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**EVIDENCE OF LATE QUATERNARY WET/DRY CLIMATE EPISODES
DERIVED FROM PALEOCLIMATIC PROXY DATA
RECOVERED FROM THE PALEOENVIRONMENTAL RECORD OF
THE GREAT BASIN OF WESTERN NORTH AMERICA:
PALEOBOTANICAL STUDIES**

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Quaternary Sciences Center

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GENERAL INTRODUCTION

Site Requirements

Assessment of site suitability and design appropriateness requires clear understandings of the directions, magnitudes and rapidity of climate changes and their impact upon ground water regimes. Because historic climate records indicate very little regarding the possible range of climate even during the last 500 years, full understanding of the possible impacts of future climate change requires knowledge not only of the range of modern climates, but also of past climates. In particular, patterns of past climate variation must be explored in order to reveal not only the possible range of mean climate, but also the potential extremes that may reasonably be expected during the next 10,000 years or so at which time stored materials will have decayed sufficiently to render them harmless. Although studies of orbital mechanics provide speculative notions of future climatic trends, they cannot be used to predict how these trends will manifest themselves in the immediate vicinity of Yucca Mountain, or even, at present, in the Intermountain West. In order to address these concerns, conditions under which extremes of wetter climate have occurred during the late Quaternary (the last 200,000 years or so) must be considered and used as a guide to the likely range of future climate variation. Reconstructed vegetation history and information related to the physiological requirements of key indicator plants provide one of the most direct means of determining past atmospheric inputs into the hydrologic system.

Project Goals

The goals of the studies being conducted by the research staff of the Quaternary Sciences Center at the Desert Research Institute are several pronged. Through the integration of several

avenues of paleoclimatic proxy data, we intend to arrive at definite conclusions regarding the frequency of periods of wetter climate, and to derive information regarding the magnitudes of these episodes, rates of their onset and demise, and the climatic conditions under which wetter climate can occur. These will in turn lead to rough estimates of :

- 1) the amounts of rainfall available for recharge during past periods of effectively wetter climate
- 2) the durations and spacing of such events that provide an indication of the amount of time that the area was subjected to these inputs

These understandings can in turn be used to estimate the possibility that such events may occur in the future and the potential hydrologic input that may result from such events.

The geohydrologist can use this information to provide estimates of:

- 1) ground water movement (flux) through the unsaturated zone
- 2) how much water is required to raise the surface of the ground water table a certain distance
- 3) the rapidity of response of the surface of the saturated zone to inputs from the surface

To accomplish these goals the paleobotanical record over a broad region is being examined to identify periods of greater effective precipitation. Although the project focus is on a region of about 200 km around Yucca Mountain, we have collected data in other areas of the Great Basin in order to be able to identify large-scale climatic patterns. Once identified and described these climatic

patterns can be separated from purely local climatic phenomena that might hinder our understanding of the Pleistocene climates of southern Nevada and the Yucca Mountain area in particular.

Index plant species are being used to constrain the temperature and precipitation ranges that occurred during those periods. Because established biotic communities can assimilate much of the water that arrives during a period of mesic climate through increases in their biomass, estimates of past vegetation density based upon pollen and other paleobotanical data are being combined with geomorphic (alluvial, fluvial and lacustrine) analyses to provide estimates of excess water availability. For example, Dr. N. Lancaster of the Desert Research Institute has been conducting aeolian geomorphic studies to provide 1) estimates of surface exposure, an indirect measure of vegetation density (a strong factor affecting rainfall interception), and 2) a measure of lake level fluctuation and fluvial activity (aeolian dunes obtain most of their supply of sand from unvegetated playas and river channel deposits).

Clearly it is not enough to study only one or two aspects of the ecosystem in order to reconstruct past climate. Each portion of the biotic and abiotic environment at the ground surface feeds back into the system as it responds to changes in hydrologic input from the atmosphere and thereby affects other parts of the system. In this way the amount of precipitation actually available for recharge may vary considerably even under the same rainfall regime.

An additional dimension of our investigations have involved paleoenvironmental studies conducted in several areas of the Great Basin. We have collected information that will reveal late Quaternary variations in the position of the polar front (which governs the westerly storm track) along a north south transect ranging from southern Oregon through southern Nevada--the potential range of variation in its position during the late Quaternary. Also, as these studies progress they will provide us with understandings of seasonal variations in the behaviour and location of the polar for

the Pleistocene and the Holocene. At any one location shifts in the position of the westerly storm track governed the nature of past rainfall, including its seasonality and amount, and its duration and intensity. Each of these factors effected ground water recharge differentially.

Finally, because we have been interested in both climatic history and process we have generated data that focus not only upon the chronologically coarse proxy climate record of the late Pleistocene, but also upon the late Holocene, a period where high resolution paleoclimatic proxy records can more accurately reveal high frequency changes in climate, rates of change, and their impacts upon other portions of the environment. Vegetation of the late Holocene is more clearly correlatable to modern analogues. These linkages lead to the development of transfer functions that may be used to assess the less robust and sparser paleoclimatic proxy data of the Pleistocene. In addition, study of the more recent record provides an understanding of the possible ranges of climate under late Holocene conditions...a period where we can resolve climatic variations of shorter duration, but of magnitudes almost as great as those of the Pleistocene. These conditions are the most likely to affect the Repository in the immediate future. This work is ongoing and will be reported as a radiocarbon chronology is better established.

TERRESTRIAL VEGETATION RECORDS

INTRODUCTION

Periods of wetter climate, their frequencies, magnitudes, rates of onset and decline, and shifts in their seasonal distribution are identified using plant remains from woodrat middens. One-hundred ninety-five radiocarbon dates on plant macrofossils from 122 woodrat midden strata collected from seven areas in southern Nevada provide climate proxy data to interpret past levels of MAP and MAT (Table 1, Figure 1). This study has focused on: 1) direct and high-precision dating of key plant species and 2) multiple dates on several species from the same strata to confirm the age of the woodrat midden strata.

MODERN CLIMATE AND VEGETATION OF SOUTHERN NEVADA DESERTS

Yucca Mountain is located in the Mojave Desert, just south of the boundary with the Great Basin Desert to the north (Hunt 1973) (Figure 1). The climate and vegetation in the region are influenced by three climatic systems (Houghton 1969; Houghton and others, 1975):

Pacific: a regime dominated by maritime polar air masses created when the edge of the polar cell moves south in winter. These cool, moist air masses from the Pacific Ocean produce cool, wet winters and hot, dry summers. Plant species favoring this regime extend into southern Nevada from west and northwest of Yucca Mountain.

Gulf: a regime dominated by maritime and continental tropical air masses resulting from

Table 1. Southern Nevada Woodrat Middens currently being analyzed.

Midden Number	Radiocarbon Age	δ 13C	Laboratory Beta #	Laboratory AMS #	Material Dated	Midden Number	Radiocarbon Age	δ 13C	Laboratory Beta #	Laboratory AMS #	Material Dated
Eureka Valley						Crankshaft Junction					
EV150490RTJ1(1)0000	13,420±110	-22.9	Beta-38739		juniper	CJ190389CLN1(1)	890±80	-23.9	Beta-38737		dung
Little Skull Mountain, Nevada Test Site, Nevada						Devil's Hole Hills, Owl Canyon, Nevada					
LSM151182LP1(2,2)	14,970±340	-20.8	Beta-25678		juniper	OC210594ARM8	37,940±470	-24.2	Beta-86040		JUNIPER*
	14,280±180	-18.0	Beta-25677		yucca*	OC020469PJM1 (2)	21,450±130	-27.5	Beta-64329	Cams-8007	sagebrush
LSM151182LP1(2,1)	13,740±130	-22.9	Beta-25679		juniper*	OC210594MLH7 (3)CM	20,250±70	-24.7	Beta-86043		RABBITBRUSH
LSM151182LP1(2,3)	11,970±110	-22.4	Beta-25676		juniper	OC210594MLH7 (5)CF	19,970±90	-22.8	Beta-86046		JUNIPER
LSM151182LP1(2,4)	10,460±140	-24.6	Beta-25675		dung*	OC210594MLH7 (1)C	18,900±80	-11.8	Beta-75419	Cams-15681	saltbush
LSM151182LP1(3,1)	10,030±120	-24.5	Beta-25680		dung	OC210594MLH7 (1)B	18,570±80	-26.1	Beta-75418	Cams-15680	Asteraceae
LSM151182LP1(3,2)	9,480±370	-24.7	Beta-26011		dung	OC210594MLH7 (4)LW	16,670±70	-27.7	Beta-86045		SAGEBRUSH
LSM151182LP1(4)	8,480±130	-23.1	Beta-26581		dung	OC210594MLH7 (4)LW	14,200±70	-21.2	Beta-86044		JUNIPER
LSM151182LP1(1)	6,680±240	-20.2	Beta-25674		dung	OC210594MLH7 (1)A	13,540±60	-23.6	Beta-86041		JUNIPER
LSM141282RR1(1)	1,940±80	-22.5	Beta-25682		dung	OC150589PEW2(1)	12,260±110	-24.8	Beta-32398		dung
LSM091282LP1(1)	1,090±70	-22.7	Beta-25681		dung		12,570±250	-22.9	Beta-32399		juniper
Fortymile Wash, Nevada Test Site, Nevada						OC210594MLH7 (1)CB	10,350±60	-25.7	Beta-86042		JUNIPER
FW300582LCP2	2,160±70	-24.7	Beta-64344	Cams-8022	twigs	OC020469PJM1(1)	9,420±130	-23.8	Beta-34790		dung
French Peak, Massachusetts Range, Nevada Test Site, Nevada							9,630±70	-28.2	Beta-64328	Cams-8006	twigs
FP230394PEW1 (1)A	310±60	-9.8	Beta-86035		twigs	OC210594SES1 (3)	9,310±50	-23.9	Beta-86051		PRUNUS
Scarp Wash, Nevada Test Site, Nevada						OC020469PJM1(3)	8,290±80	-21.2	Beta-34791		dung
SCW230394PEW1 (1)	1,160±60	-22.9	Beta-86086		CHRYSO		8,180±60	-27.2	Beta-64330	Cams-8008	twigs
SCW230394PEW1 (1)	1,040±60	-22.8	Beta-86085		CREOSO	OC210594SES1 (1)	6,700±60	-24.5	Beta-86050		CREOSOTE
Last Chance Range, Nevada						OC150589PEW1(1)CU	4,000±50	-25.7	Beta-86039		CREOSOTE
LCR180493PEW1(2,3)	11,120±70	-25.0	Beta-64349	Cams-8027	juniper	OC210594PEW3 (1)TP	3,960±50	-24.9	Beta-86048		CREOSOTE
LCR180493PEW1(2,2)A	10,360±80	-23.9	Beta-64348	Cams-8026	juniper	OC210594SES5 (1)	3,120±50	-25.2	Beta-86052		CREOSOTE
LCR130588PEW1(1)	7,790±120	-25.5	Beta-32396		dung	OC150589PEW1(1)	2,970±50	-25.0	Beta-32397		dung
Stockade Wash, Nevada Test Site, Nevada							1,740±70	-28.8	Beta-64327	Cams-8005	twigs
STW220594ARM1(1,2)bt	12,550±70	-22.3	Beta-74779	Cams-15010	L.PINE	OC210594PEW5 (2)	2,740±60	-25.7	Beta-86049		CREOSOTE
STW220594ARM1(1,2)up	12,520±60	-25.1	Beta-86122		M.MHG	OC150589PEW1(1) AM	1,650±60	-25.6	Beta-86038		CREOSOTE
	12,340±60	-22.5	Beta-86121		L.PINE	OC210594PEW4 (1)TP	690±60	-24.8	Beta-86047		SAGEBRUSH
STW220594ARM1(1,1)	12,290±70	-21.6	Beta-74777	Cams-14991	L.PINE	OC020469PJM1(4)					
	11,890±70	-23.5	Beta-74778	Cams-14992	W.FIR	Double Cave, Pahroc Range, Nevada					
STW220594ARM1 (1,4)	12,040±60	-24.5	Beta-86088		L.PINE	DC180595JPB1 (2)	35,850±400	-22.3	Beta-86104		JUNIPER
	10,150±60	-23.3	Beta-86087		JUNIPER		34,260±410	-23.2	Beta-86106		W.FIR
	12,440±60	-24.9	Beta-86089		M.MHG		30,000±240	-21.7	Beta-86105		L.PINE
STW220594ARM1 (1,3)	11,930±60	-25.3	Beta-86124		M.MHG	DC180595JPB1 (1)	35,530±380	-24.5	Beta-86030		JUNIPER
	11,400±60	-21.4	Beta-86123		L.PINE		32,790±260	-23.2	Beta-86032		W.FIR
							32,070±230	-22.5	Beta-86031		L.PINE
Ribbon Cliffs, Nellis A.F.B., Nevada						Papoose Flat, Inyo Mountains, California					
RC060795PEW4 (1,C)	26,820±150	-23.1	Beta-86083		JUNIPER	PF091894LR3 (1,2)	7,960±60	-19.3	Beta-86098		JUNIPER
	25,850±140	-23.2	Beta-86084		L.PINE		7,880±60	-23.4	Beta-86099		PINYON
RC060795PEW4 (1,B)	26,730±160	-21.5	Beta-86081		JUNIPER	PF091894LR3 (1,1)	7,180±60	-20.5	Beta-86096		JUNIPER
	26,210±130	-21.5	Beta-86082		L.PINE		4,690±60	-21.4	Beta-86097		PINYON
RC060795PEW4 (1,A)	24,460±110	-21.6	Beta-86079		JUNIPER	PF091894LR2 (2,2)	310±60	-21.3	Beta-86095		PINYON
	24,330±110	-21.3	Beta-86080		L.PINE		210±60	-21.3	Beta-86094		JUNIPER
RC250588LCP1 (1)	18,075±180	-24.6	Beta-32407	Eth-5676	L.pine	PF091894LR2 (1)	240±60	-22.0	Beta-86093		JUNIPER
	10,610±120	-25.4	Beta-32410		dung	PF091894LR2 (2,1)	180±60	-22.6	Beta-86053		JUNIPER
	9,330±140	-23.8	Beta-32409		juniper		140±60	-21.4	Beta-86054		PINYON
Pahrnagat Range-South Fork, Nevada						Pahrnagat Range-Hancock Summit					
PR100688PEW1(1,1)						PR240594PEW1 (1,1)	33,260±290	-24.4	Beta-86075		JUNIPER
PR100688PEW1(1,2)						PR240594PEW1	23,960±110	-23.7	Beta-86077		JUNIPER
PR100688PEW1(1,3)						PR100588PEW1(5,3)	22,730±1,080	-23.1	Beta-28827		dung
PR100688PEW1(1,4)						PR240594PEW1 (1,2)	21,370±90	-22.1	Beta-86076		JUNIPER
PR100688PEW1(1,5)						PR100588PEW1(5,1)	13,470±200	-21.9	Beta-34792		juniper
PR100688PEW1(1,6)						PR100588PEW1(1)	12,120±90	-24.4	Beta-31322		dung
PR100688PEW1(1,7)							11,530±150	-26.2	Beta-32402		juniper
PR100688PEW1(2)						PR100588PEW1(5,1)	11,710±150	-23.2	Beta-28826		dung
PR100688PEW1(3,1)	300±50	-22.2	Beta-86107		JUNIPER	PR100588PEW1(4,1)	9,540±120	-23.1	Beta-31329		juniper
	260±60	-22.8	Beta-86108		PINYON		9,120±110	-22.9	Beta-31328		dung
PR100688PEW1(3,2)	1,040±60	-23.9	Beta-86129		JUNIPER	PR100588PEW1(5,2)	7,030±130	-24.1	Beta-28467		dung
	920±50	-21.3	Beta-86130		PINYON	PR100588PEW1(4,2)	6,690±70	-26.3	Beta-64326	Cams-8004	juniper
PR100688PEW1(3,3)	250±60	-24.5	Beta-86127		JUNIPER	PR100588PEW1(4,2)	5,820±90	-24.5	Beta-31330		dung
	190±60	-22.2	Beta-86128		PINYON	PR100588PEW1(2,3)m	860±70	-24.4	Beta-31323		dung
PR100688PEW1(3,4)FR	2,010±60	-21.9	Beta-86125		JUNIPER	PR100588PEW1(2,4)fr	170±60	-25.3	Beta-31324		dung
	2,000±60	-21.0	Beta-86126		PINYON	PR100588PEW1(3)	170±70	-25.8	Beta-31327		dung
PR100688PEW1(3,4)	1,940±60	-23.3	Beta-86056		JUNIPER	PR100588PEW1(2,2)m	80±60	-25.2	Beta-31325		dung
	1,920±60	-20.9	Beta-86057		PINYON	PR100588PEW1(2,1)b	MODERN	-24.4	Beta-31326		dung
PR100688PEW1(4,A)	4,650±60	-21.8	Beta-86058		JUNIPER East Pahrnagat Range, Nevada						
	4,750±60	-23.1	Beta-86059		PINYON	PR120588PEW5(1)					
PR100688PEW1(4,B)	4,800±50	-24.3	Beta-86109		JUNIPER	PR120588PEW4(1)	100±60	-22.7	Beta-74763	Cams-14977	JUNIPER
	4,530±60	-21.4	Beta-86110		PINYON		140±60	-21.1	Beta-74764	Cams-14978	PINYON
PR100688PEW1(5,A)	2,530±50	-22.3	Beta-86111		JUNIPER Pahrnagat Wash, Nevada						
	2,450±50	-20.8	Beta-86112		PINYON	PRW090688PEW1(1)					
PR100688PEW1(5)	1,740±60	-19.3	Beta-74753	Cams-14967	JUNIPER	PRW090688PEW1(2)	720±90	-24.4	Beta-28464		dung
PR100688PEW1(6,A)	5,040±60	-22.6	Beta-86113		JUNIPER Northside Badger Mountain, Nevada						
	4,470±60	-21.6	Beta-86114		PINYON	PR110588PEW1 (1,1)	3,480±60	-19.8	Beta-74754	Cams-14968	JUNIPER
PR100688PEW1(7,A)	1,710±60	-23.9	Beta-86100		JUNIPER Pahrnagat Valley View, Nevada						
	1,080±50	-21.0	Beta-86101		PINYON	PVV190595PEW1 (1)	10,070±60	-25.2	Beta-86078		JUNIPER
PR100688PEW1(7,B)	1,860±60	-22.5	Beta-86131		JUNIPER	PVV190595PEW1 (2)	9,660±50	-23.2	Beta-86120		JUNIPER
	1,840±60	-20.5	Beta-86132		PINYON						

Table 1. (Continued)

Midden Number	Radiocarbon Age	$\delta^{13}\text{C}$	Laboratory Beta #	Laboratory AMS #	Material Dated	Midden Number	Radiocarbon Age	$\delta^{13}\text{C}$	Laboratory Beta #	Laboratory AMS #	Material Dated
Pahranagat Range-"Mick Jager Formation"						Pahranagat Range-North Fork					
PR110688PEW3 (2)	28,015±450	-21.8	Beta-32406	Eth-5675	juniper	PR110688PEW1 (1,1)					
	23,150±270	-26.2	Beta-32404	Eth-5673	w. fir*	PR110688PEW1 (1,2)	4,460±60	-23.9	Beta-86060		JUNIPER
	20,280±190	-24.0	Beta-32407		dung	PR110688PEW1 (1,2)	4,080±50	-19.5	Beta-86061		PINYON
	18,765±180	-24.6	Beta-32405	Eth-5674	L. pine		3,730±50	-20.6	Beta-86103		PINYON
PR110688PEW3 (3)	26,170±160	-23.0	Beta-86062		JUNIPER		2,530±60	-22.6	Beta-86102		JUNIPER
	25,250±140	-21.2	Beta-86063		L. PINE	PR110688PEW1 (2,1) bt					
	25,200±140	-22.5	Beta-86064		W. FIR	PR110688PEW1 (2) tp	5,120±60	-23.0	Beta-86115		JUNIPER
PR230594ARM1 (2)	23,890±160	-20.0	Beta-74772	Cams-14986	L. PINE		4,340±50	-20.7	Beta-86116		PINYON
	23,820±170	-19.2	Beta-74773	Cams-14987	W. FIR	PR110688PEW1 (2)tpf	6,220±60	-21.1	Beta-86118		PINYON
	23,600±160	-19.8	Beta-74771	Cams-14985	JUNIPER		5,750±60	-22.0	Beta-86117		JUNIPER
PR230594ARM1 (1)	16,010±80	-19.8	Beta-74775	Cams-14989	L. PINE	PR110688PEW1 (3)bt	4,970±60	-22.5	Beta-86133		JUNIPER
	12,600±60	-24.3	Beta-75413	Cams-15675	M. MHG		4,540±50	NA	Beta-86134		PINYON
	12,280±60	-22.3	Beta-74776	Cams-14990	W. FIR	PR110688PEW1 (3,2)tp					
	12,170±60	-21.4	Beta-74774	Cams-14988	JUNIPER	PR110688PEW1 (4)	8,570±60	-24.8	Beta-74755	Cams-14969	JUNIPER
PR230594ARM1 (1)SS	18,160±80	-22.0	Beta-86066		L. PINE		8,810±60	-22.0	Beta-74756	Cams-14970	PINYON
	12,380±60	-22.9	Beta-86065		JUNIPER	PR110688PEW1 (5)	2,010±60	-19.9	Beta-86136		PINYON
PR230594SES5 (1,1)	3,700±60	-23.8	Beta-74765	Cams-14979	JUNIPER		1,990±50	-23.7	Beta-86135		JUNIPER
	3,860±70	-22.1	Beta-74766	Cams-14980	PINYON	PR110688PEW1 (6,1)bt	2,370±90	-23.2	Beta-28469		dung
PR230594PEW5 (1,3)tp	3,560±60	-22.2	Beta-75416	Cams-15678	JUNIPER		2,300±70	-24.7	Beta-74757	Cams-14971	JUNIPER
	3,500±80	-20.1	Beta-75417	Cams-15679	PINYON		2,240±60	-20.5	Beta-74758	Cams-14972	PINYON
PR230594PEW3 (2,1)LW	2,840±70	-20.2	Beta-74769	Cams-14983	JUNIPER	PR110688PEW1 (6)tp	2,310±60	-21.8	Beta-86119		JUNIPER
	2,700±50	-19.7	Beta-74770	Cams-14984	PINYON	Pahranagat Range-South Valley					
PR230594PEW3 (2,1)	2,560±60	-20.9	Beta-74768	Cams-14982	PINYON	PR110688PEW2 (1)	1,210±120	-14.3	Beta-32403		yucca
	2,450±90	-20.6	Beta-74767	Cams-14981	JUNIPER	PR110688PEW2 (1,1)bf	310±80	-20.7	Beta-74759	Cams-14973	JUNIPER
PR230594PEW3 (1,2)A	2,450±60	-21.0	Beta-75414	Cams-15676	JUNIPER		260±60	-22.1	Beta-74760	Cams-14974	PINYON
	2,400±70	-20.4	Beta-75415	Cams-15677	PINYON	Pahranagat Range-Petroglyph Cave, Nevada					
PR230594PEW3 (1,2)B	2,550±60	-19.9	Beta-86068		PINYON	PR120588PEW4(1)					
	2,500±60	-19.6	Beta-86067		JUNIPER	Pahranagat Range-Petroglyph Rocks, Nevada					
PR230594PEW3 (1,3)	1,750±60	-20.8	Beta-86069		JUNIPER	PR271087PEW1(1)	3,190±60	-21.8	Beta-74752	Cams-14966	JUNIPER
	1,680±60	-20.3	Beta-86070		PINYON	PR271087PEW1(2,1)	1,400±100	-23.5	Beta-26014		dung
PR230594PEW4 (1,1)	9,100±60	-25.1	Beta-86071		JUNIPER		1,060±150	-23.0	Beta-26013		juniper
	9,230±50	-22.3	Beta-86072		PINYON	PR271087PEW1(2,2)	1,360±90	-24.2	Beta-28465		dung
PR230594PEW4 (1,2)	8,090±50	-20.4	Beta-86073		JUNIPER	PR271087PEW1(2,3)					
PR230594SES5 (1,2)	3,060±60	-24.2	Beta-86074		JUNIPER	Pahranagat Range-East Badger Mountain Road, Nevada					
PR110688PEW3 (1,2)	2,380±70	-19.6	Beta-74762	Cams-14976	PINYON	PR110588PEW3(1,1)					
	2,260±50	-24.0	Beta-74761	Cams-14975	JUNIPER	PR110588PEW3(1,2)	2,350±110	-22.9	Beta-64350	Cams-8028	juniper
PR110688PEW3 (1)	2,260±90	-21.6	Beta-34793		juniper	PR110588PEW3(1,3)	2,270±90	-23.2	Beta-64351	Cams-8029	juniper
	2,010±50	-24.1	Beta-34794		dung		2,280±70	-23.0	Beta-64352	Cams-8030	pinion
Timpahute Range, Nevada						Cliff Springs, Nevada Test Site, Nevada					
TR160987PEW1(1)	10,040±130	-24.0	Beta-25683		juniper	CS090990GHHI (1)	30,270±360	-24.5	Beta-64355	Cams-8033	L.pine

*juniper = Utah Juniper yucca = Joshua tree L.pine = Limber Pine dung = woodrat dung W.fir = White Fir sagebrush = Artemisia sec. Tridentae M.mhg=Mountain Mahogany

*Materials in all capital letters indicate dates on cellulose extracted from the original materials

Figure 1. Southern Nevada with major woodrat midden localities mentioned in this study identified. These include: 1) Owl Canyon; 2) Last Chance Range; 3) Little Skull Mountain; 4) Ribbon Cliffs; 5) Pahrnagat Range-southeast of Badger Mountain; 6) Pahrnagat Range-Hancock Summit; 7) Pahroc Springs. Yucca Mountain is located at #8.

strengthened flow from the Hadley cell into the desert belts. These warm, moist air masses entering the southwest from either the Gulf of Mexico or the Gulf of California produce hot, moist summers with mid-summer torrential rainfall originating during convective storms, and warm dry winters. Plants such as Creosote Bush and perhaps Pinyon Pine that favor warmer temperatures and summer rainfall extend into this area from the desert to the south.

Continental: a regime dominated by continental polar and arctic air masses derived when the polar cell moves into and south of the Yucca Mountain region. These cold, dry air masses from the North American interior extend into the Great Basin from the northeast during the winter. Such "outbreaks" restrict the plant species able to grow within the area to those with physiological limits tolerant of cold, dry winters coupled with periodic drought.

Southern Nevada climates and vegetation are further complicated by the strong rainshadow effect of the Sierra Nevada to the west. The accelerated rise of these mountains during the course of the Pleistocene (past 1.8 my) accentuated the rain shadow effect (Thompson 1991).

Vegetation in the Yucca Mountain region today is diverse (Table 2). At lower elevations, it is composed of warm Mojave Desert species from the south; at middle elevations a mix of southern woodland and Great Basin cold desert vegetation from the north; and at highest elevations, an endemic subalpine component is combined with montane and subalpine elements, which suggests

			OC210594ARM8
			OC020469PJM1(2)
			OC210594MLH7(5)cen frt
			OC210594MLH7(1)C
			OC210594MLH7(1)B
			OC210594MLH7(1)A
			OC150589PEW2(1)
			OC020469PJM1(1)
			OC020469PJM1(3)
			OC150589PEW1(1)unit on ceiling,bottom uni
			OC150589PEW1(1)above middle layer
			LSM151182LP1 (2,2)
			LSM151182LP1 (2,1)
			LSM151182LP1(2,3)
			LSM151182LP1 (2,4)
			LSM151182LP1 (3,1)
			LSM151182LP1 (3,2)
			LSM151182LP1(4)
			LSM151182LP1(1)
			LSM141282RR1 (1)
			LSM120982LP1(1)
			PR240594PEW1(1,1)
			PR100588PEW1 (5,3)
			PR240594PEW1(1,2)misc
			PR100588PEW1(5,TOP1)
			PR100588PEW1(1)
			PR100588PEW1(5,1)
			PR100588PEW1(4,1)
			PR100588PEW1 (5,2)
			PR100588PEW1(4,2)
			PR100588PEW1(2,3)mid
			PR100588PEW1(3)
			PR100588PEW1(2,4)frt
			PR100588PEW1(2,2)mdbk
			PR100588PEW1(2,1)bk
			DC180595JPB1(1)
			PR110688PEW3(3)
			PR230594ARM1(2)E side
			PR230594ARM1(1)S side
			PR230594PEW4(1,1)
			PR110688PEW1(3)bot
			PR271087PEW1 (1)
			PR230594PEW3(1,2)B
			PR110688PEW1 (6,1)
			PR110688PEW3(1)
			PR271087PEW1 (2,2)
			PR271087PEW1 (2,1)
			RC060795PEW4(1,C)
			RC060795PEW4(1,B)
			RC060795PEW4(1,A)
			TMR160987PEW1 (1)
			PR100688PEW1(4,A)

links to the Rocky Mountains and moderate connections to the Sierra Nevada (Cronquist and others 1972; Charlet 1995).

RESULTS AND DISCUSSION

The presence/absence of Limber Pine (*Pinus flexilis*) and White Fir (*Abies concolor*) in the late Pleistocene woodrat midden record identifies cooler-drier/warmer-wetter climate regimes. During certain periods these trees grew at elevations much lower than today. Modern elevational and geographic distributions are used to infer past climatic conditions.

Limber Pine

The current habitat of Limber Pine is characterized by dry, continental climate with wide annual and diurnal temperature fluctuations. The mean annual precipitation (MAP) ranges from 380-560 mm and is distributed evenly throughout the year (Steele 1990). Limber Pine is common between 1,981 m and 2,743 m elevation primarily in the Rocky Mountains. It presently grows between 2,195 m and 3,505 m elevation on the Nevada Test Site (Beatley 1976).

White Fir

The taxonomy of White Fir has recently been amended to split the population into the Sierra White Fir (*Abies lowiana*) and Rocky Mountain White Fir (*Abies concolor*) by the Flora of North America Editorial Committee (1993); most floras of western North America still join the two species as *Abies concolor*. No attempt has yet been made to differentiate the species in our midden material, although this may be possible in the future.

Sierra White Fir grows in areas dominated by the more moist Pacific climate regime with MAP ranges from 890 to 1240 mm. Rocky Mountain White Fir grows on high mountains dominated by drier continental climate with MAP ranges from 510 mm to >890 mm. White Fir is common between ~1,200 m and 2,100 m elevation (Laacke 1990). Isolated colonies of White Fir grow in the Spring Mountains and on Bald Mountain in the Groom Range of Nevada (U.S. Air Force 1986). Currently, they are associated with the Rocky Mountain taxa, but during the Pleistocene either or both of the White Fir species could have inhabited southern Nevada.

Fossil Record

Spatial and Chronological Continuity of Data

The woodrat midden data base can be affected by 1) environmental limits that constrain the geographical distribution of woodrats, and 2) wetter climates that could destroy woodrat middens after formation. Today two woodrat species elevationally overlap from valley floors (Desert Woodrat, Neotoma lepida) to the mountain tops (Bushy-tailed Woodrat, N. cinerea) occupying all but the most extreme habitats in the Great Basin (Hall 1995). The current range of the Bushy-tailed Woodrat, which seems to have been the dominant species in the Great Basin during the late Pleistocene, includes the southern Yukon, where the climate is substantially wetter and colder than that of the modern Great Basin. Woodrat middens of varying ages are found throughout the elevational and geographic ranges of these two species.

Widely divergent radiocarbon dates on materials obtained from single woodrat midden strata for the late Quaternary indicate that midden re-solution and destruction was accelerated prior to 14 ka (Spaulding 1985; Van Devender and others, 1986). Although only 23 percent of the dated

woodrat midden strata in the Yucca Mountain area are older than this date climates are adequately represented.

Timing

Limber Pine appears regularly in the record between ~ 13-11 ka, 21-14 ka, 26.5-23 ka, and 33-29 ka (Figure 2, Table 3). Four periods of White Fir occurrence at elevations lower than today center around 13-12 ka, 16-14 ka, 26-21 ka, and ~35-32 ka (Figure 3, Table 4). Periods when climate appears to exclude White Fir from communities with abundant Limber Pine occur from 21-16 ka and 32-29 ka. Periods when climate appears to include White Fir without major Limber Pine association are from 23-21 ka and 35-33 ka.

Elevational displacement

The lower elevation of middens containing Limber Pine and/or White Fir macrofossils coincides with the base of modern semi-arid Pinyon-Juniper woodland, ~1220 m. The displacement of Limber Pine and White Fir to lower elevations by as much as 1000 m during the Pleistocene records significant real increases in MAP that cannot simply be explained through reduced MAT. Corroborating data indicate Limber Pine was growing between 1,500 and 1,300 m in the Eleana, Sheep, and Spring ranges, Fortymile Canyon, and Clark Mountain during the Pleistocene (Spaulding 1981, 1985, 1994; Mead and others, 1978; Mehringer and Ferguson 1969).

Environmental Parameters

Although Limber Pine and White Fir occasionally grow together today, White Fir requires

Table 3. Lower elevational occurrences of Limber Pine (*Pinus flexilis*) within a 200 km radius of Yucca Mountain. Those dates from the current study are in **bold** letters and those from previous studies are not. Middens from previous studies include: Sheep Range (Spaulding 1981), Potosi Peak (Mead *et al* 1978), Clark Mountain (Mehring and Ferguson 1969), Eleana Range (Spaulding 1985) and Fortymile Canyon (Spaulding 1994). The localities are arranged from lowest to highest elevation.

Midden Number and Site Description	Radiocarbon Age	Laboratory Number	Material Dated	Elevation (m)
FMC-11A (1), Fortymile Canyon, NTS, NV.	15,870±70	QL-4223	Fecal Pellets	1310
PENTHOUSE 2(1), Sheep Range, NV.	28,960±2000	A-1773	Utah Juniper	1580
WILLOW WASH 4C(1), Sheep Range, NV.	24,400±760	A-1751	Utah Juniper	1585
WILLOW WASH 4C(2), Sheep Range, NV.	19,020±750	UCR-729	Utah Juniper	1585
BASIN CANYON 1, Sheep Range, NV.	15,610±260	WSU-1856	Utah Juniper	1635
PR230594ARM1(1), Pahrnatagat Range, NV.	16,010± 80	BETA-74775	Limber Pine	1695
PR230594ARM1(1)SSIDE, Pahrnatagat Range, NV.	18,160± 80	BETA-86066	Limber Pine	1695
PR110688PEW3(2), Pahrnatagat Range, NV.	18,765±180	BETA-32405	Limber Pine	1695
PR230594ARM1(2), Pahrnatagat Range, NV.	23,890±160	BETA-74772	Limber Pine	1695
PR110688PEW3(3), Pahrnatagat Range, NV.	25,250±140	BETA-86063	Limber Pine	1695
DC180595JPB1(1), Double Cave, Pahroc Range, NV.	32,070±230	BETA-86031	Limber Pine	1743
DC180595JPB1(2), Double Cave, Pahroc Range, NV.	30,000±240	BETA-86105	Limber Pine	1743
FLAHERTY MESA 1, Sheep Range, NV.	20,390±340	WSU-1864	Utah Juniper	1770
WAGON CANYON 2, Sheep Range, NV.	25,000±710	A-1656	Utah Juniper	1790
ER-3(14), Eleana Range, NTS, NV.	14,200±100	USGS-1266	Limber Pine	1800
ER-2(4), Eleana Range, NTS, NV.	14,090±320	A-2927	Limber Pine	1810
ER-2(4), Eleana Range, NTS, NV.	15,300±130	USGS-875	Limber Pine	1810
ER-2(5), Eleana Range, NTS, NV.	14,260±110	USGS-874	Limber Pine	1810
ER-2(6), Eleana Range, NTS, NV.	14,500±110	USGS-885	Limber Pine	1810
ER-2(10), Eleana Range, NTS, NV.	17,100± 90	USGS-1069	Limber Pine	1810
RC250588LCP11, Ribbon Cliffs, Nellis AFB, NV.	18,075±180	BETA-32407	Limber Pine	1829
RC060795PEW41A, Ribbon Cliffs, Nellis AFB, NV.	24,330±110	BETA-86080	Limber Pine	1829
RC060795PEW41B, Ribbon Cliffs, Nellis AFB, NV.	26,210±130	BETA-86082	Limber Pine	1829
RC060795PEW41C, Ribbon Cliffs, Nellis AFB, NV.	25,850±140	BETA-86084	Limber Pine	1829
POTOSI MTN 2C2, Potosi Mountain, Spring Range, NV.	14,430±150	LJ-4005	Limber Pine	1830
EYRIE 3(1), Sheep Range, NV.	16,490±220	WSU-1853	Utah Juniper	1855
EYRIE 1(3)1, Sheep Range, NV.	23,380±490	WSU-1864	Utah Juniper	1860
EYRIE 1(3)2, Sheep Range, NV.	9,370±120	WSU-1863	Utah Juniper	1860

Table 3. (continued)

Midden Number and Site Description	Radiocarbon Age	Laboratory Number	Material Dated	Elevation (m)
EYRIE 5(2), Sheep Range, NV.	30,470±740	WK-168	Utah Juniper	1860
EYRIE 5(3), Sheep Range, NV.	19,750±450	WK-167	Fecal Pellets	1860
CM-1, Clark Mountain, CA.	23,600±980	I-3557	Twigs	1910
CM-2, Clark Mountain, CA.	28,720±1800	I-3648	Twigs	1910
STW220594ARM113, Stockade Wash, NTS, NV.	11,400±60	BETA-86123	Limber Pine	1950
STW220594ARM114, Stockade Wash, NTS, NV.	12,040±60	BETA-86088	Limber Pine	1950
STW220594ARM111, Stockade Wash, NTS, NV.	12,290±70	BETA-74777	Limber Pine	1950
STW220594ARM112U, Stockade Wash, NTS, NV.	12,340±60	BETA-86121	Limber Pine	1950
STW220594ARM112, Stockade Wash, NTS, NV.	12,550±70	BETA-74779	Limber Pine	1950
DEADMAN 1(1), Sheep Range, NV.	17,420±250	LJ-3707	Limber/Bristlecone	1970
DEADMAN 1(2), Sheep Range, NV.	16,800±250	WSU-1860	Utah Juniper	1970
DEADMAN 1(4), Sheep Range, NV.	18,680±280	WSU-1857	Utah Juniper	1970
SOUTH CREST 1(4)2, Sheep Range, NV.	21,700±500	LJ-2840	Limber/Bristlecone	1990
SOUTH CREST 1(3), Sheep Range, NV.	25,140±900	A-1669	Utah Juniper	1990
SPIRES 2(1), Sheep Range, NV.	18,800±130	USGS-199	Fecal Pellets	2040
SPIRES 2(2), Sheep Range, NV.	16,200±350	A-1875	Limber/Bristlecone	2040
CS0909900GHH11, Cliff Springs, Belted Range, NTS, NV.	30,270±360	BETA-64355	Limber Pine	2133
CM-2, Clark Mountain, CA.	19,900±1500	GAK-1987	Limber/Bristlecone	2140
HIDDEN FOREST 3A, Sheep Range, NV.	1,600±120	A-1742	Utah Juniper	2380
HIDDEN FOREST 3B, Sheep Range, NV.	820±100	WSU-2046	Rocky Mtn. Juniper	2380
HIDDEN FOREST 3C(1), Sheep Range, NV.	10,060±130	LJ-3729	Limber/Bristlecone	2380
HIDDEN FOREST 3C(2), Sheep Range, NV.	11,940±140	LJ-3730	Limber/Bristlecone	2380
HIDDEN FOREST 3C(3), Sheep Range, NV.	11,860±160	LJ-3728	Limber/Bristlecone	2380
HIDDEN FOREST 1, Sheep Range, NV.	11,570±120	LJ-4046	Limber/Bristlecone	2400

Figure 2. *Top*) chronologic plot of the elevational distribution of directly dated Limber Pine macrofossils from ancient woodrat middens from a 200 km radius around Yucca Mountain (our own and previously published data); Dotted line is the approximate lower elevational distribution limit of Limber Pine in the Sheep Range today; *Middle*) radiocarbon dates on Limber Pine performed for this study plotted as a normal distribution at three standard deviations around the mean; and *Bottom*) radiocarbon dates on Limber Pine performed for other studies plotted as a normal distribution at three standard deviations around the mean. For the middle and bottom plots the normal distributions are a measure of radiocarbon date precision, *i.e.*, the more pointed the distribution curve the more precise the date and the flatter the curve the less precise the radiocarbon date.

Ages and Elevational Distribution of Limber Pine Trees in the Yucca Mountain Area

West Cronese

Slope

Valley

B, C

A

Kitten
Dune

Cat
Dune

○ ○ ○ Talus

\$\$\$ Paleosols

Balch

Upper
ramp

Old Dad Mountains

Upper
ramp

Lower
ramp

Lower
ramp

Table 4. Lower elevational occurrences of White Fir (*Abies concolor*) within a 200 km radius of Yucca Mountain revealed in the current study. The localities are arranged from lowest to highest elevation. Middens listed below include those analyzed by us in **bold**, and those analyzed by others in regular type. Previous investigations include: Sheep Range (Spaulding 1981), Potosi Peak (Mead *et al* 1978), Clark Mountain (Mehring and Ferguson 1969) and Fortymile Canyon (Spaulding 1994).

Midden Number and Site Description	Radiocarbon Age	Laboratory Number	Material Dated	Elevation (m)
FMC-11A (1), Fortymile Canyon, NTS, NV.	15,870± 70	QL-4223	Fecal Pellets	1310
WILLOW WASH 4A, Sheep Range, NV.	21,350±420	WSU-1858	Utah Juniper	1585
WILLOW WASH 4C(1), Sheep Range, NV.	24,400±760	A-1751	Utah Juniper	1585
PR230594ARM1(1), Pahrnagat Range, NV.	12,280± 60	BETA-74776	White Fir	1695
PR110688PEW3(2), Pahrnagat Range, NV.	23,150±270	BETA-32404	White Fir	1695
PR230594ARM1(2), Pahrnagat Range, NV.	23,820±170	BETA-74773	White Fir	1695
PR110688PEW3(3), Pahrnagat Range, NV.	25,200±140	BETA-86064	White Fir	1695
DC180595JPB1,1, Double Cave, Pahroc Range, NV.	32,790±260	BETA-86032	White Fir	1743
DC180595JPB1(2) , Double Cave, Pahroc Range, NV.	34,260±410	BETA-86106	White Fir	1743
POTOSI 2C L, Potosi Mountain, Spring Range, NV.	14,450±250	A-1778	White Fir	1830
POTOSI 2A (2), Potosi Mountain, Spring Range, NV.	14,900±180	LJ-4004	Miscellaneous	1880
CM-3, Clark Mountain, CA.	12,460±190	I-3690	Pinyon	1910
CM-1, Clark Mountain, CA.	23,600±980	I-3557	Twigs	1910
CM-2, Clark Mountain, CA.	28,720±1800	I-3648	Twigs	1910
STW220594ARM111, Stockade Wash, NTS, NV.	11,890± 70	BETA-74778	White Fir	1950
SOUTH CREST 1(4)2, Sheep Range, NV.	21,700±500	LJ-2840	Limber/Bristlecone	1990
SOUTH CREST 1(3), Sheep Range, NV.	25,140±900	A-1669	Utah Juniper	1990
HIDDEN FOREST 3B, Sheep Range, NV.	820±100	WSU-2046	Rocky Mtn Juniper	2380
HIDDEN FOREST 3A, Sheep Range, NV.	1,600±120	A-1742	Utah Juniper	2380
HIDDEN FOREST 3C(1), Sheep Range, NV.	10,060±130	LJ-3729	Limber/Bristlecone	2380

Figure 3. *Top*) chronologic plot of the elevational distribution of directly dated White Fir macrofossils from ancient woodrat middens from a 200 km radius around Yucca Mountain (our own and previously published data); Dotted line is the approximate lower elevational distribution limit of White Fir in the Sheep Range today; *Middle*) radiocarbon dates on White Fir performed for this study plotted as a normal distribution at three standard deviations around the mean; and *Bottom*) radiocarbon dates on White Fir performed for other studies plotted as a normal distribution at three standard deviations around the mean. For the middle and bottom plots the normal distributions are a measure of radiocarbon date precision, *i.e.*, the more pointed the distribution curve the more precise the date and the flatter the curve the less precise the radiocarbon date.

Ages and Elevational Distribution of White Fir Trees in the Yucca Mountain Area

warmer winter temperatures and more annual precipitation than Limber Pine. Where they co-occur upper elevations of White Fir overlap with lower elevations of Limber Pine. Because White Fir often occur at elevations well below those of Limber Pine, it appears to tolerate/require warmer temperatures than Limber Pine. Limber Pine has a lower MAP (380-560 mm) than does White Fir (510-1240 mm). Limber Pine prefers precipitation relatively evenly distributed throughout the year whereas White Fir often receives more than 80 percent of its annual precipitation in the form of snow in the northern areas of its distribution.

Pleistocene associations of Utah Juniper (*Juniperus osteosperma*) with Limber Pine and White Fir can be used to further constrain estimates of late Pleistocene precipitation (Figure 4). Directly dated late Pleistocene macrofossils from woodrat middens throughout southern Nevada indicate that Utah Juniper occurred throughout a wide elevational gradient during the late Pleistocene (Wells and Jorgensen 1964; Wells and Berger 1967; Spaulding 1977, 1981, 1985, 1994; Mehringer and Warren 1976; Wells and Woodcock 1985). At upper elevations it often occurred in association with Limber Pine and occasionally with White Fir (Mehringer and Ferguson 1969; Spaulding 1977, 1981, 1985). Due to woodrat collecting bias juniper is common-to-abundant in most late Pleistocene woodrat midden strata; this does not mean that it was consistently the most abundant species at all elevations. Both woodrat midden and pollen evidence suggest that the bulk of Utah Juniper's Pleistocene distribution lay at lower elevations and not at upper elevations (Mehringer 1967; Wells and Woodcock 1985).

Today the MAP of Utah Juniper ranges between 410 mm and 250 mm (U.S. Forest Service SCS DATA BANK; U.S. Air Force, 1986). The lower MAP value of Limber Pine overlaps with the upper MAP value of Juniper. This indicates a minimum MAP of 380 - 410 mm where the two

Figure 4. The distribution of directly dated Limber Pine, White Fir, Utah Juniper and Pinyon Pine through time and by elevation from ancient woodrat middens from a 200 km radius around Yucca Mountain (our own and previously published data). Dots provide an impression of the chronological continuity, or lack thereof of the various species. The episodic nature through time of the occurrence of Limber Pine, White Fir and Pinyon Pine and their limited spatial ranges can be gauged by comparing their occurrences against the nearly continuous chronologic and geographic distribution of Utah Juniper for the same area (many of the same localities). This plot includes several Limber Pine occurrences that do not appear in Figure 2. These were indicated in Table 3 as having been dated on a mixture of Limber and Bristlecone Pine materials, rather than exclusively being conducted upon Limber Pine materials.

Chronological Distribution of Directly Dated (AMS) Southern Great Basin Tree Species

species co-occur in the fossil record. The minimum MAP of Rocky Mountain White Fir is higher: 510 mm. This would indicate a MAP above 410 mm or increased winter soil moisture during the time periods when all 3 species are found.

Further refinement of Pleistocene MAP ranges associated with Limber Pine and White Fir can be achieved through the examination of associated shrubs, forbs, and grasses. A total of 56 taxa were identified and 18 of these were determined to be the best climatic indicators (Table 5).

In general, the more mesic shrubs (for example, Sagebrush, Artemisia spp.) found in association with Limber Pine and White Fir during the Pleistocene have upper MAP ranges around 400 mm to 420 mm. More xeric shrubs (for example, Shadscale, Atriplex spp. and Winterfat, Ceratoides sp.) have upper MAP ranges around 150 mm to 250 mm (U.S. Forest Service SCS DATA BANK). These data suggest that effective moisture during periods of wetter climate should be constrained toward the more xeric (drier) end of the MAP requirements of Limber Pine during the glacial maximum and the more mesic end of the MAP scale of Limber Pine during periods when White Fir occurred. Thus, if the lower MAP range of the modern juniper community is compared with the lower MAP values of Limber Pine, an MAP 190 percent of the present MAP (an increase from an MAP value of 200 mm to 380 mm) can be derived (ongoing refinement of MAP values may change the final percentage of increase). This increase allowed Limber Pine to migrate through the current elevational distribution of Utah Juniper to at least the current lower boundary of Juniper. At lower elevations the movement of Utah Juniper into areas currently occupied by shadscale would require MAP 133 percent of the present (a shift from 150 mm to 200 mm).

Table 5. Plant contents of radiocarbon dated middens at key localities around Yucca Mountain. Midden strata are arranged chronologically for each locality.

			OC210594ARM8
	oc	800	OC020469PJM1(2)
	oc	800	OC210594MLH7(5)cen frt
	oc	800	OC210594MLH7(1)C
	oc	800	OC210594MLH7(1)B
	oc	800	OC210594MLH7(1)A
	oc	800	OC150589PEW2(1)
	oc	800	OC020469PJM1(1)
	oc	800	OC020469PJM1(3)
	oc	800	OC150589PEW1(1)unit on ceiling,bottom uni
	oc	800	OC150589PEW1(1)above middle layer
	ls	1200	LSM151182LP1 (2,2)
	ls	1200	LSM151182LP1 (2,1)
	ls	1200	LSM151182LP1(2,3)
	ls	1200	LSM151182LP1 (2,4)
	ls	1200	LSM151182LP1 (3,1)
	ls	1200	LSM151182LP1 (3,2)
	ls	1200	LSM151182LP1(4)
	ls	1200	LSM151182LP1(1)
	ls	1200	LSM141282RR1 (1)
	ls	1200	LSM120982LP1(1)
	hs	1600	PR240594PEW1(1,1)
	hs	1600	PR100588PEW1 (5,3)
	hs	1600	PR240594PEW1(1,2)misc
	hs	1600	PR100588PEW1(5,TOP1)
	hs	1600	PR100588PEW1(1)
	hs	1600	PR100588PEW1(5,1)
	hs	1600	PR100588PEW1(4,1)
	hs	1600	PR100588PEW1 (5,2)
	hs	1600	PR100588PEW1(4,2)
	hs	1600	PR100588PEW1(2,3)mid
	hs	1600	PR100588PEW1(3)
	hs	1600	PR100588PEW1(2,4)frt
	hs	1600	PR100588PEW1(2,2)mdbk
	hs	1600	PR100588PEW1(2,1)bk
	dc	1700	DC180595JPB1(1)
	mj	1700	PR110688PEW3(3)
	mj	1700	PR230594ARM1(2)E side
	mj	1700	PR230594ARM1(1)S side
	mj	1700	PR230594PEW4(1,1)
	nf	1700	PR110688PEW1(3)bot
	pr	1700	PR271087PEW1 (1)
	mj	1700	PR230594PEW3(1,2)B
	ju	1700	PR110688PEW1 (6,1)
	mj	1700	PR110688PEW3(1)
	pr	1700	PR271087PEW1 (2,2)
	pr	1700	PR271087PEW1 (2,1)
	rc	1800	RC060795PEW4(1,C)
	rc	1800	RC060795PEW4(1,B)
	rc	1800	RC060795PEW4(1,A)
	tr	1800	TMR160987PEW1 (1)
	sf	1800	PR100688PEW1(4,A)

Pleistocene Wet Periods

Utah Juniper and Limber Pine were the common trees at intermediate elevations on the southern Nevada landscape from 12 ka to 34 ka. Brief appearances of White Fir also occurred in these communities. Juniper and Limber Pine imply long periods of dry continental climate accompanied by weak storm systems, whereas the White Fir episodes suggest strengthened moist air flow off the Pacific. This probably resulted in a precipitation shift from little seasonal differentiation to increased winter precipitation. Lowered MAT would result in reduced evaporation rates as is also implied by the wetlands common to this region during the glacials. The presence of Limber Pine at lower elevations could be due to temperature induced increases in effective moisture, but temperature driven gains in effective moisture alone cannot explain the migration of White Fir.

Vegetation at intermediate elevations during the Last Glacial Maximum (LGM) (~21 to 16 ka radiocarbon) is characterized by Limber Pine without White Fir, indicating that southern Nevada was dominated by dry continental climate with precipitation evenly distributed throughout the year, a pattern that indicates the polar cell was resident throughout the year.

White Fir appears in intermediate elevation woodrat middens during the slightly warmer periods on either side of the LGM (that is, as climate was cooling down from warmer episodes enroute to the LGM, and as it was warming after the LGM (Thompson and others, 1993). Because White Fir favors warmer MAT and higher MAP than does Limber Pine, a real increase in MAP and a shift toward an increased winter precipitation component, perhaps as snow, is indicated just prior to and after the LGM. Those conditions are consistent with part or all of the year being under westerly flow within a compressed Ferrel cell. The likelihood of Ferrel cell circulation bringing wet maritime polar air to much of Nevada is indicated, because White Fir episodes coincide with

Whitebark Pine (*Pinus albicaulis*) (a wet loving tree) in northern Nevada (Wigand and Nowak 1992). Radiocarbon date distributions currently available from woodrat midden macrofossils indicate that the durations of these periods appear to be relatively short, less than fifteen hundred years or so, and that onset and termination were quite sudden as would be expected if the cause of the climate change was related to the position of the westerlies.

CONCLUSIONS AND SUMMARY

Conclusions

During the late Pleistocene (40 to 12 ka) effective moisture was much higher throughout southern Nevada. Much of the rise in effective moisture may be explained by greatly reduced temperatures in combination with modest rises in MAP. Short episodes of 1 to 2 ky in duration punctuate these otherwise cold and dry periods; the wettest of these are centered on 23 ka to 21 ka and 35 ka to 33 ka. The various tree species found in the middens suggest the climate interpretations may be explained by the existence of the polar cell in the region during most of the late Pleistocene with episodes of intense westerly flow probably related to a constricted Ferrel cell accounting for the wet episodes.

Known MAP requirements for key plant species suggest rapid shifts toward century to millennia-long wetter, winter precipitation patterns throughout Nevada. Preliminary interpretation of MAP in southern Nevada implies increases in the range of MAP just under two times (90 percent) at higher elevation (between 1,500 m and 2,000 m) and perhaps one third or half again as great (30 percent) at lower elevation (700 m to 1,500 m).

Precipitation gradients increased significantly during the Pleistocene. MAP was

approximately 133 percent of what it is today at ~ 750 m elevation based upon the displacement of Utah Juniper. Limber Pine displacement indicates that MAP was approximately 190 percent of what it is today at ~ 1,500 m. If the increase in regional MAP had been regular, one should expect that the percent increase would be the same at all elevations. However, the difference in MAP between these two elevations during the Pleistocene reveals that the precipitation increase was about 60 percent greater at 1,500 m than it was at 750 m. Lack of data above 2,000 m for the Pleistocene prevents extrapolation of precipitation increases to higher elevations using plant remains from woodrat middens.

Summary

Based upon occurrences of Limber Pine and/or White Fir and using the MAPs derived from the vegetation data summarized above we have generated the following sequence of climate between 35 and 12 k. This applies only for elevations around 1,500 m. At elevations around 750 m estimates should be about 50 percent of those at 1,500 m. Above 2,000 m absence of data prevents estimation.

Climate designations of very wet, wet, and dry are relative.

13-12 ka	wet period	MAP ~ 460-560 mm
14-13 ka	dry period	MAP ~ 405-460 mm
16-14 ka	wet period	MAP ~ 460-560 mm
21-16 ka	dry period	MAP ~ 405-460 mm
23-21 ka	v. Wet period	MAP ~ 560-635 mm
26.5-23 ka	wet period	MAP ~ 460-560 mm
33-26.5 ka	dry period	MAP ~ 405-460 mm
~35-33 ka	V. Wet Period	MAP ~ 560-635 mm

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Field Sites

1. Buena Vista Valley
2. Pahrnagat Valley
3. Kelso Dunes
4. Fernley Basin

Modified from Benson and Thompson, 1987

Alluvial Fan Units

Holocene	L	Qf ₄	Qf _{3,4}
	M	Qf ₃	
	E		
Pleistocene	L	Qf ₂	
	M		
	E	Qf ₁

Beach Ridge

Figure 4-53

American Canyon

Coyote Creek

Klondike Canyon

Relative Percentage

Clay

Silt

Sand

Field Sites

- 1 Madison River Valley, Ritter and others (1993, 1995) and Birch Creek Valley, Funk (1976) and Pierce and Scott (1982)
- 2 Northern Rio Grande Rift, Pazzaglia and Wells (1990)
- 3 Eastern Mojave Desert, Silver Lake, Wells and others (1987) and Salt Spring Hills, Ritter (1987)
- 4 Fish Lake Valley, Reheis and others (1994 and in review)
- 5 Winnemucca Area of Humbolt River Basin, Hawley and Wilson (1965)
- 6 Buena Vista Valley, this study
- 7 Pahrnagat Valley, this study

Southwestern Montana and Central Idaho ¹	North Central New Mexico ²	Southeastern California ³	East Central California and West Central Nevada ⁴	North Central Nevada ⁵	Buena Vista Valley North Central Nevada	Lake Lahontan Chronology ⁶	Age Ka ⁷	Time Division
Qf4	Qf3	Qf4	Qfc	Qya	1,250 ± 50		3	L Holocene
Qf3		Qf3			Qf3			M
		Qf2	Qfi		6,800 ± 50		5	E
Qf2	Qf2				11,730 ± 60 11,820 ± 70 11,880 ± 50 12,220 ± 60 12,390 ± 70 12,900 ± 60 13,100 ± 70 13,560 ± 60 14,540 ± 60		10	Late Pleistocene
Qf1	Qf1	Qf1	Qfi	Qpi	Qf2		28	L Middle Pleistocene
		?						
Pre-Qf1							86	M
?								
				Qoa	Qf1		620	E

1 Madison River Valley, Ritter and others (1993, 1995) and Birch Creek Valley, Funk (1976) and Pierce and Scott (1982).

2 Northern Rio Grande Rift, Pazzaglia and Wells (1990).

3 Eastern Mojave Desert, Silver Lake, Wells and others (1987) and Salt Spring Hills, Ritter (1987).

4 Fish Lake Valley, Rehels and others (1994 and in review).

5 Winnemucca Area of Humboldt River Basin, Hawley and Wilson (1965).

6 Lake Chronology is based on Morrison (1991).

7 Quaternary age assignments adopted from Richmond (1986) and Imbrie and others (1984).

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Fig 12

Table 1. Summary of dateable samples and their associated absolute age and fan stratigraphic relation.

Sample	Alluvial Fan	Dated Material	Age	Stratigraphic Relation
	Klondike Canyon	Shells	13,100+/-70	Beach ridge deposit burying Qf2 and truncated by Qf3
	Klondike Canyon	Shells	12,390+/-70	Beach ridge deposit burying Qf2 and truncated by Qf3
	Klondike Canyon	Shells	11,880+/-50	Beach ridge deposit burying Qf2 and truncated by Qf3
ACF-UR1	American Canyon	Shells	12,900+/-60	Beach ridge deposit burying Qf2 and truncated by Qf3
ACF-UR2	American Canyon	Shells	13,560+/-60	Beach ridge deposit burying Qf2 and truncated by Qf3
ACF-BR1	American Canyon	Shells	11,880+/-50	Beach ridge deposit burying Qf2 and truncated by Qf3
ACF-BR2	American Canyon	Shells	12,220+/-60	Beach ridge deposit burying Qf2 and truncated by Qf3
BS-BR4	Buffalo Springs	Shells	11,730+/-60	Beach ridge deposit burying Qf2
BS-BR5	Buffalo Springs	Shells	11,820+/-70	Beach ridge deposit burying Qf2
WS-1	Willow Creek	Charcoal	1,250+/-50	Upper beds of Qf3
ACF-Ash1	American Canyon	Ash	6,800+/-50	Interbed in upper Qf3
WS-Ash1	Willow Creek	Ash	6,800+/-50	Interbed in Qf3