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# Vegetation and Climates of the Last 45,000 Years in the Vicinity of the Nevada Test Site, South-Central Nevada

By **W. GEOFFREY SPAULDING**

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## CONVERSION FACTORS

Metric units in this report may be converted to inch-pound units by using the following conversion factors:

<i>Multiply</i>	<i>By</i>	<i>To obtain</i>
centimeter (cm)	0.3937	inch (in.)
gram (g)	0.03527	ounce, avoirdupois (oz)
kilogram (kg)	2.205	pound (lb)
kilometer (km)	0.6214	mile (mi)
kilopascal (kPa)	10	millibar (mbar)
meter (m)	3.281	foot (ft)
millimeter (mm)	0.03937	inch (in.)
millimeter per year (mm/a)	0.03937	inch per year (in/yr)
square kilometer (km <sup>2</sup> )	0.3861	square mile (mi <sup>2</sup> )
cubic meter (m <sup>3</sup> )	35.31	cubic foot (ft <sup>3</sup> )
degree Celsius (°C)	°F = 9/5°C + 32	degree Fahrenheit (°F)

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 SYMBOLS AND DEFINITIONS LIST
 

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Amberat	crystalized (dehydrated) packrat urine
AT	arboreal taxon (taxa)
$^{14}\text{C}$	radiocarbon. carbon-14; unstable isotope of normal carbon-12
$\Delta$	relative change in a given parameter (for example, $\Delta T_a$ , change in mean annual temperature)
Extralocal	a species not present in the vicinity of the site of its fossil occurrence
Extralimital	a species not known to presently occur on a mountain mass where it is recorded as a fossil
Equable	a temperature regime characterized by a limited seasonal range of temperatures
Full glacial	a widely-used synonym for the Wisconsin maximum
IS	Sorensen's similarity coefficient or index
N	number of identified taxa
NISP	number of identified specimens
$N_{ts}$	number of taxa of trees, shrubs, and succulents
P	precipitation ( $P_a$ , average annual precipitation; $P_s$ , average summer precipitation; $P_w$ , average winter precipitation)
Percent P	percent change from present average value of precipitation
Mesic	relatively moist (mesophytic, characteristic of relatively moist habitats)
Pluvial	increased rainfall exceeding present annual values by at least 50 percent
Paleonidology	the study of ancient packrat middens
$\sigma$	standard deviation
T	average value of temperature ( $T_a$ , average annual temperature; $T_s$ , average summer temperature; $T_w$ , average winter temperature)
Percent T	percent change from present average value of temperature
Thermophile	a species characteristic of sere (hot) habitats (thermophilous, with an affinity for sere habitats)
Wisconsin maximum	the period of greatest development of continental ice sheets in the Northern Hemisphere, about 18,000 years ago
Xeric	relatively dry (xerophytic, characteristic of relatively dry habitats)
B.P.	radiocarbon years before present (1950). An age expressed in radiocarbon years before present is a statistical estimate of the remnant carbon-14 in a given sample and not directly equivalent to a sidereal or calendar year age

# VEGETATION AND CLIMATES OF THE LAST 45,000 YEARS IN THE VICINITY OF THE NEVADA TEST SITE, SOUTH-CENTRAL NEVADA

By W. GEOFFREY SPAULDING

## ABSTRACT

Major changes in the climate of the Nevada Test Site have occurred during the last 45,000 years. Understanding this climate variability is important in assessing the region's suitability for permanent nuclear-waste repositories. Future climatic changes probably will occur within the time the waste materials are hazardous. The nature and magnitude of previous fluctuations indicate the nature of future climatic change that may impact on a nuclear waste repository. Reconstructions of past vegetation are used to infer climatic conditions during the past 45,000 years. Plant macrofossils from ancient packrat (*Neotoma* spp.) middens provide the data for these analyses. Middens can be older than 50,000 years, and they are common in the region. Each contains abundant mummified plant fossils, representing the plant species growing within about 30 meters of the site. Radiocarbon-dated midden samples provide detailed records of climate-induced vegetation change.

During the Wisconsin glacial age, from at least 45,000 years ago to about 10,000 years ago, juniper (*Juniperus osteosperma*) woodland was widespread below elevations of 1,800 meters in the desert lowlands. Steppe shrubs were common, as were shrubs typical of the drier phases of current woodland. Late Wisconsin subalpine conifer woodland, typified by limber pine (*Pinus flexilis*), occurred at elevations above about 1,800 meters. Plants that are sensitive to frigid temperatures, and those restricted to moist habitats, are missing or are very rare in the glacial-age macrofossil record.

Development of desert vegetation in the lowlands of the Nevada Test Site and vicinity had begun by about 15,000 years ago. Timing of the vegetation change from woodland to desertscrub was transgressive. At higher elevation desert sites, woodland did not disappear until after about 8,000 years ago. The earliest records of desert vegetation in the vicinity of the Nevada Test Site appear to antedate those from the Sonoran Desert by at least 4,000 years.

Climatic conditions at about 45,000 years ago at the Nevada Test Site were similar to those of northern Nevada at present. Average annual temperature was at least 2° Celsius less than that of current average annual temperature. Summers were drier and colder, and winter precipitation may have exceeded current quantities by 20 percent. By about 30,000 years ago, annual temperature may have been 3° to 6° Celsius less than present values. The trend toward maximum glacial conditions appears to have been reversed briefly several times. By about 18,000 years ago, the relative decrease in annual temperature is inferred to have been 6° to 7° Celsius. Average summer temperatures were 7° to 8° Celsius cooler than those of the present, and winter precipitation exceeded present quantities by as much as 70 percent. There was a relative decrease in summer rainfall, and average

annual precipitation probably did not exceed 40 percent of current quantities. Postglacial warming began as early as 16,000 years ago, and average annual temperatures probably approached present values by about 10,000 years ago. Differences exist between these paleoclimatic reconstructions and those that indicate a "pluvial" rainfall regime during the late Wisconsin. Temperatures appear to have been lower and rainfall less than the values proposed in models of an equable glaciopluvial.

Increased atmospheric carbon dioxide within the next 500 years probably will result in a 2° to 3° Celsius increase in annual temperature and intensified rainfall in the Nevada Test Site region. Analogs with previous glacial-interglacial cycles indicate that this "superinterglacial" may be no more than a relatively brief reversal in the protracted trend toward the next ice age. Current models indicate that, within the next 10,000 years, climatic conditions may be similar to those of the last glacial age.

## INTRODUCTION

A fundamental challenge presented by the use of nuclear energy is the safe, long-term disposal of both high-level and transuranic radioactive wastes. Proper storage of these materials, by-products of both commercial enterprises and nuclear weapons manufacture, requires isolation from the biosphere for a period exceeding their hazardous duration. Estimates of this duration range from 1,000 to 100,000 years (Winograd, 1981, p. 1458; Bredehoeft and others, 1978; Interagency Review Group, 1978). Such lengths of time encompass global climatic changes greater than those that have occurred in recorded history. To assure prolonged integrity of any nuclear-waste repository, long-term environmental stability of that site needs to be considered, and impact of future climatic change needs to be anticipated.

Major global climatic changes occur at regular frequencies of about 10,000 to 100,000 years (Mitchell, J.M., 1976; Shackleton and Opdyke, 1973; Berggren and others, 1980). Changes from glacial to interglacial intervals, and back again, are quasi-periodic. These changes are caused by variations in net global solar-energy input, a consequence of the precession of Earth's orbit and the obliquity and eccentricity of its axial position (Imbrie and Imbrie, 1980, p. 943-944; Sergin, 1980, p.

1480). Based on these findings, computer-simulated climatic models have been devised that indicate a significant probability that a new ice age will begin within the next 10,000 years (Imbrie and Imbrie, 1980, p. 949-951). The present Holocene Epoch is the last in a long series of relatively brief (7,000 to 20,000 years) interglaciations punctuating much longer (70,000 to 90,000 years) glaciations (Wright, 1972, p. 279-281; Broecker and Van Donk, 1970, fig. 2; Berggren and others, 1980, fig. 11). Hence, a permanent repository for nuclear waste must withstand the effects of a major climatic change that may occur well within the hazardous duration of these materials.

### OBJECTIVES OF STUDY

A site in or near the Nevada Test Site in south-central Nevada (fig. 1) is being evaluated as a permanent repository for both transuranic-contaminated and high-level radioactive wastes. The objective of this study is to characterize long-term climatic variability inherent to this area. Specifically, paleoenvironmental and paleoclimatic reconstructions spanning the last 45,000 years are offered to facilitate calculations of potential variations in water-table levels and ground-water recharge (Winograd, 1981, p. 1461; Winograd and Doty, 1980, p. 76-85). Radiocarbon-dated plant macrofossil assemblages from ancient packrat (*Neotoma* spp.) middens in the Nevada Test Site and vicinity provide data for these paleoclimatic reconstructions. The uniformitarian assumption is made that climates of the last 45,000 years approximate the climates that will occur in the next 100,000 years.

### LOCATION OF THE STUDY AREA

The Nevada Test Site lies within the Basin and Range Province of western North America (Fenneman, 1931), on the southeastern margin of the physiographic Great Basin (Synder and others, 1964; Morrison, 1965) (fig. 1). With respect to flora, the site is located on the boundary of the Mojave Desert to the south and the Great Basin Desert to the north (Cronquist and others, 1972, figs. 55 and 56). Topography consists of desert valleys with relatively high floors (exceeding 700 m) surrounded by mountains with maximum elevations usually less than 2,100 m. Highlands of Tertiary volcanic rocks occupy much of the northern one-half of the site; while, in the south, uplands of Paleozoic carbonate rocks surround alluviated valleys. Two internally drained valleys, Yucca Flat and Frenchman Flat, are near the western boundary of the test site (fig. 2); playa elevation of Yucca Flat is 1,195 m, and playa elevation of Frenchman Flat is 939 m. Like

most valleys in southern Nevada, neither shows evidence of having contained "pluvial" lakes of Wisconsin age (Mifflin and Wheat, 1979, p. 15).

Some ground-water flow through the Nevada Test Site originates in volcanic highlands to the north, Pahute Mesa, Timber Mountain, and Yucca Mountain. The remainder enters the site from the east as underflow within the regional lower carbonate aquifer (Winograd and Thordarson, 1975, pl. 1; Winograd and Doty, 1980, fig. 1). Flow directions beneath the eastern part of the site are south and west from the highlands to springs at Ash Meadows in the Amargosa Desert. Ash Meadows is the site of an extensive network of springs; evidence exists for somewhat greater spring activity during the Wisconsin glacial age. Fossil tufa deposits occur as high as 40 m above present ground-water level in this area (Winograd and Doty, 1980, p. 48).

### REGIONAL CLIMATE

South-central Nevada is arid to semiarid; dry air masses dominate upper air flow about 70 percent of the year. Continental polar (cool and dry) and continental tropical (warm and dry) masses are the most common. Moist maritime air (both tropical and polar) occurs with a frequency of only about 28 percent. Outbreaks of very cold and dry arctic air occur during the winter; however, these account for less than 5 percent of the air-mass type dominance through the year (Houghton and others, 1975). The study area is typified by an arid to semiarid climate, and, because evidence exists for increased effective moisture during late Quaternary time, climatic phenomena that cause precipitation in this area are of particular interest. The Nevada Test Site receives moisture as a consequence of two basic storm types: (1) Those resulting from winter cyclonic activity; and (2) those caused by intense summer convection.

During the cold season (late autumn through early spring), southward migration of the subtropical high-pressure zone brings mid-latitude depressions to the southwestern United States. Winter precipitation results from either frontal-cyclonic (Pacific-type storms) or non-frontal cyclonic circulation (Great Basin lows) (Houghton and others, 1975, p. 14; Bell, 1979, p. 376). In both instances, the Sierra Nevada to the west (fig. 1) is a major barrier to moist air moving inland from the Pacific. Pacific-type storms are caused by fronts trailing southward from eastward moving low-pressure cells. These lows are imbedded in prevailing westerlies; their normal track is inland from the Pacific Northwest into Canada, north of the study area (Bryson and Hare, 1974, fig. 26). However, a semipermanent low-pressure trough sometimes develops over the western United States and diverts

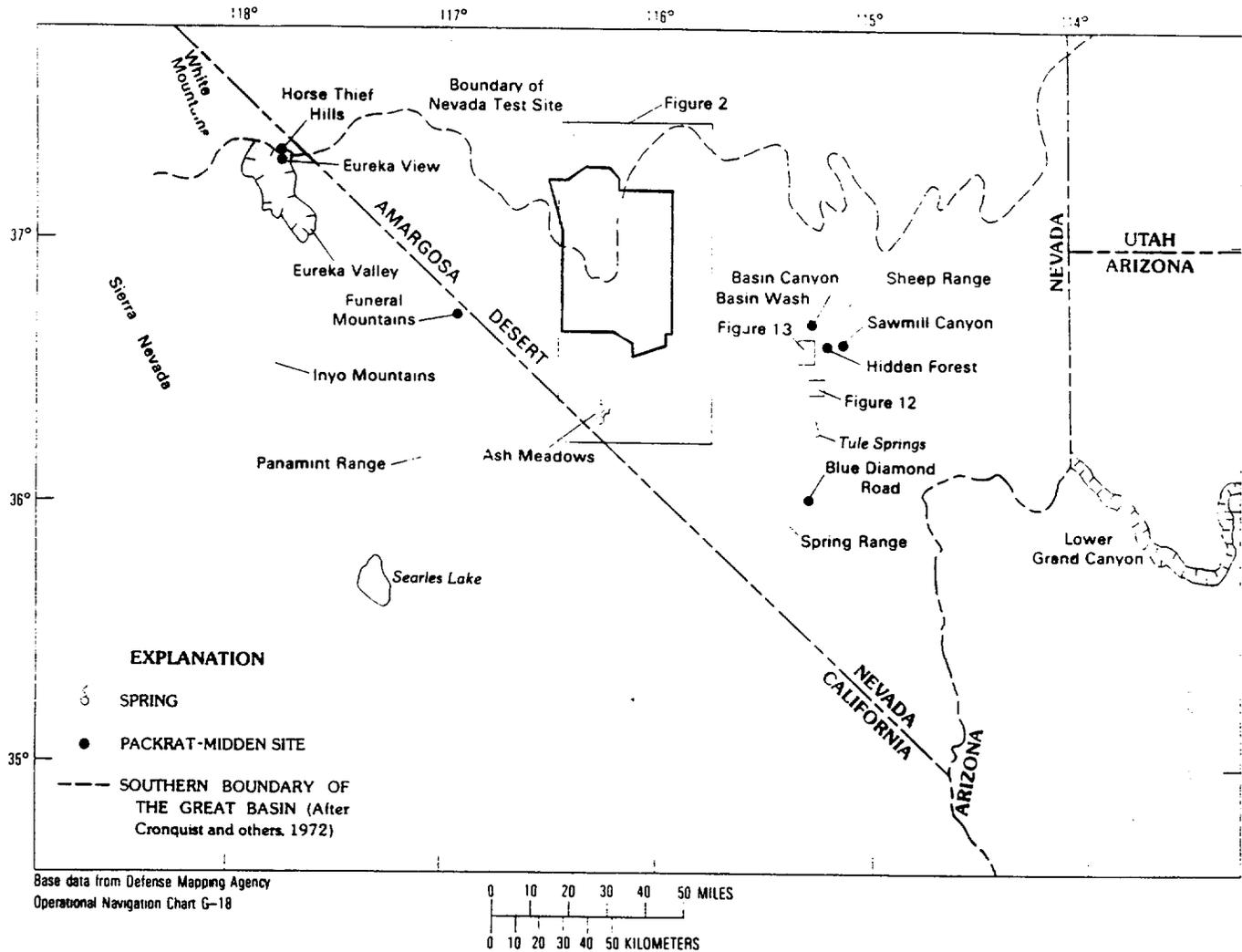


FIGURE 1. — Location of study area, the Nevada Test Site and vicinity, and locations of figures 2, 12, and 13, and other selected sites.

Pacific-type storms far enough south to affect the study area (Sellers and Hill, 1974, p. 16). Southern Nevada usually is south of the low-pressure center, and maritime air contributing to resultant precipitation comes from the southwest. These winds skirt the southern edge of the Sierra Nevada that lies to the west of the study area (fig. 1), although the Transverse and Peninsular Ranges south of the Sierra Nevada create a substantial rain-shadow. Maximum rain and snowfall from this type of disturbance usually occurs in western and northern Nevada (Houghton and others, 1975, p. 15).

In contrast to Pacific-type storms, Great Basin lows are non-frontal cyclonic disturbances; they are the chief source of winter precipitation in central and eastern Nevada. This type of "cut-off low" develops near the extremity of a front moving inland from the Pacific and is caused by strong thermal contrast between cold air behind the front and warmer air ahead of the disturbance

(Houghton and others, 1975, p. 16; Bell, 1979, p. 377). Great Basin lows may remain stationary over Nevada for a few days, but eventually move eastward under the influence of prevailing westerlies. Moisture-bearing winds are drawn into the area from the northwest. Although they occur less often than Pacific-type storms, Great Basin lows are important sources of winter precipitation, because the low is centered over the region and may remain for several days. Great Basin lows are most common from April to June; Pacific-type storms are more frequent between October and April (Houghton and others, 1975).

When the subtropical high-pressure belt shifts northward during the summer, the study area is removed from the effect of mid-latitude depressions. Summer precipitation is rarely the product of large-scale frontal activity; instead, it occurs as localized thunderstorms that are caused by intense vertical air currents over heated terrain.

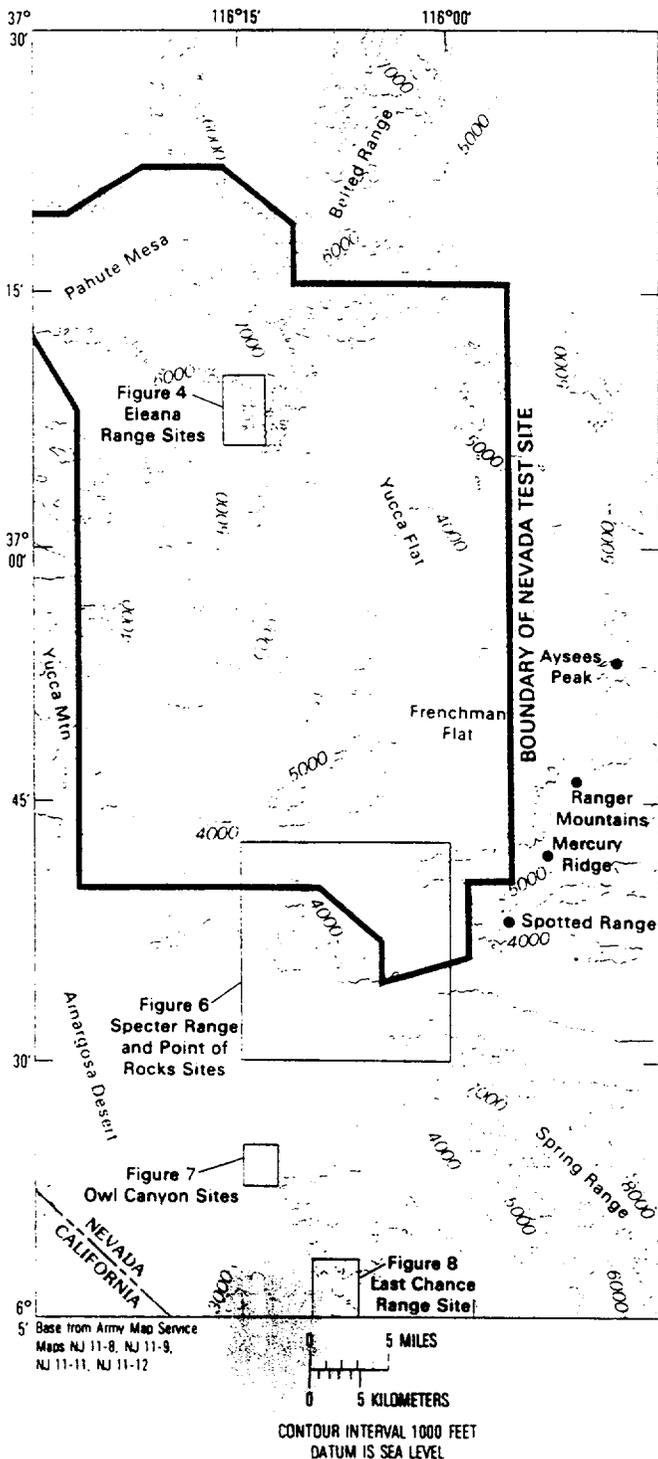


FIGURE 2. — Location of Nevada Test Site and figures 4, 6, 7, and 8 (see fig. 1 for the relative position of this map). Dots and numbers refer to packrat-midden sites discussed by Wells and Jørgensen (1964).

Such convection commonly is combined with orographic uplift and convergence over mountains to produce moisture-laden thunderheads (Bell, 1979, p. 381; Sellers and Hill,

1974, p. 10). At the Nevada Test Site, about 25 percent of the annual precipitation falls during the summer (June through early September, Beatley, 1976, p. 21), a small proportion compared to values greater than 50 percent for summer rainfall in the Sonoran and Chihuahuan Deserts to the southeast (Bryson and Lowry, 1955; Hales, 1974). In these southern deserts, the summer rainfall usually lasts from mid-July through early September, and results from maritime air carried inland from the Gulf of Mexico (Hales, 1974, p. 331; Bryson and Lowry, 1955, p. 339). This high-level (above 70 kPa) flow is circulation on the western edge of the subtropical anticyclone commonly called the Bermuda High. However, southern Nevada is beyond the western limit of these northwest winds (Mitchell, V.L., 1976, fig. 3; Hales, 1974, p. 334). Analyses indicate a negligible contribution of moisture from the Gulf of Mexico during the summer in western Arizona, adjacent Nevada, and California. Instead, surface low pressure that develops over heated desert terrain generates advective flow of maritime air northward from the Gulf of California and the Pacific Ocean (Hales, 1974, p. 341; Huning, 1978, p. 79). In the late summer (mid-July through mid-September), most of the precipitable water aloft in the Mojave Desert appears to originate from low-level northern flow, rather than from upper-level southeasterlies originating over the Gulf of Mexico.

Tropical storms of August through October produce a different kind of warm-season precipitation event. These low-pressure disturbances originate in the south and account for at least 25 percent of annual rainfall in the southern California deserts (Court, 1974, p. 212). Resultant precipitation patterns differ from those produced by summer thunderstorms: tropical storms are intense cyclonic disturbances (such as hurricane Kathleen of 1976) that affect large areas. However, the majority of rain from these storms is restricted to area south of latitude  $36^{\circ}$  north (Huning, 1978, p. 83).

#### PLANT COMMUNITIES

Adequate reconstruction of paleoenvironments of the Nevada Test Site is in part dependent on understanding the taxonomy, ecology, and biogeography of the plant species currently in the area. Many of these were also part of the Wisconsin-age vegetation, and changes in their distribution and associations provide important clues to the climatic history of the region. Diverse topography, geology, and local climates of the Nevada Test Site combine to create a complex mosaic of plant associations. Vegetation ranges from sparse desertscrub (in the sense of Brown and others, 1979) in the lowest valleys to well-developed woodland on highlands at ele-

vations above 2,000 m. Only sheer cliffs and playa floors are devoid of plants. Even seemingly barren Paleozoic carbonate hills of the Amargosa Desert support diverse communities of widely spaced shrubs and succulents of short stature.

The botanical nomenclature used in this report follows Beatley (1976) in most instances, with exceptions after Munz (1974), Cronquist and others (1972), and Holmgren and Reveal (1966). Vegetation analyses focus on plant communities of rocky slopes near fossil packrat-midden sites. These are areas of relatively heterogeneous vegetation, where rough topography presents a variety of microhabitats for different plant species. Vegetation of such areas is not well-known because plant ecologists usually prefer study sites of uniform topography supporting homogeneous vegetation for their purposes (Langford and Buell, 1968, p. 97; Mueller-Dombois and Ellenberg, 1974, p. 46-48). So, although principal plant-

community types recognized in this study (table 1) have direct analogs in Beatley's (1976, p. 27-72) treatment of the vegetation of the Nevada Test Site, some representative plant associations do not. Plants, such as matchweed (*Gutierrezia microcephala*) and Mohave pepperweed (*Lepidium fremontii*), are common dominants on rocky slopes. In contrast, some plant species that typify associations on alluvial fans, such as blackbrush (*Coleogyne ramosissima*) and desert-thorn (*Menodora spinescens*), are less abundant on rocky slopes. Vegetation classification presented in table 1 also differs from Beatley's (1976, p. 27-72), in that "transition desert" is not recognized as a plant-community type. Plant associations included in the "transition desert" by Beatley (1976, p. 41-52), such as those dominated by *Coleogyne*, *Larrea-Grayia-Lycium*, and *Lycium-Grayia*, are considered in table 1 to be representatives of Mojave desertscrub (Brown and others, 1979, p. 10).

TABLE 1. — Principal plant-community types and examples of representative plant associations on rock slopes

(Classification system follows that of Brown and others (1979))

Representative Plant Associations	Distribution and Common Associates
<b>Great Basin Conifer Woodland</b>	
<i>Pinus monophylla-Quercus gambelii-Juniperus osteosperma</i>	Volcanic highlands in the northern test site; generally at elevations above 1,950 meters (such as the eastern Pahute Mesa, Timber Mountain). Associates include <i>Artemisia tridentata</i> , <i>Symphoricarpos longiflorus</i> , <i>Purshia tridentata</i> , and <i>Lupinus argenteus</i> .
<i>Pinus monophylla-Artemisia tridentata-Juniperus osteosperma</i>	Highlands at elevations above 1,770 meters; restricted to xeric habitats at elevations above 2,100 meters. Common associates include <i>Artemisia nova</i> , <i>Cowania mexicana</i> , <i>Haplopappus nanus</i> , <i>Brickellia microphylla</i> .
<b>Great Basin Desertscrub</b>	
<i>Atriplex canescens</i> -mixed scrub	The flanks of hills and rocky mesas, usually of volcanic substrate; at elevations from about 1,500 to 2,000 meters. Common associates are usually Great Basin desertscrub species such as <i>Chrysothamnus nauseosus</i> , <i>C. viscidiflorus</i> , <i>Ephedra viridis</i> , <i>Tetradymia canescens</i> , <i>Artemisia nova</i> .
<i>Atriplex confertifolia</i> -mixed scrub	On limestone and dolomite slopes; at elevations from about 850 to 1,700 meters. Common associates are usually Mojave Desert shrubs such as <i>Amphipappus fremontii</i> , <i>Ephedra torreyana</i> , <i>Larrea divaricata</i> , <i>Gutierrezia microcephala</i> .
<b>Mojave Desertscrub</b>	
<i>Lepidium fremontii</i> -mixed scrub	On the talus slopes and ridges of calcareous mountains; at elevations from about 1,050 to 1,700 meters. Associates include a diverse complement of upper elevation Mojave desertscrub species such as <i>Coleogyne ramosissima</i> , <i>Ephedra torreyana</i> , <i>Buddleja utahensis</i> , and <i>Lycium andersonii</i> .
<i>Gutierrezia microcephala</i> -mixed scrub	Talus slopes, cliff bases, and ridges; generally at elevations below 1,400 meters on calcareous substrates. Common associates include <i>Larrea divaricata</i> , <i>Ambrosia dumosa</i> , <i>Ephedra</i> spp., <i>Amphipappus fremontii</i> , <i>Lycium pallidum</i> .
<i>Ambrosia dumosa-Larrea divaricata</i>	On talus slopes, ridges, and mesas; generally at elevations below 1,200 meters. Normally occurring with lower-elevation Mojave Desert species such as <i>Peucephyllum schottii</i> , <i>Eucnide urens</i> , <i>Gutierrezia microcephala</i> , <i>Echinocactus polycephalus</i> . <i>Atriplex confertifolia</i> is common at some sites.

Plant associations classified as Great Basin conifer woodland are distinguished by dominance of single-needle pinyon pine (*Pinus monophylla*) and Utah juniper (*Juniperus osteosperma*). In south-central Nevada, these pygmy conifer communities are restricted to elevations above 1,800 m. Dominant plant taxa in Great Basin desertscrub communities are those with northern floristic affinities, such as shadscale (*Atriplex confertifolia*) (Billings, 1949). These desertscrub associations usually occur below woodland, but above Mojave Desert vegetation. The plant species typical of lower elevation Mojave desertscrub vegetation, like creosote bush (*Larrea divaricata*) and white bursage (*Ambrosia dumosa*), have their center of distribution south of the Nevada Test Site. Exceptions include plant associations dominated by species endemic to the northern Mojave Desert, such as Shockley's boxthorn (*Lycium shockleyi*) and Bailey's greasewood (*Sarcobatus vermiculatus* var. *baileyi*). Many Mojave desertscrub species are at the northern limits of their distribution in the vicinity of the Nevada Test Site, and most are restricted to elevations below 1,800 m.

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#### PACKRAT-MIDDEN ANALYSIS

Comprehensive paleoenvironmental reconstruction depends on a reliable source of fossils. In temperate regions, our knowledge of late Quaternary climates is based primarily on organic remains preserved in lakes and bogs. However, sedimentary basins in arid regions usually do not provide well-preserved fossil remains, and other sources of information are required. In the early 1960's, a new paleoecological tool was introduced, analysis of packrat middens or paleonidology (Wells and

Jorgensen, 1964; Wells, 1976; Spaulding, 1977, p. 3), and its use has provided novel insights into the late Quaternary environments of western North America. Paleonidology is the reconstruction of past vegetation from plant remains preserved in middens deposited in rock cavities by cricetid rodents of the genus *Neotoma* (packrats, woodrats, trade-rats, or go-atters).

All species of *Neotoma* share an acquisitive behavioral trait and construct houses or dens from plant debris collected nearby (Finley, 1958; Wells, 1976). Functionally specific areas within a packrat den include nest chambers, food caches, and trash middens (Van Devender, 1973, p. 7-9). Plant debris from trash middens are the focus of this study. Middens contain primarily fecal pellets and plant remains in the form of shredded fibers, twigs, seeds, leaves, and flowers. Currently active middens are loose debris piles, while ancient middens are usually masses solidified by dehydrated urine. Middens often serve as urination points, and cementation is caused by saturation with urine which, upon drying, encases the refuse in a cohesive, crystalline mass. Crystallized packrat urine, called amberat, is hygroscopic and rehydrates during infrequent periods of high humidity. Capillary action draws rehydrated amberat to any fresh break on an indurated midden, where it then will dry and recrystallize. Within a few months, new breaks on ancient middens are sealed by a shiny layer of recently active amberat. Such surfaces are sticky whenever it is humid; in time, they incorporate dust and debris to become lusterless rinds that are no longer subject to rehydration. Hence, indurated packrat middens are self-sealing, with typically convoluted rinds that vary in thickness from a few millimeters to several centimeters (see figs. 3 and 4 for views of the Eleana Range-2 midden).

Although the properties of amberat augment longevity of indurated middens, mummification is the prime means of preservation. Middens must be sheltered from rain in a cave or beneath a rock overhang to be preserved. Decomposition is rare in well-sheltered middens. Middens from exposed sites are degraded and of a "punky" consistency, with most of the amberat leached out by repeated wetting. Extensive termite damage is common in such samples. However, given adequate shelter, plant fossils from middens remain well preserved. Some are more than 50,000 years old and are among the oldest fossils preserved by mummification.

In most instances, 80 to 95 percent of the mass of an indurated packrat midden is soluble urine and particles less than 0.85 mm in size (table 2). Most of the remaining 5 to 20 percent is composed of fecal pellets and plant debris. Identifiable plant remains normally comprise much less than 10 percent of the mass of an indurated midden, although they commonly number into the thousands per kilogram of unprocessed midden.

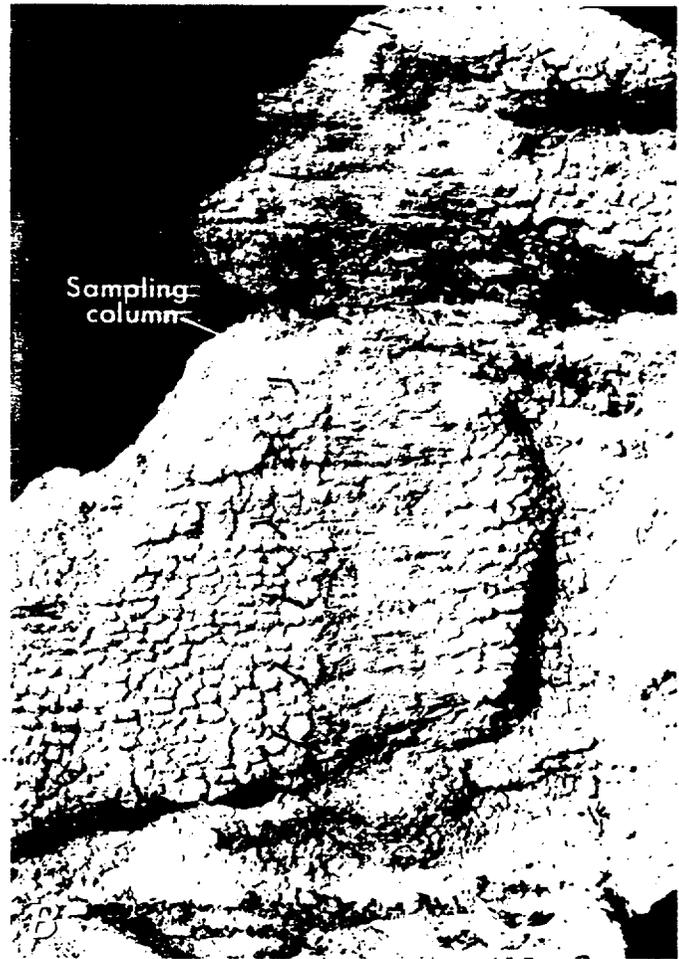


FIGURE 3. — The Eleana Range-2 packrat midden: A. General view of the external face of the midden: the rod at the top left of the midden is graduated in inches; B. Closeup view of the sampling column after removal of the weathering rind: nails are at 10-centimeter intervals; see figure 4 for the location of the Eleana Range-2 midden site.

## METHODS

Paleonidology is a new scientific discipline with few established guidelines and few standardized methods. The first time series of macrofossil assemblages from single localities only were described in 1980 and 1981 (Spaulding, 1980; Betancourt and Van Devender, 1981; Mead and Phillips, 1981). Therefore, a secondary objective of this study is to develop techniques that increase the resolution of inferences drawn from midden analysis and to test some assumptions of the discipline.

### SAMPLING

Packrat middens occur in a great variety of sizes, shapes, and situations within a rock cavity. Guidelines for site and sample selection were devised to minimize the chances of collecting contaminated samples (those containing plant fossils of more than one radiocarbon age). Deposits in vertical fissures were not collected, because different-age debris falling from above may be incorporated into a midden. Middens displaying jumbled stratigraphy were rejected, including most of those that were not well-consolidated. Using these criteria, about one-half the indurated middens located were collected, and about two-thirds of those were chosen for detailed analysis.

Most indurated *Neotoma* middens are less than 0.5 m<sup>3</sup> in volume and provide samples from only a narrow span of radiocarbon time. However, larger deposits do exist; the volume of some exceed 4 m<sup>3</sup>. A series of macrofossil assemblages from such a large deposit may span more than 10,000 years and is more useful for paleoclimatic reconstruction than one or two samples from many isolated sites. Hence, priority was given to locating and collecting those rare, large middens.

A midden judged suitable for analysis is first sketched and photographed. A vertical section of weathering rind is then removed; the exposed stratigraphy is sketched, and the position of samples to be taken is noted. A variety of chisels, wedges, and pry-bars are used to remove discrete blocks from the indurated mass. Ancient middens characteristically contain many minor laminae; major stratigraphic boundaries ususally are marked by interbedded weathering rinds. Midden sampling is facilitated by their tendency to split along the bedding planes defined by laminae. After removal, samples are placed in plastic bags. These bags are then wrapped tightly with masking tape (to avoid fracturing during transport) and labelled.

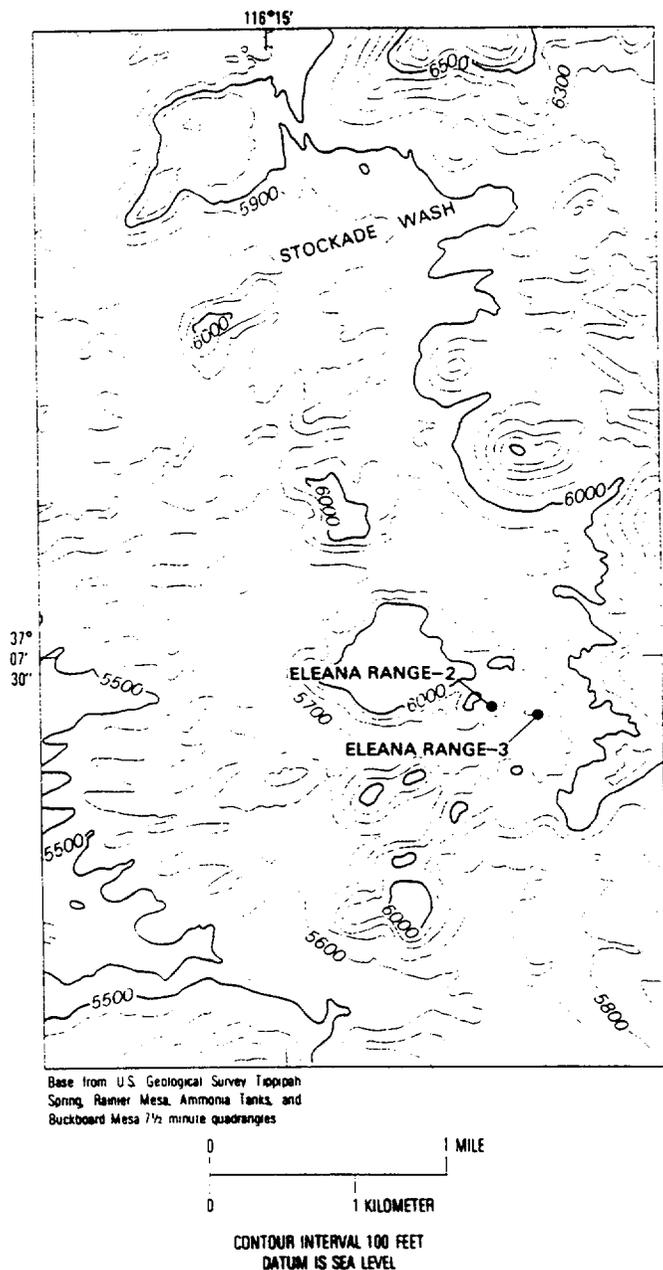


FIGURE 4. — Eleana Range fossil locality. (See figure 2 for the relative position of this map.)

All plant species within 30 m of a midden site are inventoried. Supplemental data are taken on other trees, shrubs, and succulents, and plant-community types, within 0.5 km of the site. Woody plants growing within 30 m were subjectively assigned the following abundance classes according to their importance in the local vegetation: 5, very abundant; 4, abundant; 3, common; 2, occasional; 1, rare. Most grasses and forbs are designated by an "X" in the modern plant lists, indicating their occurrence within 30 m of the midden sites.

#### ANALYSIS

In the laboratory, each midden sample is examined for stratification and, if necessary, split into subsamples for analysis. Samples are cleaned, weighed, rinsed under running water, and then immersed in warm water. Smaller subsamples usually are saved for pollen analysis. Immersion for 2 to 4 days is usually sufficient to dissolve the amberat in most indurated samples, releasing the plant macrofossils. Upon disaggregation, the mass is washed through a nested pair of No. 6 (3.35-mm mesh) and No. 20 (0.85-mm mesh) 12-inch (30.5-cm) Tyler<sup>1</sup> soil sieves. Material captured on the sieves is flushed with warm water, knocked onto paper blotters, and then dried in a forced-air oven at 50°C for 6 to 12 hours. The dried debris then is stored in labelled plastic bags. Prior to sorting, the debris is dry sieved through Nos. 6 and 20 screens to disaggregate fibrous clots that develop on the screens during wet-sieving and to remove remaining fine chaff. The different size fractions are then weighed (table 2).

Identifiable plant fragments and faunal remains are handsorted and placed in labelled plastic vials. Identifications are made by comparing the fossils with modern reference specimens under a stereo-dissecting microscope. Certain biases are incorporated into identification of this fragmentary plant material. Grasses and composites (Poaceae and Asteraceae) are frequently difficult to identify under these circumstances (Van Devender, 1973, p. 16-17; Spaulding, 1981, p. 76-79). Those that could not be identified to genus were grouped into the categories "Poaceae undetermined" or "Asteraceae undetermined." Similarly, fossils of plant genera with morphologically similar species were often difficult to identify to the species level. Hence, such fossil taxa as "*Artemisia* sec. *Tridentatae*," "*Ephedra* sp.," and "*Eriogonum* sp."

Traditionally, subjectively assigned relative values have been used to describe the abundance of taxa in a midden assemblage (for example, Wells and Berger, 1967; Phillips, 1977; Spaulding, 1981). This method was not used. Instead, the fossil data are reported in terms of the number of specimens counted in each midden sample (see Supplemental Data section). Relative abundance of a fossil taxon can be expressed as a percentage of the total number of identified specimens (*NISP*) counted in a sample (Grayson, 1979). One problem with this approach is the remains of a single arboreal taxon (*AT*) generally will be so abundant that they are impractical to count. In such instances, the total number of identified specimens minus the arboreal taxon (*NISP-AT*) still provides a useful parameter for calculating relative frequencies of all other fossil types. Relative importance of a superabun-

<sup>1</sup>Use of trade and firm names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

TABLE 2. — Dry weight and percentage composition of different size fractions of packrat-midden samples after dissolution and washing (Wtw, sum of weight of the 4.75-millimeter and 4.75–0.85-millimeter fractions; Wti, initial weight of sample; ER, Eleana Range; Spc, Specter Range; PR, Point of Rocks; OC, Owl Canyon; LCR Last Chance Range)

Site and sample no.	Initial weight (grams)	Weight of recovered material (grams) for the indicated size fractions (millimeters) below			Wtw	$\frac{Wtw}{Wti} \times 100$ (percent)
		4.75	4.75–0.85	< 0.85		
ER-2(1)	437	18.6	25.5	4.2	44.1	10.1
ER-2(2)	501	32.1	26.1	6.1	58.2	11.6
ER-2(3)	460	53.2	22.5	5.7	75.7	16.5
ER-2(4)	778	35.2	36.7	8.8	71.9	9.2
ER-2(5)	903	37.8	28.8	4.4	66.6	7.4
ER-2(6)	1,545	92.2	108.3	22.7	200.5	13.0
ER-2(7)	798	64.1	45.8	11.0	109.9	13.8
ER-2(9)	1,155	58.5	54.6	15.1	113.1	9.8
ER-2(10)	1,826	58.4	112.1	41.3	170.5	9.3
ER-2(11)	937	18.7	48.8	14.7	67.5	7.2
ER-3(2)	937	74.9	32.7	17.3	107.6	11.5
ER-3(3)	667	54.1	43.0	21.2	97.1	14.6
ER-3(4)	1,498	165.1	71.5	38.5	236.6	15.8
ER-3(6)	1,430	77.0	49.2	20.3	126.2	8.8
ER-3(7)	1,327	120.5	71.0	27.0	191.5	14.4
ER-3(8) <sub>2</sub>	1,270	89.0	58.2	30.6	147.2	11.6
ER-3(8) <sub>3</sub>	2,522	221.5	112.1	75.7	333.6	13.2
ER-3(9)	615	46.2	36.0	20.2	82.2	13.4
ER-3(10)	689	27.2	35.6	16.6	62.8	9.1
Spc-1(1)	635	110.0	47.0	10.0	157.0	24.7
Spc-1(2)	524	161.0	48.0	9.0	209.0	39.9
Spc-2(2) <sub>1</sub>	374	29.8	28.0	7.1	57.8	15.5
Spc-2(2) <sub>2</sub>	994	104.0	60.0	11.0	164.0	16.5
Spc-2(3)	991	38.8	57.4	15.4	96.2	9.7
Spc-2(6)	758	14.4	16.6	17.2	61.0	8.0
Spc-2(8)	513	34.5	26.3	12.2	60.8	11.9
Spc-2(10)	206	6.6	12.9	5.2	19.5	9.5
Spc-2(11) <sub>1</sub>	289	55.0	32.0	4.0	87.0	30.1
Spc-2(11) <sub>2</sub>	933	71.0	13.0	13.0	151.0	16.2
Spc-2(12)	934	22.0	47.1	13.9	69.1	7.4
Spc-3A(1)	1,171	21.9	53.9	10.6	75.8	6.5
Spc-3A(2)	808	26.7	51.6	13.8	78.3	9.7
Spc-3B	567	11.2	30.9	7.5	42.1	7.4
PR-1(1)	880	26.2	30.1	12.1	56.3	6.4
PR-1(3)	629	41.5	27.3	12.4	68.8	10.9
PR-2(2)	699	23.6	22.6	9.2	46.2	6.6
PR-2(3)	1,000	70.9	40.1	17.7	111.0	11.1
PR-3	712	9.3	50.1	21.4	59.4	8.3
OC-2(1)	345	15.0	22.9	10.6	37.9	11.0
OC-2(3)	569	36.2	37.2	12.5	73.4	12.5
OC-3(1)	755	6.9	17.5	4.2	24.4	3.2
OC-3(2)	730	20.0	18.1	7.1	38.1	5.2
LCR-1(2)	382	8.9	12.0	3.6	20.9	5.5
LCR-1(3)	462	17.6	28.0	12.7	45.6	9.9

<sup>1</sup>Dry sieve only.

dant fossil type can be expressed as a concentration value. Preliminary analyses indicate that a useful parameter is the ratio of the weight of the fossils of a superabundant species to the weight of the sorted midden sample (all identifiable macrofossils and fecal pellets removed).

In this study, *NISP* counted in single assemblages ranges from 192 to 2,674. A minimum number of 1,000 identified specimens was counted whenever possible. Variations in the number of identified plant taxa (*N*) in samples from the Specter Range-2 midden, as functions

of sample weight after washing and *NISP*, are presented in figure 5. Point of Rocks and Specter Range fossil localities are shown in figure 6. It appears that samples weighing less than 70 g after washing (about 350 to 700 g initial weight, depending on amberat concentration) (table 2), or those with a *NISP* of less than 600, many provide underrepresentative estimates of *N*.

A widely used similarity coefficient proposed by Sorensen (1948) takes the form:

$$IS = \frac{2c}{A + B} \times 100$$

where

*IS* (similarity index) is a percentage of the total number of taxa in both samples, with possible values ranging from 0 (none in common) to 100 (all taxa shared);

*c* is the number of plant taxa common to two samples;

*A* is the number of taxa in one sample; and

*B* is the number of taxa in the other.

This formula gives weight to the species recurring in two assemblages (Mueller-Dombois and Ellenberg, 1974, p. 215) and, as a consequence, may be less sensitive to random variability in midden content. The total number of trees, shrubs, and succulents ( $N_{ts}$ ) is used to compute *IS*, eliminating some of the bias created by the difficulty in identifying grasses and herbaceous species. If two samples have a taxon that is identified to genus in one and species in another (such as *Ephedra viridis* and *Ephedra* sp.), they are considered identical in computing *IS*.

#### MODERN ANALOGS

Validity of these paleoecological reconstructions rests on the fidelity with which macrofossil assemblages reflect past vegetation. *Neotoma* forages only within a limited area around the den. Studies of different packrat species indicate that foraging distances seldom exceed 30 m and then only when brush or broken terrain provide cover (Bleich and Schwartz, 1975; Stones and Hayward, 1968; Cranford, 1977; Smith, 1966). Therefore, plant fossils from a packrat midden are autochthonous and represent only local paleovegetation.

Analysis of active packrat middens from different vegetation types addresses two interrelated questions: (1) How closely do relative proportions of plant fragments correspond to their relative abundance in the local community; and (2) how complete an inventory of local vegetation is the list of plant taxa from a midden? Modern middens were treated in the same manner as fossil samples. Approximately 1 kg of loose debris was collected from a midden in a currently active den. A subsample of about 500 g was soaked for a short time to simulate the

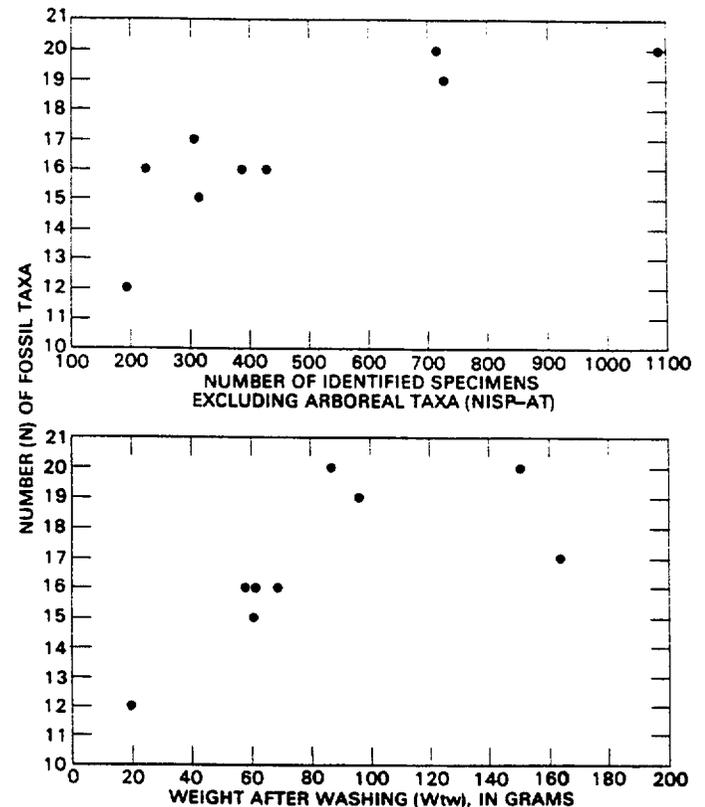


FIGURE 5. — Diversity as a function of the size of samples from the Specter Range-2 packrat midden (data are from table 2). See figure 6 for the location of the Specter Range-2 midden site.

disaggregation treatment used on indurated middens; then it was wet-sieved and dried. Dry-sieving, sorting, and identification followed. *NISP* in these modern samples ranged from 999 to 2,069 (see Supplemental Data section). Indices of similarity between local vegetation and modern midden assemblages ranged from 67 to 84. These compare favorably with an average *IS* of 77 for 6 assemblages less than 1,200 years old from the Grand Canyon (Cole, 1981, p. 38) and an *IS* of 77 for a single modern midden from the Sheep Range (Spaulding, 1981, p. 70). An additional two modern middens from the Connley Hills, outside the study area in southeastern Oregon (lat 43°16' N., long 121°04' W.), were analyzed because these sites occur in low-diversity vegetation. Indices of similarity for these samples were higher than those for middens from the study area, 91 and 100, presumably because of the low number of plant species at the sites.

Between 17 and 27 percent of the plant taxa noted in the modern middens from the Nevada Test Site and vicinity were not observed at the midden sites. Most of these are rare occurrences in the midden samples, usually represented by relative percentages (of *NISP*) of less than 1 percent. Of the plant species in the current vegetation within 30 m of the sites, between 16 and 32

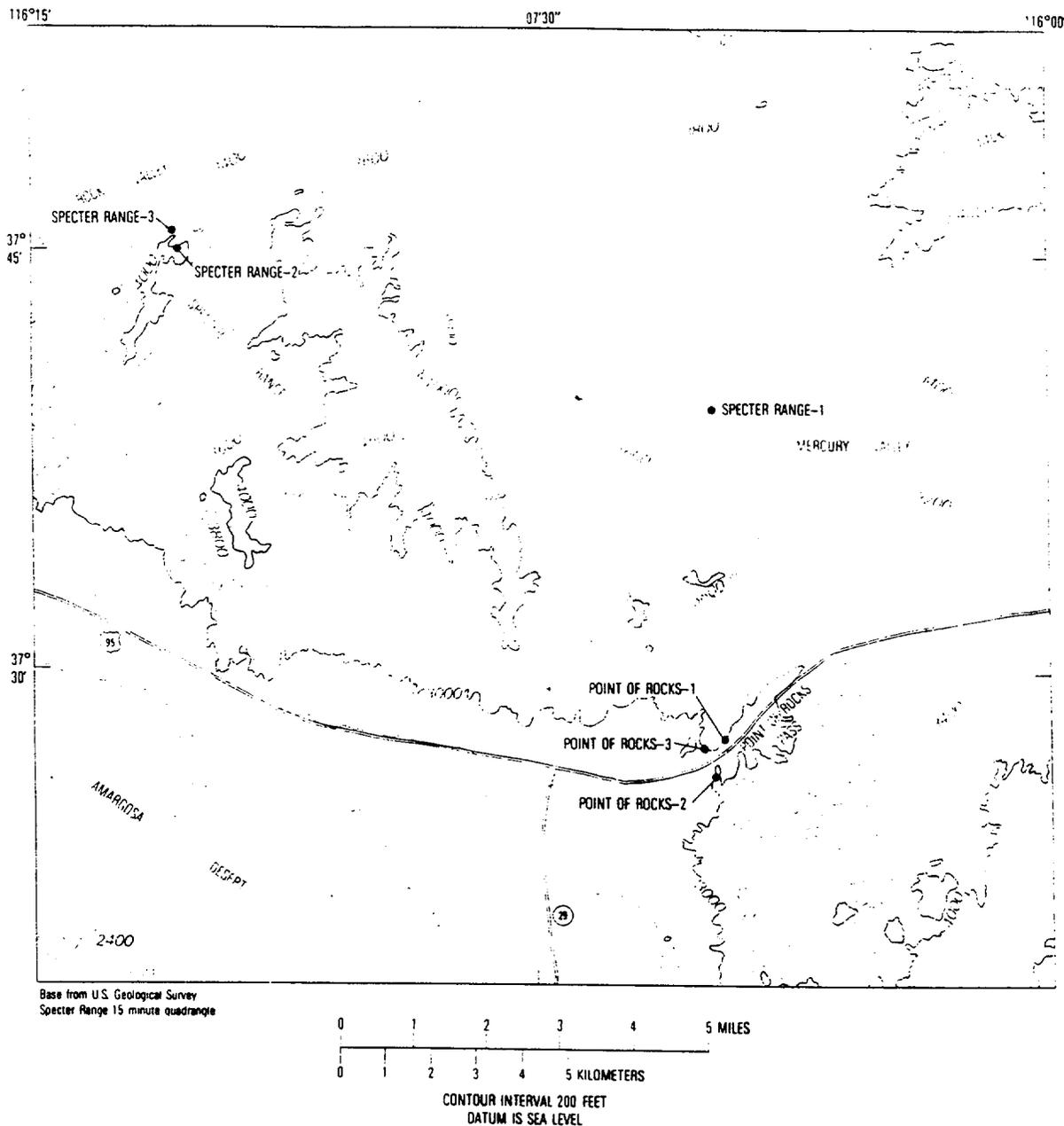


FIGURE 6. —Specter Range and Point of Rocks fossil localities (see figure 2 for the location of this map).

percent (excluding the Connley Hills samples) were not found in the modern midden debris. Again, most of these species are rare at the site today; none are common or abundant.

An array of the common species in the modern plant associations and active packrat middens is presented in table 3. The Owl Canyon-3 (fig. 7), Last Chance Range-1 (fig. 8), and Specter Range-2 (fig. 6) sites support Mojave desertscrub vegetation. The Eleana Range-3 (fig. 4)

and Connley Hills-1 sites are at transitions from Great Basin desertscrub to woodland; Connley Hills-2 is in an open juniper woodland. As mentioned previously, local vegetation of the Connley Hills sites is of low diversity ( $N_{ts} = 5$ ). Modern middens at this locality provide a contrast with those from sites supporting relatively diverse vegetation in southern Nevada ( $N_{ts} = 14$  to 19).

Differences occur between observed abundance of plant species in modern vegetation and their frequency in

TABLE 3.— Comparison of key plant taxa in modern packrat-midden debris with plants in the vegetation within 30 meters of the midden site

[See tables 11-15 in Supplemental Data section for a complete list of the plant species involved at each site; %, percent; NISP, number of identified specimens]

Site	Current vegetation (relative abundance)			Recent midden (percent of NISP)		
	Abundant (4-5)	Common (3)	Occasional (2)	Abundant (20 percent)	Common (5-20 percent)	Occasional (2-5 percent)
Owl Canyon-3	<i>Ambrosia dumosa</i>	<i>Eucnide urens</i>	<i>Echinocactus polycephalus</i>	<i>Larrea divaricata</i> (37%)	<i>Linanthus</i> sp. (8%)	<i>Cryptantha</i> sp. (4%)
	<i>Gutierrezia microcephala</i>	<i>Peucephyllum schottii</i>		<i>Gutierrezia microcephala</i> (22%)	<i>Eucnide urens</i> (6%)	<i>Peucephyllum schottii</i> (3%)
		<i>Pleurocoronis pluriseta</i>				<i>Ambrosia dumosa</i> (3%) <i>Aristida</i> sp. (2%)
Last Chance Range-1	<i>Ambrosia dumosa</i>	<i>Atriplex confertifolia</i>	<i>Gutierrezia microcephala</i>	<i>Larrea divaricata</i> (46%)	<i>Atriplex confertifolia</i> (12%)	<i>Mortonia utahensis</i> (4%)
	<i>Larrea divaricata</i>	<i>Bromus rubens</i> <i>Buddleja utahensis</i> <i>Eucnide urens</i>	<i>Nicotiana trigonophylla</i> <i>Stipa arida</i>		<i>Ambrosia dumosa</i> (8%) <i>Eucnide urens</i> (5%)	<i>Ephedra</i> sp. (3%) <i>Buddleja utahensis</i> (3%) <i>Brickellia desertorum</i> (2%)
Specter Range-2	---	<i>Atriplex confertifolia</i> <i>Ephedra torreyana</i> <i>Eriogonum heermannii</i> <i>Gutierrezia microcephala</i> <i>Prunus fasciculata</i> <i>Scopulophila rixfordii</i> <i>Stipa arida</i>	<i>Brickellia watsonii</i> <i>Buddleja utahensis</i>	<i>Atriplex confertifolia</i> (42%) <i>Ephedra torreyana</i> (21%)	<i>Scopulophila rixfordii</i> (12%) <i>Prunus fasciculata</i> (8%)	<i>Buddleja utahensis</i> (2%) <i>Poaceae</i> undet. (2%)
Eleana Range-3	<i>Atriplex canescens</i>	<i>Artemisia tridentata</i>	<i>Artemisia nova</i>	<i>Atriplex canescens</i> (39%)	<i>Poaceae</i> undet. (18%)	<i>Oryzopsis hymenoides</i> (3%)
		<i>Stipa</i> sp.	<i>Haplopappus nanus</i>		<i>Cowania mexicana</i> (15%)	<i>Artemisia</i> sec. <i>Tridentatae</i>
		<i>Ephedra viridis</i>	<i>Pinus monophylla</i> <i>Symphoricarpos longiflorus</i> <i>Juniperus osteosperma</i>		<i>Pinus monophylla</i> (8%) <i>Juniperus osteosperma</i> (7%)	
Connley Hills-1	<i>Artemisia tridentata</i> <i>Chrysothamnus nauseosus</i>	<i>Poaceae</i> undet.	<i>Bromus tectorum</i>	<i>Poaceae</i> undet. (56%) <i>Juniperus occidentalis</i> (27%)	<i>Chrysothamnus</i> sp. (9%)	<i>Chrysothamnus nauseosus</i> (2%) <i>Bromus tectorum</i> (2%)

TABLE 3.—Comparison of key plant taxa in modern packrat-midden debris with plants in the vegetation within 30 meters of the midden site—Continued

[See tables 11-15 in Supplemental Data section for a complete list of the plant species involved at each site; %, percent; NISP, number of identified specimens]

Site	Current vegetation (relative abundance)			Recent midden (percent of NISP)		
	Abundant (4-5)	Common (3)	Occasional (2)	Abundant (≥ 20 percent)	Common (5-20 percent)	Occasional (2-5 percent)
Connley Hills-2	<i>Chrysothamnus nauseosus</i>	<i>Artemisia tridentata</i>  <i>Bromus tectorum</i> <i>Juniperus occidentalis</i>	Poaceae undet.	<i>Juniperus occidentalis</i> (58%)	<i>Chrysothamnus nauseosus</i> (13%)  Poaceae undet. (9%)  <i>Artemisia tridentata</i> (8%) <i>Sysimbrium</i> sp. (5%)	<i>Chenopodium</i> cf. <i>botrys</i> (3%)  <i>Chrysothamnus</i> sp.

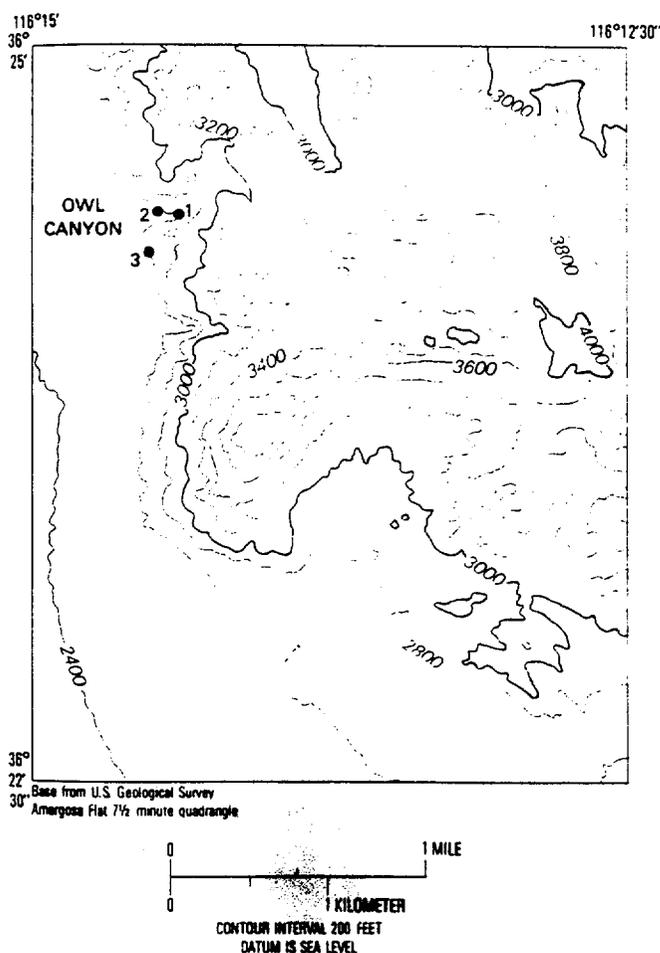


FIGURE 7.—Owl Canyon fossil locality. See (fig. 2 for the location of this map; position of the Owl Canyon-1 site is approximate.)

midden assemblage (table 3). Those species rated as common or abundant in modern vegetation (relative abundance values of 3 to 5) are not always common or abundant (relative frequencies  $\geq 5$  percent) in modern

midden assemblages. Some shrubby Asteraceae appear underrepresented; however, there are exceptions, such as the abundance of *Gutierrezia microcephala* in the Owl Canyon-3 assemblage (table 3). *Larrea divaricata* appears over-represented in the Owl Canyon-3 midden, as does *Juniperus* in both modern assemblages from the Connley Hills. However, *Larrea* appears proportionately represented in the Last Chance Range-1 assemblages, as does *Juniperus* in the Eleana Range-3 sample. The Connley Hills-1 midden is of particular interest. The nearest junipers are at the woodland border, about 28 m from the rock shelter containing the midden, and there are none in the *Chrysothamnus*-dominated association nearer the site. Nevertheless, juniper twigs and seeds comprise 27 percent of identified plant debris from the midden.

These data indicate that, in general, cacti are not disproportionately abundant in the packrat middens sampled. Pricklypear (*Opuntia erinacea*) occurs in the vicinity of Eleana Range-3, and barrel cactus (*Echinocactus polycephalus*) grows close to the Owl Canyon-3, Specter Range-2, and Last Chance Range-1 sites. Neither species is well-represented in those respective middens. Nor is the beavertail pricklypear (*Opuntia basilaris*) (armed with many small spines) well-represented in the Owl Canyon-3 or Last Chance Range-1 assemblages.

Limber pine (*Pinus flexilis*) macrofossils occur as contaminants in recent midden debris from the Eleana Range-3 site. These three needle-fragments probably came from the large Pleistocene midden less than 2 m away, pieces of which litter the floor of the rock shelter. As both Cole (1981, p. 58-60) and Phillips (1977, p. 36) note, older material may contaminate a younger midden. However, recognizable contaminants of Wisconsin age (such as juniper twigs) were not found in recent midden debris from the Owl Canyon-3, Last Chance Range-1, or Specter Range-2 sites, even though each of these shelters also contains an ancient midden.

In summary, it appears the important plant species in

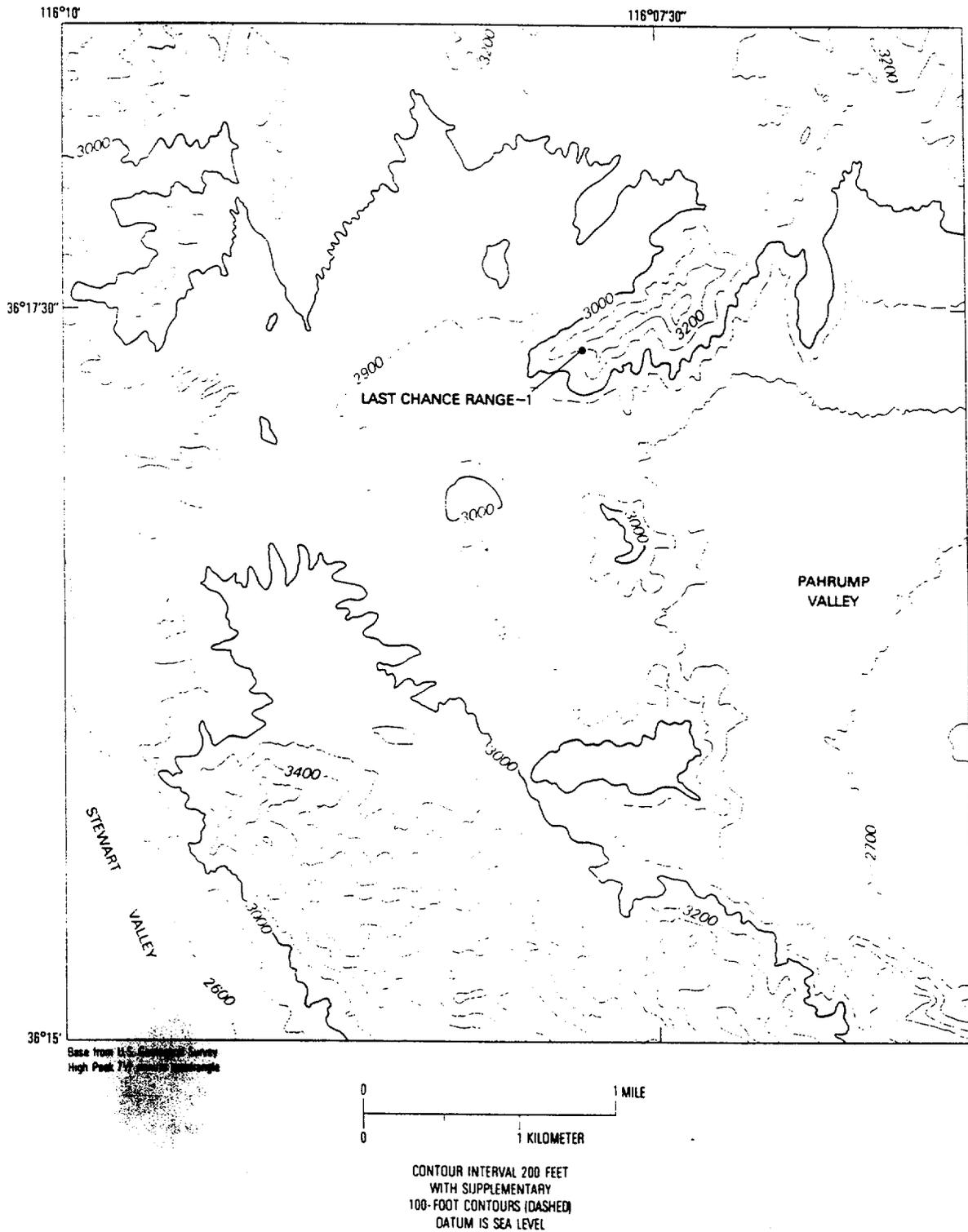


FIGURE 8. — Last Chance Range fossil locality. (See fig. 2 for the location of this map.)

the vegetation are not always important constituents of modern packrat debris piles. However, the inverse of this observation is not necessarily true. The abundant taxa in the middens are usually common constituents of the

surrounding vegetation. Variations in proportionality appear to include bias both for and against individual plant species. Invariably there seem to be several species present in the modern vegetation that are not observed

TABLE 4.— *Temperature and precipitation data from six stations in Nevada*

[Data from U.S. Weather Bureau, 1965, and Environmental Data Service, 1961-78. Abbreviations for vegetation types are: Gds, Great Basin desertscrub; Mds, Mojave desertscrub; wd, pinyon-juniper woodland; m, meter; mm, millimeter; °C, degrees Celsius]

Station (vegetation)	Beatty (Mds)			Winnemucca (Gds)			Elko (Gds)						
	North latitude: west longitude	Elevation (m)		Average temperature (°C)		Average precipitation (mm)	Average temperature (°C)		Average precipitation (mm)				
	37°00': 116°43'	1,082		Average temperature (°C)		Average precipitation (mm)	Average temperature (°C)		Average precipitation (mm)				
		Jan-uary	July	Annual	Jan-uary	July	Annual	Jan-uary	July	Annual			
1931-60		---	---	---	-2.1	21.7	8.8	215.1	-4.9	20.8	7.4	248.4	
1961-78		5.2	26.3	15.0	134.6	-1.2	22.3	9.4	205.4	-3.9	21.2	7.9	254.4
		116	116	19	117	---	---	117	117	---	---	---	---
Station (vegetation)	Austin (wd)			Eureka (wd)			Ely (wd/Gds)						
	North latitude: west longitude	Elevation (m)		Average temperature (°C)		Average precipitation (mm)	Average temperature (°C)		Average precipitation (mm)				
	39°30': 117°05'	2,014		Average temperature (°C)		Average precipitation (mm)	Average temperature (°C)		Average precipitation (mm)				
		Jan-uary	July	Annual	Jan-uary	July	Annual	Jan-uary	July	Annual			
1931-60		-1.3	21.1	8.6	302.3	---	---	---	-5.6	19.7	6.8	221.0	
1961-78		-0.8	21.4	8.6	364.9	-2.1	21.0	8.0	348.6	-4.9	19.7	6.8	244.7
		117	117	114	---	114	114	114	114	---	---	---	---

<sup>1</sup>Number of years of record (1961-78) if less than 18.

in the midden debris, and several species in the midden that are not found within the arbitrary 30-m foraging radius. The practical upper limit of Sorensen's (1948) similarity indices between middens and contemporary vegetation appears to be about 85 percent where plant communities are reasonably diverse (more than 15 woody species within a 30-m radius).

CLIMATIC RECONSTRUCTION

Inferences of past climate are made from plant fossils and are based on the premise that there have been no significant changes in environmental requirements of these species during the last 50,000 years. There is abundant evidence for stability in the morphology of the species used as climatic indicators; however, the hypothesis that genotype is stable over such time periods is untestable. This study presents quantitative climatic reconstructions based on changes in plant-species distribution and comparisons between estimated climate considered necessary to support a given fossil-plant association and climate that currently exists at that site. Two sources of modern climatic data are used. The first source is data collected by Beatley (1974, 1976) for the express purpose of delimiting climatic variables responsible for present vegetation distribution in the Nevada Test Site. The second source is U.S. Weather Bureau

records of precipitation and temperature for six selected stations in Nevada (table 4). Four stations (Beatty, Eureka, Ely, and Austin) are in upland settings rather than near valley bottoms; the environment at these sites is more comparable to that of upland fossil sites. The two data sets are not directly comparable because the instrument stations used by Beatley (1974, p. 250) were at plant level (30 cm), and of different design than those of the U.S. Weather Bureau (at 1.5-m height). Temperature values presented by Beatley (1974, p. 250) are obtained from maximum-minimum thermometers; mean values are derived by averaging extreme temperatures recorded during the 2-week interval between readings.

The first step in these reconstructions is to estimate present climate of the fossil site. Data provided by Beatley (1974, table 1) are used to extrapolate estimated ranges of temperature and precipitation at fossil localities. One uncertainty is that most midden sites are on steep slopes, where orientation to the sun and relative elevation are important determinants of local climate. In contrast, Beatley's stations are on gentle slopes where orientation and relative altitude are less important, but where the effect of nocturnal cold-air drainage may be more pronounced. Such factors were considered when the current climatic parameters for critical fossil localities were estimated (table 5). The second step is to estimate the climate represented by a given fossil-plant assemblage, a

TABLE 5.—Estimated range of values for mean annual temperature and precipitation at four key fossil localities in the Nevada Test Site and vicinity

Habitat abbreviations are: Af, alluvial fan; MR, mesa top or ridge top; TL, talus slopes and ledges; W, dry wash. Abbreviations for plant species are: Amdu, *Ambrosia dumosa*; Arno, *Artemisia nova*; Artr, *Artemisia tridentata*; Atca, *Atriplex canescens*; Atco, *Atriplex confertifolia*; Gumi, *Gutierrezia microcephala*; Hysa, *Hymenoclea salsola*; Juos, *Juniperus osteosperma*; Ladi, *Larrea divaricata*; Lypa, *Lycium pallidum*; Pimo, *Pinus monophylla*; Prfa, *Prunus fasciculata*; m, meter; mm, millimeter; °C, degrees Celsius

Site(s)	Elevation (m)	Orientation (from grid north)	Habitats			Vegetation			Analogous climatic stations				Estimated values for fossil locality		Remarks	
			Primary	Secondary	Tertiary	Primary	Secondary	Tertiary	Site No.	Elevation (m)	Vegetation type	Mean precipitation (mm)	Mean temperature (°C)	Mean precipitation (mm)		Mean temperature (°C)
Eleana Range -2 and -3	1,805	180°-205°	TL	MR	Af	Atca	Juos-Pimo	Arno-Artr	61	1,756	Arno	206.0	12.4	215-	11-	Fossil locality less than 1 kilometer from sites 61 and 62.
									62	1,750	Artr	205.5	11.9	225	12	
									65	1,676	Atca	183.6	10.9			
Specter Range-2	1,190	15°-25°	TL	MR	---	Gumi-Prfa	Atco	---	2	1,088	Ladi	169.4	14.5	170-	13-	Fossil locality less than 1 kilometer from site 3.
									3	1,038	do.	176.3	16.7	190	14	
									4	1,055	do.	148.1	14.7			
									30	943	Atca	126.0	13.5			
									31	940	Atco	131.1	13.5			
Point of Rocks-1	900	147°-230°	TL	Af	W	Lypa-Gumi	Ladi	Hysa	1	1,027	Ladi	140.7	15.2	110-	13.5-	Fossil locality in the bottom of a canyon.
									2	1,088	do.	169.4	14.5	120	14.5	
									20	994	do.	136.4	14.7			
									38	949	Lypa	121.9	13.7			
Owl Canyon -2 and -3	795	180°-230°	TL	---	W	Amdu-Ladi	---	Gumi-Amdu	1	1,027	Ladi	140.7	15.2	105-	16.5-	---
									7	963	do.	124.0	14.5	115	17.5	
									8	938	do.	120.1	16.2			
									9	989	do.	132.3	14.2			

<sup>1</sup>From Beatley (1974, table 1)

process with even more uncertainties. In this analog approach, dominant plant species in macrofossil assemblages are assumed to characterize the local paleocommunity. If, for example, a midden contains abundant juniper and sagebrush with other Great Basin Desert shrubs, then temperature and precipitation values are estimated that coincide with sites at the lower limit of woodland in a relatively dry part of the State, where juniper grows with such shrubs today. In contrast, if a macrofossil assemblage contains abundant juniper and pinyon pine associated with woodland shrubs, then extrapolated climatic values are derived from sites that support such vegetation today, well above the lower limit of woodland. The range of present values at the fossil site are then subtracted from estimated values for past climate to derive changes in mean annual temperature ( $\Delta T$ ) and precipitation. Precipitation change is expressed as a percent change from present values (percent  $P$ ). Values of  $\Delta T$  and percent  $P$  should be comparable, whether derived from Beatley's data base or U.S. Weather Bureau records, provided that separate sets of calculations consistently use one or the other. This approach represents only the first approximation to interpret an extensive fossil record.

## RADIOCARBON DATING

Questions concerning the dating of packrat middens are as critical as those addressing the representative nature of the plant macrofossil assemblage. It is assumed that macrofossils from a midden sample are contemporaneous within the standard deviation ( $1\sigma$ ) of that sample's radiocarbon ( $^{14}\text{C}$ ) age. The mixing of different-age macrofossils would lead to erroneous species associations, compromising paleoenvironmental reconstructions derived from them.

If the assumption of contemporaneity holds true, satisfactory dates could be obtained from any fraction of a packrat midden. Materials used for radiocarbon dating packrat middens range from whole samples of leafy strata and uriferous residue (Wells and Jorgensen, 1964, p. 1172; Wells, 1977, p. 239) to *Neotoma* fecal pellets and fragments of single plant species (Van Devender, 1977a, p. 237). Because mixing of different-age material is a possibility, a monospecific date is a more reliable estimate of the age of occurrence of that species (Van Devender, 1973, p. 31-33; Phillips, 1977, p. 21-22; Cole, 1981, p. 32). Multiple radiocarbon dates, using

different materials. should be used to verify the age of critical samples.

An assessment of 21 multiple-dating tests on packrat middens used in various studies (Spaulding, 1981, table 6) shows that 17 of the 58 radiocarbon dates were not within the expected age range at  $1\sigma$ . Some of these tests were performed because contamination was suspected; excluding these tests leaves 11 dates that represent unanticipated discordancies. Caution is needed in evaluating a macrofossil assemblage controlled by a single radiocarbon date.

A total of 71 samples were dated using carbon-14 techniques (table 6). Nineteen of the 46 macrofossil assemblages collected in the vicinity of the Nevada Test Site were dated at least twice. In addition, this study was designed to intensively sample large middens from a few sites to gain chronologic continuity at individual localities. Twelve middens from 7 localities were analyzed (table 6). Contrasts between samples thus could be used to identify anomalous assemblages that then were redated to verify their age.

The Eleana Range-3 packrat midden is of particular interest because of its great age and large size. It was subject to intensive radiocarbon analysis in an attempt to verify the ages of some of the oldest dated assemblages from the Southwest. Multiple dates are particularly important on samples with finite dates older than 30,000 years, when the quantity of radiocarbon remaining in a sample is extremely small. Materials dated were curl-leaf mountain mahogany (*Cercocarpus ledifolius*) and Utah juniper (*Juniperus osteosperma*) wood, limber-pine (*Pinus flexilis*) seed coats, *Neotoma* fecal pellets, unidentified twigs, and undifferentiated organic debris (a mix of sticks, fecal pellets, and plant fiber) (table 6). Other than the wood and seeds, monospecific samples could not be dated. Fragments of a single plant taxon rarely were abundant enough to provide the minimum 10 g desired to date a sample older than 30,000 years.

Most of the units from the Eleana Range-3 midden appear to be contaminated. Multiple-dating tests were done on eight assemblages after the first series of radiocarbon ages failed to demonstrate normal superposition (fig. 9). Only one of the assemblages yields paired dates that are concordant at  $1\sigma$ , ER-3(7)<sub>2</sub> (table 6). Multiple ages on samples ER-3(3) and 3(8)<sub>3</sub> overlap at  $2\sigma$ . The range of dates from the midden is from 14,200 to 49,900 B.P. (radiocarbon years before the present) (table 6). Anomalously young ages occur at the bottom of two of the three sample columns (fig. 9). Dates on large pieces of wood were as much as 15,000 years older than on associated midden material; such contamination of younger strata with older debris may occur more often in large rock shelters and caves, where fossil material may be readily available. Packrats apparently may incorporate

older sticks that were foraged from other parts of the shelter into a midden. Thus, large pieces of wood may be undesirable as dating material, because of their attractiveness as materials for packrat-den construction.

Some of the galleries behind and between ledges of indurated midden contain different-age organic debris. A tunnel-like cavity between samples ER-3(13) and 3(14) that extends to the back wall of the shelter (fig. 9) was filled with loose reddish-brown dirt and seeds. Limber-pine seed shells from this fill were dated at 14,200 B.P. (table 6). This indicates that at least part of the midden was occupied during the late Wisconsin as well as during the middle Wisconsin.

Van Devender (1973, p. 17-18) first noted that packrat middens do not necessarily contain normally superimposed layers and that a packrat may deposit debris beneath a ledge formed by an older indurated midden. Based on the radiocarbon analyses of the Eleana Range-3 midden, it seems appropriate to extend this observation to note that some, but by no means all, middens may be so reworked by packrats throughout the millenia that they are undesirable for detailed paleoenvironmental reconstruction, no matter what their age. Only three assemblages from this midden had paired dates that were concordant at  $2\sigma$  (table 6); only these assemblages will be used for paleoenvironmental reconstruction. These samples ER-3(3), 3(7)<sub>2</sub>, and 3(8)<sub>3</sub>, may possess enough temporal integrity to warrant detailed discussion.

Dating results on the Eleana Range-2 midden (site ER-2; 10,600 to 17,100 B.P.) are more encouraging. The first series of dates from the midden revealed that normal superposition appears to be the rule rather than the exception (table 6.) However, the lowermost unit yields anomalously young dates (fig. 10). This stratum also is friable and contains more insect fragments than the units above. The abundant mouse and pika (*Ochotona* sp.) feces suggest reworking by burrowing animals subsequent to initial deposition. Paired radiocarbon dates of 14,310 (on *Neotoma* feces) and 10,800 B.P. (on undifferentiated plant debris) (table 6) from sample ER-2(11) indicate that a mixing of older and younger material has occurred.

Radiocarbon analyses of samples from the Specter Range-2 midden (site Spc-2; 18,700 to 32,000 B.P.) also indicate normal superposition of layers, with the exception again of the bottom stratum. Dates on sample Spc-2(12) are considerably younger than those from overlying strata (fig. 11; table 6). Unlike the dates on the lowest sample from the Eleana Range-2 midden, paired dates from sample Spc-2(12) are coeval at  $1\sigma$ , yielding no evidence of mixing of different-age debris. This may be because the Specter Range-2 midden is suspended about 1 m above the floor of the rock shelter, perhaps precluding

## VEGETATION AND CLIMATES OF THE LAST 45,000 YEARS. NEVADA TEST SITE

TABLE 6.—Packrat-midden sites, samples, and radiocarbon dates

[Artr. *Artemisia* sec. *Tridentatae*; Cele. *Cercocarpus ledifolius*; fp. *Neotoma* fecal pellets; Juos. *Juniperus osteosperma*; lv. leaves; Mout. *Mortonia utahensis*; Pifl. *Pinus flexilis*; sd. seeds; tg. twigs; uod. undifferentiated organic debris; upd. unidentified plant debris; wd. wood; Yusc. *Yucca schidigera*; 1σ. 1 standard deviation]

Site	Unit	Sample No.	Radiocarbon date ( $\pm 1\sigma$ )	Laboratory No. <sup>1</sup>	Material dated	Weighted average <sup>2</sup>
Eleana Range (ER) 2 (lat 37°07'18" N., long 116°14'03" W., elevation 1,810 m).	I	ER-2(1)	10,620 $\pm$ 120	USGS-876	Juos tg & sd	---
	I	ER-2(2)	11,700 $\pm$ 85	USGS-914	Artr tg	---
	II	ER-2(3)	13,180 $\pm$ 65	USGS-884	fp	---
	II	ER-2(4)	14,090 $\pm$ 320	A-2927	Pifl lv	---
	II	ER-2(4)	15,300 $\pm$ 130	USGS-875	Pifl wd	---
	III	ER-2(5)	14,260 $\pm$ 110	USGS-874	Pifl wd	---
	IV	ER-2(6)	14,500 $\pm$ 110	USGS-885	Pifl lv	---
	IV	ER-2(6)	14,830 $\pm$ 80	USGS-886	fp	14,720 $\pm$ 70
	IV	ER-2(7)	14,760 $\pm$ 100	USGS-887	fp	---
	IV	ER-2(7)/ 2(8)	15,380 $\pm$ 100	USGS-888	Cele wd	---
	IV	ER-2(9)	15,890 $\pm$ 120	USGS-889	fp	---
	IV	ER-2(10)	17,100 $\pm$ 130	USGS-890	fp	---
	IV	ER-2(10)	17,100 $\pm$ 90	USGS-1069	Pifl lv	17,100 $\pm$ 70
	V	ER-2(11)	10,800 $\pm$ 90	USGS-892	upd	---
	V	ER-2(11)	14,310 $\pm$ 110	USGS-893	fp	---
Eleana Range (ER) 3 (lat 37°07'15" N., long 116°13'49" W., elevation 1,800 m).	I	ER-3(2)	49,800 <sup>+3,100</sup> -2,300	USGS-971	uod	---
	I	ER-3(2)	42,500 $\pm$ 1,300	USGS-1260	fp & tg	---
	I	ER-3(3)	37,400 $\pm$ 1,000	USGS-915	upd	---
	I	ER-3(3)	39,400 $\pm$ 760	USGS-991	uod	38,670 $\pm$ 610
	II	ER-3(4)	37,950 $\pm$ 450	USGS-972	fp	---
	II	ER-3(4)	42,800 $\pm$ 1,000	USGS-1261	tg	---
	III	ER-3(6)	40,600 $\pm$ 850	USGS-973	uod	---
	III	ER-3(7) <sub>1</sub>	49,900 <sup>+1,900</sup> -1,500	USGS-916	Cele wd	---
	III	ER-3(7) <sub>2</sub>	44,500 $\pm$ 1,100	USGS-974	fp	---
	III	ER-3(7) <sub>2</sub>	46,100 <sup>+1,200</sup> -1,600	USGS-975	uod	45,110 $\pm$ 870
	IV	<sup>3</sup> ER-3(p)	38,600 $\pm$ 1,100	USGS-687	upd	---
	V	ER-3(8) <sub>2</sub>	44,100 $\pm$ 1,300	USGS-917	Cele wd	---
	V	ER-3(8) <sub>3</sub>	39,800 $\pm$ 1,200	USGS-918	Cele wd	---
	V	ER-3(8) <sub>3</sub>	37,600 $\pm$ 350	USGS-976	fp	37,800 $\pm$ 340
VI	ER-3(9)	34,800 $\pm$ 550	USGS-1264	uod	---	
Eleana Range (ER) 3 (cont.)	VI	ER-3(9)	36,290 $\pm$ 330	USGS-1061	fp	---
	VI	ER-3(10)	47,100 <sup>+2,600</sup> -2,000	USGS-919	Juos wd	---
	VI	ER-3(10)	32,500 $\pm$ 800	USGS-993	fp	---
	VI	ER-3(10)	35,450 $\pm$ 650	USGS-1265	uod	---
	VIII	ER-3(12)	45,400 $\pm$ 1,500	USGS-920	Cele wd	---
	IX	ER-3(13)	22,940 $\pm$ 150	USGS-992	fp	---
	IX	ER-3(13)	29,120 $\pm$ 170	USGS-1062	upd	---
	---	<sup>4</sup> ER-3(u)	40,500 $\pm$ 1,000	USGS-977	uod	---
	---	<sup>5</sup> ER-3(14)	14,200 $\pm$ 100	USGS-1266	Pifl sd	---
Specter Range (Spc) 1 (lat 36°38'31" N., long 116°05'00" W., elevation 1,040 m).	---	Spc-1(1)	300 $\pm$ 40	UW-635	upd	---
	---	Spc-1(2)	100 <sup>+200</sup> -100	UW-630	Yusc lv	---

TABLE 6. — Packrat-midden sites, samples, and radiocarbon dates — Continued

Site	Unit	Sample No.	Radiocarbon date ( $\pm 1\sigma$ )	Laboratory No. <sup>1</sup>	Material dated	Weighted average <sup>2</sup>
Specter Range (Spc) 2 (lat 36°40'16" N., long 116°12'33" W., elevation 1.190 m).	I	Spc-2(2) <sub>1</sub>	18,760 $\pm$ 110	USGS-1063	uod	---
	I	Spc-2(2) <sub>1</sub>	18,710 $\pm$ 150	USGS-994	Juos tg & sd	18,740 $\pm$ 90
	I	Spc-2(2) <sub>2</sub>	21,400 $\pm$ 1200	UW-637	Pimo lv	---
	I	Spc-2(2) <sub>2</sub>	19,080 $\pm$ 370	UW-638	Juos tg & sd	19,280 $\pm$ 350
	II	Spc-2(3)	23,330 $\pm$ 150	USGS-998	Juos tg	---
	II	Spc-2(3)	23,250 $\pm$ 100	USGS-1064	uod	23,270 $\pm$ 80
	II	Spc-2(6)	25,900 $\pm$ 260	USGS-995	Juos tg & uod	---
	III	Spc-2(8)	27,900 $\pm$ 300	USGS-997	Juos tg & sd	---
	III	Spc-2(8)	29,810 $\pm$ 280	USGS-1065	uod	---
	III	Spc-2(10)	29,140 $\pm$ 310	USGS-1066	uod	---
	III	Spc-2(11) <sub>1</sub>	32,260 $\pm$ 2,800	UW-639	Juos tg & sd	---
	III	Spc-2(11) <sub>2</sub>	32,100 $\pm$ 1,400	UW-640	Juos tg & sd	---
	IV	Spc-2(12)	25,280 $\pm$ 220	USGS-996	Juos tg	---
	IV	Spc-2(12)	25,060 $\pm$ 190	USGS-1067	uod	25,150 $\pm$ 140
Specter Range (Spc) 3 (lat 36°40'35" N., long 116°12'28" W., elevation 1.100 m).	---	Spc-3A(1)	20,200 $\pm$ 1,800	A-2398	Juos tg & sd	---
	---	Spc-3A(2)	10,660 $\pm$ 250	A-2399	fp	---
	---	Spc-3A(2)	13,090 $\pm$ 320	A-2400	Juos tg	---
	---	Spc-3B	28,460 $\pm$ 2,200	A-2401	Juos tg	---
Point of Rocks (PR) 1 (lat 36°34'13" N., long 116°04'45" W., elevation 900 m).	---	PR-1(1)	9,880 $\pm$ 190	A-2395	fp	---
	---	PR-1(1)	9,780 $\pm$ 230	A-2396	upd	9,840 $\pm$ 150
	---	PR-1(3)	11,680 $\pm$ 650	A-2397	upd	---
Point of Rocks (PR) 2 (lat 36°33'48" N., long 116°04'55" W., elevation 930 m).	---	PR-2(2)	9,560 $\pm$ 220	A-2393	upd	---
	---	PR-2(3)	9,260 $\pm$ 180	A-2394	upd	---
Point of Rocks (PR) 3 (lat 36°34'10" N., long 116°05'10" W., elevation 910 m).	---	PR-3	14,810 $\pm$ 400	A-2927	tg	---
Owl Canyon (OC) 1 <sup>6</sup> (lat 36°24' N., long 116°14' W., elevation ca. 790 m).	---	OC-1	13,150 $\pm$ 500	I-4237	Juos tg	---
Owl Canyon (OC) 2 (lat 36°24'27" N., long 116°14'23" W., elevation 800 m).	---	OC-2(1)	10,260 $\pm$ 520	A-2402	fp	---
	---	OC-2(2)	10,070 $\pm$ 220	A-2403	fp	---
Owl Canyon (OC) 3 (lat 36°24'18" N., long 116°14'29" W., elevation 790 m).	---	OC-3(1)	32,870 $\pm$ 1,370	A-2412	Juos tg & sd	---
	---	OC-3(2)	>28,700	A-2413	Juos tg & sd	---
Last Chance Range (LCR) 1 (lat 36°17'25" N., long 116°07'40" W., elevation 960 m).	---	LCR-1(2)	9,280 $\pm$ 210	A-2414	Mout lv	---
	---	LCR-1(3)	11,760 $\pm$ 90	A-2415	Juos tg & sd	---

<sup>1</sup>USGS, U.S. Geological Survey Radiocarbon Laboratory; A, University of Arizona, Laboratory of Isotope Geochemistry; UW, University of Washington, Department of Chemistry Radiocarbon Laboratory; I, Teledyne Isotopes.

<sup>2</sup>Average of paired dates from one sample, weighted toward the radiocarbon date with the smaller  $\sigma$  (the more precise date) (Long and Rippeteau, 1974, p. 208).

<sup>3</sup>Prospect sample removed for detailed stratigraphic analysis.

<sup>4</sup>Sample from loose float on floor of shelter.

<sup>5</sup>Loose fill in cavity between two indurated midden units.

<sup>6</sup>Midden located and collected by P.J. Mehringer, Jr. (Mehringer and Warren, 1976). The site could not be relocated.

WEST

EAST

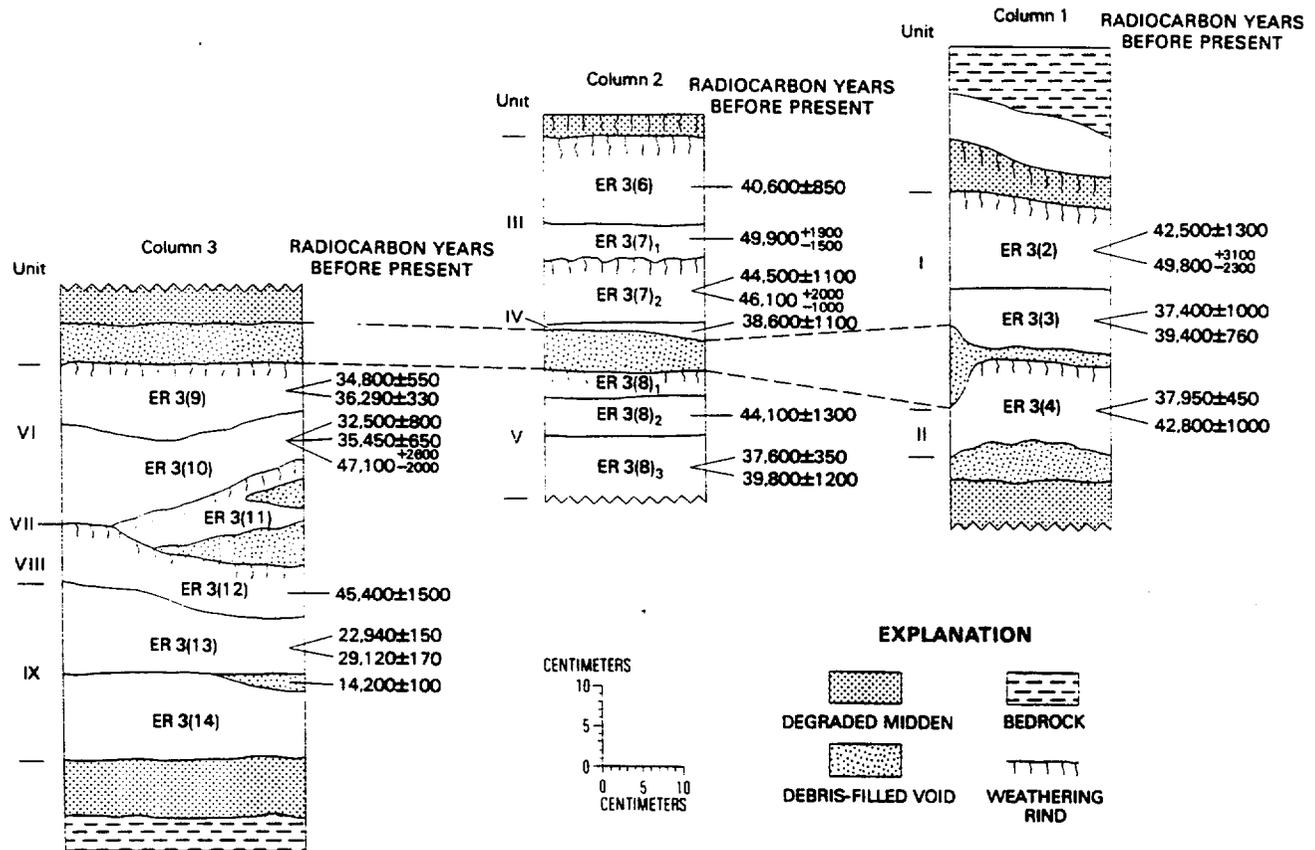


FIGURE 9. — Sample columns from the Eleana Range-3 packrat midden (dashed lines indicate inferred correlations).

the bioturbation that occurs in the lower parts of middens that rest on rock-shelter floors.

### THE FOSSIL RECORD IN SELECTED AREAS

Fossil packrat-midden sites in south-central Nevada can be placed into two categories. The first are those sites that lie within the floristic Mojave Desert, with middens that record vegetation on dolomite, limestone, or derived calcareous conglomerates. In the vicinity of the Nevada Test Site, these range from elevations as low as 790 m in the Amargosa Desert, to 1,830 m in the Spotted Range (figs. 1, 2). The second category are midden sites from the Eleana Range in the floristic Great Basin Desert (figs. 1, 4). These rock shelters, developed in volcanic tuffs, lie at an elevation of about 1,800 m. Detailed lists of fossils from these sites are given in the Supplemental Data section, tables 16-25.

### PERIPHERY OF AMARGOSA DESERT

The lowest midden sites in the region are on the eastern edge of the Amargosa Desert, at elevations ranging from 790 to 960 m (fig. 1). These are also the only sites

that provide records of glacial-age desert vegetation. Macrofossil assemblages from the Owl Canyon locality (fig. 7) date to the middle and latest Wisconsin (table 6). Present vegetation is sparse Mojave desertscrub on xeric dolomitic substrate. The most common plants on the rock slopes include matchweed (*Gutierrezia microcephala*), desert spruce (*Peucephyllum schottii*), white bursage (*Ambrosia dumosa*), and creosote bush (*Larrea divaricata*). The site of the Owl Canyon-1 midden, collected and dated by P. J. Mehringer, Jr., could not be relocated. It is near the mouth of the same canyon where the Owl Canyon-2 site is located (fig. 7; P. J. Mehringer, Jr., Washington State University, oral commun., 1980). Radiocarbon dated at  $13,150 \pm 500$  B.P. [laboratory number I-4237 (table 6)] (Mehringer and Warren, 1976, p. 125), this midden contains abundant Utah juniper (*Juniperus osteosperma*) and Utah agave (*Agave utahensis*), indicating an open woodland at Owl Canyon-1 near the end of the Wisconsin (Spaulding, 1981, p. 152).

The two other sites, Owl Canyon-2 and 3, are on xeric south-facing slopes (fig. 7), and are of different age. Macrofossil assemblages from Owl Canyon-3, at an elevation of 790 m, contain abundant rubber rabbitbrush

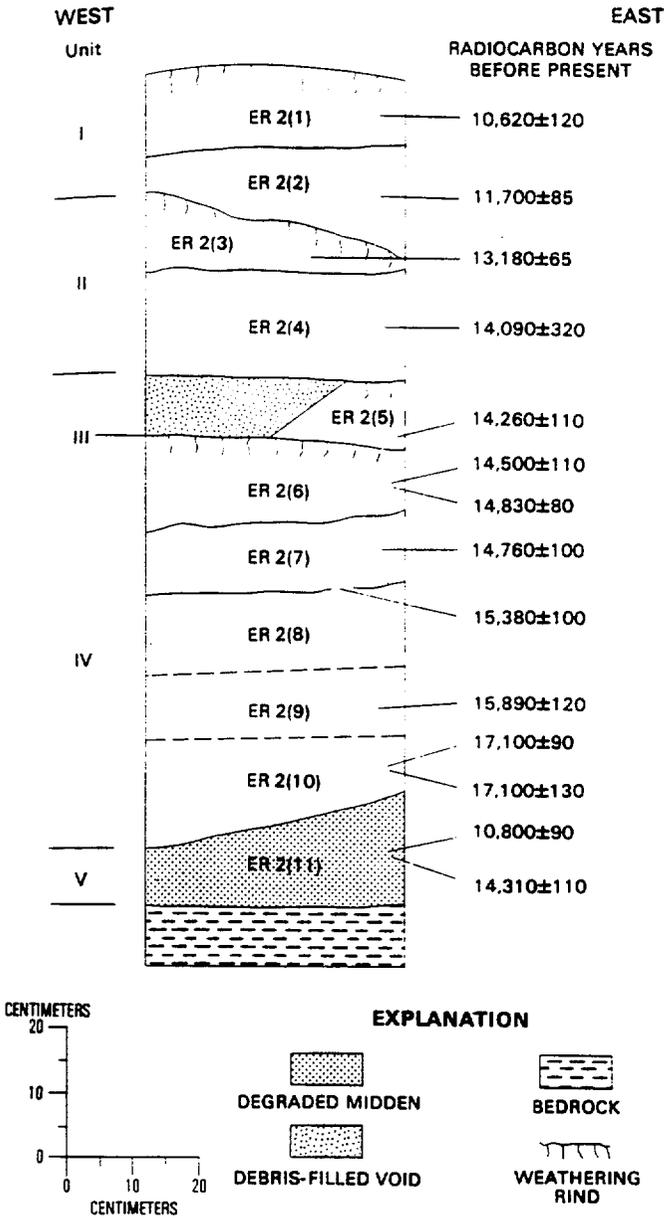


FIGURE 10. — Sample column from the Eleana Range-2 packrat midden.

(*Chrysothamnus nauseosus*) and Utah juniper, and common Utah agave, and they date to the middle Wisconsin (about 33,000 B.P. and >29,000 B.P.) (table 6). Both rubber rabbitbrush and Utah agave are characteristic of higher elevation deserts. Agave is not known below elevations of about 1,200 m (Beatley, 1976, p. 269). The abundance of shrubs and succulents in the Owl Canyon-3 assemblages may indicate desertscrub vegetation with occasional junipers, rather than a juniper woodland.

Two samples from the Owl Canyon-2 midden are radiocarbon-dated at 10,070 and 10,260 B.P. (table 6). They contain abundant Utah agave, but lack appreciable quan-

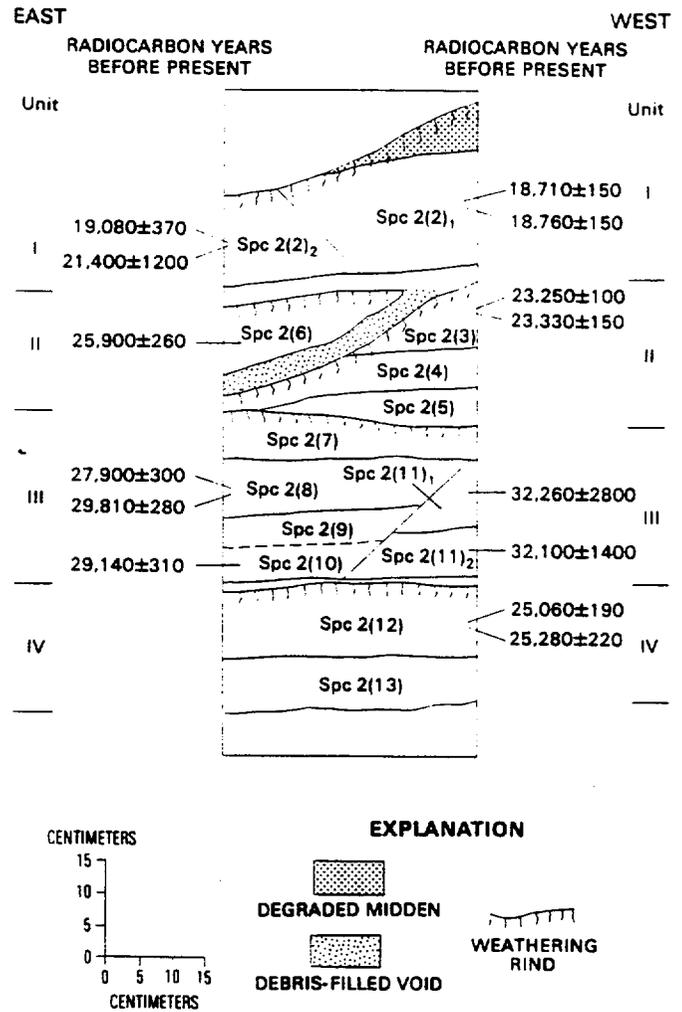


FIGURE 11. — Sample column from the Specter Range-2 packrat midden.

ties of rabbitbrush and contain no juniper (see Supplemental Data section). Desertscrub vegetation apparently was well-developed at this site by the close of the Wisconsin. However, none of the xerophytic species that characterize the present local vegetation are recorded. Instead, the terminal-Wisconsin plant community appears to have been dominated by shrubs and succulents that commonly occur at higher elevations (above 1,200 m) today.

Late Wisconsin and early Holocene desert vegetation also is documented by packrat middens at the Point of Rocks locality. At an elevation of 910 m, the Point of Rocks-3 site is about 5 m above a talus slope head on the southwest-facing flank of a ridge (fig. 6). A sparse desertscrub community dominated by white bursage (*Ambrosia dumosa*), creosote bush, and chaff-bush (*Amphipappus fremontii*) occurs at the site today. The Point of Rocks-3 midden is dated at 14,810±400 B.P. (table 6) and contains abundant snowberry (*Symphoricarpos longiflorus*), an extralocal shrub, and common shadscale (*Atriplex confertifolia*) (see Supplemental Data section). It lacks

the remains of juniper and, as such, it is the oldest reported macrofossil record of desertscrub vegetation from the American southwest.

The Point of Rocks-1 site, at an elevation of 900 m, is about 30 m from the floor of the large wash issuing into the Amargosa Desert from Point of Rocks Pass (fig. 6). A radiocarbon date of 11,680 B.P. on sample PR-1(3) (table 6) is associated with a macrofossil assemblage containing abundant cactus spines (*Opuntia* sp.) and the common twigs and flowers of scalebroom (*Lepidospartum latisquamum*) and matchweed. Like the Owl Canyon-2 and Point of Rocks-3 assemblages, sample PR-1(3) contains no arboreal species and is one of the first reported records of glacial-age desertscrub. Today, scalebroom is restricted to washes at elevations above 1,525 m (Beatley, 1976, p. 143). Its presence in this assemblage may indicate that some plant species in sample PR-1(3) were collected in the wash about 20 m away. Alternatively, conditions might have been such that this riparian species occurred on rocky slopes that are now too xeric to support it. Such a phenomenon has been noted in the midden record from the Sonoran Desert where some perennials, presently restricted to washes, occurred on hillsides during the late Wisconsin (Van Devender, 1973, p. 59.). The younger PR-1(1) sample, dated at 9,840 B.P. (table 6), is dominated by desert bitterbush (*Purshia glandulosa*), another extralocal species. Like the Owl Canyon-2 and 3 assemblages, those from Point of Rocks-1 document mesophytic desertscrub vegetation, dominated by species no longer near the site; with the exception of Owl Canyon-3, they contain no tree species.

Point of Rocks-2 site, at an elevation of 930 m, overlooks the alluvial fan that slopes westward to the Amargosa Desert, not far southwest of the Point of Rocks-1 site (fig. 6). At 9,260 and 9,560 B.P. the two desertscrub assemblages from Point of Rocks-2 are the youngest from the Amargosa Desert (table 6). Not coincidentally they contain more of the plant species that presently occur at the site, such as creosote bush and chaff-bush, than do the older midden samples from Point of Rocks-1 or Owl Canyon.

The highest elevation midden site on the periphery of the Amargosa Desert is in the western Last Chance Range at an elevation of 960 m (figs. 2,8). The LCR-1(3) assemblage is dated at 11,760 B.P. (table 6), less than 100 radiocarbon years older than the PR-1(3) assemblage. Nevertheless, in contrast to sample PR-1(3), LCR 1(3) contains abundant juniper, indicating that between 11,600 and 11,800 B.P., the lower limit of woodland in this area was not far above an elevation of 900 m. The LCR-1(2) assemblage at 9,280 B.P., is of comparable age to the PR-2 samples (table 6). Like the Point of Rocks-2 assemblages, LCR-1(2) contains many of the plants that

grow at the site today, although three of the four most abundant taxa are extralocal. Juniper was still present at this site at about 9,300 B.P., while it apparently was absent from the Point of Rocks and Owl Canyon localities well before this time.

#### SPECTER RANGE

Packrat middens from the northern Specter Range yield a different chronology of vegetation change. Macrofossil assemblages from the Specter Range-2 site, on the north side of a ridge at an elevation of 1,190 m (fig. 6), span more than 13,000 years, from about 32,000 to 18,700 B.P. (table 6). Mojave Desert vegetation at the site today contrasts with midden samples that indicate a middle Wisconsin juniper or juniper-shadscale woodland, and a pinyon pine (*Pinus monophylla*)-juniper woodland during the Wisconsin maximum.

The Specter Range-3 site, downslope and north of Specter Range-2 site, is less than 50 m from the head of an alluvial fan that extends into Rock Valley (fig. 8). The ages of sample Spc-3A(1) at 20,200 B.P. and sample Spc-3B at 28,500 B.P. are approximately contemporaneous with some of the Specter Range-2 samples (table 6). Like the Spc-2 record, these Spc-3 assemblages document a juniper woodland lacking pinyon pine, but contain greater proportions of shrubs, such as winterfat (*Ceratoides lanata*), sagebrush, and shadscale.

Preliminary onsite inspection of the Specter Range-1 midden, from the cliff bordering a large wash on the western edge of Mercury Valley (fig. 8), indicated it was younger than 3,000 B.P. However it was collected and analyzed because a marked dichotomy was noted between plant fragments visible in the midden and the surrounding vegetation. The top layer has a radiocarbon date of  $300 \pm 40$  B.P., whereas the bottom unit is subrecent ( $100^{+200}_{-100}$ ) (table 6). The older sample is dominated by fourwing saltbush (*Atriplex canescens*), whereas the younger sample contains abundant creosote bush.

#### ELEANA RANGE

The Eleana Range is a southerly extension of the Belted Range and Pahute Mesa (fig. 2). Two adjacent sites on south-facing slopes, Eleana Range-2 and -3 (fig. 4), contain large indurated middens. Today, these sites are at the boundary between Great Basin desertscrub, occupying the talus slopes and valleys, and pinyon pine-juniper woodland, occurring on the mesa tops and north-facing slopes. The Eleana Range-2 midden records past vegetation from Wisconsin maximum to latest Wisconsin time. Samples from Units II through IV, from 13,200 to 17,100 B.P. (fig. 10), provide evidence for a limber-pine (*Pinus flexilis*) woodland with Great Basin Desert and

woodland shrubs as important understory species. The youngest samples are from Unit I. Dated at 11,700 and 10,600 B.P. (table 6), they indicate a shift to a woodland dominated by juniper, pinyon pine, and pricklypear (*Opuntia erinacea*) species present in the modern woodland nearby.

As mentioned previously, radiocarbon analyses indicate that many assemblages from the complex Eleana Range-3 midden may be contaminated. Three samples that have statistically similar paired radiocarbon dates, and thus may contain valid species associations are: (1) Sample ER-3(8)<sub>3</sub> at 37,800 B.P.; (2) sample ER-3(3) at 38,700 B.P.; and (3) sample ER-3(7)<sub>2</sub> at 45,100 B.P. (ages expressed are weighted averages of two <sup>14</sup>C dates on each sample (Long and Rippeteau, 1974) (table 6). These assemblages reflect an open juniper woodland that differed from both late Wisconsin plant communities recorded by the Eleana Range-2 midden and the present vegetation. Extralocals, such as curl-leaf mountain mahogany (*Cercocarpus ledifolius*), were present, and species important in the current woodland nearby were absent, such as Gambel oak (*Quercus gambelli*) and pinyon pine.

#### EARLY RECORDS FROM THE NEVADA TEST SITE

Wells and Jorgensen (1964) were the first to report on the significance of ancient packrat middens. Their initial studies were conducted in the vicinity of the Nevada Test Site (fig. 2) where some indurated packrat middens were found to contain abundant juniper. The presence of this tree fossil at sites supporting only desert vegetation today led Wells' colleagues to suspect that the middens were of considerable antiquity (Wells, 1976, p. 224). Of this early series, the lowest elevation sites are from the Ranger Mountains and lie between elevations of 1,100 and 1,130 m (fig. 2). The Ranger Mountains-1 midden, dated at 16,800±300 B.P., contains a depauperate macrofossil assemblage, while samples from the Ranger Mountains-2 midden, dated variously from 10,100±160 to 28,900±1,200 B.P., contain abundant shadscale and common pricklypear (Wells and Berger, 1967, table 1). Mercury Ridge-3 (at 1,250 m) is the only other midden of Wisconsin age, dated at 12,700±200 B.P. The remaining middens from Mercury Ridge, as well as those from Aysees Peak and the Spotted Range, are all of early Holocene age. All contain juniper, and the Spotted Range-2 midden also contains common pinyon pine (*Pinus monophylla*), although there is a discrepancy in the radiocarbon dates for this midden (reported as >40,000 and 9,550±90 B.P.) (Wells and Jorgensen, 1964, table 1; Wells and Berger, 1967, table 1). These middens document the persistence of juniper at high desert sites for more than 3,000 years after its extirpation from lower altitude sites in the Amargosa Desert (Spaulding, 1983).

#### SHEEP RANGE AND EUREKA VALLEY

Only four mountain ranges in the Mojave Desert have considerable relief above 2,200 m, the approximate lower limit of montane vegetation in this region. From west to east, these ranges are the Inyo Mountains and Panamint Range of California and the Spring and Sheep Ranges of Nevada (fig. 1). Late Quaternary vegetation of the Sheep Range, 60 km east-southeast of the Nevada Test Site, has been the subject of a recent packrat-midden study (Spaulding, 1981). This record consists of 52 macrofossil assemblages from 30 sites that span 900 m of topographic relief. Sheep Range midden sites extend the fossil record from limestone and dolomite substrates to 2,400 m. Such rocks generally are lacking above an elevation of 1,600 m in the Nevada Test Site. Current vegetation of the Sheep Range is like that of the Nevada Test Site, given similar topography and parent rocks: the packrat-midden record is also similar. Below approximately 1,800-m elevation, Wisconsin age packrat middens from the southeastern Sheep Range (fig. 12) and the western Sheep Range (fig. 13) yield records of juniper-shrub vegetation analogous to records from sites such as Specter Range-2. Late Wisconsin middens from above 1,800-m elevation in the Sheep Range yield assemblages dominated by subalpine conifers (*Pinus flexilis* and *Pinus longaeva*) (Spaulding, 1981, fig. 27).

Midden data from the Sheep Range are synthesized in the regional fossil record of the northern Mojave Desert (fig. 14) with middens from the Nevada Test Site and vicinity. Two isolated records from the Blue Diamond area in the southern Spring Range (Spaulding, 1981, p. 153-157) and middens from the Eureka Valley in California, 140 km west-northwest of the Nevada Test Site (fig. 1) (Spaulding, 1980), also are included in figure 14. Packrat middens from the Eureka Valley are the only comprehensive Holocene time series from the northern Mojave Desert (see Supplemental Data section, table 25) and supplement the midden record from the periphery of the Amargosa Desert. Middens from the Amargosa Desert document the presence of late Wisconsin and early Holocene desert vegetation that differed from current desert-scrub. Eureka Valley middens show transformation of this anomalous desert-scrub to an essentially modern-vegetation type.

#### TULE SPRINGS

Pollen-stratigraphic and geologic investigations at Tule Springs, in the Las Vegas Valley about 80 km southeast of the Nevada Test Site (fig. 1), provided some of the first detailed information on the late Quaternary environments of the Mojave Desert (Martin and Mehringer, 1965; Mehringer, 1967; Haynes, 1967). Although some conclusions reached during this earlier work require revision

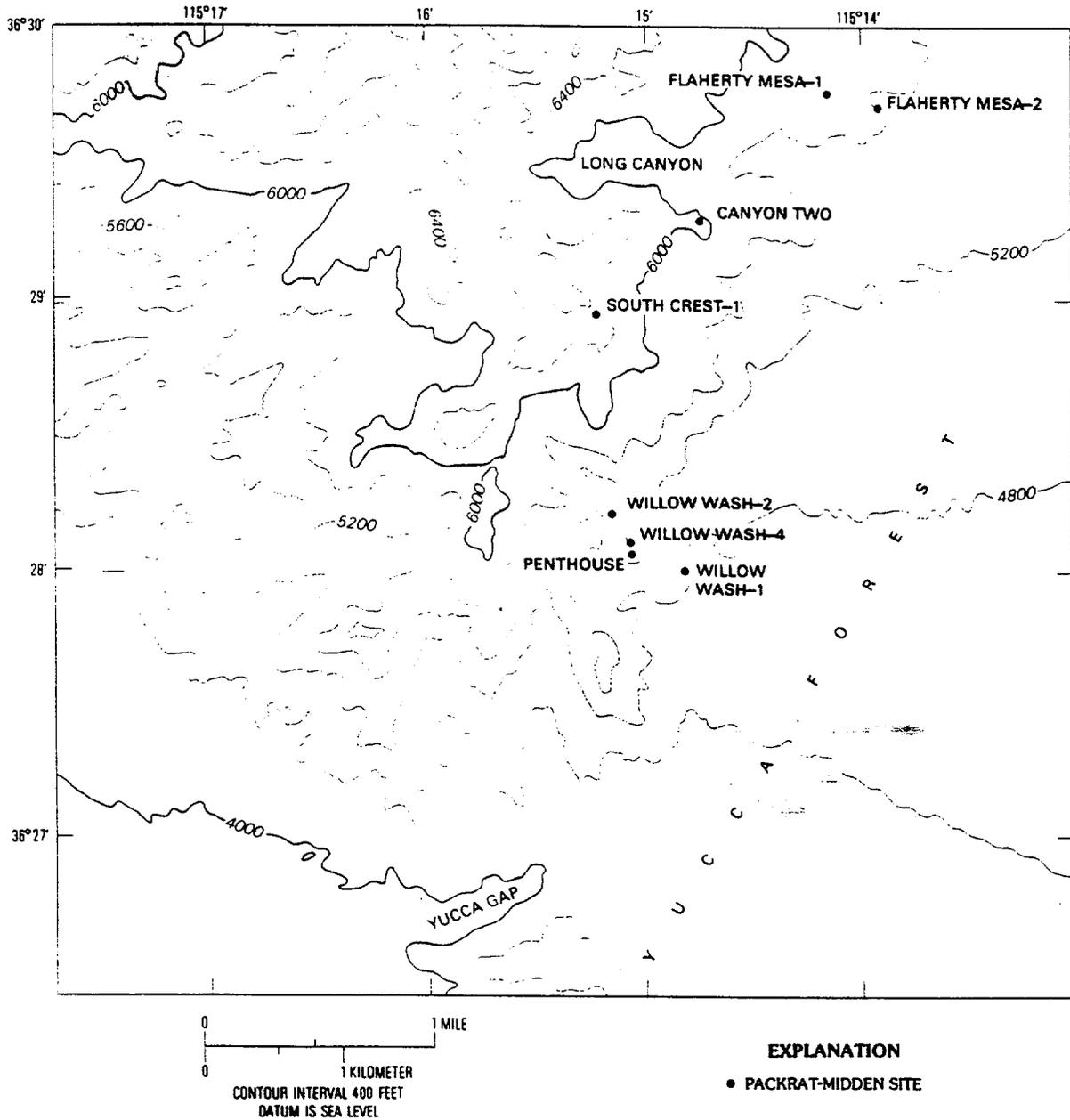


FIGURE 12. —Location of packrat-midden sites in the southeastern Sheep Range.

(Spaulding and others, 1983), palynological evidence for the expansion of woodland and Great Basin Desert plants during the Wisconsin corroborates evidence provided by packrat middens from nearby mountains. Important paleoecological inferences from Tule Springs came from pollen spectra of spring mound sediments of latest Wisconsin age. Relatively high frequencies of *Juniperus* and *Artemisia* pollen, coupled with juniper wood in the sediments, indicates an open juniper woodland with Great Basin Desert

species on the floor of the Las Vegas Valley (Mehringer, 1967, p. 184-185).

GRAND CANYON

Wisconsin-age environments of the Grand Canyon have been the subject of several investigations. Packrat middens from the lower Grand Canyon of Arizona, 215 km east-southeast of the Nevada Test Site (fig. 1), provide

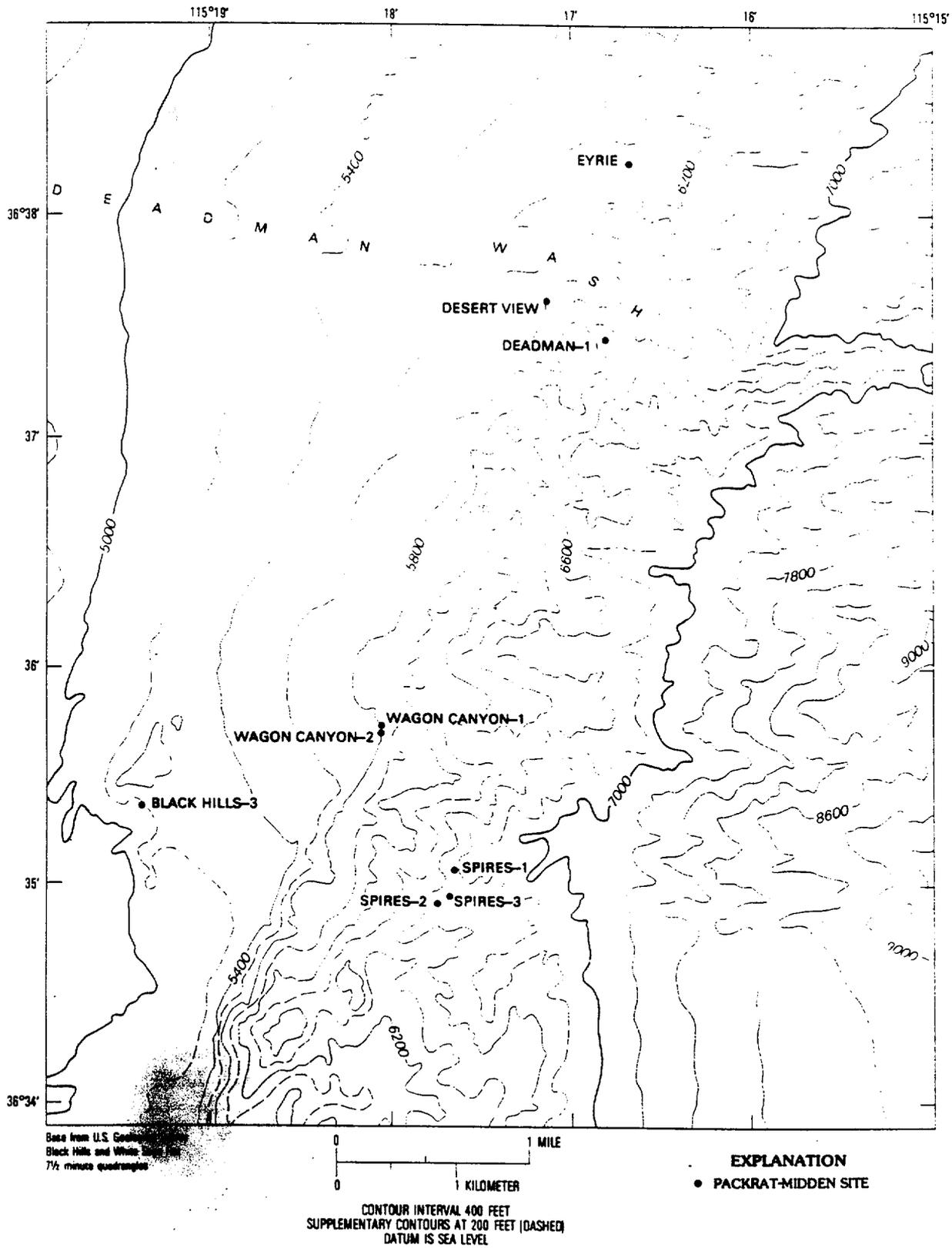


FIGURE 13. — Location of packrat-midden sites in the western Sheep Range.

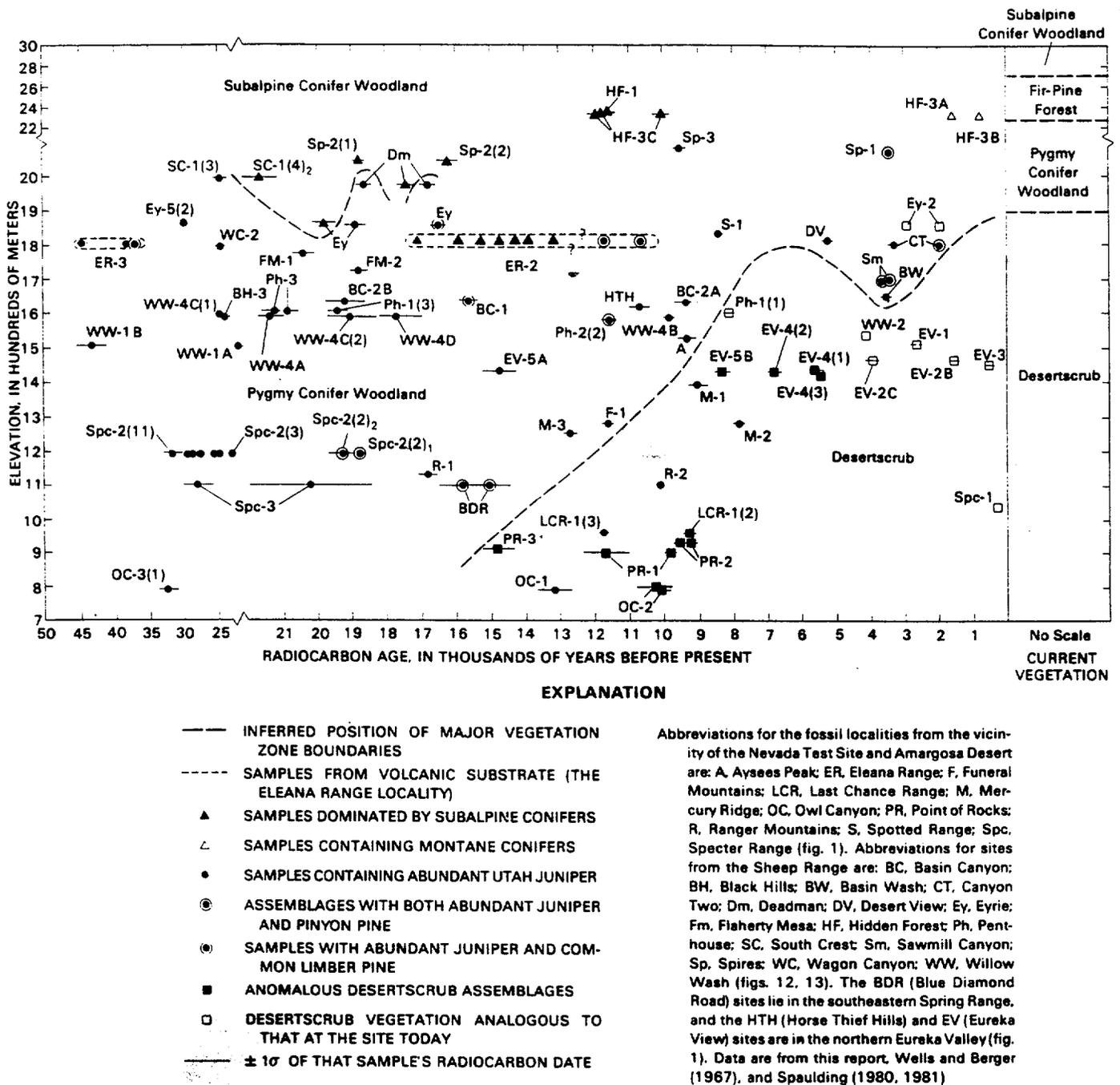


FIGURE 14. — Age and elevational distribution of late Quaternary packrat-midden samples from the northern Mojave Desert. Dashed lines indicate the approximate elevation of major vegetation zone boundaries on xeric slopes. Note changes in scale. The column to the right presents the current vegetation zonation.

an elaborate record from limestone slopes between elevations of 440 and 675 m (Phillips, 1977). Although current vegetation at most sites is desertscrub, late Wisconsin macrofossil assemblages document a juniper woodland with a diverse complement of desert species (such as *Atriplex confertifolia*, *Agave utahensis*, *Ephedra* sp., *Echinocactus polycephalus*) and some woodland associ-

ates (such as *Symphoricarpos* sp., *Opuntia whipplei*) (Phillips, 1977; Mead and Phillips, 1981). Many species common in the late Wisconsin woodland of the lower Grand Canyon, such as blackbrush (*Coleogyne ramosissima*), single-leaf ash (*Fraxinus anomala*), and brittlebrush (*Encelia farinosa*), are rare or missing in similar-age middens from the Nevada Test Site and Sheep Range, partly because of the

higher elevations of these Nevada sites. It also is probable that the precipitation regime of the Grand Canyon region was different from areas to the west and north. Assemblages in late Wisconsin packrat middens from farther east in the central Grand Canyon (Cole, 1981) are even more different from the Nevada fossil record, although these records are from the same altitudinal range.

The timing of latest Wisconsin vegetation change in the Lower Grand Canyon was distinctly different from that recorded by packrat middens from the Nevada Test Site and vicinity. Grand Canyon sites as low as 560-m elevation supported juniper woodland well into the Holocene (until about 8,500 B.P.) (Phillips, 1977, p. 85; Van Devender, 1977b; Cole 1982). In contrast, middens from the Amargosa Desert as high as 930-m elevation show that woodland gave way to desert vegetation by at least 14,800 B.P. at some localities (fig. 14) (Spaulding, 1983).

### LATE QUATERNARY VEGETATION AND CLIMATE

The Wisconsin macrofossil record from the northern Mojave Desert spans 1,600 m of topographic relief, from Owl Canyon in the Amargosa Desert (800 m) to the Hidden Forest (2,400 m) in the Sheep Range (Spaulding, 1981, p. 144). The record provides a data base sufficient for estimates of paleoclimate that can be compared with estimates from other regions. Major environmental changes, such as that which occurred at the end of the Wisconsin, are evident in the composite packrat-midden record (fig. 14), but lower magnitude fluctuations can be better studied in time series from single midden sites. Plant community change usually takes place in the context of a single vegetation type; variations occurred in the composition of woodland during the Wisconsin, and changes occurred in desertscrub vegetation during the Holocene. Time series macrofossil assemblages at different sites, coupled with the use of relative frequencies of macrofossils, help discern these more subtle changes.

The Climate: Long-Range Investigation Mapping and Prediction (CLIMAP) project members' (1976, fig. 1) reconstruction of full glacial (18,000 B.P.) surface conditions of North America shows the Southwest as a region of sparse vegetation with a high surface albedo. However, woodland was widespread in this region, with a resultant albedo that was lower than today's. The cause of this discrepancy is the assumption that lowered temperatures during the late Wisconsin led to reduced competency of the atmosphere and, therefore, to less precipitation and sparse vegetation. However, this was not the case. Lowered temperatures and increased winter precipitation during the full glacial led to decreased evapotranspiration, greater

effective moisture, and increased vegetation cover in the arid West. The initial paleobotanical evidence for this difference (Martin and Mehringer, 1965; Mehringer, 1967; Wells and Berger, 1967) was not well depicted by CLIMAP (1976).

### MIDDLE WISCONSIN ENVIRONMENTS

The middle Wisconsin has been correlated with oxygen-isotope stage 3 in the deep-sea core record (Dreimanis and Raukas, 1975, p. 109-110 and 116), with bracketing dates of about 62,000 and 23,000 B.P. (Prell and Hayes, 1976, fig. 3; Ruddiman and McIntyre, 1981, fig. 2). Variations in the oxygen 16/oxygen 18 ( $^{16}\text{O}/^{18}\text{O}$ ) ratios in the tests of benthic foraminifera in deep-sea cores provide an index of global ice volume (Shackleton and Opdyke, 1973) and indicate that interstadial conditions prevailed during this period. This was a time of generally lower continental ice sheet volume and warmer global temperatures, between the early and late Wisconsin stades [isotope stage 4 for the early Wisconsin and stage 2 for the late Wisconsin (Dreimanis and Raukas, 1975)].

Packrat-midden samples cannot be placed in a well-defined stratigraphic framework; each must be associated with a radiocarbon age. Because the practical upper limit of most radiocarbon-dating laboratories is about 30,000 B.P., only the last 7,000 years of the middle Wisconsin lie within the dating range of most studies. The relatively large number of finite dates from Nevada Test Site that range from 30,000 to 45,000 B.P. are the result of radiocarbon assays performed at the high-precision facility of the U.S. Geological Survey at Menlo Park, California (Robinson, 1979).

### 45,000 TO 35,000 YEARS BEFORE PRESENT

Four finite-age macrofossil assemblages from the northern Mojave Desert are older than 35,000 B.P. (fig. 14). The three from the Eleana Range-3 midden provide the oldest time series from a single site in the Southwest. The ER-3(7)<sub>2</sub> assemblage is associated with two radiocarbon dates with a weighted average of 45,000±900 B.P. (Long and RippetEAU, 1974) (table 6). It indicates vegetation broadly similar to today's: An open woodland of Utah juniper and mountain mahogany (*Cercocarpus ledifolius*), with well-developed stands of sagebrush (figs. 15, 16). Limber pine, the dominant tree during the succeeding full glacial, is absent from the ER-3(7)<sub>2</sub> sample, as are many of the plants present today (such as *Pinus monophylla*, *Quercus gambelii*, *Rhus trilobata*, and *Atriplex canescens*).

Based on the ER-3(7)<sub>2</sub> macrofossil assemblage, precipitation at about 45,000 B.P. is inferred to have been no higher than the present values of roughly 185 to 205 mm/yr<sup>-1</sup> (table 5). Affinity of the fossil flora to present northern steppe and dry woodland suggests that a smaller

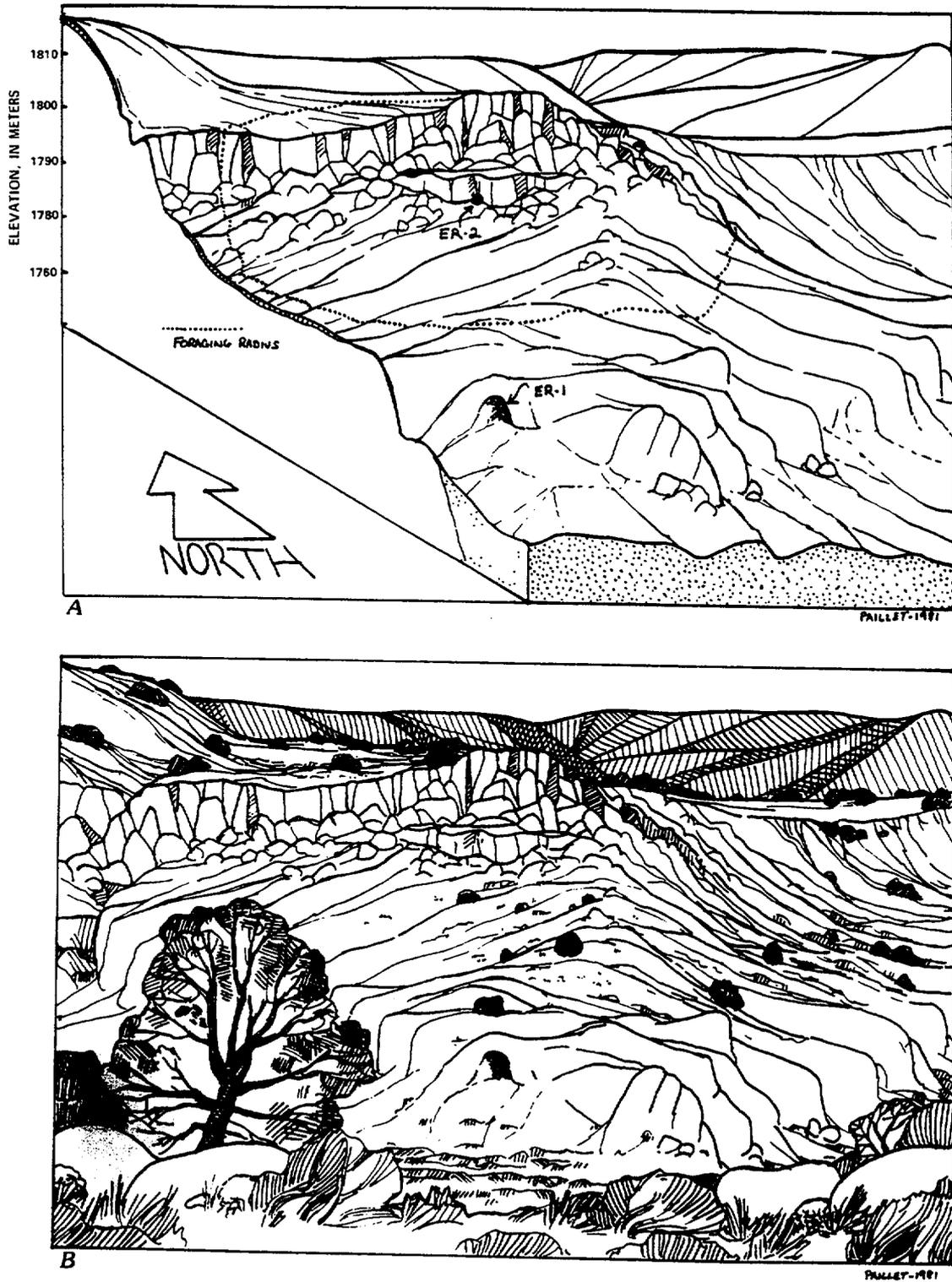


FIGURE 15. — Eleana Range fossil locality: A. Physiography of the Eleana Range-1 and 2 sites; B. Modern vegetation at the Eleana Range-1 and 2 sites. Sketches by Frederick Paillet, U.S. Geological Survey, 1981. (See fig. 4 for location of sites.)



FIGURE 16. — Reconstructions of the Wisconsin vegetation of the Eleana Range: A. Full-glacial (Wisconsin maximum) limber-pine woodland; B. Juniper-steppe shrub vegetation during the middle Wisconsin (about 45,000 years ago). Sketches by Frederick Paulst, U.S. Geological Survey, 1981.

proportion of precipitation fell during the summer (less than 10 percent as opposed to the present value of about 25 percent). Absence of thermophilous species, such as saltbushes (*Atriplex* spp.), hopsage (*Grayia spinosa*), and appreciable quantities of pricklypear (*Opuntia* spp.), from the ER-3(7)<sub>2</sub> sample implies an average annual temperature 1° to 3°C lower than at present (table 5).

Only one other macrofossil assemblage from this region is broadly correlative with the ER-3(7)<sub>2</sub> sample: Willow Wash-1B from the southeastern Sheep Range (figs. 12, 14) (Spaulding, 1981, p. 86). Dated at 43,700±2,300 B.P. (USGS-548), this sample provides evidence for juniper woodland at a site that presently supports desert scrub vegetation, well below the lower limit of woodland (an elevation of 1,585 m). It is intriguing to note that, while the ER-3(7)<sub>2</sub> macrofossil assemblage bears a general resemblance to current dry woodland and steppe vegetation near the site (figs. 15,16), the Willow Wash-1B juniper assemblage provides a greater contrast with present vegetation there. However, indices of similarity between these two samples and current vegetation at their respective sites are comparable, with a value of 40 for the ER-3(7)<sub>2</sub> sample and 36 for the Willow Wash-1B sample (Spaulding, 1981, table 39). This indicates that the apparent stronger contrast between the Willow Wash-1B fossils and current flora is primarily because a single species, Utah juniper, no longer occurs there. Species common in more mesic phases of today's woodland are missing from the Willow Wash-1B sample, as they are from the ER-3(7)<sub>2</sub> sample. The presence of several desert shrubs and succulents (such as *Opuntia whipplei* and *Hecastocleis shockleyi*) in the middle Wisconsin woodland at Willow Wash suggests that winter minimum temperatures were within 2° to 3°C of today's values.

Two younger assemblages from the Eleana Range-3 midden, ER-3(3) and ER-3(8)<sub>3</sub>, have radiocarbon dates that overlap at 1σ (table 6). Macrofossils from these two assemblages suggest increased effective moisture and higher temperatures about 6,300 years after the deposition of ER-3(7)<sub>2</sub>. *Artemisia* sec. *Tridentatae* frequencies are lower in both ER-3(3) and ER-3(8)<sub>3</sub>; this decline is accompanied first by an increase in *Juniperus osteosperma* in ER-3(3) (dated at about 38,700 B.P.), and then *Pinus flexilis* and *Cercocarpus ledifolius* in ER-3(8)<sub>3</sub> (dated at about 37,800 B.P.) (table 6; fig. 17). The macrofossils of *Grayia spinosa* are a notable occurrence in ER-3(3). Normally restricted to desert communities, its presence here indicates that maximum mid-Wisconsin temperatures, within 1° to 2°C of present annual values, may have occurred around 38,700 B.P. The associated increase in juniper and decline in sagebrush frequencies (fig. 17) implies an increase in precipitation, perhaps 10 to 20 percent above today's values (table 5). This increase may

have resulted in part from warmer summers and enhanced warm-season rainfall.

Macrofossils from the youngest sample in this interstadial sequence, the ER-3(8)<sub>3</sub> sample, at about 37,800 B.P., indicate highest effective moisture. *Juniperus osteosperma* is in part replaced by *Pinus flexilis* and *Cercocarpus ledifolius* (fig. 17). The importance of these dry woodland and subalpine species, coupled with the continued absence of plants of relatively mild-moist habitats (such as *Pinus monophylla*, *Pinus ponderosa*, *Quercus gambelii*), indicate the increase in effective moisture resulted from a temperature decline. Similar plant associations presently occur on south-facing slopes at about 2,800 m in the Toquima Range, 180 km to the north-northwest. The difference in elevation between analogous Toquima Range sites and Eleana Range-3 (about 1,000 m) indicates a decline of 5°C in mean annual temperature relative to present values, assuming an annual temperature lapse rate of -0.5°C/100m (Major, 1977, p. 65 and 68). Average annual precipitation 10 to 20 percent greater than present values (table 5) also is consistent with the fossil record from the ER-3(8)<sub>3</sub> sample.

#### 35,000 TO 23,000 YEARS BEFORE PRESENT

Thirteen macrofossil assemblages from the northern Mojave Desert date to the latest part of the middle Wisconsin. Specter Range-2 site at an elevation of 1,190 m provides the only detailed chronosequence from this period. The oldest assemblages are rather poorly dated at about 32,000 B.P. (Sp-2(11)<sub>1</sub> and 2(11)<sub>2</sub>) (table 6). In contrast to current Mojave desert scrub vegetation at the site, these samples contain abundant Utah juniper, as well as abundant-to-common shadscale (*Atriplex confertifolia*) and rock spirea (*Petrophytum caespitosum*). Five younger samples, ranging in age from 29,100 to 23,300 B.P., also contain abundant Utah juniper (fig. 18).

Rock spirea is a mesophytic petrophyte (rock-loving plant) now extinct in the Specter Range. *Scopulophila rixfordii*, on the other hand, is a thermophilous petrophyte still present nearby. It is not surprising that variations in relative frequency of these taxa in the Specter Range-2 assemblages are inversely related (fig. 18). These fluctuations may represent short term changes in effective moisture, with high frequencies of *Scopulophila* indicating effectively drier conditions. Increases in the percentage of *Petrophytum*, characteristic of moister habitats, may indicate mesic episodes. Near-disappearance of both these species during the ensuing late Wisconsin (fig. 18) probably was caused by competition with more robust mesophytes.

While fluctuations of *Scopulophila* and rock spirea appear to reflect short-term changes, the longer duration decline in shadscale, accompanied first by an increase in

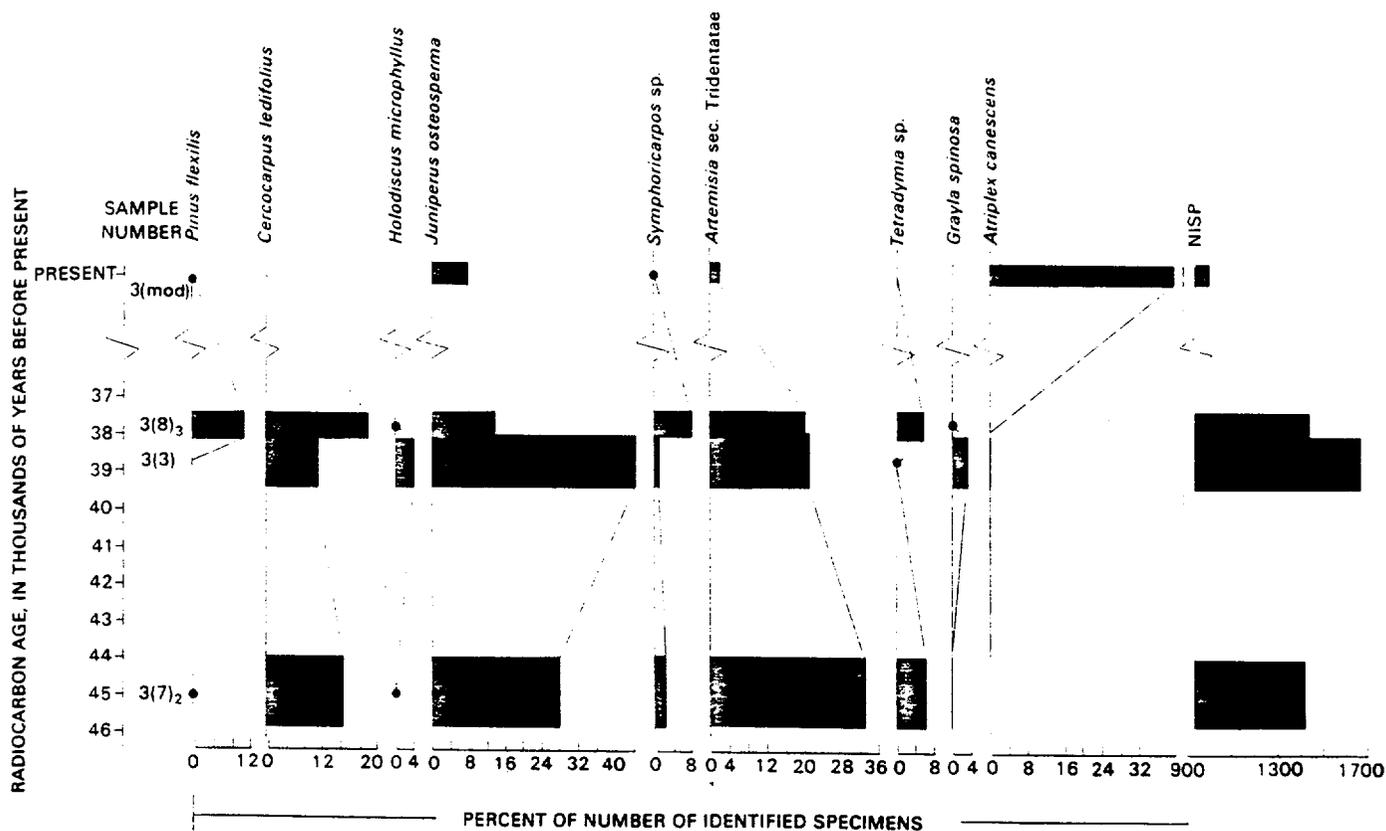


FIGURE 17. — Relative frequencies of selected plant taxa in macrofossil assemblages from the Eleana Range-3 midden. (Vertical width of the bars is proportional to  $\pm 1\sigma$  of the sample's radiocarbon date, except for the ER-3 (modern) sample assemblage: solid circle represents  $\leq 1$  percent of number of identified specimens.)

sagebrush and horsebrush (*Tetradymia* sp.) and then little-leaf mountain mahogany (*Cercocarpus intricatus*), implies a progressive increase in effective moisture from 32,000 to 25,000 B.P. (fig. 18). The Spc-2(3) fossil assemblage, dated at 23,300 B.P., indicates a reversal in this trend. It contains higher frequencies of shadscale and fewer mesophytes than older samples.

Isolated middens from elevations ranging from 790 to 1,990 m provide additional data on environments of the Nevada Test Site during the last millennia of the middle Wisconsin. The oldest are broadly correlative with the Spc-2(11) samples. At the lower end of the elevational gradient, in the Amargosa Desert, the OC-3(1) assemblage is radiocarbon-dated at about 33,000 B.P. (fig. 14; table 6). Abundant rubber rabbitbrush (*Chrysothamnus nauseosus*) and juniper in this midden sample indicate steppe vegetation with scattered trees. At the upper end of the altitudinal gradient, the Eyrie-5(2) assemblage, from a south-facing slope at an elevation of 1,860 m in the Sheep Range, is dated at 30,740 B.P. (figs. 13, 14). It records a xerophytic juniper woodland with pricklypear (*Opuntia polyacantha*), sagebrush, and little-leaf mountain mahogany (Spaulding, 1981, table 23).

Younger macrofossil assemblages, dating from 28,300 to 23,300 B.P., also yield records of juniper woodland with a diverse complement of xerophytic woodland and Great Basin Desert shrubs (Spaulding, 1981). *Juniperus osteosperma* was the only frequent arboreal species in this widespread woodland; pinyon pine is virtually unknown from the middle Wisconsin middens in the northern Mojave Desert. Occasional limber pine and white fir (*Abies concolor*) in the highest middle Wisconsin assemblage, SC-1(3) at an elevation of 1,990 m in the Sheep Range (fig. 14), indicate that this site was near the lower limit of montane conifer vegetation (Spaulding, 1981, p. 111).

Middle Wisconsin juniper-desert shrub assemblages from this region are broadly analogous to present vegetation at dry lower reaches of woodland. Contrasting estimated modern temperature and precipitation at such a site (the Eleana Range locality) with that for the Specter Range-2 site (table 5) indicates that average annual precipitation at about 30,000 B.P. was 10 to 25 percent more than at present and that mean annual temperatures were at least  $3^{\circ}\text{C}$  lower than at present. The lower woodland boundary in more arid parts of the Sheep Range lies at about an elevation of 1,980 m. Calculations

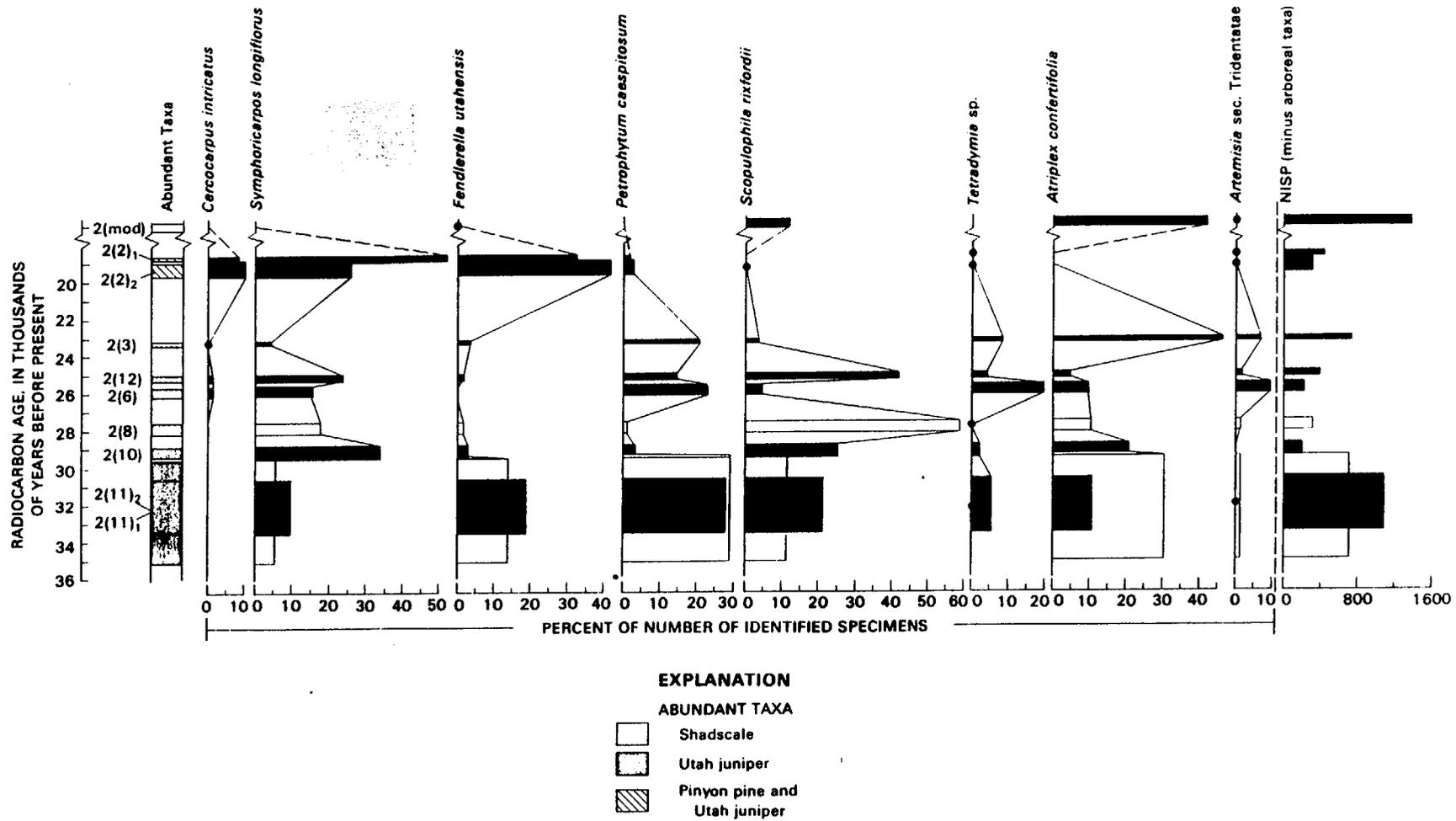


FIGURE 18. — Relative frequencies of selected plant taxa in macrofossil assemblages from the Specter Range-2 midden. Vertical width of the bars is proportional to  $\pm 1\sigma$  of the sample's radiocarbon date (table 6), except for the Spc-2(8) and Spc-2(modern) samples. Open bars for samples Spc-2(8) and Spc-2(11)<sub>1</sub> denote uncertain chronologic positions; solid circle represents  $\leq 1$  percent of number of identified specimens. See table 6 for radiocarbon dates on those samples.)

based on an elevational depression of juniper of 790 m (to the Specter Range-2 site at 1,190 m) and a lapse rate of  $0.5^{\circ}\text{C}/100\text{ m}$  yield a  $\Delta T_a$  value of  $-4.0^{\circ}\text{C}$ . However, calculations based on an elevational depression of 1,190 m to the Owl Canyon locality (790 m) yield a  $\Delta T_a$  of  $-6.0^{\circ}\text{C}$ .

The altitudinal zonation of vegetation in the northern Mojave Desert during the Wisconsin glacial age was unlike zonation that occurs under the present climatic regime. Utah juniper ranged from elevations less than 800 m to at least 2,000 m; xerophytic woodland and steppe shrubs were common associates over much of its 1,200 m altitudinal distribution. Arboreal species that often occur with Utah juniper at present (such as pinyon pine and ponderosa pine at higher elevations) are rarely recorded or completely missing from the fossil record. Trees most commonly associated with juniper in fossil assemblages from the higher altitude Sheep Range sites (Spaulding, 1981) are xerophytic subalpine conifers, bristlecone pine (*Pinus longaeva*) and limber pine (*Pinus flexilis*). Present extent of such plant associations in the Sheep Range is compared in figure 19 with their documented distribution in the Nevada Test Site area during the middle Wisconsin; the comparison illustrates an apparent paradox. An increase in effective moisture sufficient to permit *Juniperus osteosperma* to grow at xeric low-altitude sites like Owl Canyon should have allowed other arboreal species to become successfully established at least at elevations above 1,500 m, assuming that gradients of effective moisture were the same then as now. However, xerophytic juniper woodland occurred on moist as well as dry sites to an elevation of at least 1,750 m (figs. 14, 19); perhaps lapse rates of precipitation during the Wisconsin were different from present rates.

#### LATE WISCONSIN ENVIRONMENTS

The late Wisconsin stage of North America, the last period of major continental ice-sheet expansion, is correlated with oxygen-isotope stage 2 in deep-sea cores, coeval with the late Weichselian and Devensian stades of Eurasia (Bowen, 1978; Flint, 1971). Radiocarbon analyses of subsurface sediments from Searles Lake, California, 160 km southwest of the Nevada Test Site, provide the best independent dates for the duration of this period in the Mojave Desert. The Parting Mud unit of Searles Lake encompasses the entire late Wisconsin; an average of seven radiocarbon dates on disseminated carbon from the bottom 50 cm of the unit is  $23,300 \pm 1,175$  B.P. (Stuiver and Smith, 1979, p. 74). Applying a correction factor of -900 radiocarbon years to this age to compensate for low radiocarbon per carbon ratios in high-bicarbonate waters (Peng and others, 1978, p. 327) yields a date of  $22,600 \pm 1,175$  B.P. for initiation of late Wisconsin conditions at Searles Lake. The corrected average of seven radiocarbon dates

from the top of the Parting Mud (Stuiver and Smith, 1979, p. 73), marking the end of late Wisconsin conditions, is  $9,600 \pm 165$  B.P.

#### VEGETATION

A date of about 22,600 B.P. for the beginning of late Wisconsin environmental conditions in the Mojave Desert is in accord with packrat-midden evidence from the Nevada Test Site. Although a gradual trend toward more mesophytic vegetation at Specter Range-2 began as early as 26,000 B.P. (fig. 18), major biotic turnover from a juniper-shadscale to pinyon-juniper woodland did not occur until after about 23,300 B.P. (sample Spc-2(3)) (table 6). Indeed, the Spc-2(3) assemblage indicates a reversal to conditions drier than those recorded by sample Spc-2(6) dated at about 25,000 B.P., and sample Spc-2(12), dated at about 26,000 B.P. (fig. 18).

The 4,000-year hiatus between sample Spc-2(3) and the late Wisconsin age Spc-2(2) assemblages (figs. 14, 18) provides only a maximum age of 23,300 B.P. for the beginning of the late Wisconsin. No middens from the Nevada Test Site yield additional samples dating to this period except Specter Range-3A. This rather poorly dated assemblage ( $20,200 \pm 1,800$  B.P.) (table 6) yields no evidence for a major vegetation change. Samples from the South Crest midden in the Sheep Range, a xeric site at an elevation of 1,990 m (fig. 12) document a transition from juniper to subalpine-conifer woodland prior to  $21,700 \pm 500$  B.P. (fig. 14) (Spaulding, 1981, p. 111, fig. 27). This change, from a xerophytic juniper woodland to one apparently dominated by bristlecone pine (*Pinus longaeva*) and limber pine (*Pinus flexilis*), marks the initiation of a stadial climatic regime. Hence, packrat middens provide bracketing radiocarbon dates of 23,300 and 21,700 B.P. for the beginning of late Wisconsin climatic conditions in the vicinity of the Nevada Test Site.

The Wisconsin maximum, or full glacial, is dated at about 18,000 B.P. (CLIMAP, 1976), although local glacial maxima varied by several thousand years (Gates, 1976, p. 1138; Bowen, 1978). In the Sheep Range, there were two periods when subalpine vegetation occurred below 2,000 m; either (or both) could represent the full glacial. The first, recorded by packrat middens from the South Crest and Eyrie localities in the Sheep Range, ended by 19,000 B.P. The second, with midden evidence from the Eyrie and Deadman localities in the Sheep Range, occurred between 18,600 and 16,800 B.P. (fig. 14) (Spaulding, 1981, fig. 27). The magnitude of the latter event appears to have been great; at the Eyrie and Deadman sites, there were changes from xerophytic vegetation characterized by Utah juniper and pricklypear cacti (*Opuntia polyacantha* and *Opuntia phaeacantha*) to subalpine vegetation dominated by limber and bristlecone pine (Spaulding, 1981, tables 23 and 24) (fig. 14).

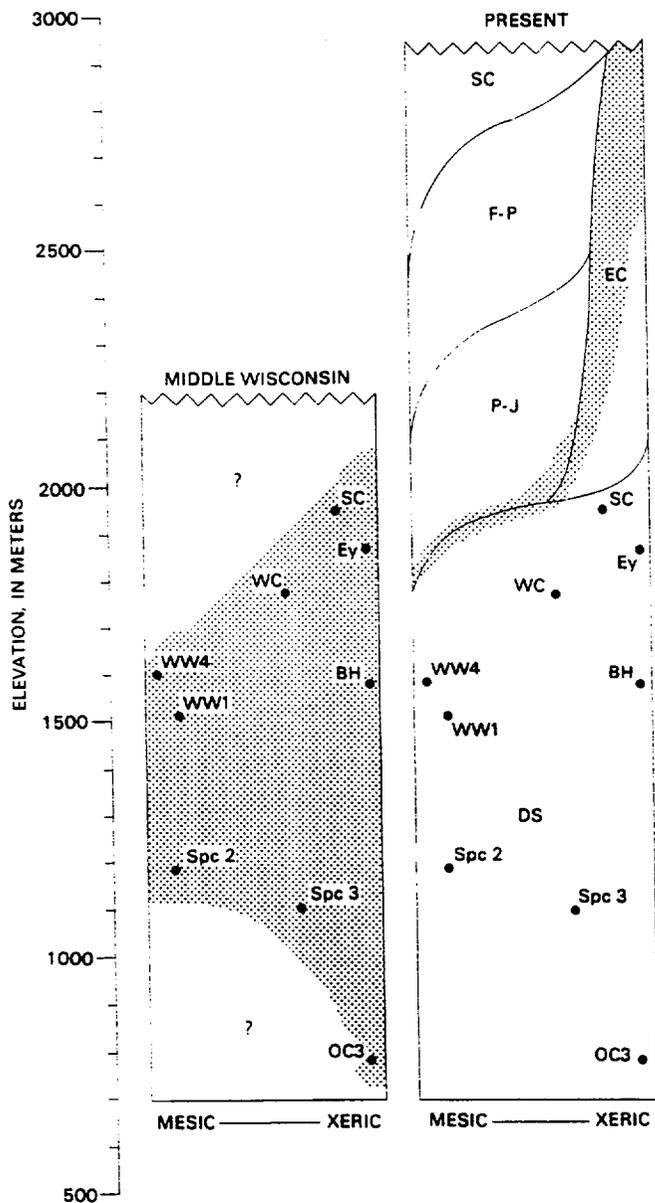


FIGURE 19. — Distribution of middle Wisconsin juniper-shrub macrofossil assemblages compared to the modern extent of similar associations in the Sheep Range. Abbreviations for the fossil sites are: BH, Black Hills; Ey, Eyrie; OC, Owl Canyon; SC, South Crest; Spc, Specter Range; WC, Wagon Canyon; WW, Willow Wash. Abbreviations for the modern plant community types are: SC, subalpine-conifer woodland; F-P, white fir-ponderosa pine (*Abies concolor*-*Pinus ponderosa*) forest; EC, evergreen sclerophyll chaparral; P-J, pinyon-juniper woodland; DS, desertscrub. Stippled pattern shows distribution of similar assemblages during the middle Wisconsin and present day.

Specter Range-2 midden samples recording a mesophytic pinyon-juniper woodland between 19,300 and 18,700 B.P. (fig. 18) do not appear to correspond to either period of lowered subalpine vegetation in the Sheep Range (fig.

14). They may conflict with evidence for extensive, xerophytic juniper woodland at higher elevations in the region. A mesophytic pinyon-juniper association at the Specter Range-2 site (an elevation of 1,190 m) contrasts with late Wisconsin-age plant fossil assemblages commonly lacking pinyon pine from elevations 1,500 to 1,970 m in the Sheep Range (fig. 14). The cause of this anomaly is not readily apparent.

The Eleana Range-2 packrat midden spans most of the last one-half of the late Wisconsin from 17,100 to 10,600 B.P. Samples older than 13,000 B.P. document a limber-pine woodland that contrasts with both older middle Wisconsin records from the Eleana Range-3 site and present desertscrub and sparse woodland at the locality (figs. 15, 16). Changes in macrofossil frequencies toward the end of the limber-pine phase at Eleana Range-2 appear to reflect late-glacial climatic change. A trend toward effectively drier conditions is indicated by the decline of silvery-lupine (*Lupinus cf. argenteus*) and fern-bush (*Chamaebatiaria millefolium*), two extralocal shrubs, accompanied by increasing relative frequencies of the xerophytic shrub, dwarf-goldenweed (*Haplopappus nanus*) (fig. 20). Decreasing relative percentages of plants typical of current Great Basin steppe (*Artemisia* sec. *Tridentatae*, *Tetradymia* sp., *Chrysothamnus* spp.) accompany these changes. This trend may have started as early as 16,000 B.P. and appears to have been well underway by 13,000 B.P. Variations in percentages of mountain mahogany (*Cercocarpus ledifolius*) may represent reversals, when available moisture was somewhat higher (fig. 20). These data are in general accord with the record from Searles Lake (fig. 1), indicating a change at about 16,200 B.P. (corrected date) from a lake at its maximum expansion to one undergoing dessication, with some reversals (Smith, 1979, p. 111).

The trend of increasingly xerophytic vegetation at Eleana Range-2 culminated in a profound change between 13,200 and 11,700 B.P. Limber pine-shrub woodland gave way to a community apparently dominated by Utah juniper, pinyon pine, and pricklypear (*Opuntia polyacantha*) (fig. 20). This transformation from a plant association with subalpine and steppe affinities to one resembling modern woodland in nearby mesic habitats signals the end of Wisconsin vegetation conditions at this site. Indices of similarity (fig. 21) show that latest Wisconsin ER-2(1) and 2(2) assemblages have many more species in common with current vegetation than do the middle Wisconsin samples from the nearby Eleana Range-3 site. Presumably this reflects a fundamental alteration of the regional climate. Climate during the terminal Wisconsin, although somewhat more mesic than the present, was quite unlike the climate of either the middle Wisconsin interstadial or most of the late Wisconsin stadial.

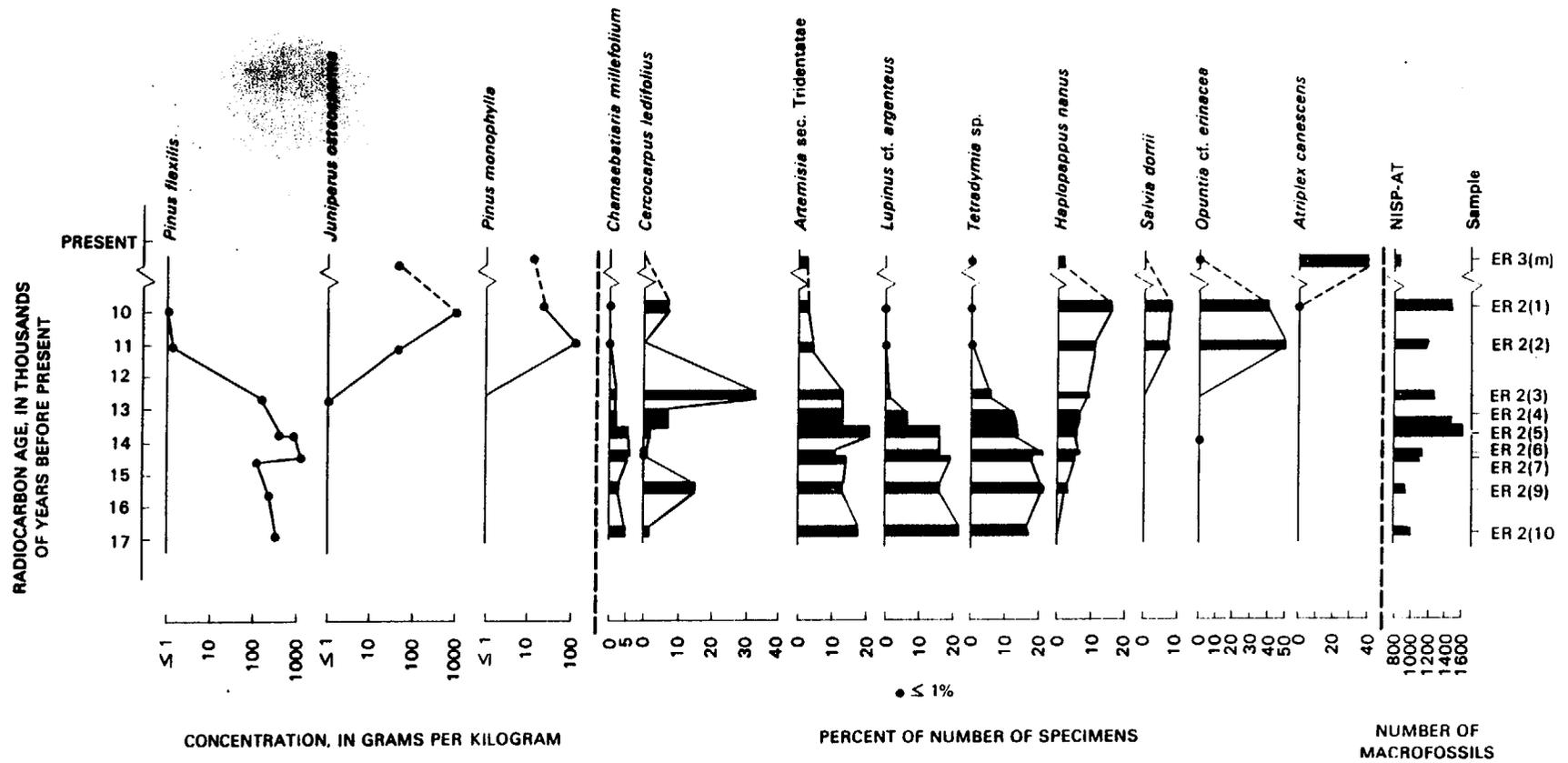


FIGURE 20. — Abundance of selecter plant taxa in macrofossil assemblages from the Eleana Range-2 (ER-2) midden. A modern sample from the nearby Eleana Range-3 (ER-3) site is presented at the top for comparison. Concentration values for the tree species are grams of fossils of a given taxon per kilogram of sorted matrix. Abundance values of the remains of shrub and succulent species are presented as percentages of NISP-AT (Number of identified specimens excluding arboreal taxa). Solid circle represents  $\leq 1$  percent of number of identified specimens.

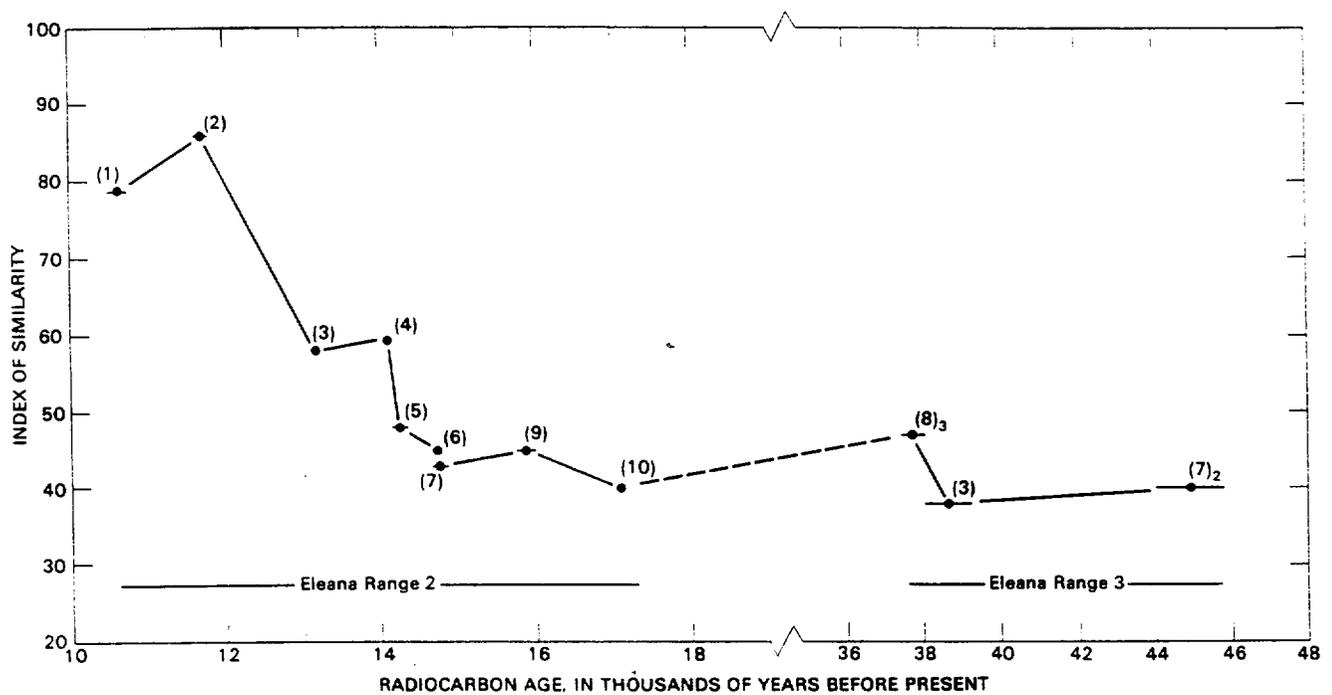


FIGURE 21. — Changes in similarity between Wisconsin and modern flora of the Eleana Range locality (note the break and change in the time scale; Sorensen's index of similarity is to the left). Compare the generally small indices of similarity for the late Pleistocene floras with the inferred continuity of physiognomy and structure of the vegetation (figs. 15, 16). Horizontal bars indicate  $\pm 1\sigma$  of that assemblage's radiocarbon age.

#### CLIMATIC REGIME

The record of global environmental change shows that late Wisconsin climates represent maximum departure from present interglacial conditions (CLIMAP, 1976; Bowen, 1978). A perspective on environments of this period in the vicinity of the Nevada Test Site is gained by contrasting reconstructions presented here with earlier paleoclimatic models proposed for this region.

The most obvious evidence for differing ice-age climates in the Southwest are the empty basins that once contained vast freshwater lakes. In Nevada and Utah, the estimated total area of water during the late Wisconsin exceeds 89,000 km<sup>2</sup> (Mifflin and Wheat, 1979, p. 53-55). Antevs (1948, p. 172-174; 1952, p. 98) correlated maximum expansion of these lakes with the greatest development of continental ice sheets in the Northern Hemisphere, a hypothesis corroborated by more recent studies (Broecker and Orr, 1958; Morrison and Frye, 1965). Their expansion most often has been attributed to greatly increased annual precipitation (50 to 100 percent over current amounts), coupled with a modest decline in average annual temperatures (2.5° to 5.0°C below those of the present) (table 7). This "pluvial" model of late Wisconsin climate in the Southwest invokes equable temperatures (cool summers and mild winters), characterized by con-

siderably more rainfall than at present (Van Devender and Spaulding, 1979; Wells, 1979). However, the implicit climatic assumptions in the term "pluvial" demand rigorous testing.

Reconstruction of late-glacial vegetation based on fossil-pollen analysis have provided support for the pluvial model of southwestern climate. In particular, the hypothesized existence of extensive areas of ponderosa pine parkland and pinyon-juniper woodland was taken as evidence of mild, moist conditions (Martin and Mehringer, 1965; Mehringer, 1965, 1967). However, the macrofossil record of xerophytic vegetation in the Mojave Desert fails to verify these reconstructions (Wells and Berger, 1967, p. 1647; Spaulding, 1981, p. 207-208). More recently, Wells (1979, p. 311) has suggested that packrat-midden data also indicate an equable late Wisconsin climate, characterized by a "\*\*\*\* pluvial increase in precipitation over the Southwest." One aspect of late-glacial biogeography used to support this thesis is the gradient of decreasing lower limits of pinyon pine at fossil sites with declining latitude, from the Mojave to the Sonoran Deserts. In the western Sonoran Desert, *Pinus monophylla* occurred as low as an elevation of 510 m (Van Devender and Spaulding, 1979, table 1); in the northern Mojave Desert, its lowest fossil record is more than twice as high (1,190-m elevation at the

TABLE 7. — Paleoclimatic reconstructions for the full-glacial period of the American Southwest  
 $\Delta T_a$ , changes in °C (degrees Celsius) in annual temperature;  $\Delta T_s$ , changes in °C in summer temperature;  $\Delta T_w$ , changes in °C in winter temperature;  $\Delta P$ , change in annual precipitation in cm (centimeters);  $P$ ,  $\Delta P$ /modern  $P$ ;  $E$ , (evaporation),  $\Delta E$ /modern  $E$

Author	Data base	Location	$\Delta T_a$	$\Delta T_s$	$\Delta T_w$	$\Delta P$	$P$	$\Delta E$
Antevs (1952)	Hydrologic budgets	Lake Lahontan, Nevada	-2.5 to -3.0	---	---	+8 to +16	50 to 100	-31
Antevs (1954)	Relict snowlines	North-central New Mexico	---	-5.6	---	+23	---	---
Bachhuber and McClellan (1977)	Foraminifer distributions	Lake Estancia, New Mexico	---	-9.7	---	---	---	---
Brakenridge (1978)	Relict cirques and cryogenic deposits	Montana to Arizona (lat 45°40'N to 33°20'N)	-7.0	---	---	0	0	---
Broecker and Orr (1958)	Hydrologic budgets	Lake Lahontan, Nevada	-5.0	---	---	+21	80	---
Galloway (1970)	Solifluction deposits	Sacramento Mountains, New Mexico	-10.5	-10.0	---	-4.6	---	---
Leopold (1951)	Hydrologic budgets and snowline changes	Lake Estancia, New Mexico	-6.6	-9.0	-2.8	+18 to +25	50 to 70	-39 to -46
Mifflin and Wheat (1979)	Hydrologic budgets	Nevada, state-wide	-2.8	---	---	+8.4 to +24	68	-10
Reeves (1966)	Hydrologic budgets	Llano Estacado, west Texas	-5.0	-8.0	---	+39	89	-27
Snyder and Langbein (1962)	Hydrologic budgets	Lake Spring, Nevada	-5.0	-7.2	---	+20	67	-30
Van Devender (1973)	Packrat middens	Western Arizona	-3.0 to -3.9	---	---	+12.3 to +22.0	---	---

<sup>1</sup>Minimum estimate.

<sup>2</sup>State-wide average.

<sup>3</sup>Extrapolated by Morrison (1965); Schumm (1965); and Mifflin and Wheat (1979).

<sup>4</sup>Extrapolated by Schumm (1965) and Brakenridge (1978).

Specter Range-2 site)<sup>2</sup>, and it was uncommon below 1,550 m (Spaulding, 1976, p. 160) (fig. 14). Spaulding and others (1983) decline to accept Wells' (1979, p. 324) hypothesis that this vegetation gradient represented "\*\*\*\* pluvially increased summer rain\*\*\*\*"; instead, they propose that it was caused by the near-absence of summer rain north of about lat 36°N. A second argument advanced by Wells (1979, p. 320) to support the model of an "equable glaciopluvial" is that: "In the Mojave Desert province, the upper part of the Pleistocene woodland zone was similar to the more mesic phases of the existing pinyon-juniper woodland\*\*\* (Wells and Berger, 1967)." The only macrofossil record of mesic pinyon-juniper woodland north of lat 35°N, reported by Wells and Berger (1967, table 1) is of apparent early-Holocene age (9,450±90 B.P.) and is largely irrelevant to the discussion of late Wisconsin climates. Based on an analysis of over 30 Wisconsin-age assemblages, Spaulding (1981, p. 184) notes that pinyon and other mesophytic woodland plants are actually rare or missing from glacial-age woodland vegetation in the northern Mojave.

The paleoecological record from the Nevada Test Site and vicinity reveals a late Wisconsin vegetation dominated by plant species adapted to relatively cold, dry environments.

There is no evidence for the presence of frost-sensitive desert plants, such as creosote bush, desert spruce, or white bursage, even at lowest elevation sites. Also, at higher elevations, there are few glacial-age fossils of plants characteristic of moist, temperate environments, such as ponderosa pine, Gambel oak, or Rocky Mountain juniper (*Juniperus scopulorum*). Instead, there was a zone of xerophytic pygmy-conifer woodland dominated by Utah juniper and, on rare occasion, single-needle pinyon pine and juniper together, from the lowest elevation sites up to elevations of between 1,800 and 2,000 m. A zone of subalpine conifer woodland characterized by limber pine on volcanic rocks, and limber pine and bristlecone pine together on calcareous substrate, occurred above an elevation of about 2,000 m (fig. 14) (Spaulding, 1981). Great Basin Desert and steppe shrubs, such as sagebrush, horsebrush (*Tetradymia* sp.), and rabbitbrushes (*Chrysothamnus* spp.) were widespread in both types of woodland. There is no evidence for the distinct zone of mesophytic montane conifers (dominated by *Pinus*, *ponderosa*, *Abies concolor*, and *Juniperus scopulorum*) that currently separates pygmy conifer from subalpine woodland (fig. 14). These macrofossil data indicate a climate quite unlike that stipulated by pluvial models.

Lower limits of woodland plant species were depressed during the Wisconsin, although the amount of elevational displacement varied among different taxa (fig. 22). Minimum-displacement estimates for the two conifers most common

<sup>2</sup>Recent (October 1983) discovery of pinyon pine (*Pinus monophylla*) in a midden from the Stripped Hills, about 10 km west of the Specter Range-2 site, establishes a lower elevational record of 1,090 m for this species in the northern Mojave Desert.

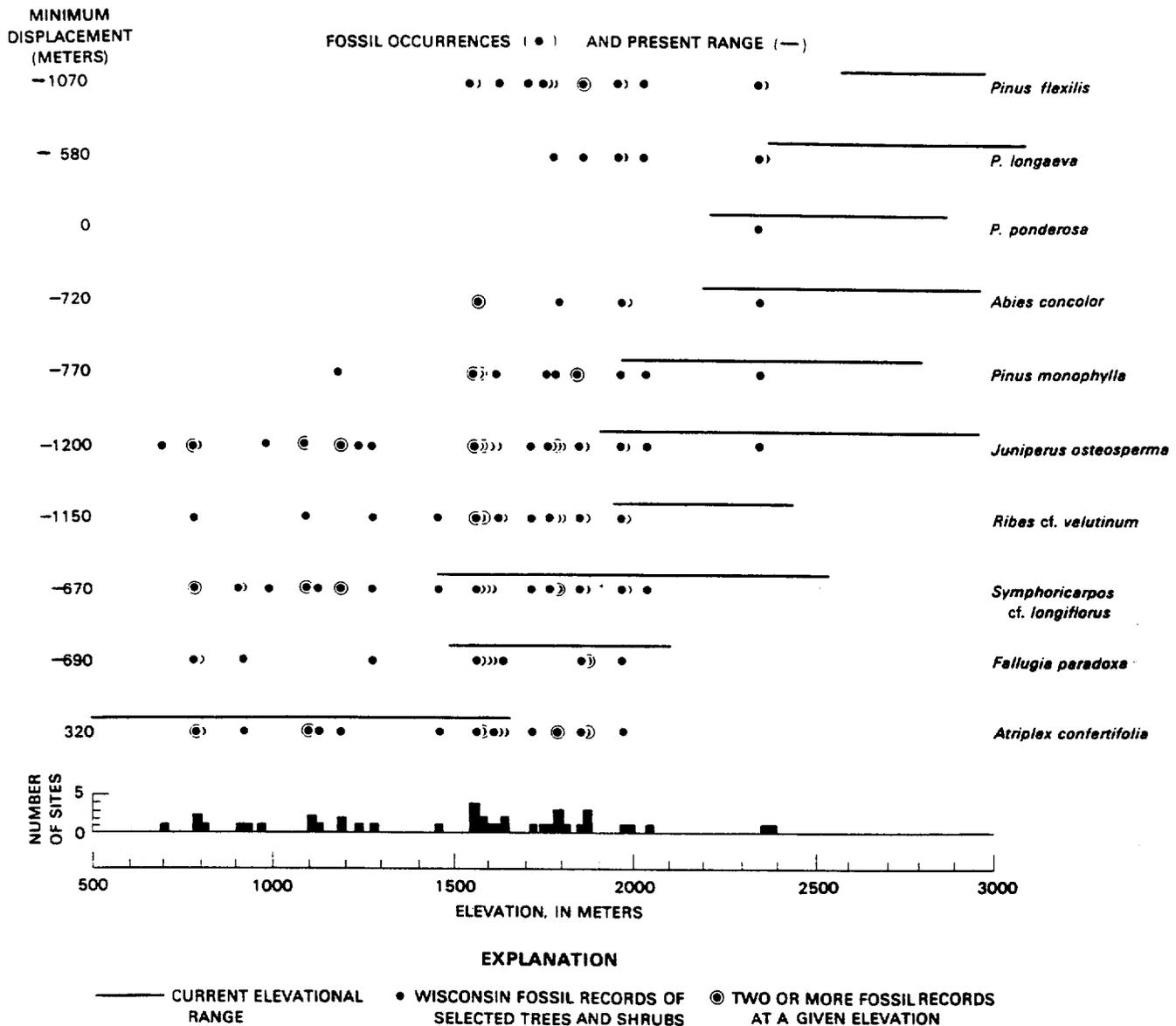


FIGURE 22. — Current elevational range and Wisconsin fossil records of selected trees and shrubs; estimates of minimum displacement are to the left and (except for *Atriplex confertifolia*) are the elevation of a species' lowest fossil record subtracted from the elevation of its present lowest occurrence. All sites are north of lat 36°20' N. and south lat 37° N., west of long 115° W. and east of long 117° W., on calcareous substrate only.

in the late Wisconsin vegetation of southern Nevada, limber pine and Utah juniper, are among the greatest estimates; both occurred more than 1,000 m below their current lower limits. If it is assumed that the lower limit of these two species is determined by evapotranspirational stress caused by high summer temperatures, lapse-rate calculations can be used to derive estimates of full-glacial summer temperature declines ( $\Delta T_s$ ). Studies by Major (1977 p. 65) of present-day temperature regimes in arid and semi-arid mountains of California indicate summer lapse rates of  $-0.6$  to  $-0.75^\circ\text{C}/100$  m. Applying these rates to displacement values for juniper and limber pine yields minimum estimates of  $\Delta T_s$  of about  $-6^\circ$  to  $-9^\circ\text{C}$

(table 8). The range of overlap of values for the two species is from about  $-7^\circ$  to  $-8^\circ\text{C}$ .

Relative decline of full-glacial winter temperatures ( $\Delta T_w$ ) is a critical parameter in these reconstructions. A modest  $\Delta T_w$  of, say,  $-3.0^\circ\text{C}$  would indicate an equable temperature regime with a low annual range of variation and a modest estimate of mean annual temperature decline. However, the marked lack of thermophilous plant species in even lowest elevation middens provides a strong argument against a conservative estimate of  $\Delta T_w$ . An example is creosote bush, which, according to Beatley (1974, table 1), is excluded from sites with mean minimum temperatures lower than  $-1.4^\circ\text{C}$ , and sites with extreme minimum

TABLE 8. — Estimates of minimum displacement of Utah juniper and limber pine and resultant calculations of the full-glacial decline in summer temperatures for southern Nevada

† Lowest elevation fossil record for *Juniperus osteosperma* is from Mehringer (1967); lowest record for *Pinus flexilis* is from Spaulding (1981). †  $T_s$ , relative decline in full-glacial summer temperatures; °C, degrees Celsius; m, meter

Species	Lowest fossil site: elevation	Present lower limit	Minimum displacement
<i>Juniperus osteosperma</i>	Tule Springs, Las Vegas Valley; 700 m	1,900 m	1,200 m
<i>Pinus flexilis</i>	Willow Wash-4, Sheep Range; 1,585 m	2,650 m	1,065 m

Lapse rate calculations of $\Delta T_s$		
Lapse rate <sup>1</sup> (°C/100 m)	Minimum displacement	$\Delta T_s$
-0.60	1,200 m	-7.2°C
- .70	1,200 m	-8.4°C
- .75	1,200 m	-9.0°C
- .60	1,065 m	-6.4°C
- .70	1,065 m	-7.5°C
- .75	1,065 m	-8.0°C

<sup>1</sup>Values from Major (1977).

TABLE 9. — Range of minimum temperature values at 39 sites presently supporting creosote bush (*Larrea divaricata*), and estimates of the minimum decline in late Wisconsin winter temperatures necessary to exclude that species from all sites

†  $\Delta T_w$ , postulated minimum relative decline in full-glacial winter temperature; °C, degrees Celsius; data are from Beatley (1974, table 1)

Mean Minimum Temperatures		
Lowest value (A)	Highest value (B)	$\Delta T_w$ (A-B)
-1.4°C (site 34)	4.5°C (site 5)	-5.9°C

Mean of Extreme Minimum Temperatures		
Lowest value (A)	Highest value (B)	$\Delta T_w$ (A-B)
-16.8°C (site 34)	-10.8°C (site 15)	-6.0°C

temperatures below -16.8°C (table 9). Because a  $\Delta T_w$  of less than -6.0°C would leave some low-elevation sites in the region with mean minima above -1.4°C (as measured by Beatley's method) and not exclude *Larrea divaricata* from the study area, full-glacial decline in winter temperatures must have exceeded that value (table 9).

Shadscale (*Atriplex confertifolia*) was widespread in the late Wisconsin juniper woodlands of southern Nevada. It occurred at higher elevations than it does today, probably in response to the absence of potential competitors that appear to determine its present upper limits (Spaulding, 1981, p. 205). There is little fossil evidence for desert scrub species that occur at intermediate elevations above shadscale today, and the glacial-age juniper woodland seems to have been less diverse than present vegetation at the fossil sites (Spaulding, 1981, p. 194-199). This apparent decrease in floristic diversity is attributed to winter temperatures lower than those indicated by models of equable late-glacial climates. Expansion of shadscale, today typical of the most frigid desert habitats in the vicinity of the Nevada Test Site (Beatley, 1974, 1975), provides strong qualitative support for a relatively large decline in late Wisconsin winter temperatures and a fairly arid precipitation regime.

Averaging these minimum estimates of  $\Delta T_s$  and  $\Delta T_w$  yields a minimum value of about -7°C for the decline of mean annual temperature ( $\Delta T_a$ ) during the late Wisconsin. Subtracting this estimate of  $\Delta T_a$  from the current mean annual temperature at the lowest elevation fossil locality, Owl Canyon at 795 m, yields a range of temperature values (10° to 11°C) characteristic of the lower reaches of modern woodland in the region (table 5). This is in agreement with glacial-age macrofossil assemblages from low-elevation sites dominated by dry-woodland and cold-desert plants.

Reconstruction of the late Wisconsin precipitation regime of the Nevada Test Site and vicinity begins with estimates of seasonality. The late-glacial flora indicates a pronounced absence of summer rain. The abundance of Great Basin Desert taxa and scarcity of plants that today appear to require at least some summer moisture (such as *Quercus* spp., *Coleogyne ramosissima*) indicates the contribution of warm-season rainfall was less than 10 percent of the annual total. This is not unexpected because, during a glacial climatic regime, lowered temperatures would tend to suppress development of subtropical high-pressure systems presently responsible for winds that bring summer rains to the monsoonal Southwest (Van Devender and

Wiseman, 1977) and impede development of surface low-pressure systems that draw maritime air northward from the Gulf of California (Huning, 1978, p. 80).

The late Wisconsin flora of the northern Mojave Desert provide no evidence for the drastic relative increase in annual precipitation (in excess of 50 percent above present values) proposed by some authors (table 7). At this point, general analogs seem to provide the best approach for deriving estimates of full-glacial precipitation. In the White Mountains of California (fig. 1), average annual precipitation ( $P_a$ ) near the lower limit of subalpine (limber pine) woodland (at about 2,800 m) (Mooney and others, 1962, fig. 4) is calculated to be about 300 mm, based on a value of 350 mm/yr<sup>-1</sup> at the Crooked Creek Research Station (at an elevation of 3,096 m) (La Marche, 1973, p. 635), and a local precipitation lapse rate of 17 mm/100 m (Major, 1977, p. 66). Assuming this value (300 mm) approximates average annual precipitation during the full glacial at the Eleana Range locality, the estimated relative increase of  $P_a$  is 33 to 39 percent above today's amounts (table 5). This modest increase is supported by two tree-ring chronologies from the Eleana Range-2 packrat midden (fig. 23). Annual-ring widths of these two radiocarbon-dated limber pine specimens are extremely small, averaging less than 0.2 mm. It is unlikely that such sensitive tree rings would have been produced except by trees under appreciable stress. Estimates of relative increase in precipitation of less than 40 percent also are consistent with the full-glacial record of pinyon-juniper woodland at the Specter Range-2 site. A 30 to 40 percent increase over today's amounts (table 5) would result in values estimated to be between 226 and 265 mm/yr<sup>-1</sup>. Present precipitation at Ely, Nevada, which lies at the lower limit of pinyon-juniper woodland, is 221 to 245 mm/yr<sup>-1</sup> (table 4).

#### THE TRANSITION PERIOD

Several authors (Wright, 1976; Davis, 1981; Watts, 1980) have emphasized the time-transgressive nature of vegetation change at the end of the last glacial age in other parts of the continent; this also appears to have been the case in the Mojave Desert. Contrary to the assertion of Van Devender and Spaulding (1979, p. 709), the packrat-midden record provides no evidence for contemporaneous vegetation change at all sites at about 11,000 years ago (Spaulding, 1983, p. 256). Because synchronicity of vegetation change is not evident, there is a need for arbitrary time lines. The conventional dates of 10,000 B.P. for the end of the Wisconsin and 8,000 B.P. for the end of the early Holocene are adopted here.

#### MAJOR VEGETATION CHANGES

The latest Wisconsin (12,000 to 10,000 B.P.) vegetation at the Eleana Range-2 site was dominated by plants that presently occur nearby although a greater variety of mesophytes occurred, including some full-glacial relicts. The abundance of pinyon pine and Utah juniper in ER-2(2) and 2(1) also indicates a denser vegetation than exists at the site today. Progressive desertification after about 10,600 B.P. caused opening of the pinyon-juniper woodland and final extirpation of such extralocals as limber pine and curl-leaf mountain mahogany.

Development of postglacial woodland at the Eleana Range occurred between about 13,200 and 11,700 B.P. This is surprisingly early, relative to the date of about 11,000 B.P. for the end of Wisconsin vegetation conditions throughout the Southwest suggested by Van Devender and Spaulding (1979, p. 706). However, the Eleana Range record agrees with many glacial, oxygen-isotope, and pollen chronologies that show impact of increasing northern-hemispheric temperatures by at least 12,000 B.P. (Dansgaard and others, 1971; Porter, 1971; Barnosky, 1981; Mehringer, 1967). The maximum of northern hemisphere summer insolation was reached by about 11,000 B.P. (Broecker and van Donk, 1970, fig. 10; Ruddiman and McIntyre, 1981, fig. 2). Thus, an early date for the response of vegetation at the Eleana Range-2 site to a warming climate is not unexpected, particularly if species such as limber pine were near the limits of their environmental tolerance here during late Wisconsin time.

An early change to postglacial vegetation conditions also took place at low elevations on the periphery of the Amargosa Desert. The Point of Rocks midden records (at elevations ranging from 900 to 930 m) indicate that, at least at some sites, woodland gave way to desertscrub prior to 14,800 B.P. The surprisingly early dates for desert vegetation at the Point of Rocks-3 site (14,800 B.P.) and at the Point of Rocks-1 site (11,800 B.P.), indicates that woodland vegetation was not continuous below an elevation of about 1,000 m after about 15,000 years ago (Spaulding, 1983). Instead, low elevations in the vicinity of the Nevada Test Site may have supported a mosaic of woodland, occupying mesic habitats, and desertscrub on xeric sites.

In contrast to the early records of shrub vegetation in the lowlands, middens from higher elevation desert sites show that juniper woodland persisted as late as 9,400 B.P. in the Sheep Range (Spaulding, 1981, p. 191) and 7,800 B.P. in the Spotted Range (Wells and Berger, 1967, table 1). These localities were in the upper part of the late Wisconsin zone of pygmy-conifer woodland (above an elevation of 1,200 m) (fig. 14). Effective moisture was sufficient at such higher altitudes to maintain xerophytic

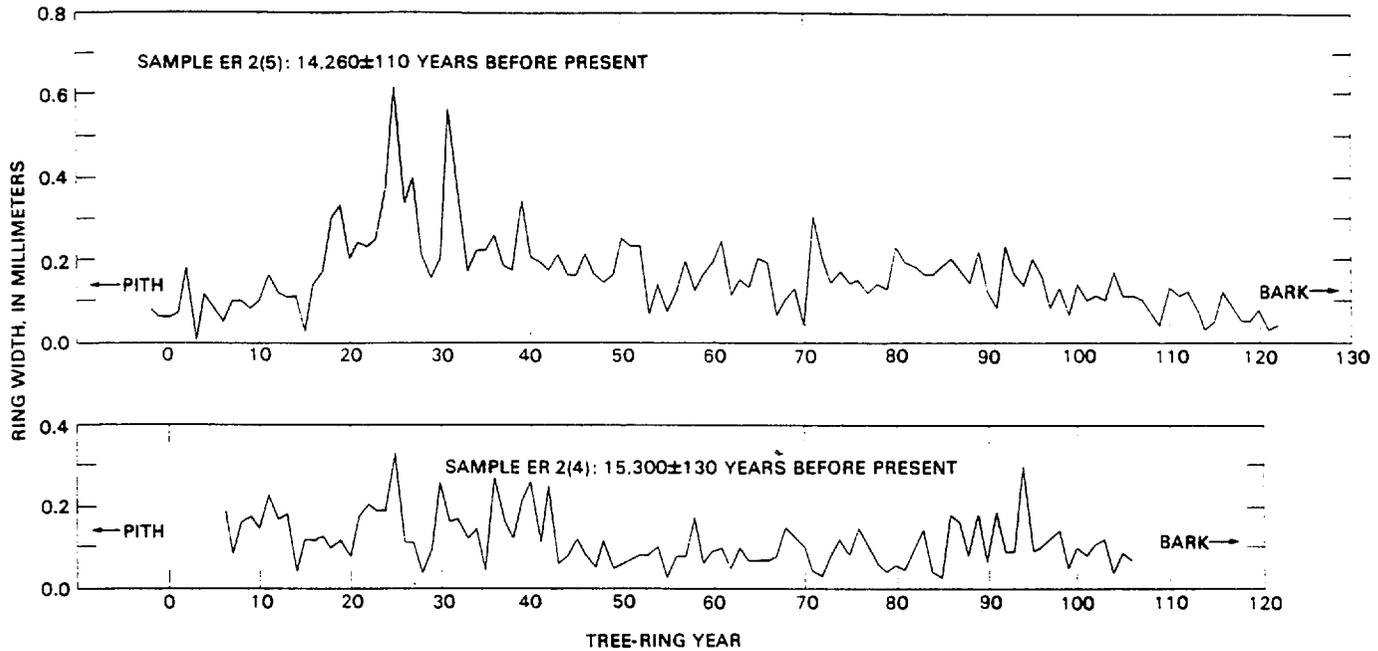


FIGURE 23.—Tree-ring chronologies from two limber-pine specimens from the Eleana Range-2 (ER-2) midden. (The radiocarbon date for each specimen also is shown; table 6.) The specimens are tied neither to a calendar year nor to the relative age of the tree and the time scale at the bottom is for illustrative purposes only. Cross-dating is not implied by the superposition of those two chronologies. Analysis by Harriet Garfinkel, Lincoln Laboratory, Massachusetts Institute of Technology.

woodland species after they had been extirpated from the lowlands.

An insight into the dynamics of vegetation change at the end of the glacial age is provided by contrasting similarity indices for midden samples from Owl Canyon and the Eleana Range. Macrofossil assemblages from the Owl Canyon-2 midden document vegetation conditions after juniper woodland gave way to desertscrub, and the two youngest assemblages from Eleana Range-2, after limber pine gave way to pinyon-juniper woodland. However, similarity coefficients between Owl Canyon-2 assemblages and the present vegetation at the Owl Canyon-2 site are less than 10, while those comparing ER-2(1) and 2(2) samples to the modern vegetation exceed 70 (see Supplemental Data section) (fig. 21). The Eleana Range locality was near the upper limit of late Wisconsin pygmy-conifer woodland (fig. 14); plants such as juniper, pinyon pine, and pricklypear reached the Eleana Range-2 site soon after the triggering climatic change. However, thermophilous shrubs that typify present vegetation at Owl Canyon (such as creosote bush, desert spruce, and white bursage) were apparently absent from the region during the late Wisconsin. The dissimilarity between the latest Wisconsin and modern flora at Owl Canyon is thus ascribed, in large part, to lag time in northward migration of warm-desert shrubs.

The major vegetation change in the region at the end of the last glacial age, from subalpine-conifer to pinyon-juniper woodland and, at lower elevations, from pygmy-conifer woodland to desertscrub, occurred at different times at different sites (fig. 14). An important variable that affected the timing of major vegetation change, exclusive of the timing of the forcing climatic change, was the position of the fossil site relative to the environmental tolerance of species growing there. Middens from xeric sites near the lower limit of a given vegetation zone (such as Owl Canyon, Point of Rocks, or the Eleana Range) record relatively early response to postglacial warming. Records from mesic sites, and from higher elevations within a given vegetation zone, are not as sensitive and document less vegetation response until the climate change had progressed quite far.

Desert vegetation took at least 6,000 years to spread over most of its present elevational range (fig. 14). In the northern Mojave, the transformation from woodland to desertscrub was nearly complete by about 9,000 B.P. These findings diverge from the model proposed by Van Devender (1977b, p. 190-191; Van Devender and Spaulding, 1979, p. 708) indicating that widespread woodland persisted throughout the early Holocene in most of the Mojave Desert, abruptly giving way to desertscrub at about 8,000 B.P. Early Holocene woodlands probably

were more widespread farther south in the current Sonoran Desert.

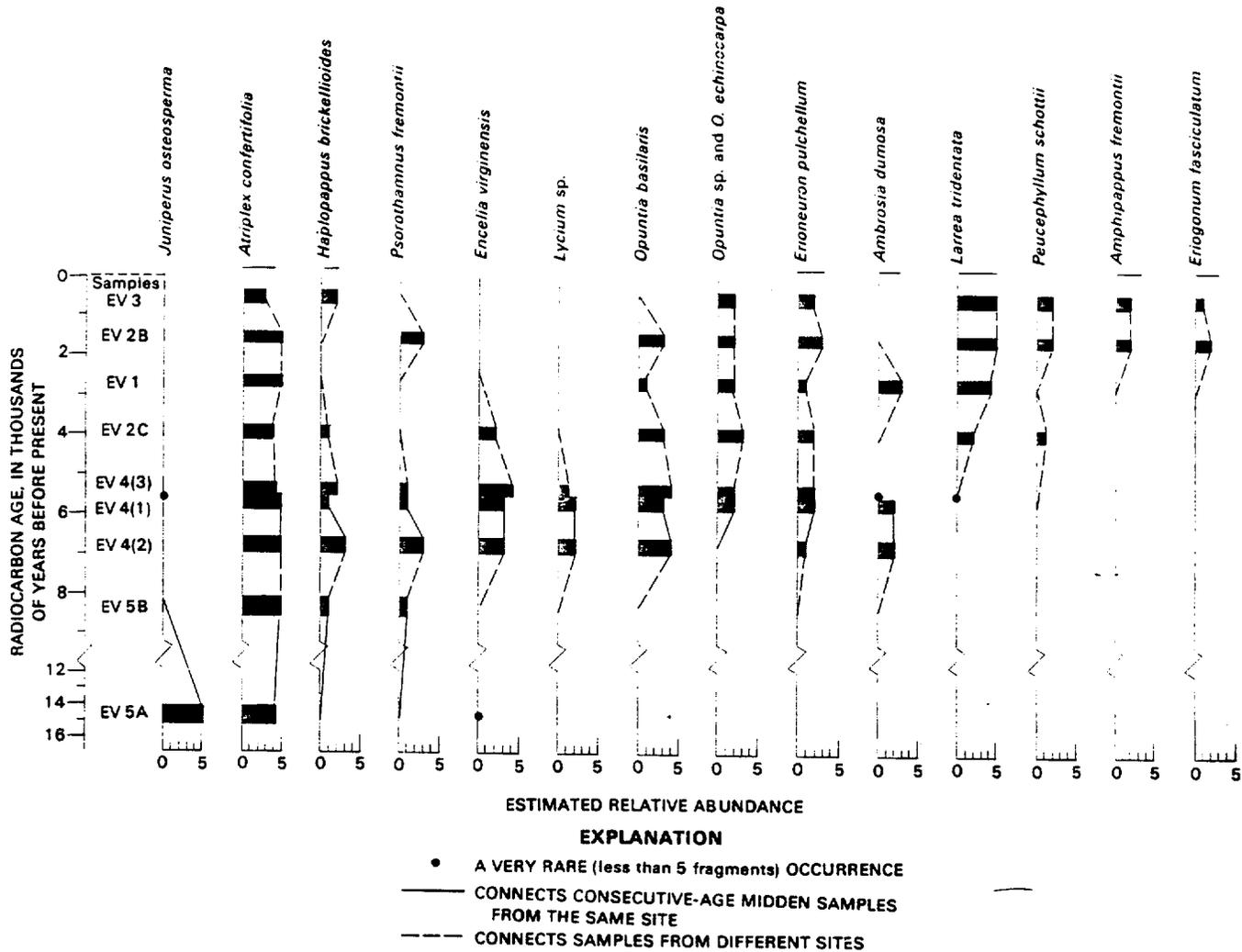
Both final desiccation of the vast inland lakes of the Great Basin and ultimate demise of woodland vegetation in desert lowlands occurred between 10,000 and 8,000 years ago. At Searles Lake, desiccation was complete by about 9,600 B.P., the end of a period of declining lake levels that, with one major reversal, began as early as 16,200 B.P. (Smith, 1979, fig. 41; Peng and others, 1978, p. 325). In the vicinity of the Nevada Test Site, anomalous desertscrub vegetation had replaced woodland at most sites below an elevation of 1,600 m by about 9,000 B.P. (fig. 14). Anomalous desertscrub is a general term applied to past plant associations characterized by extralocal shrubs and succulents that also lack important elements of modern vegetation. Late Wisconsin and early Holocene middens from the periphery of the Amargosa Desert, and the Eureka Valley, document such vegetation (fig. 14). Most shrub species abundant in the Point of Rocks, Owl Canyon-2, and Last Chance Range midden assemblages (at elevations between 800 and 960 m) typify present vegetation at elevations between 1,400 and 2,000 m.

It is not known when anomalous desertscrub vegetation gave way to plant communities characteristic of the present vegetation at the Amargosa Desert sites. At the Eureka Valley locality, 160 km to the northwest, final development of current plant associations was delayed until after 5,000 B.P. (fig. 24). The lag in this development, from the time of extirpation of woodland to establishment of desertscrub vegetation similar to today's, resulted in part from the time it took for warm-desert species to migrate northward. Expansion of these shrubs to more northerly latitudes probably began before 10,000 B.P.; middens in the Amargosa Desert provide the earliest evidence for their arrival in the vicinity of the Nevada Test Site. Assemblages from Point of Rocks-1 and 2 sites, dating between 10,000 and 9,000 B.P., are the oldest to contain such xerophytes as creosote bush (*Larrea divaricata*) and chaff-bush (*Amphipappus fremontii*). Creosote bush does not appear in the Eureka Valley record until about 5,500 B.P., and chaff-bush does not appear until 1,500 B.P. (fig. 24). Prior claims for the presence of creosote bush of Wisconsin age in the northern Mojave Desert (Spaulding, 1976, p. 160; 1980, p. 89) must await confirmation by radiocarbon dates run directly on those fossil remains. Until such tests are made, these earlier records must be considered dubious; they are not replicated in this study. Migration lags were an important aspect of postglacial vegetation development in the eastern United States (Davis, 1981; Watts, 1980) and, despite previous statements to the contrary (Van Devender and Spaulding, 1979, p. 710), appear to have played an equally important role in the transition to modern vegetation in the Southwest.

#### CLIMATES OF THE TRANSITION PERIOD

The latest Wisconsin and early Holocene vegetation of most of the Mojave Desert was xerophytic, relative to that at comparable sites in the Sonoran Desert. Desertscrub communities appear to have developed earlier in the Mojave. The oldest record of shrub-dominated vegetation in the vicinity of the Nevada Test Site exceeds 14,500 years. In the southern Mojave Desert, evidence for the early inception (by at least 10,500 B.P.) of desertscrub comes from middens in the Marble Mountains, 230 km south of the Nevada Test Site (Spaulding, 1980). The elevation of these early desert-vegetation records in the Mojave Desert varies from 465 m in the Marble Mountains to 960 m in the Last Chance Range of Nevada. At the same time (11,500 to 9,000 B.P.), juniper woodland occurred at least as low as 520-m elevation in the Whipple Mountains of the western Sonoran Desert, 310 km south-southeast of the Nevada Test Site in the Colorado River Valley. Mead and others (1978, p. 185-186; Van Devender, 1977b) report that radiocarbon dates on these woodland assemblages are as young as 8,900 B.P. Other sites in western Arizona that confirm the presence of low-elevation woodland in the Sonoran Desert include those from the Artillery and New Water Mountains (Van Devender, 1973, table 3). Closer to the Nevada Test Site, in the extreme eastern part of the Mojave Desert, juniper woodland extended to at least an elevation of 560 m in the lower Grand Canyon (fig. 1). This early Holocene woodland was rich in shrub and succulent species; radiocarbon dates on these assemblages are as young as 8,900 B.P. (Phillips, 1977, table 1).

The early development of desertscrub vegetation in the Mojave Desert, and persistence of woodland in the Sonoran Desert and Grand Canyon, appears to have been a function of differing precipitation regimes. The cline of increasingly xerophytic vegetation from southeast to northwest parallels the existing gradient of warm-season precipitation from the summer-wet (monsoonal) Sonoran Desert to the summer-dry Mojave Desert. Thus, the dichotomy between paleovegetation of the two regions during the latest Wisconsin and early Holocene was probably also due to differences in the relative amount of summer rainfall. This author suggests that, beginning by 14,000 B.P., increasing summer temperatures led to a marked increase in summer, and perhaps autumn, precipitation in the present monsoonal Southwest (Sonoran and Chihuahuan Deserts). Transition period woodlands in these areas were probably maintained at low elevations by relatively high levels of effective moisture during the growing season. The Mojave Desert is farther removed from the sources of warm-season precipitation and may have been beyond the limits of major influence of this phenomenon. Desertscrub vegetation developed earlier in the Mojave Desert because there was inadequate



**FIGURE 24.** — A time series of packrat-midden samples from the Eureka View locality, northern Eureka Valley, Inyo County, California: estimated abundance of the species in the present vegetation is presented at the top for comparison: width of bars is equal to  $\pm 1\sigma$  of that sample's radiocarbon age (note break and change in time scale). EV, Eureka View; subjectively assigned relative abundance values are: 5, very abundant; 4, abundant; 3, common; 2, occasional; 1, rare.

precipitation to compensate for increasing warm-season moisture deficits.

Between 12,000 and 8,000 years ago, the obliquity of the Earth was such that summer was a time of more intense insolation than it is today, and winters were less heated than at present (Bryson and Swain, 1981, p. 143-144; Kutzbach, 1981, p. 59). Peaks in northern-hemispheric summer insolation and seasonal contrast may have resulted in 20 to 100 percent more summer rainfall than at present in some monsoonal regions (Kutzbach and Otto-Bleisner, 1982; Bryson and Swain, 1981, table 2). Midden localities that document woodland vegetation in the desert West at this time, such as the lower Grand Canyon and the Whipple Mountains, are south and east of the Nevada Test Site and are closer to sources of tropical maritime air—the Gulfs of California and Mexico.

The early postglacial woodland of the monsoonal Southwest probably did not result from persistence of the glacial-age precipitation regime, as suggested by Van Devender (1977b, p. 192). Rather, juniper and other xerophytic woodland species may have been maintained at lower elevations than they occur at present by enhanced summer rainfall. Although there was probably a relative increase in summer rainfall over today's meager amounts in the Mojave Desert, it was insufficient to maintain woodland at low elevations.

At about 10,000 years ago, summer and fall precipitation in the vicinity of the Nevada Test Site may have exceeded present amounts by as much as 50 percent. This inference is based on the distribution pattern of woodland across the Southwest and the timing of its disappearance in different areas. Plant species indicative of increased summer

rainfall became more important in the Nevada Test Site midden record between 12,000 and 10,000 years ago. The abundance of *Agave utahensis* and cacti in the Owl Canyon-2 and Point of Rocks-2 assemblages is consistent with a thesis of increased warm-season precipitation during the Wisconsin to Holocene transition. In the Searles Lake area: the apparent latest Wisconsin expansion of shrub live-oak (*Quercus turbinella*) (Spaulding and others, 1983) may be evidence of increased summer rain. The interior race of this species is presently restricted to mountains of the monsoonal Southwest (Little, 1976, map 147). There may have been insufficient time for many other summer-rain dependent species to migrate into the area. Most appear to have been absent from the Southwest during the late Wisconsin (Van Devender and Spaulding, 1979, p. 708), and it may have taken them thousands of years to reach the borders of the present-day Mojave Desert.

The source of warm-season precipitation during the latest Wisconsin and early Holocene presumably was to the south in the Gulf of California and Pacific Ocean, or to the southeast in the Gulf of Mexico. Tropical storms of August through October that presently move up the trough of the Colorado River Valley may have been more common than they are today. There is no immediate evidence for a relative increase in precipitation over current values during the winter half-year, although effective moisture during the winter probably was greater than today. While summer temperatures are inferred to have been as much as 1° to 2°C higher than today, winter temperatures may have been 1°C lower than today. This is based on the observation that seasonal contrasts were unusually large in the northern hemisphere between 11,000 and 9,000 B.P. (Broecker and Van Donk, 1970, p. 190; Bryson and Swain, 1981, p. 143; Kutzbach and Otto-Bleisner, 1982).

#### THE LAST 8,000 YEARS

It generally is agreed that the middle Holocene was a time of increased northern-hemispheric temperatures (Deevey and Flint, 1957). However, estimates of the duration of this period of warm temperatures, and timing of the thermal maximum, differ from region to region. It appears that the period of maximum temperatures during the Holocene was time-transgressive (Wright, 1976, p. 594). As with previous portions of this report, this climatic event is considered within the context of a time-stratigraphic unit, the middle Holocene. The date chosen for the beginning of the middle Holocene, 8,000 years ago, is close to the time of final demise of woodland in high desert habitats of the northern Mojave Desert (fig. 14) (Wells and Berger, 1967, table 1), as well as its

decline throughout wide areas in the present Sonoran Desert (Van Devender, 1977b).

#### MIDDLE HOLOCENE CLIMATIC VARIATIONS

Pollen-stratigraphic data from north-central and north-western North America are in general agreement with the Mojave Desert record. All show that the transition to postglacial vegetation conditions was complete by, at the latest, 9,000 B.P. (Barnosky, 1981; Webb and Bryson, 1972; Heusser, 1977; Wright, 1976). The apparent conflict with evidence for delayed development of desert vegetation in the Sonoran and Chihuahuan deserts (Van Devender, 1977b; Van Devender and Wiseman, 1977, p. 21) is probably due to more summer precipitation in these areas. Final extirpation of extralocals such as juniper in the lowlands of the monsoonal Southwest was delayed until the end of the early Holocene, when increased summer precipitation no longer compensated for warm-season moisture stress.

Martin (1963, p. 61) was among the first to suggest that the middle Holocene was a time of increased effective moisture, based on pollen data from southeastern Arizona. While little confirmation of an initial, early Holocene (10,500 to 8,000 B.P.) arid period is available (Van Devender, 1977b), Martin's hypothesis that there was enhanced summer rainfall between about 8,000 and 4,000 B.P. has been strengthened by additional studies in the Chihuahuan Desert (Mehring and others, 1967; Van Devender and Wiseman, 1977; Van Devender and Worthington, 1977). Lacustrine evidence indicates that this also was the case in the Mojave Desert, although the relative amount of summer rain probably was less. The hypsithermal-age saline lake in the Searles Basin (fig. 1) attained a depth of up to 45 m above the present playa surface. It may have been caused by a relative increase in frequency and amount of summer rain, although it is unknown why it was dry during the preceding early Holocene. An uncorrected radiocarbon date on wood from the Overburden Mud laid down by this saline lake is 3,520±190 B.P.; an uncorrected radiocarbon date on disseminated organic carbon is 6,630±390 B.P. (Smith, 1979, p. 112, fig. 3).

Variations in the lower limit of pinyon-juniper woodland in the Sheep Range (fig. 1) also indicate increased effective moisture during the middle Holocene. Two middens from sites in current desert, about 150 m below the woodland boundary, contain abundant Utah juniper and common pinyon pine and are dated at 5,210±95 (the Desert View site) and 3,520±100 B.P. (the Basin Wash site) (fig. 14) (Spaulding, 1981, p. 209). Additional evidence for a moist hypsithermal in the vicinity of the Nevada Test Site includes the presence of extralocal

pricklypears (*Opuntia polyacantha* and *Opuntia phaeacantha*) in the Desert View midden, as well as the mesophytes longleaf brickett (a *Brickellia* cf. *longifolia*) and desert-willow (*Chilopsis linearis*) in the desertscrub assemblage from the Willow Wash-2 site in the Sheep Range (4,125±90 B.P.) (Spaulding, 1981, table 11).

As mentioned previously, it appears the middle Holocene also was a time of higher temperatures. Isolated middens from the Sheep Range, dating from about 4,130 to 3,240 B.P., yield evidence for warmer winters. The record of desert-willow in the Willow Wash-2 midden is pertinent because the species is frost-sensitive and is restricted from such protected, cool sites today, even when there is adequate moisture. Warmer winter minima may be indicated by the presence of blue yucca (*Yucca baccata*) in the CT-1(1) (3,310±100 B.P.) and Spires-1 middens (3,240±100 B.P.) (fig. 14); both sites presently lie more than 70 m above its upper limit (Spaulding, 1981, p. 136).

Northward migration of warm-desert shrubs continued through the middle Holocene. On xeric south slopes in the Eureka Valley (fig. 1), anomalous desertscrub characterized by shadscale, rayless brittlebush (*Encelia virginensis*), and cactus (*Opuntia* spp.) gave way to shadscale-creosote bush vegetation between 3,900 and 2,600 B.P. (fig. 24). While the unusual aspect of mid-postglacial plant communities at the Eureka View locality resulted in part from delayed immigration of thermophiles, many species that occurred on these xeric dolomite slopes during the middle Holocene are now restricted to more mesic habitats.

La Marche's (1973) dendrochronologic reconstruction of climate variation in the White Mountains of California, 35 km northwest of the Eureka Valley (fig. 1), provides an independent data base for the middle and late Holocene. The remains of bristlecone pine (*Pinus longaeva*) trees occur far above present treeline there, which is rather firm evidence of fluctuations in its upper limit caused by long-term temperature changes. A period of relatively high temperatures is inferred from the start of the record at about 7,400 B.P. to between 3,500 to 3,000 B.P. La Marche (1973, p. 655) suggests that subsequent late Holocene lowering of treeline was caused chiefly by a decline in warm-season temperatures. For the purposes of this study, a date of 3,000 B.P. for the end of the middle Holocene is accepted.

#### LATE HOLOCENE FLUCTUATIONS

Although records of vegetation change over the last 3,000 years are plentiful, they usually reflect environmental changes of a lower magnitude than most of those

discussed previously. Many late Holocene assemblages indicate increased effective moisture relative to both middle Holocene and modern conditions. In the Sheep range, the Canyon Two-1(1) midden sample (1,990±70 B.P.), at an elevation of 1,740 m, contains abundant juniper and common pinyon pine (fig. 14). An older sample from this midden, CT-1(2) at 3,310±100 B.P., contains only occasional juniper and no pinyon pine. This late Holocene record of woodland vegetation comes from a site that is surrounded by blackbrush desertscrub today. The current lower limit of woodland in this part of the range (fig. 12) is at an elevation of about 2,010 m, more than 200 m above the Canyon Two site (Spaulding, 1977). Other middens from the Sheep Range that contain remains of woodland conifers 100 to 200 m below their current lower limits include the Basin Wash sample (3,520±100 B.P.) and the Ey-2(1) sample at 2,920±90 B.P. (fig. 11) (Spaulding, 1981, p. 141, p. 123-125).

Late Holocene vegetation change is evident in packrat middens from the Eureka Valley and the Specter Range. Assemblages from the Eureka Valley record final extirpation of such extralocals as indigo bush (*Psoralea fremontii*), cacti (*Opuntia basilaris* and *Opuntia echinocarpa*), and desert spruce (*Peucephyllum schottii*), between about 1,600 B.P. and the present (fig. 24). A decline in the proportion and amount of summer precipitation may have caused local extinction of indigo bush and cacti. However, it is likely that lower winter temperatures eliminated desert spruce from this, its northernmost documented occurrence. The closest locality where *Peucephyllum* occurs today is on south-facing slopes of the Last Chance Range of California, 12 km southeast of the Eureka Valley sites.

Two assemblages from the Specter Range-1 site document desertscrub vegetation analogous to today's, although there appears to have been a shift in plant-community composition. Fourwing saltbush (*Atriplex canescens*) is the most abundant species in the sample dated at 300±100 B.P. [sample Spc-1(1)], while creosote bush and matchweed (*Gutierrezia microcephala*) are more important in the younger Spc-1(2) assemblage (100<sup>+200</sup><sub>-100</sub> B.P.) (table 6). This apparent shift to a xerophytic plant community in the last 300 radiocarbon years may be because of climatic change. An equally likely cause may be the effect of cattle grazing in the late 19th and early 20th century. A decline in the more palatable saltbush and an increase in unpalatable and disturbance-indicator shrubs (*Larrea divaricata*, *Gutierrezia microcephala*, *Hymenoclea salsola*) support the latter hypothesis. Similar observations are possible based on the data from subrecent packrat middens from the Eureka Valley (Spaulding, 1980).

## ASSESSING PALEOENVIRONMENTAL RECONSTRUCTIONS

Packrat-midden analysis affords a high-resolution view of the environmental history of the Nevada Test Site and vicinity. However, potential errors and unknown variables that exist should be considered. Errors could be introduced in estimating modern climates at the fossil sites, in reconstructing past vegetation, or in extrapolating climatic parameters from reconstructions. Retrodictive studies, such as this one, describe phenomena that no longer exist; conclusions derived from such analyses cannot be tested through observation. However, they can be tested by attempts to replicate the fossil record and by application of proposed paleoclimatic parameters to models of physical systems, such as pluvial lakes and cryogenic deposits.

### ACCURACY OF REPRESENTATION AND GENERAL ANALOGS

Plant-macrofossil assemblages from ancient packrat middens possess distinctive characteristics that permit identification of specific vegetation types. Analyses of modern middens in this study, and those performed by Cole (1981, p. 36-41; 1982), indicate that sufficient fidelity exists in the midden-vegetation relationship to permit accurate reconstruction to at least the community-type level (table 1). The possibility that first-order errors have been made in this study (such as reconstruction of juniper woodland when ponderosa-pine forest was actually present) is remote. Errors may exist in second-order reconstructions of specific plant associations (table 1), but this also is unlikely. Analyses of modern packrat middens show that plant species that are abundant or common in nearby vegetation are well-represented in the assemblages. Therefore, it is unlikely that a macrofossil assemblage would be interpreted as representing, say, a juniper-shrub woodland, when a pinyon-juniper woodland was actually present. Studies of modern middens thus far have failed to demonstrate consistent biases in foraging behavior of packrats that would invalidate the conclusions presented here. These paleoecological reconstructions usually are based on multiple macrofossil assemblages controlled by multiple radiocarbon dates. Non-representative assemblages may be sampled on occasion, but these would have little effect on paleoecological reconstructions based on many samples.

Diverse bioclimatic regions of the western United States provide a range of general analogs to the fossil records that are used to infer the nature of late Quaternary climates. Use of such analogs provides an effective paleo-environmental tool, even though exact analogs between vegetation and environments of the late Pleistocene and

those of today probably do not exist (Hare, 1976; Birks, 1981). Thus, the climate that existed at the time when xerophytic juniper woodland was widespread is assumed to have been more similar to that of current dry woodland than to that of less similar vegetation types in existence now. There are no logical alternatives to the assertion that, because the late Wisconsin vegetation of the Nevada Test Site region resembled current vegetation of northern Nevada, the past climate probably was more similar to the present climate of that area than any other area.

The fossil record provides evidence for various paleoecological phenomena which, in turn, are used to reconstruct different aspects of the past climate. Among the most important used in this study are values of the relative vertical displacement of individual species and the inferred absence of particular taxa from the region during the late Wisconsin.

### ELEVATIONAL DISPLACEMENT

Estimates of minimum elevational displacement of limber pine and Utah juniper (table 8) are based on a large data set. Contributing environmental variables, such as aspect, exposure, and substrate, were considered in the calculation of displacement estimates (Spaulding, 1981, p. 166-171). Wells (1977, p. 238) has cautioned that a vertical uncertainty of 100 m may exist in such estimates, because of the possibility of downslope transport of plant fragments from higher elevations. This is balanced, to some extent, by the probability that the lowest fossil record of a particular species does not reflect the lowest elevation that it attained. Neither consideration should seriously affect the validity of minimum estimates. For example, the three lowest fossil records of limber pine on calcareous substrate in the region are within 50-m elevation of each other and are from different sites (Spaulding, 1981, table 35). At one of these sites, Basin Canyon-1 at an elevation of 1,635 m in the Sheep Range (Spaulding, 1981, p. 136-140), limber pine is well represented in the macrofossil assemblages. It is improbable that these fossils represent downslope transport, because: (1) They are present in quantity; (2) the locality does not possess extreme topographic relief (Spaulding, 1981, fig. 20); and (3) two other middens from a different locality provide similar elevational records.

Occurrence of limber pine and Utah juniper far below their lowest modern populations is attributed to cooler summers during the late Wisconsin. These two taxa were chosen as indicator species of summer temperatures because they are the most xerophytic arboreal taxa in present subalpine (limber pine) and woodland (Utah juniper) vegetation. The assumption is made that their downward displacement primarily was due to increased

effective moisture caused by lowered temperatures, not by increased precipitation. The alternative that their expansion was due to a relative increase in rainfall is less likely. An increase in precipitation exceeding 50 percent of current amounts would have resulted in the expansion of mesophytic species (such as ponderosa pine or spruce) absent in the regional fossil record. Moreover, summer temperatures, rather than winter or average annual temperatures, are considered the critical variable controlling the lower limit of these trees because moisture deficits caused by higher temperatures occur during the summer.

There are no independent means available to test validity of lapse rates (table 8) used to convert estimates of minimum elevational displacement to estimates of changes in summer temperature ( $\Delta T_s$ ). However, it is perhaps less likely that actual Wisconsin-maximum lapse rates deviated significantly from values used here (table 8). Indeed, values of  $\Delta T_s$  derived from the fossil records of Utah juniper and limber pine are close to those proposed by other workers using quite different methods (table 7).

#### NEGATIVE EVIDENCE

Absence of a species from a particular region is an important consideration in the study of present biogeographic and bioclimatic phenomena. Absence of shrubs intolerant of extremely low nocturnal temperatures, such as creosote bush, from the northern reaches of the Nevada Test Site is an indication of the severity of that region's winters (Beatley, 1974, 1975). Unfortunately, it is impossible to demonstrate conclusively with the fossil record that a particular species was not present somewhere in the region. Despite comprehensive collections, the past vegetation of some habitats, such as alluvial fans, remains unknown. Some species may have been restricted to isolated sites with favorable microclimates during the Wisconsin. However, this would not invalidate the observation that the climate of that period did not favor those species. In the face of a large data base, it would be less reasonable to claim that these inferences are impermissible simply because they are based on negative evidence. However, negative inferences should be drawn from large data sets only and supported by other lines of evidence, and there is always the need for further replication.

Absence of creosote bush from the Wisconsin fossil record is attributed to winter temperatures that ranged below the limit of tolerance of that species. To this assumption can be added one qualification based on the possibility of competitive exclusion. Today certain habitats exist that are warm enough in the winter to support creosote bush; however, creosote bush is rare or absent. These sites are characterized by higher rainfall, and, in

the vicinity of the Nevada Test Site, such plant communities usually are dominated by blackbrush and, occasionally, species of *Lycium* (Beatley, 1974, p. 255). Although competition between plants is difficult to demonstrate (Grime, 1979), it is likely that creosote bush is absent from these communities because species such as blackbrush are more robust competitors in somewhat wetter habitats. Absence of creosote bush from the fossil record also may be due to such competitive exclusion, but it is considered unlikely. Many plant taxa that were common at lower elevations during the Wisconsin are typical of habitats that are too cold today for creosote bush. Plant species such as blackbrush are rare in the fossil record in the vicinity of the Nevada Test Site prior to about 12,000 years ago.

#### RADIOCARBON DATING

Accurate radiocarbon dating of packrat middens is crucial to these paleoclimatic reconstructions. Mindful of past debates over methods in packrat-midden dating (Van Devender, 1977a; Wells, 1977), considerable care was taken in both the collection and description of ancient middens, and in the selection of samples for detailed analysis. As mentioned previously, less than 50 percent of the indurated middens located in the field were collected. Further examination and dissection of midden samples in the laboratory led to the rejection of others, on the basis of poor stratigraphic integrity and possible mixing of different-age plant debris. It is believed that many potential dating errors can be avoided by such rigorous sample selection. Reliability of these results is enhanced further by the use of time series from single sites. In a site-specific context, anomalous samples can be recognized more easily and subjected to further radiocarbon analyses. Therefore, there is little reason to suspect serious errors in the inferred vegetation associations or in the chronologies of vegetation and climate change presented here.

#### FUTURE CLIMATIC CHANGE

Various mechanisms operate on different scales of time (wavelengths) to affect climate. They range from diurnal solar forcing, with a frequency measured in hours, to epeiorogenic-orogenic events with a quasi-periodicity of, perhaps, between 10 to 100 million years (Mitchell, 1976, p. 482-485). Based on current knowledge of climate dynamics and the geological record of past changes, major global climatic fluctuations likely will occur within the next 10,000 years. This is within the hazardous lifespan of radioactive wastes contemplated for storage at the Nevada Test Site. Although any prediction of the impact of future climatic change on the environment of

the Nevada Test Site is untestable (except indirectly by climate modeling) and speculative, it is nevertheless a critical aspect of overall assessment of site suitability.

Recent studies point to two separate phenomena as likely forcing mechanisms that may cause significant climatic change in the next 10,000 years. These are increases in global atmospheric carbon dioxide and changes in the elements of the Earth's orbit. Each is operating on a different time frequency. The former is anthropogenic and is occurring on periods of 100 years and less. Surface-troposphere warming caused by increasing atmospheric carbon dioxide concentrations is rapid enough that the effects may be visible before the end of the century (Kellogg and Schwart, 1981; Schlesinger, 1983). However, the combined effect of three orbital parameters that appear to drive the glacial-interglacial cycles [axial tilt, eccentricity, and deviation of the earth-sun distance (precession)] has demonstrable cycles of 10,000 to 100,000 years. Because climate changes caused by astronomic modulation of solar insolation are of lower frequency, their immediate effects are not as apparent.

#### ATMOSPHERIC CARBON DIOXIDE

Likely consequences of increased atmospheric carbon dioxide have been identified using both general circulation and radiative-convective models of global climate (Ramanathan and Coakley, 1978; Manabe and Stouffer, 1979). Most analyses are based on a projected doubling or quadrupling of carbon dioxide content of the atmosphere within the next 400 years. The result will be an increase in heating the surface-troposphere system by reflection of long-wave radiation from the Earth. The models of Ramanathan and others (1979, p. 4956) predict an increase in northern-hemispheric mean surface temperature of 3.2°C, assuming a doubling of atmospheric carbon dioxide. Manabe and Wetherald (1975, p. 9) note that a consequence of doubled atmospheric carbon dioxide concentration is the increase in heat energy available for evaporation. Hence, intensity of the "hydrologic cycle" (the entire ocean-land, evaporation-precipitation system in this case) would be enhanced, in their model, by about 7 percent. A projected increase in rainfall also is implied by intensification of subtropical high-pressure systems by tropospheric warming (Manabe and Wetherald, 1975, p. 13). Schlesinger (1983) has recently reviewed model simulations of CO<sub>2</sub>-induced climate change.

In general, the projected relation of increased atmospheric temperatures to increased precipitation is analogous to paleoclimatic reconstructions that indicate an increased flow of tropical maritime air to land during the latest Wisconsin and middle Holocene. Increased temperatures during the early postglacial may have led to an enhanced summer monsoon in subtropical arid regions

(Kutzbach, 1981, p. 60; Bryson and Swain, 1981, table 2). Another feature shared by both models, those used to predict the effect of carbon dioxide heating and those used to reconstruct the impact of increased insolation, is considerable seasonal and latitudinal variability in results (Ramanathan and others, 1979, p. 4956; Broecker and von Donk, 1970, p. 188; Kutzbach, 1981, p. 61).

The most important possible consequence of the increase in radiative heating of the surface-troposphere system is melting of the Antarctic ice cap (Etkins and Epstein, 1982; Kukla and Gavin, 1981). Obviously, the resultant rise in sea level will have no direct effect on the environment of the Nevada Test Site. However, the anticipated rise in temperatures may well have a significant impact on the general climate of the Southwest and the Nevada Test Site in particular. Summer temperatures are expected to be higher than at present by a minimum of about 3°C. Monsoonal circulation also will be enhanced. An increase in summer and fall precipitation by as much as 50 to 100 percent over current amounts is not unrealistic (Bryson and Swain, 1981, table 2). This relative increase in precipitation is dependent on: (1) Intensity of the warming; (2) accuracy of current model-atmosphere projections; and (3) proximity of any given site to the source of maritime air. Because the Nevada Test Site is beyond the influence of monsoonal rains today, it is reasonable to anticipate less increase in annual rainfall here (perhaps no more than 50 percent) than in areas farther south and east.

#### THE NEXT ICE AGE

The relationship between variations in the Earth's orbital configuration and the record of ice-sheet contraction and expansion is well documented (Imbrie and Imbrie, 1980). The astronomical theory of climate states that modulation of solar radiation by changes in precession, obliquity, and eccentricity is the principal cause of Pleistocene ice ages. In particular, the Milankovitch model (Imbrie and Imbrie, 1980) relates orbitally controlled decreases in northern latitude summer insolation to the descent of snowline and development of perennial snowfields (Adam, 1975; Johnson and McClure, 1976). Several feedback mechanisms then would enhance their growth to continental ice sheets (Ruddiman and McIntyre, 1981, p. 617-618). In a like manner, deglaciations such as that which occurred at the end of the Wisconsin are associated with peaks in summer insolation in the northern hemisphere (Broecker and van Donk, 1970, fig. 10; Ruddiman and McIntyre, 1981).

Given the inherent predictability of orbital parameters affecting incident solar radiation, and an adequate statistical model relating these variations to continental glaciation, future major global climate change can be predicted.

Broecker and van Donk (1970, p. 194) were among the first to observe that, based on their analyses, "\*\*\*\* the next 50,000 years should see unusually rapid expansion of continental ice sheets." This agrees with the subsequent work of Berger (1978, fig. 4e) that presents variations in astronomical parameters and isolation curves for the next 250,000 years. A minimum in northern-hemispheric summer insolation will occur within the next 10,000 years. That this may result in initiation of a new glacial age is seen in the model projections of Imbrie and Imbrie (1980, figs. 7 and 8). Their nonlinear model was constructed to simulate global climatic response to orbital variations, as observed in the deep-sea core record of  $^{16}\text{O}/^{18}\text{O}$  variations. After adjustment and tuning, good agreement was reached between the model's response to orbital input and the actual oxygen-isotope record of continental glaciation over the last 250,000 years (fig. 25). The model's response to future orbital input is seen as a continuation of the cooling trend that has been underway for about the last 6,000 years, culminating in a glacial maximum in about 60,000 A.P. (years after present). Another, less-pronounced stade is evident in the model output at about 23,000 A.P. (fig. 25). The gradual excursion of global climate to maximum stadial conditions, followed by relatively abrupt deglaciation after 60,000 A.P., is consistent with the "sawtooth" character of the primary glacial-interglacial cycle (Broecker and van Donk, 1970; Ruddiman and McIntyre, 1981, p. 625).

In this context, it is useful to reaffirm the statement that the Wisconsin maximum at about 18,000 B.P. represents a maximum departure from current interglacial conditions. The magnitude of that stadial episode generally is representative of what may be expected during the next glacial maximum, based on oxygen-isotope record estimates of global ice volume. The last four glacial maxima, during isotope stages 2, 6, 8, and 10, all appear to have been of comparable magnitude, as is the projected maximum at about 60,000 A.P. The implication that there is an approximately equivalent limit to each glacial buildup, attained immediately preceding each deglaciation, is supported by studies of the mechanisms of continental glaciation (Ruddiman and McIntyre, 1981; Broecker and van Donk, 1970).

The combined potential impact of changing atmospheric carbon dioxide concentrations and orbitally induced solar-insolation variations can be summarized as follows: A brief but pronounced "super-interglacial" may well occur within the next 500 years, followed by a continued trend to the next glacial age, reaching a maximum in about 60,000 years. The relative duration of the former event may be quite brief, perhaps no more than a short-lived perturbation in the progression of glacial ages. While more modeling is needed, it is doubtful that the carbon

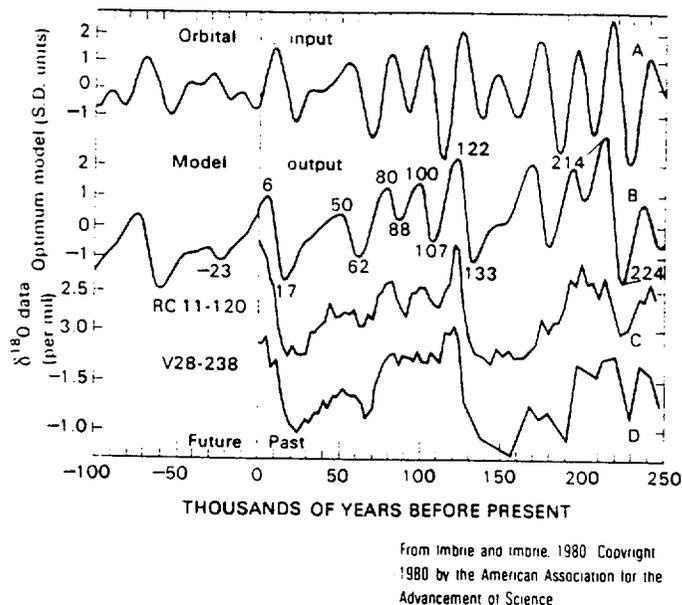


FIGURE 25. — Inferred past changes in global ice volume and modeled future trends (from Imbrie and Imbrie, 1980, p. 948; copyright 1980 by the American Association for the Advancement of Science); orbitally induced irradiation variations for July at lat  $65^{\circ}$  N. are presented in A; resultant output of Imbrie and Imbrie's (1980, fig. 7) optimum climatic response model is shown in B; fluctuations in world ice-sheet volume are recorded in oxygen-isotope variations in two equatorial deep-sea cores RC11-120 and V28-238 (C and D).

dioxide induced warming of the global climate will permanently affect the orbitally forced cycle of glacial ages.

## SUMMARY AND CONCLUSIONS

Packrat middens provide an elaborate history of the late Quaternary environments of the Nevada Test Site. Radiocarbon-dated plant-macrofossil assemblages allow reconstruction of both the past vegetation and chronology of its change over the last 45,000 radiocarbon years. These, in turn, are the basis of models of local and regional paleoclimate. Nearly 100 individually dated macrofossil assemblages from the northern Mojave Desert, spanning 1,600 m of vertical relief, allow detailed characterization of the climatic stability of this region in general and the Nevada Test Site in particular.

A limited number of studies in western North America present paleoenvironmental reconstructions defined by specific climatic parameters (table 8). Because of the uncertainties inherent in such investigations (Hare, 1976; Birks, 1981; see also the fifth chapter of this report), many analyses resort to generalized conclusions. However, terms such as "equable," "pluvial," and "mild" are of limited use unless specified by a range of absolute values.

TABLE 10.—Summary of estimates of late Quaternary climate for the Nevada Test Site and vicinity

[ $\Delta T_w$ , estimated changes in °C (degrees Celsius) of average winter temperature;  $\Delta T_s$ , estimated changes in °C of average summer temperature;  $\Delta T_a$ , estimated changes in °C of average annual temperature; %  $P_s$ , estimated percent changes in average summer precipitation relative to current amounts; %  $P_w$ , estimated percent changes in average winter precipitation relative to current amounts; %  $P_a$ , estimated percent changes in average annual precipitation relative to current amounts; B.P., radiocarbon years before present]

Time (B.P.)	$\Delta T_w$	$\Delta T_s$	$\Delta T_a$	% $P_s$	% $P_w$	% $P_a$
45,000	-2 to -3	---	-1 to -3	<sup>1</sup> -60	+20	0
38,700	---	---	-1 to -2	-40	+25 to +50	+10 to +20
37,800	---	---	-5	---	---	+20
30,000	---	---	-3 to -6	---	---	+10 to +25
18,000	-1.6	-7 to -8	-6 to -7	-40 to -50	+60 to +70	+30 to +40
10,000	-1 to -2	+1 to +2	0	<sup>2</sup> 50	0	+10 to +20

<sup>1</sup> Minimum estimate.

<sup>2</sup> Maximum estimate.

Only explicit estimates can be used to model response of hydrologic systems to climatic change, and to test alternative models of past climates. Quantitative paleoclimatic estimates in this study (table 10) do incorporate a number of uncertainties that have been discussed previously. Therefore, the climatic reconstructions are expressed as either a range of values or as a limiting (maximum or minimum) parameter.

During the Wisconsin, plant communities differed in both distribution and composition from plant communities of today. Environmental gradients governing altitudinal segregation of plant species into vegetation zones were altered, and a different scheme of zonation was the result (figs. 14, 22). In a region that now supports desert vegetation, Utah juniper woodland extended from near local base level up to a transition with limber pine woodland. Great Basin Desert plants, such as sagebrush, shadscale, and rabbitbush, were common in these woodlands. Although there is no evidence for vegetation without trees prior to about 15,000 years ago, steppe-shrub communities may have existed on alluvial fans unsampled by the midden method (Thompson and Mead, 1982) and on isolated, xeric habitats. There also is no evidence for glacial-age temperate-montane forest at higher elevations. Based on the macrofossil data, only two Wisconsin vegetation zones can be identified: Xerophytic pygmy-conifer woodland at low elevations (less than 1,800 m) and subalpine-conifer woodland above that. This contrasts with the present sequence of vegetation zonation from desert scrub to, first, pygmy-conifer woodland; then, montane forest; and, finally, subalpine woodland (fig. 14). Not only was vegetation zonation during the Wisconsin simpler than today's, but plant associations also appear to have been less diverse. Many Mojave Desert species are rare or missing from the macrofossil record, as are many woodland and forest plants presently found in mild, moist environments.

The local chronology of climatic change is consistent with the global record of transitions from middle to late

Wisconsin and from late Wisconsin to Holocene. Records of middle Wisconsin interstadial (about 45,000 to 23,000 years ago) environments document xerophytic juniper shrub associations at most sites. This was a time of reduced summer rainfall and accentuated winter precipitation. Average annual precipitation during the most mesic phase was perhaps as much as 20 percent above current amounts. The available record indicates that the warmest part of the middle Wisconsin was between about 45,000 and 39,000 years ago, with average annual temperatures perhaps only 1° to 3°C below current values (table 10). Temperatures declined in the last 10,000 to 15,000 years of the middle Wisconsin interstadial, although there appear to have been marked reversals characterized by higher temperatures.

The descent of subalpine woodland to at least an elevation of 1,800 m in the Eleana and Sheep Ranges marks the beginning of the late Wisconsin stade (about 23,000 to 10,000 years ago) in this region. In the Specter Range, a vegetation turnover from juniper-shrub to pinyon-juniper woodland by about 19,000 B.P. may be evidence of the Wisconsin maximum. The northern Mojave fossil record provides no evidence for either equable temperatures (cool summers and warm winters) or a pluvial precipitation regime (annual rainfall exceeding 50 percent of current amounts). Late Wisconsin vegetation of the Nevada Test Site and vicinity was dominated by subalpine, dry woodland, and steppe species; it lacked frost-sensitive taxa and was of apparent lower diversity. A cold, continental climate with winter temperatures at least 6°C below those of today is indicated. Summer temperatures were depressed at least an equivalent amount, and average annual temperatures were perhaps 6° to 7°C lower than at present (table 10). There was a distinct lack of summer rain and a relative increase in winter precipitation by as much as 70 percent above current values. However, the estimated increase in average annual precipitation was, at the most, about 40 percent above present amounts (table 10).

This reconstruction of late Wisconsin climate in the northern Mojave Desert differs to some extent with reconstructions proposed for the monsoonal Sonoran and Chihuahuan Deserts to the south and east. Macrofossil evidence from that region has been interpreted as indicating both a pluvial precipitation regime and equable temperatures (Van Devender, 1973, table 3; Van Devender and Spaulding, 1979, p. 708; Wells, 1979, p. 311). Contrasts between inferred paleoclimates in the vicinity of the Nevada Test Site and those to the southeast may be accounted for by regional climatic variations. The relative increase in late Wisconsin precipitation in the Sonoran and Chihuahuan Deserts apparently was greater than in the Mojave Desert. Two factors can account for this. First, an enhanced zonal (west to east) flow of upper-level air, coupled with southerly displacement of winter storm tracks, may have occurred as a consequence of a steepened arctic-equator temperature gradient during the late Wisconsin. The resultant increase in the frequency of Pacific-type winter storms is postulated to have been most pronounced south of lat 36° N. To the north, the relative increase in winter precipitation probably was less due to the barrier to easterly maritime air flow posed by the Sierra Nevada (fig. 1) (Van Devender and Spaulding, 1979, p. 708). A second factor is attenuation of the present southeast-northwest cline of summer precipitation during the late Wisconsin. The northern Mojave, which today receives roughly 25 percent of its annual increment of precipitation during the summer, may have received practically no warm-season rainfall during the late Wisconsin. Farther to the south and east, there is evidence for some summer rainfall (Van Devender, 1973, p. 88), although it probably was less than today's amounts (Van Devender and Wiseman, 1977, p. 21).

The relative decline in full-glacial (about 18,000 B.P.) temperatures proposed for the Nevada Test Site area, in the northern Mojave Desert (table 10), is roughly twice that estimated for sites in the current Sonoran Desert (Van Devender, 1973, table 3). This may be due, in part, to the pluvial environment and more southerly position of the latter region. Increased relative humidity and cloud cover would lead to relatively warm nocturnal temperatures. However, the evidence for very mild late-glacial winters in the monsoonal Southwest is equivocal. For example, the presence of chuckwalla (*Sauromalus obesus*) and desert tortoise (*Gopherus agassizi*) in the late Wisconsin woodlands of the Sonoran and Chihuahuan Deserts has been a basis for inferring a negligible decline in winter temperature (Van Devender and others, 1977, p. 61; Van Devender and Mead, 1978, p. 474). However, these animal species today occur as far north as Beatty, Nevada, where the mean January temperature is about 4.5°C (table 4). Their presence in late Wisconsin woodlands in the vicinity of Tucson, Arizona (mean January temperature

of about 9.8°C) would be consistent with a winter temperature decline of at least 5°C. Winter temperatures at least 5°C lower than at present also would explain the absence from the fossil record of many frost-sensitive subtropical plants characterizing the present Sonoran Desert (Van Devender, 1976, p. 65; Spaulding and others, 1983).

Vegetation change marking the end of the late Wisconsin was underway by at least 14,000 years ago in the northern Mojave Desert. At higher altitudes, the Wisconsin to Holocene transition (about 12,000 to 8,000 B.P.) is seen as the demise of subalpine conifer associations and inception of the present pinyon-juniper woodland and ponderosa pine forest. Below an elevation of about 1,800 m, the transition was characterized by extirpation of woodland plants and development of desertscrub vegetation. This major environmental change was both space- and time-transgressive (fig. 14). At sensitive sites, postglacial vegetation conditions were attained before about 12,000 years ago and, at more "complacent" sites, after 9,500 B.P. Widespread desert vegetation developed at least 2,000 years earlier in the Mojave than in most areas of the Sonoran and Chihuahuan Deserts.

Climatic change of the Pleistocene to Holocene transition involved apparent concurrent increases in annual temperatures and summer rain, as well as a decline in winter precipitation. From about 11,000 to 10,000 years ago summer precipitation may have been as much as 50 percent higher than at present, although annual amounts in the northern Mojave probably were within 20 percent of current values (table 10). Late persistence of woodlands at low elevations in the Sonoran and Chihuahuan Deserts (Van Devender, 1977b) probably was due to this period of enhanced monsoonal precipitation. Annual range of temperatures at this time probably was somewhat greater than at present, with cooler winters and warmer summers. Winter temperatures increased into the Holocene; the middle Holocene (between 8,000 and 3,000 B.P.) may have been characterized by average annual temperatures 1° to 2°C above present values. Summer precipitation probably exceeded present amounts until between 3,000 and 4,000 years ago.

Gradually declining temperatures have typified the last 4,000 to 6,000 years. It is likely that, at present, this trend is being reversed by heating caused by increasing atmospheric carbon dioxide concentrations. Temperatures in excess of 3°C above present values and increased rainfall may occur within the next 500 years. However, this anticipated "super-interglacial" interval is not expected to permanently reverse the orbitally driven trend toward the next ice age. If current theoretical models are adequate, then a new glacial age is to be expected within the next 10,000 years.

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## **SUPPLEMENTAL DATA**

Modern packrat middens. |Data from modern packrat middens analyzed in this study, tables 11-15.|

Ancient packrat middens. |Data from ancient packrat middens analyzed in this study, tables 16-25.|

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TABLE 11. — *Plants in a recent midden from the Owl Canyon-3 site and plants growing in three habitats within 30 meters*

[Relative abundance values for modern vegetation data are in parentheses; they indicate: 5. very abundant; 4. abundant; 3. common; 2. occasional; 1. rare; X. present within 30 meters; NISP, number of identified specimens; N, number of plant taxa;  $N_{TS}$ , number of species of trees, shrubs, and succulents; IS, Sorensen's index of similarity; SW, southwestern; NW, northwestern]

Species	Modern vegetation (relative abundance)			Recent midden count
	SW slope	NW slope	Wash	
<u>Ambrosia dumosa</u>	(4)	(3)	(3)	55
<u>Amphipappus fremontii</u>	(1)	(3)	-	3
<u>Aristida</u> sp.	-	-	-	50
Asteraceae undet.	-	-	-	165
<u>Atriplex confertifolia</u>	-	-	-	4
Boraginaceae undet.	-	-	-	9
<u>Brickellia arguca</u>	(1)	-	-	2
<u>B. desertorum</u>	(1)	-	-	10
<u>Bromus rubens</u>	(1)	(2)	-	1
<u>Cheilanthes feei</u>	(X)	-	-	-
<u>Chorizanthe brevicornu</u>	-	-	-	9
<u>Cryptantha</u> sp.	(1)	(1)	(1)	76
<u>Echinocactus polycephalus</u>	(2)	(1)	(1)	7
<u>Ephedra torrevana</u>	(1)	-	(1)	-
<u>Ephedra</u> sp.	-	-	-	7
<u>Eriogonum heermannii</u>	-	(1)	-	4
<u>Erioneuron pulchellum</u>	(2)	-	(1)	15
<u>Eucnide urens</u>	(3)	(1)	(1)	125
<u>Festuca octoflora</u>	(1)	-	-	-
<u>Galium stellatum</u>	-	(1)	-	-
<u>Gilia rippleyi</u>	(X)	-	(X)	-
<u>Gutierrezia microcephala</u>	(4)	(5)	(4)	453
<u>Haplopappus brickelliioides</u>	(1)	(1)	-	-
<u>Hilaria rigida</u>	-	-	(2)	-
<u>Larrea divaricata</u>	(1)	(2)	-	764
<u>Linanthus</u> sp.	-	-	-	172
<u>Nicotiana trigonophylla</u>	(1)	-	-	-
<u>Opuntia basilaris</u>	(1)	-	-	-
<u>Peucephyllum schottii</u>	(3)	(3)	-	56
<u>Physalis crassifolia</u>	-	-	-	1
<u>Plantago</u> sp.	-	-	-	4
<u>Pleurocornis pluriseta</u>	(3)	(1)	-	-
Poaceae undet.	-	-	-	15
<u>Prunus fasciculata</u>	(1)	-	-	-
<u>Salvia derryi</u>	-	(1)	(3)	21
<u>Sitanion harrisii</u>	(1)	-	-	-
<u>Sphaeralcea obtusica</u>	(1)	(1)	(1)	35
<u>Stipa arida</u>	(1)	-	(2)	6
NISP	-	-	-	2,069
N	24	15	12	26
$N_{TS}$	16	12	7	14

IS (SW slope vegetation to recent midden): 73

IS (NW slope vegetation to recent midden): 77

IS (wash vegetation to recent midden): 67

Number of plant taxa in midden debris, not observed in vegetation: 6

Number of plant taxa in local vegetation, not observed in the midden: 7



TABLE 13. — *Plants in a recent midden from the Specter Range-2 site and those growing within 30 meters*

Relative abundance values for modern vegetation data are in parentheses; they indicate: 5, very abundant; 4, abundant; 3, common; 2, occasional; 1, rare; X, present within 30 meters; NISP, number of identified specimens; N, number of plant taxa; N<sub>TS</sub>, number of species of trees, shrubs, and succulents; IS, Sorensen's index of similarity<sup>1</sup>

Species	Modern vegetation (relative abundance)		Recent midden count
	Crest	Slopes	
<u>Ambrosia dumosa</u>	(1)	-	-
<u>Amphipappus fremontii</u>	(3)	-	-
<u>Artemisia</u> sec. <u>Tridentatae</u>	-	-	2
<u>Atriplex confertifolia</u>	(3)	(2)	533
Boraginaceae undet.	-	-	6
<u>Brickellia watsonii</u>	-	(2)	-
<u>Brickellia</u> sp.	-	-	1
<u>Bromus rubens</u>	(2)	(2)	7
<u>Buddleja utahensis</u>	-	(2)	28
<u>Cryptantha confertiflora</u>	-	(X)	-
<u>Echinocactus polycephalus</u>	(1)	-	-
<u>Ephedra torrevana</u>	(2)	(3)	262
<u>Eriogonum deflexum</u>	-	(X)	-
<u>E. heermanni</u>	(1)	(3)	6
<u>E. inflatum</u>	(X)	-	-
<u>Fendlerella utahensis</u>	-	-	3
<u>Galium stellatum</u>	(1)	(1)	-
<u>Gilia</u> sp.	-	-	2
<u>Gutierrezia microcephala</u>	(3)	(3)	20
<u>Haplopappus brickellioides</u>	-	(1)	3
<u>Krameria parvifolia</u>	(1)	(1)	-
<u>Larrea tridentata</u>	1/	-	1
<u>Leptodactylon pungens</u>	(1)	-	81
<u>Lycium andersonii</u>	-	(1)	-
<u>Oryzopsis hymenoides</u>	-	-	1
Poaceae undet.	-	-	27
<u>Prunus fasciculata</u>	(1)	(3)	103
<u>Salvia dorrii</u>	(2)	(1)	14
<u>Scopulophila rixfordii</u>	-	(3)	151
<u>Sitanion hystrix</u>	-	(1)	-
<u>Sphaeralcea ambiguus</u>	(1)	-	-
<u>Sphaeralcea</u> sp.	-	-	9
<u>Stipa arida</u>	(1)	(2)	-
<u>Stipa</u> sp.	-	-	1
<u>Thamnos montana</u>	(2)	(1)	4
NISP	-	-	1,266
N	18	19	23
N <sub>ts</sub>	13	12	15

IS (crest vegetation to recent midden debris): 64

IS (slope vegetation to recent midden debris): 74

Number of plant taxa in midden debris, not observed in vegetation: 5

Number of plant taxa in local vegetation, not observed in the midden: 5

<sup>1</sup> Present but more than 30 meters from the site.

## VEGETATION AND CLIMATES OF THE LAST 45,000 YEARS, NEVADA TEST SITE

TABLE 14.—Plants in recent midden debris from the Eleana Range-3 site and those growing within 30 meters

[Relative abundance values for modern vegetation data are in parentheses; they indicate: 5, very abundant; 4, abundant; 3, common; 2, occasional; 1, rare; X, present within 30 meters; NISP, number of identified specimens; N, number of plant taxa;  $N_{ts}$ , number of species of trees, shrubs, and succulents; IS, Sorensen's index of similarity]

Species	Modern vegetation (relative abundance)	Recent midden count
<u>Artemisia nova</u>	(2)	-
<u>A. tridentata</u>	(3)	-
<u>Artemisia</u> sec. <u>Tridentatae</u>	-	19
<u>Atriplex canescens</u>	(4)	387
Boraginaceae undet.	-	10
<u>Brickellia californica</u>	(1)	-
<u>Bromus rubens</u>	(X)	-
<u>Cowania mexicana</u>	(1)	153
<u>Cryptantha confertiflora</u>	(X)	-
<u>Cryptantha</u> sp.	-	1
<u>Ephedra torreyana</u>	(1)	-
<u>E. viridis</u>	(2)	-
<u>Ephedra</u> sp.	-	16
<u>Eriogonum caespitosum</u>	(1)	-
<u>E. fasciculatum</u>	(1)	-
<u>E. inflatum</u>	(X)	-
<u>E. microthecum</u>	(1)	-
<u>Festuca</u> sp.	(1)	-
<u>Forsellia nevadensis</u>	-	2
<u>Haplopappus nanus</u>	(2)	12
<u>Heterotheca villosa</u>	(X)	-
<u>Juniperus osteosperma</u>	(1)	75
<u>Leptodactylon pungens</u>	(1)	-
<u>Linum lewisii</u>	(X)	5
<u>Opuntia erinacea</u>	1/	1
<u>Oryzopsis hymenoides</u>	(X)	26
<u>Penstemon</u> sp.	-	1
<u>Phacelia</u> sp.	(X)	3
<u>Pinus flexilis</u>	-	3
<u>P. monophylla</u>	(2)	79
Poaceae undet.	-	177
<u>Purshia tridentata</u>	-	1
<u>Quercus gambelii</u>	1/	2
<u>Rhus trilobata</u>	(1)	5
<u>Salvia columbariae</u>	(X)	-
<u>Senecio multilobatus</u>	(X)	-
<u>Sphaeralcea</u> sp.	(1)	17
<u>Stanleya pinnata</u>	(1)	-
<u>Stipa</u> sp.	(3)	-
<u>Symphoricarpos longiflorus</u>	(2)	-
<u>Symphoricarpos</u> sp.	-	4
NISP	-	999
N	29	22
$N_{ts}$	16	15

IS (current vegetation to recent midden debris): 77

Number of plant taxa in midden debris, not observed in vegetation: 6

Number of plant taxa in local vegetation, not observed in the midden: 9

1/ Present but not more than 30 meters from the midden.

TABLE 15. — *Plants in a recent midden from the Connley Hills-1 and -2 sites, and those growing within 30 meters of each locality*

[Relative abundance values for modern vegetation data are in parentheses; they indicate: 5, very abundant; 4, abundant; 3, common; 2, occasional; 1, rare; X, present within 30 meters; NISP, number of identified specimens; *N*, number of plant taxa; *N*<sub>ts</sub>, number of species of trees, shrubs, and succulents; *IS*, Sorensen's index of similarity]

Species	Connley Hills-1		Connley Hills-2	
	Modern vegetation (relative abundance)	Recent midden count	Modern vegetation (relative abundance)	Recent midden count
<i>Amsinckia</i> sp.	(X)	2	-	-
<i>Artemisia tridentata</i>	(4)	25	(3)	138
Boraginaceae undet.	-	8	-	-
Brassicaceae undet.	(X)	-	-	-
<i>Bromus tectorum</i>	(2)	35	(3)	18
<i>Chenopodium</i> cf. <i>botrys</i>	-	-	-	50
<i>Chrysothamnus nauseosus</i>	(5)	37	(5)	230
<i>C. viscidiflorus</i>	(1)	2	(1)	-
<i>Chrysothamnus</i> sp.	-	148	-	40
<i>Descurainia</i> sp.	(X)	11	(X)	97
<i>Juniperus occidentalis</i>	(1)	432	(3)	1,059
<i>Oryzopsis hymenoides</i>	-	8	-	7
Poaceae undet.	(3)	904	(2)	156
<i>Purshia tridentata</i>	-	-	-	15
<i>Ribes cereum</i>	(1)	1	(1)	8
NISP	-	1,613	-	1,818
<i>N</i>	10	12	8	11
<i>N</i> <sub>ts</sub>	5	5	5	6

*IS* (current vegetation to recent midden at Connley Hills 1): 100

*IS* (current vegetation to recent midden at Connley Hills 2): 91

Number of plant taxa in Connley Hills 1 midden debris, not observed in vegetation: 0

Number of plant taxa in vegetation at Connley Hills 1, not observed in the midden: 0

Number of plant taxa in Connley Hills 2 midden debris, not observed in vegetation: 2

Number of plant taxa in vegetation at Connley Hills 2, not observed in the midden: 0

## VEGETATION AND CLIMATES OF THE LAST 45,000 YEARS, NEVADA TEST SITE

TABLE 16. — *Plants from the Owl Canyon (OC) Locality*

[Relative abundance values for modern vegetation data are in parentheses: they indicate: 5. very abundant; 4. abundant; 3. common; 2. occasional; 1. rare; X. present within 30 meters; NISP. number of identified specimens; N. number of plant taxa; N<sub>sp</sub>. number of species of trees, shrubs, and succulents; IS. Sorensen's index of similarity]

	Owl Canyon-2		Owl Canyon-3				
	Vegetation (relative abundance)	Macrofossil assemblages sample number and count		Vegetation (relative abundance)	Macrofossil assemblages sample number and count		
		OC-2(1)	OC-2(3)		OC-3(mod)	OC-3(1)	OC-3(2)
Approximate radiocarbon age	-	10,260	10,070	-	-	32,900	>28,700
Species							
<u>Agave utshensis</u>	-	706	437	-	-	324	185
<u>Agropyron</u> sp.	-	1	3	-	-	-	-
<u>Ambrosia dumosa</u>	(3)	-	-	(3)	55	-	-
<u>Amphipappus fremontii</u>	(1)	-	-	(2)	3	-	-
<u>Amsinckia</u> sp.	-	1	1	-	-	-	-
<u>Anemone tuberosa</u>	-	5	5	-	-	-	-
<u>Aristida</u> sp.	-	-	-	-	50	-	-
<u>Artemisia</u> sec. <u>Tridentatae</u>	-	-	-	-	-	2	-
Asteraceae undet.	-	5	13	-	165	-	5
cf. <u>Astragalus</u> sp. (2 spp.)	-	12	15	-	-	-	-
<u>Atriplex confertifolia</u>	-	2	-	-	4	41	4
Boraginaceae undet.	-	1	7	-	9	-	1
<u>Brickellia arguta</u>	(1)	-	-	(1)	2	-	-
<u>B. desertorum</u>	-	-	-	(1)	10	-	-
<u>Brickellia</u> sp.	-	22	51	-	-	-	-
<u>Bromus rubens</u>	(X)	-	-	(X)	1	-	-
<u>Buddleja utahensis</u>	-	83	161	-	-	4	6
<u>Cheilanthes feeli</u>	-	-	-	(X)	-	-	-
<u>Chorizanthe</u> cf. <u>brevicornu</u>	(X)	-	-	-	9	-	-
<u>Chrysothamnus nauseosus</u>	-	-	9	-	-	468	1,345
<u>Cirsium</u> sp.	-	207	88	-	-	25	-
<u>Cryptantha</u> sp.	(X)	-	-	(X)	76	-	-
<u>Echinocactus polycephalus</u>	(3)	-	-	(2)	7	-	7
<u>Encelia</u> sp.	-	-	1	-	-	-	-
<u>Ephedra torreyana</u>	-	-	-	(1)	7	-	-
<u>Ephedra</u> sp.	-	1	-	-	-	1	-
<u>Eriogonum heermanni</u>	-	-	-	(1)	4	-	-
<u>Eriogonum</u> sp.	(X)	-	-	-	-	-	-
<u>Eriogonum pulchellum</u>	(2)	-	-	(1)	15	-	-
<u>Eucnide urens</u>	(3)	-	-	(2)	125	-	-
Fabaceae undet.	-	-	-	-	-	-	2
<u>Fallugia paradoxa</u>	-	2	3	-	-	2	-
<u>Festuca octoflora</u>	-	-	-	(X)	-	-	-
<u>Gallium stellatum</u>	-	-	-	(1)	-	-	-
<u>Gilia rippleyi</u>	(X)	-	-	(X)	-	-	-
<u>Gutierrezia microcephala</u>	(2)	-	-	(4)	453	-	-
<u>Juniperus osteosperma</u>	-	-	1	-	-	1/	1/
<u>Haplopappus brickellioides</u>	-	-	-	(1)	-	-	-
<u>Hilaria rigida</u>	-	-	-	(X)	-	-	-

TABLE 16. — *Plants from the Owl Canyon (OC) Locality—Continued*

	Owl Canyon-2			Owl Canyon-3			
	Vegetation (relative abundance)	Macrofossil assemblages sample number and count		Vegetation (relative abundance)	Macrofossil assemblages sample number and count		
		OC-2(1)	OC-2(3)		OC-3(mod)	OC-3(1)	OC-3(2)
<u>Larrea divaricata</u>	(3)	-	-	(2)	764	-	-
<u>Lepidium</u> ct. <u>fremontii</u>	-	-	2	-	-	-	-
cf. <u>Leptodactylon</u> sp.	-	1	-	-	-	3	-
<u>Linanthus</u> sp.	-	-	-	-	<del>172</del>	-	-
<u>Lycium</u> sp.	-	3	-	-	-	-	-
<u>Nicotiana trigonophylla</u>	-	-	-	(1)	-	-	-
<u>Opuntia basilaris</u>	-	12	21	(1)	-	-	1
<u>Opuntia</u> sp.	-	-	-	-	-	130	129
<u>Penstemon</u> sp.	-	-	1	-	-	-	-
<u>Peucephyllum schottii</u>	(3)	-	-	(3)	56	-	-
<u>Physalis crassifolia</u>	-	-	-	-	1	-	-
<u>Plantago</u> sp.	-	-	-	-	4	-	-
<u>Pleurocoronis pluriseta</u>	(3)	-	-	(3)	-	-	-
Poaceae undet.	-	63	75	-	15	2	9
<u>Prunus fasciculata</u>	-	44	33	(1)	-	4	-
<u>Psoralea fremontii</u>	-	7	3	-	-	3	-
<u>Salvia dorrii</u>	-	17	1	(2)	21	6	7
<u>Scopulophila rixfordii</u>	-	91	115	-	-	279	614
<u>Sitanion hystrix</u>	-	-	-	(X)	-	-	-
<u>Sphaeralcea ambigua</u>	(1)	-	-	(1)	35	-	-
<u>Sphaeralcea</u> sp.	-	29	12	-	-	2	11
<u>Stipa arida</u>	(4)	-	-	(X)	-	-	-
<u>Stipa</u> sp.	-	-	3	-	6	-	-
<u>Symphoricarpos longiflorus</u>	-	-	-	-	-	33	34
NISP	-	1,315	1,063	-	2,069	1,329	2,360
N	17	23	24	28	26	18	16
N <sub>ca</sub>	10	14	15	20	16	16	13
IS (to current vegetation)	-	8	8	-	72	27	24

<sup>1/</sup>Very abundant (>1,000), not counted.

## VEGETATION AND CLIMATES OF THE LAST 45,000 YEARS, NEVADA TEST SITE

TABLE 17.—*Plants from the Point of Rocks (PR) 1 site*

[Relative abundance values for modern vegetation data are in parentheses; they indicate: 5, very abundant; 4, abundant; 3, common; 2, occasional; 1, rare; X, present within 30 meters; NISP, number of identified specimens; N, number of plant taxa;  $N_{TS}$ , number of species of trees, shrubs, and succulents; IS, Sorensen's index of similarity]

	Vegetation (relative abundance)	Macrofossil assemblages sample number and count	
		PR-1(1)	PR-1(3)
Approximate radiocarbon age		9,840	11,680
Species			
<u>Amaranthus</u> sp.	-	-	4
<u>Ambrosia dumosa</u>	(2)	-	-
<u>Ambrosia</u> sp.	-	-	1
<u>Amsinckia tessellata</u>	-	1	-
<u>Amsinckia</u> sp.	(X)	-	-
<u>Aristida</u> sp.	(X)	-	-
<u>Artemisia</u> sec. <u>Tridentatae</u>	-	62	13
Asteraceae undet.	-	12	50
<u>Atriplex canescens</u>	-	30	10
<u>Atriplex confertifolia</u>	(1)	-	-
Boraginaceae undet.	-	-	1
<u>Brickellia arguta</u>	(2)	-	-
<u>B. watsonii</u>	(1)	-	-
<u>Brickellia</u> sp.	-	-	-
<u>Bromus rubens</u>	(X)	-	56
<u>Ceratoides lanata</u>	-	36	-
<u>Cheilanthes fesi</u>	(X)	-	-
<u>Chorizanthe rigida</u>	(X)	-	-
<u>Coleogyne ramosissima</u>	-	8	17
<u>Cryptantha</u> sp.	-	-	1
<u>Echinocactus polycephalus</u>	(2)	-	-
<u>Ephedra funerea</u>	(2)	-	-
<u>Ephedra torrevans</u>	(1)	-	-
<u>Ephedra</u> sp.	-	64	-
<u>Eriogonum inflatum</u>	(X)	-	-
<u>Erioneuron puichellum</u>	(3)	-	-
<u>Erodium cicutarium</u>	(X)	-	-
<u>Euclide urens</u>	(2)	-	-
<u>Forsythesia nevadensis</u>	-	5	89
<u>Galium stellatum</u>	(2)	-	-

TABLE 17.—Plants from the Point of Rocks (PR)-1 site—Continued

	Vegetation (relative abundance)	Macrofossil assemblages sample number and count	
		PR-1(1)	PR-1(3)
<u>Gilia</u> sp.	-	-	1
<u>Gucierrezia microcephala</u>	(4)	76	152
<u>Krameria parvifolia</u>	(1)	-	-
<u>Langloisia serosissima</u>	-	-	7
<u>Larrea divaricata</u>	(2)	-	-
<u>Lepidium</u> cf. <u>fremontii</u>	-	142	-
<u>Lepidium</u> sp.	-	-	13
<u>Lepidospartum latisquamum</u>	-	25	185
<u>Leptodactylon pungens</u>	-	60	-
<u>Lycium andersonii</u>	(1)	-	-
<u>L. pallidum</u>	(3)	-	-
<u>Lycium</u> sp.	-	5	3
<u>Menodora spinescens</u>	-	43	14
<u>Nicotiana trizonophylla</u>	(1)	-	-
<u>Opuntia basilaris</u>	(1)	-	16
<u>O. echinocarpa</u>	1/	-	-
<u>O. cf. ramosissima</u>	-	-	18
<u>Opuntia</u> sp.	-	49	258
<u>Penstemon</u> sp.	(1)	-	-
<u>Peucephyllum schottii</u>	(1)	-	-
<u>Phacelia</u> sp.	(X)	-	-
<u>Plantago</u> sp.	(X)	1	1
Poaceae undec.	-	30	42
<u>Porophyllum gracile</u>	(1)	-	-
<u>Prunus fasciculata</u>	-	6	117
<u>Purshia glandulosa</u>	-	566	-
<u>Purshia</u> sp.	-	-	2
<u>Salvia dorrii</u>	-	1	-
<u>Scopolophila rixfordii</u>	-	-	3
<u>Sphaeralcea ambigua</u>	(2)	-	-
<u>Sphaeralcea</u> sp.	-	19	7
<u>Symphoricarpos longiflorus</u>	-	1	17
<u>Thamnosma montana</u>	(1)	2	-
<u>Yucca brevifolia</u>	-	12	-
NISP	-	1,256	1,098
N	31	24	28
N <sub>cs</sub>	19	19	17
IS (to current vegetation)	-	37	39

1/ Species in the vicinity, but occurring more than 30 meters from the site.

## VEGETATION AND CLIMATES OF THE LAST 45,000 YEARS, NEVADA TEST SITE

TABLE 18.—Plants from the Point of Rocks (PR)-2 and -3 sites

[Relative abundance values for modern vegetation data are in parentheses; they indicate: 5. very abundant; 4. abundant; 3. common; 2. occasional; 1. rare; X. present within 30 meters; NISP, number of identified specimens; N, number of plant taxa;  $N_{ts}$ , number of species of trees, shrubs, and succulents; IS, Sorensen's index of similarity]

	Point of Rocks-2		Point of Rocks-3		
	Vegetation (relative abundance)	Macrofossil assemblages		Vegetation (relative abundance)	Macrofossil assemblages sample number and count PP-3
		PR-2(2)	PR-2(3)		
Approximate radiocarbon age	-	9,560	9,260	-	14,800
Species					
<u>Agave utahensis</u>	-	186	195	-	-
<u>Ambrosia dumosa</u>	(2)	-	-	(4)	-
<u>Amphipappus fremontii</u>	(2)	3	45	(3)	-
<u>Amsinckia</u> sp.	(X)	2	-	(X)	5
<u>Aristida</u> cf. <u>adscensionis</u>	(X)	2	-	(3)	-
<u>Artemisia</u> cf. <u>bigelovii</u>	-	31	21	-	-
<u>Artemisia</u> sec. <u>Tridentatae</u>	-	-	-	-	2
Asteraceae undet.	-	5	30	-	14
<u>Atriplex</u> cf. <u>canescens</u>	-	-	1	-	-
<u>A. confertifolia</u>	(4)	-	-	(1)	415
Boraginaceae undet.	-	9	17	-	1
<u>Brickellia arguta</u>	(3)	-	-	(1)	-
<u>Bromus rubens</u>	(X)	-	-	(X)	-
<u>Buddleja utahensis</u>	-	-	-	-	11
<u>Ceratoides lanata</u>	-	-	9	-	-
<u>Cheilanthes feei</u>	(X)	-	-	(X)	-
<u>Chorizanthe brevicornu</u>	-	-	-	(X)	-
<u>C. rigida</u>	(X)	-	-	-	-
<u>Chorizanthe</u> sp.	-	2	-	-	-
<u>Chrysothamnus nauseosus</u>	-	-	6	-	101
<u>Coleogyne ramosissima</u>	-	66	103	-	11
<u>Coryphantha vivipara</u>	-	-	-	-	1
<u>Cryptantha</u> spp.	-	4	8	-	21
<u>Draba</u> sp.	-	2	3	-	-
<u>Echinocactus polycephalus</u>	(1)	1	-	(1)	1
<u>Encelia virginensis</u>	-	-	3	-	-
<u>Ephedra tunerea</u>	(1)	-	-	(2)	-
<u>E. torreyana</u>	(2)	96	236	(1)	-
<u>Ephedra</u> sp.	-	-	-	-	123
<u>Eriogonum heermannii</u>	-	-	-	-	5
<u>E. inflatum</u>	(X)	-	-	-	-
<u>Erioneuron pulchellum</u>	(2)	8	15	-	-
<u>Eucnide urens</u>	-	-	-	(2)	-
<u>Eurotia lanata</u>	-	-	9	(1)	-
<u>Fallegia paradoxa</u>	-	-	-	-	1
<u>Festuca octoflora</u>	-	-	-	-	-
<u>Forsythesia</u> sp.	-	-	2	(X)	4
<u>Galium stellasii</u>	(2)	-	-	-	-
<u>Gilia</u> sp.	-	34	53	-	-
<u>Gutierrezia microcephala</u>	(3)	-	-	(2)	-
<u>Gutierrezia</u> sp.	-	-	1	-	-
<u>Haplopappus brickellioides</u>	(3)	-	-	(2)	9
<u>Haplopappus</u> cf. <u>nanus</u>	-	-	-	-	9
<u>Hilaria ridgii</u>	(2)	-	-	(1)	-
<u>Krameria parvifolia</u>	(2)	-	-	-	-
<u>Lappula redowskii</u>	-	-	1	-	-
<u>Larrea divaricata</u>	(1)	30	2	(3)	-
<u>Lepidium fremontii</u>	(2)	102	8	(1)	-
<u>Lepidium</u> sp.	-	-	-	-	-
<u>Leptocacrylon pungens</u>	-	1	7	-	1

TABLE 18.—Plants from the Point of Rocks (PR)-2 and -3 sites—Continued

	Point of Rocks-2		Point of Rocks-3		
	Vegetation (relative abundance)	Macrofossil assemblages sample number and count		Vegetation (relative abundance)	Macrofossil assemblages sample number and count PR-3
		PR-2(2)	PR-2(3)		
<u>Lycium andersonii</u>	(1)	-	-	-	-
<u>Lycium sp.</u>	-	-	2	-	17
<u>Mirabilis sp.</u>	-	2	-	-	19
<u>Nicotiana trigonophylla</u>	-	-	-	(2)	-
<u>Opuntia basilaris</u>	-	32	34	-	-
<u>O. cf. erinacea</u>	-	-	34	-	-
<u>Dryopsis hymenoides</u>	(1)	2	3	-	-
<u>Penstemon sp.</u>	-	-	-	-	2
<u>Petrophytum caespitosum</u>	-	-	-	-	14
<u>Peucephyllum schottii</u>	(2)	-	-	(2)	-
<u>Phacelia sp.</u>	-	1	-	(X)	4
<u>Pleurocoronis plurisetata</u>	(2)	-	-	-	-
Poaceae undet.	-	57	104	-	17
<u>Prunus fasciculata</u>	-	-	-	-	1
<u>Scopulophila rixfordii</u>	-	442	220	-	-
<u>Sphaeralcea ambigua</u>	-	-	-	(2)	-
<u>Sphaeralcea sp.</u>	-	84	171	-	151
<u>Stephanomeria pauciflora</u>	(1)	-	-	-	-
<u>Stipa sp.</u>	-	-	1	-	-
<u>Symphoricarpos longiflorus</u>	-	1	-	-	961
<u>Thamnosma montana</u>	(1)	2	29	(2)	-
<u>Tidestromia oblongifolia</u>	-	3	18	-	-
<u>Yucca brevifolia</u>	-	-	-	-	13
<u>Y. schidigera</u>	1/	-	-	-	-
NISP	-	1,210	1,390	-	1,968
N	27	28	31	27	28
N <sub>ts</sub>	17	12	18	15	18
IS (to current vegetation)	-	41	40	-	24

1/ Species in the vicinity but occurring more than 30 meters from the site.

## VEGETATION AND CLIMATES OF THE LAST 45,000 YEARS, NEVADA TEST SITE

TABLE 19. — *Plants from the Last Chance Range (LCR)-1 site*  
 (Relative abundance values for modern vegetation data are in parentheses; they indicate: 5, very abundant; 4, abundant; 3, common; 2, occasional; 1, rare; X, present within 30 meters; NISP, number of identified specimens; N, number of plant taxa;  $N_{TS}$ , number of species of trees, shrubs, and succulents;  $IS$ , Sorensen's index of similarity)

Approximate radiocarbon age	Vegetation (relative abundance)	Macrofossil assemblages sample number and count		
		LCR-1(mod)	LCR-1(2)	LCR-1(3)
Approximate radiocarbon age	-	-	9,280	11,760
Species				
<u>Agave utahensis</u>	-	-	45	76
<u>Ambrosia acanthicarpa</u>	-	-	-	17
<u>A. dumosa</u>	(4)	127	-	-
<u>Amsinckia sp.</u>	-	-	4	1
<u>Anemone tuberosa</u>	-	-	-	4
<u>Artemisia sec. Tridentatae</u>	-	-	-	82
Asteraceae undet.	-	71	-	6
<u>Atriplex confertifolia</u>	(3)	189	-	-
Boraginaceae undet.	-	11	13	1
<u>Brickellia arguta</u>	-	-	1	-
<u>B. desertorum</u>	(1)	35	-	-
<u>Bromus rubens</u>	(3)	12	-	-
<u>Buddleja utahensis</u>	(3)	45	101	9
<u>Castilleja sp.</u>	-	-	-	6
<u>Cercocarpus intricatus</u>	-	-	2	37
<u>Cheilanthes feei</u>	(X)	-	-	-
<u>Chorizanthe brevicornu</u>	(X)	2	3	-
<u>C. rigida</u>	(X)	1	1	-
<u>Cirsium sp.</u>	-	-	-	10
<u>Cryptantha cf. pterocarya</u>	-	-	1	-
<u>Cryptantha sp.</u>	-	14	1	5
<u>Echinocactus polycephalus</u>	(1)	5	1	-
cf. <u>Echinocereus sp.</u>	-	-	-	1
<u>Encelia virginensis</u>	-	-	14	-
<u>Ephedra funerea</u>	(1)	-	-	-
<u>E. torreyana</u>	(1)	-	-	-
<u>E. viridis</u>	-	-	5	-
<u>Ephedra sp.</u>	-	52	-	32
<u>Eriogonum fasciculatum</u>	(1)	-	-	-
<u>Eriogonum heermanni</u>	(1)	-	-	-
<u>E. inflatum</u>	(X)	-	-	-
<u>Eriogonum sp.</u>	(X)	11	-	-
<u>Erioneuron pulchellum</u>	(1)	9	2	-
<u>Eschscholtzia sp.</u>	-	-	-	1
<u>Eucnida aerea</u>	(3)	74	29	-
<u>Forbesia nevadensis</u>	-	-	-	64
<u>Gilia sp.</u>	(1)	-	-	-
<u>Gilia sp.</u>	(X)	6	1	-
<u>Guthriea microcephala</u>	(2)	1	-	719
<u>Haplophragma brickelliodes</u>	-	2	7	-
<u>Juniperus osteosperma</u>	-	-	170	1/
<u>Larrea divaricata</u>	(4)	728	-	-
<u>Lepidium fremontii</u>	-	11	28	-
<u>Lepidium sp.</u>	-	-	-	29
<u>Lesquerella sp.</u>	-	-	1	-
<u>Lycium andersonii</u>	(1)	-	-	-
<u>Lycium sp. (not L. andersonii)</u>	-	-	110	14
<u>Mirabilis sp.</u>	-	2	-	-
<u>Mortonia utahensis</u>	(1)	65	854	4
<u>Muhlenbergia porteri</u>	(1)	-	-	-
<u>Nicotiana trigonophylla</u>	(2)	5	-	-
<u>Opuntia basilaris</u>	(1)	9	3	2
<u>O. cf. echinocarpa</u>	-	-	16	-
<u>Opuntia sp.</u>	-	-	-	10

TABLE 19.— *Plants from the Last Chance Range (LCR)-1 site—Continued*

	Vegetation (relative abundance)	Macrofossil assemblages sample number and count		
		LCR-1(mod)	LCR-1(2)	LCR-1(3)
<u>Penstemon</u> sp.	-	-	5	-
<u>Phacelia</u> sp.	(X)	-	3	-
<u>Plantago</u> sp.	-	12	2	-
<u>Pleurocoronis pluriseta</u>	(1)	-	-	-
Poaceae undet.	-	15	43	13
<u>Prunus fasciculata</u>	-	4	-	41
<u>Salvia dorrii</u>	(1)	10	36	820
<u>S. mohavensis</u>	(1)	2	-	-
<u>Sphaeralcea</u> sp.	-	24	19	32
<u>Stanleya</u> cf. <u>elata</u>	-	-	3	-
<u>Stipa arida</u>	(2)	12	-	-
<u>Symphoricarpos longiflorus</u>	-	-	4	183
<u>Yucca brevifolia</u>	-	-	217	-
NISP	-	1,566	1,751	2,219
N	31	28	34	28
N <sub>cs</sub>	19	19	20	18
IS (to current vegetation)	-	79	31	32

<sup>1/</sup>Very abundant (>1,000), not counted.

## VEGETATION AND CLIMATES OF THE LAST 45,000 YEARS. NEVADA TEST SITE

TABLE 20. — *Plants from the Specter Range (Spc)-2 site—Continued*  
 [Relative abundance values for modern vegetation data are in parentheses; they indicate: 5. very abundant; 4. abundant; 3. common; 2. occasional; 1. rare; X. present within 30 meters; NISP. number of identified specimens; N. number of plant taxa;  $N_{TS}$ . number of species of trees, shrubs, and succulents;  $IS$ . Sorensen's index of similarity]

Approximate radiocarbon age Species	Vegetation (relative abundance)		Macrofossil assemblages sample number and count									
	Crest and talus		Spc-2(mod)	Spc-2(2) <sub>1</sub>	Spc-2(2) <sub>2</sub>	Spc-2(3)	Spc-2(6)	Spc-2(8)	Spc-2(10)	Spc-2(11) <sub>1</sub>	Spc-2(11) <sub>2</sub>	Spc-2(12)
				18,740	19,290	23,280	25,900	1/27,900	29,140	1/32,260	32,100	25,150
<u>Ambrasia dumosa</u>	(1)	-	-	-	-	-	-	-	-	-	-	-
<u>Amphipappus fremontii</u>	(3)	-	-	-	-	-	-	-	-	-	-	-
<u>Artemisia</u> sec. <u>Tridentatae</u>	-	-	2	1	2	48	21	4	-	9	6	5
Asteraceae undet.	-	-	2	-	-	-	-	2	8	3	-	-
<u>Atriplex confertifolia</u>	(3)	(2)	533	-	-	336	21	33	40	217	118	18
Boraginaceae undet.	-	-	6	1	2	-	-	-	-	1	1	-
Brassicaceae undet.	-	-	-	-	-	-	1	-	-	-	-	-
<u>Brickellia watsonii</u>	-	(2)	-	-	-	-	-	-	-	-	-	-
<u>Brickellia</u> sp.	-	-	1	-	-	-	-	-	-	-	-	-
<u>Bromus rubens</u>	(2)	(2)	7	-	-	-	-	-	-	-	-	-
<u>Buddleja utahensis</u>	-	(2)	28	-	-	-	-	-	-	-	-	-
<u>Castilleja</u> sp.	-	-	-	-	-	-	-	-	-	-	-	-
<u>Ceratoides lanata</u>	-	(1)	-	-	-	-	4	1	2	2	1	25
<u>Cercocarpus intricatus</u>	-	-	-	35	32	1	-	-	-	-	-	-
<u>Chrysothamnus nauseosus</u>	-	-	-	-	-	5	-	3	-	-	-	5
<u>C. viscidiflorus</u>	-	-	-	1	4	3	-	-	-	-	-	12
<u>Chrysothamnus</u> sp.	-	-	-	-	-	-	13	-	-	-	-	-
<u>Coleogyne ramosissima</u>	(1)	-	1	-	-	-	-	-	-	-	-	-
<u>Cryptantha</u> cf. <u>confertiflora</u>	-	(1)	-	-	-	-	-	-	-	-	5	-
<u>Echinocactus polycephalus</u>	(1)	-	-	-	-	-	-	-	-	-	-	-
<u>Ephedra torreyana</u>	(2)	(3)	262	-	-	-	-	-	-	-	-	-
<u>Ephedra</u> sp.	-	-	-	1	2	-	-	-	-	1	-	-
<u>Erigeron</u> sp.	-	-	-	1	-	-	-	-	-	-	-	-
<u>Eriogonum deflexum</u>	-	(X)	-	-	-	-	-	-	-	-	-	-
<u>E. cf. fasciculatum</u>	-	-	-	-	-	5	2	-	-	-	2	-
<u>E. heermanni</u>	(1)	(3)	6	-	3	2	1	-	-	-	1	5
<u>E. inflatum</u>	(X)	-	-	-	-	-	-	-	-	-	-	-
<u>Fendlerella utahensis</u>	-	-	1	138	128	28	-	6	5	100	211	7
<u>Forsythesia cf. nevadensis</u>	-	-	-	-	-	-	-	-	1	-	-	-
<u>Galium stellatum</u>	(1)	(1)	-	-	-	-	-	-	-	-	-	-
<u>Gilia</u> sp.	-	-	2	-	-	-	-	-	-	-	-	-
<u>Gutierrezia microcephala</u>	(3)	(3)	20	-	-	-	-	-	-	-	-	-
<u>Haplopappus brickelliioides</u>	-	(1)	3	-	-	-	-	-	9	-	-	-
<u>H. cooperi</u> - type	-	-	-	-	-	-	14	10	-	29	19	-
<u>Hecastocleis shockleyi</u>	-	-	-	-	-	-	-	-	-	1	4	3
<u>Juniperus osteosperma</u>	-	-	-	2/	2/	2/	2/	2/	2/	2/	2/	2/
<u>Krameria parvifolia</u>	(1)	(1)	-	-	-	-	-	-	-	-	-	-
<u>Larrea divaricata</u>	3/	-	1	-	-	-	-	-	-	-	-	-
<u>Lepidium</u> sp.	-	-	-	-	-	3	2	-	-	-	-	-
<u>Leptodactylon pungens</u>	(1)	-	81	-	-	-	-	-	-	-	-	-
<u>Lesquerella</u> sp.	-	-	-	8	13	-	-	-	-	1	3	1
<u>Lycium andersonii</u>	-	(1)	-	-	-	-	-	-	-	-	-	-
<u>Mortonia utahensis</u>	-	-	-	-	-	-	-	-	-	16	-	3
<u>Opuntia</u> sp.	-	-	-	1	-	-	-	-	-	1	-	-
<u>Oryzopsis hymenoides</u>	-	-	1	-	25	3	4	1	-	1	1	1
<u>Penstemon</u> cf. <u>petiolatus</u>	-	-	-	-	-	-	-	-	-	-	-	4
<u>Petrophytum caespitosum</u>	-	-	-	7	12	150	51	3	6	207	303	57
<u>Pinus monophylla</u>	-	-	-	631	2/	-	-	-	-	-	-	-
<u>Pleurocoronis pluriseta</u>	-	-	-	-	-	-	-	8	-	-	-	-
Poaceae undet.	-	-	27	3	1	2	2	-	4	-	1	-
<u>Prunus fasciculata</u>	(1)	(3)	103	-	-	-	-	-	-	-	-	-
<u>Purshia tridentata</u>	-	-	-	-	-	-	-	1	-	1	-	-

TABLE 20. — Plants from the Specter Range (Spc)-2 site—Continued

Vegetation (relative abundance)	Macrotossil assemblages sample number and count											
	Ledges		Spc-2(mod)	Spc-2(2) <sub>1</sub>	Spc-2(2) <sub>2</sub>	Spc-2(3)	Spc-2(6)	Spc-2(8)	Spc-2(10)	Spc-2(11) <sub>1</sub>	Spc-2(11) <sub>2</sub>	Spc-2(12)
	Crest	and talus										
<i>Salvia dorrii</i>	(2)	(1)	14	-	-	1	-	-	-	-	-	-
<i>Scopulophila rixfordii</i>	-	(3)	151	-	1	27	11	185	48	91	229	160
<i>Sitanion histrix</i>	-	(1)	-	-	-	-	-	-	-	-	-	-
<i>Sphaeralcea ambigua</i>	(1)	-	-	-	-	-	-	-	-	-	-	-
<i>Sphaeralcea</i> sp.	-	-	9	-	-	-	-	-	-	-	-	-
<i>Stanleya</i> sp.	-	-	-	-	2	21	-	-	-	1	1	-
<i>Stipa arida</i>	(1)	(2)	-	-	-	-	-	-	-	-	-	-
<i>Stipa</i> sp.	-	-	1	-	-	1	-	-	-	-	-	-
<i>Streptanthus</i> sp.	-	-	-	3	-	-	-	-	-	-	-	-
<i>Symphoricarpos longiflorus</i>	-	-	-	224	78	30	34	56	65	39	102	91
<i>Tetradymia</i> sp.	-	-	-	4	1	61	44	1	4	2	57	14
<i>Thamnosma montana</i>	(2)	(1)	4	-	-	-	-	-	-	-	-	-
NISP	-	-	1,268	1,059	306	727	225	314	192	713	1,089	386
N	18	20	24	16	17	19	16	15	12	20	20	16
N <sub>CS</sub>	14	13	17	11	11	13	11	13	9	14	12	12
IS (to current vegetation)	-	-	72	7	13	19	20	12	21	18	19	13

<sup>1</sup>/ Exact chronologic position uncertain, see table 6.

<sup>2</sup>/ Very abundant (>1,000), not counted.

<sup>3</sup>/ Species in the vicinity, but occurring more than 30 meters from the site.

## VEGETATION AND CLIMATES OF THE LAST 45,000 YEARS, NEVADA TEST SITE

TABLE 21. — *Plants from the Specter Range (Spc)-3 site*

Relative abundance values for modern vegetation data are in parentheses; they indicate: 5, very abundant; 4, abundant; 3, common; 2, occasional; 1, rare; X, present within 30 meters; NISP, number of identified specimens; N, number of plant taxa;  $N_{Tg}$ , number of species of trees, shrubs, and succulents; IS, Sorensen's index of similarity

Approximate radiocarbon age	Vegetation (relative abundance)	Macrofossil assemblages sample number and count		
		Spc-3A(1)	Spc-3A(2)	Spc-3B
	-	20,200	1/	28,460
Species				
<u>Ambrosia dumosa</u>	(1)	-	-	-
<u>Amphipappus fremontii</u>	(2)	-	-	-
<u>Aristida</u> sp.	(1)	-	-	-
<u>Artemisia</u> sec. <u>Tridentatae</u>	-	2	36	127
Asteraceae undet.	-	-	19	8
<u>Atriplex confertifolia</u>	(2)	118	9	201
Boraginaceae undet.	-	-	-	1
<u>Brickellia arguta</u>	(3)	-	-	-
<u>B. watsonii</u>	(1)	-	-	-
<u>Buddleja utahensis</u>	(3)	-	-	-
<u>Castilleja</u> sp.	-	-	1	-
<u>Ceratoides lanata</u>	(2)	166	4	21
<u>Cercocarpus intricatus</u>	-	1	62	-
<u>Cheilanthes feei</u>	(X)	-	-	-
<u>Chrysothamnus nauseosus</u>	-	-	3	3
<u>Coleogyne ramosissima</u>	2/	-	16	-
<u>Cowania mexicana</u>	-	-	5	-
<u>Cryptantha</u> cf. <u>pterocarva</u>	-	-	10	-
<u>Cryptantha</u> sp.	(X)	-	15	-
<u>Descurainia</u> sp.	-	-	2	-
<u>Echinocactus polycephalus</u>	(1)	-	-	-
<u>Encelia virginensis</u>	(1)	-	-	-
<u>Ephedra funerea</u>	(1)	-	-	-
<u>E. nevadensis</u>	(1)	-	-	-
<u>Ephedra</u> sp.	-	-	207	-
cf. <u>Eriogonum fasciculatum</u>	-	-	-	1
<u>E. heermannii</u>	-	1	1	-
<u>E. inflatum</u>	(X)	-	-	-
<u>Fendlerella utahensis</u>	-	3	32	17
<u>Forsellesia</u> cf. <u>nevadensis</u>	-	1	4	2
<u>Galium stellatum</u>	(1)	-	-	-
<u>Gilia</u> sp.	-	-	24	2
<u>Gravia spinosa</u>	(2)	3	1	-
<u>Gutierrezia microcephala</u>	(2)	2	1	-
<u>Haplopappus cooperi</u> (or <u>nanus</u> )	-	-	7	2
<u>Juniperus osteosperma</u>	-	3/	3/	3/
<u>Larrea tridentata</u>	2/	-	-	-
<u>Lepidium fremontii</u>	(3)	2	5	2
cf. <u>Leptodactylon pungens</u>	-	-	1	2

TABLE 21. — *Plants from the Specter Range (Spc)-3 site—Continued*

	Vegetation (relative abundance)	Macrofossil assemblages sample number and count		
		Spc-3A(1)	Spc-3A(2)	Spc-3B
<u>Lesquerella</u> sp.	-	1	-	2
<u>Lycium andersonii</u>	(2)	-	-	-
<u>L. pallidum</u>	(2)	-	-	-
<u>Lycium</u> sp.	-	-	1	-
<u>Mirabilis</u> sp.	-	-	2	-
<u>Mortonia utanensis</u>	-	-	-	1
<u>Opuntia</u> cf. <u>erinacea</u>	-	-	5	-
<u>Opuntia</u> sp.	-	5	-	-
<u>Orvzopsis hymenoides</u>	(X)	3	2	1
<u>Petrophytum caespitosum</u>	-	12	1	15
<u>Phacelia</u> cf. <u>rotundifolia</u>	(X)	-	-	-
<u>Phacelia</u> sp.	-	-	6	-
<u>Plagiobothrys Jonesii</u>	(X)	-	-	-
<u>Poa fendleriana</u>	(1)	-	-	-
Poaceae undet.	-	-	5	1
<u>Scopulophila rixfordii</u>	(3)	10	8	114
<u>Sphaeralcea amigua</u>	(2)	-	-	-
<u>Sphaeralcea</u> sp.	-	2	-	-
<u>Stephanomeria pauciflora</u>	(1)	-	-	-
<u>Stipa arida</u>	(2)	-	-	-
<u>Symphoricarpos longiflorus</u>	-	91	609	162
<u>Tetradymia axillaris</u>	(1)	-	-	-
<u>Thamnosma montana</u>	(1)	-	-	-
<u>Yucca brevifolia</u>	-	-	-	1
<u>Yucca</u> sp.	-	-	3	-
NISP	-	423	1,107	686
N	33	18	33	22
N <sub>ts</sub>	20	15	22	15
IS (to current vegetation)	-	34	43	17

<sup>1/</sup>Contaminated sample, see table 6.

<sup>2/</sup>Species in the vicinity, but occurring more than 30 meters from the site.

<sup>3/</sup>Very abundant (>1,000), not counted.

## VEGETATION AND CLIMATES OF THE LAST 45,000 YEARS. NEVADA TEST SITE

TABLE 22. — *Plants from the Specter Range (Spc)-1 site*

[Relative abundance values for modern vegetation data are in parentheses; they indicate: 5, very abundant; 4, abundant; 3, common; 2, occasional; 1, rare; X, present within 30 meters; NISP, number of identified specimens; N, number of plant taxa;  $N_{TS}$ , number of species of trees, shrubs, and succulents;  $IS$ , Sorensen's index of similarity]

	Vegetation (relative abundance)			Macrofossil assemblages sample number and count	
	In wash	On rocks and terrace	On top of ridge	Spc-1(1)	Spc-1(2)
Approximate radiocarbon ages	-	-	-	300±40	100 <sup>+200</sup> <sub>-100</sub>
Species					
<u>Acanthopappus sphaerocephalus</u>	-	-	(1)	-	-
<u>Ambrosia dumosa</u>	(2)	-	(1)	3	21
<u>A. eriocentra</u>	(1)	-	-	-	-
<u>Amsinckia</u> sp.	-	-	-	1	3
<u>Arabis</u> sp.	(X)	(X)	-	-	-
<u>Aristida glauca</u>	-	(X)	-	-	-
Asteraceae undet.	-	-	-	22	21
<u>Atriplex canescens</u>	(3)	(1)	-	625	140
<u>A. confertifolia</u>	-	-	-	30	-
Boraginaceae undet.	-	-	-	2	5
<u>Brickellia arguta</u>	-	(3)	-	8	2
<u>B. desertorum</u>	-	(2)	-	-	-
<u>Bromus rigidus</u>	(X)	-	-	-	-
<u>B. rubens</u>	(X)	(X)	-	-	10
<u>Buddleja utahensis</u>	-	(1)	-	4	29
<u>Castilleja</u> sp.	-	-	(X)	-	-
<u>Ceratoides lanata</u>	-	(1)	-	40	22
<u>Chorizanthe rigida</u>	-	-	1/	-	-
<u>Chrysothamnus viscidiflorus</u>	-	-	-	1	-
<u>Coleogyne ramosissima</u>	-	-	1/	-	1
<u>Coryphantha vivipara</u>	-	-	(1)	-	-
<u>Cryptantha</u> sp.	(X)	-	(X)	-	-
<u>Cuscuta</u> sp.	(1)	-	-	1	-
<u>Descurainia</u> sp.	-	-	-	1	2
<u>Dichelostemma pulchellum</u>	(X)	-	-	-	-
<u>Echinocactus polycephalus</u>	-	-	(1)	-	-
<u>Echinocereus</u> sp.	-	-	-	-	1
<u>Encelia virginensis</u>	-	-	1/	-	-
<u>Ephedra nevadensis</u>	(3)	-	(1)	-	-
<u>E. torreyana</u>	-	(1)	-	-	-
<u>Ephedra</u> sp.	-	-	-	77	70
<u>Eriogonum heermanni</u>	-	(4)	-	3	4
<u>E. fasciculatum</u>	-	-	-	5	8
<u>E. inflatum</u>	-	(X)	-	-	-

TABLE 22. — *Plants from the Specter Range (Spc)-1 site—Continued*

	Vegetation (relative abundance)			Macrotossil assemblages sample number and count	
	In wash	On rocks and terrace	On top of ridge	Spc-1(1)	Spc-1(2)
<u>Erioneuron pulchellum</u>	-	(1)	-	-	-
<u>Euphorbia</u> sp.	-	-	-	2	1
<u>Festuca oviflora</u>	-	-	(X)	-	-
<u>Gilia</u> sp.	(X)	(X)	-	-	6
<u>Grayia spinosa</u>	-	-	(1)	15	55
<u>Cutierrezia microcephala</u>	-	(1)	-	75	171
<u>Hilaria rigida</u>	-	-	(X)	-	-
<u>Hymenoclea salsola</u>	(3)	-	-	15	84
<u>Krameria gravi</u>	-	-	1/	1	-
<u>Larrea divaricata</u>	(4)	-	-	87	576
<u>Lepidium fremontii</u>	(1)	-	-	34	23
<u>Lepidium</u> sp.	(X)	-	-	-	-
<u>Leptodactylon pungens</u>	-	-	(1)	-	-
<u>Lycium andersonii</u>	(2)	(2)	-	-	-
<u>L. pallidum</u>	(1)	-	-	-	6
<u>Lycium</u> sp.	-	-	-	34	23
<u>Machaeranthera tortifolia</u>	(1)	-	(1)	-	-
<u>Mirabilis bigelovii</u>	-	(X)	-	12	48
<u>Opuntia basilaris</u>	-	-	(1)	-	-
<u>Opuntia</u> sp. (not <u>O. basilaris</u> )	-	-	(1)	-	-
<u>Oryzopsis hymenoides</u>	-	-	(X)	1	5
<u>Oxytheca perfoliolata</u>	(X)	-	-	-	-
<u>Phacelia</u> sp.	(X)	-	-	2	-
<u>Plantago</u> sp.	-	-	-	1	2
Poaceae undet.	-	-	-	8	8
<u>Psoralea fremontii</u>	-	-	(1)	2	6
<u>Salazaria mexicana</u>	(1)	-	(1)	1	3
<u>Salsola kali</u>	(X)	-	-	-	-
<u>Scopulophila rixfordii</u>	-	(X)	-	-	-
<u>Sphaeralcea ambigua</u>	(1)	(2)	-	8	57
<u>Stanleya pinnata</u>	(1)	-	-	-	-
<u>Stipa</u> sp.	-	(X)	-	-	-
<u>Thamnosma montana</u>	(1)	-	(1)	16	3
<u>Yucca schidigera</u>	-	-	1/	-	-
<u>Yucca</u> sp.	-	-	-	6	55
NISP	-	-	-	1,165	1,469
N	26	19	18	35	34
N <sub>ts</sub>	11	11	13	25	24
IS (to current vegetation, combined)	-	-	-	73	70

1/ Species in the vicinity, but occurring more than 30 meters from the site.

TABLE 23.—Plants from the Eleana Range (ER)-2 site  
 [Relative abundance values for modern vegetation data are in parentheses; they indicate: 5, very abundant; 4, abundant; 3, common; 2, occasional; 1, rare; X, present within 30 meters; NISP, number of identified specimens; N, number of plant taxa;  $N_{TS}$ , number of species of trees, shrubs, and succulents;  $IS$ , Sorensen's index of similarity]

Approximate radiocarbon age	Species	Vegetation (relative abundance)	Macrofossil assemblages sample number and count									
			ER-2(1)	ER-2(2)	ER-2(3)	ER-2(4)	ER-2(5)	ER-2(6)	ER-2(7)	ER-2(9)	ER-2(10)	
			10,600	11,700	13,200	14,090	14,300	14,600	14,800	15,900	17,100	
	<i>Agropyron</i> sp.	(X)	-	-	-	3	-	-	-	-	-	
	<i>Arcuthobium</i> sp.	-	-	-	19	-	-	-	-	-	-	
	<i>Aristida</i> sp.	(X)	-	-	-	-	-	-	-	-	-	
	<i>Artemisia nova</i>	(1)	-	-	-	-	-	-	-	-	-	
	<i>A. tridentata</i> sec. <i>Tridentatae</i>	-	30	45	153	178	317	100	139	111	172	
	Asteraceae undet.	-	82	21	146	335	95	41	71	43	25	
	<i>Atriplex canescens</i>	(4)	6	-	-	-	-	-	-	-	-	
	Boraginaceae undet.	-	24	41	29	4	23	9	13	8	8	
	<i>Brickellia californica</i>	(1)	-	-	-	-	-	-	-	-	-	
	<i>Brickellia</i> sp.	-	2	2	-	-	-	-	-	-	-	
	<i>Bromus tectorum</i>	(X)	-	-	-	-	-	-	-	-	-	
	<i>Castilleja</i> sp.	-	-	-	-	2	1	-	-	-	-	
	<i>Cercocarpus ledifolius</i>	-	114	-	390	106	25	1	6	139	10	
	<i>Chamaebatista millefolium</i>	-	4	11	14	56	90	61	54	20	24	
	<i>Chrysothamnus nauseosus</i>	(2)	15	19	44	48	102	24	29	55	15	
	<i>C. viridiflorus</i>	(1)	9	2	82	184	111	43	109	24	20	
	<i>Cirsium</i> sp.	-	1	-	-	-	-	-	-	-	-	
	<i>Gouania mexicana</i>	1/	-	-	-	-	-	-	-	-	-	
	<i>Cryptantha confertiflora</i>	(X)	-	-	-	-	-	-	-	-	-	
	<i>Cryptantha</i> sp.	-	-	2	-	1	-	-	-	-	-	
	<i>Echinocereus triglochidiatus</i>	1/	-	-	-	-	-	-	-	-	-	
	<i>Ephedra nevadensis</i>	(1)	-	-	-	-	-	-	-	-	-	
	<i>E. stricta</i>	(2)	-	-	-	-	-	-	-	-	-	
	<i>Eriogonum fasciculatum</i>	1/	-	-	-	23	-	-	-	-	-	
	<i>E. inflatum</i> var. <i>deltatum</i>	(X)	-	-	-	-	-	-	-	-	-	
	<i>E. microthecum</i>	(X)	-	-	-	-	-	-	-	-	-	
	<i>Eriogonum</i> sp.	-	3	5	-	-	5	1	-	1	-	
	<i>Euphorbia</i> sp.	-	1	3	1	-	-	-	-	-	-	
	<i>Festuca</i> sp.	(X)	-	-	-	-	-	-	-	-	-	
	<i>Forbesia nevadensis</i>	1/	-	-	-	-	-	-	-	-	-	
	<i>Gilia</i> sp.	-	-	-	-	1	-	-	1	-	-	
	<i>Hesperopappus nanus</i>	(1)	211	131	108	106	87	67	51	19	-	
	<i>Heterotheca villosa</i>	(X)	-	-	-	-	-	-	-	-	-	
	<i>Hilaria jamesii</i>	(X)	-	-	-	-	-	-	-	-	-	
	<i>Holodiscus microphyllum</i>	-	4	-	7	20	5	2	11	2	1	
	<i>Hesperis matronalis</i>	1/	2/	270	1	-	-	-	-	-	-	
	<i>Leptidium</i> sp.	-	-	-	1	-	-	-	-	-	-	
	<i>Leptodactylon purpureum</i>	-	32	1	-	2	5	2	2	15	3	
	<i>Lesquerella</i> sp.	-	9	-	1	-	1	3	-	1	1	
	<i>Limonium lewisii</i>	(X)	-	-	-	-	-	-	-	-	-	
	<i>Lupinus</i> cf. <i>argenteus</i>	-	7	6	12	86	256	170	191	155	212	
	<i>Michaeranthera canescens</i>	(2)	-	-	-	-	-	-	-	-	-	
	<i>Michaeranthera</i> sp.	-	1	-	-	-	-	-	-	-	-	
	<i>Opuntia grisea</i>	1/	586	576	-	-	-	-	-	-	-	
	<i>Opuntia</i> sp.	-	-	-	-	1	-	-	-	-	-	
	<i>Oryzopsis hymenoides</i>	(X)	14	6	7	27	37	18	15	11	15	
	<i>Pennisetum</i> sp.	1/	1	-	2	-	-	3	24	2	2	
	<i>Petalodora pomila</i>	1/	1	1	2	6	2	-	-	8	-	
	<i>Phacelia mustelina</i>	(X)	-	-	-	-	-	-	-	-	-	
	<i>Phacelia</i> sp.	(X)	-	-	-	-	-	-	-	-	-	
	<i>Pinus flexilis</i>	-	6	22	2/	2/	2/	2/	2/	2/	2/	
	<i>P. monophylla</i>	1/	95	225	-	-	-	-	-	-	-	
	Portulacaceae undet.	-	58	127	116	46	203	302	164	108	80	

TABLE 23. — Plants from the Eleona Range (ER)-2 site — Continued

	Vegetation (relative abundance)	Macrofossil assemblages																	
		ER-2(1)	ER-2(2)	ER-2(3)	ER-2(4)	ER-2(5)	ER-2(6)	ER-2(7)	ER-2(9)	ER-2(10)									
<i>Pinus</i> <i>taeuschulata</i>	1/	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Parashola</i> <i>tridentata</i>	-	65	40	-	-	24	12	18	4	1	-	-	-	-	-	-	-	-	-
<i>Onoclea</i> <i>gambellii</i>	1/	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Rhus</i> <i>trilobata</i>	1/	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Ribes</i> cf. <i>velutinum</i>	-	2	-	-	-	2	3	-	-	-	-	-	-	-	-	-	-	-	-
<i>Salix</i> <i>donnellii</i>	-	99	88	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Senecio</i> <i>multilobatus</i>	(X)	-	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Silene</i> <i>hystrix</i>	(X)	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Sphaeralcea</i> cf. <i>ambigua</i>	1/	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Staphylea</i> <i>pinnata</i>	(1)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Stellaria</i> sp.	(X)	-	2	-	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-
<i>Symphoricarpos</i> <i>longiflorus</i>	1/	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Symphoricarpos</i> sp.	-	6/	31	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Tetradymia</i> <i>canescens</i>	(3)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Tetradymia</i> sp.	-	6	3	67	183	208	222	186	214	160	-	-	-	-	-	-	-	-	-
HSP	-	1,521	1,719	1,186	1,461	1,570	1,088	1,069	927	988	-	-	-	-	-	-	-	-	-
HSP-AT	-	1,480	1,173	1,185	1,461	1,570	1,088	1,069	927	988	-	-	-	-	-	-	-	-	-
N	28	33	27	20	25	24	20	17	20	16	-	-	-	-	-	-	-	-	-
H <sub>2</sub> S	10	23	18	13	17	15	12	11	12	10	-	-	-	-	-	-	-	-	-
L <sub>2</sub> /L <sub>3</sub>	-	79	86	58	59	48	45	41	45	40	-	-	-	-	-	-	-	-	-

1/ Species in the vicinity, but more than 30 meters from the site.

2/ Very abundant (&gt;1,000), not counted.

3/ Includes those fossil trees, shrubs, and succulents that now occur in the vicinity, but more than 10 meters from the site.



TABLE 24. — *Plants from the Eleana Range (ER)-3 site—Continued*

Vegetation (relative abundance)	Macrofossil assemblages sample number and count											
	ER-3(mod)	ER-3(2)	ER-3(3)	ER-3(4)	ER-3(6)	ER-3(7) <sub>2</sub>	ER-3(8) <sub>2</sub>	ER-3(8) <sub>3</sub>	ER-3(9)	ER-3(10)	ER-3(13)	
<i>Quercus gambelii</i>	2/	2	-	-	-	-	-	-	-	-	-	-
<i>Rhus trilobata</i>	(1)	5	-	-	-	-	-	-	-	-	-	-
<i>Ribes cf. velutinum</i>	-	-	1	-	1	-	-	-	1	-	-	-
<i>Ribes sp.</i>	-	-	-	1	-	4	-	-	-	-	-	-
<i>Salvia columbariae</i>	(X)	-	-	-	-	-	-	-	-	-	-	-
<i>S. dorrii</i>	-	-	-	-	-	-	-	-	-	-	-	1
<i>Senecio multiflorus</i>	(X)	-	-	-	-	-	-	-	-	-	-	-
<i>Sphaeralcea sp.</i>	(1)	17	-	-	-	-	-	-	-	-	-	1
<i>Stanleya pinnata</i>	(1)	-	-	-	-	-	-	-	-	-	-	-
<i>Stipa sp.</i>	(X)	-	-	-	-	-	-	-	-	1	-	-
<i>Symphoricarpos longiflorus</i>	(2)	-	-	-	-	-	-	-	-	-	-	-
<i>Symphoricarpos sp.</i>	-	4	-	27	79	39	28	135	101	97	132	86
<i>Tetradymia sp.</i>	-	-	125	18	78	37	81	126	71	92	100	26
NISP	-	999	1,068	1,646	2,014	1,616	1,386	1,347	1,434	1,780	2,674	2,322
N	33	22	14	17	21	19	14	16	19	19	15	20
N <sub>cs</sub>	20	14	11	12	14	12	10	12	14	11	10	16
IS (to current vegetation)	-	71	32	38	47	38	40	50	47	39	40	44

1/ Age uncertain, see table 6.

2/ Species in the vicinity, but more than 30 meters from the site.

## VEGETATION AND CLIMATES OF THE LAST 45,000 YEARS, NEVADA TEST SITE

TABLE 25.—Plants from the Eureka View (EV) fossil locality<sup>1</sup>

[Macrofossil data are presented in terms of relative abundance classes: 5, very abundant; 4, abundant; 3, common; 2, occasional; 1, rare; 0, less than five fragments, a possible contaminant. B.P., before present; N, total number of plant taxa; N<sub>p</sub>, total number of woody perennials; IS, Sorensen's index of similarity between macrofossil assemblage and the modern plant community (using N); %, percent. Data from Spaulding (1980)]

Approximate radiocarbon age	Relative abundance of species in macrofossil assemblage									
	EV-1	EV-2A	EV-2B	EV-2C	EV-3	EV-4 (1)	EV-4 (2)	EV-4 (3)	EV-5A	EV-5B
2,635± 140 B.P.	No date	1,580± 140 B.P.	3,930± 180 B.P.	535± 150 B.P.	5,595± 210 B.P.	6,795± 190 B.P.	5,435± 220 B.P.	14,720± 530 B.P.	8,330± 250 B.P.	
<b>Species</b>										
<i>Ambrosia dumosa</i> <sup>2/</sup>	3	1	-	-	-	2	2	1	-	-
<i>Amphipappus fremontii</i> <sup>2/</sup>	-	-	2	-	2	-	-	-	-	-
<i>Amsinckia intermedia</i>	-	-	-	-	-	1	-	-	1	1
<i>A. tessellata</i>	2	2	-	-	-	-	-	-	-	-
<i>Amsinckia</i> sp. <sup>2/</sup>	-	-	-	1	-	-	-	-	-	-
<i>Aristida adscensionis</i> <sup>2/</sup>	-	-	-	-	-	-	-	-	-	-
<i>Artemisia</i> sec. <i>Tridentatae</i>	0	-	-	-	-	-	1	-	2	-
<i>Atriplex confertifolia</i> <sup>3/</sup>	5	4	5	4	3	5	5	4	4	5
<i>Brickellia arguta</i> <sup>2/</sup>	-	-	-	-	-	-	-	-	-	-
<i>Cheilanthes feei</i> <sup>2/</sup>	-	-	-	-	-	-	-	-	-	-
<i>Chorizanthe</i> cf. <i>brevicornu</i>	-	1	1	-	-	-	-	-	-	-
<i>Chorizanthe</i> cf. <i>rigida</i> <sup>2/</sup>	1	1	1	1	-	-	-	-	-	-
cf. <i>Chrysothamnus</i> sp.	-	-	-	-	-	-	-	-	-	-
<i>Cryptantha</i> sp.	-	-	2	-	2	-	-	-	2	-
<i>Echinocactus polycephalus</i> <sup>2/</sup>	2	0	1	1	-	-	-	-	1	-
<i>Encelia virginensis</i>	-	-	-	2	-	3	3	4	0	-
<i>Ephedra nevadensis</i> <sup>2/</sup>	-	-	-	-	-	-	-	-	-	-
<i>Ephedra</i> cf. <i>viridis</i>	-	-	-	-	-	-	-	-	-	-
<i>Ephedra</i> sp.	-	1	2	-	-	-	-	-	3	-
<i>Eriogonum inflatum</i> <sup>2/</sup>	-	1	-	-	-	-	-	-	-	3
<i>E. fasciculatum</i> <sup>2/</sup>	-	2	2	-	1	-	-	-	-	-
<i>Eriogonum</i> sp.	1	-	1	-	-	-	-	-	-	-
<i>Erioneuron pulchellum</i> <sup>2/</sup>	1	1	3	2	2	2	1	2	1	-
<i>Euclide urens</i> <sup>2/</sup>	-	-	-	-	-	-	-	-	-	-
<i>Euphorbia</i> sp.	-	-	-	-	-	-	-	-	-	-
<i>Festuca</i> sp.	-	2	-	-	-	-	1	-	2	-
<i>Foresellisia nevadensis</i>	-	-	-	-	-	-	-	-	-	1
<i>Gilia</i> sp. <sup>2/</sup>	1	1	1	-	1	-	-	-	1	-
<i>Gutierrezia microcephala</i> <sup>2/</sup>	-	-	1	-	-	-	-	-	-	1
<i>Haplopappus brickellioides</i> <sup>2/</sup>	-	-	-	1	2	1	3	2	-	1
<i>H. laticifolius</i> <sup>2/</sup>	-	-	-	-	-	-	-	-	-	-
<i>Haplopappus</i> sp.	1	-	-	-	-	-	-	-	-	-
<i>Hecastocleis shockleyi</i>	-	-	-	-	-	-	-	-	-	-
<i>Juniperus osteosperma</i>	-	-	-	-	-	0	-	-	3	-
<i>Larrea tridentata</i> <sup>3/</sup>	4	5	5	2	5	-	-	0	5	-
<i>Lepidium</i> cf. <i>fremontii</i>	2	1	1	-	-	1	1	2	1	2
<i>Lepidium</i> sp.	-	-	-	-	1	-	-	-	-	-
<i>Lycium</i> sp.	-	-	-	-	-	2	2	1	-	-
cf. <i>Machaeranthera</i> sp.	-	-	-	-	-	-	-	-	1	-
<i>Mirabilis</i> sp.	-	-	-	-	-	1	-	-	-	-
<i>Nama</i> sp. <sup>2/</sup>	-	-	-	-	-	-	-	-	1	1
<i>Nicotiana trigonophylla</i> <sup>2/</sup>	-	-	-	1	-	-	-	-	-	-
<i>Opuntia basilaris</i>	1	1	3	3	-	3	4	4	-	-
<i>O. echinocarpa</i>	2	-	-	-	-	-	-	-	-	-
<i>Opuntia</i> sp.	-	-	2	3	2	2	-	-	-	-
<i>Penstemon</i> sp.	-	-	1	1	-	-	-	-	1	-
<i>Peucephyllum schottii</i>	-	-	2	1	2	-	-	-	-	-
<i>Phacelia crenulata</i> <sup>2/</sup>	-	-	-	-	-	-	-	-	-	-
<i>Phacelia</i> sp.	1	1	1	-	-	1	2	1	-	-
<i>Physalis</i> cf. <i>crassifolia</i> <sup>2/</sup>	3	1	1	1	-	1	-	-	1	1
<i>Pinus</i> cf. <i>flexilis</i>	-	-	-	-	-	-	-	-	1	-
<i>Psoralea fremontii</i>	-	-	3	-	-	1	3	1	-	1

TABLE 25.— *Plants from the Eureka View (EV) fossil locality—Continued*<sup>1</sup>

	Relative abundance of species in microfossil assemblage									
	EV-1	EV-2A	EV-2B	EV-2C	EV-3	EV-4 (1)	EV-4 (2)	EV-4 (3)	EV-5A	EV-5B
<i>Salvia dorrii</i>	-	-	-	-	-	-	-	-	1	-
cf. <i>Sclerocactus</i> sp.	-	-	-	-	-	-	-	-	1	-
<i>Scopulophila rixfordii</i> <sup>2/</sup>	1	-	-	1	1	1	2	1	-	1
<i>Sphaeralcea</i> sp.	-	-	-	-	-	-	-	-	1	-
<i>Stipa</i> sp. <sup>2/</sup>	-	1	2	1	1	-	-	1	-	-
<i>Symphoricarpos</i> cf. <i>longiflorus</i>	-	-	-	-	-	-	-	-	1	-
<i>Tidestomia oblongifolia</i>	1	-	-	1	-	-	-	-	-	-
<i>Viguiera reticulata</i> <sup>2/</sup>	3	-	-	-	2	-	-	-	-	-
N (26)	19	18	22	18	14	16	13	12	22	12
N <sub>p</sub> (15)	12	8	13	11	9	11	10	10	14	6
N <sub>p</sub> /N (100) (58%)	63%	44%	59%	61%	64%	69%	77%	77%	64%	50%
IS	62	64	58	54	50	38	31	41	17	37

<sup>1/</sup> In the northern Eureka Valley, Inyo County, California (1,390 to 1,555 meters; T. 7 S., R. 38 E., S<sub>4</sub>W<sub>4</sub> sec. 23; Soldier Pass, California-Nevada 15' quadrangle).

<sup>2/</sup> Plant species presently at site.

<sup>3/</sup> Dominant plant species presently at site.