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A geoarchaeological chronology of Holocene dune building on San Miguel Island, California

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Abstract: A data base of 114 ^{14}C dates from 40 archaeological sites in San Miguel Island sand dunes provides a general chronology for Holocene dune building. Although rising seas have probably submerged earlier evidence, postglacial dune building on San Miguel began as early as 10 000 years ago. More intensive dune building dates to the middle and late Holocene, including large parabolic dunes that traverse the island and climb some of the highest landforms. Native American peoples lived on and altered island sand dunes for nearly 10 000 years, and native burning and other landscape alterations may have contributed to periodic destabilization of island dunefields. Accumulation of cultural debris also facilitated anthropogenic soil formation in many coastal localities, however, and over the millennia midden debris protected large expanses of the island's coastal perimeter from wind erosion. With the introduction of sheep *c.* AD 1850, destabilization and erosion of dune soils caused by overgrazing and other human impacts reached unprecedented levels, devastating the island's natural ecology. In recent decades, with the removal of sheep and other exotic animals from the island, the dunes have begun to restabilize.

Key words: California Channel Islands, shell middens, sand dunes, coastal geoarchaeology, Holocene.

Introduction

Although Cooper (1967) and others extensively mapped dunefields along the Pacific Coast of North America, systematic efforts to date local or regional pulses in dune formation have been limited. As part of a study designed to re-evaluate the chronology and extent of Pacific Coast dunefields (Peterson *et al*., 2004), we synthesized an extensive body of data on the timing of Holocene dune building on San Miguel Island off the southern California Coast (Figure 1). As Johnson (1972), Orme (1990), Compton and Franceschini (2005) and others have shown, radiocarbon (^{14}C) dating of archaeological materials found in palaeosols or on palaeosurfaces in dunes is a powerful tool for reconstructing the chronology and dynamics of dune building in coastal settings.

On California's Channel Islands – despite broad implications for understanding ancient and modern geography, hydrology, flora and fauna, and human land use – the chronology of dune formation is poorly understood. Cooper (1967) had not visited the Channel Islands at the time of his synthesis of Pacific Coast dunes. Orr (1967, 1968) worked on the archaeology and geochronology of Santa Rosa Island landforms in the 1950s and 1960s, but only at a small number of dune localities. Johnson (1972) analysed the geographic context of San Miguel Island dunes and the processes involved in their formation and transformation, but obtained limited chronological data for Holocene dunes. Here we build on Johnson's work to examine the chronology of dune formation on San Miguel over the past 10 000 years.

Background

Located approximately 44 km from the Santa Barbara Coast, San Miguel is the westernmost of the Northern Channel Islands. The islands, although not connected to the California mainland during the Quaternary, were united as a single landmass (Santarosae) during the height of the last glacial, when San Miguel's shoreline extended seaward between 4 and 20 km (see Wenner and Johnson, 1980: 505). Strong winds buffet San Miguel most of the year, blowing predominantly from the northwest. Maximum elevation of the island is 253 m, but extensive wave-cut tablelands range between about 45 and

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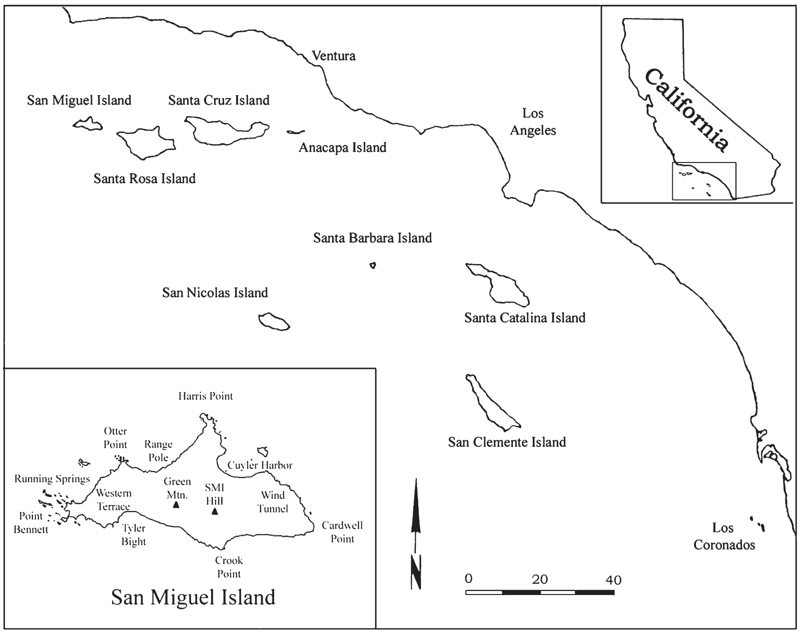

Figure 1 Location map for San Miguel Island

120 m above sea level. The landscape is dominated by Holocene sand dunes and Pleistocene aeolianites (Johnson, 1980: 103). Largely unconsolidated and relatively unstable, Holocene dunes form some of the most dramatic landforms on the island. Because of their unique composition, soils and hydrology, the dunes support distinctive plant and animal communities (see Schoenherr *et al.*, 1999: 237–40). The well-drained dunes were also favoured living areas for the Chumash Indians and their ancestors. Rich in carbonate sands and high in pH, the dune soils of San Miguel are conducive to preserving many archaeological materials.

At various times in the past, sand dunes climbed many of the steep cliffs and slopes of the north coast, streamed across the tablelands and hills of the island, and reached the south coast and the sea (Figure 2). Pleistocene dunes on San Miguel, which appear to have a considerably greater volume and areal extent than Holocene dunes, range from moderately indurated to heavily cemented. Many are underlain by thick and impermeable caliche horizons. In contrast, Holocene dunes range from essentially unconsolidated to lightly indurated, depending on their age and geographic context. Recent geological reconnaissance suggests that Holocene dunes are comprised, in part, of Pleistocene dune sands reactivated by postglacial sea-level rise, coastal erosion and other processes.

Palaeosols are present in both Pleistocene and Holocene dunes, ranging from a few centimetres to several metres thick. Our chronological data come almost exclusively from archaeological soils of Holocene age, so our focus is on the age of Holocene dune activity rather than the nature of intervening palaeosols. Because of the dynamism of many Holocene dunes and the density of past human settlement, the thickness and structure of dune palaeosols on San Miguel Island are determined primarily by the degree of anthropogenic enrichment (by wood ash, charcoal, plant and animal tissues, and artefacts). These anthropogenic soils range from a few centimetres to several metres thick, depending on the length and intensity of human occupation. B-horizons in these anthropogenic dune soils are generally weakly developed or absent (Figure 3). Quantitative analysis of 169 soil samples from seven stratified shell middens (SMI-485, 488, 492, 503, 504, 510 and 525) on the northwest coast of San Miguel demonstrated that the site soils were dominated by coarse sands, with occasional loamy sands containing as much as 18% silt-sized particles. Most of the soil samples were moderately alkaline, with pH values ranging between 7.82 and 9.66 (Neibla, 1984).

Much of San Miguel Island has been surveyed by archaeologists (e.g., Greenwood, 1978; Rozaire, 1978). More than 600 sites have been recorded, including many shell middens with multiple occupational components. The earliest evidence for

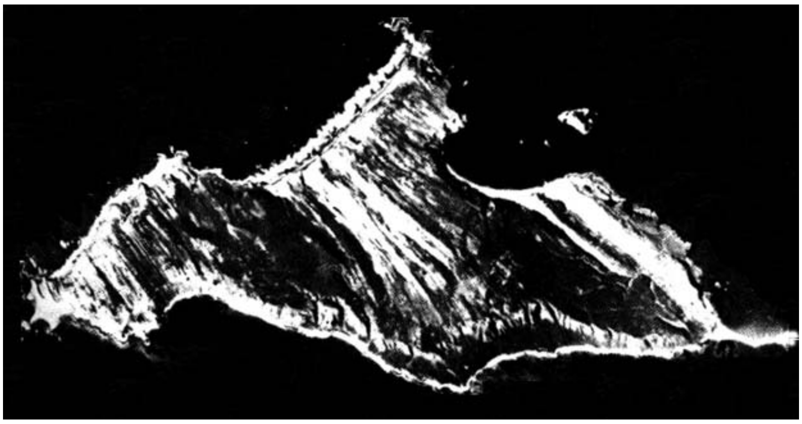

Figure 2 Aerial photograph of San Miguel Island in 1972, showing active dunes and deflated areas oriented from northwest to southeast

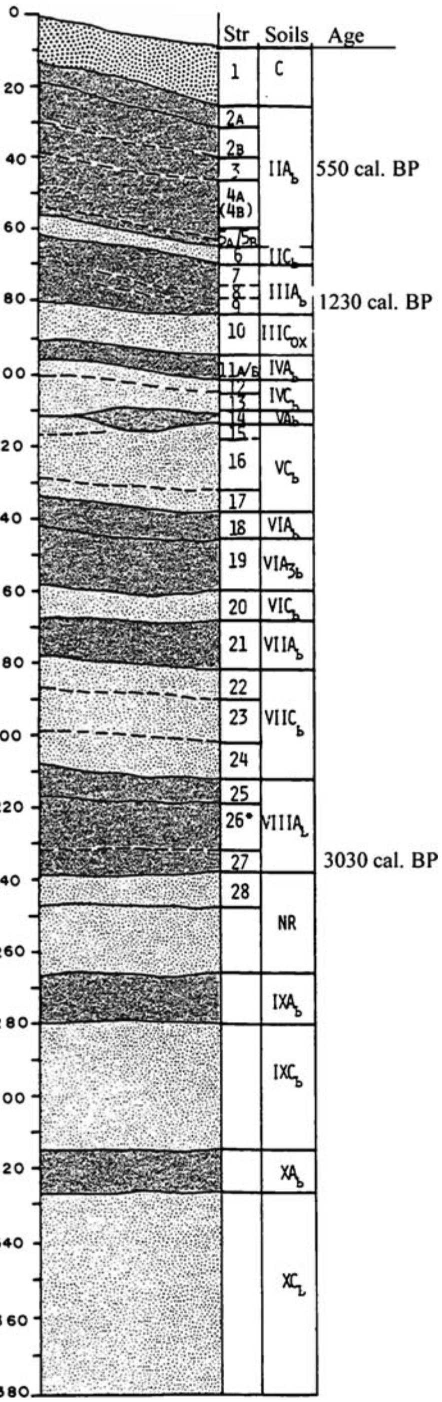

Figure 3 Stratigraphic profile at SMI-525 at Point Bennett, northwest San Miguel Island, showing multiple anthropogenic A-horizons formed in dune sands spanning the past 3000 to 3500 years

human occupation dates to approximately 10 500 radiocarbon yr BP (RYBP) or 11 700 cal. BP (Erlandson *et al.*, 1996), with an essentially continuous record from approximately 10 000 cal. BP to the present. Europeans first contacted the Chumash in AD 1542, when Spanish ships commanded by Juan Rodriguez Cabrillo wintered in Cuyler Harbor on the north coast. Such contacts were sporadic until AD 1769, when the Spanish began building missions and forts (presidios) in California. Contact with Europeans and Old World diseases devastated the Chumash, and the last islanders left or were removed from San Miguel *c.* AD 1820 (Erlandson *et al.*, 2001). By the 1850s, island ecology was fundamentally altered by the cessation of Chumash fishing, hunting and foraging activities, the introduction of sheep, other livestock and exotic plants and animals, and the commercial extirpation of sea otters and other marine mammals (Erlandson *et al.*, 2004).

Most Native American sites on the island are built in dune soils where deflation caused by historical overgrazing, coastal erosion and other processes have impacted them (see Rick, 2002). Even many heavily eroded dunes still contain stratified shell midden deposits, however, and these provide a remarkable record of island ecosystems and human interaction with them. Well-preserved marine shells, charcoal and other organics suitable for ^{14}C dating (Erlandson and Moss, 1999) are still present in most sites. Careful selection and handling of ^{14}C samples (including dating of individual shells or small burned twigs) from well-stratified archaeological deposits minimizes problems associated with stratigraphic mixing or the ‘old wood’ effect. Dating of charcoal-shell pairs and historic shells of known age also provides a framework for effectively calibrating and comparing dates on samples from marine versus atmospheric carbon reservoirs (Erlandson *et al.*, 1996; Kennett *et al.*, 1997).

We have obtained ^{14}C dates for many San Miguel shell middens, many associated with palaeosols stratified in Holocene dunes. For this paper, we compiled 114 ^{14}C dates from 40 archaeological sites stratified in coastal dunes, providing an opportunity to examine the chronology of Holocene dune building on the island (Table 1). Owing to preservation problems associated with Holocene sea-level rise, coastal erosion and historical deflation, understanding the full extent of various dune-building events is problematic. Where possible, however, we draw conclusions from observations of the thickness, extent and location of Holocene dune deposits.

Chronology of Holocene dunes on San Miguel Island

Terminal Pleistocene and early Holocene (12 000–6700 RYBP)

On San Miguel, Holocene dunes are generally underlain by a well-developed palaeosol of terminal Pleistocene and early Holocene age that can often be traced for long distances in sea cliff, gully and surface exposures. Johnson (1972: 206) referred to this soil or soil complex as the Simonton palaeosol, for the cove on the northwest coast where it was prominently exposed. Here, he documented the landward edge of a dune advance marked by the Yardang eolianites, bracketed between palaeosols containing charred tree stumps dated to approximately 21 000 and 17 700 RYBP.[1] This dune advance was associated with the low lastglacial sea stand, when the coast of Santarosae was up to 20 km northwest of the modern shoreline. In places, where the Simonton soil was not covered by Holocene dunes, soil formation continued through the Holocene, forming what Johnson referred to as the Green Mountain soil. Where the Simonton soil is buried beneath Holocene dunes, especially where archaeological organics are present, it forms a prominent stratigraphic marker that can be used to date the earliest Holocene dune building along the north coast of the island.

Based on the few dates available for archaeological or geological strata, Johnson (1972: 209) and Orr (1968) suggested that Holocene dune building began on San Miguel and Santa Rosa islands about 7500 to 7000 years ago. On the northwest coast of San Miguel near Pt Bennett, however, we documented two early middens formed in thin dune soils or sands, one (SMI-522) between about 9800 and 9600 years old and another (SMI-606) between about 9400 and 8100 years old. These sites are located roughly 3.0–1.5 km from the

Table 1 Radiocarbon chronology for Holocene dune building on San Miguel Island, California[a]

Site (SMI-)	Provenance data	Position[b]	Sample no.	Material[c]	Uncorrected ^{14}C age	^{13}C/^{12}C adjusted age	Calibrated age range (1 σ), cal. BP
9	Eroding dune soil	DP	OS-31602	B	–	1090±55	530 (490) 450
	Sea cliff	BD	OS-30355	M	–	5110±70	5300 (5250) 5050
87	East Unit: top	CD	Beta-146120	B	2530±60	2960±60	2540 (2420) 2340
	East Dune: surface	CD	OS-26071	AF	–	2980±35	2540 (2450) 2350
	East Dune: rock feature	CD	OS-27236	C	2510±55	2510±55	2740 (2610) 2470
	East Dune: top	CD	Beta-134832	B	2660±70	3090±70	2730 (2690) 2490
	East Unit: bottom	CD	Beta-145425	B	2830±60	3260±60	2860 (2780) 2740
	West Dune: Tar feature	CD	Beta-134831	M	2990±80	3420±80	3130 (2980) 2860
	West Unit: top	CD	Beta-146121	M	3000±80	3430±80	3150 (2990) 2860
	Uppermost West Dune	CD	Beta-145426	M	3030±60	3460±60	3160 (3050) 2940
	West Unit: bottom	CD	Beta-145427	B	3070±50	3500±50	3200 (3110) 3000
	West Red abalone Calane midden: upper	DP	Beta-134835	R	3760±90	4190±90	4090 (3960) 3830
	Central swale: basketry	DP	Beta-134833	M	3920±60	4350±60	4280 (4160) 4080
	West Dune: basal swale	DP	Beta-134834	R	4140±60	4570±60	4550 (4460) 4400
	East Dune: base	DP	OS-37144	B	–	4650±110	4790 (4560) 4420
149	Shell midden in dune soil	CD	OS-37141	M	–	2840±55	2340 (2310) 2210
150	Base of 10–15 cm dune soil	CD	Beta-180922	M	880±60	1300±60	680 (645) 605
152	Fishhook in dune soil	CD	OS-37145	R	–	3060±80	2720 (2650) 2440
	−25–30 cm in dune soil	CD	Beta-181390	R	2380±80	2830±80	2350 (2300) 2160
153	Red abalone midden	DP	Beta-181391	R	4020±70	4460±70	4420 (4350) 4230
159	Shell midden in dune soil	CD	OS-37140	M	–	925±50	420 (320) 280
161	Red abalone midden	DP	CAMS-?	C	–	3960±60	4520 (4420) 4300
163	House 6, Auger D, 64 cm below surface	DP	OS-33375	M	–	880±35	320 (290) 270
172	Red abalone midden	DP	Beta-42606	R	5730±90	6160±90	6440 (6330) 6270
350?	Red abalone midden	BD	I-3717	R	6030±150	6460±150	6860 (6670) 6490
	Red abalone midden	BD	OS-35401	S	–	7120±45	7440 (7410) 7360
	Soil (SS?) in interdune swale	BD	I-4583	C	9750±150	9750±150	11260 (11180) 10810
388	−20 cm in 40 cm thick midden	DP	I-4587	R	6450±130	6880±130	7310 (7200) 7010
	Seacliff: Red abalone midden	BD	Beta-194507	R	6570±60	6980±60	7360 (7270) 7230
396	15–20 cm thick dune palaeosol	DP	Beta-181392	B	4220±70	4650±70	4780 (4570) 4440
	Midden soil eroding from dune	DP	Beta-194508	M	4240±70	4650±70	4710 (4570) 4490
	Midden soil eroding from dune	DP	Beta-194509	M	4580±50	4990±50	5090 (5020) 4920
433	Simonton soil (SS)	BD	I-4852	S	7580±140	8010±140	8380 (8240) 8100
438	20 cm: Simonton soil	BD	UCLA-148B	S	7940±80	8370±80	8760 (8600) 8510
	20 cm: Simonton soil	BD	UCLA-148A	C	9360±200	9360±200	11060 (10570) 10240
442	Midden in Simonton soil	BD	Beta-180923	M	7820±80	8250±80	8590 (8455) 8375
467	Black abalone midden	DP	Beta-171121	B	4510±70	4950±70	5050 (4950) 4840
481	Upper East Dune	CD	OS-33353	M	–	1000±35	470 (430) 380
	Top of vertical face	CD	Beta-139977	R	860±60	1290±60	670 (640) 560
	Midden in Middle Dune area	CD	Beta-180925	M	1120±80	1540±80	945 (885) 760
	Unit 1: Stratum 1E: base	CD	Beta-145429	B	1230±60	1660±60	1050 (960) 920
	Unit 1; Stratum 1E: base	CD	Beta-150317	M	1400±60	1830±60	1240 (1170) 1070
	Unit 1; Stratum 1A: top	CD	OS-27182	B	–	1870±35	1260 (1220) 1160
	Vertical Exposure: bottom	DP?	Beta-139978	B	1550±70	1980±70	1360 (1290) 1240
	West Stratum 1: top	CD	Beta-139980	B	1560±60	1990±60	1370 (1300) 1260

Table 1 (*continued*)

Site (SMI-)	Provenance data	Position[b]	Sample no.	Material[c]	Uncorrected ^{14}C age	$^{13}C/^{12}C$ adjusted age	Calibrated age range (1 σ), cal. BP
481	West Stratum 1: bottom	CD	Beta-139979	B	1600±60	2030±60	1410 (1330) 1280
	Fishhook: Middle Dune area	CD	OS-38218	R	–	2150±50	1530 (1480) 1400
	10 cm thick soil, south area	DP	Beta-180924	M	1820±50	2250±50	1680 (1585) 1520
	A2, 4 m below dune crest	DP	Beta-148498	B	3180±70	3610±70	3340 (3250) 3160
	A4, 7–7.5 cm below dune crest	DP	Beta-148500	M	3280±100	3710±100	3470 (3360) 3250
	A3, 5–5.5 m below dune crest	DP	Beta-148499	M	3540±60	3970±60	3760 (3670) 3580
	A5, 8–8.5 m below dune crest	DP	Beta-148501	R	3790±40	4180±40	3400 (3930) 3860
	Red abalone midden	DP	Beta-134836	R	5140±80	5570±80	5840 (5700) 5600
	Mussel lens below Beta-134836	DP	Beta-145318	M	5330±80	5750±80	5980 (5900) 5840
	Red abalone lens: 8–15 cm below surface	DP	Beta-145317	R	5430±70	5870±70	6160 (6000) 5930
	Basal shell midden (SS?)	BD	OS-27939	M	–	6340±50	6620 (6540) 6460
	Base of vertical dune (SS)	BD	Beta-134837	R	6520±80	6950±80	7330 (7250) 7180
485	Sample A1, south profile	CD	Beta-107350	B	720±70	1150±70	570 (520) 480
488	Stratum 4, 45–60 cm	CD?	Beta-6741	M	2630±60	3060±60	2710 (2650) 2470
492	Stratum 9, 48–64 cm	CP	Beta-5808	R	1560±70	1990±70	1380 (1300) 1250
	Stratum 4, 212–230 cm	DP	Beta-5807	M	4920±80	5350±80	5580 (5480) 5420
503	15–25 cm	CP	Beta-5809	S	1390±90	1820±90	1260 (1160) 1050
	Dune Profile, Stratum 1	DP	Beta-107351	R	2480±70	2890±70	2440 (2330) 2290
	North Profile: Stratum 8	DP?	Beta-107987	R	2590±60	3020±60	2690 (2510) 2380
	Stratum 2: 184–189 cm	DP	Beta-6742	R	3610±50	4040±50	3830 (3760) 3680
504	Stratum 12: 200–230 cm	CH	Beta-6743	M	2960±60	3390±60	3050 (2940) 2850
510	Stratum 6: 89–97 cm	DP	Beta-6744	M	1430±60	1860±60	1260 (1200) 1130
520	Surface: dune soil in NE area	CP	OS-37736	M	–	3630±25	3330 (3290) 3220
	Surface: dune soil in SE area	CP	Beta-171805	R	5250+80	5680+80	5920 (5860) 5720
522	Dune soil on SS (0–5 cm)	DP	Beta-164081	B	8390+70	8830+70	9390 (9020) 8940
	Dune soil: lower midden (20–25 cm)	DP	Beta-151616	B	8790+120	9220±120	9830 (9610) 9160
	Dune soil: lower midden (30–35 cm)	DP	OS-37737	M	–	9390±30	9920 (9820) 9620
	Dune soil: lower midden	DP	OS-27943	M	–	9450±70	10250 (9830) 9720
	Dune soil: lower midden	DP	OS-37963	C	–	8870±40	10150 (10000) 9890
525	Stratum 3: 30–37 cm	DP	Beta-6746	M	770±50	1200±50	620 (550) 520
	Stratum 9: 70–79 cm	DP	Beta-6745	M	1460±70	1890±70	1290 (1230) 1150
	Profile D175 cmbs	DP	Beta-139976	B	1920±70	2350±70	1810 (1700) 1600
	Fishhook, Unit 1C, Stratum 4	DP	OS-3000	R	2280±35	2730±35	2260 (2150) 2100
	Stratum 27: 227–235 cm	DP	Beta-5810	B	3020±70	3450±70	3150 (3030) 2920
	Stratum 16: 166–175 cm	DP	Beta-6747	M	3080±70	3510±70	3230 (3130) 2990
528	A1, Stratum I, Unit 2	CD?	Beta-114032	H	1420±70	1860±70	1270 (1200) 1120
	A4, Stratum I, Unit 2	CD?	Beta-114035	H	1620±70	2070±70	1480 (1380) 1300
	A6, Stratum 1, Unit 1	CD?	Beta-114037	H	1660±70	2100±70	1510 (1410) 1320
	A2, Stratum I, Unit 1	CD?	Beta-114033	H	1710±90	2150±90	1570 (1480) 1350
	A5, Stratum II	DP?	Beta-114036	H	4420±70	4870±70	4950 (4840) 4800
	A3, Stratum III	DP?	Beta-114034	H	5210±70	5670±70	5900 (5850) 5720
535	Sea cliff: −1.8–2 m	DP	Beta-145314	M	3170+70	3580+70	3330 (3230) 3110
536	Bead on dune slope, sea cliff	CP	OS-42694	O	–	1260±30	640 (610) 570
	Midden soil, sea cliff	DP	OS-42693	M	–	3920±30	3670 (3610) 3550
602	Unit 2, Stratum A	DP	Beta-114533	M	310±50	740±50	250 (130) 0
	Unit 2, 39 cm	DP	Beta-98743	M	460±60	900±60	410 (300) 270

Table 1 (*continued*)

Site (SMI-)	Provenance data	Position[b]	Sample no.	Material[c]	Uncorrected ^{14}C age	$^{13}C/^{12}C$ adjusted age	Calibrated age range (1 σ), cal. BP
602	Unit 5, 48 cm	DP	Beta-98744	M	650 ± 60	1100 ± 60	530 (500) 460
	Unit 5, 10 cm	DP	Beta-98742	M	650 ± 70	1100 ± 70	540 (500) 450)
605	Unit 1: Stratum 4	BD	Beta-145309	B	5710 ± 60	6150 ± 60	6400 (6310) 6270
	Unit 1: Stratum 3	BD	Beta-145812	M	5940 ± 90	6370 ± 90	6680 (6580) 6450
	Unit 1: Stratum 5c	BD	Beta-145311	L	5920 ± 40	6390 ± 40	6660 (6610) 6530
	Surface: outside cave	BD?	Beta-134838	M	5970 ± 80	6400 ± 80	6710 (6620) 6490
	Unit 1: Stratum 5a	BD	Beta-145310	M	6010 ± 80	6440 ± 80	6740 (6650) 6550
606	Busted Balls #1: north locus	SS/DP	OS-28485	C	–	7370 ± 40	8190 (8180) 8060
	Busted Balls #1: north locus	SS/BD	Beta-164080	C	7660 + 80	7700 + 80	8560 (8440) 8400
	Busted Balls #1: north locus	SS/BD	OS-27944	M	–	8400 ± 80	8840 (8630) 8540
	Busted Balls #1: north locus	SS/DP	Beta-145307	M	8330 ± 80	8760 ± 80	9270 (8980) 8920
	Busted Balls #1: south locus	SS/BD	Beta-145308	M	8490 ± 90	8920 ± 90	9420 (9060) 9000
607	Bath Beach #1: south locus	SS/BD	Beta-145306	M	7570 ± 90	7990 ± 90	8330 (8200) 8130
	Bath Beach #1: north locus	SS/BD	OS-27948	M	–	8550 ± 55	8920 (8860) 8780
610	Running Springs Cliffs	SS/BD	OS-27940	M	–	8940 ± 60	9420 (9080) 9020
	Running Springs Cliffs (duplicate)	SS/BD	OS-28282	M	–	9080 ± 60	9750 (9430) 9040
611	Midden in dune palaeosol	DP	Beta-171804	R	3350 ± 70	3780 ± 70	3540 (3440) 3360
BaBe3	Bath Beach #3: palaeosol	SS/BD	OS-27945	B	–	9090 ± 75	9750 (9440) 9090
BuBa2	Busted Balls Cove: N. locus	SS/BD	OS-31685	M	–	8270 ± 45	8570 (8480) 8410
	Busted Balls Cove: S. locus	SS/BD	OS-31686	M	–	8480 ± 45	8880 (8780) 8650
BuBa4	Busted Balls Cove	SS/BD	OS-27942	L	–	7860 ± 55	8160 (8100) 8000
	Busted Balls Cove (duplicate)	SS/BD	OS-27953	L	–	7970 ± 50	8290 (8180) 8150
BuBa5	Busted Balls Cove	SS/BD	OS-27941	M	–	8070 ± 55	8370 (8320) 8210

[a] All dates were calibrated with Calib 4.3 (see Stuiver and Reimer, 1993), with a ΔR of 225 ± 35 years for all shell samples (see Kennett *et al*., 1997). $^{13}C/^{12}C$ ratios were determined by ^{14}C lab or an average of 430 years was added for marine shell samples for which $^{13}C/^{12}C$ were unavailable (Erlandson, 1988). Data compiled from Breschini *et al*. (1996), Erlandson (1994), Erlandson and Rick (2002), Johnson (1972: 83), Kennett (1998), Rick (2004) and the author's personal files.

[b] Stratigraphic position of dune samples: CD, caps dune; DP, dune palaeosol; BD, below dune; SS, Simonton soil; CH, C-horizon.

[c] AF, Abalone fishhook; B, Black abalone; C, charcoal; L, Owl limpet; M, California mussel; O, *Olivella*; R, Red abalone; S, Marine shell.

contemporary coastline, on raised marine terraces near freshwater springs. This suggests that dunes were forming by the end of the Pleistocene on a broad coastal plain now submerged beneath the sea. In places, these dunes had begun to climb the terraced slopes above the coastal plain, where they may have affected the availability of freshwater sources crucial to early maritime peoples in an arid landscape. Along most of the northwest coast, however, middens dated between about 9700 and 7000 cal. BP are embedded in the Simonton soil, suggesting that such early Holocene dunes rarely reached the current coastline. By the end of the early Holocene, sea-level rise had slowed considerably, sea levels were approaching recent levels and the coastline was nearing its current position.

Middle Holocene (*c.* 6700–3400 RYBP)

Starting about 7000 to 6500 years ago, evidence for dune building on San Miguel is much more widespread. Dune deposits of this age are generally much thicker and more extensive than early Holocene deposits. Many shell middens found in middle Holocene dune soils contain numerous large red abalone shells, leading Johnson (1972) to define a distinctive 'Abalone' palaeosol in the dunes of Simonton Cove. At Otter Point, a 6600 yr old shell midden in Otter Cave (SMI-605), located on a steep (> 55°) slope about 35 m above sea level, is buried beneath about 1 m of sand. At SMI-492 on the northwest coast and SMI-520 on the southeast coast, red abalone middens dated between 6000 and 5500 cal. BP suggest that some dunes had climbed the steep escarpment of the northwest coast, streamed across the 1.25-km-wide western plateau, and reached the southeast coast at Tyler Bight. In a 30-m-high dune at Otter Point, at least six shell midden palaeosols dating to the middle and late Holocene have been identified, and about 15–20 m of dune sand appears to have accumulated between about 7000 and 3500 years ago (Figure 4). Substantial middle Holocene dunes are also evident in Simonton Cove (e.g., SMI-388, 396), where Johnson (1972: 350) documented the accumulation of roughly 40 m of sand at SMI-433 in Range Pole Canyon some time after 8240 cal. BP. Shell middens in Middle Holocene dunes have also been identified at elevations of over 100 m on Harris Point, suggesting that dunes had climbed the steep slopes of eastern Simonton Cove. At SMI-87 in Cuyler Harbor, located at the mouth of an area known as the Wind Tunnel, we dated several middens in dune palaeosols between about 5500 and 2400 years ago (Rick, 2002, 2004). Humans may have abandoned this site when dunes were forming, as nearby freshwater springs and shellfish beds were buried under beach or dune sand. From the mouth of the Wind Tunnel, parabolic dune ridges extend for about 5–6 km southeast to Cardwell Point. Although heavily impacted by historical erosion, numerous shell middens still exist along the margins of the Wind Tunnel. Few have been dated, but at Cardwell Point a red abalone midden (SMI-172) built in dune sand has been dated to about 6300 cal. BP.

Late Holocene (*c.* 3400 RYBP–present)

Widespread dune building continued during the late Holocene, at least episodically. Some of the largest sites on San Miguel date to the late Holocene and are found atop dune ridges at elevations of 50–120 m or more. On the western terrace, several large middens (SMI-485, 488 and 510) cap sizeable dunes located on the plateau between about 75 m and 120 m above sea level. The dunes at these sites appear to lack any intermediate palaeosols or older midden strata. Dating within the past 2700 years, these sites suggest that several large dunes only reached the western plateau during the late Holocene. Other large sand dune complexes scattered around the shoreline are capped by middens dated between about 3500 and 200 years ago, including large sites near Running Springs (SMI-503/504), Otter Point (SMI-481) and the northeast edge of Cuyler Harbor (SMI-163). At SMI-525, a large and complex midden near Pt Bennett, as many as nine archaeological components are interdigitated with dune sands dated between about 3300 and 550 years ago (see Figure 3). Here, every A-horizon is anthropogenic in origin, its thickness governed primarily by the volume of cultural refuse deposited by the Chumash site occupants.

Vast accumulations of marine shells, animal bones, burned rock and artefacts attest to the extensive Chumash occupation of San Miguel Island in the late Holocene. Through their use of fire and other cultural activities, the Chumash and their ancestors may have caused episodes of vegetation stripping and dune destabilization prior to European contact (Johnson, 1972: 271, 1980: 120). However, the late Holocene archaeological record suggests that Chumash activities also contributed to soil formation and dune stability. The addition of abundant shell, burned rock, artefacts and other cultural debris helped stabilize dune surfaces and contributed to the accumulation of widespread anthropogenic soils, some of them several metres deep. Although this soil enrichment was probably an unintentional byproduct of human occupation, it contributed to the development of an increasingly cultural landscape on San Miguel Island through the Holocene. Similar processes have been defined for the anthropogenic Plaggen soils of northwestern Europe (see Simpson *et al*., 1998).

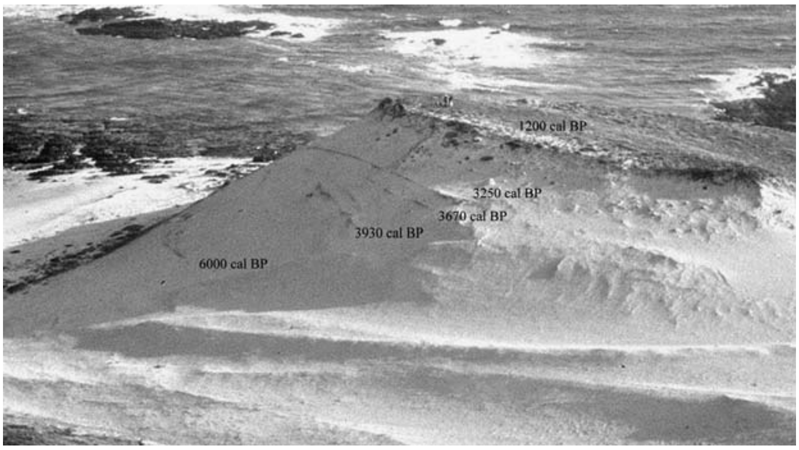

Figure 4 Active dune at SMI-481, Otter Point, where at least eight archaeological palaeosols have been mapped. (Note figures standing atop dune for scale). A red abalone midden embedded in the Simonton soil underlying the dune has been dated to 7250 cal. BP; over 20 m of dune sand have accumulated here over the past 6000 years. (Photograph by J. Erlandson)

A general increase in the number and size of Native American archaeological sites through time suggests that the number of people inhabiting the Northern Channel Islands grew through the Holocene (Erlandson *et al.*, 2001). Some environmental impacts may have increased as Chumash populations grew (Erlandson *et al.*, 2004), but the stabilizing effect of midden soils may have increased as the number and extent of occupation sites expanded. Even today, the erosion of island shell middens produces layers of shell fragments and artefacts that help protect the sides and top of many dunes from further erosion.

After the removal of the Island Chumash and the introduction of domestic livestock by Americans, 10 000 years of dune building and soil formation on San Miguel Island was almost undone within a few decades. Early historic accounts describe San Miguel as relatively lush, covered with low shrubs and dwarf trees (Johnson, 1980: 107). Small numbers of domestic livestock introduced to the island *c.* AD 1850 grew to herds of about 6000 sheep, 125 cattle, 100 hogs, and 25 horses by AD 1863, however, and severe droughts in AD 1863–64 and 1870 led to heavy overgrazing, transforming much of the island into ‘a barren waste of drifting sand and blowing soil’ (Johnson, 1980: 108; Erlandson *et al.*, 2004). Ranching continued for almost a century and vast expanses of dunes and soils were eroded down to sterile and rugged caliche flats. On many of these denuded surfaces, all that remains are scatters of sandblasted stone artefacts that mark the former location of Chumash settlements. Severe erosion continues in places on the island, but the removal of sheep and other livestock by the US Navy and National Park Service has initiated a dramatic recovery in island vegetation and the partial stabilization of its remaining dunes and soils.

Conclusions

On San Miguel Island, the Chumash and their predecessors occupied sand dunes and dune soils for at least 10 000 years, leaving behind hundreds of shell middens ranging from small temporary camps to large villages. Our data base of 114 ^{14}C dates from 40 island archaeological sites documents episodes of dune building throughout the Holocene. Prior to about 8000 years ago, dune building appears to have been limited mostly to low coastal plains now largely submerged by postglacial sea-level rise. In places, however, dunes had begun to climb the northern escarpment of the island by 10 000–9000 years ago, accumulating on intermediate landforms 20–25 m above modern sea level. Spurred by global, regional and local processes (e.g., sea-level stabilization, coastal erosion, climate change, wildfires, etc.), much more extensive dune building occurred in the middle and late Holocene. The formation of these Holocene dunefields fundamentally altered the geography, hydrology, biology and soil regimes of the island.

Johnson (1972, 1980) suggested that episodic vegetation stripping and soil erosion have a long history on San Miguel, triggered first by wildfires, droughts and pygmy mammoths (*Mammuthus exilis*) (see also Wooley, 1998), later by Native Americans, and in historic times by the overgrazing of domesticated livestock. Johnson made a plausible case for episodic vegetation stripping by island mammoths, which appear to have been extinct by about 13 000 years ago (Agenbroad, 1998). The Chumash and their ancestors may have intentionally or accidentally burned the landscape, contributing to periodic vegetation stripping and soil erosion. While intentional burning is well documented for the mainland Chumash, however, it is much less clear for San Miguel and the other Channel Islands (see Timbrook *et al.*, 1982; Timbrook, 1993). Instead, the deposition of vast quantities of shell midden material by the Island Chumash during the last 4000 to 3000 years may have increased soil and dune stability on San Miguel, armouring dunes with protective blankets of shell and other cultural debris, enriching the nutrient content of dune soils, and encouraging vegetation growth. This idea requires further study, but it appears consistent with the comparatively large number of palaeosols (and deep accumulations of shell middens) found in the many large Holocene dunes that remain on the island today.

In contrast to a general record of Holocene dune building and relative soil stability (excluding global sea-level rise and related coastal erosion), the introduction of domesticated livestock in the mid-1800s devastated the island’s vegetation, dunes, soils and terrestrial ecology to a degree unprecedented in at least the past 15 000–10 000 years. Droughts and other climatic changes may have exacerbated the effects of this overgrazing, but such events have occurred throughout the Holocene without triggering comparable erosion episodes. Thus, the mismanagement of a relatively fragile island ecosystem by commercial ranching enterprises appears to be responsible for much of the massive degradation of the San Miguel landscape.

We do not currently have sufficient information to document all the causes or consequences of episodic dune building and destabilization on San Miguel Island. Existing data are also not adequate to document whether there were spatially coherent island-wide periods of dune building and destabilization, or whether localized dune fields in various parts of the island formed, stabilized and destabilized independently of one another. We hope these problems will be solved by the continued dating and documentation of dune sites and soils, including high-resolution ^{14}C dating.

Note

1 On northeast Santa Rosa Island, Wooley (1998) documented a relatively extensive dune advance dated to *c.* 13 000 RYBP that may be related to vegetation stripping and dune activation caused by mammoths. Similar deposits may well be found on San Miguel, where pygmy mammoths appear to have been abundant in the late Pleistocene, with further study and dating of the island’s dunes and aeolianites.

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