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On the importance of stratigraphic control for vertebrate fossil sites in Channel Islands National Park, California, USA: Examples from new *Mammuthus* finds on San Miguel Island

Jeffrey S. Pigati [a, *], Daniel R. Muhs [a], John P. McGeehin [b]

[a] U.S. Geological Survey, Denver Federal Center, Box 25046, MS-980, Denver, CO, 80225, USA
[b] U.S. Geological Survey, 12201 Sunrise Valley Drive, MS-926A, Reston, VA, 20192, USA

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ABSTRACT

Quaternary vertebrate fossils, most notably mammoth remains, are relatively common on the northern Channel Islands of California. Well-preserved cranial, dental, and appendicular elements of *Mammuthus exilis* (pygmy mammoth) and *Mammuthus columbi* (Columbian mammoth) have been recovered from hundreds of localities on the islands during the past half-century or more. Despite this paleontological wealth, the geologic context of the fossils is described in the published literature only briefly or not at all, which has hampered the interpretation of associated ^{14}C ages and reconstruction of past environmental conditions. We recently discovered a partial tusk, several large bones, and a tooth enamel plate (all likely mammoth) at two sites on the northwest flank of San Miguel Island, California. At both localities, we documented the stratigraphic context of the fossils, described the host sediments in detail, and collected charcoal and terrestrial gastropod shells for radiocarbon dating. The resulting ^{14}C ages indicate that the mammoths were present on San Miguel Island between ~20 and 17 ka as well as between ~14 and 13 ka (thousands of calibrated ^{14}C years before present), similar to other mammoth sites on San Miguel, Santa Cruz, and Santa Rosa Islands. In addition to documenting the geologic context and ages of the fossils, we present a series of protocols for documenting and reporting geologic and stratigraphic information at fossil sites on the California Channel Islands in general, and in Channel Islands National Park in particular, so that pertinent information is collected *prior* to excavation of vertebrate materials, thus maximizing their scientific value.

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1. Introduction

Mammoths (genus *Mammuthus*) first appear in the fossil record during the early Pliocene (~5–4 Ma) in southern and eastern Africa (Maglio, 1973; Kalb et al., 1996) and later in Europe, during the interval 3.5–2.5 Ma (Lister et al., 2005). *Mammuthus* expanded its range dramatically in the early Pleistocene, eventually covering much of Eurasia as the proboscideans became adapted to cool climates. This allowed them first to reach extreme northern Asia and Beringia, and then cross the land bridge into North America (Lister and Bahn, 2007). By ~2.2–1.8 Ma, mammoths had expanded across North America as far south and east as Florida (Webb et al., 1989; Webb and Dudley, 1995; Muhs et al., 2015), which suggests that they had colonized most of the continent by that time.

At least four, and as many as five, distinct species of *Mammuthus* are currently recognized in the Pleistocene record of North America, including *M. meridionalis*, *M. primigenius*, *M. columbi*, and *M. exilis*, and perhaps *M. trogontherii* (Agenbroad, 1984, 2005; Lister and Sher, 2015). In the southwestern United States, mammoths reached southern California by 1.4–1.2 Ma, where the remains of *M. meridionalis* dating to this time period have been found in Anza-Borrego Desert State Park (McDaniel and Jefferson, 2006). Columbian mammoths (*M. columbi*) appear in this area at about the same time (~1.1 Ma; McDaniel and Jefferson, 2006) and are the most common species found in late Pleistocene sediments on the southern California mainland (Stock and Harris, 1930; Agenbroad, 1984; Springer et al., 2010).

Mammoths inhabited the Channel Islands beginning at least ~80 ka and possibly as early as ~150 ka or even ~250 ka based on the

* Corresponding author.
E-mail address: jpigati@usgs.gov (J.S. Pigati).

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presence of a pygmy mammoth (*M. exilis*) tusk in a marine terrace on Santa Rosa Island that dates to Marine Oxygen Isotope Stage (MIS) 5a (Muhs et al., 2015). Pygmy mammoths evolved on the islands from Columbian mammoths, which likely swam across the Santa Barbara Channel during glacial period(s) when sea level was low and the distance between the islands and the mainland was relatively short (Johnson, 1978; Wenner and Johnson, 1980; Muhs et al., 2015). Although Columbian mammoths are considered to be the original island mammoths (Johnson, 1978, 1981; Madden, 1981; Roth, 1993) and served as ancestral stock to the pygmies (Agenbroad, 2001), fossils of pygmy mammoths are far more common than those of their ancestors, by a ratio of roughly 10 to 3 (Agenbroad, 2012).

Historically, mammoth fossils were first identified on the California Channel Islands during the Coast and Geodetic Survey of 1856 and reported in the scientific literature initially by Stearns (1873). Half a century later, Stock and Furlong (1935) formally designated the pygmy mammoth as a new species, *Mammuthus exilis*, which is unique to the islands. Following their study, little work was done on the island mammoths until the arrival of Phil Orr of the Santa Barbara Museum of Natural History in the mid-1950s. Although Orr's primary focus was archeology, he recognized that mammoth bones were plentiful in late Pleistocene sediments and hypothesized that the earliest human occupants of the islands may have interacted with mammoths prior to their extinction (Orr, 1956a, 1968; Orr and Berger, 1966). Although this hypothesis is still under debate Orr's work inspired a series of later studies, most notably by Larry Agenbroad (e.g., Agenbroad, 1984; 1998; 2001; 2003; 2005; 2012; Agenbroad et al., 2005) and Don Johnson (Johnson, 1972, 1981, 1978; Johnson et al., 1980). To date, nearly 400 different localities containing mammoth fossils—most of which are located on Santa Rosa Island—have been documented on the Channel Islands (Justin Wilkins, written comm., 2015). Prospecting and monitoring activities in Channel Islands National Park continue today under the purview of the National Park Service (NPS).

1.1. Previous documentation at mammoth sites on the islands

The California Channel Islands represent a spectacular natural laboratory for studies focusing on evolution and dwarfism, the timing and causes of elephant immigration from the mainland, responses of endemic flora and fauna to past episodes of climate change, and the possible interaction between humans and Pleistocene megafauna. Such studies involve the paleontological resources of the islands and it is therefore imperative that the geologic and stratigraphic context of the fossils are documented in detail and disseminated to the scientific community.

Little is known about the location of mammoth fossils that were removed from the islands prior to the 1950s. Documentation improved during Orr's tenure, as he usually stated the name of the canyon or general area where the specimens were found and occasionally reported latitude and longitude. Subsequent researchers followed suit, either through marking the site locations on a map or including coordinates (Table 1). Today, site locations are routinely determined using handheld GPS devices.

Table 1
Summary of published radiocarbon ages associated with *Mammuthus* remains on the California Channel Islands.

Island[1]	Lab#	Reported age[2] (in thousands of ^{14}C yrs)	Taxa	Material dated	Reported latitude (°N)	Reported longitude (°W)	Paired date?	Stratigraphic context?	Original citation
SRI	UCLA-705	8.00 ± 0.25	*M. exilis*	Bone collagen; same specimen as L-290T; too young (contamination)	34°00′20″	120°11′20″	Yes[4a]	None	Berger et al. (1965)
SRI	Beta-14660	10.70 ± 0.09	*M. exilis*	Unknown	N/A	N/A	No	None	Agenbroad (2012)
SRI	Beta-133594	11.01 ± 0.07	*M. exilis*	Charcoal in association with vertebra of pygmy mammoth	"Garanon Canyon"		Yes[4b]	None	Agenbroad (2005)
SRI	CAMS-71697	11.03 ± 0.05	*M. exilis*	Bone collagen; Stafford XAD protocol; same stratigraphic level as B-133594	N/A	N/A	Yes[4b]	None	Agenbroad (2005)
SRI	UCLA-106	11.80 ± 0.80	*M. exilis*	Charcoal in direct contact with pygmy mammoth bone	34°59′00″	120°10′00″	No	None	Fergusson and Libby (1962)
SRI	Beta-279387	12.12 ± 0.06	*M. columbi*	Unknown	N/A	N/A	No	None	Agenbroad (2012)
SRI	Beta-131341	12.41 ± 0.04	*M. exilis*	Unknown	N/A	N/A	No	None	Agenbroad (2012)
SRI	L-290T	12.50 ± 0.25	*M. exilis*	Charcoal from mammoth bearing sediments	34°00′20″	120°11′20″	Yes[4a]	None	Broecker and Kulp (1957)
SRI	UCIAMS-68006	12.55 ± 0.05	*M. columbi*	Unknown	N/A	N/A	No	None	Agenbroad (2012)
SRI	CAMS-24429	12.84 ± 0.41	*M. exilis*	Bone collagen from right femur; Stafford XAD protocol; AMS	near Carrington Point		No	"Dune sand"	Agenbroad (1998, 2003)[5]
SRI	Beta-96610	13.77 ± 0.06	*M. exilis*	Charcoal in association with mammoth remains; AMS	south coast		No	None	Agenbroad (1998, 2003)[5]
SRI	L-244	15.82 ± 0.28	*M. exilis*	Partially charred and badly decomposed wood from below pygmy mammoth	N/A	N/A	No	None	Broecker et al. (1956)
SRI	M-599	16.70 ± 1.50	*M. exilis*	Charcoal in association with pygmy mammoth remains	N/A	N/A	No	None	Crane and Griffin (1958)
SRI	Beta-131340	16.81 ± 0.05	*M. exilis*	Unknown	N/A	N/A	No	None	Agenbroad (2012)
SRI	Beta-278091	17.50 ± 0.07	*M. columbi*	Unknown	N/A	N/A	No	None	Agenbroad (2012)
SRI	Beta-92053	18.13 ± 0.07	*M. exilis?*	Charcoal in association with mammoth remains	southwestern coast		No	None	Agenbroad (1998, 2003)[5]
SRI	Beta-85077	18.88 ± 0.19	*M. exilis?*	Charcoal in association with mammoth remains	northern coast		No	None	Agenbroad (1998, 2003)[5]
SRI	CAMS-62265	26.68 ± 0.33	*M. exilis*	Unknown	N/A	N/A	No	None	Agenbroad (2012)
SRI	L-290R	29.70 ± 3.00	*M. exilis*	Charred mammoth bone	N/A	N/A	Yes[5]	None	Broecker and Kulp (1957)
SRI	UCLA-1898	30.40 ± 2.50	*M. exilis*	Bone collagen from uncharred bone; same stratigraphic level as L-290R	N/A	N/A	Yes[4c]	None	Bada et al. (1974)