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Early Holocene Juniper Woodland and Chaparral Taxa in the Central Baja California Peninsula, Mexico

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A packrat midden located in the Sierra San Francisco, Baja California Sur, Mexico, dating to ca. 10,200 ^{14}C yr B.P., contains remains of California juniper (*Juniperus californica*) and other taxa now associated with southern California chaparral. California juniper does not occur in the Sierra San Francisco today, although "relict" populations of a few chaparral taxa still occur at higher elevations. This midden record documents the early Holocene occurrence of Baja California coniferous woodland and chaparral vegetation far south of its present distribution or its previously known extent from other fossil records. Based on modern climatic tolerances of California juniper and other taxa, central Baja California experienced a mild Mediterranean-type climate at least 5°–6°C cooler than the climate of today, with at least twice the winter precipitation the region now receives.

Key Words: **Packrat middens; *Neotoma*; Baja California; early Holocene; chaparral; *Juniperus californica*.**

INTRODUCTION

Knowledge of the late Pleistocene–Holocene vegetation history of Baja California is critical to understanding (1) the origins of disjunct species of chaparral and woodland plants (Moran, 1983) and mammals (e.g., *Eutamias merriami*; Orr, 1960) on montane "islands" along the Baja peninsula; (2) the age and changing distribution of Sonoran Desert vegetation associations (Axelrod, 1979; Van Devender, 1990); (3) the effects of oceanic and climatic conditions in the eastern Pacific on adjacent terrestrial biomes (Heusser and Sirocko, 1997; Heusser, 1998); (4) the historical processes responsible for plant diversity and endemism in arid regions (Wiggins, 1980; Cody *et al.*,1983); and (5) the environmental contexts of prehistoric human occupations in the region (Hyland and Gutiérrez, 1995). Despite rapid advances in our knowledge of late Quaternary vegetation history of the deserts of southwestern North America (Betancourt *et al.*, 1990), the vegetation history of the Baja California peninsula remains poorly documented (Van Devender, 1990; Metcalfe *et al.*, 2000), although this situation is now beginning to change (e.g., Van Devender, 1997; Peñalba and Van Devender, 1997, 1998; Clark and Sankey 1999; Sankey *et al.*, 2001). Here, I contribute to the emerging picture of late Quaternary phytogeography in Baja California by describing and discussing the contents of a packrat midden of Younger Dryas age from the western slope of the Sierra San Francisco, central Baja California peninsula, Mexico.

THE SIERRA SAN FRANCISCO MIDDEN LOCALITY

The Sierra San Francisco midden locality was discovered in 1996, as part of a larger investigation into the vegetation history of Baja California through the study of packrat (*Neotoma*) middens. It is situated at approximately 780 m elevation, near the top of a long flat-topped ridge between Mesa Los Crestones and Mesa La Ascensión, on the southwest slopes of the Sierra San Francisco in Baja California Sur (27°32.5′N, 113°6.0′W; Fig. 1). This ridge is bounded on both sides by steep canyons of 100 m to several hundred meters depth that wind up into the higher Sierra to the east, which reach a maximum elevation of ∼1600 m. A small homogeneous chunk of heavily indurated packrat midden material was found in a small crevice at the base of an ∼3-m-high basalt outcrop, adjacent to the main road leading into the Sierra from the west (Fig. 2).

Present-day vegetation in the vicinity of the packrat midden is dominated by shrubs and succulents typical of the sarcophyllous and sarcocaulescent Sonoran Desert (Wiggins, 1980), including limberbush (*Jatropha cuneata*), elephant tree (*Bursera microphylla*), palo fierro (*Ebanopsis confinis*), desert agave (*Agave deserti*), and estafiate (*Ambrosia camphorata*), along with a variety of cacti and other shrubs (Table 1). The locality falls within the Vizcaíno phytogeographic province (Shreve, 1951), close to its southeasternmost intersection with the Central Gulf Coast and Magdalenan provinces, as mapped by Turner and Brown (1982). The present-day local vegetation appears to fit most closely in the Basaltic Desert Scrub and Central Gulf Coast Desert Scrub vegetation classes of Zippin and Vanderweir (1994).

Modern-day climate of the midden locality can be interpolated from nearby weather station records (Table 2; Fig. 1). These records suggest an average annual precipitation of approximately of 125–150 mm, with ∼25–35% falling in winter, 30–40% in summer, and ∼25–30% in fall (Hastings and Turner, 1965; Hastings and Humphrey, 1969; Amundson *et al.*, 1994). The area is near the southern edge of the gradual ecotone between

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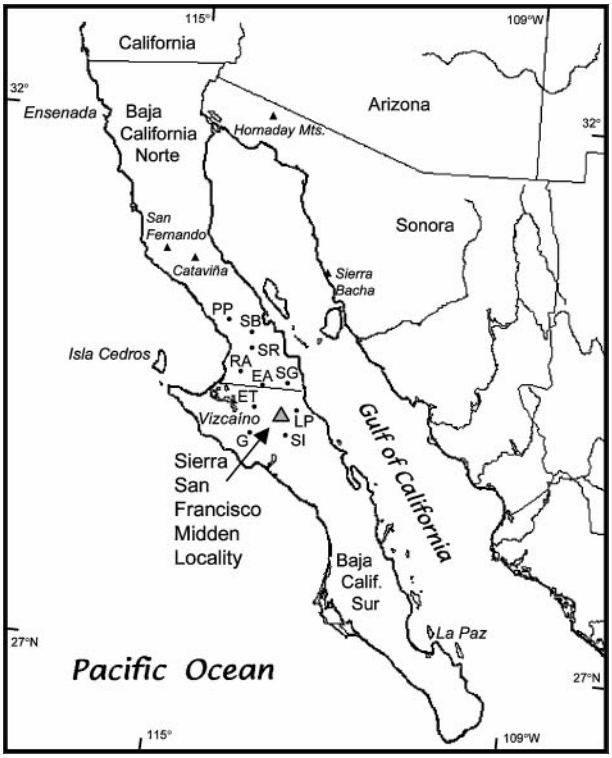

FIG. 1. Location of Sierra San Francisco midden, Baja California Sur. Other packrat midden locations discussed in text are shown, as are nearby weather stations (refer to column 1 of Table 2 for codes).

the current Mediterranean, winter-precipitation climate of the northern Peninsula and the subtropical, summer-precipitation regime of the southern Peninsula (Reyes *et al.*, 1988). Interannual precipitation variability in this area is extremely high, owing to occasional localized deluges from tropical storms (Hastings and Turner, 1965; Markham, 1972). Annual temperatures in the region typically average ~20°C (January ~15°C, July ~26°C).

The midden locality is on the Pacific side of the central Baja California mountain chain, so its local climate is moderated somewhat by cool moist air from the Pacific Ocean. That influence is probably not great because of the intervening broad expanse of the Vizcaíno Peninsula. The altitude of the midden is slightly above the Pacific coastal fog belt that frequently blankets the Vizcaíno Peninsula and fills the canyons beside the ridge. It is unlikely that the midden would have survived intact if repeatedly wetted by fog, so the fog belt has probably never reached the elevation of the midden since it was formed.

METHODS AND DATING

The small midden was collected in its entirety from its crevice and subsequently weighed (211.5 g) and disaggregrated by soaking in dH_2O and sieving through 0.5-mm mesh screen. The residue trapped on the screen was air-dried, and plant remains were sorted using a binocular dissecting microscope. Plant remains were identified using voucher reference specimens collected in the field and in several herbaria (see Acknowledgments).

A radiocarbon age estimate of the midden was obtained from a 10.6-g sample of packrat dung, submitted to the Desert Research Institute radiocarbon laboratory. The resulting date, $10{,}219 \pm 160$ ^{14}C yr B.P. corresponds to a calibrated age range of 12,370–11,500 cal yr B.P. at 1σ and 12,820–11,310 cal yr B.P. at 2σ, using the CALIB 4.3 conversion package (Stuiver and Reimer, 1993; Stuiver *et al.*, 1998a, 1998b). The age falls within

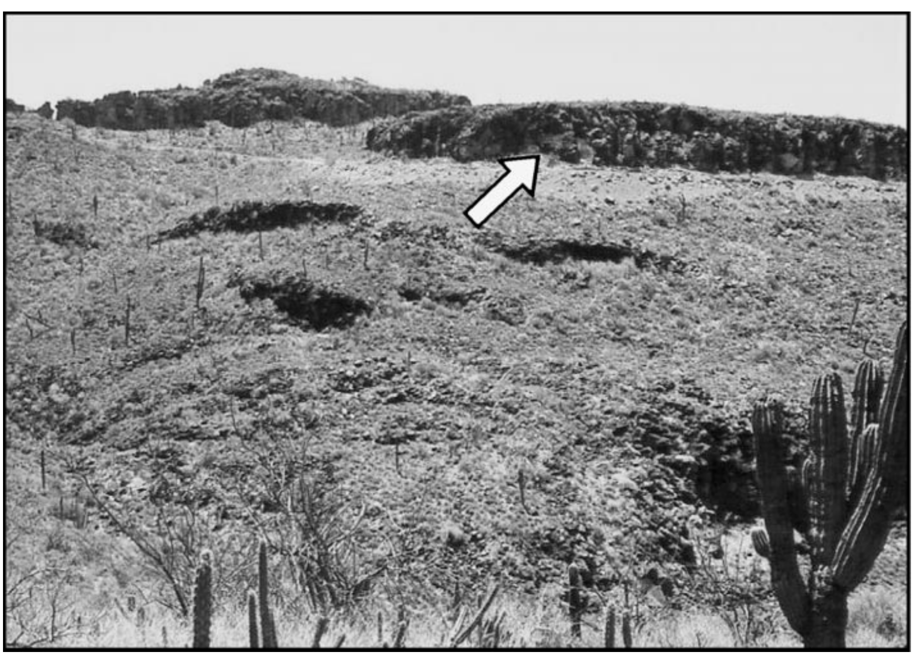

FIG. 2. Location of Sierra San Francisco packrat midden (arrow), at base of ~3-m-high basalt outcrop.

TABLE 1
Modern Plants Noted in Vicinity of Packrat Midden, Sierra San Francisco, Baja California Sur, Mexico

Taxon	Abundance
Desert agave (*Agave deserti*)	Abundant
Estafiate (*Ambrosia camphorata*)	Abundant
Limberbush (*Jatropha cuneata*)	Abundant
Elephant tree (*Bursera microphylla*)	Common
Golden-eye (*Viguera laciniata*)	Common
Palo fierro (*Ebanopsis confinis*)	Common
Cholla cactus (*Opuntia cholla*)	Common
Silver cholla (*Opuntia* cf. *alcahes*)	Common
Barrel cactus (*Ferocactus* cf. *gracilis*)	Occasional
Brittlebush (*Encelia farinosa*)	Occasional
Torote (*Bursera hindsiana*)	Occasional
Pitahaya (*Stenocereus gummosus*)	Occasional
Cardón (*Pachycereus pringlei*)	Occasional
Candelilla (*Pedilanthus macrocarpa*)	Occasional
Fairy duster (*Calliandra californica*)	Occasional
Palo adán (*Fouquieria diguettii*)	Occasional
Acacia (*Acacia sp.*)	Rare
Foothill paloverde (*Parkinsonia microphylla*)	Rare
Aralia (*Aralia scopulorum*)	Rare
Grasses (Poaceae)	Occasional
Mustard family (Brassicaceae)	Occasional

the Younger Dryas climatic episode, the final cold event during the last glacial–interglacial transition. The Younger Dryas episode is well documented in sediment cores taken along the eastern margin of the North Pacific Ocean, including the Santa Barbara Basin (Kennett and Ingram, 1995; Behl and Kennett, 1996) and the Gulf of California (Keigwin and Jones, 1990). Effects of the Younger Dryas cool interval are also indicated by glacial advances (Reasoner and Jodry, 2000), modest rises in the levels of certain arid western continental lake systems (Benson *et al.*, 1992), and increased spring activity and peat development (Quade *et al.*, 1998).

MIDDEN CONTENTS

The plant remains found in the midden differ almost completely from the Sonoran Desert vegetation that occupies the locality today. Instead, the midden contains remains of plants commonly found in coastal sage and chaparral associations in southern California and northern Baja California, several hundred kilometers north (Table 3). Plants of northern affinity include California juniper (*Juniperus californica*), laurel sumac (*Malosma laurina*), Baja manzanita (*Arctostaphylos peninsularis*), American wild carrot (*Daucus pusillus*), Pacific blacksnakeroot (*Sanicula* cf. *crassicaulis*), sixweeks fescue (*Vulpia* cf. *octoflora*), and California brome (*Bromus* cf. *carinatus*).

TABLE 2
Weather Station Summary Records from Central Baja California, Surrounding Sierra San Francisco Midden

Station (Code)	Period of record (Reference[a])	Average temperature (°C)			Mean precipitation (mm)			
		Jan	July	Annual	Jan	July	Annual	% summer (Jun–Sep)
Punta Prieta (PP), 200 m	1960–1990 (1)				16.4	1.7	120.2	14.5
28.97°N, 114.17°W	1954–1967 (2)	15.1	25.6	20.0	15.8	1.1	92.6	20.1
San Borja (SB), 375 m	1960–1990 (1)				16.8	7.6	129.4	24.9
28.78°N, 113.93°W	1955–1967 (2)	15.0	25.2	19.9	19.4	3.8	142.5	30.8
San Regis (SR), 300 m	1960–1990 (1)				16.9	8.4	135.6	21.0
28.60°N, 113.95°W								
Rancho Alegre (RA), 500 m	1960–1990 (1)				27.5	7.4	166.4	23.1
28.28°N, 113.88°W	1954–1966 (2)	14.2	24.1	19.2	42.8	12.7	205.7	23.7
Santa Gertrudis (SG), 550 m	1955–1967 (2)	15.5	28.5	21.3	19.2	18.6	147.9	56.1
28.08°N, 113.11°W								
El Arco (EA), 300 m	1960–1990 (1)				17.8	6.5	120.7	34.7
28.00°N, 113.43°W	1953–1967 (2)	15.6	25.1	20.4	26.9	7.4	140.4	39.2
El Tablón (ET), 80 m	1956–1967 (2)	14.4	26.6	20.4	23.6	1.9	113.9	33.1
27.62°N, 113.34°W								
La Palma Norte (LP), 110 m	1955–1967 (2)	16.7	29.0	24.3	16.5	6.0	107.6	45.8
27.61°N, 112.66°W								
Guadelupe (G), 120 m	1954–1966 (2)	15.4	28.1	21.8	14.6	7.7	71.4	40.7
27.30°N, 113.39°W								
San Ignacio (SI), 105 m	1960–1990 (1)	15.1	27.8	21.3	11.2	9.5	92.7	49.6
27.28°N, 112.90°W	1938–1967 (2)				10.1	7.0	92.1	48.2

Note. Stations are listed north to south, following gradient from Mediterranean to subtropical climate dominance. Locations of stations are shown in Fig. 1. Weather summary data from 1960–1990 are given where available. Other climate summary data representing various shorter intervals (taken from Hastings and Humphrey, 1969) are presented for comparison, since Baja California climate records are fairly sparse. Two stations (Santa Gertrudis and La Palma Norte) are located on the Gulf of California side of the peninsula and are influenced more by continental Gulf climate than by maritime Pacific climate.

[a] Reference: (1) A. Douglas and P. Englehart, personal communication, 2001; (2) Hastings and Humphreys (1969).

TABLE 3
Plant Remains from Packrat Midden, Sierra San Francisco, Baja California Sur

Taxon	Abundance
California juniper (*Juniperus californica*; twigs, fruit)	4
Laurel sumac (*Malosma laurinus*; twigs, fruits, seeds)	4
Baja manzanita (*Arctostaphylos peninsularis*; fruits)	3
American wild carrot (*Daucus pusillus*; fruits)	3
Pacific blacksnakeroot (*Sanicula* cf. *crassicaulis*; fruits)	2
Sixweeks fescue (*Vulpia* cf. *octoflora*; caryopses)	2
California brome (*Bromus* cf. *carinatus*; caryopses)	2
Pea family (Fabaceae; pod fragments)	2
Nightshade family (Solanaceae; seeds)	2
Bursage (cf. *Ambrosia* sp.; fruit)	1
Mint family (Lamiaceae; stem fragment)	1
Bedstraw (*Galium* sp.; fruit)	1
Cactus (Cactaceae, cereoid-type; seed)	1
Fascicled browntop (*Brachiaria* cf. *fasciculatum*; florets)	1

Note. Abundances ranked on qualitative scale, with most abundant remains in midden given a 4, least abundant given a 1, and abundance of remains of other taxa scaled in between.

Some taxa, including California juniper and Baja manzanita, are absent from the Sierra San Francisco today. The nearest known stand of California juniper grows above 1200 m elevation on north-facing slopes of Cerro Sauco in the Sierra San Borja (SB, Fig. 1), ca. 150 km to the north (Moran, 1983; R. Moran, field notes). California juniper also occurs on Isla Cedros (Wiggins, 1980), some 200 km to the northwest of the midden locality near Bahía Tortuga. Baja manzanita has its southernmost limits in the Sierra San Borja (maximum elevation 1820 m; Wells, 1972; Moran, 1983). Pacific blacksnakeroot occurs under shrubs and on shady slopes only in the far northwest part of Baja California today, while the wild carrot is more widespread, found in the northern mountains and on grassy hillslopes as far south as Comondú (Wiggins, 1980). The two grasses, sixweeks fescue and California brome, are now found mainly in the Sierra Juárez and Sierra San Pedro Mártir in northern Baja California (Wiggins, 1980; Gould and Moran, 1981), but both have been found in mountains to the south, including Sierra San Francisco (Gould and Moran, 1981). Laurel sumac, a characteristic coastal sage and chaparral species, today grows in the Sierra San Francisco above 1000 m elevation (R. Moran, field notes) and is found in scattered mountain localities as far south as the Cape (Moran, 1983; Turner *et al.*, 1995:266–268). Laurel sumac can also be found at lower elevations in streambeds or around springs in the fog belt on the Pacific Coast as far south as Bahía Tortuga on the Vizcaíno Peninsula, where it is protected from prevailing aridity and killing frosts (Shreve, 1936).

Moran (1983) described as "relictual" those chaparral plants and others with northern biogeographic affinities that grow on the higher peaks along Baja California's central mountain spine. The Sierra San Francisco midden record documents that such vegetation grew at moderate elevations (<800 m) along the piedmont of these mountains as late as ~11,800 cal yr B.P. Several of these taxa grew considerably further south than their present-day "relictual" distribution indicates.

The only plant represented in the midden with southerly, subtropical affinities is fascicled browntop (*Brachiaria fasciculata*). Two small florets of fascicled browntop were found in the midden, identified to the species level (and distinct from *Brachiaria arizonica*, an ecologically and biogeographically more likely candidate) by a lemma having a transversely rugose coat, beaked but not apiculate, and a distinctive circular (rather than ovoid) basal scar. This grass is found today in Baja California primarily in coastal areas and at lower to middle elevations in the southern mountains (Gould and Moran, 1981). I have seen no herbarium records of fascicled browntop from the Sierra San Francisco, but it occurs in the Sierra de la Giganta between 600 and 900 m elevation, 250 km south of the midden site.

Comparison with Other Records

The Sierra San Francisco midden lacks nearby samples to compare and monitor vegetation change over time at this locality. Fortunately, other midden records from Baja California allow it to be placed into a broader biogeographic context. Van Devender (1997) recently reported the results of midden samples from near Cataviña and San Fernando (see Fig. 1), located at approximately 640 m elevation in the northern Vizcaíno Desert subdivision (cf. Wells, 1976, 1987). Of most interest are samples dating ca. 10,100 ^{14}C yr B.P., which contain remains of chaparral plants and California juniper. According to Van Devender (1997), the "analogs of the early Holocene assemblages are located in 'soft' chaparral from Ensenada to San Diego." The Sierra San Francisco midden contents are quite similar to those found at Cataviña and San Fernando of the same age, extending the record of juniper and other chaparral taxa at relatively low elevations (<800 m) ~300 km further south.

Early Holocene midden records from northwestern Sonora near the Gulf of California (Van Devender *et al.*, 1990a, 1994) are from lower altitudes, below ~250 m. These middens document the occurrence of plants typically found in Baja California plant communities today; coniferous woodland and chaparral elements were rare to absent during the early Holocene at these lower elevations nearer the Gulf.

PALEOCLIMATIC IMPLICATIONS

The persistence of chaparral and woodland plants in the uplands of central Baja California ca. 10,000 ^{14}C yr B.P. suggests that climatic conditions in this region were much like those of montane settings in northwestern Baja California today. Likely climate analogs can be estimated from the present-day climatic tolerances of midden constituents such as California juniper (Thompson *et al.*, 1999). Where California juniper grows today in southern California and the mountains of northern Baja California, annual precipitation is typically above 250 mm, with nearly all of that occurring in fall and winter. Mean annual temperature is about 15°C, with mean temperature between 5°–10°C in winter and 21°–27°C in summer. By contrast, present-day precipitation at the midden locality is much less (about 100–150 mm), with a large but variable proportion (30–40%) from summer storms. Mean annual temperatures and average winter temperatures are currently 5°–6°C above the typical limit of California juniper; average summer temperatures are 1°–2°C above the usual tolerances as well. This general comparison suggests that central Baja California received at least twice the winter precipitation it receives at present, that winters were at least 5°–6°C cooler (although rarely freezing) and summers at least 2°C cooler.

The abundance of laurel sumac in the midden provides additional constraints on climate. Although the biogeographic affinities of laurel sumac are clearly northern, it grows in a few scattered locations in higher mountains of the southern Baja California peninsula, as noted above. It is common in areas with a mild frost-free climate, particularly where warm-season conditions are not too hot and dry, and mainly in areas with winter-dominant precipitation. Laurel sumac cannot be considered as evidence for enhanced summer precipitation because it is now most prevalent in dry-summer Mediterranean climates, so it likely signifies a mild, equable climate with precipitation falling mainly in the winter. Laurel sumac is exceptional among chaparral plants in its tendency to grow year-round, without a dry-season dormant period (Mooney, 1977). This ability may have allowed it to become one of the few chaparral taxa to successfully adapt to a summer-wet regime in the southern Baja peninsula.

There is little evidence of plants adapted to warm-season precipitation growing in the vicinity of the Sierra San Francisco midden during its deposition. Only a single element of any succulent is represented, a seed of a cereoid-type cactus, and the subtropical grass fascicled browntop is represented by only two florets. This grass, with a C4 photosynthetic pathway, now grows in southern Baja California and subtropical areas where summer rainfall predominates, and its presence could conceivably indicate that summer precipitation was greater than at present. But as Van Devender *et al.* (1990b) noted, “rather than indicating summer precipitation, the presence of C4 grasses [in late Wisconsin and early Holocene Sonoran Desert middens] is probably due to their ability to respond at low elevations to available moisture at relatively cool temperatures.” This inference, he noted, contrasts strongly with results from some climate models of the early Holocene, which predict warmer terrestrial and sea-surface temperature and enhanced summer precipitation (Van Devender *et al.*, 1987, 1994; Van Devender, 1990; cf. Spaulding and Graumlich, 1986; Thompson *et al.*, 1993).

Van Devender (1997) suggested that “expansion of [Early Holocene] winter-rainfall, cool-summer vegetation [in Baja California] indicates colder sea surface temperatures, likely due to strengthening of the California Current.” Several lines of evidence indicate that marine and terrestrial ecosystems along the eastern Pacific Coast underwent significant fluctuations at the time when the Sierra San Francisco midden was being deposited (Keigwin and Jones, 1990; Kennett and Ingram, 1995; Behl and Kennett, 1996; Heusser and Sirocko, 1997; Heusser, 1998). However, there is little evidence for colder sea-surface temperature (SST) offshore central Baja California during this time. The Santa Barbara Basin record indicates cool sea-surface temperatures (∼10°C) during the Younger Dryas (Kennett and Ingram, 1995; Kennett and Venz, 1995), as do records to the north (e.g., Mix *et al.*, 1999). Most Southern California records, however, indicate that SST began warming by at least 14,000 ^{14}C yr B.P. (perhaps much earlier; see Herbert *et al.*, 2001) and was essentially modern by 10,000 ^{14}C yr B.P., with little evidence of significantly cooler waters during the Younger Dryas (Mortyn *et al.*, 1996; Doose *et al.*, 1997; Gardner *et al.*, 1997). Conclusions are limited for Baja California because of the sparseness of marine records south of 32°N, yet the existing marine core evidence does not show California Current waters as far south as Baja California during the early Holocene. Recent paleoclimate model simulations also suggest that Younger Dryas cooling of the North Pacific decreased SST (Mikolajewicz *et al.*, 1997), but the cooling effects occurred north of 30°N, and mainly north of 50°N.

SUMMARY

Plants characteristic of modern southern California chaparral, juniper woodlands, and the transition between chaparral/coastal sage scrub and Sonoran desertscrub grew in central Baja California ca. 10,200 ^{14}C yr B.P. (∼11,800 cal yr B.P) at 27.5°N, ∼500 km south of their current main distribution in Baja California. The plants found in this midden sample are completely different from those that grow in the vicinity today but are consistent with early Holocene middens known from the northern Vizcaíno Desert. The plants found in the Sierra San Francisco midden indicate a mild, equable Mediterranean climate, with cool winters but little frost, relatively cool summers, and predominantly winter precipitation at least double the amount that the area receives today.

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