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Reconstruction of the Late Pleistocene to Late Holocene vegetation transition using packrat midden and pollen evidence from the Central Mojave Desert

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ABSTRACT

The Mojave Desert of the American West is characterized by plant species that reflect a unique mixture of winter precipitation and summer monsoon climate. Currently, the Mojave Desert experiences a strong summer monsoonal pattern with weak winter precipitation. Data from pollen and packrat midden analyses have revealed a history of Mojave Desert vegetation during the transition from the late Pleistocene to late Holocene (~17500 Cal. years B.P. to ~ 1200 Cal. years B.P.) that highlight a summer dominated monsoonal pattern, similar to those in the greater American Southwest. We compare pollen data from a lava tube in the Cima volcanic field, located in south-central region of the Mojave Desert, with plant macrofossil data from several woodrat midden localities in the region. The record for the Cima volcanic field reveals a vegetation history spanning the last ~ 8300 Cal. years B.P., with data from ancient woodrat middens detailing the record from ~17500 Cal. years B.P. to 7,800 Cal. years B.P. A Bryson macro-physical climate model for the transition from the late Pleistocene to the Late Holocene was created and compared to our findings to assess possible relationships between climatic variations and the arrival of diagnostic plant species within the Mojave Desert.

Keywords: Late Pleistocene, Late Holocene, Mojave Desert, pollen, summer monsoon, woodrat midden analysis

Introduction

The transition from the Pleistocene to Holocene (LP/H) resulted in significant climate-driven change within Mojave Desert plant communities. Plant species exhibited both geographic expansion from the Sonoran Desert and more localized elevational shifts establishing modern vegetation zones. Packrat middens and sediment pollen analyses are some of the most reliable proxies to recreate vegetation history and past climate (Cole 1985). Packrat middens often contain abundant pollen and plant microfossils, encased in crystalized woodrat urine (Cole 1985). A pollen record obtained from sediment within a lava tube of the Cima volcanic field enabled a reconstruction of early Holocene vegetation communities at low elevation. The LP/H transition in southern California (Quade *et al* 1998; Wigand & Rhode 2002) was quite dramatic east of the Sierra Nevada.

Spaulding (1985) and Koehler *et al.* (2005) indicate that the key elements of Mojave Desert vegetation arrived by 9,500 Cal. years B.P. Creosote bush and white bursage are considered co-dominants, though Wigand's (2003) research just south of the Coso Range at the northwestern edge of the Mojave Desert indicates that with increased winter

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precipitation, white bursage is favored. Conversely during years exhibiting increased summer precipitation, creosote bush is favored.

Climate at the end of the Pleistocene probably favored white bursage, because periods of increased winter precipitation may still have been common. The impact of climate change on landscape dynamics at the end of the Pleistocene has been previously discussed by Harvey *et al*. (1999). The authors indicate that alluvial fans in the Mojave Desert during the LP/H transition was very active, exhibiting debris flows feeding onto the fan surfaces, headward fan trenching, and distal progradation. Increased geomorphology activity in the Mojave Desert during the LP/H may have been due primarily to decreased vegetation cover. The replacement of Pygmy juniper and sagebrush at the end of the Pleistocene by creosote bush and white bursage led to a more open discontinuous vegetation cover in the Mojave Desert. Schumm's model (Langbein & Schumm 1958) indicates drier conditions result in reduced vegetation density. When reduced vegetation cover coincided with episodes of high-intensity summer rains, it resulted in increased hillslope debris flow activity in the Mojave Desert. Fine sediments eventually filled the pluvial basins of the region, and as the basins dried up. the fine particles were transported as aeolian sediments onto the Cima volcanic field. In this research, we examine late Quaternary Mojave Desert vegetation history, derived from pollen and packrat midden proxies, to reveal the timing and order of arrival of diagnostic species into the region.

Materials and methods

Study area

The Mojave Desert lies between the summer monsoon-dominated Sonoran Desert to the southeast and the zonal, winter storm-dominated Great Basin Desert to the northwest. It therefore exhibits a combination of the climates of two regions resulting in a fluctuating summer monsoonal pattern originating from the southeast Mojave Desert. Generally, the Mojave Desert is characterized by three climatically distinct regions. These include: a) the western region dominated by cool winters and warm summers; b) the central region, which has generally warmer winters than the eastern and western regions and hot summers; and c) the eastern region, which has cooler and wetter winters with greater precipitation (McKinney 2018).

The Cima volcanic field is located southwest of Las Vegas, Nevada (Fig. 1), and consists of roughly 60 associated lava flows and 40 cinder cones of Pleistocene age covering 150 km^2 of the Ivanpah uplift (Dohrenwend *et al*. 1984; Turrin *et al*. 1985; Wilshire *et al*. 1987; Wood *et al*. 2005). Potassium-Argon (K-Ar) dating of cinder cones within the Cima volcanic field provide an age range of 0.015 m yr to 1.09 ± 0.08 m yr (Dohrenwend *et al*. 1986). The lava flows are mostly alkali olivine basalt, hawaiite and basanite, and occur in two flow types, 1) elongate flows with low gradients, and 2) roughly equant flows (of similar length and width) with high gradients (Dohrenwend *et al*. 1984).

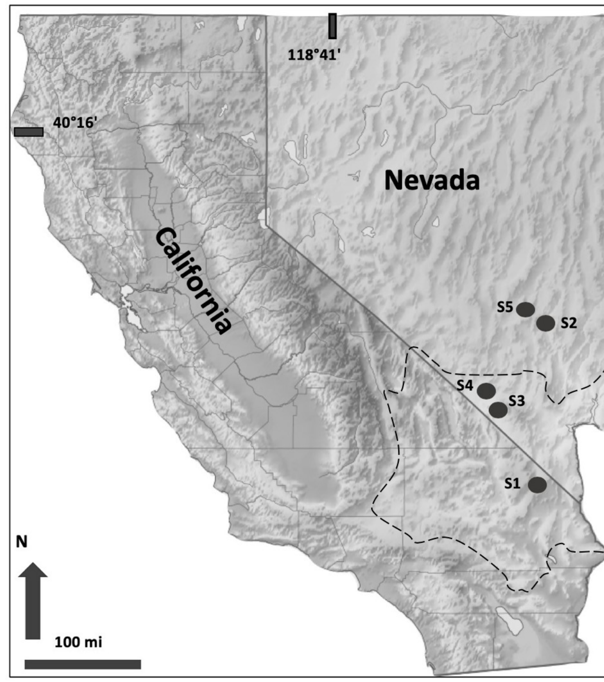

Figure 1. Map of the Mojave Desert, Southern Nevada and California, and sites discussed in this text: S1: Cima volcanic field, S2: Pahranagat Range, S3: Owl Canyon, Devils Hole Range, S4: Little Skull Mountain, Nevada test site, S5: Timpahute Range

The mean annual precipitation of Cima volcanic field is well within the range for arid to semiarid zones, at 12-25 cm and the plant community of the Cima volcanic field is dominated by creosote bush (*Larrea tridentata*), white bursage (*Ambrosia dumosa)*, brittle bush (*Encelia farinosa*) and Mormon tea (*Ephedra trifurca*) though higher elevations (> 1300 masl) contain Joshua tree (*Yucca brevifolia*) (Brown *et al*. 1990).

Pollen sampling

Six sediment samples were collected in 2012 from sediments inside one of the Cima lava tubes. Pollen was recovered using sodium polytungstate flotation (Wigand 1987). The processed samples were stained and mounted in silicon oil before being counted at 400 power with a light microscope.

Packrat middens

Plant macrofossils from 18 packrat middens from near the Nevada Test Site were analyzed during this study. The middens were mapped, described, photographed and subsamples taken over a period of several years. Samples were soaked in distilled water for 24 hours, screened through nested screens, and dried. The resultant macrofossil material was then sorted and weighed and entered into a database.

Chronology

Twenty plant macrofossil and organic-rich sediment samples were dated by Beta Analytic Inc, Miami, Florida using accelerator mass spectrometry (AMS). The dates were calibrated using IntCal13 curve 133 (Reimer *et al*. 2013).

Paleoclimate Simulation

A Bryson MCM synoptic climate model simulation was generated for the central Mojave Desert highlighting the last 15,000 years. The simulation was based on 30 year means from the Las Vegas, Nevada, climate means of 1971 to 2000 (Bryson & Bryson 2000) and compares correlations between predicted climatic variation and our reconstructed vegetation histories.

Results

Chronology

AMS dating results are presented in Tables 1 and 2. The three sediment samples from the Cima volcanic field span the last 8,300 Cal. years B.P. Middens ages ranged between 7,853 ± 119 Cal. years B.P. to 17,480 ± 282 Cal. years B.P., covering the entire LP/H transition (Tab. 2).

Pollen assemblages

Ten pollen types were identified, and their abundance analyzed within the Cima volcanic field samples (Fig 2). *Pinus* (pine) (1.75 %) and *Eriogonum* (buckwheat) (10.53 %) were exclusive to the upper portion of the sample trench (younger than 2510 Cal. years B.P.). *Artemisia* was also only found in the upper portion of the trench where it ranged from 1.22 to 2.63 %. *Ambrosia* pollen is one of the most common pollen types throughout the core, but its abundance was greatest (95 %) at ~8300 Cal. years B.P. *Spharaelcea* was found throughout the middle and upper portion of the trench, ranging between 5.26 to 42.11 %, but not in the lower portion at all.

Table 1. AMS ^{14}C dates for sediment sample in Cima volcanic site

Sample	Depth(cm)	14C (yr.BP)	14C (cal. yr.BP)
CV-30	30	2400	2510
CV-90	95	3500	3785
CV-135	135	7500	8300

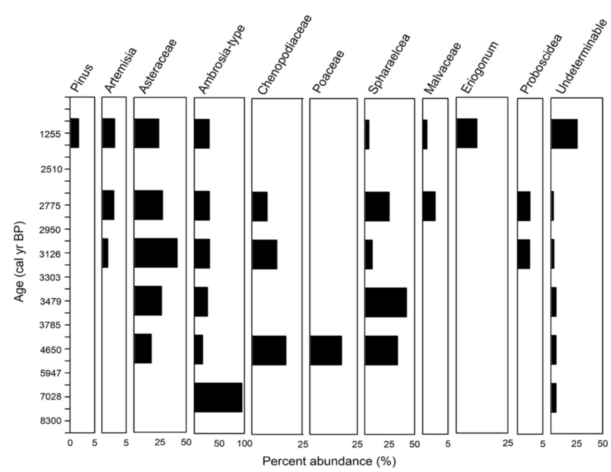

Figure 2. The relative abundance (%) and concentration of pollen for Cima volcanic field.

Table 2. Site location and radiocarbon dates from central Mojave Desert packrat middens.

Sample	Location	Lab code	Elevation (m)	Latitude	Longitude	14C (yr BP)	14C (cal yr BP)	Material
MJ1	Pahranagat Range	Beta28467	1600	37°22'40"N	115°18'1"W	7,030±130	7,853 ± 119	dung
MJ2	Owl Canyon, Devils Hole Range	Beta-64330	790	36°23'54"N	116°14'26"W	8,180± 60	9,150 ± 92	twigs
MJ3	Little Skull Mountain, Nevada test site	Beta26581	1150	36°43'43"N	116°19'36"W	8,480±130	9,454 ± 136	dung
MJ4	Pahranagat Range	Beta31328	1600	37°22'40"N	115°18'1"W	9,120±110	10,328 ± 125	dung
MJ5	Pahranagat Range	Beta-86072	1715	37°22'25"N	115°17'15"W	9,230± 50	10,397 ± 85	piñon
MJ6	Owl Canyon, Devils Hole Range	Beta34790	790	36°23'54"N	116°14'26"W	9,420±130	10,742 ± 240	dung
MJ7	Little Skull Mountain, Nevada test site	Beta 26011	1150	36°43'43"N	116°19'36"W	9,480±370	10,830 ± 516	dung
MJ8	Timpaute Range	Beta 25683	1780	37°34'31"N	115°39'40"W	10,040±130	11,634 ± 261	juniper
MJ9	Little Skull Mountain, Nevada test site	Beta 25675	1150	36°43'43"N	116°19'36"W	10,460±140	12,340 ± 240	dung
MJ10	Pahranagat Range	Beta 32402	1600	37°22'40"N	115°18'1"W	11,710±150	13,600 ± 193	juniper
MJ11	Little Skull Mountain, Nevada test site	Beta25676	1150	36°43'43"N	116°19'36"W	11,970±110	13,950 ± 240	juniper
MJ12	Pahranagat Range	Beta31322	1600	37°22'40"N	115°18'1"W	12,120± 90	14,150 ± 259	dung
MJ13	Pahranagat Range	Beta-74776	1695	37°22'25"N	115°17'13"W	12,280± 60	14,394 ± 306	fir
MJ14	Owl Canyon, Devils Hole Range	Beta32398	812	36°23'54"N	116°14'26"W	12,260±110	14396 ± 342	dung
MJ15	Owl Canyon, Devils Hole Range	Beta-86041	812	36°23'54"N	116°14'26"W	13,540± 60	16,521 ± 380	juniper
MJ16	Pahranagat Range	Beta34792	1600	37°22'40"N	115°18'1"W	13,470±200	16,363 ± 479	juniper
MJ17	Little Skull Mountain, Nevada test site	Beta 25679	1150	36°43'43"N	116°19'36"W	13,740±130	16,841 ± 255	juniper
MJ18	Little Skull Mountain, Nevada test site	Beta 25677	1150	36°43'43"N	116°19'36"W	14,280±180	17,480 ± 282	yucca

Packrat middens

Table 3 gives dates for the expected arrival of major plant components of the Mojave Desert (Fig. 3).Most macrofossil materials came from shrubs including: *Artemisia tridentate* (big sagebrush), *Purshia tridentate* (bitterbrush), *Symphoricarpos longiflorus* (snowberry), *Prunus fasciculata* (desert apricot), *Salvia dorrii* (purple sage), *Tetradymia glabrata*, (smooth horsebrush) *Ephedra* sp. (Mormon tea), *Atriplex canescens* (four-wing saltbush), *Atriplex confertifolia* (shadscale), and *Larrea tridentate* (creosote bush). Macrofossils of grasses, (*e.g.*, *Stipa hymenoides*) *Yucca brevifolia* (Joshua Tree), Cactaceae (cactus) and some trees, including *Pinus flexilis* (limber pine), *Abies concolor* (white fir), *Juniperus osteosperma* (Utah juniper), *Pinus monophyla* (piñon pine) and *Celtis reticulata* (hackberry) were also recovered. All plant macrofossils are from woodrat middens found at elevations between 790 to 1710 m (i.e. from the top of the bajadas to middle elevations in the mountain ranges). Some elements appear much earlier than previously reported (*e.g.*, *Yucca brevifolia* (Joshua Tree)). One component, *Larrea Tridentata* does not appear until 9,500 Cal. years B.P.

Paleoclimate simulation

The MCM climate reconstruction reveals that summer precipitation within the Mojave Desert during the LP/H has the great variability, followed by that of spring precipitation. Fall and winter precipitation were much less variable., though during the LP/H both fall and spring precipitation have episodes of high variability that correspond to those periods when summer precipitation exhibits its highest variability. As will be discussed below, episodes of highest frequency and magnitude in summer precipitation are crucial to the appearance of characteristic Mojave Desert plant species**.**

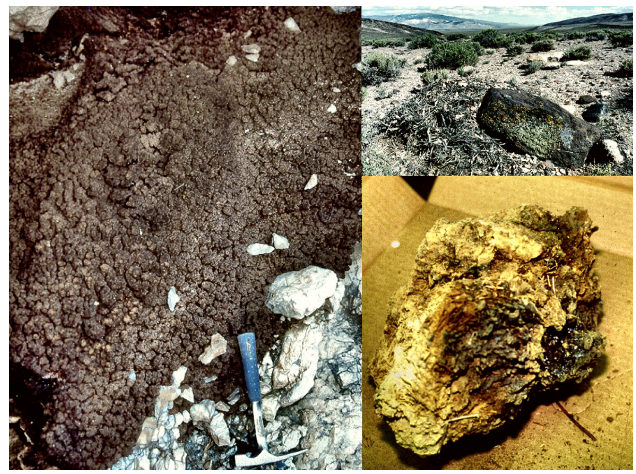

Figure 3. Woodrat midden from the central Mojave Desert collected during the Yucca Mountain High-level Nuclear Waste Repository Site characterization program (left), modern woodrat nest (upper right), and woodrat midden sample ready for processing (lower right).

Table 3. Plant microfossil assemblages from central Mojave Desert packrat middens.

Elevation(m)	Age in ^{14}C years B.P.	*Pinus fexilis*	*Abies concolor*	*Juniperus osteosperma*	*Pinus monophylla*	*Celtis reticulata*	*Artemisia tridentata*	*Purshia tridentata*	*Symphoricarpos longi-florus*	*Prunus fasciculata*	*Salvia dorrii*	*Tetradymia glabrata*	*Ephedra*	*Yucca brevifolia*	*Atriplex canescens*	*Atriplex confertifolia*	*Larrea tridentata*	Grass	*Stipa hymenoides*	*Cactus*	*Cactaceae*
1600	7000			●	●								●		●	●			●		●
800	8200			●	●				●	●	●	●	●				●				●
1200	8500					●															
1600	9100			●			●		●				●						●		●
1700	9200			●	●				●										●		●
800	9500			●					●	●	●		●			●	●		●		●
1200	9500			●							●		●						●		●
1800	10000			●				●													●
1200	10500			●				●			●		●						●		●
1600	11700	●		●					●				●		●	●			●		●
1200	12000			●				●											●		
1600	12000			●			●		●				●						●		●
1700	12300	●	●	●															●		●
800	12300			●								●				●					
800	13500			●					●							●					
1600	13500			●								●							●		●
1200	13700			●							●		●	●					●		●
1200	14300			●												●			●		●

Discussion

Preservation is clearly an issue with pollen samples from the Cima volcanic field. The pollen counts (Pollen Sum and Total Pollen) indicate that the number of pollen present declines dramatically below 70 cm (Tab. 4). Calculation of the actual pollen per sample using the *Lycopodium* spores recovered and the pollen grains counted. indicate that even below the first 20 cm or so preservation declines dramatically. Pollen type diversity indicates that even though some types are rare, it is clear that preservation is much worse below 70 cm as many pollen types disappear from the record. The surface textures of most of the pollen grains has been destroyed, or severely degraded, even in the uppermost sample suggesting either bacterial activity, or oxidation. Despite issues with preservation, the number of *Lycopodium* recovered for statistical purposes were generally sufficient to provide adequate estimates of pollen populations, except for the lowest sample. *Lycopodium* values for sample six are low, however estimates of its pollen population are probably close to the abundance of pollen in the sample. Creosote bush pollen is not found in this record. Both *Ambrosia dumosa* (white bursage) and *Larrea tridentate* (creosote bush) are common within the Cima volcanic field basalt flows today (Figs. 4, 5).

Table 4. Pollen and spore count statistics, and population estimates for the Cima volcanic field samples. Note that the pollen sum (total terrestrial pollen) and pollen total (total terrestrial and aquatic pollen-we did have Cyperaceae and Sedge pollen) decreases rapidly with depth. Also, the total Ambrosia pollen, and total pollen population estimates per sample decreases rapidly with depth as well.

Sample Number	Pollen Sum	Total Pollen	Total Spores	Lycopodium Recovered	Mean Ambrosia Population Estimate	Total Pollen Population Estimate
CV-1	114	115	0	24	52651	176,539
CV-2	40	40	0	90	4955	16,518
CV-3	82	82	0	79	11761	38,577
CV-4	19	19	3	102	1821	6,923
CV-5	6	6	1	58	640	3,845
CV-6	1	1	0	8	4645	4,646

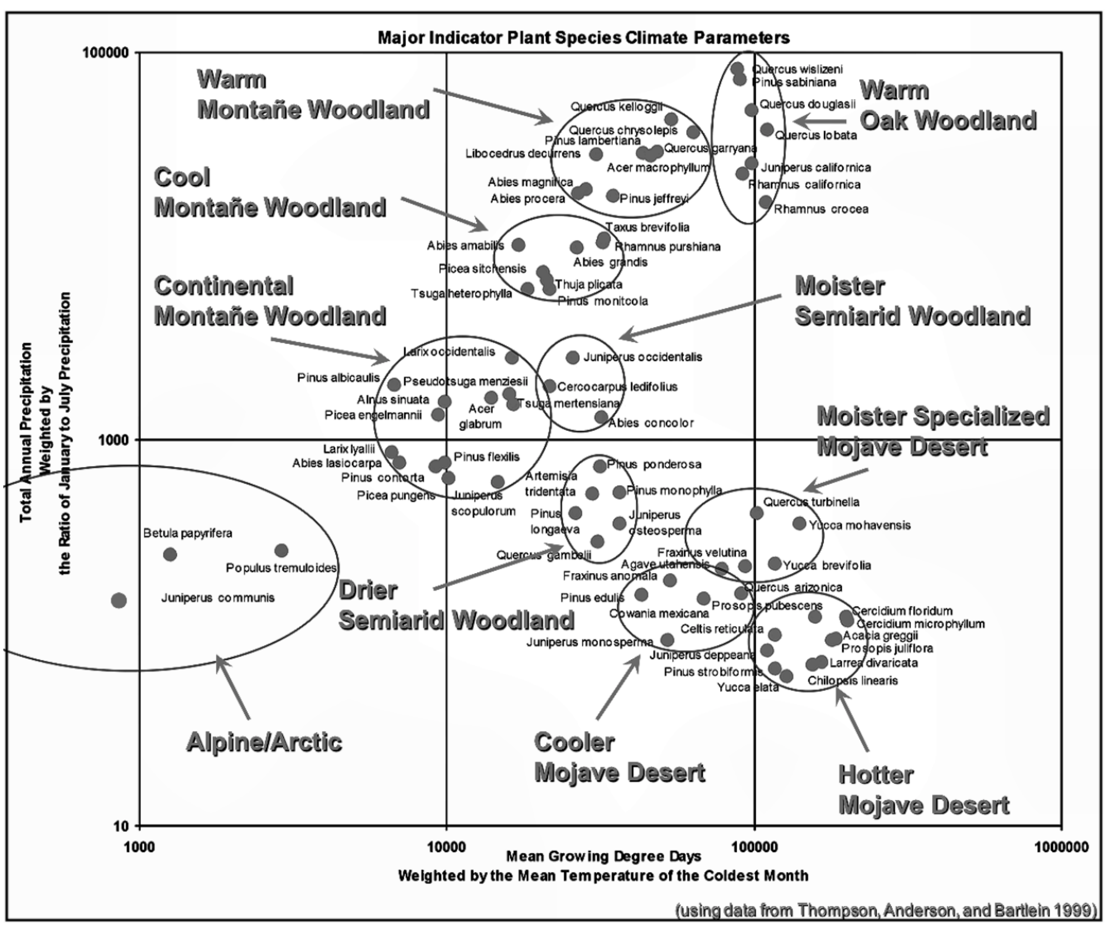

Figure 4. Plant assemblages based upon climate parameters identified in Thompson *et al*. 1999. The y axis uses precipitation variables, and the x axis uses temperature variables to establish the climatic clustering of plant species.

Figure 5. The surface of the distal end (western end) of the Cima volcanic field lava flows. Here a plant community dominated by creosote bush and white bursage is mixed with occasional desert holly (J. McCrea photo).

In our counts, only *Ambrosia dumosa* pollen appears in the record. This does not mean that *Larrea tridentata* was not present at the Cima volcanic field, rather the discrepancy may be due to the nature of creosote bush flowers. *Larrea tridentata* is insect pollinated with several species of native bees being specially adapted to its pollination (Fig. 6). Because creosote bush is insect pollinated, it also produces much less pollen. On the other hand, *Ambrosia dumosa* is wind pollinated and has no petals so that the wind may blow the pollen directly off the anthers, and flowers are arranged along a stalk that can intercept the pollen in the wind (Fig. 6). In addition, white bursage produces abundant pollen several magnitudes greater than creosote bush, so there is a much greater statistical probability of it appearing in a poorly preserved pollen record. This issue also characterized the pollen record from Lower Pahranagat Lake north northeast of Las Vegas (Wigand 2017). Creosote bush was the dominant plant in the community surrounding Lower Pahranagat Lake, but it rarely appeared in the pollen record. Though creosote bush and white bursage may appear just as abundant on the landscape their presence in the pollen record can be significantly different. Finally, two other common pollen types recovered from the Cima volcanic field samples are *Sphaeralcea* (globe mallow) and *Eriogonum* (buckwheat) (Fig. 6). The globe mallow blooms in spring and is quite common throughout the Mojave Desert. Buckwheat is very common throughout the Mojave Desert and blooms in the spring as well and may represent several different species.

The regional woodrat midden record indicates that some components of the Mojave Desert vegetation community arrived during the late Pleistocene (*e.g.*, *Yucca brevifolia)*. Others appear briefly and disappear and reappear again during the early Holocene. This seems to mirror the high variability of the climate during this period. In the MCM climate reconstruction, summer precipitation has several episodes of highly variable precipitation. Both the short frequency and high magnitude of rainfall during these periods is unique when the climate reconstruction for the last 17,000 years is viewed. The spring and fall precipitation pattern generally follow that of summer, but at much reduced magnitudes (Fig. 7). The first period of high magnitude and high frequency summer (and spring and fall) precipitation occurs between 15,000 and 14,000 Cal. years B.P. It is at this time *Yucca brevifolia* appears at Little Skull Mountain at the southern end of the Nevada Test Site. The second episode occurs between 13,500 and 11,000 Cal. years B.P. and is characterized by a slight increase in shrub species diversity. It is not until 9,500 Cal. years B.P. that the full array of Mojave Desert shrub species becomes common and wide spread at all lower elevations in the woodrat midden record (Tab. 4). After 10,500 Cal. years B.P. the current range of climate conditions became stabilized and Mojave Desert plant species came to characterize the vegetation assemblages of the region. Until 10,500 Cal. years B.P. the movement of Mojave Desert plant species into the region may be visualized as waves lapping onto the seashore as the tide rises. Each intrusion of a plant species may have been characterized by species establishment followed by local extinctions as the climate temporarily reverted to less favorable conditions.

Conclusion

The pollen from the Cima volcanic field reveals a record from at least ~8,300 Cal. years B.P. to the present of typical Mojave Desert vegetation. Though preservation is clearly an issue, pollen types offrom plants of the modern Mojave

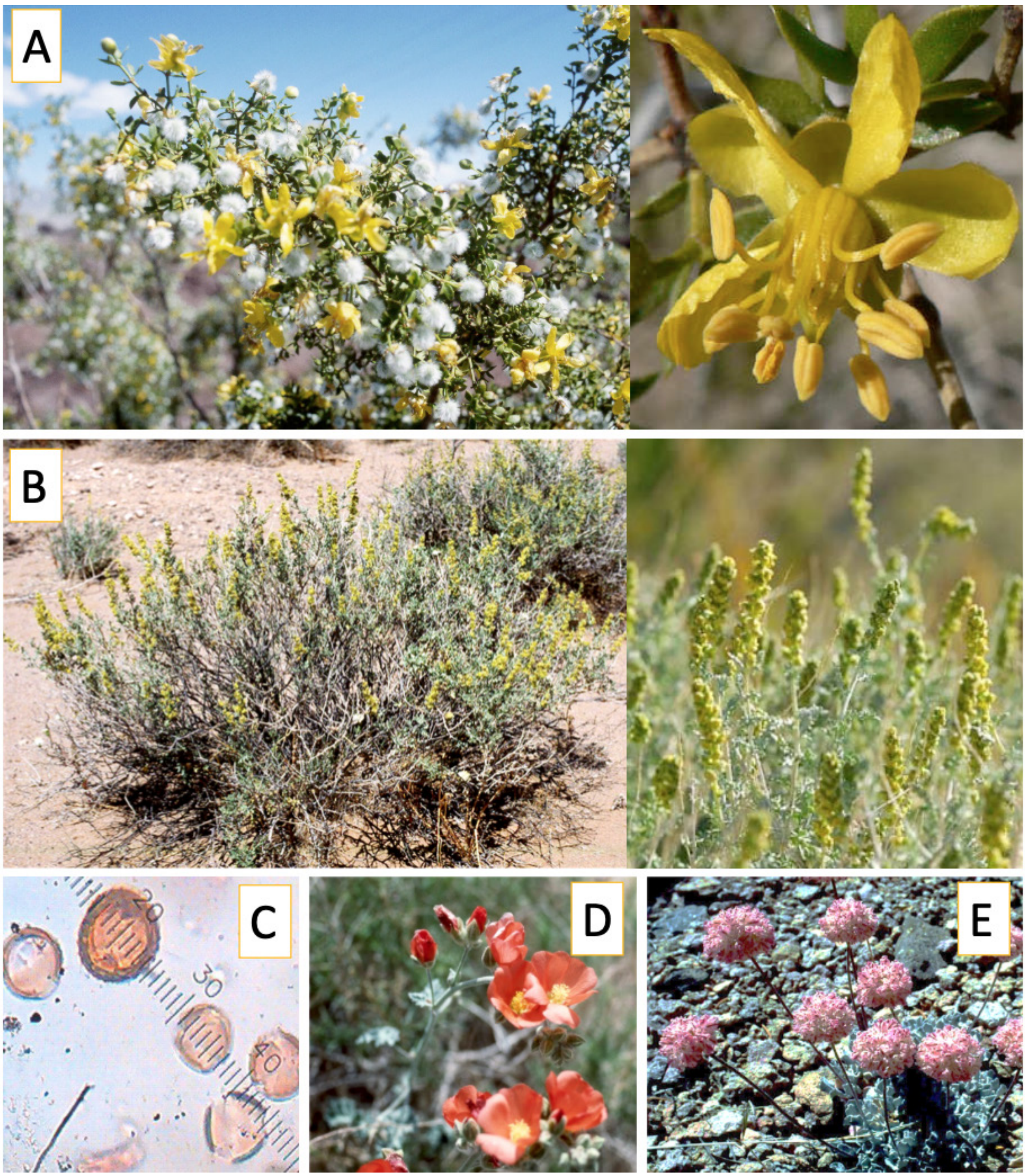

Figure 6. A. Photos of *Larrea tridentata* illustrating the flower structure and their arrangement on the plant. This is efficient for insect pollination but not wind pollination; **B.** Photos of *Ambrosia dumosa* illustrating the structure of the flowers and the efficient flower stalk arrangement for wind pollination; **C.** Creosote bush (the smaller pollen grain) is a thick-walled pollen grain and should survive some degradation. White bursage is the larger thick-walled pollen grain with rough surface structure. Although creosote bush should be there, its pollination ecology does not provide sufficient opportunities for it to be preserved in the record; **D.** Globe mallow; **E.** Buckwheat.

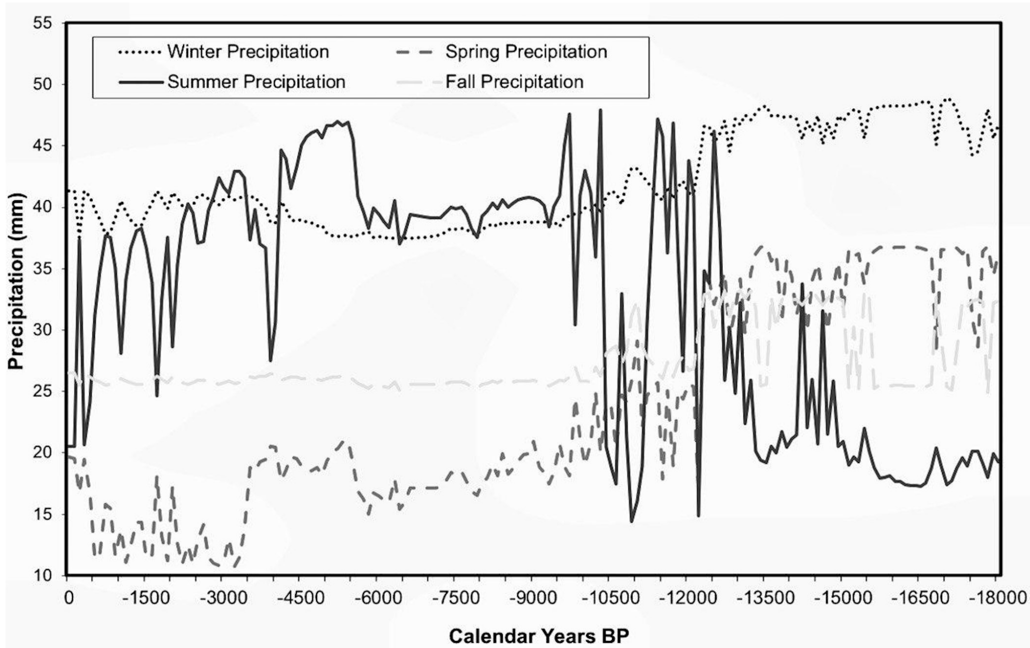

Figure 7. MCM modeled seasonal precipitation for the northeastern Mojave Desert region for the last 15,000 cal. B.P.

Desert are found throughout the record. Although pollen of creosote bush was not present, studies have shown that this is often an artifact of pollen preservation. This record in combination with the woodrat midden record of the area surrounding Yucca Mountain provides evidence for an earlier Holocene establishment of Mojave Desert vegetation community than previously thought. It also indicates that the formation of the Mojave Desert plant community was characterized by intermittent establishments during episodes of favorable climate and retreats and possible local extinctions during less favorable periods of climate. Some species became established as early as 16,000 years ago during the late Pleistocene.

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