracode species are so habitat-specific that they are highly suited to detailed paleoenvironmental interpretations. Ostracode valves are composed of low-magnesium calcite and are readily preserved in many lake environments (Forester, 1987, pp. 266-267). They are common in the sediments of Lake Bonneville, and variation in the number and proportion of different taxa has proved useful in identifying changes in lake level (see Thompson and others, 1990; Oviatt and others, 1994). Nine samples have been briefly analyzed to provide an assessment of the lacustrine sequence in Cathedral Cave. These include: (1) a section 10 cm thick of the lower Stratum II muds which was divided into six subsamples, (2) two samples from the lower and upper marls of Stratum IV, and (3) a single sample from the reworked Stratum V beach material. The samples from Stratum II were contiguous, and the boundaries were based on color and textural changes on a cleaned surface. These samples were labeled with the depth ranges (from the bottom up) in centimeters. Ostracode samples were prepared using

Table XXXVIII

Numbers of small animal bones and small animal scat/pellet bones by stratum at Cathedral Cave (Tallies include taxonomically identified specimens)

	XI	X	IX	VIII	VII	VI	Total
Total Small Animal	130	20	70	149	284	44	697
No. of Scat/Pellets	80	7	30	62	94	15	288
% Scat/Pellets	61.5	35.0	42.9	41.6	33.1	34.1	41.3

a method developed by Forester (1985), which involves a hot water bath, addition of baking soda, a freeze-thaw cycle, and wet sieving. The ostracodes were examined under a stereomicroscope. Table XXXIX gives ostracode species in order of relative abundance; the lists are based on visual estimates and no counts were made. Gastropods and fish remains were noted when encountered. These identifications are tentative, and no definitive interpretation can be attempted as yet.

Fecal Pellets - These were recovered from all of the Zone Two strata, but are most abundant in the most recent deposits (table XL$_1$). The presence of artiodactyl fecal pellets indicates that antelope, deer, or mountain sheep entered the cave, possibly during inclement weather, much as they did at Homestead Cave (see chapter five). The presence of lagomorph pellets may be related to raptor predation. Fecal pellets from woodrats (*Neotoma* sp.) were recovered from Strata X-XI. Fecal pellet widths provide a measure of body size and, in turn, can provide an estimate of the species which most likely produced them (Smith and others, 1995). The correlation is not straightforward, as problems with sexual dimorphism and the presence of juveniles complicates interpretation. For this reason, we used only the largest 15% of the pellets at Homestead Cave as a guide to the presence/absence of the bushy-tailed woodrat (*N. cinerea*). Adult males of this species weigh 175 - 440 g and, if the pellet width/body mass relationship suggested by Smith and others (1995) is valid, produce 4.5 - 6.0 mm wide fecal pellets. Adult males of the desert woodrat (*N. lepida*), on the other hand, average only 175 g, and produce pellets in the range of 4.0 - 4.5 mm. Unfortunately, the number of fecal pellets from the Cathedral Cave test excavation is small and any conclusions must be considered tentative (table XL$_2$). However, the presence of pellets larger than 4.75 mm in width suggests that bushy-tailed woodrats may have been present in the cave during the latter part of the depositional sequence. Three of five specimens from Stratum XI and seven of 19 from Stratum X are greater than 4.75 mm wide. The largest in both strata exceeds 5.6 mm in width. These large fecal pellet widths suggest body weights on the order of 250-500 g. While no *N. cinerea* remains were identified in the skeletal data reviewed above, the modern occurrence of bushy-tailed woodrats at Homestead Cave (Grayson and others, 1996) suggests that they probably also inhabit other cool cave habitats in the Homestead Knoll area.

Plant Macrofossils - Plant macrofossils are absent from all but the four most recent depositional units. Identifiable remains occur only in Strata X and XI and, thus, date to 750 yr B.P. or later. These consist of branches of desert shrubs, primarily rabbitbrush (*Chrysothamnus* sp.) and lesser amounts of sagebrush (*Artemisia* sp.). Similar branches, most of which are charred on one or both ends, are found on the cave surface and appear to have been brought into the cave historically for use as torches. Since both Strata X and XI are part of the modern surface and have been covered in spots by backdirt from relic hunter's holes, it is possible all of this material is a product of historical human visitation to the cave. Some of it may also have been brought to the cave by prehistoric peoples who occupied other caves in the northern Lakeside Mountains (Madsen and Kirkman,1988; Shaver, chapter six). However, no cultural materials which might support this conclusion were identified in the test excavations.

Table XXXIX

Ostracodes in samples of lacustrine deposits from Cathedral Cave (samples are listed from the bottom up in stratigraphic order; identified ostracodes are listed in order of relative abundance)

Stratum II:	
Sample 1, 0 - 1.5 cm -	*Candona caudata, Limnocythere ceriotuberosa, L. staplini, C. decora*, undetermined others, *Amnicola* sp., fish bones, tufa lumps.
Sample 2, 1.5 - 3.2 cm -	*C. caudata, L. ceriotuberosa, C. decora, L. staplini*, undetermined others, *Amnicola* sp., fish bones, small tufa lumps.
Sample 3, 3.2 - 4.2 cm -	*C. caudata*, *C. decora*, *L. ceriotuberosa*, *L. staplini*, *C. adunca*, undetermined others, fish bones.
Sample 4, 4.2 - 5.6 cm -	*C. caudata*, *C. adunca*, *L. ceriotuberosa*, *L. staplini*, *C. decora*, undetermined others, fish bones, few tufa lumps.
Sample 5, 5.6 - 9.6 cm -	*C. adunca*, *C. caudata*, *L. ceriotuberosa*, *C. decora*, *L. staplini*, undetermined others, fish bones.
Sample 6, 9.6 - 10 cm -	*C. caudata*, *L. ceriotuberosa*, undetermined others, carbonate lumps [most ostracode valves broken or carbonate coated, suggesting reworking].
Stratum IV:	
Sample 7, lower marl -	*C. caudata*, *C. eriensis* (?), *L. staplini*, *L. ceriotuberosa*, *L. sappaensis*, undetermined others.
Sample 8, upper marl -	*C. caudata*, *L. ceriotuberosa*, *L. staplini*, *Cytherissa lacustris*, *C. decora*, undetermined others, snail fragments, tufa lumps, fish bone fragments.
Stratum V:	
Sample 9 -	*C. caudata*, *C. lacustris*, *L. ceriotuberosa*, *L. staplini*, *C. rawsoni,* undetermined others, *Amnicola* sp., fish bones, abundant tufa lumps, charophyte (?) stem encrustations [many ostracode valves have carbonate coating and are reworked].

Table XL$_1$

Numbers of fecal pellets from the Cathedral Cave sample column

Stratum	Artiodactyla	*Neotoma*	Lagomorph	Microtine	Carnivore
XI	3	8	6	1	1
X	5	19	4	-	-
IX	1	-	1	-	-
VIII	1	-	-	-	-
VII	1	-	-	-	-

Table XL$_2$

Woodrat fecal pellet widths from Cathedral Cave (in mm)

Stratum XI:	4.04, 4.21, 4.52, 4.54, 4.55, 5.02, 5.04, 5.64
Stratum X:	3.64, 3.72, 3.80, 4.03, 4.09, 4.15, 4.33, 4.40, 4.45, 4.60, 4.61, 4.66, 4.78, 4.83, 5.04, 5.04, 5.24, 5.36, 5.63

CATHEDRAL CAVE FISHES

(by Jack M. Broughton)

Table XLI provides the numbers of identified fish specimens by element from Stratum II at Cathedral Cave. The criteria used to arrive at those identifications are provided in chapter nine. A total of 547 identified fish specimens are represented in this deposit; all of those are sculpin. The mottled sculpin (*Cottus bairdi*) is represented by three preopercles. Five preopercles were identified as either Bear Lake sculpin (*Cottus extensus*) or Utah Lake sculpin (C. echinatus). Both *C. extensus* and *C. bairdi* are represented in the Homestead Cave fauna as well as from the Hot Springs and Black Rock late Pleistocene deposits of Lake Bonneville (Smith and others, 1968). Since *C. echinatus* has yet to be securely identified in any Lake Bonneville ichthyofauna, the materials identified as *C. extensus/echinatus* most likely represent *C. extensus*.

That the Cathedral Cave deposits lack most of the fish species known to have occupied Lake Bonneville is intriguing and may reflect something unique about the sampling mechanism involved in forming that deposit. Indeed, ostracode data suggest that the material represents a deep-water phase Bonneville and Provo-level deposit that accumulated under 100-200 m (300-600 ft) of water. The presence of Bear Lake sculpin is consistent with this suggestion, since these are the most abundant fish that occur in the greater depths of Bear Lake. These fish are also known to actively burrow into the soft marl sediments in the bottom of the lake (McConnell and others, 1957; Dalton and others, 1965; Sigler and Sigler, 1996). Although *C. bairdi* is a bottom-dwelling, cold-water stream fish over most of its range (Sigler and Sigler, 1996), deep-water lake populations are also known for this species in eastern North America, such as in Lake Erie (Trautman, 1981, pp. 708-710; Keleher, 1952).

INTERPRETATION AND IMPLICATIONS

The primary purpose of the Cathedral Cave test excavations was to determine the nature of the cave deposits and to investigate the potential significance of any faunal record it might contain. To this end, we explored three test areas in the main chamber of the cave, and stratigraphically excavated a 1 x 0.5 m sample column of the upper post-Lake Bonneville deposits. Analysis of skeletal material larger than 2.5 mm suggests that deposition by raptors and woodrats was limited in both amount and duration. Only 750 faunal specimens were recovered from a 1.1 m deep depositional sequence which spans less than the last 5000 years. Compared to the 3 m deep, 11.3 ka sample column at Homestead Cave containing two million or more faunal specimens, the interpretive utility of the Cathedral Cave record is marginal. However, materials in the cave do provide some limited support for the Homestead Cave record which suggests bushy-tailed woodrats were reintroduced into the cool, moist cave habitats of the northern Lakeside Mountains during the late Holocene.

The identification of high-elevation, deep-water Lake Bonneville deposits spanning most of the last lake highstand is, perhaps, the most significant result of the test excavations. Detailed investigation of these deposits remains to be accomplished, but preliminary analyses suggest two deep-water phases, separated by a regressional event, are present. The former are represented by laminated marls, the latter by tufa/travertine deposits. The chronological placement of these lake deposits remains uncertain, but the single available limiting radiocarbon dates suggests that it occurred during the regressive phase of the last major lake cycle. There are, however, two possible interpretations.

The less probable, but more traditional, interpretation is that the sequence represents the early transgression of the lake to the Stansbury level about 22 ka, followed by the Stansbury oscillation about 20 ka, and a high lake phase from 20 to 13 ka. This interpretation is complicated by the presence of *Candona adunca* in lower marls. This species of ostracode has previously been found only in the deepest phases of Lake Bonneville, suggesting these lower marls date to the 18 to 14.5 ka period. It is not yet possible to distinguish which of two alternative hypotheses for the origin of the tufa/travertine deposits is the more likely. The intrepretation we favor, for the moment, is that the sequence is the result of only the last half of the last lake cycle, with the

Table XLI

Numbers of identified fish specimens per taxon by element for Stratum II of Cathedral Cave

ELEMENT	*Cottus* sp.	*Cottus bairdi*	*Cottus extensus/echinatus*	Total
Vomer	6	-	-	6
Frontal	1	-	-	1
Prootic	5	-	-	5
Basioccipital	10	-	-	10
Exooccipital	13	-	-	13
Parasphenoid	7	-	-	7
Articular-angular	14	-	-	14
Dentary	13	-	-	13
Maxilla	16	-	-	16
Otolith	2	-	-	2
Palatine	8	-	-	8
Premaxillary	16	-	-	16
Quadrate	13	-	-	13
Epihyal	16	-	-	16
Ceratohyal	19	-	-	19
Ventral hypohyal	3	-	-	3
Hyomandibular	9	-	-	9
Opercle	9	-	-	9
Preopercle	6	3	5	14
Subopercle	6	-	-	6
Cleithrum	4	-	-	4
Vertebra	335	-	-	335
Ultimate vertebra	8	-	-	8
Total	539	3	5	547

travertines and upper marls representing a pause and minor transgression within the overall regressive phase. This interpretation is supported by a limiting date of ~15.3 ka on pollen from the base of the upper lacustrine clays. It is complicated, however, by limited evidence for such an event elsewhere, together with the relatively deep-water conditions suggested by the upper marls.

Regardless, the mere possibility of these alternatives is illustrative of the uniqueness of the depositional setting and of the relative importance of Cathedral Cave. It may be that *C. adunca* has not been found in Stansbury level depostits because only central basin localities, as opposed to lake-margin environments such as at Cathedral Cave, have been investigated previously. Alternatively, it may be that a reversal of the post-Provo lake regression was so ephemeral that evidence of it is rarely preserved except in protected environments such as Cathedral Cave. It seems likely that one or more millennial-scale climatic cycles occurred during the regressive phase, however, and it is probable that such shoreline data will eventually be found.

ACKNOWLEDGMENTS

We thank R. S. Thompson, D. R. Currey, and C. G. Oviatt for their insights into the depositional history at Cathedral Cave.

CHAPTER ELEVEN

Middle and Late Wisconsin Vegetation in the Bonneville Basin

by
David Rhode

INTRODUCTION

A major goal of the investigations reported in this chapter and the next is to develop a detailed vegetation history of the northern Bonneville basin, using evidence derived primarily from packrat middens. At first this research was directed specifically toward establishing a natural context for interpreting archaeobotanical materials found in Danger Cave and Floating Island Shelter, in the Silver Island Mountains (Madsen and Rhode, 1990; Rhode and Madsen, 1998). As research proceeded, and the library of middens built up, the scope of the research naturally grew to encompass a broader spatial coverage and longer temporal span. In particular, a wealth of packrat middens that date between 11 and 14 ka gives us a new biological archive that can be compared with the geomorphic record of the decline of Pleistocene Lake Bonneville (Rhode and Madsen, 1995) and with existing pollen and packrat midden evidence from within the Bonneville basin and beyond (Bright, 1966; Mehringer, 1977, 1985; Madsen and Currey, 1979; Wells, 1983; Thompson, 1984, 1990; Davis and others, 1986; Beiswenger, 1991). More recently, a set of middens was found at one locality in the Goshute Mountains, near the western margin of the Bonneville basin, that extends the paleovegetation record from 14 ka back beyond the limits of radiocarbon dating (~50 ka). Additionally, the small array of plant remains recovered from Homestead Cave (chapter five) provides some local paleovegetational context for interpreting the rich diachronic patterns revealed by the abundant faunal remains (see chapters seven, eight, and nine).

As a consequence, a major part of the research has now shifted towards exploring the vegetation history of the Bonneville basin during the last glacial period, with a focus on vegetation changes during the interval of deglaciation and decline of Lake Bonneville 14 to 10 ka. The vegetation history of the Wisconsin glacial period, from about 50 to 10 ka, is the subject of this chapter. As of this writing over 40 samples from 9 localities in the northern Bonneville basin have been dated to the Wisconsin (figure 104). Together with paleoecological records known from previous research elsewhere in the region, these provide a relatively detailed picture of changing vegetation in relation to climate variation and lacustrine history in the Bonneville basin. Chapter twelve outlines the vegetation history of the Bonneville basin during the subsequent Holocene.

SAMPLE LOCATIONS AND METHODS

The middens forming the basis of this report were found in caves, overhangs and crevices, principally in limestone bedrock outcrops, where they were protected from moisture and thus preserved for thousands of years. Midden preservation depends on long-term protection from moisture; rock outcrops with abundant fractures, or with exfoliating surfaces, tend not to contain very old middens. During the extensive searches made in the course of this research, it was noted that the abundant caves and shelters found in rock outcrops at the margins of the Bonneville basin often contained older middens, while the abundant caves and shelters in the basin's center lack them. Isostatic rebound following the decline of Lake Bonneville may have introduced extensive

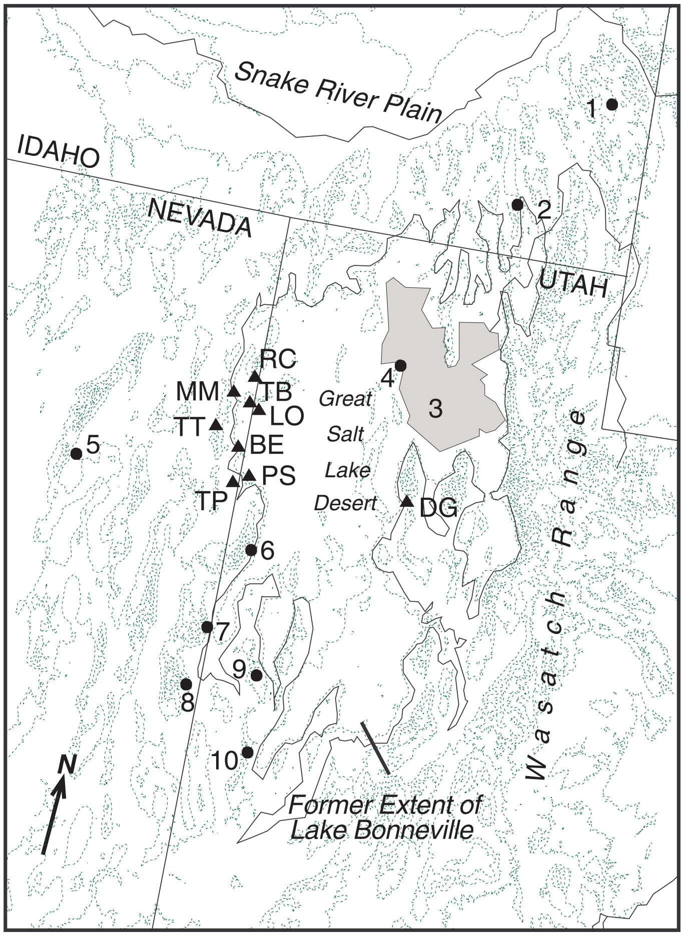

Figure 104. *Mid- to late Wisconsin paleoenvironmental localities in and around the Bonneville basin. Triangles mark midden localities described in this chapter, while circles represent locations of other paleoenvironmental records discussed. ▲DG = Devils Gate, TT = Top of the Terrace, TB = Triple Barrel, PS = Pristine Shelter, LO = Leppy Overhang, BE = Bonneville Estates, MM = Marblehead Mine, RC = Raven Cave, TP = Twin Peaks. ●1 = Grays Lake, 2 = Swan Lake, 3 = Great Salt Lake, 4 = Homestead Cave, 5 = Ruby Marsh, 6 = Granite Creek Canyon, 7 = Council Hall Cave and northern Snake Range midden localities, 8 = Southern Snake Range midden localities, 9 = Confusion Range midden localities, 10 = Wah Wah Mountains midden localities. Approximate scale 1″ = 140 km.*

fractures in the rock outcrops near the center of the Bonneville basin, and outcrops near the margins may be less fractured, which could account for the distribution of more ancient middens. As a result, the midden record is biased toward locations on the western margin of the Great Salt Lake Desert, with relatively little coverage in the mountains of the central Bonneville basin. Nor have older middens been found in the mountains of the eastern Bonneville basin, perhaps because these are better watered and subject to greater destruction through time.

When a midden was found, its location was photographed and mapped on a 7.5′ topographic sheet and a description was made of the plants growing within 30 m of its location (the presumed foraging radius of packrats; compare with Finley, 1990). A chunk of the midden was then transported to the lab for analysis. Midden samples often contain several discrete strata, representing different episodes of deposition, and frequently very different time periods and plant assemblages (figure 105). Samples of discrete midden strata were isolated using hammer and chisel; then the sample was disaggregated in distilled water, trapped on 0.5 mm mesh geological screens, and air dried. Identifiable plant materials were sorted and then quantified using an ordinal scale developed by Van Devender (1973) and refined by Thompson (1984): (1) = rare (1 to 2 pieces), (2) = present (3 to 20 pieces), (3) = common (21 to 100 pieces), (4) = abundant (101 to 500 pieces), and (5) = dominant (over 500 pieces). Midden samples were dated primarily with the AMS radiocarbon method run on individual plant species or dung. All radiocarbon age estimates are corrected for $^{13}C/^{12}C$ fractionation but are not calibrated to calendar years. Identifications of taxa were made utilizing reference specimens collected in the field or present in the herbarium at the University of Nevada, Reno, and are identified according to nomenclature followed in *A Utah Flora* (Welsh and others, 1987). Modern vegetation and relevant topographic data are provided in table XLII.

The results of analysis of the midden samples collected in the region are discussed below in chronological fashion. The focus of discussion for each period is, first, the middens investigated as part of this research, and second, paleovegetation records from other sources in and near the Bonneville basin, to develop an integrated picture of vegetation patterns in the region as a whole. Comparisons with regional lake and climate history will be considered in chapter thirteen.

Figure 105. *Large packrat midden (TOT #2) from Top of the Terrace, Goshute Mountains. Note the stratification exposed within the midden.*

MIDDLE WISCONSIN (ISOTOPE STAGE 3) INTERSTADIAL PERIOD, 50,000 - 28,000 YR B.P.

Midden Results

Only one packrat midden locality contains samples with age estimates older than 14 ka. This locality, a rockshelter called Top of the Terrace, is situated at an altitude of 2012 m on a west-trending ridge in the Goshute Mountains, west of the Bonneville basin. The shelter contains a large, well-dated sequence of midden samples ranging from 14,000 to over 50,000 yr B.P. in age. Analysis of these middens is not yet complete, but the preliminary results provide a valuable picture of changing vegetation patterns in the poorly known interval from the middle Wisconsin interstadial through the height of the late Wisconsin full glacial period (figure 106).

The oldest samples from Top of the Terrace scale beyond the limits of radiocarbon dating, so their ages are unknown and difficult to determine. These samples contain abundant remains of Utah juniper (*Juniperus osteosperma*), accompanied by sagebrush (*Artemisia* sect. tridentatae), horsebrush (*Tetradymia* sp.), snowberry (*Symphoricarpos* sp.) and cactus (*Opuntia* sp.). Utah juniper is common in the area today as well, but it disappeared from the area by about 46 ka, and did not reappear in the area until the middle Holocene, some 40,000 years later. These midden samples also contain pellets from pikas (*Ochotona princeps*), a cold-adapted lagomorph that has not been recorded as living in the Goshute Mountains today, and marmot, which is also not recorded as occurring in the Goshutes and usually lives in subalpine habitats higher than the site (the marmot bones, but not the pika pellets, could have been brought into the site from some distance away by raptors). The combination of remains from the relatively thermophilic Utah juniper mixed with remains from these subalpine mammals may reflect the kind of "non-analogue" or "intermingled" species pairs documented elsewhere in packrat middens (see Van Devender, 1990, p. 159; Spaulding, 1981) and faunal assemblages (Graham, 1985). Alternatively, the samples may reflect mixture of temporally distinctive remains, but this is increasingly unlikely in multiple separate samples and difficult to determine since the remains are older than the reach of radiocarbon dating.

By 46 ka, Utah juniper woodland was replaced by montane meadow vegetation, including shrubs such as sagebrush, currant (*Ribes* cf. *montigenum*) and shrubby cinquefoil (*Potentilla fruticosa*), which suggests that cool, relatively moist conditions prevailed in the region. Montane shrub communities found today in the upper elevations of higher mountains such as the Jarbidge Range or the Ruby Mountains

Table XLII
Elevation, topographic position, and modern vegetation of midden localities described in chapter eleven

Midden	Code	Elev. (m)	Aspect	Modern Vegetation
Bonneville Estates	BE	1590	SE	BE 1: *Grayia spinosa, Halogeton glomeratus, Stipa hymenoides, Ceratoides lanata, Elymus elymoides, Kochia americana, Brickellia* sp., *Phlox* sp., *Tetradymia nuttallii, Atriplex canescens, Bromus tectorum, Ephedra nevadensis, Artemisia nova, Hilaria jamesii, Gutierrezia sarothrae, Haplopappus watsonii*
		1530	NE	BE 2: *Grayia spinosa, Bromus tectorum, Stipa hymenoides, Phlox* sp., *Haplopappus watsonii, Ceratoides lanata, Artemisia nova, Atriplex confertifolia, Ephedra nevadensis* (rare)*, Tetradymia spinescens*
		1530	NE	BE 3: *Grayia spinosa, Sarcobatus vermiculatus, Bromus tectorum, Halogeton glomeratus*
		1525	NE	BE 4: *Tetradymia spinosa, Grayia spinosa, Sarcobatus vermiculatus, Phlox* sp., *Haplopappus watsonii,* Poaceae
Top of the Terrace	TT	2012	S	*Ephedra viridis, Bromus tectorum, Purshia mexicana* var. *stansburiana, Artemisia tridentata, Juniperus osteosperma, Haplopappus watsonii, Elymus cinereus, Phlox* sp., *Brickellia* sp.
Twin Peaks	TP	1585	NE	*Artemisia tridentata, Bromus tectorum, Grayia spinosa, Chrysothamnus viscidiflorus, Tetradymia spinescens, Tetradymia nuttallii, Purshia mexicana* var. *stansburiana, Stipa hymenoides, Haplopappus watsonii, Pinus monophylla* (rare)*, Artemisia nova, Ephedra nevadensis, Atriplex canescens, Opuntia* cf. *polyacantha, Petrophytum caespitosum,* other Poaceae
Triple Barrel	TB	1585	S	*Bromus* sp., *Ephedra nevadensis, Atriplex confertifolia, Sphaeralcea* sp., Brassicaceae*, Atriplex canescens, Brickellia* sp., *Elymus spicatus, Artemisia ludoviciana, Stephanomeria* sp., *Halogeton glomeratus, Oenothera* sp., *Tetradymia* sp., *Phlox* sp., *Mentzelia laevicaulis, Purshia mexicana* var. *stansburiana,* Boraginaceae*, Haplopappus* sp.
Raven Cave	RC	1510	SE	*Atriplex canescens, Atriplex confertifolia, Phacelia* sp., *Salsola iberica, Grayia spinosa, Tetradymia spinescens, Gutierrezia sarothrae, Ephedra nevadensis, Bromus tectorum,* other Poaceae, *Halogeton glomeratus, Brickellia* sp., *Hilaria jamesii, Phlox* sp., *Chrysothamnus nauseosus*
Pristine Shelter	PS	1585	N	*Grayia spinosa, Elymus cinereus, Bromus tectorum, Ceratoides lanata, Phlox* sp., *Atriplex canescens, Atriplex confertifolia, Ephedra nevadensis, Stipa hymenoides, Tetradymia spinescens, Halogeton glomeratus, Artemisia nova, Lomatium* sp., other Poaceae
Marblehead Mine #1	MM 1	1825	S	*Juniperus osteosperma, Purshia mexicana* var. *stansburiana, Bromus tectorum, Marrubium vulgare, Elymus cinereus, Sphaeralcea* cf. *coccinea, Leptodactylon* sp., *Grindelia squarrosa, Calochortus nuttallii, Petrophytum caespitosum, Sisymbrium altissimum, Cirsium* sp., *Stipa hymenoides, Opuntia polyacantha, Argemone munita, Artemisia tridentata*
Devils Gate	DG 1	1800	N	*Juniperus osteosperma, Cercocarpus intricatus, Elymus cinereus, Petrophytum caespitosum, Phlox* sp., *Artemisia tridentata, Opuntia* cf. *polyacantha, Forsellesia nevadensis,* other Poaceae
Leppy Overhang	LO	1475	S	*Atriplex confertifolia, Atriplex canescens, Artemisia tridentata, Purshia mexicana* var. *stansburiana, Tetradymia* sp., *Halogeton glomeratus, Ephedra nevadensis, Sarcobatus vermiculatus, Bromus tectorum*

may be analogous to the vegetation represented in the midden samples with age estimates of ~46 ka. By about 45 ka, limber pine (*Pinus flexilis*) appeared in the area, and it became a dominant conifer through ~28 ka. This subalpine conifer tends to grow in cold, dry, harsh conditions. Fern bush (*Chamaebatiaria millefolium*), a montane woodland shrub of drier habitats, first appeared in large quantities by 36 ka, tracking the abundance of limber pine. Shadscale (*Atriplex confertifolia*) also occurs in small but consistent quantities during the peak of limber pine abundance. Shadscale grows abundantly today at lower valley elevations as a xeric desert dominant, but this C4 shrub apparently tolerated the dry, cold conditions under low atmospheric CO_2 that characterized the Middle Wisconsin, and it expanded its range at the expense of C3 plants (Ehleringer and others, 1997). Mesophilic shrubs declined significantly in representation during this time: cinquefoil and currant disappeared from the record after 40 ka. The dominance of limber pine and abundance of relatively dry montane shrubs at the expense of mesophiles suggests cold but dry conditions in montane settings in the northwestern Bonneville basin from 30 to 40 ka.

Other Records

A small number of other paleovegetation and paleolake records in the Bonneville basin and vicinity help to confirm this reconstruction of middle Wisconsin-age vegetation. Packrat middens with age estimates between 40 to 28 ka from the Snake Range and southern Bonneville basin indicate that montane settings supported coniferous woodlands dominated by bristlecone pine (*Pinus longaeva*), with associates including sagebrush, rabbitbrush, snowberry, Utah juniper and mesophilic shrubs (Thompson, 1984; Wells, 1983). Pollen dating from the same period in Council Hall Cave (Thompson, 1984) reflects montane vegetation dominated by pine and steppe shrubs including sagebrush, with conifers such as juniper, spruce and fir represented in very small quantities. The presence of pollen of xerophytic shrubs such as chenopods and greasewood may indicate that these taxa dominated valley floors at the time (Thompson, 1984). Pollen from the topmost levels of long sediment cores taken from near Wendover and Knolls contain relatively high values of pine pollen prior to ~30 ka (Martin and Mehringer, 1965).

On the Snake River Plain, north of the Bonneville basin, sagebrush steppe was the dominant plant community during this period (Bright and Davis, 1982; Mehringer, 1985; Davis and others, 1986; Beiswenger, 1991). Conifers were apparently limited to foothills and rocky terrain. The pollen sequence from Ruby Marsh, located in Ruby Valley, ~100 km west of the Bonneville basin, indicates the presence of a shallow, saline marsh/playa, surrounded by sagebrush steppe (Thompson, 1984, 1992a) from 40 to 28 ka. Pine pollen is common, reaching its highest proportions in the 40,000-year record, but it is not very abundant, indicating that pines [probably limber pine, bristlecone pine and/or whitebark pine (*Pinus albicaulis*)] were "probably present regionally, though not at the edge of the lake, and perhaps not in the southern Ruby Mountains" (Thompson, 1992a, p. 11). The very small amount of juniper pollen present shows that these conifers were apparently absent or very rare by 40 ka.

Together, these records point to cold but dry conditions before ~28 ka in the eastern Great Basin generally. The climatic reconstructions based on vegetation data are consistent with low lake levels in the Bonneville basin before 28 ka (Scott and others, 1983; Oviatt and others, 1992).

LATE WISCONSIN (ISOTOPE STAGE 2) GLACIAL PERIOD, 28,000-14,000 YR B.P.

Midden Results

Once again, Top of the Terrace provides the only source of packrat middens from the northern Bonneville basin dating to this period (figure 106). Engelmann spruce (*Picea engelmannii*) appeared in midden samples dating as early as 35 ka, and it increased in abundance during the next few thousand years. Limber pine declined to relatively low levels. Upper montane meadow plants such as currant and cinquefoil reappeared. Fern bush and shadscale were eliminated while sagebrush maintained fairly consistent representation throughout. The increased abundance of spruce and mesophilic montane shrubs suggest increasingly moist and cool conditions by ~22 ka.

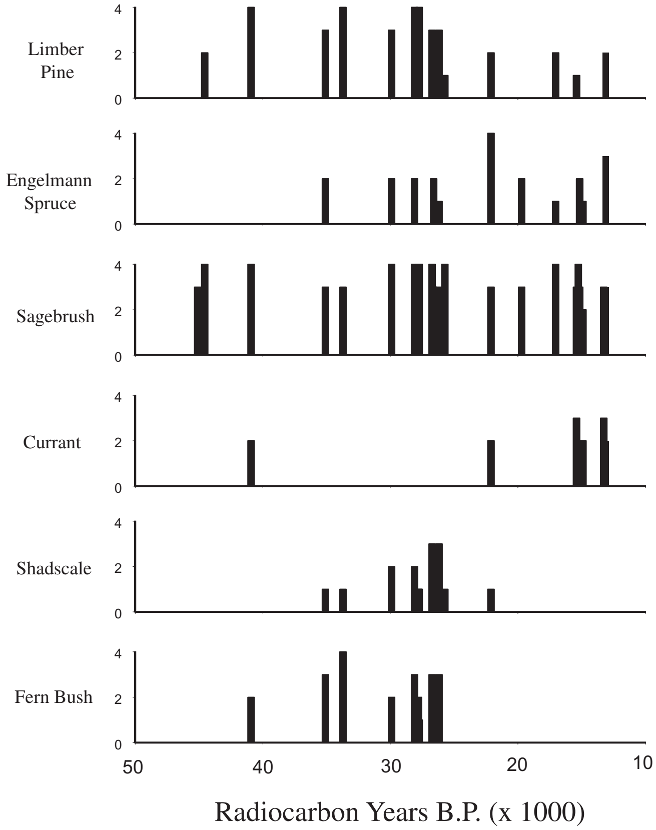

Figure 106. *Major constituents of samples from Top of the Terrace midden spanning the last 50+ ka. 1= rare; 2= present; 3= common; 4= abundant.*

Much colder conditions are indicated in a midden sample with an age estimate of ~17,000 yr B.P., shortly after the late Wisconsin glacial period had reached its maximum. This sample indicates that local vegetation was alpine to subalpine in character, dominated by sagebrush, some grass and sparse cinquefoil, with rare occurrences of limber pine and spruce. This sample also contains several wetland plants, including bulrush (*Scirpus* sp.) and pondweed (*Potamogeton* sp.), as well as fish bones. It is highly unlikely that pondweed grew within the foraging radius of packrats living on the ridge containing Top of the Terrace Shelter. More likely is the possibility that the seeds of aquatic plants were ingested by fish or waterfowl, then deposited into the cave by fish- or bird-eating predators in their regurgitations, which were subsequently collected by packrats to be included in the middens. Nevertheless, the seeds imply a nearby permanent body of water, possibly Lake Waring in the valley below but possibly also Lake Bonneville.

The record from Top of the Terrace dating between 17 to 14 ka suggests that spruce increased somewhat in abundance, while limber pine was present but uncommon. Montane mesophilic shrubs such as currant and cinquefoil increased in abundance, suggesting that climatic conditions were moister and somewhat warmer than during the full glacial.

Other Records

Augmenting the Top of the Terrace midden record are several other paleovegetation and paleolake records from the eastern Great Basin dating to the last glacial interval (figure 104). Foremost among these is the record from Lake Bonneville, which had begun to rise rapidly after 28 ka (Oviatt and others, 1992; see chapter two). By 26 ka the lake was roughly 100 m deep, and it continued to rise for the next 10,000 years, with several significant fluctuations, including the major Stansbury oscillation dating from 22 to 20 ka (Oviatt, 1997; Oviatt and others, 1990; Oviatt and others, 1992). At its highstand, about 16 ka, Lake Bonneville was 370 m deep, covered an area of about 51,750 km^2, and flowed northward into the Snake River drainage over a sill near Zenda, Idaho.

Pollen records from the Bonneville basin dating older than ~24 ka show relatively low to moderate values of pine and spruce and relatively large values of sagebrush and shrubs of the Chenopodiaceae family, presumably shadscale, saltbush (*Atriplex canescens*) and greasewood (*Sarcobatus vermiculatus*). These pollen profiles reflect widespread sagebrush-shadscale associations in valley bottoms, with pine and some spruce in montane settings (Mehringer, 1977, 1985; Spencer and others, 1984; Thompson and others, 1990). A transition to a deep, freshwater Lake Bonneville is indicated at ~24 ka (Mehringer, 1985) by large increases in pine pollen, the appearance of spruce, and the decline of chenopods. The dating of the transition to deep-water conditions contrasts somewhat with the geomorphic record of Lake Bonneville's rise. Oviatt and others (1992) indicate that the lake began to increase significantly in size as early as 28 ka and that it was approximately 100 m deep by 26 ka. The difference may be related to dating uncertainties and/or large-lake effects on pollen rain representation: pines may not have increased in overall abundance on the landscape, but their pollen may have been concentrated and over-represented in lake sediments after ~24 ka. The chenopod shrubs, on the other hand, probably lost substantial habitat as rising levels of Lake Bonneville flooded valley bottoms and margins.

In the southern Bonneville basin, the extremely sparse midden record dating from 28 to 20 ka shows continued dominance of bristlecone pine, without other conifers such as spruce or Utah juniper, but with a diverse shrub cover including abundant mountain mahogany as well as sagebrush, rabbitbrush (*Chrysothamnus* spp.), green mormon tea (*Ephedra viridis*), currant, snowberry and greasebush (*Forsellesia nevadensis*) (Thompson, 1984). After 20 ka, bristlecone pine continued to dominate, but it shared the woodlands with other conifers including spruce, prostrate juniper (*Juniperus communis*), Rocky Mountain juniper (*Juniperus scopulorum*) and (rarely) limber pine; a similar roster of shrubs occurred as before, along with the uncommon addition of shadscale (Wells, 1983; Thompson, 1984). Pollen from Council Hall Cave contains large proportions of pine pollen with small quantities of spruce and variable abundance of juniper-type, and relatively stable amounts of sagebrush pollen during this general interval, though the dating is relatively coarse (Thompson, 1984).

Sagebrush steppe appears to be consistently represented as the dominant vegetation formation through the full glacial on the Snake River Plain, north of the Bonneville basin. The Grays Lake record (Beiswenger, 1991) shows that conifer pollen (mainly pine and spruce) increased in abundance after 26 ka, suggesting that woodlands grew at relatively low elevations in the mountains and foothills, as well as on isolated rocky terrain in valley bottoms. Beiswenger (1991) suggests that the increase of conifers, continued abundance of sagebrush, and negligible increase in grass pollen at Grays Lake supports an interpretation of greater winter and spring precipitation, with no increase in summer precipitation, in an environment with average temperatures 7-10°C colder than today.

In Ruby Valley, 100 km west of the Bonneville basin, the lacustrine record from Ruby Marsh shows an increase in lake level after 23 ka (Thompson, 1992a). The large, freshwater Lake Franklin deepened to ~ 30 m ~18 to 15 ka, drowning what had been marshland. Pollen from these sediments show relatively little change in sagebrush steppe composition or abundance in the region, however.

In sum, the late Wisconsin vegetation record of the Bonneville basin documents the existence of a cold-adapted sagebrush steppe with scattered stands of spruce and pine in the northern basin and surrounding areas, and a more diversified woodland-steppe mosaic in the southern Bonneville basin, dominated by bristlecone pine. This vegetation reconstruction suggests that full glacial conditions in the northern basin were very cold and also quite dry, while conditions in the southern basin were also cold but moister. This north-to-south vegetation gradient represented in the late-glacial paleobotanical record was noted by Thompson and Mead (1982; compare to Thompson, 1990; Rhode and Madsen, 1995) and may reflect a stronger latitudinal gradient of temperature and precipitation associated with a postulated southward shift in the position of the jet stream during the full glacial (Antevs, 1948; Benson and Thompson, 1987; COHMAP, 1988; Kutzbach and others, 1993; Thompson and others, 1993).

The increased abundance of spruce over limber pine is consistent with the rise of Lake Bonneville. Both conifers prefer cold climates, but limber pine prefers cold and very dry environments, while spruce is better adapted to moister conditions. Limber pine was most abundant before 28 ka, when Lake Bonneville had not yet undergone its rise; as Lake Bonneville expanded, limber pine dropped out and was replaced by spruce. The correspondence between woodland composition and glacial lake history during the time before 14 ka is strikingly close.

TERMINAL WISCONSIN DEGLACIATION, 14,000-10,000 YR B.P.

Midden Results

In contrast to the single midden locality known in the northern Bonneville basin with and age estimate older than 14 ka, midden samples with age estimates between 14 to 10 ka are quite common (table XLIII). Some 18 separate samples from 9 localities have been dated to this period, and other samples from these sites undoubtedly fall in this time interval but have not yet been dated. These samples reflect substantial vegetation change during the terminal Wisconsin deglaciation, trending toward the warmer and drier interglacial climate of the Holocene. The period is also notable in that it marks the earliest documented occupation of human

Table XLIII

Plant constituents of woodrat middens dated 14,000-10,000 yr B.P. from the Bonneville basin and vicinity

Sample #	**BE 1a**	**TB 1**	**TT 4a**	**BE 2a**	**TP 2a**	**RC 1c**	**BE 4b**	**RC 1a**	**DG 1a**	**TP 2b**	**RC 1b**	**TB 2**	**LO 3**	**PS 1**	**BE 4a**	**MM 1a**	**BE 3a**	**BE 1c**
Age(^{14}C yr B.P.)	13,820 ±90	13,470 ±100	13,260 ±80	13,060 ±85	13,050 ±100	12,910 ±50	12,810 ±70	12,550 ±50[1]	12,370 ±60	12,250 ±60	12,050 ±70	12,020 ±150	11,920 ±40[2]	11,830 ±70	11,800 ±50	11,580 ±60[3]	11,020 ±60	10,050 ±60
Lab #	Beta-70607	Beta-68148	Beta-79560	NRSL 10437	NRSL 10447	Beta-77814	Beta-76179	Beta-76180	Beta-68656	Beta-68657	NRSL-10446	Beta-68149	Beta-120584	Beta-68146	Beta-120583	Beta-73387	Beta-76178	NRSL-10438
Material Dated[4]	Artr	Dung	Juco	Tetr	Pifl	Pifl	Juco	Atco	Pifl	Pifl	Artr	Pifl	Pifl	Juco	Pisp	Pien	Atco	Atco
Trees																		
Abies lasiocarpa									2									
Juniperus scopulorum																2		
Picea engelmannii			1														3	
Pinus flexilis					5	5	2	5	5	4	1	4	4	2	3	4	1	
Pinus sp.				1														1
Shrubs and subshrubs																		
Amelanchier sp.									2									
Artemisia sect. *tridentatae*	3	2	2	3		2	3	5	2	4	3	5	4	4	3	4	4	3
Atriplex confertifolia								2									3	3
Atriplex sp.				3							2				1			
Celtis reticulata									3									
Chrysothamnus viscidiflorus		2		3		3	2	3		2	2		3	2	3	2	2	2
Forsellesia nevadensis	1																	1
Gutierrezia sp.							3						2	2		2	3	
Haplopappus sp				3					2	1	2							
Jamesia americana									1									
Juniperus communis	2		3	1	5	2	3	4		3	1	4		3		4	2	
Lycium sp.											1							
Pachistima myrsinites									3									
Petrophytum caespitosum										3			2					
Potentilla fruticosa		4			1			1					2					
Purshia mexicana var *stansburiana*										1								
Purshia cf. *tridentata*											1							

Sample #	**BE 1a**	**TB 1**	**TT 4a**	**BE 2a**	**TP 2a**	**RC 1c**	**BE 4b**	**RC 1a**	**DG 1a**	**TP 2b**	**RC 1b**	**TB 2**	**LO 3**	**PS 1**	**BE 4a**	**MM 1a**	**BE 3a**	**BE 1c**
Age(^{14}C yr B.P.)	13,820 ±90	13,470 ±100	13,260 ±80	13,060 ±85	13,050 ±100	12,910 ±50	12,810 ±70	12,550 ±50[1]	12,370 ±60	12,250 ±60	12,050 ±70	12,020 ±150	11,920 ±40[2]	11,830 ±70	11,800 ±50	11,580 ±60[3]	11,020 ±60	10,050 ±60
Lab #	Beta- 70607	Beta- 68148	Beta- 79560	NRSL 10437	NRSL 10447	Beta- 77814	Beta- 76179	Beta- 76180	Beta- 68656	Beta- 68657	NRSL- 10446	Beta- 68149	Beta- 120584	Beta- 68146	Beta- 120583	Beta- 73387	Beta- 76178	NRSL- 10438
Material Dated[4]	Artr	Dung	Juco	Tetr	Pifl	Pifl	Juco	Atco	Pifl	Pifl	Artr	Pifl	Pifl	Juco	Pisp	Pien	Atco	Atco
Ribes cf. *montigenum*	2	3	4															
Shepherdia sp.					1					3								
Symphoricarpos sp.	2		3				2	1	2	3	1		3	3		3		2
Tetradymia sp.	2			3		1	2	2			2			2		2	3	
Forbs and Succulents																		
cf. *Angelica* sp.		2					2										2	
Astragalus sp.				2							2							
Chaenactis sp.					1													
Cirsium cf. *neomexicanum*		4	3				2			2								
Cirsium cf. *eatonii*								2		1	1							
Cryptantha sp.											1			1				
cf. *Cymopterus* sp.				2														
cf. *Encelia* sp.		1															1	
cf. Enceliopsis nudicaulis				1														
Hackelia sp.				1	1												1	
cf. *Lepidium* sp.				1														
Lithospermum sp.		1																
Mentzelia sp.				1														
Opuntia sp.														1		2		
Phacelia sp.						2		2			2		1					
Polygonum sp.														2				
Potentilla sp.							2						1					
cf. *Rumex* sp.				2														
cf. *Sidalcea* sp.								1										
Asteraceae				3	1						2							
Fabaceae					2			2					1				1	
Scrophulariaceae						1												
Grasses																		
Elymus sp.		3	2						1				1			1		
Festuca cf. *octoflora*				1														
Stipa hymenoides				2				1						1				
cf. *Stipa* sp.														1				
Poaceae	1	3					2			2	1							

Notes:

1. A second date on limber pine needles is 12,070 ± 160 ^{14}C yr B.P. (Beta-40280).
2. A second (conventional radiocarbon) date on limber pine needles is 10,760 ± 200 ^{14}C yr B.P. (Beta-40379).
3. A second date on limber pine needles is 11,390 ± 60 ^{14}C yr B.P. (Beta-73388).
4. Artr = *Artemisia* sect. *tridentatae*, Pifl = *Pinus flexilis*, Juco = *Juniperus communis*, Pien = *Picea engelmannii*, Pisp = *Pinus* sp., Tetr = *Tetradymia* sp, and Atco = *Atriplex confertifolia*

inhabitants in the region. Much of the packrat midden information from this interval has been previously reported in Rhode and Madsen (1995), though several new middens dating to this interval are now known, and the age of one midden reported in that paper has been revised through redating.

Beginning about 14 ka, as Lake Bonneville started to decline from the Provo level (Oviatt and others, 1992), the western margin of Lake Bonneville supported a montane shrub vegetation dominated by sagebrush, snowberry and currant (table XLIII). Prostrate juniper and shrubby cinquefoil were also common in some locations. Herbaceous plants, including thistle (*Cirsium* spp.) and wild rye (*Elymus* cf. *cinereus*), were also common. This montane shrub vegetation was similar in many respects to that now found in subalpine settings in the Great Basin, but it also occasionally contained some taxa, including rabbitbrush and horsebrush, that are now more commonly found in the xeric desert scrub vegetation of lower elevations.

With the exception of prostrate juniper, conifers were absent or a minor component of this vegetation, particularly in lowlands. In montane settings, such as at Top of the Terrace, mesophilic shrub vegetation dominated at this altitude much as it did at lower elevations nearer the margins of Lake Bonneville, though Engelmann spruce and probably limber pine were present in small numbers. This midden record indicates that montane shrub vegetation covered altitudes up to at least 2000 m in the interior ranges of the northeastern Great Basin from 14 to 13 ka. The Top of the Terrace midden also contains numerous pika pellets, in a range that pikas do not now inhabit (Hall, 1946; Grayson, 1993, Lawlor, 1998).

Beginning about 13 ka, limber pine began to spread widely into lower elevations of the northern Bonneville basin, growing in both the hills and plains adjacent to the lake basin and to at least the lower reaches (above ~1800 m asl) of neighboring mountains. The transition from mesophilic montane shrub community to limber pine woodland at ~13 ka indicates a significant drying trend within a still-cool temperature regime. Needles, seeds, and cone parts of limber pine are very common in middens with age estimates of 12,900-11,500 yr B.P. and persist as late as 10,700 yr B.P. Below ~1800 m elevation, limber pine is the only arboreal conifer represented, often occurring in small quantities in middens dominated by sagebrush, snowberry, prostrate juniper, silver buffaloberry (*Shepherdia argentea*) and other shrubs. Several shrubby taxa that dominated the earlier montane steppe vegetation were common understory plants at this time, particularly prostrate juniper, sagebrush and snowberry. Other shrubs that had been common before 13 ka, particularly the mesophilic currant and cinquefoil, became rare or disappeared. In montane settings, above about ~1800 m elevation, limber pine dominated in woodlands that also included other conifers: Engelmann spruce and Rocky Mountain juniper in the Toano Range west of the Bonneville basin (MM #1), subalpine fir (*Abies lasiocarpa*) in the Stansbury/Onaqui Mountains (DG #1) on the east side (table XLIII).

Fish remains are found in several middens (RC 1a, TB 1, TB 2, and LO 3), probably incorporated in the middens by woodrats collecting remains left by fish-eating predators or scavengers. Taxa represented include whitefish, sucker and a large salmonid, that indicate the existence of a lake large enough to support fish whose preferred habitat is cold, oligotrophic, deep-water lake environments. One midden (RC 1a) also contains fecal pellets of pika, a lagomorph that now occurs only in subalpine and alpine environments in the region. The presence of pika pellets in the Raven Cave midden documents the existence of pikas associated with limber pine at low elevations in the Pilot Range. This midden is located near the top of a small, somewhat isolated hogback ridge, precluding the possibility that the pellets were transported from significantly higher elevations (Hafner, 1993). Using Hafner's formula for estimating the local minimum elevation of appropriate pika habitat yields a lower elevation limit of 2316 m, which implies a displacement of at least 805 m, corresponding to a minimum lowered temperature (by the adiabatic lapse rate) of ~4.8°C. Whether pikas could in fact survive at this "local minimum elevation" today is unknown, as pikas no longer live in the Pilot Range; but pikas have been trapped as low as 2134 m in the Ruby Mountains, the nearest locality where they exist today (Hall, 1946).

Xerophytic shrubs were scarce in the regional vegetation before about 11.5 ka, but they began to dominate in the lowlands after that time. Shadscale, a widespread and dominant desert shrub in the region today, occurs rarely in middens dated older than 11 ka. Shadscale is present but uncommon in a midden dominated by limber pine in the southern Pilot Range (RC 1a), with an age estimate of 12,550 ± 50 yr B.P. (Beta 76180). A stratigraphically separate sample from the same midden (RC 1c) contained abundant limber pine but no shadscale; the limber pine in this sample was dated by the AMS method to 12,910 ± 50 yr B.P. (Beta 77184). However, other middens dating older than ~11 ka lack shadscale altogether, indicating that it was rare in the region prior to this time.

To estimate the climatic conditions of the period during which limber pine grew at low elevations in the Bonneville basin, those conditions under which limber pine grows today were analyzed. In the Great Basin today, limber pine usually dominates in settings marked by relatively cool temperatures and severe water stress: ridges and slopes with thin, rocky soils, persistent winds, and limited snow cover during winter (Ellison, 1954). Specific climatic tolerances of limber pine may be fairly broad, however (Billings, 1990), and the present distribution of limber pine may be restricted more by competition with other taxa than by climatic constraints (Thompson, 1984, p. 131). The climatic tolerances of limber pine were obtained using climatic records from weather stations in and around the present distribution of limber pine, as mapped by Little (1971). Climatic parameters chosen to represent conditions at these stations include temperature (January, July, and annual), precipitation (January, July, and annual), and heating and cooling degree days. Resulting climate-space representations are shown in figure 107. For comparison, the Wendover weather station is shown as a large solid triangle, and open triangles are other weather stations representative of the Bonneville basin (Dugway, Callao, Grouse Creek, Tooele, Ibapah, Vernon, Fish Springs).

The climate-space diagrams indicate that conditions that favor growth of limber pine are significantly cooler and more mesic than occur around Wendover today, with growing-season climate differing much more than winter climate (figures 107, 108). Modern January temperature and precipitation at Wendover is on the warm and dry end of modern limber pine

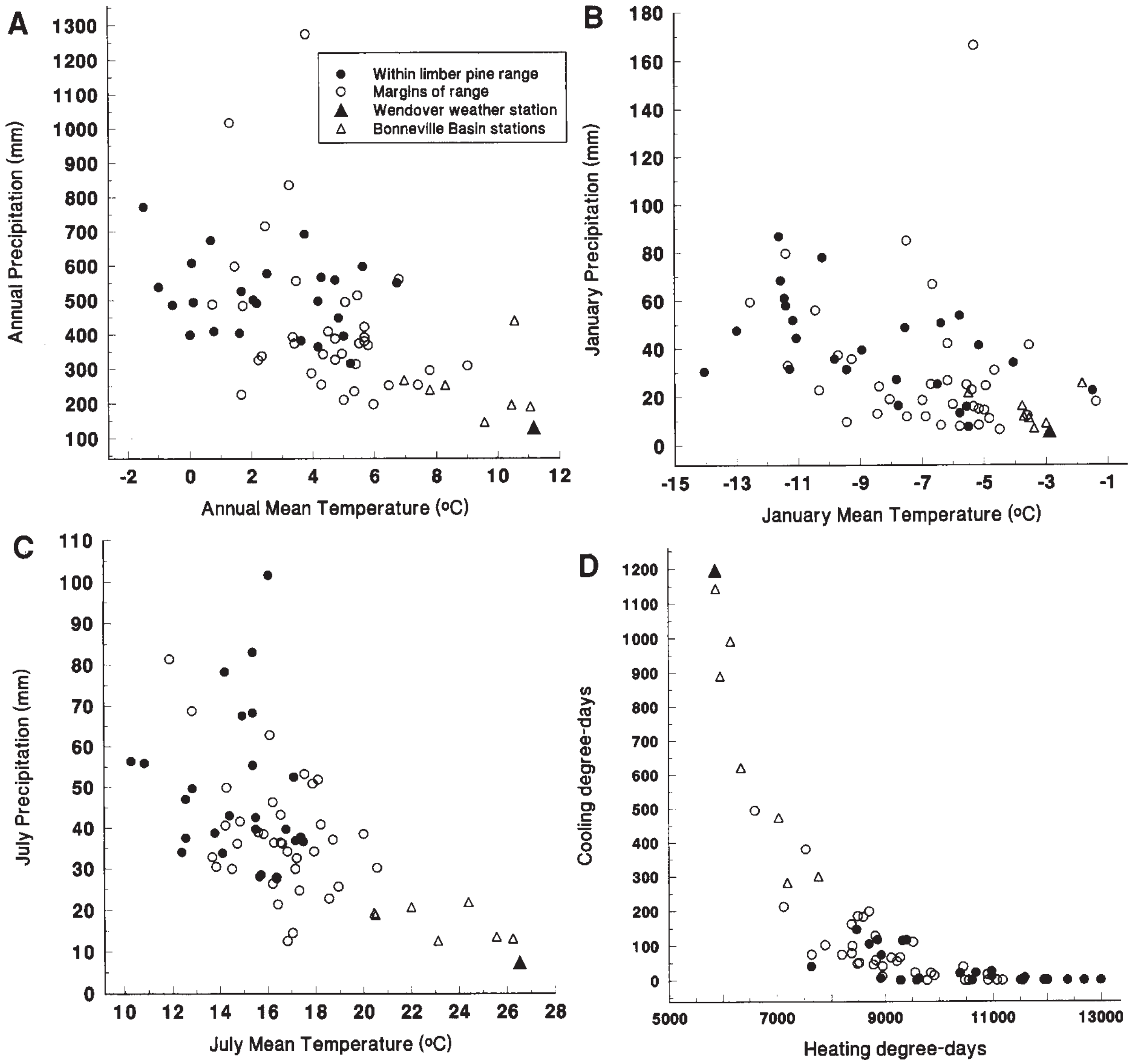

Figure 107. *Climatic parameters of weather stations within distribution of limber pine, as mapped by Little (1971). Closed circles represent weather stations located within the mapped distribution of limber pine, open circles represent weather stations located at the margins of the mapped distribution of limber pine, and triangles represent weather stations in the Bonneville basin; the largest triangle is Wendover: (A) Annual temperature and precipitation; (B) January temperature and precipitation; (C) July temperature and precipitation; (D) Total heating degree-days and cooling degree-days.*

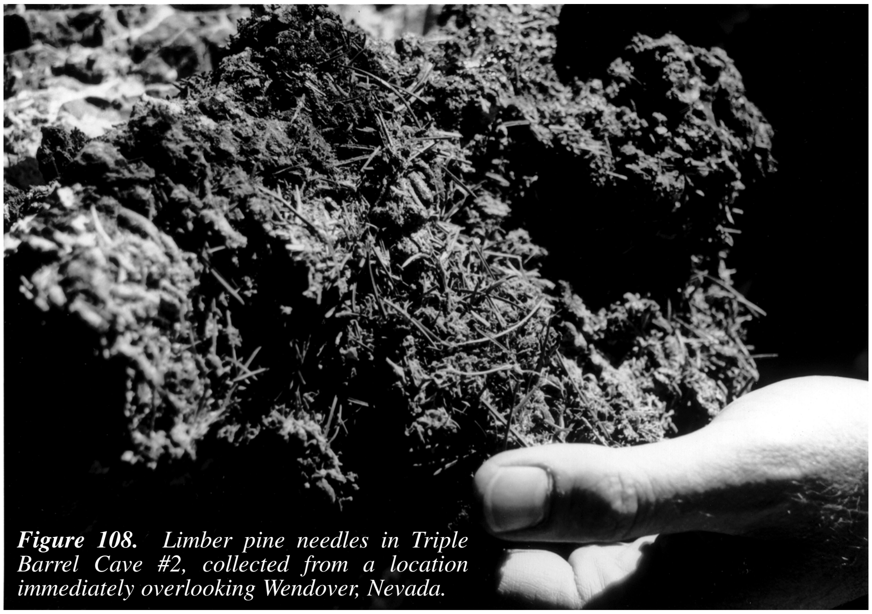

Figure 108. *Limber pine needles in Triple Barrel Cave #2, collected from a location immediately overlooking Wendover, Nevada.*

climate-space, but it does not fall significantly outside that climate-space. On the other hand, modern July temperature and precipitation at Wendover is significantly warmer and drier than is experienced within the modern limber pine distribution. Growing-season moisture stress appears to be a major limiting factor for limber pine growth, primarily driven by high summer temperatures; precipitation appears to be somewhat less limiting than temperature, at least relative to modern climate at Wendover. These data suggest that the climate 13 to 11 ka that supported limber pine in the Bonneville basin was substantially cooler in the summer than it is today, with precipitation slightly greater than modern levels. It is unlikely that precipitation was very much greater, however, because mesophilic plants (such as currant and cinquefoil) were rare or absent from the midden record once limber pine appeared, and because more mesophilic conifers that can readily outcompete it in moister climates are absent from the lowland record.

The climate-space model developed here is useful for showing the climatic boundary conditions that permitted limber pine to grow at low elevations at 13 to 11 ka, but because those boundary conditions are rather broad, the model is less useful for estimating actual conditions under which limber pine grew in the Bonneville basin. We do not know where actual climatic parameters were positioned within the climate-space "envelope." Assuming that summer temperature was the principal parameter separating the climate of today from the climate that prevailed 13 to 11 ka, and assuming that summer temperature is the main constraint on lower treeline elevation of limber pine in the mountains surrounding the Bonneville basin today, the magnitude of late Pleistocene summer temperature depression may be better estimated. Today, limber pine grows on similar south-facing slope settings above 2600 m in the Pilot Range, 1100-1200 m above its known level 13 to 11 ka. If the dry air thermal lapse rate applies (0.6°C/100 m), this difference in elevation implies that terminal Wisconsin temperatures (at least summer temperatures) were depressed by at least 6.6°C in the vicinity of Wendover.

Factors such as competition with singleleaf pinyon may restrict limber pine to high elevations in the western Bonneville basin, complicating or confounding paleoclimatic inferences drawn from modern limber pine treelines. Additionally, part of the ecological amplitude of late-glacial limber pine populations may have been lost as those populations became extirpated or severely restricted in distribution during the Holocene (Thompson, 1990). Furthermore, Van de Water and others (1994) have shown that limber pine populations throughout the intermountain west showed increased water-use efficiency during the deglacial interval, possibly in response to increasing CO_2 in the atmosphere. As a result, limber pine is likely to have altered its sensitivity to climatic parameters during this time period, and this fact alone may account for the rapid spread of limber pine into the lowlands of the northern Bonneville basin during this interval. Despite these potential difficulties, an estimate of terminal Wisconsin summer-temperature depression of ~6-7°C is similar in magnitude to that suggested by Thompson (1990) for the east-central Great Basin, and by Betancourt (1990) for the Colorado Plateau. Evidence for significantly cooler summers during the latter part of the period between 13 and 11 ka is also provided by the faunal remains in Stratum I at Homestead Cave, which include several small montane mammal taxa not found in the vicinity of the cave today (see chapter seven).

The cooler climatic conditions indicated here are significantly cooler than was suggested by Siegal's (1983) interpretation of isotopic evidence, although some of these data do suggest "a return to cooler temperatures and more dominant winter precipitation" between 14 and 11 ka (Thompson and others, 1993, p. 485). This reconstruction also differs in magnitude, though not in direction, from surface temperature estimates produced by the COHMAP model, which predicts summer temperatures only slightly lower than present at 12 ka (Kutzbach and others, 1993; Thompson and others, 1993). Climatic conditions in the Bonneville basin may have been mediated locally by the persistence of a relatively large lake, localized conditions that are not considered at the generalized scale of the COHMAP reconstruction.

By 11 ka, desert scrub vegetation dominated by shadscale and sagebrush apparently replaced limber pine woodlands in the lowlands west of the Bonneville basin. A midden from Bonneville Estates (BE 3a), with an age estimate of 11,020 ± 60 yr B.P. (Beta 76178), is dominated by xeric desert shrubs, such as sagebrush, shadscale, horsebrush, snakeweed and rabbitbrush. Limber pine and prostrate juniper are rare to uncommon elements in the midden. In some lowland settings, limber pine woodlands without xerophytic desert shrubs may have persisted at least as late as 10,700 yr B.P., according to a conventional radiocarbon age estimate from the Leppy Overhang midden (LO 3), located just above the Provo level strandline at 1475 m elevation north of Wendover. Additional limber pine needles from this midden returned an AMS age estimate of 11,920 ± 40 yr B.P. (Beta 120584), suggesting that limber pine persisted in this locality for over a thousand years.

Other Records

The midden record from the northern Bonneville basin is supplemented by an equally abundant terminal Wisconsin paleovegetation record from the southern Bonneville basin, as well as several pollen sequences. In the mountains of the southern Bonneville basin, bristlecone pine remained a common woodland conifer from ~14 ka until shortly before 10 ka. (Thompson, 1984; Wells, 1983). Spruce diminished in abundance after 14 ka, as did several montane shrubs at particular localities, in response to increasing temperatures and decreasing precipitation. Xerophytes or thermophilous shrubs took their place. Limber pine increased significantly in frequency, especially after 11 ka, probably in response to drier conditions. Utah juniper and Douglas fir also began to appear by about 10 ka in the southern Bonneville basin near the end of this period.

Pollen data from Great Salt Lake Core C (Spencer and others, 1984; Thompson and others, 1990) show high relative abundance of pine and spruce until after 12.4 ka, after which sagebrush, greasewood and Chenopodiineae rapidly increase. The pollen record contains a significant stratigraphic gap between ~12.2 and 9.6 ka, limiting the utility of this record for interpreting terminal Wisconsin vegetation changes. Pollen from Grays Lake (Beiswenger, 1991) documents a shift by ~12 ka from a pine-sagebrush parkland, reflecting cold, dry glacial conditions, to a woodland/steppe mosaic including spruce, pine and sagebrush, that indicates warmer (but still cool) and moister conditions. Subsequent postglacial warming resulted in upslope retreat of spruce and pine and expansion of sagebrush and xerophytic chenopods at lower elevations. Pollen data from Swan Lake, in Idaho, show high values of pine, spruce and fir between 12 and 11 ka; these conifer woodlands were replaced by sagebrush steppe vegetation sometime between 11 and 10 ka (Bright, 1966). The terminal Wisconsin record from Ruby Marsh is limited by a stratigraphic unconformity dating between 15.4 and 10.7 ka, that may represent a turbidite flow in deep water, or alternatively may indicate a period of desiccation of the lake (Thompson, 1992a). Sediments with age estimates between 10.7 and 10.4 ka indicate a moderately large, freshwater lake in the basin, coeval with the Gilbert Lake phase in the Bonneville basin. There is relatively little change in terrestrial pollen abundance from the preceding 20,000 years of the late Wisconsin record, indicating the continued domination of cold sagebrush steppe in Ruby Valley.

Altogether, these records indicate significant warming ~14 to 12 ka throughout the Bonneville basin, supporting montane meadows and woodlands in the north and more thermophilic woodland plants in the southern part of the Bonneville basin. However, the warming that occurred between 14 and 12 ka was not so great as to prevent what are now subalpine conifers from colonizing large areas at low elevations along the Bonneville highstand shoreline. As the record shows, limber pine woodlands expanded significantly to the margins of the Bonneville basin during this period, and expanded in the mountains of the southern Bonneville basin as well. Growing season temperatures were probably 6°C cooler than at present. Most midden records in the Bonneville basin reflect a drying trend through this period, although some paleovegetation records north of the basin (see Beiswenger, 1991) suggest that precipitation may have increased to the north.

This warming and drying trend in the Bonneville basin continued after 11 ka, but the paleovegetation record from this time period is at present quite sparse. What little data exist suggest that a substantial reduction in pine woodlands and an increase in sagebrush-grass and shadscale associations by 11 ka. Unfortunately, there is presently not enough evidence to document the kinds of vegetation changes that occurred during the Gilbert lake cycle as dated by Oviatt and others (1992), or whether vegetation changes reflect enhanced moisture conditions (Currey, 1990; Oviatt, 1988b). Additional research and appropriately aged paleovegetation records are needed to address this issue, important not only for local paleoenvironmental history but also for testing general climate models, establishing global climate/vegetation correlations, and developing an environmental context for the first known human habitation of the Bonneville basin.

CHAPTER TWELVE

Holocene Vegetation History in the Bonneville Basin

by
David Rhode

INTRODUCTION

The transition from the last glacial period to the interglacial Holocene resulted in dramatic changes in the distribution and composition of plant associations in the Bonneville basin. Much of this change commenced prior to the Holocene (see chapter eleven), but substantial alterations to plant associations have continued through the last 10,000 years. These alterations are partly a lagged response to the glacial/interglacial climatic transition, partly related to smaller-scale climatic variations during the Holocene, and partly a function of human and other biological impacts. Most modern plant communities developed their present composition and distribution during the Holocene, but the timing of establishment of modern communities and plant distributions differs by taxon and by community in an individualistic fashion.

This chapter discusses the analysis of packrat middens dating to the last 10,000 years, collected in the Bonneville basin as part of this project (figure 109). The record of vegetation provided by these middens, together with other previously obtained midden records, pollen cores and archaeological sites, provides the basis for a relatively detailed history of Holocene vegetation change in the Bonneville basin. Twenty-eight midden localities, yielding 37 radiocarbon-dated Holocene-age samples, were analyzed as part of this project. Methods for treatment of midden samples follow the discussion in chapter eleven. Relevant topographic information and modern vegetation components are given in table XLIV.

To facilitate discussion, the Holocene is divided into four periods: the early Holocene (10 to 8 ka), middle Holocene (8 to 4 ka), Neopluvial (4 to 2 ka), and latest Holocene (<2 ka). Vegetation patterns in the Bonneville basin tended to differ within each of these intervals. However, it should be kept in mind that these intervals are mainly divisions of convenience, that climate was not necessarily stable during each of these intervals, and that the distribution of certain plant taxa changed significantly within each interval.

EARLY HOLOCENE, 10,000-8000 YR B.P.

High-resolution paleoenvironmental records from several localities worldwide repeatedly show that the transition from the late Wisconsin to the Holocene was marked by a rapid shift from glacial to interglacial climate modes (see chapter thirteen). A rapid transition also characterized the beginning and end of the Younger Dryas, during which climate apparently reverted from interglacial back to glacial-like conditions. The effects of the Younger Dryas on lake level in the Bonneville basin are not certain, though some authors (see Oviatt an others, 1992; Benson and others, 1992) have linked the Gilbert shoreline to a Younger Dryas-age lake (but see Zachary and Oviatt, 1999). As noted in chapter eleven, however, paleovegetation records dating to this interval (including packrat middens) are scarce in the Bonneville basin and surrounding areas, so it is not certain how plant distributions in the region responded to the Younger Dryas climatic episode. The end of the Younger Dryas was apparently fairly abrupt (see chapter thirteen), and this transition is here taken to mark the onset of the interglacial Holocene period.

Two main opposing views characterize the nature of early Holocene climate in the Bonneville basin (see Grayson, chapter seven). One view holds that the early Holocene was cooler and wetter than today, transitional between the glacial late Wisconsin and the warmer, drier middle Holocene (see Antevs, 1955). This cool, rather moist climate would have (1) supported montane conifers at elevations lower than those species presently grow, (2) promoted sagebrush steppe vegetation in valley bottoms rather than more xerophilic saltbush scrub, and (3) allowed relatively cool-adapted faunas to persist in lowland habitats, where they cannot survive today. Grayson (chapter seven) argues that the small mammal faunas from Homestead Cave support this “cool, moist” characterization of early Holocene climate in the region.

The second view holds that the early Holocene climate was significantly warmer than today (see Antevs, 1948), and probably wetter as well, with a greater proportion of annual precipitation falling during the summer growing season months. This “warm, summer-wet” view is bolstered by paleoclimatic estimates drawn from global circulation models based on earth orbital parameters (Kutzbach and Guetter, 1986; COHMAP, 1988; Kutzbach and others, 1993; Thompson and others, 1993). About 10 ka, the Earth passed closest to the sun in July, rather than January as it does today, and the Earth’s tilt was slightly greater than today. As a result, summer solar radiation in the northern hemisphere was approximately 8% greater during the early Holocene than today, the greatest of any time in the past 18,000 years (COHMAP, 1988; Kutzbach and Webb, 1993). Model results predict that summers in the northern hemisphere would have been warmer than at present, and winters slightly colder. General circulation models also suggest that summer precipitation may have been greater than today, because continental interiors were warmer in summer, which enhanced onshore flow of storm fronts from the Gulf of Mexico and eastern Pacific (Kutzbach and Webb, 1993). Spaulding suggested that evidence of this enhanced summer precipitation regime can be found in packrat midden data from the Sonoran and Mojave Deserts (Spaulding, 1985, 1990; Spaulding and Graumlich, 1986), but other researchers, notably Van Devender (1990; Van Devender and others 1987), disagree with this interpretation. Whether this enhanced summer rainfall pattern, if it

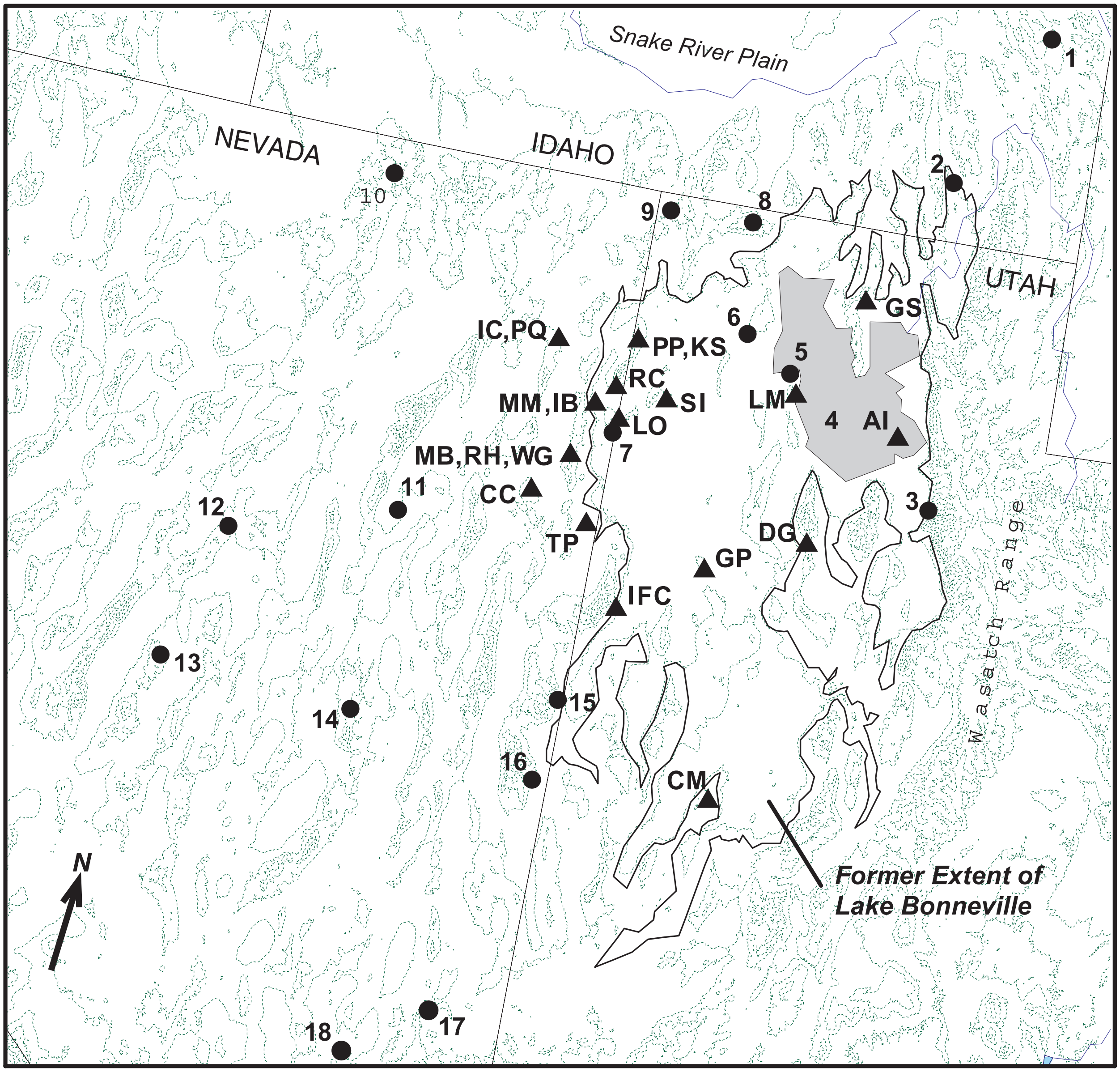

Figure 109. Holocene paleoenvironmental localities in and around the Bonneville basin. Triangles mark midden localities described in this chapter, while circles represent locations of other paleoenvironmental records discussed. ▲ *AI = Antelope Island (Elephant Head, Red Rocks, Sentry Cave), CC = Cherry Creek Mountains, CM = Cricket Mountains, DG = Devils Gate, GS = Golden Spike, GP = Granite Peak, IB = Itchy Ban, IC = Icicle Cave, IFC = Indian Farm Canyon, KS = Killian Spring, LO = Leppy Overhang, LM = Lakeside Mountains (Gillespie Hills, HAG, Homestead Knoll), MB = Morgan Basin, MM = Marblehead Mine, PP = Patterson Pass, RC = Raven Cave, RH = Red Hand Cave, SI = Silver Island Canyon, TP = Twin Peaks, WG = West Goshutes.* ● *1 = Grays Lake, 2 = Swan Lake, 3 = Snowbird Bog, 4 = Great Salt Lake, 5 = Homestead Cave, 6 = Crescent Spring and Hogup Cave, 7 = Danger Cave, 8 = Curelom Cirque, 9 = Swallow Shelter, 10 = Mission Cross Bog, 11 = Ruby Marsh, 12 = Potato Canyon Bog, 13 = Gatecliff Shelter, 14 = Indian Garden, 15 = Council Hall Cave and northern Snake Range midden localities, 16 = southern Snake Range midden localities, 17 = Meadow Valley Wash, 18 = Lower Pahranagat Lake. Approximate scale 1″ = 100 km.*

existed, penetrated into the Bonneville basin is not certain. If the general circulation model predictions actually happened, we should expect evidence of greater abundance of plants requiring more growing season precipitation (for example, summer grasses, ponderosa pine) than occurs today.

Ideally, the paleovegetation record in the region might be able to resolve which of these viewpoints is more likely. Unfortunately, early Holocene packrat midden records are scarce in the Bonneville basin (table XLV), especially by comparison with the abundance of middens dated to the terminal Wisconsin (compare table XLIII). A few early Holocene pollen records augment the sparse midden record of the period (Bright, 1966; Madsen and Currey, 1979; Spencer and others, 1984; Thompson and others, 1990; Beiswenger, 1991; Thompson, 1992a).

Midden Records

The available midden record suggests that xerophytic sagebrush and shadscale scrub dominated on the margins of the Bonneville basin, but some records indicate the presence of relatively mesophilic shrubs in lowland settings as well

Table XLIV
Elevation, topographic position, and modern vegetation of Holocene-age midden localities described in chapter twelve

Midden	Code	Elevation (m)	Aspect	Modern vegetation constituents
Cherry Creek 1	CC	1920	N	*Artemisia tridentata, Ribes cereum, Chamaebatiaria millefolium, Chrysothamnus viscidiflorus, Rosa woodsii, Pinus monophylla, Juniperus osteosperma, Abies concolor, Elymus cinereus, Holodiscus dumosus, Symphoricarpos* sp., *Cercocarpus ledifolius*
Devils Gate 1	DG	1800	N	*Juniperus osteosperma, Cercocarpus intricatus, Elymus cinereus, Petrophytum caespitosum, Phlox* sp., *Artemesia tridentata, Opuntia* cf. *polyacantha, Forsellesia nevadensis,* other Poaceae
Elephant Head	EH	1325	N	*Lomatium* cf. *dissectum, Artemisia dracunculus, Chrysothamnus viscidiflorus, Montia perfoliata, Hilaria jamesii, Poa* sp., *Gutierrezia sarothrae*
Gillespie Hills	GH	1320	E	*Bromus tectorum, Salsola iberica, Descurainia* sp., *Cirsium* sp., *Artemisia dracunculus, Sphaeralcea coccinea, Halogeton glomeratus, Phlox* sp., *Artemisia tridentata, Atriplex canescens, Stipa hymenoides, Amsinckia menziesii, Chrysothamnus* sp., *Tetradymia glabrata*
Golden Spike	GS	1495	E	*Bromus tectorum, Sisymbrium* cf. *altissimum, Helianthus annuus, Chrysothamnus viscidiflorus, Artemisia tridentata, Gutierrezia sarothrae, Polygonum bistortoides, Cirsium* sp.
Granite Peak	GP	1400	E	*Juniperus osteosperma, Artemisia tridentata, Lomatium* cf. *dissectum*
HAG	HAG	1310	E	Recently heavily burned; *Stipa hymenoides, Bromus tectorum, Halogeton glomeratus, Cirsium* sp., *Sphaeralcea* sp., *Atriplex confertifolia, Haplopappus watsonii, Stephanomeria* sp., *Brickellia* sp.
Homestead Knoll	HK	1300	N	*Sarcobatus vermiculatus, Atriplex confertifolia, Tetradymia spinosa, Grayia spinosa, Bromus tectorum*
Icicle Cave	IC	2200	SE	*Prunus* cf. *virginiana, Acer glabrum, Rhus aromatica, Alnus incana, Petrophytum caespitosum, Heuchera* sp., *Cercocarpus ledifolius, Elymus* cf. *cinereus,* other Poaceae, *Symphoricarpos* sp., *Artemisia tridentata, Holodiscus dumosus, Balsamorhiza* sp., *Pinus monophylla, Juniperus osteosperma, Chrysothamnus* cf. *viscidiflorus*
Indian Farm Canyon	IFC	2000	S	*Pinus monophylla, Juniperus osteosperma, Rosa woodsii, Artemisia tridentata, Elymus cinereus, Rhus aromatica, Atriplex confertifolia* (rare), *Brickellia* sp., *Cercocarpus intricatus*
Itchy Ban	IB	1850	N	*Juniperus osteosperma, Pinus monophylla, Artemisia tridentata, Forsellesia nevadensis, Cercocarpus intricatus, Petrophytum caespitosum, Gilia* sp., *Delphinium* sp., *Symphoricarpos* sp., *Opuntia* sp., Poaceae, Asteraceae
Killian Springs 1	KS	1950	S	*Haplopappus* cf. *watsonii, Opuntia* cf. *polyacantha, Linanthus* sp., *Purshia tridentata, Pinus monophylla, Juniperus osteosperma, Artemisia tridentata,* Poaceae
Killian Springs 2	KS	1950	S	*Elymus cinereus, Artemisia tridentata, Chrysothamnus viscidiflorus, Juniperus osteosperma, Pinus monophylla, Purshia tridentata, Brickellia* sp., other Asteraceae
Leppy Overhang	LO	1475	S	*Atriplex confertifolia, Atriplex canescens, Artemisia tridentata, Purshia mexicana* var. *stansburiana, Tetradymia* sp., *Halogeton glomeratus, Ephedra nevadensis, Sarcobatus vermiculatus, Bromus tectorum, Forsellesia nevadensis*
Marblehead Mine 1	MM 1	1800	N	*Juniperus osteosperma, Cercocarpus intricatus, Elymus cinereus, Petrophytum caespitosum, Phlox* sp., *Artemisia tridentata, Haplopappus watsonii*
Marblehead Mine 2	MM 2	1800	N	*Pinus monophylla, Juniperus osteosperma, Cercocarpus intricatus, Elymus cinereus, Petrophytum caespitosum, Phlox* sp., *Artemisia tridentata, Opuntia* cf. *polyacantha, Forsellesia nevadensis,* other Poaceae
Morgan Basin	MB	2100	NW	*Pinus monophylla, Purshia mexicana* var. *stansburiana, Juniperus osteosperma, Grindelia* cf. *squarrosa, Artemisia tridentata,* other Poaceae, cf. *Brickellia* sp.
Patterson Pass	PP	2100	E	*Juniperus osteosperma, Pinus monophylla, Purshia mexicana* var. *stansburiana, Cercocarpus intricatus, Haplopappus watsonii, Phacelia* sp., *Bromus tectorum,* Brassicaceae, *Artemisia tridentata*

Pequop Cave 2	PQ	2050	NW	*Elymus cinereus, Artemisia tridentata, Cercocarpus ledifolius, Pinus monophylla, Juniperus osteosperma, Petrophytum caespitosum, Haplopappus watsonii, Phlox* sp.*, Rhus aromatica, Bromus* sp.*, Wyethia amplexicaulis*
Raven Cave	RC	1510	SE	*Atriplex canescens, Atriplex confertifolia, Phacelia* sp.*, Salsola iberica, Grayia spinosa, Tetradymia spinosa, Gutierrezia sarothrae, Ephedra nevadensis, Bromus tectorum,* other Poaceae, *Halogeton glomeratus, Brickellia* sp.*, Gutierrezia* sp.*, Hilaria jamesii, Phlox* sp.*, Chrysothamnus nauseosus*
Red Hand Cave	RHC	1830	N	*Pinus monophylla, Juniperus osteosperma, Elymus cinereus, Artemisia nova, Lomatium dissectum, Haplopappus* sp.*, Petrophytum caespitosum, Stipa* sp.*, Phlox spinosa, Brickellia* sp.*, Haplopappus watsonii, Cercocarpus intricatus, Forsellesia nevadensis, Chamaebatiaria millefolium*
Red Rocks	RR	1500	W	*Artemisia* cf. *dracunculus, Lomatium* sp.*, Erodium cicutarium, Cirsium* sp.*, Montia perfoliata, Haplopappus watsonii, Chrysothamnus viscidiflorus, Hilaria jamesii, Aster* sp.*, Bromus rubens*
Sentry Cave	SC	1620	W	*Bromus tectorum, Chrysothamnus nauseosus,* cf. *Hilaria jamesii, Artemisia dracunculus, Artemisia tridentata* (rare), *Haplopappus* cf. *watsonii, Cirsium* sp.*, Cymopterus purpureus, Astragalus utahensis, Juniperus osteosperma* downslope >100 m distant
Silver Island Canyon 1	SIC 1	1800	SE	*Juniperus osteosperma, Bromus tectorum, Elymus* sp.*, Purshia mexicana* var. *stansburiana, Petrophytum caespitosum, Gutierrezia microcephala, Brickellia scabra, Penstemon* sp.*, Phlox* sp.*, Chrysothamnus nauseosus,* Poaceae, *Juniperus scopulorum* down canyon 100 m
Silver Island Canyon 2	SIC 2	1780	S	*Juniperus osteosperma, Bromus tectorum, Brickellia* sp.*, Elymus cinereus, Artemisia tridentata, Purshia tridentata, Gutierrezia* sp.*, Atriplex canescens* (rare), *Liliaceae* (rare), *Leptodactylon* sp.
Twin Peaks	TP	1585	NE	*Artemisia tridentata, Bromus tectorum, Grayia spinosa, Chrysothamnus viscidiflorus, Tetradymia spinosa, Tetradymia glabrata, Purshia mexicana* var. *stansburiana, Stipa hymenoides, Haplopappus watsonii, Pinus monophylla* (rare), *Artemisia nova, Ephedra nevadensis, Atriplex canescens, Opuntia* cf. *polyacantha, Petrophytum caespitosum,* other Poaceae
West Goshutes 1	WG 1	1900	SE	*Forsellesia nevadensis, Ephedra viridis, Bromus tectorum, Juniperus osteosperma, Pinus monophylla, Purshia mexicana* var. *stansburiana, Haplopappus watsonii, Brickellia* sp.*, Atriplex confertifolia,* cf. *Elymus spicatus, Chrysothamnus viscidiflorus*
West Goshutes 2	WG 2	2250	SE	*Purshia tridentata, Haplopappus watsonii, Pinus monophylla, Juniperus osteosperma, Artemisia tridentata, Elymus* sp.*, Opuntia* sp.*, Chrysothamnus viscidiflorus, Bromus* sp.*,* cf. *Aster* sp.*, Cirsium* sp.*, Phlox* sp.

(table XLV). At the Leppy Overhang locality, a midden sample (LO 1c) dating to 9340 yr B.P. contains remains of shadscale, horsebrush and other arid desert shrubs. At the Twin Peaks locality (TP 3a), a midden sample dating to 9280 yr B.P. is dominated by sagebrush, with shadscale as a relatively minor component (both of these localities had harbored limber pine 2500 years earlier; see chapter eleven). The abundance of sagebrush and limited representation of shadscale 9300 yr B.P. at the Twin Peaks locality contrasts with the situation found at the Leppy Overhang, where shadscale dominated. This contrast is still present at the two localities: sagebrush prevails at the Twin Peak locality, while shadscale dominates at the Leppy Overhang site.

As noted previously in chapter five, hackberry commonly grew in the outcrops around Homestead Cave from before 10 ka until ~8 ka or slightly later, after which time it disappeared from the local area. Hackberry is also the dominant plant macrofossil found in a small, badly weathered midden (GH 1) from the Gillespie Hills, located near Homestead Cave on the northern edge of the Lakeside Mountains, directly adjacent to Great Salt Lake (table XLIV). Endocarps in this midden gave a conventional radiocarbon age estimate of ~6670 yr B.P., while an AMS date on a single endocarp returned an age estimate of ~8110 B.P. (Wang and others, 1997). The latter age estimate is more in line with the evidence from Homestead Cave, though it is quite possible that the midden represents a palimpsest assemblage dating from a relatively long interval, and that hackberry persisted in the rocky Gillespie Hills into the early middle Holocene. Hackberry prefers rocky substrates where it can absorb water trapped in cracks in outcrops (DeBolt and McCune, 1995). The area is presently too dry to support hackberry, although hackberry is found at relatively low elevations in the more massive and better-watered Oquirrh and Stansbury Mountains not far away, and it has been reported from the Lakeside Mountains (Albee and others, 1988).

Early Holocene midden records from upland settings in the northern Bonneville basin are very scarce. Only one upland midden is known from this time period, and it represents the very latest end of the early Holocene, at ~8060 yr B.P. This midden comes from Indian Farm Canyon, in the Deep Creek Range, southwest of the Great Salt Lake Desert. It contains abundant Rocky Mountain juniper, skunkbush sumac and hackberry, with smaller quantities of mesophilic shrubs including chokecherry and elderberry. A mesophilic montane juniper-shrub community is indicated, quite differ-

Table XLV
Early Holocene midden samples from Bonneville basin and vicinity

Sample Name	**TP 3a**	**LO 1c**	**GH 1**	**IFC 2**[1]
^{14}C Date	9280 ± 60	9340 ± 90	8110 ± 60	8060 ± 60
Lab #	Beta - 76181	Beta - 68872	RA C019	Beta - 82953
Material Dated[2]	Atco	Dung	Cere	Jusc
Trees				
Pinus monophylla				1
Pinus sp. (cf. *flexilis*)				2
Juniperus scopulorum				5
Shrubs				
Artemisia sect. *tridentatae*	3	1	2	
Chrysothamnus sp.	2	1	2	
Tetradymia sp.		1	1	
Atriplex confertifolia	2	4	2	
Gutierrezia sp.			1	
Rhus cf. *aromatica* var. *trilobata*				5
Sambucus cf. *mexicana*				2
Celtis cf. *reticulata*			5	3
Forsellesia nevadensis		3		
Prunus cf. *virginiana*				2
Symphoricarpos sp.		1		
Forbs, Grasses and Succulents				
cf. *Helianthus* sp.				1
Other Poaceae			1	

1. A second date, on a *Pinus monophylla* seed coat, is 540 ± 65 yr B.P. (NSRL-10439).
2. Material dated: Dung = *Neotoma* pellets, Atco = *Atriplex confertifolia*, Cere = *Celtis reticulata* pericarps, and Jusc = *Juniperus scopulorum.*

ent from the singleleaf pinyon-Utah juniper woodland extant today.

The midden record from the southwestern Bonneville basin (Wells, 1983; Thompson, 1984, 1990) is more montane than lowland in distribution, but it too is very sparse. This record suggests that lower montane settings were dominated by a mosaic of mesophilic shrubs and a sparse woodland dominated by Rocky Mountain juniper and the newly immigrant Utah juniper. Conifers such as bristlecone pine, limber pine and common juniper retreated to higher subalpine altitudes, persisting at lower elevations only on shaded north-facing slopes. The Council Hall Cave pollen record suggests that conifers were relatively scarce, while trees such as aspen, mountain mahogany and chokecherry increased in abundance, and sagebrush and grass were common (Thompson, 1984). According to Thompson (1990), cool early Holocene temperatures apparently allowed mesophilic plants to grow at lower elevations than today. These records from the southern Bonneville basin indicate that early Holocene climatic conditions may have been cooler and moister than at present, consistent with the interpretation of the faunal remains from Homestead Cave (Grayson, 1998; see chapter seven). In contrast, Siegal (1983) used ratios of hydrogen isotopes from plant remains in several of Thompson's middens to suggest that temperatures around 10 ka were approximately the same as today, at most perhaps 1°C cooler.

Other Records

The Great Salt Lake Core C pollen record documents the decline of conifer woodlands and expansion of xerophytic shrub communities in the Bonneville basin shortly after ~9.7 ka (Spencer and others, 1984). The declining abundance of conifer pollen (relative to all pollen) in Snowbird Bog, located in Little Cottonwood Canyon, Wasatch Range, also documents rapid early Holocene warming sometime prior to ~7.9 ka (Madsen and Currey, 1979). The pollen record from Swan Lake, north of the Bonneville basin, reveals a strong decline in pine (especially limber pine) and other conifers and substantial increases in sagebrush and grass beginning about 10.3 ka and lasting until approximately 8.4 ka. Chenopodiaceae - *Amaranthus* pollen increases slightly during this interval, apparently reflecting the increase in saltbush and shadscale communities as lowland soils increased in alkalinity (Bright, 1966, p. 24). Increased warming toward the end of the early Holocene is reflected in the pollen sequence from Grays Lake on the margins of the Snake River Plain, where a transition from sagebrush steppe to sagebrush/shadscale steppe is dated to ~8.5 ka (Beiswenger, 1991). A similar sequence is found at Ruby Marsh, ~120 km west of the Bonneville basin, where the transition dates from 8.5 to 8 ka (Thompson, 1992a).

Harper and Alder (1972) examined plant remains from early Holocene archaeological strata in Danger Cave, specifically ratios of sagebrush vs. shadscale and greasewood vs. pickleweed. They suggested, albeit with some surprise and discomfort, that the earliest Holocene began with a relatively dry period, ~10,150 yr B.P., then became cool and moist about 9750 yr B.P., and subsequently grew warmer and drier by about 8.5 ka. Harper and Alder pointed to parallels in the pollen record from Swan Lake, particularly a general increase in pine and spruce pollen after about 10.2 ka. However, this sequence is not well supported by most other early Holocene records, including the Homestead Cave sequence. The beginning of the early Holocene may not have been as cool or moist as later on, but the interpretation Harper and Alder (1972) drew from the Danger Cave record, that the climate at 10 ka was as warm and dry as at 6.8 ka, is nowhere supported. The Danger Cave record may reflect factors other than climate, such as soil development on exposed lake sediments (Bright, 1966) or taphonomic vectors.

Summary

A mosaic of saltbush scrub and sagebrush steppe communities dominated vegetation in lowlands of the Bonneville basin during the early Holocene. Greasewood and other halophytic chenopods colonized large areas of playa margin around the old lakebed of former Lake Gilbert during this interval (Harper and Alder, 1972). Lowland plant associations were more mesophilic in character than they are today, containing plants such as hackberry that are no longer found abundantly in lowland settings, as well as a higher abundance of sagebrush and grass than exists in lowland shrub communities today. Wetlands were more extensive in certain valley areas than presently, indicating a higher regional water table, probably left over from the preceding glacial period, and possibly a wetter climate as well (see chapter thirteen). As Bright (1966) noted for Swan Lake, patterns of soil development undoubtedly strongly affected the evolving composition and distribution of plant communities as taxa colonized the vast lowlands of the Bonneville basin.

A mosaic of sagebrush-grass steppe and mesophilic aspen or brush communities, with relatively few conifers, apparently dominated upland areas. Among the conifers the temperate mesophilic Rocky Mountain juniper was dominant in the north and co-dominant with the newly arrived Utah juniper in the south. Conifers, such as limber pine and bristlecone pine, now restricted mainly to subalpine habitats, were present at lower elevations, but generally on protected north-facing slopes. Utah juniper had not yet arrived in the northern Bonneville basin, and singleleaf pinyon pine apparently had not begun its rapid northward migration until near the end of the early Holocene.

The widespread occurrence of Rocky Mountain juniper in upland settings, and the more restricted distribution of Utah juniper to southerly latitudes, suggest that early Holocene climates were cooler than today, and possibly (though not necessarily) somewhat wetter. Comparison of weather station data from the present distribution of Rocky Mountain juniper vs. Utah juniper (figure 110) indicates that the two taxa differ most significantly in their preferred temperature regimes: Utah juniper typically requires warmer winters and tolerates warmer summers than Rocky Mountain juniper. The two taxa do not differ greatly in the seasonal abundance of precipitation required, though weather stations in the range of Rocky Mountain juniper do have significantly greater annual precipitation and somewhat higher summer precipitation than those found in Utah juniper habitat.

It seems most likely, therefore, that the early Holocene climate that fostered the dominance of Rocky Mountain juniper was cooler and had possibly wetter summers than the present climate which supports Utah juniper. How much cooler and wetter is harder to say. This is so because (1) climate may not have been the main limiting factor in the dis-

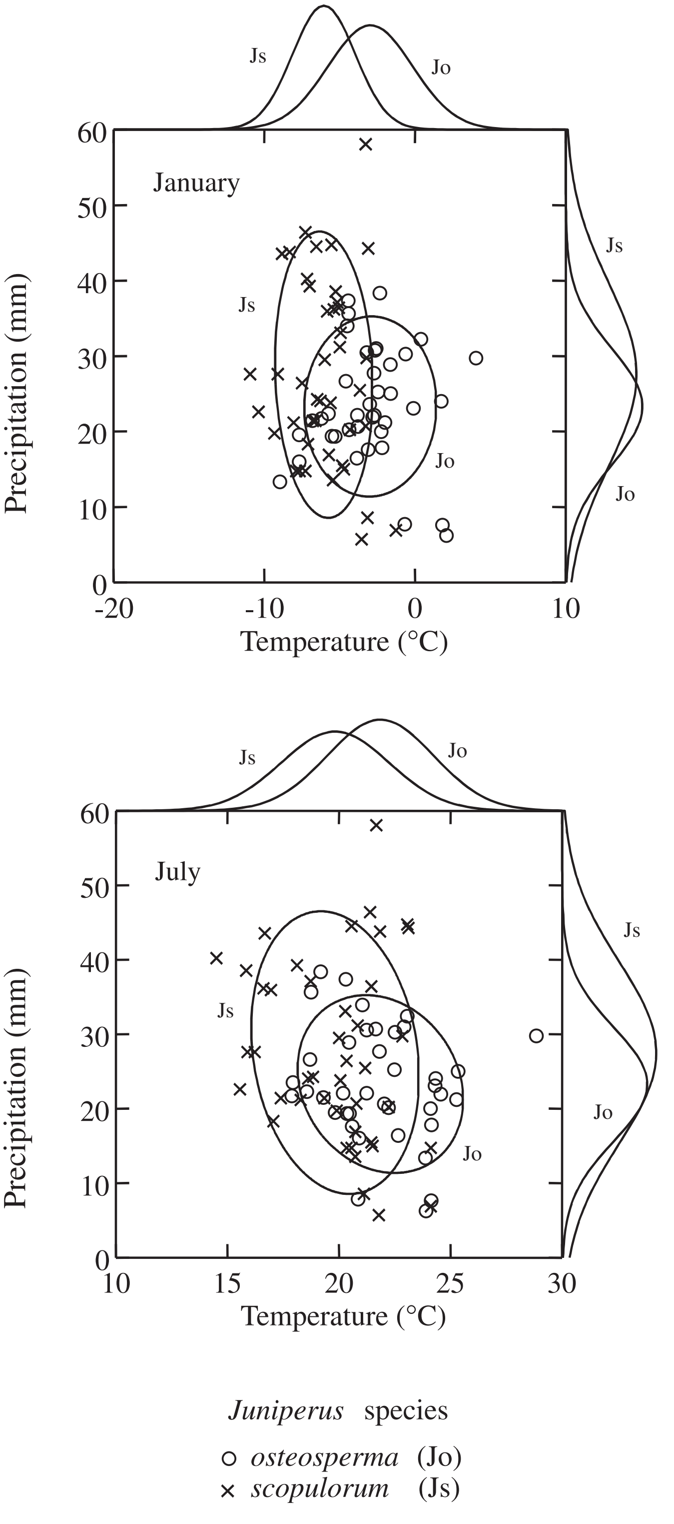

Figure 110. *Average January and July temperature and precipitation values (1961-1990) at weather stations in Idaho, Nevada, Utah and Wyoming that lie within the distribution of Utah juniper (*J. osteosperma*) and Rocky Mountain juniper (*J. scopulorum*), as mapped by Little (1971). Climate data are from U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Climatic Data Center.*

tribution of Utah juniper (another possible factor could be rate of population expansion), (2) both taxa tolerate a rather wide latitude of climatic conditions with broad overlap, rendering precise estimates difficult, and (3) climatic tolerances may be affected by competitive relationships within plant communities, which can change over time. However, if the weather station data can be applied, it appears that a transition from exclusively Rocky Mountain juniper to exclusively Utah juniper would require a warming of at least 3-5°C overall.

The evidence from both plant and animal distributions tends to support a "cool, possibly wet" Anathermal of Antevs (1955), and runs counter to the expectations of general circulation models based on orbital forcing parameters, that would predict warmer (and possibly wetter) summer conditions by at least 10 ka. A region-wide trend toward warmer temperatures and probably less effective moisture is manifested by ~8.5 ka in pollen records. This evidence of warming and drying conditions is consistent with the evidence of faunal change documented at Homestead Cave (chapter seven).

MIDDLE HOLOCENE, 8000-4000 YR B.P.

The middle Holocene was a period marked by distinctive vegetation changes in the Bonneville basin. These changes include significant range extensions by several important woodland taxa such as pinyon pine and Utah juniper, as well as changes in composition of extant woodland and shrub communities. In addition, the middle Holocene, the core of Antevs' so-called Altithermal, is famous for its presumed effects on human occupation of the intermountain west. Grayson (1993) recently showed that, except for the Bonneville basin, very few Great Basin archaeological sites have radiocarbon dates indicating occupation during the middle Holocene, leading him to suggest that perhaps Baumhoff and Heizer (1965) were right in stressing that the region was a rather poor place for people to live at that time. However, Grayson specifically excluded the Bonneville basin from his examination, for good reason: the record of occupation in the Bonneville basin does appear to differ from the rest of the basin, most notably because the well-dated Danger and Hogup caves, together with a number of other Bonneville basin caves, were occupied through much of the middle Holocene. But if the occupation history of the Bonneville basin did truly differ from the rest of the basin, why did it differ? Does it have anything to do with Antevs' Altithermal? Was this region spared the effects of the Long Drought, or does the paleovegetation record reflect significantly warmer and drier conditions?

This last question, regarding Bonneville basin vegetation reflecting "Altithermal" climate, can be considered here, though with a relatively limited base of data. Only four midden samples are known from the northern Bonneville basin and vicinity that give age estimates between 8 and 5.5 ka, the first two-thirds of the middle Holocene (table XLVI), and only five samples give age estimates between 5.5 and 4 ka, which apparently had a different climate than the earlier period. An additional record from the Cricket Mountains (CM 1), in the southern Bonneville basin, is also presented in this table. These samples provide limited but nevertheless useful information on the timing of migration of certain taxa into the region, on the nature of vegetation community composition, and on climatic conditions during this interval.

The lowland midden record for the middle Holocene is practically nonexistent. One midden, from Leppy Overhang (LO 2b), suggests that by 7.5 ka, *Atriplex* dominated an association containing other shrubs such as sagebrush, greasebush, rabbitbrush, boxthorn, cliff rose and desert snowberry. No other middens from lowland settings that date to the middle Holocene are known from the northern Bonneville basin.

Middens from upland areas are confined to mountains west of the northern Bonneville basin region: the Toano, Pequop, Cherry Creek, and Silver Island ranges (figure 109). These records suggest that lower montane woodlands were still dominated by Rocky Mountain juniper, often with a secondary component of pinyon pine. Pinyon pine is not represented in the midden record until about 6 ka, though it is found in archaeological sediments from Danger Cave dating at least 600 years earlier (Rhode and Madsen, 1998). Sagebrush and rabbitbrush were the commonest understory shrubs, while a few mesophilic shrubs (dogwood, ninebark, shrubby cinquefoil, snowberry, chokecherry) are present in small quantities in several samples.

The fact that Rocky Mountain juniper, a relatively cool-tolerant, mesophilic continental juniper, dominated in upland woodlands of the northern Bonneville basin, rather than the more thermophilic Utah juniper, may indicate that middle Holocene climate had greater effective growing season precipitation than today. Alternatively, winters could have been cold enough to restrict the northward movement of Utah juniper during this period. Utah juniper was apparently absent in the northwestern Bonneville basin region until after 5100 yr B.P., near the end of the middle Holocene, where it occurs in small quantities in a single midden (IB 1) from the Toano Range. A dated record from Devils Gate 1A, in the Onaqui Mountains, suggests that Utah juniper occurred in mountain ranges to the south and east of the Bonneville basin at 6600 yr B.P. (see table XLIII, chapter eleven); the midden is mixed with earlier materials, so its plant associates are not known. Utah juniper was common during the middle Holocene in the southern Bonneville basin (Thompson, 1984, 1990), as the record from Cricket Mountain (CM 1) indicates (table XLVI).

In a few protected settings, such as the north-facing middens from Cottonwood Canyon (CC 1b) in the Cherry Creeks and from Icicle Cave (IC 3d) in the Pequop Mountains, limber pine was a minor component of the woodlands dominated by Rocky Mountain juniper and pinyon pine. These middens predate the complete retreat of limber pine to subalpine elevations, but the main populations of these conifers were probably located at higher elevations than the midden record presently reaches. Limber pine nut hulls also occur in sediments of Danger Cave dating between 7 and 8 ka (Rhode and Madsen, 1998). These nut hulls suggest that limber pine may have grown at relatively low elevations in nearby mountains.

In the southwestern Bonneville basin, conifers such as limber pine, bristlecone pine and Rocky Mountain juniper, as well as mesophilic shrubs, had declined significantly in abundance or were restricted to higher elevations by the beginning of the middle Holocene (Thompson, 1984). Pinyon pine, Utah juniper, ponderosa pine and white fir became increasingly abundant. Thompson (1984, 1990) has suggested that these taxa may reflect increased amounts of summer pre-

Table XLVI
Middle Holocene midden samples from Bonneville basin and vicinity

Sample Name	**CM 1**	**CC 1b**	**LO 2b**	**MM 1b**	**IC 3d**	**IB 1**	**SI 2b**	**SI 1**	**CC 1E**
^{14}C Date	7900 ± 100	7690 ± 70	7520 ± 60	5960 ± 90	5340 ± 50	5070 ± 50	4410 ± 90	4150 ± 130	4016 ± 75
Lab #	Beta- 8020	Beta- 79087	Beta- 68144	Beta- 73389	Beta- 120585	Beta- 82952	Beta- 70606	Beta- ?	DRI- 3135
Material Dated[1]	Juos	Pifl	Dung	Pimo	Pimo	Pimo	Dung	Jusc	Dung
Trees									
Acer macrophyllum		1			2				
Juniperus osteosperma	3					2			
Juniperus scopulorum				5	5	3		5	3
Pinus flexilis		2			1				
*Pinus monophyll*a				3	2	3	3		
Shrubs									
Artemisia sect. *tridentatae*		2	2	3	3		4	2	4
Atriplex confertifolia				2			1		3
Atriplex sp.	3		4						
Brickellia sp.								2	
Chrysothamnus sp.			2	3	2		4		3
Cornus cf. *sericea*		3							
Ephedra sp.			2						
Forsellesia nevadensis			2						
Haplopappus sp.								1	
Gutierrezia cf. *microcephala*	1								
Gutierrezia cf. *sarothrae*				?				1	
Juniperus communis					2				
Lycium sp.			2						
Physocarpus sp.					3				
Potentilla cf. *fruticosa*				3					
Prunus cf. *virginiana*		3			2				
Purshia mexicana var. *stansburiana*			1						
Purshia cf. *tridentata*	2								
Rosa cf. *woodsii*		2							
Symphoricarpos sp.			2						
Tetradymia sp.	2						3		
Forbs and Succulents									
Astragalus sp.			1						
Cirsium sp.							1	3	2
Chenopodium sp.					1				
Cryptantha humilis			1						
Galium sp.			2						
Lithospermum cf. *ruderale*				2					
Opuntia cf. *polyacantha*	1	1	2	3	1				
cf. *Petrophytum caespitosum*						1			
Asteraceae			1						
Cactaceae									1
Grasses									
Elymus cf. *cinereus*							1	1	
Elymus spicatus			1		2				
Stipa hymenoides			2						
Stipa sp.					1				
Other Poaceae								1	

1. Material dated: Dung = *Neotoma* pellets, Jusc = *Juniperus scopulorum,* Juos = *Juniperus osteosperma,* Pifl = *Pinus flexilis,* Pimo = *Pinus monophylla*

cipitation from subtropical sources, in addition to warmer growing-season temperatures.

Other Records

A variety of other middle Holocene vegetation records in the Bonneville basin reveals a pattern of increased warming and drying (Currey and James, 1982; Thompson and others, 1993). The pollen record from Great Salt Lake reported by Mehringer (1985) documents high ratios of shadscale and other chenopod plants relative to sagebrush and conifers between 7 and 5 ka, suggesting that the early part of the middle Holocene was warmer and drier than today. Between 5 and 4 ka, relative pollen abundance approached modern values, suggesting that climatic conditions were generally cooler and/or wetter in the latter part of the middle Holocene than in the first half.

At Swan Lake (Bright, 1966), the middle Holocene is characterized by relatively high values of sagebrush and chenopod pollen, low quantities of grass, and small but persistent quantities of juniper and oak. Bright placed the middle Holocene period between 7.8 and 3.1 ka, suggesting that the vegetation characteristic of the middle Holocene began when "grass was replaced by alkali-loving plants as alkalinity in the soils increased" (Bright, 1966, p. 25). On the whole, vegetation of the period "was little different in either aspect or distribution from that of today and therefore reflects a warm semiarid climate."

Pollen from Snowbird Bog, in the Wasatch Range, indicates the period from 8 to 6 ka was warm and dry, while the following period until 5.2 ka was not quite as warm and probably wetter as well (Madsen and Currey, 1979). The Ruby Marsh sediment record documents lower-than-modern water levels and an expansion of shadscale at the expense of sagebrush steppe vegetation starting ~7 ka, continuing until about 4 ka (Thompson, 1992a). Mission Cross Bog, in the Jarbidge Mountains northwest of the Bonneville basin, shows evidence for an increase in juniper woodland and shadscale steppe and a reduction in the extent of subalpine conifers from about 8 to 5 ka B.P. (Thompson, 1984).

Harper and Alder (1970) found that plant remains from strata dating from 7.8 to 3.2 ka in Hogup Cave also indicated environmental conditions somewhat more arid than the early Holocene. A similar sequence was found at Danger Cave, in strata dating from ~8 ka until the end of the record ~4 ka. The ratio of sagebrush to saltbush remains in Hogup Cave suggested one possible reversal toward greater effective moisture, roughly dated at ~6 ka. Plant remains from these caves suggest that arid conditions returned after ~6 ka, and persisted until about 3.2 ka. Evidence for this brief mesic interlude ~6 ka was also traced to slight fluctuations in the Swan Lake, Great Salt Lake, and Curelom Cirque pollen records (Currey and James, 1982; Harper and Alder, 1970, 1972; Mehringer, 1977). At Potato Canyon Bog, in central Nevada, a pronounced increase in the abundance of pine occurred approximately 6.5 to 6 ka, significantly different from "the complex period of possibly lower effective moisture that preceded it" (Madsen, 1985b, p. 122). At nearby Gatecliff Shelter pine and juniper pollen increased markedly in water-laid sediments dated ~5.5 to 5 ka (Thompson and Kautz, 1983), an interval that Davis (1983) characterized as relatively mesic and "summer-wet." Evidence for this mesic interval is lacking in some other records, however (examples: Danger Cave, Snowbird Bog, Great Salt Lake Core C). The interval may be correlated with a prominent mesic period occurring around 5.5 ka elsewhere in the Great Basin (Wigand and Rhode, in press), and with a rise in the level of Great Salt Lake tentatively dated ~5 ka (McKenzie and Eberli, 1987), but such correlations await better dating control.

Summary

The middle Holocene in the Bonneville basin had distinctly more xeric-adapted vegetation than did the early Holocene. Lowlands were covered more by chenopod-dominated scrub communities and less by sagebrush and grass. Uplands were clothed in juniper woodlands and shrub communities that gradually replaced the mesophilic conifer woodlands and shrublands of the early Holocene, although these middle Holocene upland woodlands appear to have been still more mesophilic than those present in the same localities today. Upland woodlands in the southwestern Bonneville basin were dominated by Utah juniper and pinyon pine, while those in the northwestern basin were dominated by Rocky Mountain juniper and pinyon pine. Pinyon pine rapidly migrated northward along the west margin of the Bonneville basin within a few centuries of 7 ka. Utah juniper apparently expanded northward as well, especially in the southwestern and southeastern basin, but it was delayed in its migration into the northwestern basin until the latter third of the middle Holocene. Greater penetration of 'monsoonal' summer storms and increased growing season precipitation has been suggested as one possible reason to account for the northward migration of pinyon pine and the persisting dominance of Rocky Mountain juniper in upland settings (Thompson, 1984; Wigand and Rhode, in press). Several records indicate that an anomalously mesic interval occurred roughly 6 to 5.5 ka, and that the last third of the middle Holocene, after ~5.5 ka, was cooler and had greater effective moisture (possibly derived from winter storms) than the earlier part.

THE NEOPLUVIAL, 4000–2000 YR B.P.

The end of the middle Holocene is marked by the onset of a "neolacustrine" or "neopluvial" cool-wet episode (Antevs, 1948; Currey and James, 1982; Mehringer, 1985, 1986; McKenzie and Eberli, 1987). Cores from the Bonneville basin indicate several episodes of freshening and deepening of Great Salt Lake as early as 5 ka, with a sustained high period from 3 to 2 ka (Currey and others, 1984; McKenzie and Eberli, 1987). This neopluvial fluctuation toward cooler, wetter conditions clearly affected vegetation distributions in the northeastern Great Basin, but the effects were modest compared with those of the Pleistocene-Holocene shift.

The midden record representing the neopluvial is more abundant than that representing the previous several thousand years. A total of 12 midden samples have been dated between 2 and 4 ka in the northern Bonneville basin and vicinity (table XLVII). Several pollen records (see Bright, 1966; Madsen and Currey, 1979; Mehringer, 1977; Thompson, 1984, 1992a) augment the midden series.

Midden records

Many of the available midden samples have contents that are consistent with the vegetation that grows around them today, indicating that the flora of the region was largely modern by this time. Plant communities were generally close to their modern distribution and composition. One significant exception concerns the distribution of Utah juniper and Rocky Mountain juniper. Utah juniper apparently arrived in the middle to late Holocene in this region, as noted previously. In some areas Utah juniper was a minor component in woodlands dominated by Rocky Mountain juniper

Table XLVII
Neopluvial-age packrat middens from Bonneville basin and vicinity

Sample Name	**CC 1D**	**WG 1**	**GS 2a**	**RC 2**	**GS 1**	**WG 2b**	**HAG**	**SC 5**	**IC 1**	**PQ**	**EH 1**	**RR 1**
^{14}C Date	3900	3850	3670	3310	3110	3080	3010	2910	2830	2660	2490	2470
	± 60	± 70	± 50	± 60	± 50	± 50	± 50	± 70	± 70	± 80	± 50	± 40
Lab # (Beta-)	79088	86499	117564	68873	117563	117566	102021	115493	73386	68145	115492	115495
Material Dated[1]	Pimo	Dung	Juos	Dung	Juos	Pimo	Tetr	Dung	Artr	Dung	Dung	Juos
Trees												
Acer glabrum									1			
Juniperus osteosperma	2	5	5		5	4	1	4	3	4		5
Juniperus scopulorum	3								3			
Pinus monophylla	3	3				3			3	4		
Shrubs												
Acamptopappus cf. *sphaerocephalus*		2										
Artemisia sect. *tridentatae*	3		2		3	2		4	5	2	3	
Atriplex confertifolia				5			3				2	
Atriplex sp.		2				3						
Brickellia sp.		1		1	1							
Chrysothamnus sp.	3		2		3			1				
Ephedra sp.				1			1					
Forsellesia nevadensis		3		3								
Gutierrezia cf. *sarothrae*	1				2							
Haplopappus sp.					1			1				
Lycium sp.							2					
Prunus cf. *virginiana*	1											
Purshia mexicana var. *stansburiana*		2										
Purshia sp.						1						
Rhus aromatica var. *trilobata*								2			1	
Rosa cf. *woodsii*	1											
Sarcobatus vermiculatus							2					
Symphoricarpos cf. *longiflorus*				1								
Symphoricarpos sp.	2									1		
Tetradymia spinosa							3					
Tetradymia glabrata							2					
Tetradymia sp.			2									
Forbs and Succulents												
Amaranthus sp.					1							
Amsinckia menziesii							2					
Argemone sp.					1							
Artemisia cf. *ludoviciana*											2	
Asteraceae	2	1	2		2					1	1	
Astragalus sp.			1		2			1		1		
Chenopodium sp.					2		1		1		1	
Corispermum hyssopifolium							1					
Galium sp.					1				1			
Ipomopsis sp.		3										
Lappula redowskii					1		1					
Lomatium sp.							2					
Opuntia cf. *polyacantha*		2				2		1	2	2		
Phacelia sp.							1					
Potentilla sp.										2		
Asteraceae	2	1	2		2					1	1	
Cactaceae	1	2										
Fabaceae					1		1					
Scrophulariaceae										1		
Grasses and Monocots												
Elymus cinereus										2	1	
Elymus spicatus						1					2	
Festuca sp.		2			1							
Scirpus sp.			2									
Stipa hymenoides		2					1					
Other Poaceae	1		2		2		1					

[1] Material dated: Artr = *Artemisia tridentata*, Dung = *Neotoma* pellets, Juos = *Juniperus osteosperma*, Pimo = *Pinus monophylla*, and Tetr = *Tetradymia* sp.

(for example, Cherry Creek [CC] 1D, Silver Island Canyon [SI] 2), but in nearby areas it was the dominant woodland conifer (for example, West Goshutes [WG] 1). Utah juniper is the most common juniper in all of these areas now. Rocky Mountain juniper has apparently become much less common in woodlands of the region since about 2 ka.

Several midden records from areas near Great Salt Lake indicate that Utah juniper grew at elevations at least 50-100 m lower than it occurs today during this interval (table XLVII). Records of juniper below its present distribution are found at the Golden Spike locality (GS), dating 3700 and 3100 yr B.P., the HAG locality at 3000 yr B.P., and two midden localities on Antelope Island: Sentry Cave (SC) at 2900 B.P. and Red Rocks (RR) at 2500 yr B.P.

Another example of range shifts of important taxa during the neopluvial is green mormon tea. Green mormon tea is a common shrub in uplands throughout the region, including the vegetation surrounding midden localities on the western slope of the Goshute Mountains today, but midden samples dating 3850 and 3100 yr B.P. lack green mormon tea. Other paleoecological records also indicate that green mormon tea may have been a late entry into the vegetation of the northern and central Great Basin, within the past 3000 years (see Thompson and Kautz, 1983). However, green mormon tea is found in hardly any midden samples of any age, suggesting that the lack of green mormon tea in middens may be partly related to collection habits of packrats rather than abundance in the landscape.

Consequently, the midden record from the northern Bonneville basin and vicinity indicates that while modern vegetation associations were largely in place by the late Holocene, the abundance of certain plant taxa within those vegetation associations varied significantly through time. Some taxa such as green mormon tea and Utah juniper may have achieved their present importance in the vegetation only within the last 2000 years. In addition, the distribution of some taxa shifted in elevation in response to climatic variation, as the example of Utah juniper shows.

In the southern Bonneville region, by contrast, Thompson (1984) found only rather modest vegetation changes through the last few thousand years, suggesting that late Holocene climates were relatively stable, at least on the scale recorded in midden plant records. However, it should be noted that Thompson's study was not specifically directed toward examining rather subtle late Holocene shifts in vegetation communities: the focus of his pioneering midden work was, quite properly, geared toward larger-scale patterns in vegetation history over the last 40,000 years.

Other records

Several paleovegetation records in the eastern Great Basin document significant climatic and vegetation shifts between 4 and 2 ka. At Swan Lake (Bright, 1966), warm dry middle Holocene conditions became cooler by 3.1 ka, with a lowering of forest treeline, a prominent increase in grass, and a decrease in shadscale scrub and sagebrush steppe. Warmer conditions apparently returned by 1.7 ka, with increased sagebrush and less limber pine. A cooler late Holocene climate from ~5 ka onward is also reflected in the pollen from Snowbird Bog in the Wasatch Range (Madsen and Currey, 1979). At Ruby Marsh the pollen record indicates that, after ~4.5 ka, "shadscale declined in importance in the valley bottom and marsh waters deepened, in turn reflecting cooler temperatures and/or greater precipitation" (Thompson, 1992a, p. 13). The record from Mission Cross Bog, in the Jarbidge Mountains, shows an increase in pollen from spruce, fir and pine beginning after 5 ka with a peak around 3.6 ka, suggesting that this was the most mesic episode in the past 8000 years (Thompson, 1984). At Gatecliff Shelter, central Nevada, packrat midden, pollen, and sedimentary evidence (Davis, 1983; Thompson and Hattori, 1983; Thompson and Kautz, 1983) indicate that a cool, winter-wet interval began rather suddenly about 3.4 ka, during which time green mormon tea became established in the region. The period between 3.4 and 2.8 ka may have been cooler and moister than any time in the past 6000 years. At Potato Canyon Bog, increased amounts of pine and arboreal pollen relative to sagebrush and non-arboreal pollen during the period from about 4 to 2 ka indicates increased effective moisture (Madsen, 1985b).

Summary

These data consistently show that the period from about 3.5 to about 2 ka was the coolest and most mesic period since the early Holocene, but was probably not quite so cool and wet as the early Holocene itself. Vegetation throughout the Bonneville basin was close to its modern distribution, but both midden and pollen records document that certain modern taxa had not yet reached their modern range, and that some taxa (such as Utah juniper) grew at significantly lower elevations than today. Sagebrush and cool-season grasses dominated vegetation in lowlands, while saltbush steppe decreased in abundance. In uplands, pines increased in abundance, and Utah juniper appears to have spread widely, though Rocky Mountain juniper was still common and in places dominant. The pollen record indicates that the neopluvial period was characterized by significant fluctuations in vegetation distribution, probably reflecting significant climatic fluctuations during this episode. However, the packrat midden record is at present not sufficiently detailed to adequately document these fluctuations.

LATEST HOLOCENE,
2000 YR B.P. - PRESENT

In general, the latest Holocene has been warmer and drier than the first part of the late Holocene. All major vegetation associations had reached their 'modern' (pre-contact) content and distribution by the beginning of this interval. The latest Holocene has not been marked by great climatic stability, however. Significant excursions toward periods of less effective moisture occurred within the past 2000 years and at least one significant cool period - the Little Ice Age - occurred a few hundred years ago. These also had effects on vegetation patterns. Finally, within the past 150 years plants native to Eurasian steppes and deserts followed the roads and cattle trails of latter-day settlers and ranchers. These invasions of non-native plants wrought the greatest changes in Bonneville basin vegetation since the Pleistocene/Holocene transition.

Midden Records

Eight midden samples are dated from the last 2,000 years in the northwestern Bonneville basin (table XLVIII). Contents of an additional sample from the Cricket Mountains, in the southern Bonneville basin, are also given in this table. These records tend to be very consistent with native vegetation growing in the vicinity of the middens today. With one exception, the middens from the last 2000 years contain no evidence of marked shifts in the elevation or range of any native plant taxa. The sole exception is from the Silver Island Mountains, where a midden dating ~2 ka contains Rocky Mountain juniper as a common component. Today the area is dominated almost exclusively by Utah juniper (a single Rocky Mountain juniper tree was observed in a narrow canyon several hundred meters upslope from the midden locality). At the coarse scale provided by the midden record, during the last 2000 years plant communities were quite similar in composition and distribution to those found in the region today, with the exception that modern vegetation also contains abundant exotic invaders such as *Bromus*, *Halogeton* and *Salsola*.

Other Records

An increase in the abundance of hackberry endocarps in Stratum XVII of Homestead Cave was previously noted in chapter five. This resurgence of hackberry coincides with increases in certain montane mammals (chapter seven) and with the reappearance of fish bones (chapter nine) in Homestead Cave. These lines of evidence indicate greater effective moisture about 1200 years ago. At both Swallow Shelter (Dalley, 1977) and Hogup Cave (Kelso, 1970), grass pollen increased beginning ~1.5 ka, again indicating greater effective growing season moisture. Harper and Alder (1970) also reported greater representation of grasses between 1.5 and 0.5 ka. Madsen (1985b) suggested a slight increase in effective moisture from 1.5 to 1.0 ka based on higher pine pollen abundance in Potato Canyon Bog. A postulated in-

Table XLVIII
Latest Holocene packrat middens from Bonneville basin and vicinity

Sample Name	SI 2a	KS 2	RHA	MB 2	GP 1	PP 2	CM 3	HS 2	KS 1
^{14}C Date	1940 ± 60	1240 ± 80	1230 ± 50	1180 ± 80	1170 ± 50	1130 ± 50	970 ± 50	510 ± 50	460 ± 70
Lab # (Beta-)	70605	43729	117568	43730	68656	117567	8022	102022	43728
Material Dated[1]	Juos	Juos	Juos	Dung	Juos	Pimo	Juos	Tetr	Dung
Trees									
Juniperus osteosperma	2	2	5	5	5	5	3		4
Juniperus scopulorum	4								
Pinus monophylla		2	5	5		4			3
Shrubs									
Artemisia sect. *tridentatae*					2	1	2	2	2
Atriplex confertifolia				3	2		3	3	
Cercocarpus intricatus			2						
Chrysothamnus sp.								2	
Ephedra sp.							4		
Forsellesia nevadensis			2						
Haplopappus sp.			2						1
Purshia mexicana var. *stansburiana*	5						2		
Tetradymia spinosa							3	4	
Tetradymia sp.					2				
Forbs and Succulents									
Chenopodium sp.			1						
Cirsium sp.							1		
Eriogonum cf. *fasciculata*								1	
Lithospermum cf. *ruderale*	1	1							
Lomatium sp.							1		
Opuntia cf. *polyacantha*									2
Cactaceae		2							
Grasses and Monocots									
Bromus sp.								2[2]	
Elymus cinereus	2								
Festuca sp.		1							
cf. *Iris* sp.							1		
Other Poaceae	1	1					2		

1. Material dated: Dung = *Neotoma* pellets, Juos = *Juniperus osteosperma*, Pimo = *Pinus monophylla*, and Tetr = *Tetradymia* sp.
2. Probable historic contaminants.

crease in summer precipitation during this period may have supported the spread and success of the Fremont peoples' maize-based horticultural systems in the Bonneville basin from ~1.5 to 0.9 ka.

Cores from the Bonneville basin indicate freshening and deepening of Great Salt Lake (Currey and others, 1984; McKenzie and Eberli, 1987) from about 0.5 to 0.2 ka (the "Little Ice Age"). An increase in sagebrush pollen and higher water levels at Ruby Marsh during the last 500 years indicates "the coolest and/or moistest conditions since the early Holocene," presumably correlated with the Little Ice Age (Thompson, 1992a). Harper and Alder (1970, 1972) compared the late Holocene record of plant remains from Hogup Cave and Danger Cave with the plants that grow around those sites today, to suggest that the modern climate ranks among the driest and warmest of the entire Holocene.

Summary

The midden record underscores the fact that vegetation patterns during the past 2000 years were largely similar to the modern period. However, the coarse record presently available does not provide sufficient spatial and temporal detail to detect subtler changes in regional vegetation that can be better observed in pollen records. In particular, increased growing season precipitation ~1.5 to 0.5 ka probably enhanced growth of upland grasses and likely favored the spread of Fremont horticultural societies. This period of summer moisture and relatively warm winters may have also favored pinyon pine, allowing woodlands to expand to slightly lower elevations ~1.5 ka (Hemphill and Wigand, 1995; Wigand, 1997; Wigand and Rhode, in press). Substantially cooler conditions apparently occurred beginning about 500 yr B.P., lasting for some 300 years. These Little Ice Age conditions resulted in upslope retreat of pinyon woodlands, expansion of sagebrush at the expense of grasses, and possibly the end of the Fremont experiment in the northern Bonneville basin.

CONCLUSIONS

Holocene vegetation patterns in the Bonneville basin can be summarized as follows. Early Holocene vegetation consisted of lowland areas dominated by sagebrush-grass steppe and more thermophilic and alkali-loving saltbush scrub, while uplands were covered in a mosaic of a shrubland containing relatively mesophilic shrubs, stands of aspen and mountain mahogany, and patchy woodlands dominated by Rocky Mountain juniper, along with Utah juniper in the southern basin, and containing conifers such as limber pine and bristlecone pine in protected habitats. After 8 ka, increasingly warm and dry conditions resulted in an increase in the extent of saltbush scrub at the expense of sagebrush-grass steppe, a decline in the abundance of mesophilic shrubs in the uplands, and an upslope retreat of pines to their present subalpine positions. Pinyon pine migrated rapidly northward during this interval, perhaps in response to milder winters and possibly enhanced growing season precipitation. This period appears to have continued until about 6 to 5 ka, when slightly moister conditions apparently returned. The vegetation evidence for this moisture increase is not strong, however. This interval may also have had somewhat warmer winters, that may have facilitated the northward migration of Utah juniper.

Significantly moister conditions are recorded after ~4 ka, with the onset of the neopluvial. Great Salt Lake rose significantly, and sagebrush steppe expanded into areas formerly occupied by saltbush scrub. Utah juniper was by now present in the northern Bonneville basin, though not everywhere dominant, sometimes growing at elevations at least 100 m lower than it occurs today. Certain taxa expanded their ranges during this time, including green mormon tea. By 2000 years ago, the modern "pre-historic" vegetation communities were essentially in place. Various plant taxa within these communities fluctuated in relative abundance in response to climatic fluctuations during the past 2000 years, most significantly a summer-wet interval ~1.5 to 0.5 ka, followed by the cool, winter-wet Little Ice Age, and lastly by the relatively warm and dry interval in which we now live. Vegetation changes wrought during the past 150 years, as a result of exotic invaders brought with Euroamerican occupation, rival the changes that occurred at the glacial-interglacial climate transition, especially in the lowland shrub and grassland communities.

The foregoing discussion reveals several general trends about vegetation history in relation to Holocene climatic change. The most dramatic vegetation changes occurring during the Holocene were ultimately brought about by the glacial-to-interglacial climatic shift, a transition that had begun several thousand years before. As interglacial climates developed during the Holocene, certain plant taxa expanded their ranges by thousands of kilometers, mostly northward and eastward. Other plant taxa, which had been favored by glacial climates, retreated to subalpine altitudes and into cool-mesic, protected refugia. The general floristic outcome of this process was additive, with more taxa added to the region's flora than lost.

This process of equilibration of a plant's range to new climatic conditions can take time. Certain plant taxa may require several centuries or more to expand to their new bounds of climatic tolerances after such a transition, depending on generation time and mode of propagule dispersal. This lag between climate change and plant distribution is often called "vegetation inertia" (Cole, 1985; Markgraf, 1986; Thompson, 1990). However, it is not clear whether this type of "inertia" had much detectable effect in the Bonneville basin. Some taxa probably extended their ranges quite rapidly in response to a favorable combination of climatic conditions, but those conditions may not have come about until after the Holocene began. Utah juniper, for example, did not reach the northern Bonneville basin until the middle Holocene. Is this case of vegetation inertia following the glacial-interglacial climate shift? Possibly, but Utah juniper had migrated rather rapidly through the southern Bonneville basin during the early Holocene. It probably stopped south of the northern Bonneville basin because of early Holocene climatic constraints, not because of an inherently slow rate of migration.

One of the most remarkable discoveries in the past decade is the abrupt nature of climate change that characterized the late Pleistocene and early Holocene. Ice cores collected from Greenland and Antarctica documented abrupt shifts from glacial to interglacial climate states, shifts that may have occurred within a few decades or less (see chapter thirteen). Similar rapid climate-related shifts in sediment composition and chemistry are also found in ocean cores in the North Atlantic, Caribbean, and off the coast of Santa Barbara, to name a few key localities. These records also suggest that glacial-type climate regimes apparently were much more variable than Holocene climate, when measured on the scale of centuries to millennia. These findings raise anew a question about the rates of Holocene climate change: was climate change during the Holocene primarily rapid, step-like and episodic on the century to millennium scale, or did Holocene climates shift in a more gradual, prolonged ramp-like fashion? This question bears not only on the mechanics of the interglacial climate system (and the potential consequences of our current meddling with it); it also has important implications about how vegetation communities and human populations were able to respond to climate shifts in the past. Presumably, human groups could adaptively track a gradual shift to warmer and drier conditions with greater success than if the shift was contained within the space of a few decades.

Rates of climate change are difficult to determine, however, from vegetation evidence alone. In part the difficulty lies with the records available to closely measure vegetation change, and in part the difficulty lies in the basic relationship of vegetation change to climatic change. Packrat middens, for example, are poorly suited to document close rates of change in regional vegetation, because individual samples are discontinuous in time and highly localized in space, showing in considerable detail the plants growing in a very narrow, very specific time and place. They are ideally suited to show presence vs. absence of specific taxa in specific places at specific times, much less so continuous fluctuations of abundance through time over a region. Pollen records, on the other hand, are much better suited to show the latter. However, a pollen record can also be a variable monitor of the regional pollen rain, as the size and character of the lake or bog fluctuates through time. These are some of the measurement problems. Problems associated with the relationship between vegetation change and climate change include "vegetation inertia," discussed earlier, and what may be called the threshold problem: the distribution or abundance of some plant species may not change very much despite variation in some climatic parameter, but will change rapidly once some threshold in that parameter or combination of parameters is reached. For example, pinyon pine may have made its very rapid march northward up the west side of the Bonneville basin only when winters became warm enough and growing season precipitation increased sufficiently to allow the survival and spread of seedlings in established plant communities.

Given these caveats, some pollen records in the Bonneville basin and surrounding regions strongly suggest that vegetation change occurred quite rapidly during certain brief intervals, presumably in response to rapid fluctuations in climate. The pollen record from Swan Lake, for example, shows a series of spiky "saw blades" (Faegri and Iversen, 1975, p. 137) illustrating the rapidly shifting abundance of key plant taxa such as grasses, sagebrush, chenopods, pine and especially sedge. The magnitude of difference between one sample and its near neighbors is compelling evidence that vegetation can change with striking rapidity. Similar "saw blades" are evident in pollen records from Great Salt Lake Core C (Spencer and others, 1984) and Crescent Spring (Mehringer, 1985).

These spikes in these records are often short-lived (hence "spikes"), indicating highly variable conditions within episodes lasting a millennium or more. If the records are smoothed to remove these high-frequency fluctuations, more gradual trends of vegetation change become evident; see, for example, the smoothed pollen record from Great Salt Lake (chapter one, figure 4; see also Mehringer, 1985) or Snowbird Bog (chapter one, figure 5). But the gradual appearance of these trends may be an artifact of sample homogenization, sample spacing, and the smoothing calculation itself. The underlying climatic shifts may be more rapid than the smoothed pollen records suggest.

This pattern of seemingly gradual trends overtopped by higher-frequency spiky fluctuations is also well known in tree-ring series. However, examination of these series on different temporal scales also shows relatively rapid shifts on the century to millennial scale. The 4500-year-long record

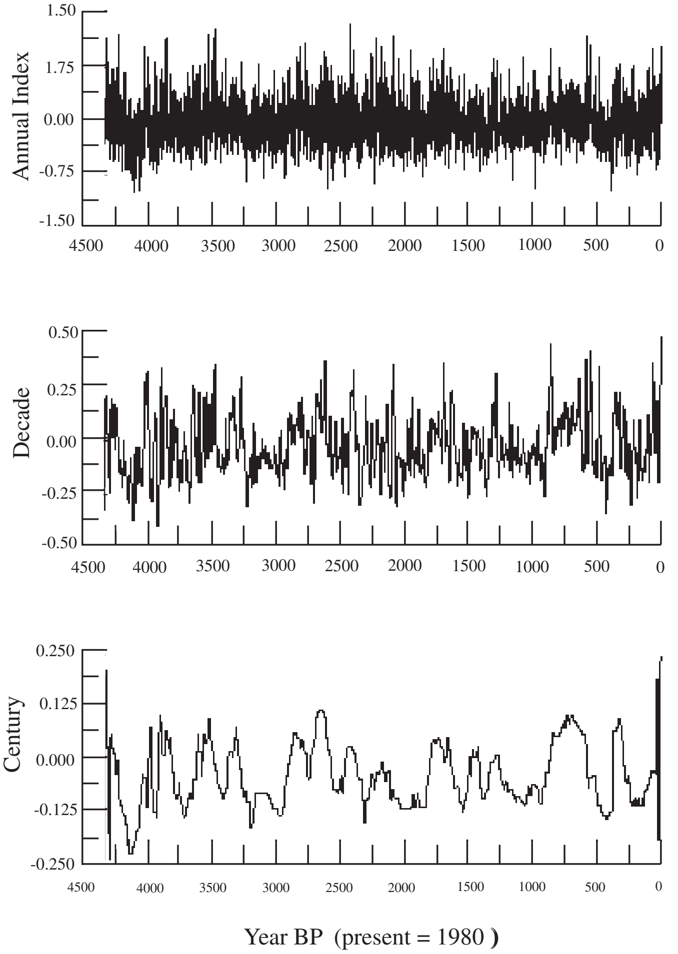

Figure 111. *Bristlecone pine tree-ring index series for Indian Garden, Nevada, site NV515 in the International Tree-Ring Data Bank, collected and prepared by D. A. Graybill (1984). Top diagram shows annual index values. Middle diagram shows index values smoothed with a running 10-year median smoother. Bottom diagram is smoothed with a running 100-year median smoother. Note the relatively abrupt (rather than gradual) shifts in index values during the past few thousand years. Note also the changes in the y-axis scaling, as the magnitude of variation decreases with the length of the smoothing algorithm.*

from Indian Garden, in central eastern Nevada, illustrates this pattern (figure 111). The calculated index of annual tree-ring growth is highly variable throughout the record. When this variation is smoothed with a 10-year running median filter, the variation between decades is much less marked (note the difference in scale of the index on the y-axis), but the shifts are still quite rapid. When the index variation is smoothed with a 100-year running median filter, rapid shifts are still evident.

These tree-ring and pollen records suggest that Holocene climate may have shifted relatively rapidly on annual, decadal and century to millennium scales. Apparently these shifts could be quite rapid at all of these scales, though the amplitude of climatic variation observable over longer, century to millenium time scales is much less dramatic than occurs on the shorter annual to decadal time frames. Chapter thirteen explores the episodic nature of climates during the late Pleistocene and Holocene in greater depth, and with a broader array of evidence from Homestead Cave and the Bonneville basin.

CHAPTER THIRTEEN

Summary and Integration

OVERVIEW

A column of stratified deposits laid down primarily by raptors and woodrats was collected from Homestead Cave on the northwestern margin of the Lakeside Mountains. Our goal was to explore the nature of environmental change in the Bonneville basin generally, but specifically to relate those changes to lake-level history and the history of human occupation in the region.

Raptors, in the case of Homestead Cave most likely Barn and Great Horned Owls (but see figure 112), are comprehensive foragers within a 3-5 km range of their home roost and collect a wide array of small mammals, birds and reptiles. Bones from these prey are regurgitated in the form of pellets below their roosts and constitute a useful sample of environmental conditions at the time they are laid down.

Figure 112. *View of a western screech owl (*Otus kennicottii*) perched on the trench shoring around the excavation area in Homestead Cave.*

The 1 x 1 m column from the cave was 2.9 m deep, and contained 18 "excavatable" depositional units with readily identified upper and lower surfaces. Microlaminae within these units could be recognized, and in some cases mapped, but could not be cleanly separated. The age of these deposits is controlled by 21 radiocarbon dates spanning the last ~13,200 calendar years (~11,300 ^{14}C yr B.P.). Deposition appears to have been relatively continuous, with periods of slow, or no, deposition at ~11,000, ~8500, and ~5000 calibrated calendar years ago. The column contained more than two million faunal elements, of which more than three hundred thousand can be identified to a useful taxonomic level.

This faunal record complements a floral record derived primarily from fossil woodrat middens collected from localities around the northern Bonneville basin, and secondarily from a limited variety of plants in Homestead Cave itself. Woodrats (*Neotoma* sp.) commonly collect a majority of plant types found within 50-100 m of their nests (Dial and Czaplewski, 1990; Frase and Sera, 1993). Urine and fecal matter deposited with this collected vegetation in perch areas cements the mass into middens which are often preserved for tens of thousands of years in protected areas. The dating and analyses of flora in such middens can provide a snapshot of vegetational communities at any one time and place. With a sufficiently large library of middens from a limited area, it is possible to reconstruct vegetational changes over extended periods of time. We collected and dated 62 samples from middens collected at 40 localities in and adjacent to the Great Salt Lake basin. A large number of these date to a period of 14 - 10 ka spanning the Pleistocene/Holocene transition, but several are 30,000-40,000 years old or older and 37 samples are of Holocene age. Though limited in number, these younger middens, used in conjunction with plant remains from stratified caves around the margin of the Great Salt Lake Desert and with previously recovered middens, are sufficient to estimate the nature of changing plant communities in the Bonneville basin during the Holocene.

Together, these floral and faunal records provide an increasingly detailed record of environmental change in the Bonneville basin over the last 50,000 years. When combined with geomorphic data derived from glacial and lake level sequences, these biotic proxy records also provide a comprehensive summary of changing climatic conditions over an extended period. Since climatic change and environmental change are inextricably linked, however, it is important to recognize how patterns of climate change affect changing environmental conditions in the Great Basin. As yet, such patterns of change are poorly known at the local level, but it is becoming increasingly evident that climate systems are linked on a global scale and that climatic cycles recognized in longer and more detailed records from Greenland ice cores and from North Atlantic deep sea cores are probably applicable to the Bonneville basin. Below we summarize late Pleistocene/Holocene environmental change, within a structure of globally recognized climatic cycles, after reviewing how such cycles may be related to changing Bonneville basin climates.

GLOBAL-SCALE CLIMATIC CHANGE AND THE BONNEVILLE BASIN

It has long been recognized that long-term climatic changes are related most directly to changes in the relative distance between the earth and the sun and, hence, vary with perturbations in the earth's orbit and axis. For late Quaternary climates, the 19,000 and 23,000-year precession cycles and the 41,000-year obliquity cycles are particularly important (see Grootes and Stuiver, 1997). Climatic change on a millennial scale of 1000-2000 years has also been recognized in proxy records from ice cores and from cores taken from the ocean and large continental lakes (see Benson and others, 1998). As yet, however, it is not clear how these shorter-term Dansgaard-Oeschger cyclical variations may relate to the celestial mechanics that drive the longer cycles. It is also not clear how such cycles may be represented in terrestrial environmental records.

What is becoming increasingly clear, however, is that the transitions between the steady-state conditions that characterize these millennial-scale cycles are relatively abrupt, often on the order of a decade or less, and certainly within the lifetime of an individual. In Greenland ice cores and cores from the North Atlantic, these cycles take a characteristic form during the glacial period. They are initiated with a rapid rise in temperature of 5-8°C in a matter of decades, gradually return to moderate conditions over the course of ~1000 yr, and end with a rapid return to very cold temperatures prior to the start of a warming event which initiates a new cycle. The amplitude of the cycles appears to be much smaller during the Holocene (on the order of 1-3°C), but the form seems to be relatively similar. Currently, nine cycles have been recognized in these detailed core records during the 12,000 years of recorded human occupation in the Great Basin (see Bond and others, 1997). While it is becoming evident that change in the water budget of the Bonneville basin is correlated with millennial-scale cycles evident in the ice core record, all nine of the Holocene cycles have yet to be recognized locally. This may be due to a combination of factors, such as the relatively coarse nature of the local environmental record, the reduced magnitude of Holocene oscillations and the presence of other, longer cycles with periodicities of 6,100 and 11,100 years which may obscure local manifestation of millennial-scale fluctuations (see Mayewski and others, 1997). Once detailed and sensitive records, such as those from tree rings and lake varves, are available, many, but perhaps not all, of the Holocene cycles may become evident.

In the absence of these detailed records, however, I want to incorporate those aspects of climatic change that may not yet be fully recognized into a model which usefully predicts patterns of environmental change in the Bonneville basin. By doing so, it should be possible to detect where the current paleoenvironmental reconstruction is weakest and where attention should be directed to strengthening the available informational base. It is possible to do this by examining differing types of climatic proxy data, such as changing lake levels and vegetation communities, against the global climatic sequence to detect where differences occur and, in turn, determine whether these differences are a product of a limited data base or represent real local climatic differences. Proceeding in such a way also makes it possible to move beyond description and towards a more deductive approach to understanding paleoenvironmental change in the Bonneville basin. It also allows me to summarize late Pleistocene and Holocene environmental change in the Bonneville basin within a structure that may be more realistic than the tripartite early/middle/late schemes which are usually employed.

In this regard the most useful climatic proxy record comes from Lake Bonneville and its successor, Great Salt Lake. More precise and shorter-term records, such as tree rings, are difficult to interpret because they are more sensitive to local geomorphology and microclimatic conditions. Fluctuations of a lake the size of Lake Bonneville, on the other hand, reflect change in the regional water budget due to broad changes in precipitation and evaporation rates linked to the ocean-atmospheric system via the polar jet stream (see Benson and others, 1997). Both Milankovitch and Dansgaard-Oeschger cycles, evident in core records, should be evident in Lake Bonneville deposits, and, indeed, both cycles have been observed (see Oviatt and others, 1992; Oviatt, 1997). Evidence for the millennial-scale cycles is spotty, however, and is limited for the Pleistocene/Holocene transition and the early Holocene. It seems likely that other millennial-scale oscillations occurred throughout the late Quaternary in the Bonneville basin and it may be possible to predict when they occurred and where evidence for them may be found.

As shown in figure 113 I have constructed a schematic diagram of a 20,000-year Milankovitch cycle with an amplitude of 16°C (A), and one of a series of Dansgaard-Oeschger cycles with amplitudes of 6°C (B). While ice core records suggest that the length of these cycles varies rather broadly, I have used a 1500-year cycle since it closely matches the 1470 ± 500 year cyclicity defined by Bond and others (1997) from North Atlantic deep sea cores. I then imposed these 1500-year cycles on the 20,000-year cycle (C), using it as the average base-line, centering the series at 10 ka and moving forward and backward from this point. Ten ka was chosen for the starting point because the most obvious match between short-term Lake Bonneville oscillations and the millennial-scale cycles of the core records is likely to be the end of the dramatic Younger Dryas climatic cycle. I then modified the resulting curve by imposing upon it two major aspects of basin morphology, a basin floor elevation and an overflow elevation (D). By comparing the resulting schematic with the current reconstructions of lake history (figure 114), it is possible to derive a number of useful predictions about late Quaternary lake-level fluctuations which are not evident from an evaluation of a descriptive history of the lake alone.

First, it is readily apparent that the schematic climate model and the known lake history are similar in several important aspects. At the high and low points of the 20,000-year cycle, evidence for short-term oscillations is likely to be limited because of the constraints imposed by the shape of the basin. At the highest elevations, shoreline evidence will be limited to periods when the lake dropped below its outflow channel and beach levels associated with the peaks of each oscillation will not be found. However, evidence of these millennial-scale events should be, and have been (see Oviatt, 1997), found in core and shoreline data representing the regressive phases of each oscillation. At the lowest elevations, evidence from shoreline data is also likely to be limited since beach features formed at the peak of each oscillation are probably at or below the range of modern lake-level fluctuations (but see Murchison, 1989a). Evidence for such changes is likely to be more apparent in core data (see Spencer and others, 1984; McKenzie and Eberli, 1987). Shoreline data should be available for elevations at the peak of each oscillation between these upper and lower limits, and should be found for oscillations that occurred during both the transgressive and regressive phases of the longer scale cycle.

For the most part, shoreline features that largely correspond to events predicted from the schematic model have been found (see Currey, 1980, 1988, 1990; Currey and others, 1984; Currey and Oviatt, 1985; Oviatt, 1988a; Murchison, 1989a; Oviatt and others, 1990; Oviatt and others, 1992), and the model seems to accurately reflect the expression of globally linked climatic changes in the history of Lake Bonneville and Great Salt Lake. The actual age of the

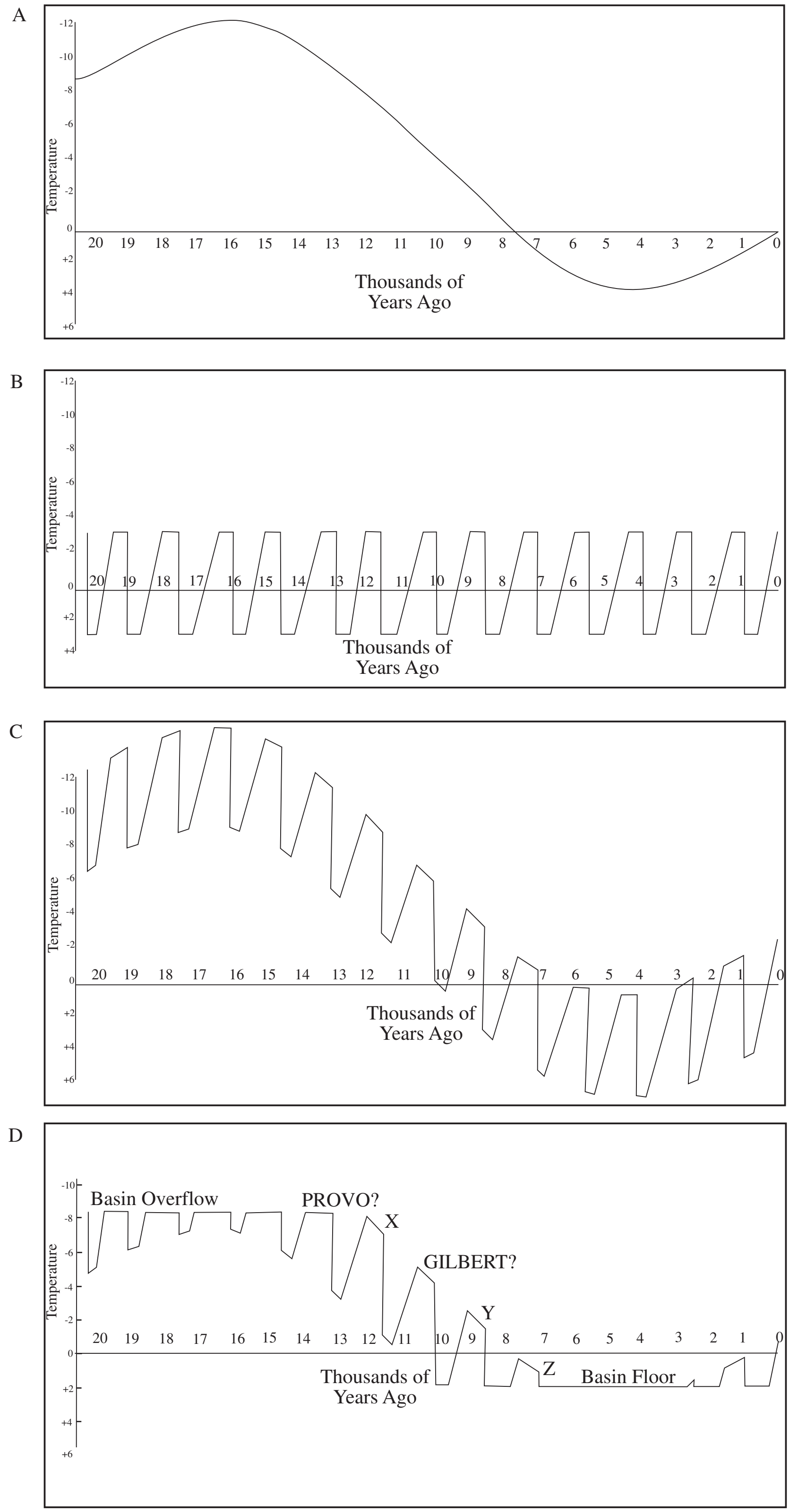

Figure 113. *Schematic of climatic forcing cycles and the late Quaternary history of Lake Bonneville: (A) 20,000-year cycles with a 16°C amplitude; (B) 1500 year Dansgaard-Oeschger cycles with an amplitude of 6°C centered at 10 ka; (C) 1500-year cycles imposed on the 20,000-year cycle; (D) Curve constrained by basin morphology and linked to possible shorelines. X, Y, and Z represent possible cycles which may have shoreline signatures, but which are as yet unrecognized or undated.*

peak of each oscillation can be crudely estimated from McKenzie and Eberli (1987) for the later Holocene (dating of the core from which these Holocene oscillations are derived is itself largely a product of estimation), from Murchison (1989a) for the middle and early Holocene and from Oviatt (1997) for much of the late Pleistocene. Evidence for two and possibly three oscillations predicted by the model during the regressive phase is more obscure, and, in these cases, the model may serve as a hypothesis guiding the investigation of these possible events.

Assuming the oscillation peaking between 11-10 ka represents the Gilbert oscillation, the model predicts two preceding oscillations during the regressive phase. An oscillation occurring sometime during the formation of the Provo still-stand is predicted, but since that level was controlled by an overflow threshold rather than by climatic factors, it may not be evident in the physical lake history. A second oscillation likely dates to sometime between ~14-12 ka (figure 113D [x]), and probably peaked at an elevation somewhere between Gilbert and Provo levels. The model also predicts at least two and possibly three oscillations (figure 113D [x & y]) peaked during the early Holocene following the Gilbert fluctuation. The earliest of these probably peaked at an elevation somewhere between that of the Gilbert level at ~1298 m and the late Holocene highstand at ~1286 m, and occurred on the order of ~9.3 ka. The subsequent oscillation, with a peak likely dating to ~7.8 ka, probably reached a maximum lake level elevation within the range of late Holocene oscillations, and associated shoreline features may be obscured. A third and possibly a fourth unrecorded oscillation may also have occurred after the 6800 ^{14}C yr B.P. Mazama ash fall at the height of the mid-Holocene warm period, but may be completely undetectable in lake proxy data.

There is tantalizing evidence that oscillations corresponding to these predicted fluctuations are part of the Bonneville record. There is limited shoreline data suggesting an early Holocene lake fluctuation reached ~1289-1293 m, roughly midway between the Gilbert level and the highest levels reached by the lake during the late Holocene (Currey and others, 1984; Murchison, 1989a; Miller and Langrock, 1997). As yet, this shoreline is undated, but estimates of its age place it ~9.6 ka. This may actually be the Younger Dryas-age lake in the Bonneville basin, as Zachary and Oviatt (1999) suggest the Gilbert shoreline may have formed prior to 12 ka. If so, it simply means the lake cycles discussed here must be pushed back one interation in the millennial-scale climate change sequence.

Subsequent oscillations within the range of the modern lake history occurred between 8-7 ka and again ~5.9 ka (Murchison, 1989a). There is also some evidence for a lake fluctuation at about Stansbury level sometime during the regressive

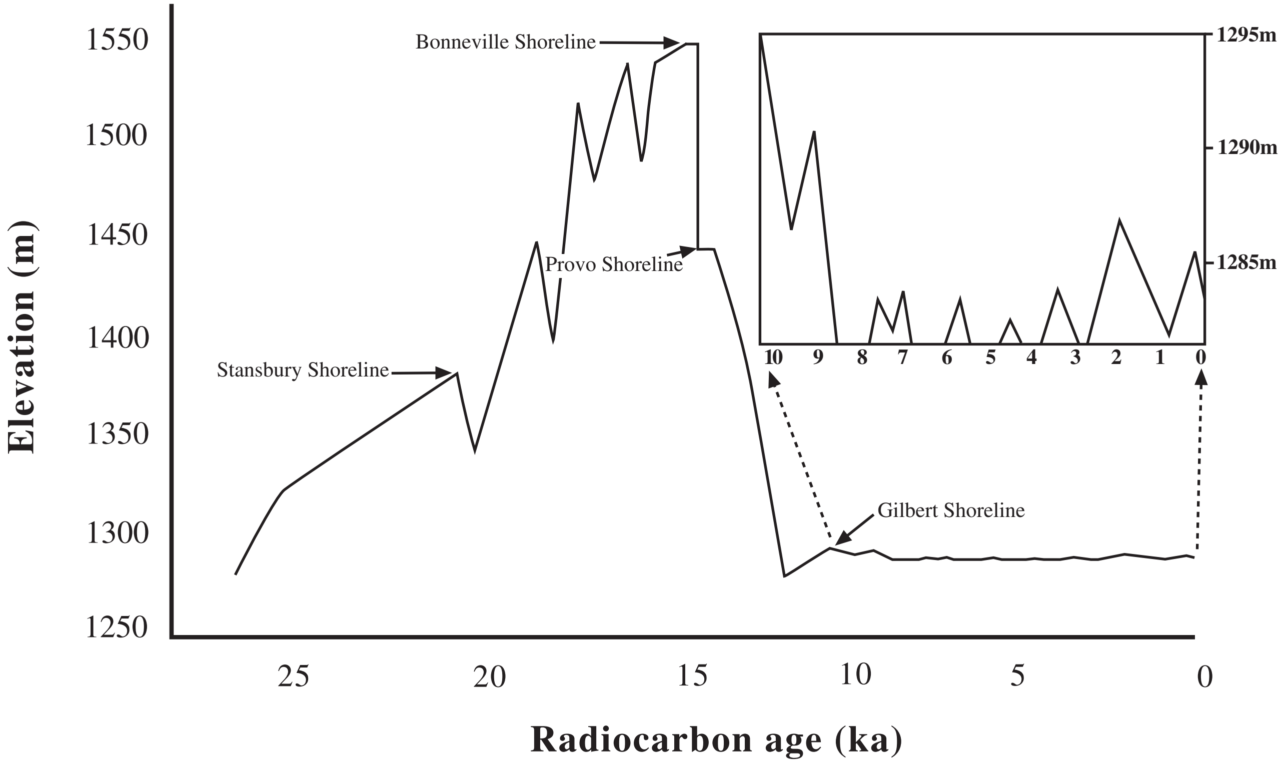

Figure 114. *Late Quaternary shoreline history of Lake Bonneville/Great Salt Lake (adapted from Currey and others, 1983; Currey and others, 1984; Murchison, 1989a; Oviatt and others, 1992; Oviatt, 1997).*

phase of Lake Bonneville, and predating the Gilbert oscillation. At the Old River Bed and north of the lake near Snowville, Utah, regressive-phase marl is interrupted by an erosional unconformity (and a stone line), which is overlain by more marl (Oviatt, 1998 personal communication). This oscillation is also as yet undated, and, with the possible exception of Cathedral Cave, shoreline data corresponding to this event have yet to be recognized. However, two cycles of channel formation separated by a period of reduced or no stream flow and extensive erosion of soft lake bed sediments have been recognized in the Old River Bed sequence, and the older cycle appears to be pre-Gilbert in age (Oviatt and Madsen, 2000). There is a very real possibility that evidence for this oscillation may be hidden among the complex of Stansbury beaches that span a relatively broad elevation between ~1360 and ~1405 m. The Stansbury level is geomorphologically complex and shoreline data were originally interpreted to be the product of a post-Provo highstand (see Gilbert, 1890; Antevs, 1945, 1948; Ives, 1951; Hunt, 1953; Eardley and others, 1957; Morrison, 1961, 1965; Currey, 1980). Only in the last few decades has evidence for a pre-highstand Stansbury oscillation begun to dominate interpretations of when the beach formed (see Currey, 1990; Oviatt and others, 1990; Oviatt and others, 1992). It now appears possible that both interpretations may be correct, and, like the Provo level (see Sack, 1999), the lake may have occupied the Stansbury level during both the transgressive and regressive phases of the last highstand.

It is difficult to project this schematic model beyond these limited, albeit potentially useful, predictions of probable shorelines dating to oscillations immediately prior to and immediately following the Gilbert fluctuation. One difficulty is simply the large range of variation in the length of the cycles. During the Holocene they range in length from ~800 to ~2200 calendar years and extrapolation backward and forward using a fixed interval of 1500 years will likely produce spurious results as estimates get farther from the starting point. A related difficulty is that the length of the cycles appears to be slightly shorter during the Holocene than during the last glacial interval (1374 ± 502 versus 1536 ± 563 cal yr B.P.), so it may be inappropriate to use a single fixed cycle length when predicting a lake history (Bond and others, 1997). A short cycle with a periodicity of ~210 calendar years caused by modulation of solar output may also obscure or enhance millennial-scale cycles at times (Grootes and Stuiver, 1997). Nevertheless, it seems readily apparent that millennial-scale cycles in the fluctuations of Lake Bonneville closely match those found in ice core and deep sea core records and, where they do not, the core records provide a useful guide to where to look for events that may yet be discovered in the Bonneville record.

LATE QUATERNARY CLIMATIC CYCLES IN THE BONNEVILLE BASIN

Given the apparent correlation between cycles evident in sea cores and those found in the Great Basin, I here apply the more complete North Atlantic core record in defining cycles of environmental change that span the late Pleistocene and Holocene in the region. While cycles can be said to start at any point in the sequence, the ice-rafted debris events in the deep sea are used to denote the beginning of each cycle (table XLIX). It is important to note that the ages for the ice-rafted debris events, and, hence, for the start of each cycle, are estimates only, and there may be some refinement as further results are obtained. For example, the end of the Younger Dryas is calculated to be ~11,640 calendar years (Alley and others, 1993) rather than the 11,000 yr suggested by Bond and others (1997). It is equally important to recognize these are temporal correlations only, and I do not mean to suggest direct similarities in temperature and precipitation regimes with cycles evident in the North Atlantic. While these climatic cycles may be globally linked, their expression likely differs from place to place. Within the limits of the data, however, these ages may eventually prove to be a useful estimate of the climatic framework that constrains Bonneville basin paleoenvironmental change. Certainly such a structure is more useful to us in summarizing the data presented here than are the tripartite schemes common to Great Basin environmental studies.

Table XLIX
Probable age of peak events in millennial-scale climatic cycles during the Holocene in the Bonneville basin
(adapted from Bond and others, 1997)

Approximate Calendar Age	Approximate Radiocarbon Age
400 B.P.	Little Ice Age
1400 B.P.	1600 B.P.
2800 B.P.	2700 B.P.
4300 B.P.	4000 B.P.
5900 B.P.	5200 B.P.
8200 B.P.	7400 B.P.
9500 B.P.	8600 B.P.
10,300 B.P.	9100 B.P.
11,100 B.P.	9800 B.P.
12,500 B.P.	10,600 B.P.

As yet, it is difficult to employ millennial-scale climatic cycles in estimating Bonneville basin climate change. This is particularly true for the relatively short cycles that characterize the early Holocene, since the resolution available in most proxy records is not sufficient to distinguish them. Recognition that these cycles exist is perhaps most important in terms of the rapid-change events that characterize their start and which undoubtedly affected human foragers in the basin. Such events may be triggers for rapid behavioral change and, hence, may show up in the archaeological record as the chronological boundaries between cultural divisions defined on the basis of technological differences. The actual overall climatic conditions associated with each cycle are less clear. Moreover, while the ~1500 year periodicity of these cycles is also evident in ice core records, their impact on actual climatic changes is uneven, and a somewhat different sequence has been defined from the Greenland ice records. The ice core sequences, which seem to have a global signature (see Mayewski and others, 1997), may be most appropriately applied to the Bonneville basin.

Ice core records suggest that increases in terrestrial dust and sea salt, interpreted to have resulted from enhanced winter-like circulation patterns and storm conditions over North America, occurred during a number of extended periods during the Holocene. These are associated with periods of glacial advance and higher lake levels during the Little Ice Age, the neoglacial and the Younger Dryas, and likely represent similar changes at regular intervals during the Holocene. Periods of increased windiness occurred at ~100-580, 2400-3100, 5000-6100, 7800-8800 and 11,300-12,900 calendar years ago (Mayewski and others, 1997). These periods also appear to be associated with cooler temperatures in the ice core records (O'Brien and others, 1995). The ages of the periods have been converted to radiocarbon years in table XLX in order to provide correspondence with most available proxy records.

Table XLX
Probable age of Bonneville basin climatic cycles
(adapted from Mayewski and others, 1997;
calibration from Stuiver and others, 1998)

Approximate Calendar Age	Approximate Radiocarbon Age
0-100 B.P.	Modern
100-580 B.P.	50-550 B.P.
580-2400 B.P.	550-2400 B.P.
2400-3100 B.P.	2400-2950 B.P.
3100-5000 B.P.	2950-4450 B.P.
5000-6100 B.P.	4450-5300 B.P.
6100-7800 B.P.	5300-7000 B.P.
7800-8800 B.P.	7000-8000 B.P.
8800-11,300 B.P.	8000-9950 B.P.
11,300-12,900 B.P.	9950-10,900 B.P.

In the following discussion I employ these periods to organize a summary of late Quaternary environmental change in the Bonneville basin. In so doing, it is important to recognize that these periods were unlikely to have been environmentally uniform, even though much of the available data may suggest that to be the case. Since many organisms are adapted to a range of climatic conditions, periods of rapid change may go unrecognized in the prehistoric record. This is particularly true for long-lived species, such as trees, and many of the animals that depend upon them. As a result, biotic records may often present an "average" picture of environmental conditions over an extended period of time, and lead to statements such as "temperatures were 2-3°C colder than at present during the early Holocene." While such statements are quite common in the following discussion, we want to make it clear that we recognize that climatic conditions were much more variable on annual to century scales. Fortunately, this somewhat biased view of stable conditions is mitigated on a global scale by the ice core and sea core records, and on a local scale by recognition of fluctuations in the levels of Lake Bonneville and Great Salt lake. The size of the lake appears to be much more sensitive to climatic change, and, where relevant, we have included evidence of lake-level fluctuations in our discussion. Unfortunately, Holocene fluctuations of Great Salt Lake are poorly known and poorly dated and it is difficult to pinpoint exactly when high and low points may have occurred. As a result, the biotic record is emphasized in the following discussion.

MAJOR ENVIRONMENTAL CHARACTERISTICS OF BONNEVILLE BASIN CLIMATIC CYCLES

Interpluvial - Pluvial (>50,000-15,000 YR B.P.)

Top of the Terrace in the Goshute Mountains west of the Bonneville basin is the only midden locality with samples dating to this period and short-term climatic events are not evident in this single series. Along with the few other paleovegetation records of this age (see Beiswenger, 1991, Davis and others, 1986; Mehringer, 1986; Thompson, 1984, 1992a; Wells, 1983), four broad periods of vegetation change can be identified. A period older than the radiocarbon time-scale is characterized by a mixed comunity of Utah juniper, sagebrush, horsebrush, cactus, and snowberry. This vegetation suggests moderate temperatures and a relatively dry precipitation regime, but it is difficult to define the climatic parameters which support this "non-analogue" plant community. Between ~46 and ~36 ka, the Utah juniper woodland was replaced by montane meadow vegetation including sagebrush, currant, cinquefoil and limber pine. This community suggests temperatures were cooler and somewhat moister during this period. Between ~36 ka and ~28 ka, currant and cinquefoil disappeared and were replaced by more xeric brush cummunities including shadscale and fern bush. Englemann spruce appears in the record, but the woodland community is dominated by limber pine. While this vegetation complex is indicative of cold, dry climatic conditions, its distribution may have been enhanced by low atmospheric CO_2. Cold, moist climatic conditions returned between ~28 ka and ~14 ka as Lake Bonneville rose to its highest levels. In the Top of the Terrace record, limber pine declines, shadscale and fern bush disappear, and upper montane meadow plants such as currant and cinquefoil reappear and become common after ~20 ka. Millennial-scale climate changes are evident in the lake record for the period (Oviatt, 1997), but cannot yet be detected in the more limited biotic record.

Pre-Gilbert - 10,900 YR B.P.

After ~14 ka, Lake Bonneville began to retreat from its overflow level at the Provo threshold. The ice core records cited above suggest the possibility that one or more millennial-scale cycles may have occurred after the lake reached its highest point at the Bonneville level. One of these may be represented by the enigmatic Keg Mountain oscillation (see Currey and Oviatt, 1985; Oviatt and others, 1992), but any cycle that occurred while the lake was at the Provo level was likely masked by the lowering of the threshold during the Bonneville flood. Glaciers in nearby mountain ranges had been significantly reduced by this time, but still remained of substantial size and vegetation records suggest summer temperatures remained quite cool. The Little Cottonwood Canyon glacier, for example, did not retreat past Snowbird Bog until ~12.3 ka (Madsen and Currey, 1979), and may have deposited the mid-canyon Hogum Fork till at an elevation well below the bog during a period corresponding to an early regressive-phase oscillation of the lake. Mountain shrub vegetation, similar to that now found in subalpine settings in the Great Basin, dominated the foothills along the western margin of the lake with conifers such as white fir and spruce dominating lower elevations along the eastern lake margin. Large Pleistocene megafauna such as mammoths, camels, ground sloths, musk oxen and short-faced bears continued to occur around the lake margins, but population sizes may have started to decline.

Sometime between ~14 and ~12 ka, shoreline deposits in Cathedral Cave suggest that lake levels dropped rapidly. However, lake waters remained sufficiently cold and fresh that they could support all of the Lake Bonneville fish fauna, including Bonneville cisco and cutthroat trout. Sometime thereafter the lake rebounded to levels above ~1325 m. The limiting date from Cathedral Cave suggests this occurred sometime after ~15.3 ka, and other shoreline data place it sometime after ~14 ka (see Benson and others, 1990). The peak of this event may date to ~13.5-13.0 ka and match the late glacial cooling event marked by extensive seasonal sea-ice cover (Rochon and others, 1998). During this period, the Little Cottonwood Canyon glacier retreated past Snowbird Bog and cirques in the Raft River Mountains became ice free (Mehringer, 1986). A large number of fossil woodrat middens date to this period, and it is possible to make relatively reliable reconstructions of the nature and distribution of plant communities in the Bonneville basin. About this time mountain shrub vegetation through much of the central and western Bonneville basin began to be replaced by flora adapted to cool, dry conditions and dominated by a limber pine woodland, although subalpine fir and spruce continued to grow along canyon bottoms and stream margins. Summer temperatures may have been as much as ~6°C cooler than at present. Insect remains in middens dating to this period suggest increased moisture relative to the present (Wigand and Rhode, in press).

The Gilbert shoreline may have been formed during another regressive-phase oscillation dating to sometime before ~12 ka (see Zachary and Oviatt, 1999), but after ~12 ka lake waters retreated to elevations approaching that of the modern lake. Flow in the Old River Bed channel was severely reduced or halted altogether, and deflation/ oxidation of the lacustrine muds on basin floors was initiated. By 11.3 - 11.2 ka Lake Bonneville regressed to elevations below the Gilbert level and a massive die-off of lake fishes began. How long this die-off may have lasted is uncertain, but the population structure of fish from the lower part of Stratum I suggests that it was relatively rapid. Until shortly before this time waters were cold and deep enough to support eleven species of fish. Four of these species have not previously been reported for Lake Bonneville and two, bull trout (*Salvelinus confluentus*) and bluehead sucker (*Catostomus discobolus*), have not been found in fossil form anywhere in the entire Great Basin. These data from Homestead Cave are supported by fish remains in woodrat middens from the western side of the basin dating to as late as 11.9 ka. Oxidized lacustrine deposits on the floor of the basin suggest that the lake reached elevations as low as 1280 m before it began to rebound once more. A similar drying episode dating to this period, bracketed by higher lake levels, occurs in a nearby alpine lake (Gillette and Madsen, 1992, 1993). How long this period of dryer and/or warmer conditions lasted is unclear, but if it is related to the short warm period immediately preceding the Younger Dryas in the European climate sequence (see Björck and others, 1996) and the "Clovis drought" recognized in much of western North America (Haynes, 1991), then it may have lasted less than 500 years. Bonneville fish may not have been the only victims of this event, as the last of the Pleistocene megafauna in the Bonneville basin date to this period (the single exception is a short-faced bear from Huntington Canyon on the eastern margin of the basin which dates to ~10.9 ka).

Towards the end of the period, shadscale and sagebrush began to replace limber pine and common juniper in Bonneville basin lowland settings, particularly on exposed slopes. Sometime after 12 ka (dating is unclear), xeric desert scrub species, such as greasewood, and other chenopods began to replace coniferous woodlands (see figure 4, chapter one). At higher elevations in the southern Bonneville basin bristlecone pine disappears from some of the smaller mountain ranges such as the Confusion Range (Wells, 1983). This change in flora was far from uniform and many subalpine species continued to be present in areas of cold air drainage, on north-facing slopes and along stream channels.

If Dansgaard-Oeschger cycles can be said to start with a warming event, then it may be that this short but intense warm period dating to ~11.3-11.2 ka may more correctly be placed with the well-known Younger Dryas climatic period which followed. Until local proxy data are better controlled chronologically, however, the break between climatic cycles can be placed at ~10.9 ka.

10,900-9950 YR B.P.

Global climatic conditions are relatively well known for the Younger Dryas. In ice core records, it is characterized by a rather abrupt return to near full-glacial conditions and by a high degree of annual to decadal climatic volatility (figure 115; Mayewski and others, 1993). Securely dated continental records (see Birks and Mathews, 1978; Denton and Hendy, 1994; Björck and others, 1996) place the beginning of the Younger Dryas no earlier than 11.2 ka and the end at ~10 ka (note the slightly different age range for the Younger Dryas). In the Bonneville basin, the Younger Dryas may be correlated with a return of Lake Bonneville (after this period called Great Salt Lake) to relatively high levels (Oviatt and others, 1992). The presence of diving ducks in the Homestead Cave record at this time is consistent with a large lake during this period, although the Old River Bed sequence suggests stream flow was much reduced as compared to the earlier regressive-phase lake cycle (Oviatt and Madsen, 2000). The lake may have been deep enough and cold enough to support the restocking of the entire Lake Bonneville fish fauna, but, if so, species adapted to warmer and more saline conditions were more successful. By ~10.4 ka no fish were present in the lake, however. The high-elevation lake in Huntington Canyon also refilled during this period (Madsen, 2000). On a global scale, the Younger Dryas appears to have been more seasonally equable than following periods (Zielinski and Mershon, 1997) and there is some evidence, derived primarily from insects in the Huntington Canyon lake deposits (Elias, 1996), that seasonal equability is also characteristic of the period in the Bonneville basin and adjacent areas.

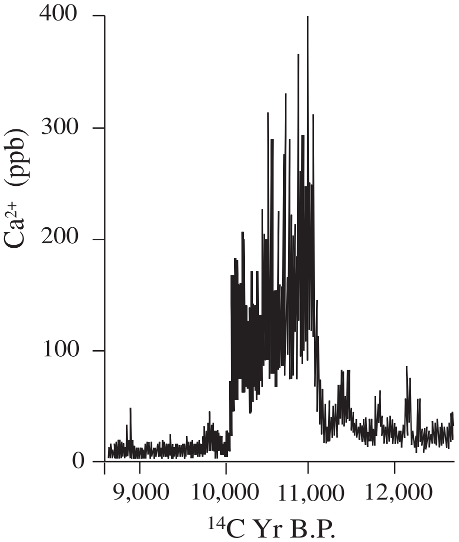

Figure 115. *Volatility of Younger Dryas climates suggested by rapid change in calcium concentrates present in the GISP 2 Greenland ice core (adapted from Mayewski and others, 1993).*

At lower elevations, vegetation in the Bonneville basin during this period was composed primarily of open brush communities with limited amounts of woodland elements. While these are primarily the same xeric desert shrubs found in the area today, such as sagebrush, shadscale, horsebrush, snakeweed and rabbitbrush, their distribution was different. The Homestead Cave faunal record, for example, suggests that a relatively more mesic sagebrush/grass community was growing in areas now covered with greasewood and horsebrush. Limber pine and common juniper were largely gone and neither Utah juniper nor pinyon pine had yet invaded. Rocky Mountain juniper was common in the Bonneville basin, but was not present around Homestead Cave. Woodpeckers in the Homestead Cave sequence suggest that many of the small, dry washes common on lower elevation Bonneville basin slopes contained enough water to support riparian communities including small deciduous trees such as chokecherry. Along stream channels at slightly higher elevations, limber pine and subalpine fir continued to grow.

Most of Stratum I at Homestead Cave was deposited during this period. An array of small mammal species, such as the pygmy rabbit, marmot, bushy tailed woodrat and northern pocket gopher, currently common to mid-elevation and higher locations today, were present at lower elevations during the period. The distribution of larger herbivores is not well known, but there is no record of now-extinct megafauna and the array of large mammal species appears to have been largely similar to that found today. Overall conditions can be characterized as those of an open, cold, desert steppe, with sagebrush communities dominating lower slopes and extending down into valley locations. Tree-lined stream channels extended well down into valley locations, but woodlands between these riparian stringers were more limited than at present.

9950-8000 YR B.P.

About 10.1 ka Lake Bonneville (after this period called Great Salt Lake) dropped abruptly, but consistent with the pattern of Dansgaard-Oeschger cycles, rose once more to an elevation of ~1290 m. This lake cycle probably peaked sometime prior to 9 ka. (Murchison, 1989a), but is as yet poorly investigated and undated. Murchison and Mulvey (2000), however, suggest a date of ~9.7 ka obtained by Rubin and Alexander (1958) on materials from the Weber River delta may date this episode. The Little Cottonwood Canyon glacier retreated past Albion bog near the head of the canyon by ~9.6 ka, but was likely still present in its upper reaches. A deglacial pause resulting in deposition of the Devils Castle till occurred sometime between ~9.6 and ~7.5 ka and may correlate with the early Holocene lake oscillation (Madsen and Currey, 1979). Water continued to flow in the Old River Bed until as late as 9 ka (Oviatt and Madsen, 2000). Beginning with this period and continuing through the rest of the Holocene, ice core records indicate less annual to decadal volatility, but conversely greater seasonal differences in temperatures (Ditlevsen and others, 1996).

At Homestead Cave the deposits in Strata II, III, and possibly IV and V, were deposited during this period. Faunal data suggest conditions continued to be cooler and moister than at present, but the percentages of many species such as pygmy rabbit, Ord's kangaroo rat, the little pocket mouse, bushy tailed woodrat, marmot and northern pocket gopher are substantially smaller than in Stratum I and decrease in numbers throughout the period. The number of waterfowl decreases as well, but the variety of other birds increases, suggesting more diverse habitats were present near the cave. Midden data suggest xerophytic sagebrush and shadscale scrub communities continued to dominate lowland areas, but also show that conditions were somewhat cooler and/or moister than present. Limber pine continued to grow at relatively low elevations in sheltered montane locations and at lower overall elevations than at present (Rhode and Madsen, 1998). Pollen records from Swan Lake at the northern extreme of the Bonneville basin (Bright, 1966) suggest a two-step change during the period, with spruce/pines rapidly replaced by sagebrush steppe shortly before 10 ka and a transition to sagebrush/shadscale steppe after ~9 ka. Similar sequences are found at nearby Grays Lake (Beiswenger, 1991) and Ruby Marsh to the west (Thompson, 1992a), but the change is more precisely dated to between ~8.5 and 8.0 ka. Hackberry began to grow around Homestead Cave at this time. Since hackberry prefers rocky substrates where it can absorb water trapped in cracks, its presence suggests conditions were dryer than during the preceding period but still moister than now. Rocky Mountain juniper expanded its range during this period, but Utah juniper began to invade the Bonneville basin, particularly to the south. This distribution appears to have been controlled by climatic conditions and suggests summer temperatures may have been as much as 3-5°C colder than present.

8000-7000 YR B.P.

At or slightly prior to 8 ka a major shift to warmer conditions in the Bonneville basin appears to have occurred rather rapidly. By the end of the period Little Cottonwood Canyon was fully deglaciated. A ratio of conifer pollen to all other pollen at Snowbird Bog used as a gauge of temperature shows a rapid transition from minimum Holocene cool temperatures to maximum warm levels shortly before 8 ka (figure 5, chapter one). This event is likely related to the changes cited above in the Swan Lake, Grays Lake and Ruby Marsh records. At least one and possibly two oscillations of Great Salt Lake levels occurred during this period, but these are well within the elevation of modern short-term fluctuations (Murchison, 1989a). Murchison and Mulvey (1999), for example, report a date of 7650 ± 90 yr B.P. on marsh deposits associated with a lake rise to 1283 m, an elevation well within the envelope of the historical record.

It is during this climatic cycle that pinyon pine first makes its appearance in the Bonneville basin. Its migration may, in part, be related to its use by people, as the earliest record is from Danger Cave where pinyon nut hulls first appear in the cave's archaeological record between ~7.4 and ~6.7 ka (Rhode and Madsen, 1998). At Homestead Cave, the number of hackberry endocarps drops off markedly after 8.2 ka, suggesting a marked drying trend occurred at that time. This is associated with a reduction in the diversity of avian species caused primarily by the disappearance of waterfowl. Gulls also disappear from the record after Stratum IV. Upland small mammal species such as Ord's kangaroo rat, pygmy rabbit, bushy tailed woodrat and marmot virtually disappear from the record. Trees may have been restricted to small riparian stands of deciduous species at medium to high elevations. Greasewood and horsebrush replaced sagebrush around Homestead Cave. The dominant juniper in the northern Bonneville basin continued to be Rocky Mountain juniper rather than Utah juniper and a number of species, such as mormon tea, had not yet made their appearance.

Overall, perhaps the greatest environmental change in the Homestead Cave record takes place between this period and the preceding climatic cycle. After ~8.2 ka, there is a significant reduction in the diversity of animals, and probably plants as well. Simply put, the late Pleistocene and early Holocene in the Bonneville basin were significantly richer, in terms of numbers of small mammal species, than was the remainder of the Holocene. This trend is reversed in the avian fauna, where the loss of waterfowl is countered by the presence of more terrestrial taxa.

7000-5300 YR B.P.

Environmental records for the middle Holocene in the Bonneville basin are relatively sparse. During this period Great Salt Lake may have dried up almost completely, with desiccation polygons forming at what is now the deepest area of the lake (Currey, 1980), but appears to have rebounded by ~5.9 ka to an elevation of ~1283 m (4210 ft) (Murchison, 1989a; Murchison and Mulvey, 2000). A sudden surge in conifer pollen at Curelom Cirque in the Raft River Mountains may be related to this 6 ka lake peak (Mehringer and others, 1971). A change in sagebrush/saltbush ratios at Hogup Cave (Harper and Alder, 1970) also suggests a brief period of greater effective moisture. The Ruby Marsh record suggests shadscale replaced sagebrush in many low-elevation areas (Thompson, 1992a), and maximum Holocene warm temperatures continued to be recorded at the high-elevation Snowbird Bog locality, although here, too, a brief, slightly cooler period is recorded (Madsen and Currey, 1979). Both Utah juniper and pinyon pine expanded their range in the Bonneville basin during this time, but a paucity of middens containing these species indicates their distribution was spotty at best. Limber pines were eliminated from all low-elevation areas, including cold air drainages.

Strata VII through X were likely deposited at Homestead

Cave during this climatic cycle. Beginning in Stratum VII, Horned Larks, which prefer open shrub habitats with sparse vegetation, along with other passerine birds with similar adaptations, increase in frequency. The frequency of ducks and shorebirds is also at its lowest during this climatic cycle and the following period. *Neotoma* fecal pellets are completely absent from the deposits in Strata VI-XI, suggesting their extirpation from the immediate vicinity of the cave. However, the desert woodrat continued to be collected from the higher elevations of the Lakeside Mountains and deposited in the cave by raptors. Artiodactyl fecal pellets show a marked cyclicity in frequency suggesting they may be related to the relative abundance of forage locally.

The proportion of the chisel-toothed kangaroo rat to Ord's kangaroo rat is extremely high in Strata VII-X, suggesting that shadscale largely replaced sagebrush around Homestead Cave throughout most of this period. A small deviation in that trend in Stratum IX dated to ~6 ka may correspond to a similar shift in the Hogup Cave record. The number of harvest mice is also extremely low throughout the period, indicating there was a marked reduction in grass cover and other herbaceous vegetation. Great Basin pocket mice became locally extinct. Together the small mammal and bird record suggests sagebrush/grass communities in the northern Lakeside Mountains were largely replaced by open shadscale scrub communities with little ground cover.

5300-4400 YR B.P.

Environmentally, this middle Holocene climatic cycle is almost indistinguishable from the period that preceded it. Isotope records from Great Salt Lake cores suggest an oscillation event occurred during the period (McKenzie and Eberli, 1987), but there is as yet no shoreline evidence for such a cycle (Murchison, 1989a). However, an increase in artiodactyl fecal pellets in Stratum X at Homestead Cave may correspond to such an event. Murchison and Mulvey (2000) interpret a Holocene sequence on Antelope Island to indicate a mean lake-level elevation of 1280 m or lower during this period. Pollen in a core from Great Salt Lake indicates the proportion of sagebrush and conifers relative to shadscale and other Chenopodiaceae returns to modern levels after being at their Holocene low during the preceding period (Mehringer, 1985). At Snowbird Bog, conditions become markedly cooler after ~5.3 ka, but the upper part of the sequence is poorly dated and it is unclear to what climatic cycle this cooling event may be related.

At other localities, such as the Ruby Marsh and Swan Lake, there is little record of environmental change during this climatic cycle. The period is poorly represented in the Homestead Cave faunal sequence, but what is there also shows little change from the preceding period. However, both pinyon pine and Utah juniper continued to expand towards their modern woodland distributions. Rocky Mountain juniper was still present at lower elevations in the north, but in the southern Bonneville basin it had largely been replaced by Utah juniper. The direction of this replacement seems to have been from southeast to northwest. The migration route followed by single leaf pinyon is not yet clear, and it appears to have continued to expand its territory into historical times. By the end of this climatic cycle, however, pinyon was likely present on all the major mountain ranges where it occurs at present. These changes are probably related more to ongoing vegetational dynamics involving the Pleistocene/Holocene transition than to millennial-scale climatic changes.

4400-2950 YR B.P.

A gradual return to cooler temperatures was initiated in this climatic cycle. After ~4.4 ka in the Ruby Marsh, shadscale was reduced at the expense of sagebrush and the water depth increased. At Crescent Spring in the Great Salt Lake Desert, conifer and sagebrush pollen increase at the expense of shadscale and other xeric desert scrub vegetation (Mehringer, 1985). Towards the end of this period, at ~3.1 ka in the Swan Lake record, the sagebrush steppe was partially replaced by lower conifer zones. Isotope records from Great Salt Lake suggest that this cycle, as with others, started with a warming period, but grew increasingly colder (McKenzie and Eberli, 1987), with a lake cycle peaking at ~1284 m dating to ~3.4 ka (Murchison, 1989a).

At Homestead Cave, these cooler conditions are marked by the reappearance of small numbers of ducks and shorebirds, and by the return of woodrats to the cave itself (desert woodrats continued to be present in the northern Lakeside Mountains throughout the middle Holocene). The size of some fecal pellets suggest that at least some of these may have been bushy-tailed woodrats, although only one tooth (an M1) of several hundred *Neotoma* teeth from Stratum XIII is likely to represent *N. cinerea*. The endocarps of hackberry also reappear in the record, although only in small numbers. In Stratum XI and later there is an increase in taxonomic richness in the avian fauna, suggesting an increased diversity of local habitats. However, the change in the overall composition of local plant communities was probably relatively minor, as Horned Larks and other passerine birds continue to dominate the avian record. A midden from the Lakeside Mountains dating to ~3.0 ka contains vegetation much like that found locally at present, but also contains Utah juniper which may have been growing at slightly lower elevations.

Utah chub occurs in large enough numbers in Strata XII-XIII to suggest these moderately salt-tolerant fish may have been able to survive in the waters of Great Salt Lake, particularly where freshwater springs and rivers created slightly fresher conditions. Waterfowl also return to the Homestead Cave record in Stratum XIII and increase in relative abundance thereafter. These are primarily shallow-water ducks, however, suggesting that lake waters were not very deep in the vicinity of the northern Lakeside Mountains. The small mammal record is limited for this period, since the Stratum XIII materials were not analyzed, but species such as harvest mice return to the record in Stratum XII and the proportion of chisel-toothed kangaroo rats to Ord's kangaroo rats is lower in Stratum XIV than anytime during the last 8000 years. Together these species suggest a return of sagebrush-grass communities to the Homestead Cave foraging area.

2950-2400 YR B.P.

The degree of change associated with this climatic cycle is one of the most dramatic of any in the Bonneville basin during the Holocene. A major cooling event, associated with renewed glaciation (found in many Rocky Mountain locations, but not yet locally), is evident in virtually all the biotic records and in both shoreline and core records from Great Salt Lake. Middens from Antelope Island, the northern Promontory Mountains and the Cricket Mountains all suggest lower Utah juniper tree lines were reduced by ~50-100 m or more during this period. Both isotope (McKenzie and Eberli, 1987) and pollen (Mehringer, 1985) records indicate a freshening of lake waters between ~3 and ~2 ka, and shoreline data (Currey, 1990) suggest that the lake reached a maximum of ~1287 m and flooded the Great Salt Lake Desert as far west as the Utah/Nevada border (figure 10, chapter two).

Unfortunately, distinguishing between climatic cycles during the late Holocene is difficult due to both the brevity of the cycles and the poor chronological controls associated with many biotic records. At Crescent Spring, for example, the pollen record (Mehringer 1985) suggests several periods of greater effective moisture are separated by intervals of warmer and dryer conditions over the course of the last 4000 years. Determining how these cycles may be related to Dansgaard-Oeschger cycles evident in the ice core records, or even if they are, is difficult due to a limited number of radiocarbon dates. At Homestead Cave the deposits we were able to recover stratigraphically may not be sensitive enough to distinguish individual cycles. For example, it is likely the fish in Strata XII and XIII identified as part of an earlier cycle are related to the neoglacial lake highstand described here. For the most part it appears that modern plant communities were well established by 3.0 ka, with mormon tea possibly being the last major taxa to be added (Wigand and Rhode, in press), and that the last climatic cycles of the Holocene are marked by variations in proportions, but not in kinds, of plant and animal species. An exception is Rocky Mountain juniper, which continued to be a major component of woodland communities in some areas until after ~2.0 ka.

2400-550 YR B.P.

Previous research suggests lake-level oscillations associated with this climatic cycle were modest, with the lake reaching elevations of ~1283 m following an initial regression (Murchison, 1989a; Currey, 1990). Many of the beach features at this elevation along the eastern margin of the lake are associated with archaeological sites and this has informally been called the “Fremont” beach. At Swan Lake, warmer conditions ~ 1.7 ka are suggested by increasing levels of sagebrush pollen relative to that of conifers. However, after Utah juniper finally replaced Rocky Mountain juniper in the Silver Island Mountains after ~1.9 ka, the few Bonneville basin middens dating to this period indicate vegetation patterns were essentially modern in character. Together these other data indicate overall temperature and moisture changes likely fluctuated within the envelope of modern weather patterns.

The Homestead record, on the other hand, suggests much more dramatic changes occurred during this period, changes equal to or exceeding those associated with the neoglacial. An initial warm period, with concomitant lower lake levels, is reflected in the absence of fish remains in Stratum XV. Utah chub returns with a vengeance in Strata XVI and XVII, however, in proportions significantly higher than in the earlier neoglacial period. Since Stratum XVII is dated to ~1.2 ka, it is likely the relatively fresher lake water in which these fish thrived is associated with the “Fremont” beach and it is possible this lake rise reached much higher elevations. Alternatively, a subsequent lake rise to elevations sufficient to flood the Great Salt Lake Desert (see below) is currently undated and may relate to this period. Hackberry endocarps are common in Strata XV-XVII, indicating significantly moister conditions in the Homestead Cave vicinity. Voles return in small numbers in Strata XVI and XVII and the ratio of Great Basin pocket mice to little pocket mice in these same strata increases to levels not seen since the early Holocene. Bushy-tailed woodrat skeletal remains make a significant return to the record in Stratum XVII. Harvest mice also reach their Holocene peak in Strata XVI and XVII. This may be related to an increase in grass pollen at stratified Bonneville basin archaeological sites dating to this period. Wigand and Rhode (in press) suggest that this is related to an increase in summer moisture which promoted growth of ephemeral plant species.

550-50 YR B.P.

The final Holocene climatic cycle is characterized by a transgression of Great Salt Lake to what is called the “late prehistoric high” (Currey, 1990). During a period that is undated, but may be correlated with the “Little Ice Age” in Europe, the lake expanded well into the Great Salt Lake Desert, reaching an elevation of ~1285 m (4217 ft). There is no evidence of any significant change in the kinds and distribution of plant and animal species, and modern communities seem to be firmly established at this time. Between ~.7-.6 ka, widespread drought caused dramatic changes in the distribution and subsistence focus of prehistoric peoples in the region, with farmers dependent on corn, bean and squash crops shifting to full-time foraging (Madsen and Simms, 1998). Harper and Alder (1970, 1972), using plant remains from Bonneville basin cave sites, suggest that the last 600 to 1000 years have been the warmest and driest of the entire Holocene.

SUMMARY

The Homestead Cave faunal materials, together with the plant macrofossil record from woodrat middens, provides an unusually coherent, comprehensive and consistent picture of environmental change in the eastern Great Basin during the late Pleistocene and Holocene. In large measure this is due to three factors: (1) an extensive testing program designed to identify and excavate a deeply stratified cave site relatively uncontaminated by human foragers, (2) the tight stratigraphic controls employed during the cave excavations, and (3) the extensive use of radiocarbon dating (more than 100 samples were analyzed over the course of the project) to provide a chronological framework into which the collected data could be fitted. This project structure helped to significantly reduce the contradictions that often appear when disparate types of biotic and physical terrestrial records are brought together.

The climatic signals provided by these diverse proxy records suggest that the millennial-scale climatic cycles evident in ice core and sea core records appear to be present in

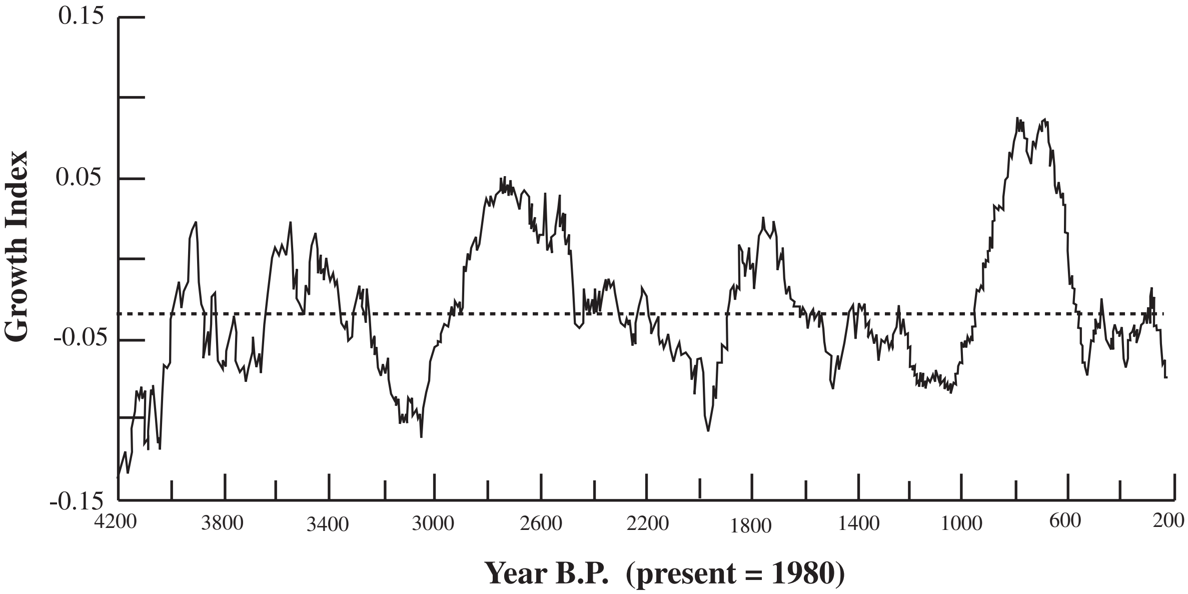

Figure 116. *Bristlecone pine tree-ring index series for Indian Garden, Grant Range, Nevada plotted with a 250-year running smoother (see figure 111). Note the close correlation between the millennial-scale climatic cycles evident in the record and Dansgaard-Oeschger cycles evident in Greenland ice core records. The peak events also closely match abrupt Holocene climate shifts recorded by Bond and others (1997) in the North Atlantic.*

the Bonneville basin as well. These often are initiated by a rapid increase in temperatures, followed by a return to moderate temperatures, and end with a cool-temperature phase. The cycles play out against a backdrop of longer-term climatic changes, and thus average temperatures and effective moisture regimes differ from one cycle to the next. These longer-term changes have been recognized by paleoecologists for much of this century, with the early Holocene being defined as cooler and moister, the middle Holocene being warmer and dryer, cool/moist conditions returning during the late Holocene, and finally modern conditions being established in the last several thousand years. What has been added with the detection of millennial-scale changes is the recognition that local climates can undergo major changes abruptly, often within years or decades. These millennial-scale cycles are locally most evident in lake-level fluctuations which appear to be more sensitive than plant and animal communities to the shorter-term climatic events. These communities are not immune to change, and particularly long or intense cycles are clearly reflected in the biotic record. For example, a tree ring record from the Grant Range just west of the central Bonneville basin clearly records four millennial-scale climatic cycles in the last 4500 years (figure 116). Like Dansgaard-Oeschger cycles, each of these is characterized by a relatively rapid and intense change in climate state followed by a gradual return to the initial condition.

The dating of these cycles is not well controlled, particularly at the local level, and some refinement of the sequence reviewed above is to be expected. Moreover, some apparent conflict in proxy indicators of climate is also to be expected since these data are differentially sensitive to climate change. For example, mature limber pines may be able to tolerate changes associated with abrupt climate events that seedlings and younger trees may not, and evidence of the change may be delayed until these mature trees eventually die. Despite the current ambiguity about the timing of these events, and about the extent of change during any particular cycle, it is becoming increasingly clear that they are present in the paleoecological record of the Bonneville basin. These cycles add to the already complex interpretation of environmental change. The data presented here, together with existing information from in and around the Bonneville basin, suggest that modern plant and animal communities are part of a long trajectory of a constantly changing species matrix. Within this trajectory, however, lies a recurring pattern of environmental change related to global millennial-scale climatic events.

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