



GEOLOGY OF THE INTERMOUNTAIN WEST

an open-access journal of the Utah Geological Association

Volume 4

2017

VERTEBRATE PALEONTOLOGY, STRATIGRAPHY, AND PALEOHYDROLOGY OF TULE SPRINGS FOSSIL BEDS NATIONAL MONUMENT, NEVADA (USA)

Kathleen B. Springer, Jeffrey S. Pigati, and Eric Scott



A Field Guide Prepared For
SOCIETY OF VERTEBRATE PALEONTOLOGY
Annual Meeting, October 26 – 29, 2016
Grand America Hotel
Salt Lake City, Utah, USA





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Cover

Buff-colored deposits sit against the backdrop of the Las Vegas Range just outside the city limits of Las Vegas. Once thought to be remnants of a large pluvial lake called Lake Las Vegas, these deposits actually record the presence of extensive desert wetlands that acted as watering holes to an array of Pleistocene megafauna, including mammoth, sloth, camel, horse, bison, American lion, dire wolf, and sabre-toothed cat.



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Vertebrate Paleontology, Stratigraphy, and Paleohydrology of Tule Springs Fossil Beds National Monument, Nevada (USA)

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ABSTRACT

Tule Springs Fossil Beds National Monument (TUSK) preserves 22,650 acres of the upper Las Vegas Wash in the northern Las Vegas Valley (Nevada, USA). TUSK is home to extensive and stratigraphically complex groundwater discharge (GWD) deposits, called the Las Vegas Formation, which represent springs and desert wetlands that covered much of the valley during the late Quaternary. The GWD deposits record hydrologic changes that occurred here in a dynamic and temporally congruent response to abrupt climatic oscillations over the last ~300 ka (thousands of years). The deposits also entomb the Tule Springs Local Fauna (TSLF), one of the most significant late Pleistocene (Rancholabrean) vertebrate assemblages in the American Southwest. The TSLF is both prolific and diverse, and includes a large mammal assemblage dominated by *Mammuthus columbi* and *Camelops hesternus*. Two (and possibly three) distinct species of *Equus*, two species of *Bison*, *Panthera atrox*, *Smilodon fatalis*, *Canis dirus*, *Megalonyx jeffersonii*, and *Nothrotheriops shastensis* are also present, and newly recognized faunal components include micromammals, amphibians, snakes, and birds. Invertebrates, plant macrofossils, and pollen also occur in the deposits and provide important and complementary paleoenvironmental information. This field compendium highlights the faunal assemblage in the classic stratigraphic sequences of the Las Vegas Formation within TUSK, emphasizes the significant hydrologic changes that occurred in the area during the recent geologic past, and examines the subsequent and repeated effect of rapid climate change on the local desert wetland ecosystem.

INTRODUCTION

Tule Springs Fossil Beds National Monument

Tule Springs Fossil Beds National Monument (TUSK) is located in the upper Las Vegas Wash, in the northern reaches of the Las Vegas Valley, Clark County, southern Nevada. TUSK was established as the 405th unit of the National Park Service on December 19, 2014,

and was created to “conserve, protect, interpret and enhance for the benefit of present and future generations the unique and nationally important paleontological, scientific, educational and recreational resources and values of the land.” Paleontological and paleoecological resources, such as fossilized plants, animals, and their traces, including both organic and mineralized remains in body and trace form, are all protected here.

Citation for this article.

Springer, K.B., Pigati, J.S., and Scott, E., 2017, *Vertebrate paleontology, stratigraphy, and paleohydrology of Tule Springs Fossil Beds National Monument, Nevada (USA): Geology of the Intermountain West*, v. 4, p. 55–98.

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The nearly 23,000-acre national monument also preserves the last vestiges of extensive middle to late Quaternary desert wetland ecosystems, which are represented in the geologic record by stratigraphically complex groundwater discharge (GWD) deposits that contain the vertebrate fossils (cover photo). This field guide provides global positioning system (GPS) coordinates, annotated photographs, and descriptions of key sites of geologic and paleontologic interest within the monument (figure 1). As of the publication date of this guide, TUSK has no designated trails, roads, or infrastructure. Therefore, these sites may be accessed by off-trail hiking only. The monument is fenced at the urban interface with the cities of Las Vegas and North Las Vegas, with entry to the park provided at a few select ingress points, most notably the northern termini of Durango Drive and Decatur Boulevard (figure 1c). Collecting or disturbing fossils, rocks, or plants within a national park unit is illegal. Please be mindful.

History of Geologic and Paleontologic Research at Tule Springs

Vertebrate fossils have been recognized from the upper Las Vegas Wash, Clark County, Nevada, for more than a century, beginning when Josiah Spurr of the U.S. Geological Survey (USGS) reported “mastodon teeth and bones ... situated in a clay bank some 10 or 15 feet high” in the wash between Corn Creek Springs and Tule Springs (Spurr, 1903). Given the preponderance of mammoth fossils and the extreme paucity of mastodon remains known from Pleistocene deposits of the southern Great Basin and Mojave Deserts, these specimens were likely mammoth (Jefferson, 1991; Scott and Cox, 2008; Springer and others, 2011). Regardless, the fossils were apparently collected, but their present whereabouts are unknown.

The earliest formal scientific investigations occurred in 1919, when Chester Stock and his student, Richard Russell, both from the University of California, Berkeley, spent a field season in southern Nevada in search of Neogene and Quaternary vertebrate fossils. While in the Las Vegas Valley, they discovered and collected fossils of horse (*Equus*), bison (*Bison*), and a partial phalanx of the extinct North American lion (*Panthera atrox*). Al-

though their findings were never formally published, these specimens are highly significant in that they are the earliest recovered Pleistocene vertebrate fossils from the Las Vegas region that can be located in a museum collection. They are presently housed at the University of California’s Museum of Paleontology (UCMP) on the Berkeley, California campus.

Tule Springs gained notoriety as a potential archaeological and paleontologic hotbed beginning in 1932–33 with the arrival of a team from the American Museum of Natural History (AMNH) led by archaeologist Fenley Hunter. Working with Albert C. Silberling, a noted and prolific fossil collector from Montana, Hunter and his team collected a small but diverse assemblage of Pleistocene fossils. They also found charcoal and a single flake of obsidian, the latter of which does not occur naturally in the region, potentially signaling the presence of early humans in the valley.

A young vertebrate paleontology curator from the AMNH, George Gaylord Simpson, learned of the Tule Springs site and was able to study the fossils upon their arrival in New York. He published a “brief and preliminary” account of Hunter’s discoveries in October 1933 (Simpson, 1933). Although Simpson himself never visited the Nevada site, he recognized—and his 1933 paper emphasized—the significance of the potential association of early humans with the Pleistocene fauna. Simpson’s (1933) note established the Tule Springs area as a promising site for further research on the question of whether humans had arrived in North America prior to the extinction of the megafauna, and, if so, the nature of their interaction with the animals.

The vertebrate fauna from the Hunter’s AMNH expedition includes the remains of ground sloth (“*Nothrotherium*” [= *Nothrotheriops* sp. cf. *N. shastensis*]), Columbian mammoth (“*Parelephas columbi*” [= *Mammuthus columbi*]), horse (“*Equus pacificus*” [= *E. scotti*]), a second, smaller species of horse, camel (*Camelops hesternus*), and probable long-horned bison (“*Bison* aff. *occidentalis*” [likely = *B. latifrons*]) (Simpson, 1933) (see figure 2). Jackrabbit (*Lepus*) and pocket gopher (*Thomomys*) are the only small mammals represented in the fauna. The fossils collected by Hunter and Silberling, along with associated maps, notes, and photographs, are archived in the vertebrate paleontology

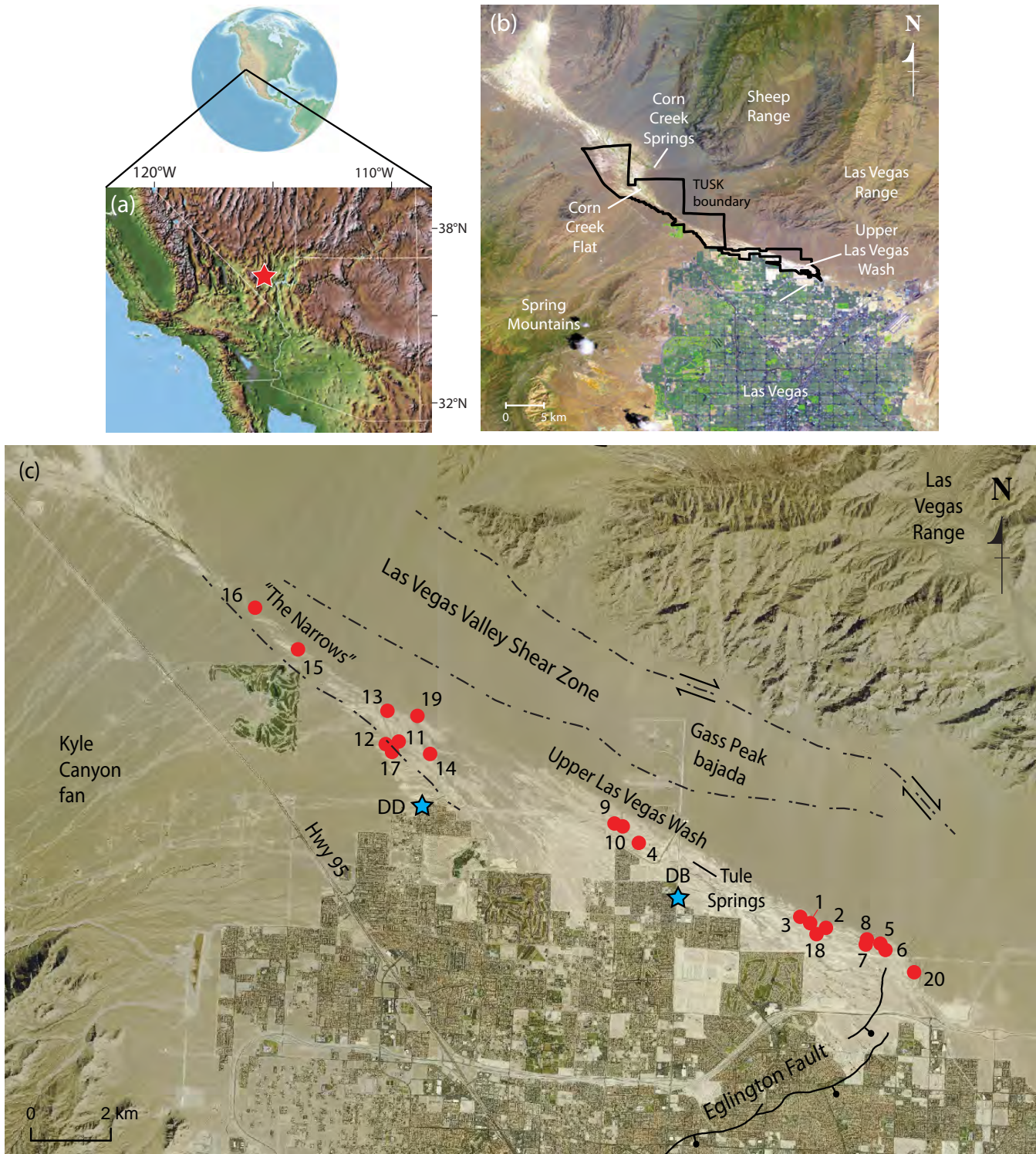


Figure 1. (a) Site location map for the Las Vegas Valley of southern Nevada (red star); (b) aerial photograph of light-colored paleowetland deposits that are exposed in large parts of the valley, including much of Tule Springs Fossil Beds National Monument (TUSK); (c) aerial photograph of the upper Las Vegas Wash showing major physiographic features. Numbers adjacent to filled red circles correspond to sites of geologic and paleontologic interest discussed herein. Blue stars show the locations of key entry points into TUSK; DB = Decatur Blvd., DD = Durango Drive. All photographs, unless otherwise noted, are from the authors.

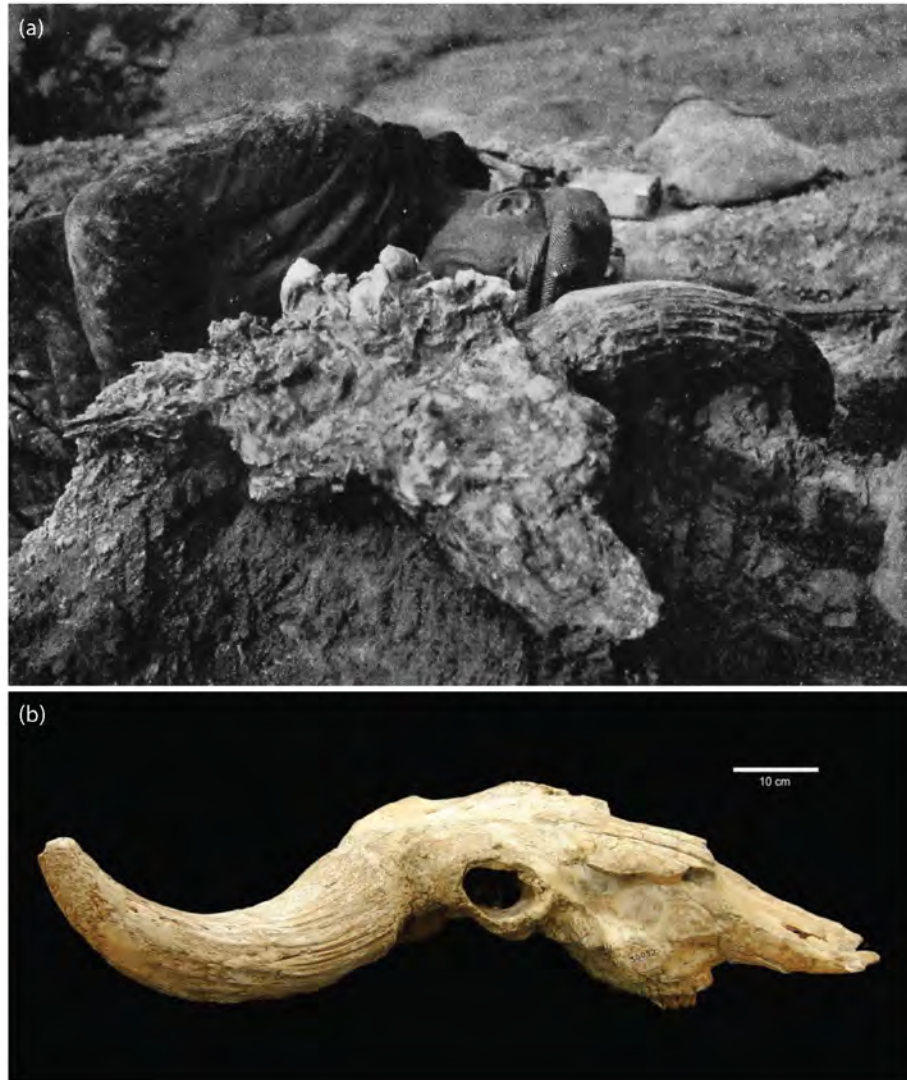


Figure 2. (a) American Museum of Natural History (AMNH) expeditions in 1932–33 resulted in the recovery of a skull of *Bison latifrons* (Simpson, 1933); (b) the same skull after museum preparation (AMNH 30052), oblique right view. Anterior is to the right. Note the pronounced length of the horn core. This specimen now resides in the AMNH.

collections of the AMNH.

News of Hunter's discovery spread quickly and in October 1933, the same month that Simpson's paper was published, archaeologist Mark Harrington of the Southwest Museum was in the field at Tule Springs. Harrington's focus at Tule Springs was to demonstrate the association of human cultural artifacts and Pleistocene megafauna as had been documented at Folsom and Clovis, New Mexico, in the late 1920s and early 1930s. These latter sites had yielded projectile points in association with remains of extinct *Bison antiquus*

(Folsom) and *Mammuthus columbi* (Clovis). At Tule Springs, Harrington collected some bone fragments, stone choppers, and charcoal, but left the upper Las Vegas Wash disappointed by the general lack of artifacts (Harrington and Simpson, 1961). "This was 1933," he reported, "and already several western American localities had been found in which man-made implements were associated with the bones of extinct Pleistocene animals ... Since Tule Springs was yielding so few artifacts, further excavation here did not seem worthwhile" (Harrington and Simpson, 1961, p. 58).

As a result, Tule Springs failed to garner further attention for two decades, but spurred on by the advent of radiocarbon dating as a research tool, Harrington and Ruth DeEte “Dee” Simpson of the Southwest Museum (and later of the San Bernardino County Museum [SBCM]) rekindled their interest in the artifacts and fossils from Tule Springs. Unable to acquire satisfactory samples of charcoal from the site during a brief visit in 1952, Simpson hunted up the original samples of charcoal collected by Harrington and his team in 1933. These samples and additional charcoal from Fenley Hunter were provided to Willard Libby, who had recently pioneered the new radiocarbon dating technique, to determine the age of one of the fossil-bearing units. The sample turned out to be older than Libby was able to date at that time, yielding results in excess of 23.8 ^{14}C ka (thousands of years) (Harrington, 1955; Simpson, 1955; Harrington and Simpson, 1961). Tule Springs was suddenly back on the archeological map, as the putative >23.8 ^{14}C ka date, if confirmed, would more than double the age of the arrival of humans in the New World as understood at the time. Armed with this new information, Harrington and Simpson were eager to return to Las Vegas because “[w]ith that age just one unmistakable flaked stone implement found in place in the charcoal would be tremendously significant” (Harrington and Simpson, 1961, p. 59).

With renewed enthusiasm, a field party from the Southwest Museum excavated at Tule Springs in 1955–56 (figure 3). They uncovered several large deposits of charcoal with minor amounts of associated faunal material, which they interpreted to be the remains of human cooking fires where Pleistocene animals were roasted and eaten. Charcoal from one such site yielded a finite age of 28.0 ^{14}C ka (Olson and Broecker, 1961), an incredible result assuming that the charcoal was indeed related to human activity. As with earlier studies conducted in the upper Las Vegas Wash by the Southwest Museum, the perceived significance of the vertebrate fossils discovered at that time was based largely upon whether or not they were associated with artifacts, and as a result collection of vertebrate fossils was not systematic.

In 1959, Willard Libby aspired to apply his Nobel Prize winning work on radiocarbon dating on a large scale. Libby had a strong interest in questions about the



Figure 3. (a) Stuart Peck (left) and Mark Harrington (right), excavating fossils in the Las Vegas Valley during the Southwest Museum expeditions at Tule Springs; (b) Southwest Museum Survey site 4 being cleared in 1955 by Charles Rozaire (left) and Dee Simpson (right). SBCM archival images.

presence of early humans in the Western Hemisphere, and wanted the new radiocarbon lab at UCLA to make an impact in this field. After considering several archaeological sites for this research effort, Libby chose Tule Springs as the most promising test case to demonstrate the potential of the new technique.

A team of scientists was organized with the primary objective of determining whether or not humans and Pleistocene animals were contemporaneous at Tule Springs, and if so, during what period of geological

time. In contrast to earlier expeditions, this study was truly interdisciplinary, combining archaeology and paleontology with geology, biology, and palynology.

In what later came to be known as the “Big Dig,” the 1962–63 excavations at Tule Springs coupled traditional archaeological and paleontological field techniques with unprecedented and massive earth-moving activ-

ities (figure 4). Bulldozers and scrapers carved enormous trenches deep into the geologic sediments at Tule Springs, exposing vertical sections up to ~12 to 13 m high, in order to map the complex stratigraphic relationships without the interference of naturally eroded topography. Ten trenches totaling more than 2.13 km in length were excavated, including Trench K, which itself

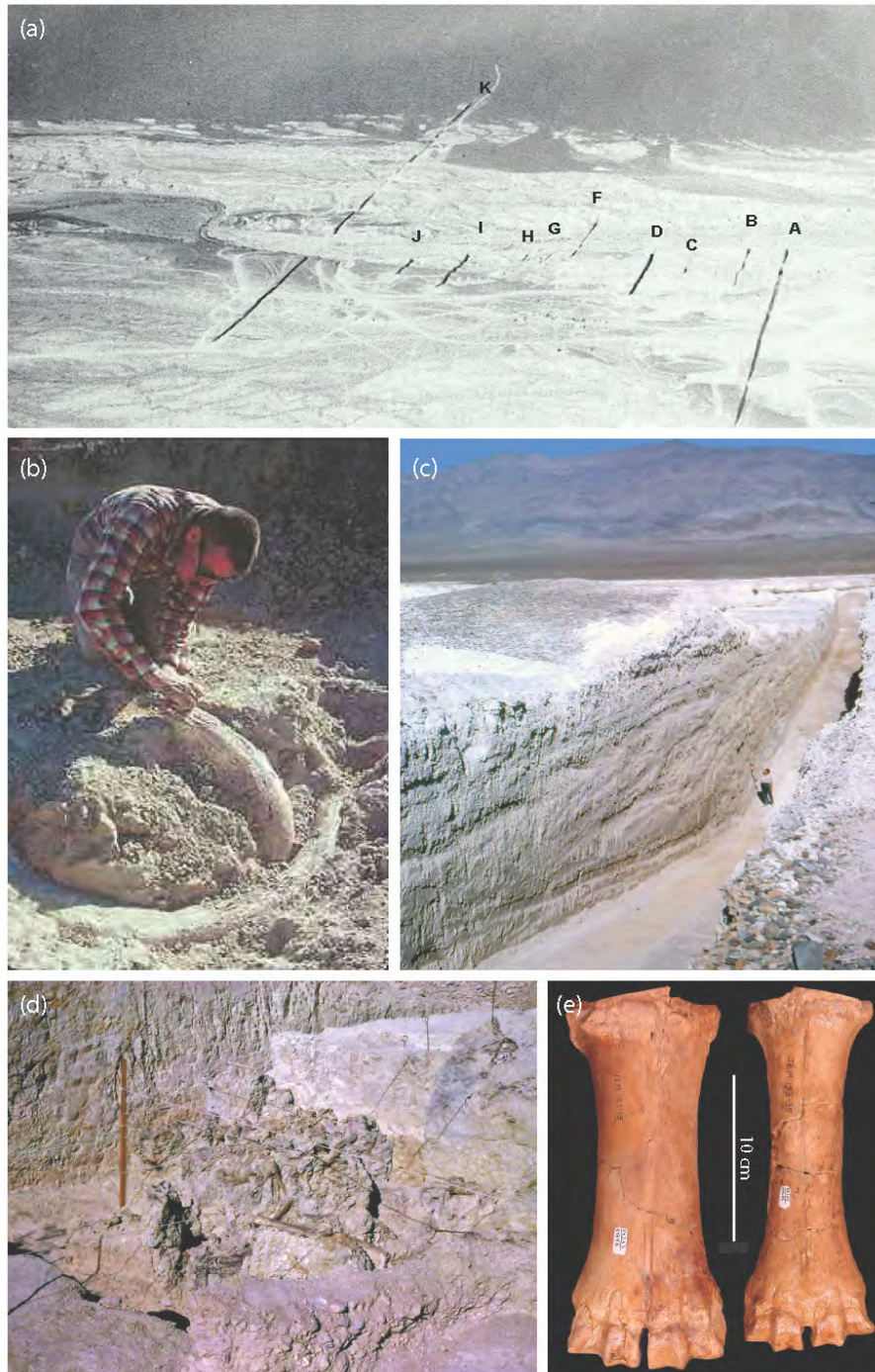


Figure 4. (a) Aerial photograph of the Tule Springs archaeological site showing trenches (A–K) that were part of the Big Dig of 1962–63 (after Wormington and Ellis, 1967; their figure 11b); (b) C. Vance Haynes, Jr. unearthing a pair of mammoth tusks at the Tule Springs archaeological site; (c) photograph of the inside of one of the trenches as it appeared shortly after excavation; archaeologist Dee Simpson for scale. SBCM archival image; (d) the *Bison* sp. “bone pile” at Locality 2, Tule Springs site, in 1963. SBCM archival image; (e) metacarpals (V-6243/64646, to left; V6243/64645, to right) of *Bison antiquus* from the “bone pile” at Locality 2, Tule Springs site; specimen access courtesy UCMP.

was more than a kilometer long (figures 4a and c).

C. Vance Haynes, Jr. directed the geological investigation (figure 4b), and subdivided the Tule Springs sediments into discrete, informally designated stratigraphic units (Haynes, 1967), referring to them collectively as the Las Vegas Formation after Longwell and others (1965). To establish a temporal framework for this new stratigraphy, more than 80 radiocarbon dates were obtained from Libby's lab at UCLA (Shutler, 1967a, 1967b), an incredible number for the time and with results produced within a week of collection—a rate that is rarely matched even today.

In addition to establishing baseline stratigraphic and chronologic frameworks, the Big Dig investigations revealed several new vertebrate taxa, including a second type of ground sloth (*Megalonyx*), North American lion (*Panthera atrox*), and pronghorn (?*Tetrameryx*) (Mawby, 1967). [Note: this was the first report of *P. atrox* from the Las Vegas Valley published in the scientific literature.] Other vertebrates, including rabbits (*Sylvilagus* and possibly *Brachylagus*), rodents (*Dipodomys*, *Microtus*, *Ondatra*), and coyote (*Canis latrans*), were also added to the fauna. Birds were documented from the assemblage for the first time, albeit on the basis of fragmentary material; the giant teratorn *Teratornis merriami* was present, as was an owl (*Bubo*), an indeterminate soaring hawk (Buteoninae), and a host of waterfowl (*Fulica*, *Mareca*, *Aythya*, *Mergus*, and Anseriformes). Importantly, the fossils were tied directly into the stratigraphy established by Haynes, allowing the scientists to begin tracking patterns of change in the vertebrate faunas through time. For example, they observed that fossils of *Bison* were present in the older members of the Las Vegas Formation (figure 4d and e), but not higher in the section, whereas ?*Tetrameryx* was reported from the younger units, but not the older. Small *Equus* was also interpreted to be more common in the younger units of the formation than the older (Mawby, 1967).

In the end, Haynes' careful excavation, stratigraphy, and chronology demonstrated that human cultural artifacts only occurred in the youngest levels of the formation—those units lacking Pleistocene megafaunal remains. The hypothesis of early humans coexisting with Pleistocene megafauna in the upper Las Vegas Wash was falsified (Wormington and Ellis, 1967) and, once

again, Tule Springs fell off the map of important sites for scientific study in North America.

Paleontologic and geologic studies in the Las Vegas Valley remained essentially dormant for more than three decades until the early 1990s, when scientists from the SBCM began work in the upper Las Vegas Wash (figure 5). These efforts, which continued into the early 2000s, were initially related to paleontologic mitigation associated with Bureau of Land Management (BLM) land transfers and construction activities, and were relatively limited in scope. Nevertheless, they were productive. In 2001 and 2002, for example, the SBCM discovered nearly 10,000 vertebrate and invertebrate fossils from 36 previously unrecorded fossil localities along the proposed route of a new transmission line running through the upper Las Vegas Wash. These discoveries added to the overall fauna and demonstrated the continued paleontologic richness of the region. To put these findings in context, Mawby's (1967) report on the fossils from the region listed just 12 localities.

In 2003 and 2004, the entire Tule Springs area was designated by public law as a "disposal area" to be sold to accommodate the burgeoning growth of the cities of Las Vegas and North Las Vegas. The BLM was required to conduct an environmental impact assessment of all protected resources in these lands, including paleontology, and to evaluate potential losses of these resources. The BLM authorized the SBCM to conduct an extensive survey of the upper Las Vegas Wash and surrounding areas, and in light of earlier reports, the results were astonishing. The survey discovered and documented 438 previously unrecognized paleontologic localities—nearly ten times the number of all previous investigations combined—firmly establishing the paleontologic wealth of the region. In addition, SBCM scientists demonstrated that understanding the geologic context of the fossils was critical for determining the significance of the resources and showed that the wetland deposits were the last to exist within the Las Vegas Valley (Springer and others, 2006). In consideration of these factors, as well as the presence of other sensitive natural and cultural resources, the BLM withheld 13,622 acres as the "upper Las Vegas Wash Conservation Transfer Area" to protect the area from development and to allow further scientific studies to occur.



Figure 5. (a) Paleontologist Eric Scott of the Dr. John D. Cooper Archaeological and Paleontological Center (formerly of the SBCM) excavating a mammoth jaw (SBCM L3160-586A) in the upper Las Vegas Wash; (b) mammoth tusk (SBCM L3160-597), one of many recovered from the extensive GWD deposits in TUSK (c) SBCM technician Conrad Salinas III recovering camel fossils from a spring-fed channel; (d) horse tooth, recovered in situ from GWD deposits in TUSK (uncataloged specimen from SBCM locality 2.6.603); (e) geologist Kathleen Springer of the USGS (formerly of the SBCM) unearthing fossils in the upper Las Vegas Wash in 2002.

Subsequent field investigations between 2008 and 2014 by the SBCM and USGS combined new geologic mapping and detailed stratigraphic analyses (Ramelli and others, 2011, 2012) with expanded and improved geologic interpretations and a more refined geochronology (Springer and others, 2015). These efforts led to the ongoing formal designations of the Las Vegas Formation (Springer and others, 2017) and Tule Springs Local Fauna (TSLF) (Scott and Springer, 2017). Over 500 fossil localities and more than 20,000 fossils were collected and curated as a result of these efforts. These detailed studies led to the recognition that extensive wetland ecosystems expanded and contracted many times during the late Quaternary in the Las Vegas Valley, tracking hemispheric and global climatic oscillations

in near lock step. Ultimately, the combination of the initial protection of these lands by the BLM, the excitement by the general public and political powers over the fossil discoveries and ongoing scientific studies, and an enthusiastic and steadfast advocacy group, called the Protectors of Tule Springs, led to the designation of Tule Springs Fossil Beds National Monument in 2014.

NOTABLE TAXA OF THE TULE SPRINGS LOCAL FAUNA

The vertebrate fauna of TUSK occurs throughout most of the temporal and spatial extent of the Las Vegas Formation. The fauna extends from ~100 ka to 13 ka at multiple localities throughout the upper Las Ve-

gas Wash. The nature of the assemblage matches published definitions for local faunas; it is “local in both time and space” (Taylor, 1960), and consists of “samples derived from localities, sites, quarries, pits, prospects, etc.” that can be “organized into aggregates of species ... which have a distribution in time and space, based on the record from a restricted geographic area” (Tedford, 1970). Based upon these definitions, and because of the importance of these remains, the late Pleistocene assemblage is being designated as the Tule Springs Local Fauna (TSLF; table 1) (Scott and Springer, 2017). All voucher specimens and catalog numbers are included in Scott and Springer (2017). Unless otherwise noted, all specimens discussed are curated in the collections of the San Bernardino County Museum. A brief discussion of some of the more significant members of the fauna is presented below.

Columbian Mammoth: *Mammuthus columbi*

The relative abundance of fossil remains of *Mammuthus* from the upper Las Vegas Wash is noteworthy. Seemingly every geologic, paleontologic, and/or archaeologic report from the region makes some mention of proboscidean bones and teeth in the wash (figure 6), whereas other Pleistocene megafauna from the region receive less consistent mention. This phenomenon likely owes its prevalence not only to the actual abundance of mammoth remains in the Las Vegas Formation, but also to the distinctive and readily identifiable nature of mammoth teeth, tusks, and bones—whether whole or fragmentary—as compared to other large mammal bones and bone portions. Both Simpson (1933) and Mawby (1967) observed that remains of mammoths were among the most common in the assemblages they studied from the upper Las Vegas Wash, and current findings (Scott and Springer, 2017) are consistent with these observations.

Mammoths were plant eaters, and given their massive bulk they would have consumed enormous amounts of food, an ecological requirement that is inconsistent with the current habitat of the area. The abundance of *Mammuthus* remains in the Las Vegas Formation demonstrates that the extensive desert wetlands provided ample forage during the late Pleistocene. Juvenile

and subadult fossils of *Mammuthus* are not uncommon in the assemblage, indicating that family groups lived in the region.

Giant Camel: *Camelops hesternus*

Camelops hesternus was widespread across western North America during the late Pleistocene, where it is thought to have lived in relatively large herds (Kurtén and Anderson, 1980). In coastal sites in southern California (Rancho La Brea), camels are less represented with respect to other large herbivores (horse, bison) (Stock and Harris, 1930; Scott, 2010), whereas they are more plentiful farther inland (Diamond Valley Lake) (Springer and others, 2009, 2010). Their abundance in the TSLF continues this trend, as camel is second only to mammoth in terms of the raw number of fossils, similar to other late Pleistocene megafaunal assemblages at other localities in the Mojave Desert (e.g., Jefferson, 1991).

North American Llama: *Hemiauchenia* sp.

Prior to 2010, the TSLF lacked evidence of the extinct North American llama, *Hemiauchenia macrocephala*, which contrasts sharply with the relative dominance of this taxon at other late Pleistocene localities in the Mojave Desert (Jefferson, 1991). However, a locality discovered that same year by the SBCM yielded a proximal right radio-ulna of a small adult camelid. Although incomplete and lacking reliable points of measurement, the specimen is sufficiently small that estimated dimensions fell well within the published size range of *Hemiauchenia* (Meachen, 2005). Given the small size and apparent adult age of the fossil, it was assigned to that genus, and thus represents the first and currently only record of this taxon from the Las Vegas Formation.

Bison: *Bison* spp.

Bison are relatively common in the assemblage from the upper Las Vegas Wash (Simpson, 1933; Mawby, 1967; De Narvaez, 1995; Scott and Cox, 2008; Scott, 2010). Two species of bison are present in the TSLF, including a long-horned species (*Bison* sp. cf. *B. latifrons*) and the smaller *Bison antiquus*, the latter based on the

Table 1. Composite vertebrate fauna, Las Vegas Formation.

(continued from previous column)		(continued on next column)	
Animalia			
Chordata			
Osteichthyes			
Teleostei			bony fish
Amphibia			
Anura			toad
	Bufonidae	<i>Bufo</i> sp.	
	Hylidae	<i>Hyla</i> sp. (large)	large frog
		<i>Hyla</i> sp. (small)	small frog
	Ramidae	<i>Rana</i> sp.	pond frog
Reptilia			
Chelonia			tortoise
Testudinidae			
	Gopherus sp.		
Lacertilia			
Iguanidae			
	<i>Sceloporus</i> sp. cf. <i>S. occidentalis</i>		sagebrush lizard
	<i>Callisaurus</i> sp. cf. <i>C. draconoides</i>		zebra-tailed lizard
	<i>Phrynosoma</i> sp.		horned lizard
Squamata			
Anniellidae			legless lizard
	<i>Anniella</i> sp.		
Serpentes			
Colubridae			
	<i>Masticophis</i> sp.		coachwhip snake
	cf. <i>Arizona</i> sp.		glossy snake
Aves			
Anseriformes			
Anatidae			
	<i>Mareca americana</i>		widgeon
	<i>Aythya collaris</i>		ring-necked duck
	<i>Aythya affinis</i>		lesser scaup
	<i>Mergus merganser</i>		common merganser
Ciconiiformes			
Teratomithidae			
	<i>Teratornis merriami</i>		teratorn
Accipitriformes			
Accipitridae			
	Buteoninae		indeterminate soaring hawk
Gruiformes			
Rallidae			
	<i>Fulica americana</i>		coot
	<i>Fulica americana minor</i>		small coot
Strigiformes			
Strigidae			
	<i>Bubo</i> sp.		owl
Mammalia			
Xenarthra			
Megalonychidae			Jefferson's ground sloth
	<i>Megalonyx jeffersonii</i>		
	Megatheriidae	<i>Nothrotherops shastensis</i>	Shasta ground sloth
	Lagomorpha		
	Leporidae		
		<i>Sylvilagus</i> sp.	cottontail rabbit
		<i>Lepus</i> sp.	jack rabbit
		? <i>Brachylagus idahoensis</i>	possible pygmy rabbit
	Rodentia		
	Sciuridae		
		<i>Amnospermophilus leucurus</i>	antelope ground squirrel
		<i>Marmota flaviventris</i>	yellow-bellied marmot
	Geomysidae		
		<i>Thomomys bottae</i>	Botta's pocket gopher
	Heteromyidae		
		<i>Dipodomys</i> sp. (large)	large kangaroo rat
		<i>Dipodomys</i> sp. (small)	small kangaroo rat
		<i>Pergnathus</i> sp.	pocket mouse
	Cricetidae		
		<i>Peromyscus</i> sp. cf. <i>P. maniculatis</i>	deer mouse
		<i>Reithrodontomys</i> sp.	harvest mouse
		<i>Onychomys</i> sp.	grasshopper mouse
		<i>Neotoma</i> sp. cf. <i>N. lepida</i>	desert wood rat
		<i>Microtus</i> sp. cf. <i>M. californicus</i>	meadow vole
		<i>Ondatra zibethicus</i>	muskrat
	Carnivora		
	Mustelidae		
		<i>Taxidea taxus</i>	badger
	Canidae		
		<i>Canis dirus</i>	dire wolf
		<i>Canis latrans</i>	coyote
	Felidae		
		<i>Puma</i> sp. cf. <i>P. concolor</i>	probable puma
		<i>Lynx rufus</i>	bobcat
		<i>Panthera atrox</i>	North American lion
		<i>Smilodon fatalis</i>	sabre-toothed cat
	Proboscidea		
	Elephantidae		
		<i>Mammuthus columbi</i>	Columbian mammoth
	Perissodactyla		
	Equidae		
		<i>Equus scotti</i>	Scott's horse
		<i>Equus</i> spp. (small)	small horse
	Artiodactyla		
	Camelidae		
		<i>Hemiauchenia</i> sp.	llama
		<i>Camelops hesternus</i>	giant camel
	Cervidae		
		<i>Odocoileus</i> sp.	deer
	Antilocapridae		pronghorn
	Bovidae		
		<i>Bison</i> sp. cf. <i>B. latifrons</i>	probable long-horned bison
		<i>Bison antiquus</i>	bison
		? <i>Euceratherium</i>	possible shrub-ox



Figure 6. Bones of a juvenile Columbian mammoth eroding out of Bed E₀ (23.04–18.16 ka) in the upper Las Vegas Wash. This locality was partially excavated as part of the “Big Dig” in 1962–63.

SBCM’s recovery of a partial skull with an intact horn core, as well as less complete crania and measurable postcrania from multiple localities.

Mawby (1967) reported fossils of extinct *Bison* from unit B₂ (= Bed B₂; see The Las Vegas Formation section below for geologic and chronologic details) but not from any of the younger fossil-bearing strata. However, the SBCM investigations confirmed the presence of *Bison* in both older and younger units of the Las Vegas Formation. *Bison* was recovered in Beds B₁, B₂, D₁ and E₀ of the Las Vegas Formation; its occurrence in Beds B₁ and E₀ extends the temporal range of this taxon in the TSLF.

Horse: *Equus* spp.

Horses are also common in the large mammal assemblage from the upper Las Vegas Wash. Both Simpson (1933) and Mawby (1967) found at least two species of horse, one large and one small. Simpson (1933) also suggested the possible presence of a third species. Cur-

rent efforts (Scott and Springer, 2017) support the latter contention; analysis of available elements suggest the large horse species *Equus scotti*, a small stout-limbed horse, and possibly a small stilt-legged species all lived in and around the Las Vegas Valley during the late Pleistocene (Scott and Springer, 2017). The proposed presence of a small stilt-legged horse in the region is strengthened by the documentation of small stilt-legged horses at the nearby Gypsum Cave locality, ~25 km east of the Las Vegas Valley (Scott and Lutz, 2014). If all three species of horses at Tule Springs are confirmed, it would contradict results of recent molecular studies that contend only two species of *Equus* were present in North America during the late Pleistocene (e.g., Weinstock and others, 2005; Orlando and others, 2008).

The fossils of *Equus scotti* from the upper Las Vegas Wash were recovered from a spring outflow stream in Bed E_{1d} and are directly associated with a calibrated ¹⁴C age of 13.69 ± 0.14 ka. These remains are the youngest and most southerly record of this species in Nevada,

and among the youngest anywhere in North America. The presence of *E. scotti* in the TSLF demonstrates its close geographic and temporal proximity to other late Pleistocene Mojave Desert localities that reportedly contain *Equus "occidentalis."* Thus, the range extension documented of *E. scotti* here may force reevaluation of these prior records.

Dire Wolf: *Canis dirus*

Until recently, the only large predator known from the Las Vegas Formation was the extinct North American lion *Panthera atrox* (Mawby, 1967). Fossil remains of this species are rare in the TSLF, even though a phalanx of *P. atrox* was among the earliest fossils discovered in the valley. Nevertheless, the paucity of fossils of large carnivorans is consistent with the interpretation that the fossils from the area represent a "normal" population distribution, in contrast to an entrapment setting (e.g., Rancho La Brea), where herbivores are far more numerous than predators.

The first confirmed record of *Canis dirus* from the Las Vegas Formation consists of a right patella discovered in association with other Pleistocene taxa (Scott and Springer, 2016). This specimen was recovered from Bed E_{1b}, which places *C. dirus* in southern Nevada towards the end of the Pleistocene, between 14.59 and 14.27 ka. This is the first confirmed record of dire wolf in the upper Las Vegas Wash, and the first in the entire Pleistocene fossil record of Nevada.

Sabre-Toothed Cat: *Smilodon fatalis*

In 2003, fossils of *Smilodon fatalis* were discovered in the upper Las Vegas Wash by the SBCM, but were not recognized until they were prepared and stabilized in 2012 (Scott and Springer, 2016). Remains of *S. fatalis* include a proximal left humerus and a distal left radius, as well as a partial sacrum. These fossils were recovered from Bed E_{1a}, which dates to between 16.10 and 14.96 ka (Springer and others, 2017), thereby establishing the presence of *S. fatalis* in southern Nevada towards the end of the Pleistocene. This new record adds to the sparse record of Pleistocene sabre-toothed cats from Nevada, as the only previous records from the state are from sites located north of the Mojave Desert (e.g.,

Kurtén and Anderson, 1980; Dansie and others, 1988; Livingston, 1991; Jefferson and others, 2004).

Bobcat: *Lynx rufus*

A single right humerus represents the first Pleistocene record of bobcat (*Lynx rufus*) from the upper Las Vegas Wash. The specimen was recovered from the floodplain deposits of Bed E₀ of the Las Vegas Formation and is associated with a calibrated ¹⁴C age of 21.04 ± 0.52 ka. Present-day bobcats are remarkably eurytopic carnivorans, inhabiting most kinds of environments from dense forest to desert, although they generally prefer broken country with cliffs and rock outcrops interspersed with open grasslands, woods, or deserts (Hoffmeister, 1986). The mosaic of ecologic settings in the Las Vegas Valley during the late Pleistocene would have offered an ideal habitat for *L. rufus*.

New Additions to the Tule Springs Local Fauna

The lower vertebrate microfauna from the TSLF includes fossils of true frog, *Rana* sp., as well as legless lizard (*Anniella* sp.), whipsnake (*Masticophis* sp.), and probable glossy snake (cf. *Arizona elegans*). None of these taxa have been reported previously from the Las Vegas Formation or from the fossil record of the Las Vegas Valley. The mammalian microfauna includes specimens of marmot (*Marmota flaviventris*), probable desert wood rat (*Neotoma* sp. cf. *N. lepida*), harvest mouse (*Reithrodontomys* sp.), and probable grasshopper mouse (cf. *Onychomys* sp.), which represent additional taxa not previously known from the Las Vegas Formation. Finally, the large mammal fauna also includes evidence of a large bovid, smaller than *Bison* but larger than a sheep (*Ovis*), that might represent extinct shrub ox (*Euceratherium* sp.) (Scott and Springer, 2017).

GEOLOGY, STRATIGRAPHY, AND PALEOHYDROLOGY OF TUSK

The broad sedimentary basin of the Las Vegas Valley was formed during the Neogene by extensional forces associated with the making of the Basin and Range province of western North America (Fleck, 1970; Page and others, 2005). The extension resulted in a series of

normal and strike-slip faults that cut across the region, including the Las Vegas Valley Shear Zone (LVVSZ), a northwest striking, right lateral strike-slip fault system (Langenheim and others, 1997, 1998; Page and others, 2005). Within the monument, the fault system is mostly buried by thick basin-fill deposits, although surface expression occurs at Corn Creek Springs, located just outside of TUSK (figure 1). The LVVSZ also marks the limit of headward erosion of the upper Las Vegas Wash, and includes discontinuities and subsurface barriers that likely influence local and regional groundwater flow patterns.

Inset within the basin-fill deposits, the Quaternary-age Las Vegas Formation was initially described by Longwell and others (1965) from a series of light-colored clay and silt deposits exposed along the upper Las Vegas Wash. Through successive periods of erosion and deposition, units within the formation are laterally discontinuous, exhibit complex stratigraphic relations, and combine to form a highly dissected, undulating badland topography. Prior to extensive urbanization of the cities of Las Vegas and North Las Vegas, sediments of the Las Vegas Formation were exposed throughout the entire valley (Longwell and others, 1965; Haynes, 1967; Matti and others, 1993; Donovan, 1996; Bell and others, 1998, 1999; Page and others, 2005; Ramelli and others, 2011, 2012). Today, exposures are restricted primarily to the upper Las Vegas Wash and Corn Creek Flat areas (figure 1).

Haynes (1967) recognized and described five Pleistocene and two Holocene informal stratigraphic units (A to G, in ascending stratigraphic order) and six intervening soils from exposures at the original Tule Springs site, which were then extrapolated throughout the upper Las Vegas Valley (Quade, 1986). Initially, these sediments were thought to be strictly lacustrine in origin (Hubbs and Miller, 1948; Maxey and Jamesson, 1948; Snyder and others, 1964; Longwell and others, 1965), but Haynes (1967) determined that at least some of the sediments were deposited in ciénegas, or desert wetlands, although he also postulated the existence of “Pluvial Lake Las Vegas” based on the spatial abundance of full-glacial age deposits in the Las Vegas Valley. Following suit, other studies have documented the presence of past episodes of groundwater discharge in the south-

ern Great Basin and Mojave Deserts in areas formerly reported as lacustrine (Mifflin and Wheat, 1979; Hay and others, 1986; Quade, 1986; Quade and Pratt, 1989; Quade and others, 1995, 1998, 2003; Pigati and others, 2011; Springer and others, 2015, 2017).

During the late Pleistocene, a climate wetter than today supported a variety of groundwater discharge settings throughout the southwestern U.S., including seeps, springs, marshes, wet meadows, ponds, and spring pools. Alluvial, fluvial, and eolian sediment became trapped by wet ground conditions and dense plant cover around these discharge points, and combined with organic material and chemical precipitates (carbonates, silicates) to form GWD deposits (Pigati and others, 2014). We are able to distinguish these deposits from lake sediments using sedimentologic and stratigraphic properties, as well as microfaunal assemblages, and are now able to recognize specific hydrologic regimes within the deposits comparable to modern spring ecosystems, including limnocrone (ponding), helocrone (marshes or wet meadows), and rheocrone (stream) flow (Springer and Stevens, 2008) (figure 7). The types of spring discharge and their spatial distribution throughout the upper Las Vegas Wash are directly related to subsurface structure (faults), aquifer complexity, and local and regional water table levels. Such recognition allows us to further constrain our understanding of past environmental and hydrologic conditions.

Our highly resolved chronologic and paleohydrologic records of the GWD deposits in the upper Las Vegas Wash show that wetlands in the valley were extremely sensitive to climate change in the recent geologic past. Multiple cycles of deposition, erosion, and soil formation demonstrate that wetland ecosystems in the valley expanded and contracted many times during the late Pleistocene, often collapsing entirely, before disappearing altogether as the last glacial period came to a close. These events exhibit temporal congruence with episodes of abrupt climate change, including Dansgaard-Oeschger (D-O) cycles and other millennial- and submillennial-scale climatic perturbations (Springer and others, 2015) (figure 8). Drought-like conditions, as recorded by widespread erosion and soil formation, typically lasted for a few centuries, which would have severely impacted the flora and fauna that depended on

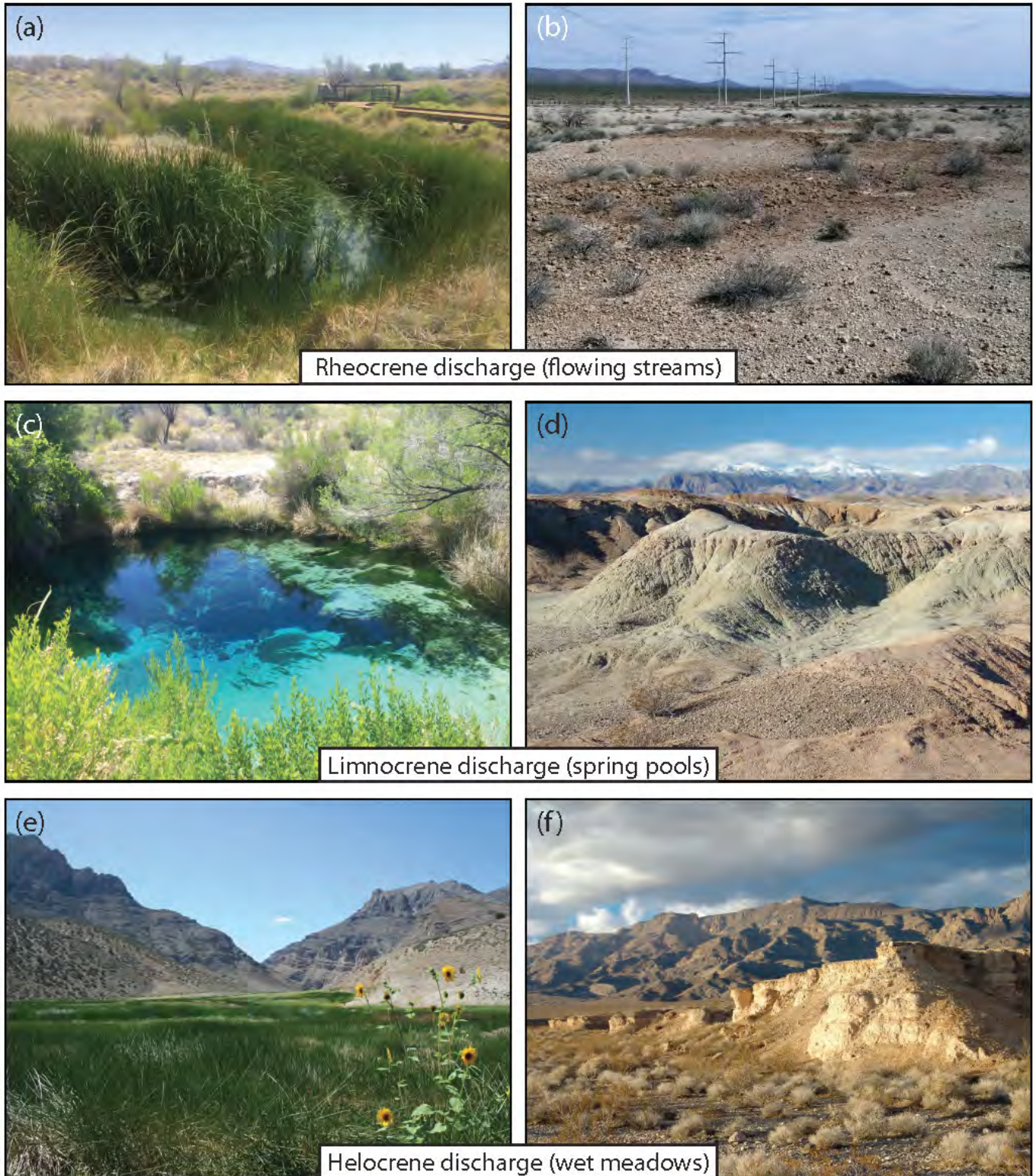


Figure 7. Examples of groundwater discharge regimes in extant wetlands (panels a, c, e) and their counterparts in the geologic record in TUSK (panels b, d, f). Rheocrene discharge is characterized by spring-fed streams and outflow channels, limnocrene discharge is characterized by discrete spring-fed pools and ponds, and helocrene discharge is characterized by extensive wet meadows and marshes.

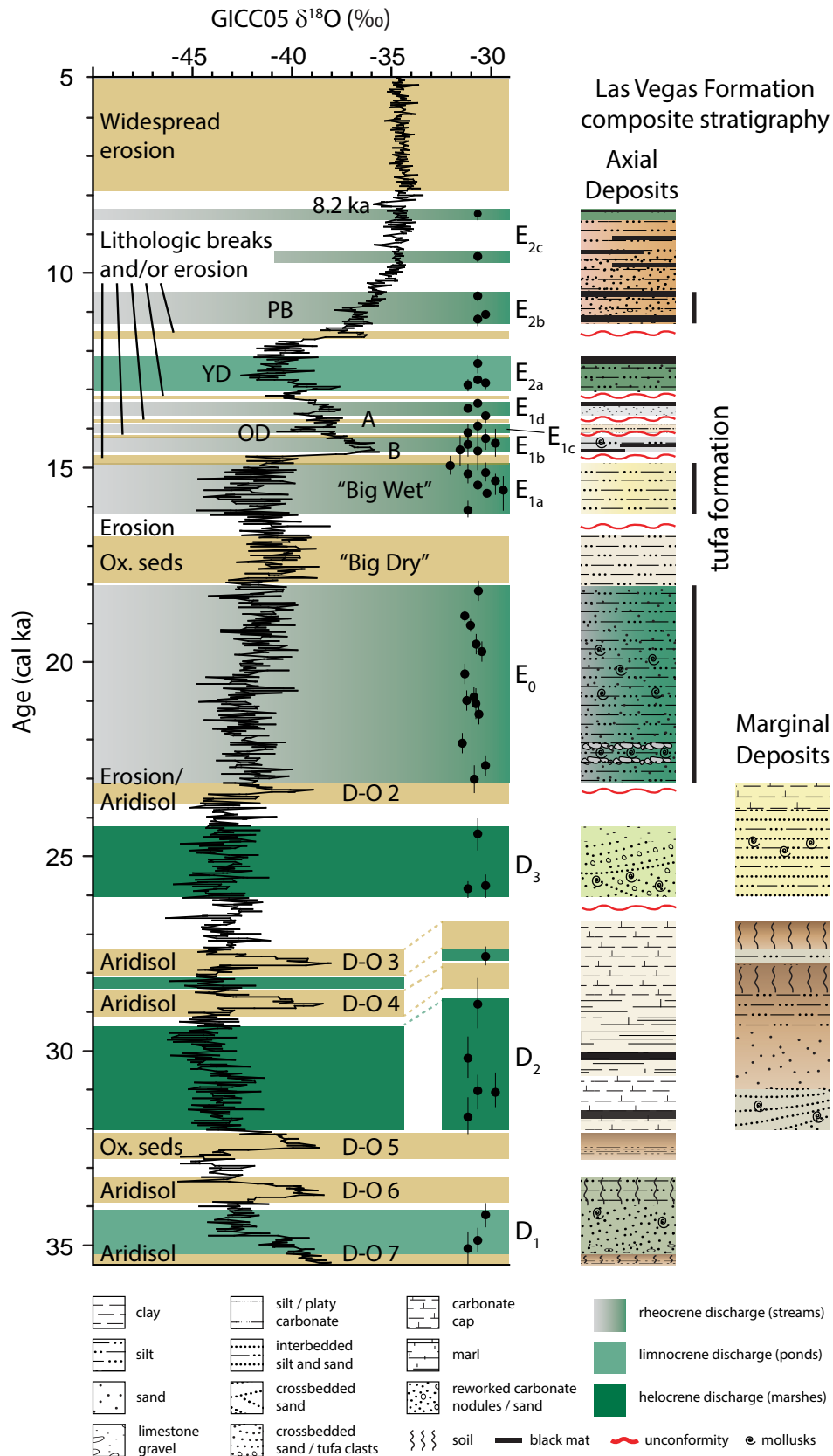


Figure 8. Caption on following page.

Figure 8 (figure on previous page). Stratigraphic and chronologic records of GWD deposits in the Las Vegas Valley of southern Nevada (after Springer and others, 2015) compared to $\delta^{18}\text{O}$ data from Greenland ice core records using the GICC05 chronology (Svensson and others, 2008). Filled circles are calibrated radiocarbon ages of the GWD deposits with uncertainties (bars) presented at the 95% (2σ) confidence level. Wetland discharge (by type) is shown in graduated shades of green. Tan horizontal bars indicate periods of aridity as evidenced by surface stability and/or erosion. D-O = Dansgaard-Oeschger cycles; “Big Wet/Big Dry” after Broecker and others (2009); B = Bølling; OD = Older Dryas; A = Allerød, YD = Younger Dryas; PB = Pre-Boreal; 8.2 ka = 8.2 ka cold event.

the springs and wetlands for water in an otherwise arid landscape (Springer and others, 2015). It is therefore critical to investigate and understand the geologic and hydrologic context of vertebrate fossil localities in detail if we are to determine how animals (and humans) survived in the ever-changing deserts of the American Southwest.

THE LAS VEGAS FORMATION

The Las Vegas Formation was designated initially by Longwell and others (1965) and Haynes (1967), and is being elevated to formal status by Springer and others (2017). The nomenclature presented herein largely follows that of Haynes (1967) but has been modified to include additional subunits that were not recognized previously. In addition, Haynes’ Unit C has been dissolved, as detailed stratigraphic analysis and a suite of ^{14}C and luminescence ages have shown that it consisted of sediments that are attributable to Members B and D (Springer and others, 2017). We describe the Las Vegas Formation, and limit the discussion below to Units (now Members) A through E because they consist of lithologies that represent various groundwater discharge regimes. Units F and G of Haynes (1967) represent dry conditions that prevailed during the Holocene. Additionally, all radiocarbon and luminescence ages discussed in this field guide are documented in Springer and others (2015, 2017). Ages are presented in ka (thousands of years) and associated uncertainties are

given at the 2σ (95%) confidence interval.

Each of the identified subunits (e.g., members, beds) described below represents a discrete “bin of time” that can be utilized to quantify changes in local faunal assemblages, reconstruct past ecosystems and environments on millennial and submillennial timescales, and evaluate the response of these systems to past episodes of abrupt climate change. In essence, we view the stratigraphic and chronologic frameworks that we have created for the Las Vegas Valley GWD deposits as “scaffolding” for future scientific studies. Below, we describe the primary physical characteristics and age ranges for each subunit within the Las Vegas Formation as a composite stratigraphy (figure 9), and note that additional stratigraphic and chronologic details for all subunits described herein are provided in Springer and others (2015, 2017).

Member A (~300 to 155 ka)

The stratigraphically lowest member of the Las Vegas Formation, Member A, crops out along the length of the upper Las Vegas Wash. It is not as widely exposed as the other members and consequently has been investigated less thoroughly. In general, Member A is complex and is characterized by abundant secondary carbonate (nodules, mottling), soil overprinting, and redoxymorphic features (figure 9). Along the valley axis, Member A consists of greenish to light-gray silts and sands that are present in spring cauldron bedforms (limnocrone discharge), deposits associated with spring outflow streams (rheocrone discharge), and numerous well-developed carbonate horizons, benches, and a massive carbonate cap formed in marshes and wet meadows (helocrone discharge). Away from the valley axis, the sediments transition to brown and gray clays and silts deposited in a drier, more marginal facies.

Member A contains a number of wetland soils, indicative of fluctuating water tables, and Aridisols, which represent drier conditions. Redoxymorphic features are abundant in Member A, an indication that fluctuating water-table levels were common during its formation. Overall, Member A spans multiple glacial–interglacial cycles (marine oxygen isotope stages [MIS] 6–8), displays a wide range of spring discharge types and soils,

and represents a long-lived and diverse desert wetland ecosystem. Vertebrate fossils have yet to be discovered from Member A in the Las Vegas Valley itself, but are anticipated based on the lithologies present. They are also known from Member A elsewhere in the Mojave Desert, most notably in the nearly complete Member A sequence in the nearby Pahrump Valley, southern Nevada-California.

Member B (~100 to 40 ka)

Member B is another long-lived sequence that exhibits a complex stratigraphy consisting of three distinct beds (B_{1-3}) that represent alluvial cut and fill sequences, flood-plain sediments, and discrete groundwater discharge deposits (figure 9).

Member B, Bed B_1 (100 to 55 ka)

The oldest subunit of Member B, Bed B_1 , was deposited between ~100 and 55 ka, and reflects variable hydrologic conditions that occurred during this time. In general, this bed consists of massive to bedded (thin to medium), tan to reddish-brown alluvial silts and sands deposited in relatively dry environments, punctuated by wetland soils and multiple carbonate-rich horizons, representing wetter times. The basal portion of Member B is a thick (>1 m) fluvial sequence deposited under (dry) conditions similar to today and contains subangular to subrounded limestone clasts as bedload at the contact with Member A. Bed B_1 also includes a rare, pale-green, silty subunit (B_{1-wet}) representing limnocrene ponding that occurred at ~72 ka. A single locality in Bed B_1 has yielded the oldest dated fossils from the Las Vegas Valley, including *Mammuthus* and *Equus*, microvertebrates, and a variety of bivalves and gastropods. Other B_1 sites contain the remains of *Mammuthus*, *Bison*, *Equus*, and *Camelops*.

Member B, Bed B_2 (55 to 45 ka)

Bed B_2 was deposited between ~55 and 45 ka, and consists of greenish-gray silt, sand, and clay in laterally discontinuous, cauldron-shaped lenticular beds and associated fluvial channels, characteristic of limnocrene and rheocrene discharge, respectively. Point-source emergence of groundwater from confined or

unconfined aquifers in the Las Vegas Valley scoured the cauldron-shaped pools. Haynes (1967) describes the internal workings of these ponds, and noted fantastic accumulations of fossils preserved in spring feeder conduits (figure 4d). Bed B_2 often contains organic material (charcoal and carbonized wood fragments), limestone gravels at the base of the bed, and aquatic gastropod shells of the genera *Helisoma*, *Pisidium*, *Physa*, and *Gyraulus*. The presence of *Helisoma*, in particular, is indicative of the limnocrene ponding that prevailed at this time.

Vertebrate fossils are especially abundant in Bed B_2 , and are commonly found in the green silts and clays of the limnocrene ponding units. Multiple B_2 localities have yielded the remains of *Mammuthus*, *Bison*, *Equus*, *Camelops*, *Aves*, and abundant microvertebrates. Based on palynological data acquired during the 1962–63 excavation, Mehringer (1967) determined that the upper Las Vegas Wash shifted from a sagebrush-dominated desert to moister and possibly cooler environment, and back during Member B_2 time.

Member B, Bed B_3 (45 to 40 ka)

Bed B_3 is composed of tan silt and sand that form channel and overbank deposits, similar to Bed B_1 , and dates to between ~45 and 40 ka. Sediments within Bed B_3 include cross-bedded sand, silt, and localized clay. As in Bed B_1 , groundwater-derived carbonate horizons are present in Bed B_3 , reflecting the presence of groundwater near the surface during short-lived wet phases within this time period. Rare vertebrate fossils are known from this unit, most occurring on deflated surfaces as float localities.

Member D (36.07 to 24.45 ka)

Member D represents the highest groundwater levels attained in the Las Vegas Valley during the late Quaternary. Widespread marshes and wet meadows formed during a period of pervasive spring discharge that left behind characteristic GWD deposits, most notably distinct and topographically extensive carbonate benches and caps. Member D consists of three distinct beds (D_{1-3}) that contain multiple black mats and exhibit lithologies that vary laterally from the valley axis (wetter)

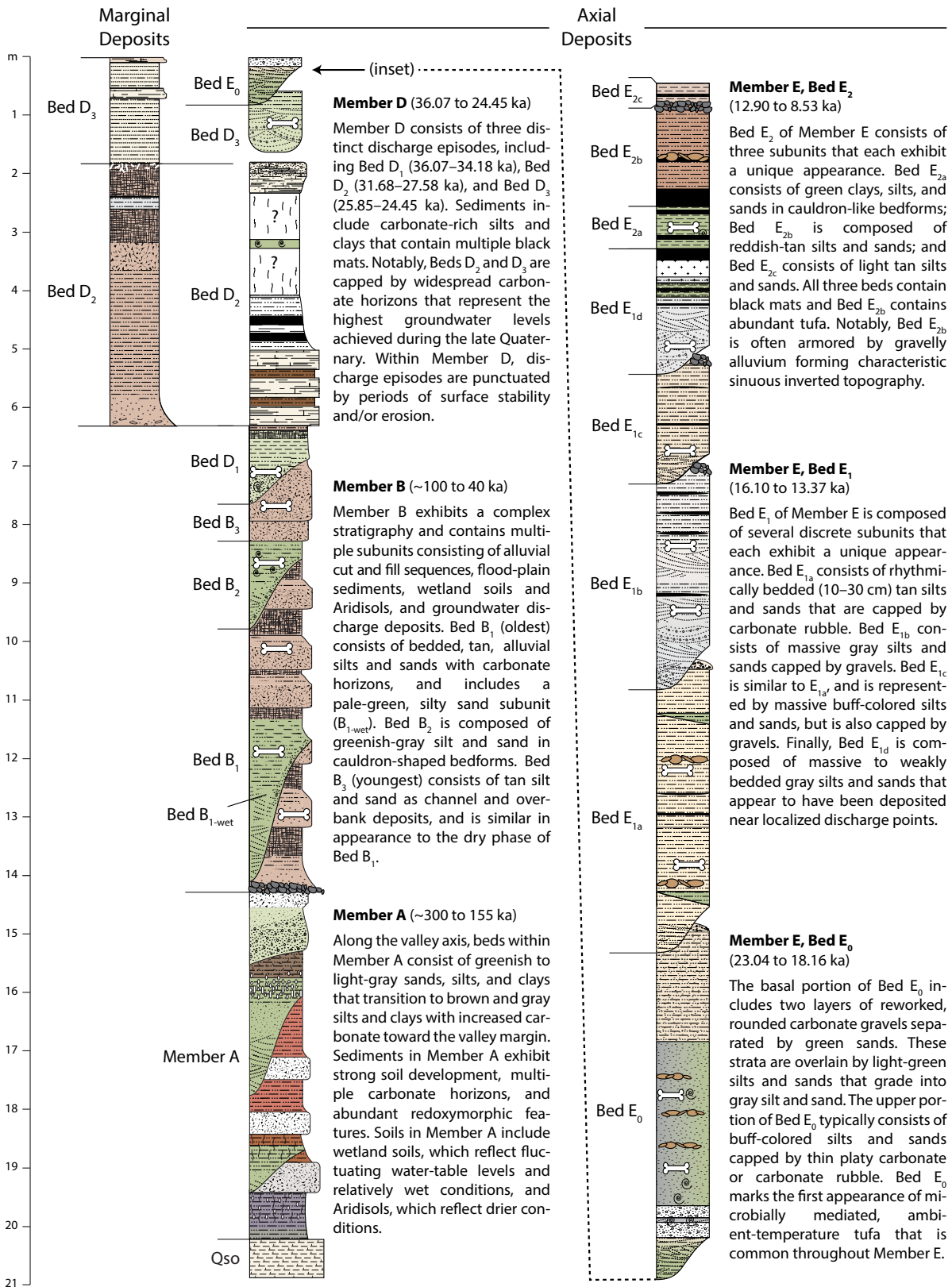


Figure 9. Composite stratigraphy and brief unit descriptions of the members and beds of the Las Vegas Formation. Note that colors shown in the stratigraphic profile are intentionally oversaturated to differentiate between members and/or beds. Age control is based on a combination of radiocarbon (¹⁴C) and luminescence (IRSL) dating (see Springer and others, 2017).

into more marginal facies (drier) upslope (figure 9). All of the beds within Member D contain vertebrate fossils.

Member D, Bed D₁ (36.07 to 34.18 ka)

Along the valley axis, Bed D₁ (36.07 to 34.18 ka) consists of light greenish-gray silts, sands, and clays that represent multiple discharge regimes. The basal portion of the bed includes reworked subangular to subrounded carbonate nodules forming a fluvial bedload up to 15 cm thick, representing rheocene discharge. The middle and upper portions of Bed D₁ consist of olive-green silts and clays with *Helisoma* and *Pisidium* shells present in cauldron-shaped pools (limnocene discharge) and clay-rich sediment with Succineidae shells representing a reducing marshy environment (helocene discharge). Away from the valley axis, the marginal facies of Bed D₁ is more grayish-brown and mottled in appearance with rare gastropod shells.

Member D, Beds D₂ and D₃ (31.68 to 24.45 ka)

Beds D₂ (31.68 to 27.58 ka) and D₃ (25.85 to 24.45 ka) represent similar discharge regimes, consisting primarily of whitish gray silts deposited in extensive marshes and wet meadows. Bed D₂ contains interbedded black mats and both beds exhibit abundant secondary carbonate. Notably, both beds are capped by widespread carbonate benches and caps that represent the highest groundwater levels achieved in the Las Vegas Valley during the late Quaternary. These features represent a sequence of relatively wet conditions, during which the sediments were deposited, followed by dry conditions, during which the carbonates became case hardened via evapotranspiration at or near the ground surface. Both beds exhibit strong facies changes from wet meadows along the valley axis to phreatophyte flats in more marginal areas. (Note the phrase “phreatophyte flats” refers to areas where the water table is shallow enough that plants can tap into it but groundwater has not breached the surface. The plants essentially act as dust traps for eolian sediment, and thus “phreatophyte flats” are represented in the GWD record by tan to light brown silts and fine sands [after Quade and others, 1995]). Within Beds D₂ and D₃, discharge episodes are separated by periods of surface stability (i.e., soil

formation) and/or erosion that formed in response to abrupt climatic perturbations (D-O 4-3 and D-O 2).

Member E (23.04 to 8.53 ka)

Member E contains eight beds (E₀, E_{1a}, E_{1b}, E_{1c}, E_{1d}, E_{2a}, E_{2b}, E_{2c}) that are temporally distinct and mappable at the outcrop scale (figure 9). Overall, the multiple cycles of deposition, erosion, and surface stability represented by Member E reflect the extreme hydrologic variability that characterized the Las Vegas Valley following the collapse of the entire wetland ecosystem just after the last glacial maximum. The spring hydrographic environments represented by Member E consist of multiple point-source discharge and outflow streams, in contrast to the pervasive marshes that existed during Member D time. Member E also marks the appearance of a series of braided fluvial channels containing microbially mediated, ambient-temperature tufas that are often intercalated with black mats. Colder temperatures inhibit the formation of this type of tufa and therefore its presence within Member E constitutes an important climatic and paleoenvironmental signal marking warmer times.

Member E, Bed E₀ (23.04 to 18.16 ka)

Bed E₀ is a newly recognized unit of the Las Vegas Formation (Ramelli and others, 2011; Springer and others, 2015); its distinctive lithologies were assigned to Member D in previous mapping efforts by Bell and others (1998). Bed E₀ represents a series of spring outflow streams and associated floodplains. The basal portion of Bed E₀ contains two medium (10 to 30 cm) beds of rounded carbonate gravels derived from the underlying carbonate cap of Bed D₂ (and possibly D₃) mixed with rounded limestone gravels, as well the first appearance of microbially mediated tufa in the Las Vegas Formation. These gravel layers are often separated by 10 to 20 cm of olive-green sands containing abundant aquatic mollusk shells, dominated by *Pisidium* and *Physa*. Overlying the basal strata are massive light-green sands and silts that exhibit numerous feeder conduits, spring chalk, and limonite staining (all indicative of vigorous spring activity), which grade upward into gray silts and sands. In turn, these gray fluvial sediments are overlain by buff-colored fine sands and silts indicative of a drier

environment and are capped by platy carbonate and/or carbonate rubble. In general, the E_0 capping carbonate is thinner and darker in color than the thick whitish caps of Member D, likely due to an increased input of dust at the end of E_0 time. An extraordinary number of vertebrate fossils localities occur within E_0 deposits.

Member E, Bed E_1 (16.10 to 13.37 ka)

Bed E_1 of Member E consists of several discrete subunits that each exhibit a unique appearance and represent distinct episodes of rheocrene flow. As with Bed E_0 , Bed E_1 contains a large number of fossil localities. Bed E_{1a} (16.10 to 14.96 ka) consists of rhythmically bedded (10 to 30 cm), buff-colored silts and sands that weather to a distinct yellowish-brown hue. The sediments are well sorted, often exhibit a hummocky and honeycombed weathering pattern in section, and are capped by carbonate rubble that is platy in some places. Bed E_{1a} often contains charcoal and incipient black mats at the base of exposed sections, as well as interbedded rounded limestone gravels. Tufa occurs within the E_{1a} deposits locally, appearing as bedload crusts, phytoclasts, and cyanoliths.

Bed E_{1b} (14.59 to 14.27 ka) exhibits massive, whitish to light gray silts and sands, and is the most easily recognized subunit within Bed E_1 . The basal portion of the bed is composed of light- to medium-gray channelized cross-bedded silt and sand. The basal channelized portion of the bed typically grades upward into the characteristic whitish silts and sands that represent wet meadow facies, and often contain black mats, feeder conduits, and multiple thin carbonate horizons. Toward the narrows (figure 1c), aquatic snail shells (*Helisoma*, *Physa*, *Pisidium*) are common within E_{1b} sediments. Importantly, Bed E_{1b} is mantled by limestone gravels as opposed to carbonate, which contributes to its distinct appearance on the landscape.

Bed E_{1c} (14.12 to 13.95 ka) is similar in appearance to Bed E_{1a} , consisting of massive buff-colored sands and silts that exhibit a honeycombed weathering pattern, also with a yellowish-brown weathered hue. In contrast, however, Bed E_{1c} is mantled by limestone gravels, similar to Bed E_{1b} . This bed is not very widespread, but where present, it often contains shells of the aquatic bi-

valve *Pisidium*, indicative of shallow flowing water.

Bed E_{1d} (13.69 to 13.37 ka) contains massive to weakly bedded gray silts and sands with reworked carbonate nodules. It is also limited geographically and includes localized light greenish-gray silts and sands deposited near spring orifices, which exhibit inclined bedding. This bed also contains aquatic shells (*Pisidium*, *Physa*) that indicate shallow flowing water.

Member E, Bed E_2 (12.90 to 8.53 ka)

Bed E_2 of Member E is represented by three subunits that each exhibit a unique appearance, all of which contain black mats. Bed E_{2a} (12.90 to 11.60 ka) consists of massive olive-green silts and sands that are present in cauldron-shaped bedforms indicative of limnocrone ponding. This facies of Bed E_{2a} is found only rarely in the upper Las Vegas Wash, likely because of the lack of a capping carbonate or gravel layer, which left it especially vulnerable to erosion. Bed E_{2b} (11.22 to 10.63 ka) consists of massive reddish-brown to buff-colored sand and silt that are armored by gravelly alluvium forming characteristic sinuous inverted topography. Bed E_{2b} contains abundant tufa. Finally, Bed E_{2c} (9.62 to 8.53 ka) consists of light-tan silts and sands that contain aquatic snail shells (*Physa*, *Pisidium*, Hydrobiidae) indicative of flowing water. This bed is only found outside the TUSK boundaries and represents the last period of intermittent groundwater discharge that occurred during the early Holocene.

GEOLOGIC POINTS OF INTEREST

Site 1: 36.31161° N, 115.16706° W (Figure 10a)

The many bluffs along the edge of the active upper Las Vegas Wash provide excellent exposures of the Las Vegas Formation. This site features a classic example of Member A of the Las Vegas Formation. Several characteristics are used to differentiate Member A from other members and beds within the formation, including strong soil development (both wetland soils and Aridisols), abundant secondary carbonate, and striking redoxymorphic features (soil mottling). Around the corner to the southeast, the lower part of Member A

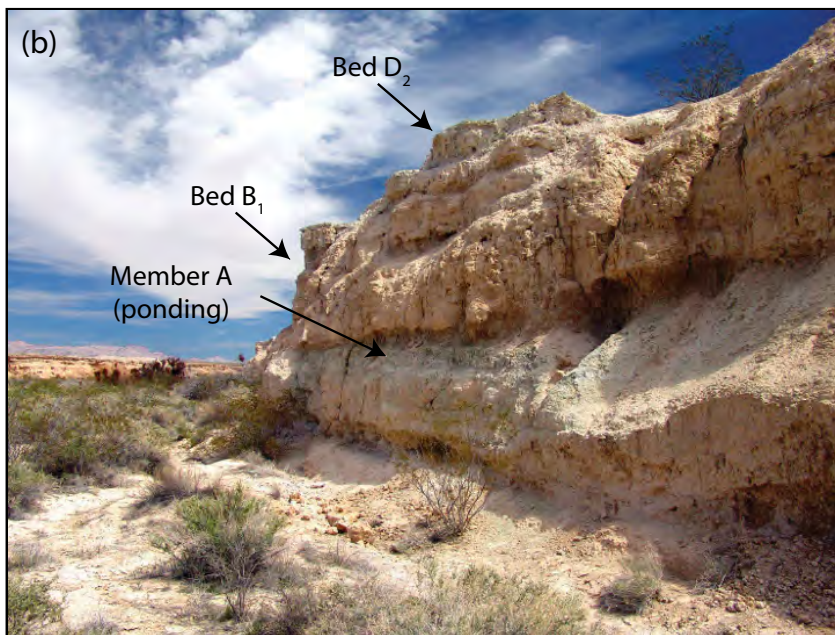
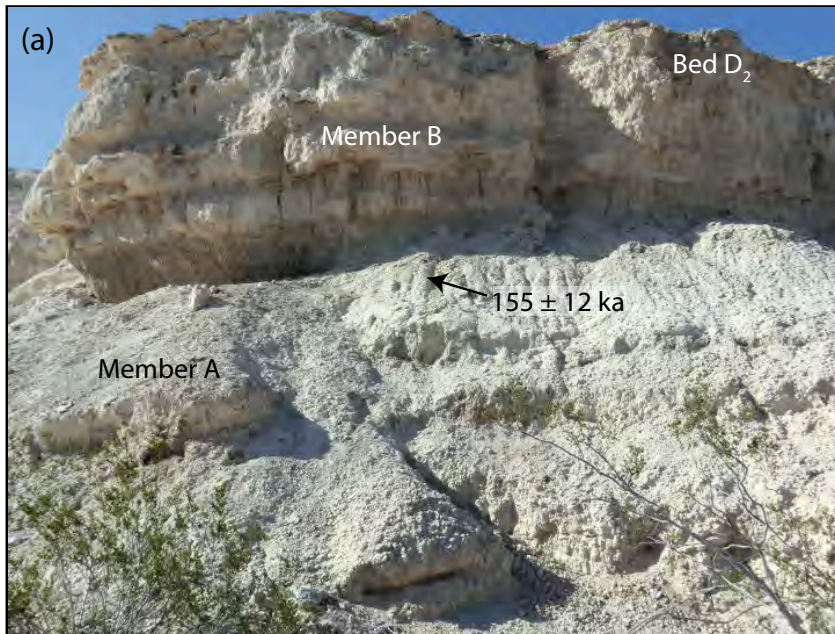


Figure 10. Member A at localities in the upper Las Vegas Wash. (a) Site 1: 36.31161° N, 115.16706° W; (b) Site 2: 36.31168° N, 115.16525° W. Overall, Member A ranges in age from ~300 to 155 ka and is characterized by complex lithologies, abundant redoxymorphic features, and extensive carbonate-rich benches and caps representing variable hydrologic conditions.

was dated to 251 ± 18 ka by luminescence techniques and includes grayish-brown clays and silts with root traces that are filled or lined with iron/manganese oxides, indicative of repeated fluctuating water-table levels and relatively wet conditions. Up section, note the reddish-tan silts and sands with numerous carbonate stringers that transition laterally to greenish-gray silts and sands with cauldron-shaped bedforms and outflow channels. Near the top of Member A at this site, a date of 155 ± 12 ka was obtained from a horizon that consists

of grayish-brown to brown clays and silts with angular blocky soil structures and root traces filled or lined with iron/manganese oxides. Multiple carbonate horizons/benches in this section and elsewhere within Member A reflect periods of surface stability that punctuated alluvial and wetland deposition. The contact with the fine-medium sands of Bed B₁ is a distinct lithologic break.

Sidebar — From site 1, a short hike (~0.35 km) across the wash to the northwest will lead you to Locality 5, one of the paleontologic and archaeological sites dis-

covered and studied in 1962–63 as part of the “Big Dig.” This locality boasts one of the many trenches excavated by heavy earth-moving equipment at that time. The deposits here include stream channels of Beds E_0 and E_{1b} , which yielded abundant vertebrate fossil material; a skull, mandible, and post-cranial elements of mammoth are notable in addition to horse, camel, antelope, tortoise, and small mammals. Additionally, human cultural artifacts were discovered at this site, but no temporal association with the vertebrate fossils could be made. Note the rounded carbonate gravels at the base of the Bed E_0 and abundant tufa in the stream channel sediments. Excavation of this locality revealed that many of the mammoth remains were encrusted by tufa.

From Locality 5, follow the stream channels of Beds E_0 and E_{1b} along the base of the bluffs due east for ~0.20 km. Bed E_{1b} is inset into Bed E_0 , and both are dramatically buttressed against the older deposits of Members B and D. The importance of understanding the complex stratigraphy resonates here, as multiple fossil localities occurred within both of these spring channel deposits, including the large accumulation of mammoth bones seen in figure 6. This site, within Bed E_0 (23.04 to 18.16 ka), was presumably excavated and collected (based on historic trash and photographs) during the 1962–63 excavations of the “Big Dig,” but was abandoned and left with multiple bones still exposed in situ. This site was rediscovered by the SBCM during their original survey for the BLM in 2004, but was not collected. Instead it served an important purpose for the next decade—it was used as an interpretative site that the local advocacy group showed visitors as they sought to garner support for the new national monument.

Site 2: 36.31168° N, 115.16525° W (Figure 10b)

Dramatic limnocrene ponding commonly occurs within Member A. The greenish-gray silts and cross-bedded sands in this cauldron-shaped bedform are overlain by Bed B_1 and the prominent carbonate cap of Bed D_2 . Traced laterally to the west, the Member A ponding unit shown in figure 10b is overlain by a soil that dates to 183 ± 15 ka.

Sidebar — At the base of the transmission tower,

immediately west of site 2, an important locality yielded a diverse faunal assemblage from an inset Bed B_2 limnocrene pond deposit. Taxa included *Mammuthus*, *Camelops*, *Equus*, *Bison*, frog, fish, and multiple varieties of mollusks. The fish, amphibians, and endemic aquatic gastropods are noteworthy, as all are indicative of localized ponding. Large mammal fossils recovered from Tule Springs are frequently fragmentary, in some cases exhibiting evidence of trampling and/or subaerial weathering prior to burial. Because of these taphonomic factors, it is often a challenge to recover large mammal fossils that are sufficiently complete to be identifiable to species. At this locality, a left magnum of *Bison* was complete enough to allow proper measurement. The specimen fell within the range of similar elements of *Bison antiquus* from Rancho La Brea as well as *Bison* previously identified from Tule Springs.

Site 3: 36.31258° N, 115.16968° W (Figures 11a and 12)

Sediments at this locality are typical of Member B, exhibiting distinct “dry, wet, dry” sequences. Throughout the upper Las Vegas Wash, Bed B_1 overlies the eroded topography of Member A unconformably. Here, Bed B_1 dates to 61 ± 10 ka and consists of tan alluvial sand and silt, and a carbonate-rich, wetland soil. Bed B_2 is inset into Bed B_1 and consists of distinctive greenish sands and silts in a cauldron-shaped limnocrene pond with endemic molluscan taxa (e.g., *Helisoma* sp.) and abundant vertebrate fossils. At this site, Bed B_2 dates to 47 ± 4 ka. The Member B sequence is completed by oxidized tan silts and sands of Bed B_3 , which dates to 44 ± 6 ka at this locality.

Sidebar — As one visits the sites in this guide, notice the spectacular inverted paleo-stream channel topography, as it is a distinctive component of the landscape. During Member E time (23.04 to 8.53 ka), limestone gravels and cobbles were deposited as alluvial pulses in pre-existing sinuous outflow stream channels. This happened multiple times as discharge ceased, resulting in mantling gravels in Beds E_{1b} , E_{1c} , and E_{2b} . The gravel is more resistant to erosion than the fine-grained sediments it mantles, protecting the former stream channels. Following erosion, the channels were left high and

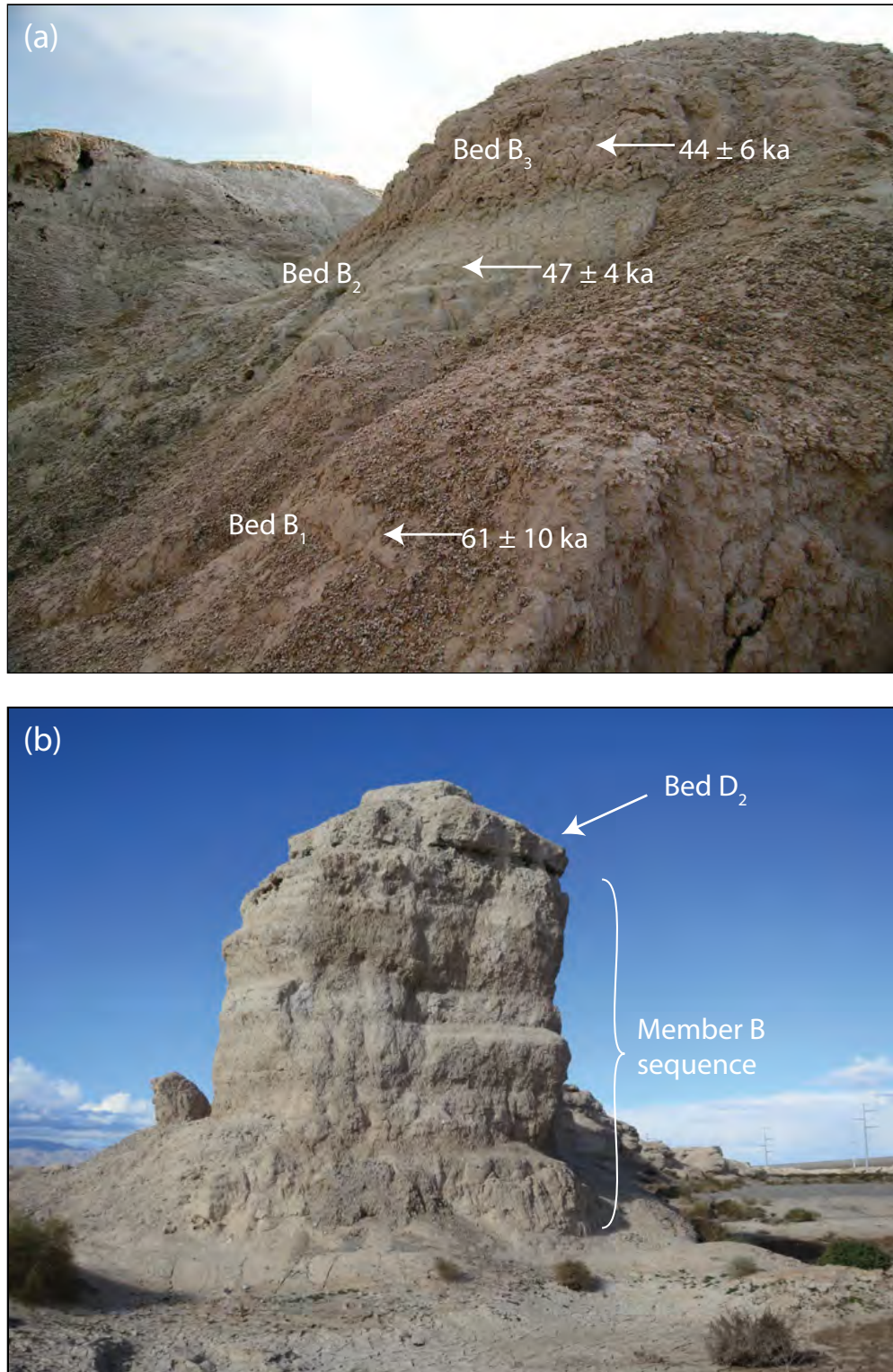


Figure 11. Member B at localities in the upper Las Vegas Wash. (a) Site 3: 36.31258° N, 115.16968° W; (b) Site 4: 36.32895° N, 115.21835° W. Overall, Member B ranges in age from ~100 to 40 ka and is characterized by tan to light-brown fluvial and alluvial sediments interbedded with discrete carbonate horizons (Beds B₁ and B₃) that collectively represent relatively dry conditions punctuated by brief wet episodes, as well as pale olive-green silts and clays in cauldron-like bedforms (Beds B_{1-wet} and B₂) that are consistent with limnocrene discharge.

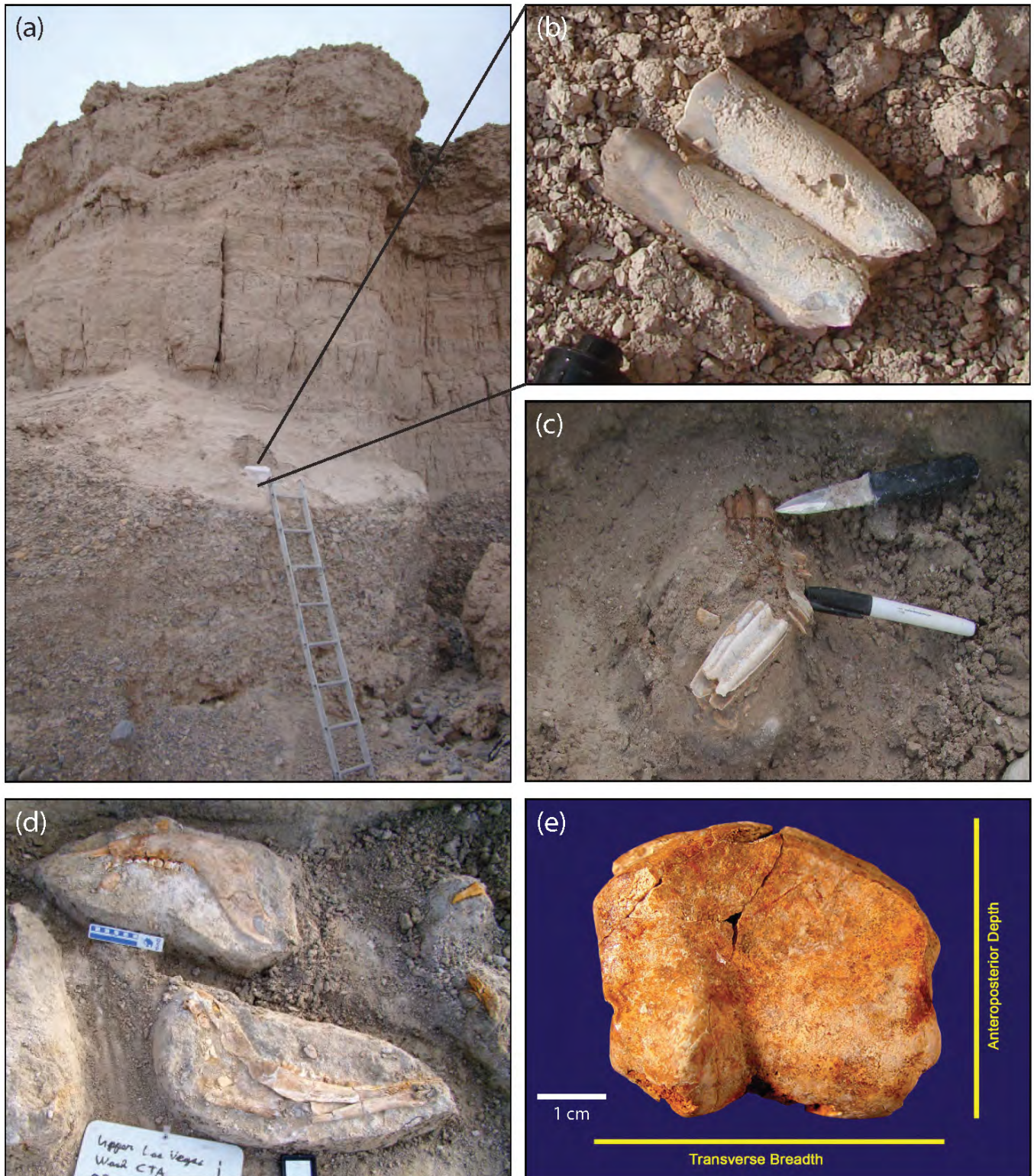


Figure 12. Vertebrate fossils from Member B. (a) Bed B₁ with typical limestone gravels at base of unit and fossil with plaster jacket ready to be collected; (b) the locality in (a) yielded a tooth and partial skull of *Camelops hesternus*. Figured tooth is SBCM L3160-657; (c) horse tooth from Bed B₁, SBCM L3160-632; (d) a pair of dentaries of *Bison* sp. from a Bed B₂ pond, SBCM L3160-818.1, L3160-818.2; (e) magnum of *Bison antiquus*, SBCM L3088-1, as noted in sidebar for site 2.

dry, and are now exposed above the surrounding landscape. The inverted paleo-stream channel topography provides a glimpse of the distribution of late Quaternary stream channel flow patterns in TUSK, and also protects the fine-grained deposits that contain abundant fossil resources.

Site 4: 36.32895° N, 115.21835° W
(Figures 11b and 12)

This sedimentary sequence demonstrates the complex stratigraphy of Member B and includes at least eight subunits that are visible in the vertical exposures, each separated by varying degrees of soil formation. Carbonate horizons derived from evapotranspiration of shallow groundwater during short-lived wet phases often accompany the soils. As at many locations, the B sequence is capped by the ubiquitous carbonate cap of Bed D₂.

Site 5: 36.30865° N, 115.14988° W
(Figures 13a and 14)

Member D represents the highest groundwater levels achieved in the Las Vegas Valley during the late Quaternary. Widespread marshes and wet meadows were present between ~36 and 24 ka and left behind a series of distinctive GWD deposits. Bed D₁ was first defined and characterized at this site with a date of 35.04 ± 0.50 ka (Ramelli and others, 2011). Overlying Member B sediments, the base of Bed D₁ consists of reworked carbonate clasts, representing rheocene stream discharge, which transition to greenish-gray silts and sands with the typical cauldron bedform of limnocene ponding, similar to Bed B₂. Mollusks typical of these ponds (*Helisoma* sp.) are abundant in the sediments, which also contain a “smear” of black mat organics, from which the date shown in figure 13a was obtained. The upper part of Bed D₁ exhibits strongly oxidized lithologies and an Aridisol, which we interpret as representing widespread drying events that correspond in time to D-O 6-5 (figure 8). At this site, Bed D₁ is overlain by an incipient Bed D₂ carbonate cap.

Site 6: 36.30857° N, 115.14934° W
(Figures 13b and 14)

The sedimentary sequence exposed here is nearly identical to site 5, but with the carbonate cap of Bed D₂ more prominently formed. The base of the section is in contact with Member A, where Bed D₁ exhibits two distinct packages of reworked carbonate clasts deposited in rheocene streams. These sediments are overlain by light greenish-gray sands, silts, and muds of Bed D₁ ponds, and a carbonate bench and intervening green-gray silt and clay of the marshes that epitomize Bed D₂ helocene discharge. Radiocarbon dates on terrestrial gastropods within the D₂ cap allow us to constrain the age of the full-glacial marshes in this axial portion of the valley. Prominent carbonate caps and benches that are resistant to erosion are important marker beds in the full-glacial sequence and form broad, topographically extensive flats throughout the Las Vegas Valley. The caps/benches form at the ground surface or very shallow subsurface via capillary migration of groundwater through the vadose zone. We attribute their formation to abrupt warming that intensified evaporative effects and depressed the water table leading to desiccation of the wetlands. The prominent D₂ carbonate cap found here and throughout the valley corresponds in time to D-O 4-3 (figure 8), reflecting the dynamic response of these wetlands to abrupt climatic fluctuations.

Site 7: 36.30945° N, 115.15371° W
(Figures 15a, b, and 16)

Geologic mapping and detailed stratigraphic studies in TUSK (Ramelli and others, 2011; Springer and others, 2015, 2017) led to the documentation of a previously unrecognized lithologic and stratigraphic unit that postdates Member D and predates Beds E₁ and E₂. The newly named Bed E₀ contains prolific vertebrate fossils (figure 16) and dates to between 23.04 and 18.16 ka. It was previously mapped as either “unit D” or “unit E” (Haynes, 1967; Page and others, 2005). Quade (2003) noted a significant hiatus between the collapse and desiccation of the full glacial marshes and the deposition of the younger sediments of Bed E₁ at ~16 ka. We documented that wetland development was reestablished by

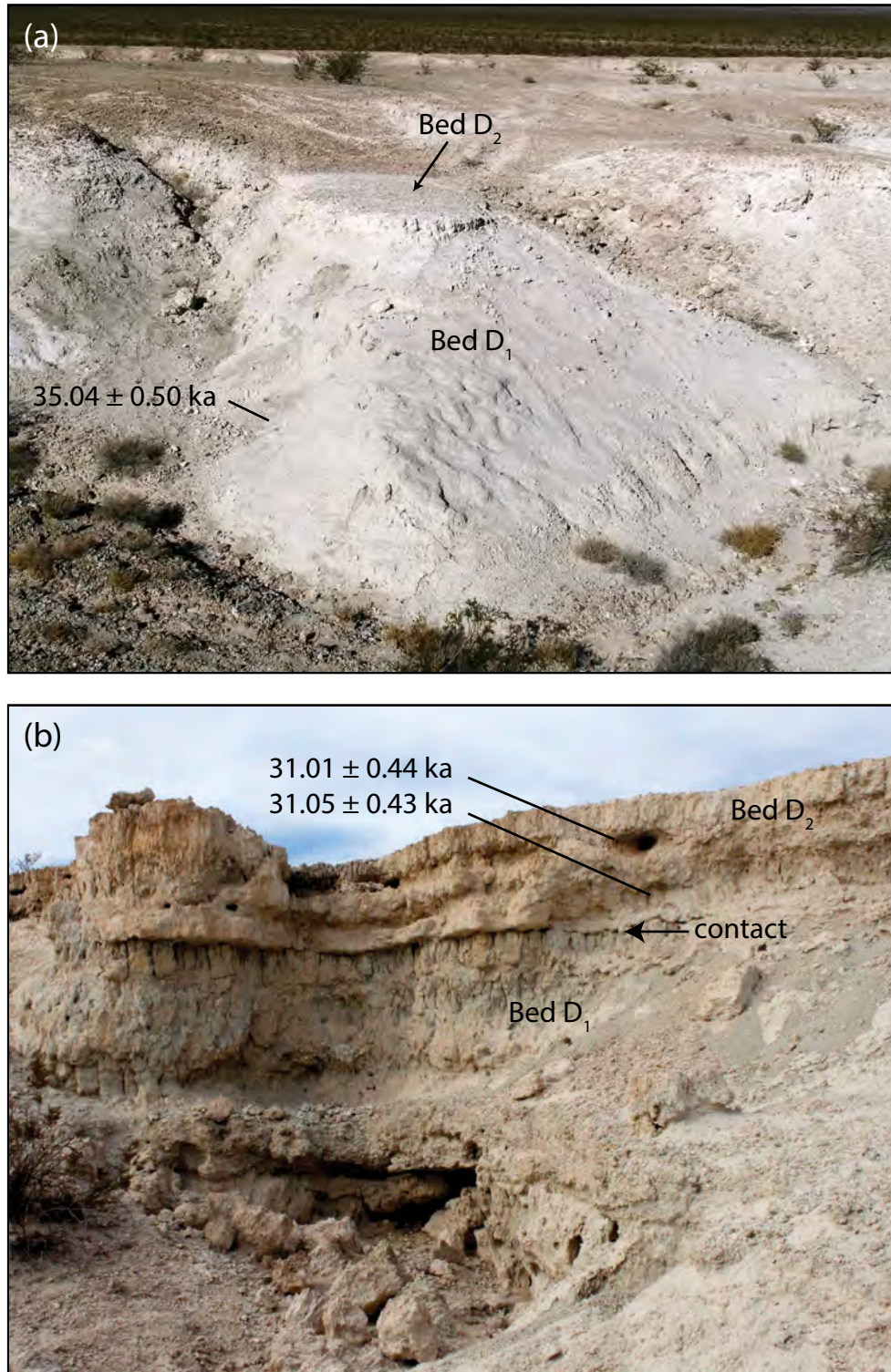


Figure 13. Member D at localities in the upper Las Vegas Wash. (a) Site 5: 36.30865° N, 115.14988° W; (b) Site 6: 36.30857° N, 115.14934° W. Member D ranges in age from 36.07 to 24.45 ka and consists of three distinct beds. Bed D₁ (36.07–34.18 ka) is composed largely of olive-green silts and clays representing limnocene and helocene discharge. This bed also contains evidence of episodic rheocene discharge toward the base, whereas Beds D₂ (31.68–27.58 ka) and D₃ (25.85–24.45 ka) exhibit extensive thick carbonate benches and caps representing helocene discharge that spanned much of the valley floor during full glacial times.

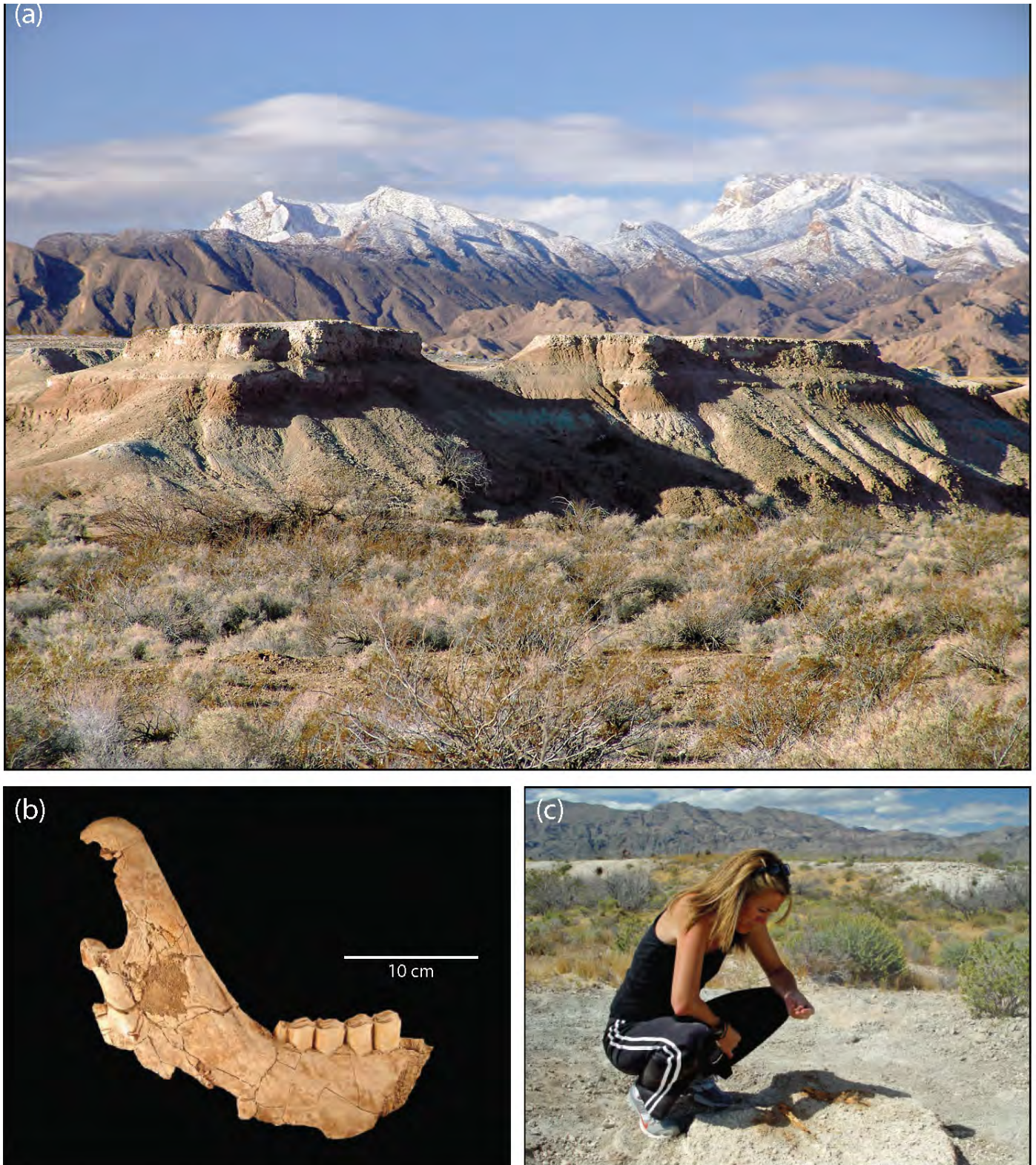


Figure 14. (a) Dramatic outcrop of Member D capping older deposits in TUSK. Member D represents pervasive spring discharge the accompanied the highest water table levels during the full glacial period, and the resultant GWD deposits are topographically high with prominent carbonate caps and benches; (b) *Camelops hesternus*, dentary with tooth, SBCM L3160-479; (c) geologist Kathleen Springer inspecting a juvenile mandible with teeth discovered in Bed D₂.

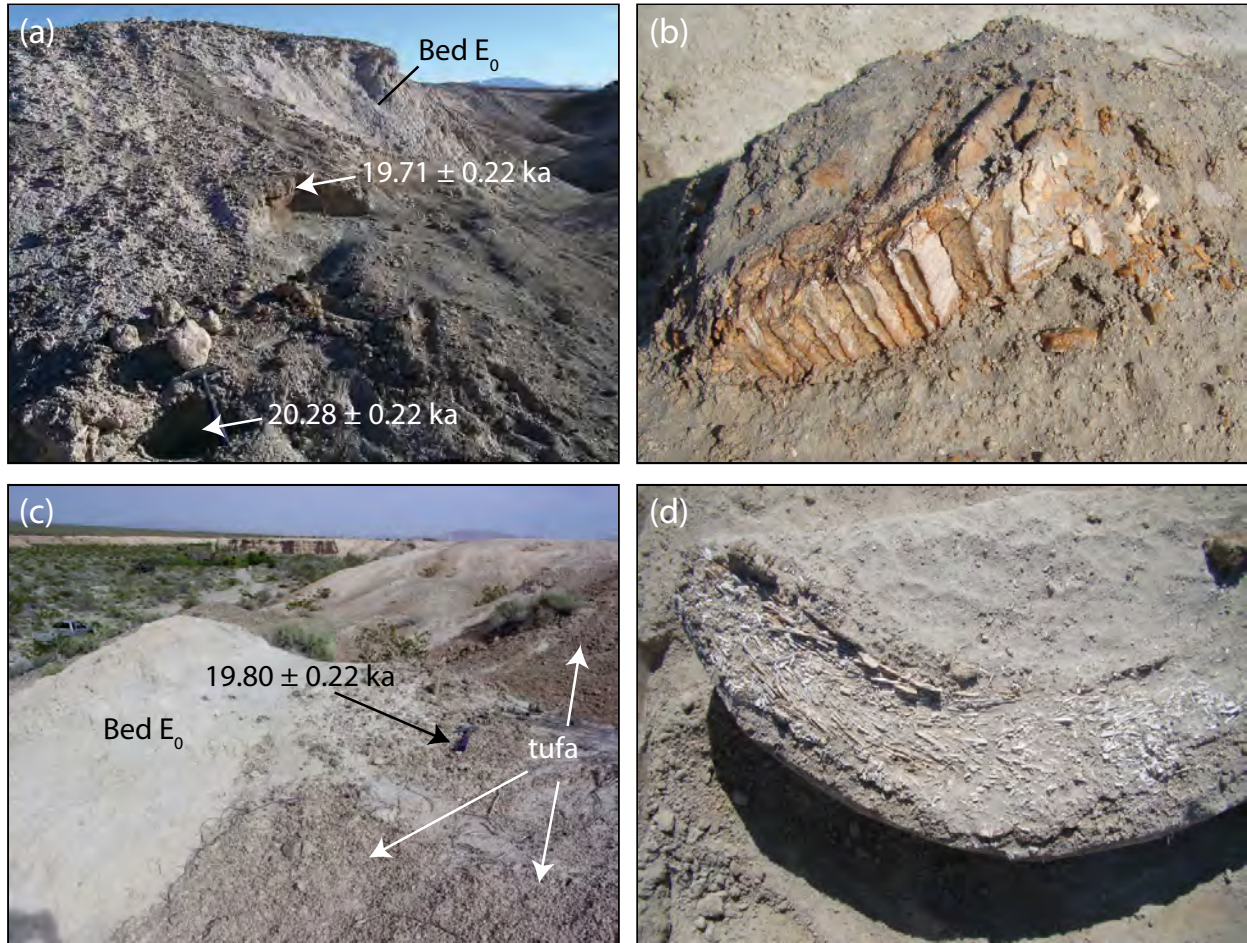


Figure 15. Bed E_0 at localities in the upper Las Vegas Wash. (a) Site 7: 36.30945° N, 115.15371° W. (b) within the E_0 beds that yielded the radiocarbon dates, an adjacent locality produced a tusk and tooth of *Mammuthus columbi*. Figured tooth is SBCM L3160-758; (c) Site 8: 36.30916° N, 115.15371° W. (d) this locality produced multiple bones, including this heavily weathered and shattered tusk of *Mammuthus* sp. (SBCM L3160-722) encrusted in tufa as well as abundant charcoal and mollusks. This newly recognized unit ranges in age from 23.04 to 18.16 ka and represents the first major episode of rheocene discharge (spring-fed streams) in the upper Las Vegas Wash. It also contains the first record of microbially mediated, ambient temperature tufa in the valley.

~23 ka, allowing a more precise chronologic constraint on the discharge hiatus following the collapse of the full-glacial marshes (based on our chronology, the hiatus is ~1.4 ka in duration). In opposition to the extensive full-glacial marshes and wet meadows of Member D, Bed E_0 represents point source rheocene discharge and outflow streams, marking a dramatic change in the type of discharge that continued throughout the late glacial period. At this outcrop, Bed E_0 exhibits an angled contact with the underlying deposits of Bed D_2 as it is inset into D_2 and represents the thalweg of a channel. It also

includes stromatolitic tufa on the opposite side of the drainage at this site, as well as remnant walls of an excavation that uncovered a large mammoth tusk and tooth (figure 15b). Note that the radiocarbon dates shown in figure 15a were obtained from charcoal in organic-rich black mats intercalated with detrital tufa fragments.

Sidebar — In the general area around sites 6, 7, and 8, it is useful to walk the surface of the GWD deposits to gain familiarity with the characteristics of, and the contact between, the D_2 surface and the inset E_0 spring channels. Carbonate is a constant in this system due to

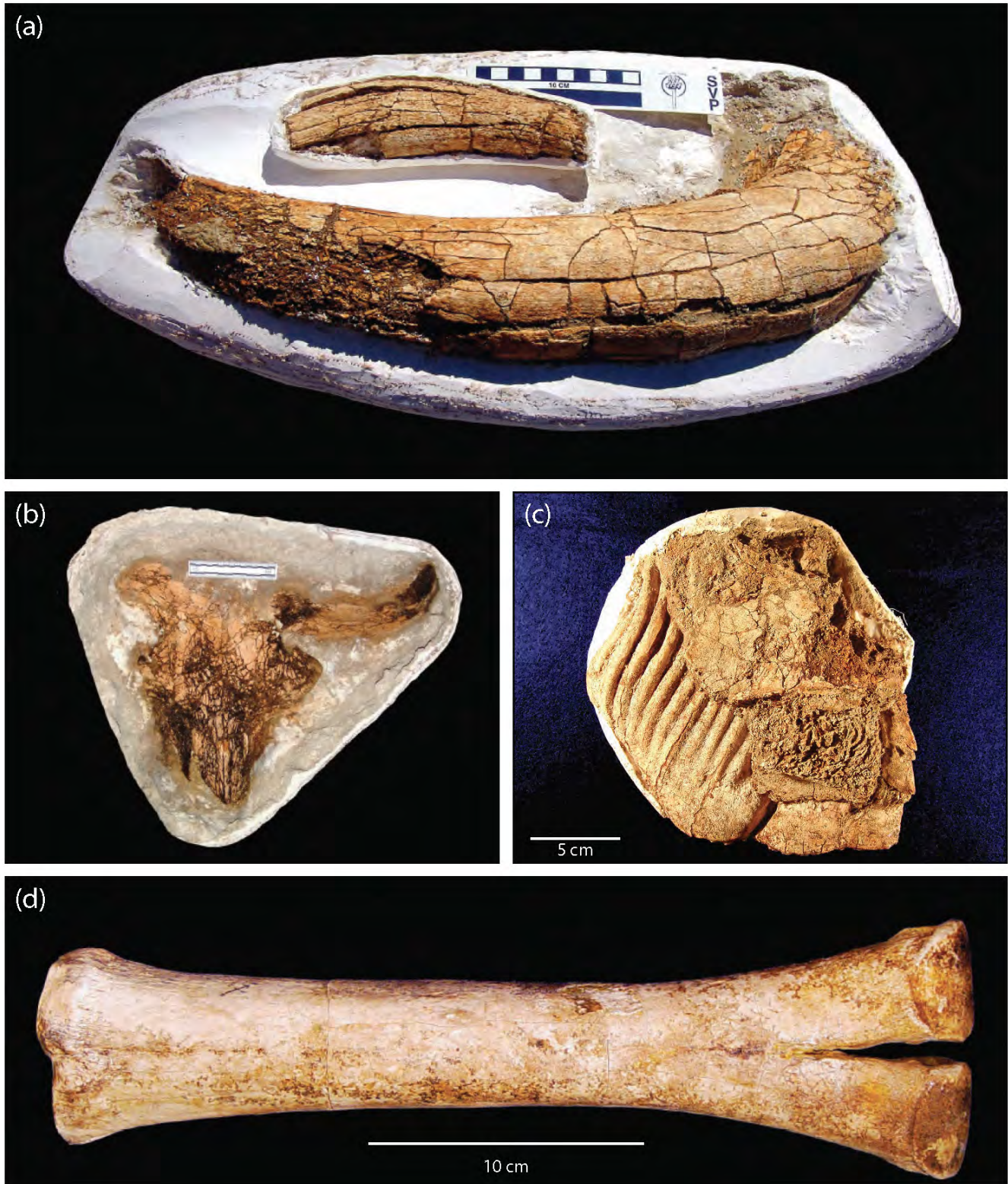


Figure 16. Vertebrate fossils from Bed E₀. (a) tusk of *Mammuthus* sp., SBCM 3160-586E; (b) partial skull and teeth of *Bison* sp., SBCM L3088-390; (c) maxilla with tooth of *Mammuthus* sp., SBCM L3160-586A; (d) SBCM L3160-460, metacarpal of *Camelops hesternus*.

recharge from the surrounding mountain ranges that are mostly composed of Proterozoic/Paleozoic limestone and dolomite. In vertical section, Bed D₂ forms prominent carbonate caps or benches, but when walking across an eroded surface, discerning the difference between it and other the units can be challenging. For example, Bed E₀ is capped by platy and/or rubbly carbonate that can be mistaken for the D₂ cap. In this area, the contact between the two carbonate units is subtle, and is best seen by color and textural changes between the white carbonate rubble of Bed D₂ and the darker, tan colored platy and/or rubbly carbonate of Bed E₀.

Site 8: 36.30916° N, 115.15371° W
(Figures 15c, d, and 16)

This site is noteworthy with respect to assessing the types of organic material used to date most of the GWD deposits in TUSK. Charcoal (charred vascular plants) is spilling out of Bed E₀ sediments at this locality (figure 15c). Here and throughout the upper Las Vegas Wash, charcoal is readily available in the deposits and was used to establish much of the chronologic framework of the Las Vegas Formation in TUSK. Small terrestrial gastropods are also present and contributed to a lesser extent to that effort.

Tufa is also prolific in the outflow stream here; note the morphology of encrusting tufa on former plant remains (phytoclast tufa). Tufa also precipitated on the vertebrate fossil material that was excavated at this locality, resulting in a tufa-encrusted mammoth tusk (figure 15d). This Bed E₀ outflow stream is very near the point source of the discharge and the date here (19.80 ± 0.22 ka) is similar to those obtained at site 7 (19.71 ± 0.22 ka and 20.28 ± 0.22 ka). It is likely that multiple point sources were discharging in this area during E₀ time.

Site 9: 36.33307° N, 115.22535° W
(Figure 17a)

There are at least 16 distinct and mappable discharge intervals identified within the Las Vegas Formation in TUSK that collectively span approximately 300 ka and reflect varied spring ecosystems. Due to multiple

phases of erosion and deflation of the GWD sediments, the spatial relationships of these deposits are complex and include multiple permutations of inset and buttressed geometries of spring discharge through time. At this site, the sedimentary sequence includes Member B sediments (Beds B₁ and B₂) that are overlain by Member D. An axial facies remnant of the Bed D₃ marsh deposits is attached to the sequence as a buttressed unconformity—this sliver of an outcrop contained mammoth fossils and yielded critical radiometric dates that allowed the full temporal breath of Member D to be determined. An outflow stream of Bed E₀ is also buttressed on Members B and D as well as occurring as a capping layer on top of the entire sequence as floodplain deposits. This capping E₀ bed proved to be a critical locality for a new record in the TSLF - *Lynx rufus* (bobcat). This locality is a reminder that the geologic context of fossil localities in the upper Las Vegas Wash must be examined in detail so that the fossils can be placed in time accurately.

Site 10: 36.33305° N, 115.22484° W
(Figure 17b)

This is another example of the myriad of inset relationships that occur in the GWD deposits in TUSK. Here, Bed E₀ is present as an outflow stream channel, inset and draped onto older Member B deposits, and consists of green silt that grades upward to tan silt. The geometry of the channel-fill deposits is characteristic of the late Quaternary rheocene spring discharge within the upper Las Vegas Wash in that the outflow streams preserved in the geologic record are roughly parallel to the flow direction of the active wash. This locality yielded an age of 22.05 ± 0.23 ka obtained from shells of terrestrial gastropods (Succineidae), and also contains shells from a variety of other terrestrial and aquatic gastropods.

Site 11: 36.34938° N, 115.28642° W
(Figure 18a)

In the upper Las Vegas Wash, Bed D₂ grades from gray silts of the axial wet meadow facies into tan silts and sands of the drier phreatophyte flat facies as one moves away from the valley axis. Bed D₃ is best exposed on the Spring

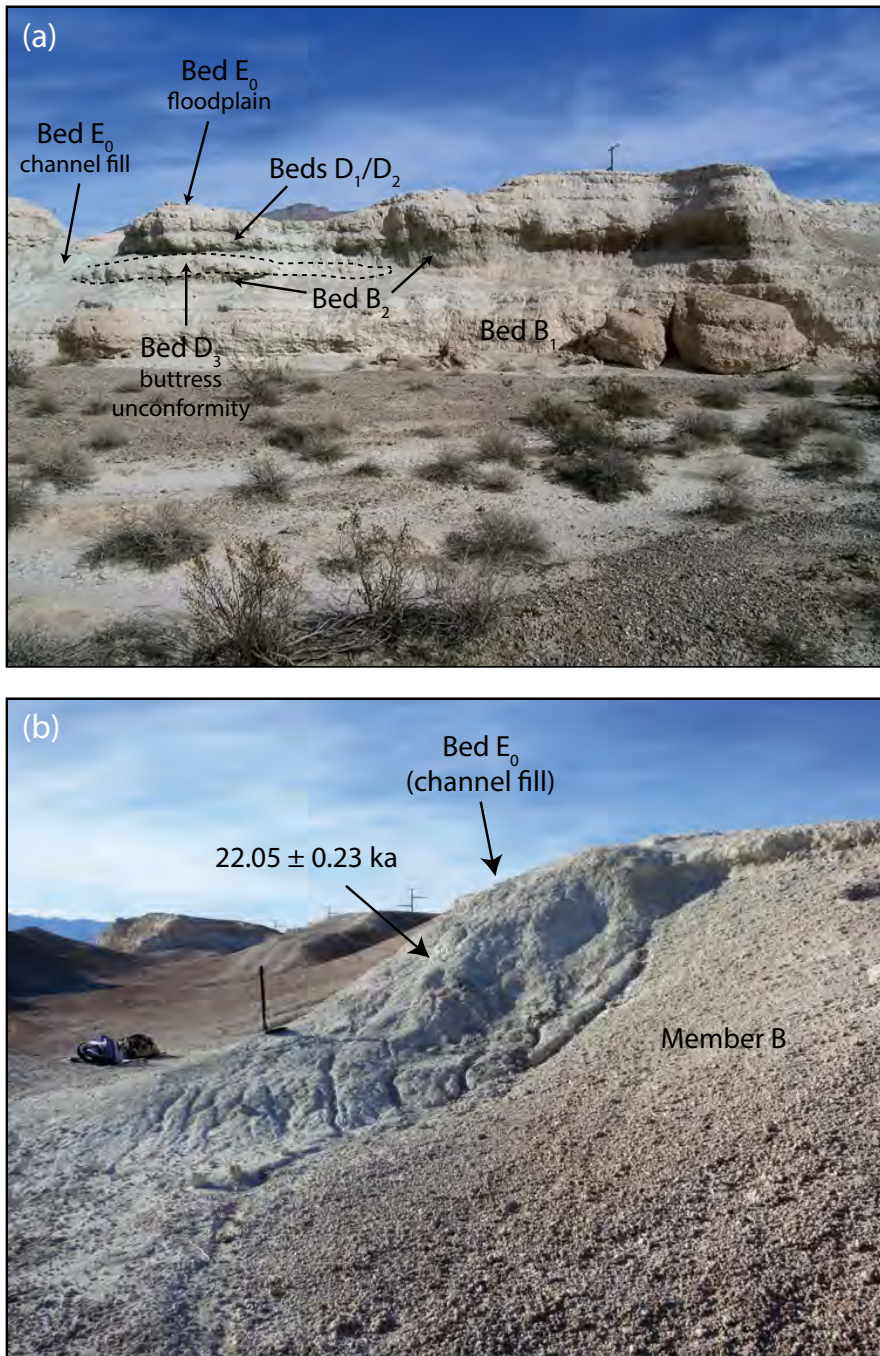


Figure 17. Photographs illustrating the multifaceted stratigraphic sequences in the upper Las Vegas Wash. (a) Site 9: 36.33307° N, 115.22535° W. Complex section showing Beds D₃ and E₀ buttressed against Beds B₁ and B₂, Member D, and Bed E₀. (b) Site 10: 36.33305° N, 115.22484° W. A channel of Bed E₀ inset into Member B sediments.

Mountains side of the upper Las Vegas Wash drainage where the marginal facies of Bed D₂ is topped by D₃ sediments and the prominent D₃ carbonate cap. At this site, marginal wetland deposits of Beds D₂ and D₃ illustrate the lateral expansion and contraction of the wetlands in response to climate fluctuation. Evidence of a brief discharge event in Bed D₂ dating to 27.58 ± 0.23 ka is positioned between two prominent soils (Aridisols). These Aridisols

represent dry conditions that correlate in time to D-O 4 and 3, respectively, and equate to the widespread and prominent Bed D₂ carbonate cap discussed at site 6. Discharge resumed here with the deposition of Bed D₃, which was followed by formation of the carbonate cap. The D₃ cap correlates temporally with D-O 2 and represents a pervasive desiccation event that ultimately led to the collapse of the vast full-glacial wetland system in the Las Vegas Valley.

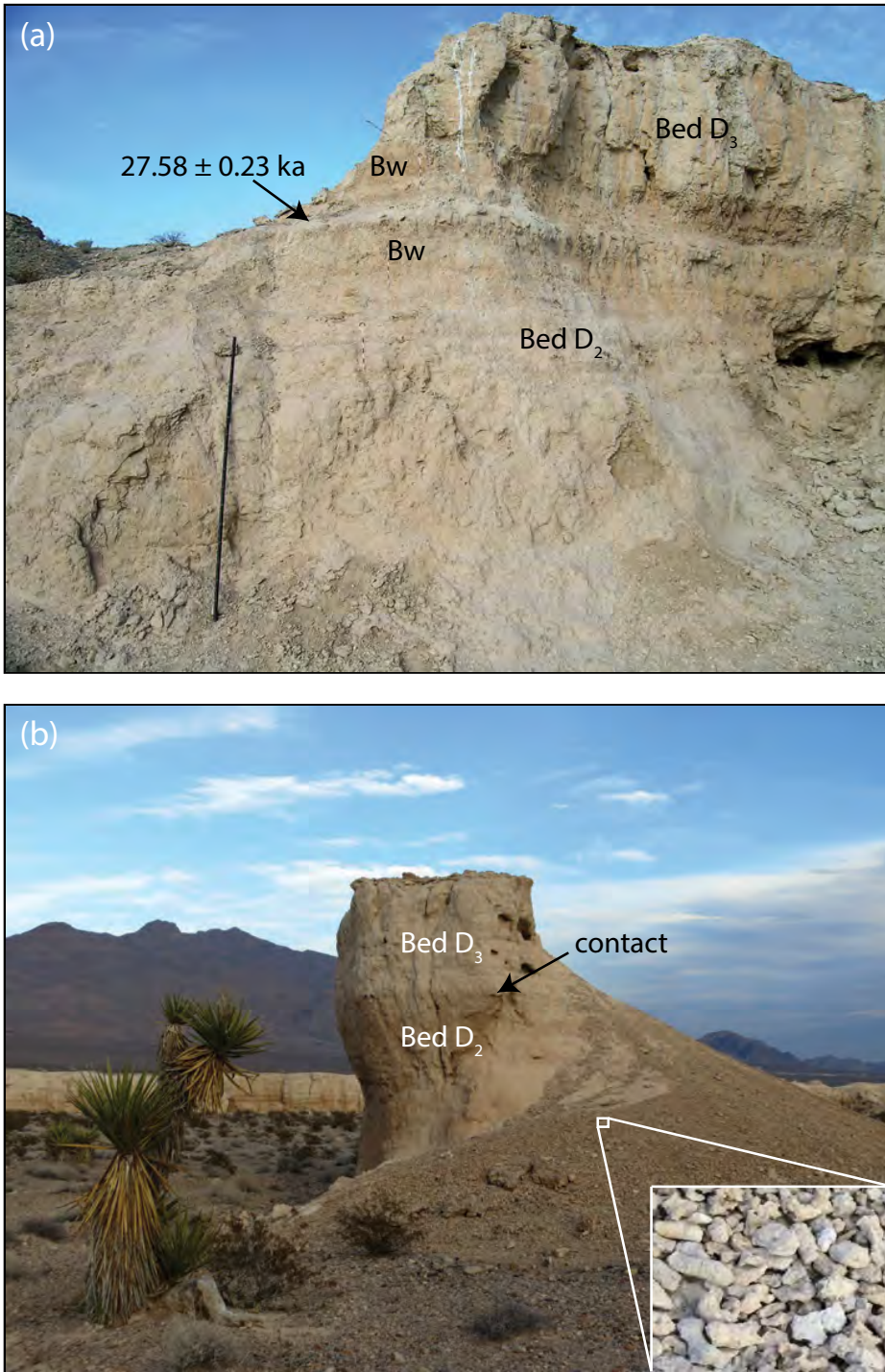


Figure 18. (a) Site 11: 36.34938° N, 115.28642° W. Marginal facies of Beds D₂ and D₃ with a thin discharge horizon dating to 27.58 ± 0.23 ka that is positioned between Aridisols (Bw); (b) Site 12: 36.34869° N, 115.28997° W. Contact between the marginal facies of Beds D₂ and D₃. Casts of possible cicada burrows are common along this contact (inset), indicating a period of surface stability prevailed at the end of D₂ time.

**Site 12: 36.34869° N, 115.28997° W
(Figure 18b)**

This site offers another excellent opportunity to examine the marginal facies of the wetland system during Member D time. Here, the D₂-D₃ contact and conspicu-

ous soils seen at site 11 (representing D-O 4-3) are very clear. The stable surface following D₂ time was populated by literally thousands of burrows (possibly from cicada nymphs), the casts of which are weathering out of this contact, a phenomena that can be seen throughout the northern area of TUSK (Quade, 1986).

**Site 13: 36.35620° N, 115.28994° W
(Figure 19)**

Following wetland development represented in the record by Bed E₀, there was a hiatus in discharge and significant erosion during the time period between 18.16 and 16.10 ka, which includes the “Big Dry” of Broecker and others (2009) (figure 8). Discharge resumed at 16.10 ka, represented by Bed E₁, and was dominated by point-source discharge resulting in emanating flowing streams (rheocene discharge) with localized tufa formation. Subunits within E₁ represent distinct discharge intervals and exhibit inset relationships into the dissected topography of Bed D₂, as well as with each other. Bed E_{1a} typically consists of rhythmically bedded, buff-colored silt and sand containing abundant tufa, and is capped by carbonate rubble. It is mappable over a large area of the northern reaches of TUSK and has yielded dates ranging from 16.10 to 14.96 ka (figure 19a). Bed E_{1a} represents a major discharge period that corresponds temporally to the “Big Wet” (Broecker and others, 2009), a widespread, high-precipitation event that also corresponds temporally to the Oldest Dryas. Bed E_{1a} discharge ended abruptly at 14.96 ka, as evidenced by intense erosion of the deposits in response to the Bølling warm period (D-O 1). The first and only confirmed specimen of *Smilodon fatalis* from the TSLF and southern Nevada was found at a locality near here in Bed E_{1a} deposits dating to 15.46 ± 0.25 ka (Scott and Springer, 2017) (figures 19d to 19g). Other vertebrate fossils in Bed E_{1a} include the camel metacarpal shown in figures 19b and 19c.

**Site 14: 36.34691° N, 115.27749° W
(Figure 20)**

Following intense erosion associated with the abrupt warming of D-O 1, rheocene discharge resumed between 14.59 and 14.27 ka as recorded by Bed E_{1b}. The basal channelized portion of Bed E_{1b} grades upward to distinctive whitish silts and sands that contain numerous black mats. Bed E_{1b} is often mantled in limestone gravels and cobbles, contributing to its distinct appearance. This site is the location of the “Super Quarry” where the SBCM extracted 500+ vertebrate fossils, including

a mammoth skull and jaw, numerous mammoth tusks, bison, horse, and other large vertebrates (figures 20a to 20d). A date of 14.59 ± 0.50 ka was obtained from charcoal within the channel deposits, establishing the site firmly within E_{1b} time. Throughout TUSK, Bed E_{1b} contains an unusual number of vertebrate fossils, including the first definitive record of *Canis dirus* from the TSLF and the state of Nevada (Scott and Springer, 2016) (figure 20e).

In addition to the spectacular paleontology, this site demonstrates once again the complexity of the GWD sedimentary sequences. Nearby exposures show Beds E_{1a} and E_{1b} commingling as they drape and fill the older dissected topography of Bed D₂, whereas at the Super Quarry, the base of the E_{1b} channel sits directly on top of Member A.

**Site 15: 36.36917° N, 115.31560° W
(Figure 21)**

Bed E_{1c} consists of yellowish to light gray silt and sand, and when not mantled in its characteristic limestone gravel clasts, is difficult to distinguish from Bed E_{1a}. However, stratigraphic and chronologic control has established that they are, in fact, separate and mappable stratigraphic units. Charcoal in black mats within Bed E_{1c} has yielded dates ranging from 14.12 to 13.95 ka. Bed E_{1c} typically overlies and is inset unconformably within the earlier discharge intervals of Beds E_{1a} and E_{1b}. The sharp lithologic transition from the conspicuously white deposits of Bed E_{1b} to the tan sediments of Bed E_{1c} marks the onset of Older Dryas cooling, yet another example of how wetland ecosystems in the Las Vegas Valley responded dynamically to abrupt climate change in the recent geologic past. This site yielded multiple elements of mammoth from Beds E_{1b} and sparse bone fragments from Bed E_{1c}. Bed E_{1c} is newly recognized and vertebrate fossils are, so far, rare in this bed.

**Site 16: 36.37807° N, 115.32807° W
(Figure 22)**

Exposures of Bed E_{1d} are not very common in the upper Las Vegas Wash, but where present, represent a discrete discharge interval that includes rheocene dis-

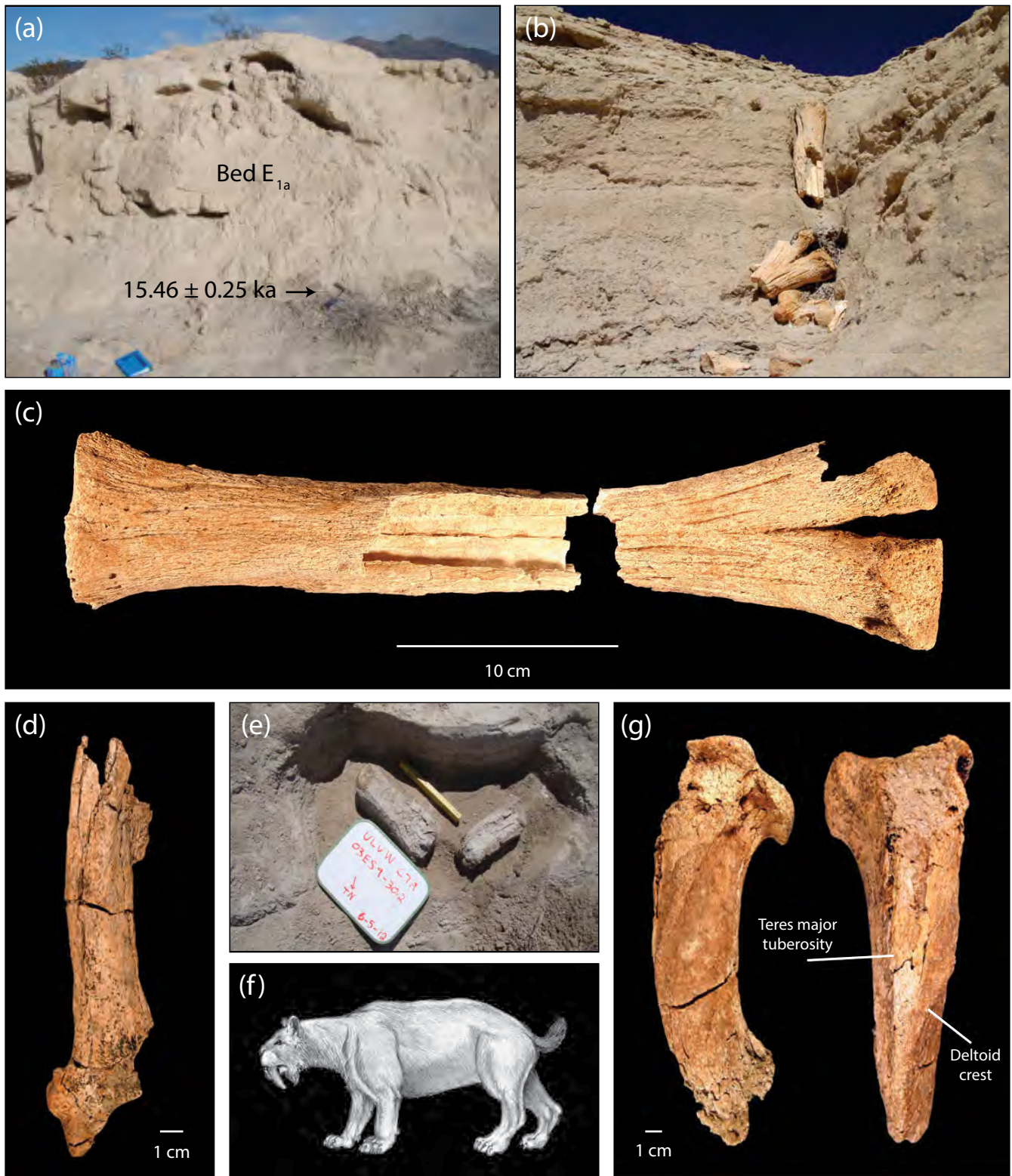


Figure 19. (a) Bed E_{1a} at site 13: 36.35620° N, 115.28994° W; a date of 15.46 ± 0.25 ka was obtained from charcoal at this locality; (b) metacarpal of *Camelops hesternus* eroding out of the deposits, and (c) same specimen, prepared. SBCM L3160-645.1; (d) SBCM L3160-1019, distal left radius of *Smilodon fatalis*, dorsal view; (e) in situ radius and humerus of *Smilodon fatalis*; (f) *Smilodon fatalis*; art by Adrienne Picchi; (g) SBCM L3160-1018, proximal left humerus of *Smilodon fatalis*, lateral (left) and anterior (right) views. Photographs shown in panels d and g are after Scott and Springer (2016).



Figure 20. (a-d) Bed E_{1b} at site 14: 36.34691° N, 115.27749° W, referred to as the “Super Quarry;” (a, b) the excavation of the quarry took nearly a year to complete; seen at various stages; (c) one of five *Mammuthus* sp. tusks recovered; (d) partial skull and teeth of *Mammuthus* sp.; (e) SBCM L3160-1257, right patella of *Canis dirus*, dorsal view.

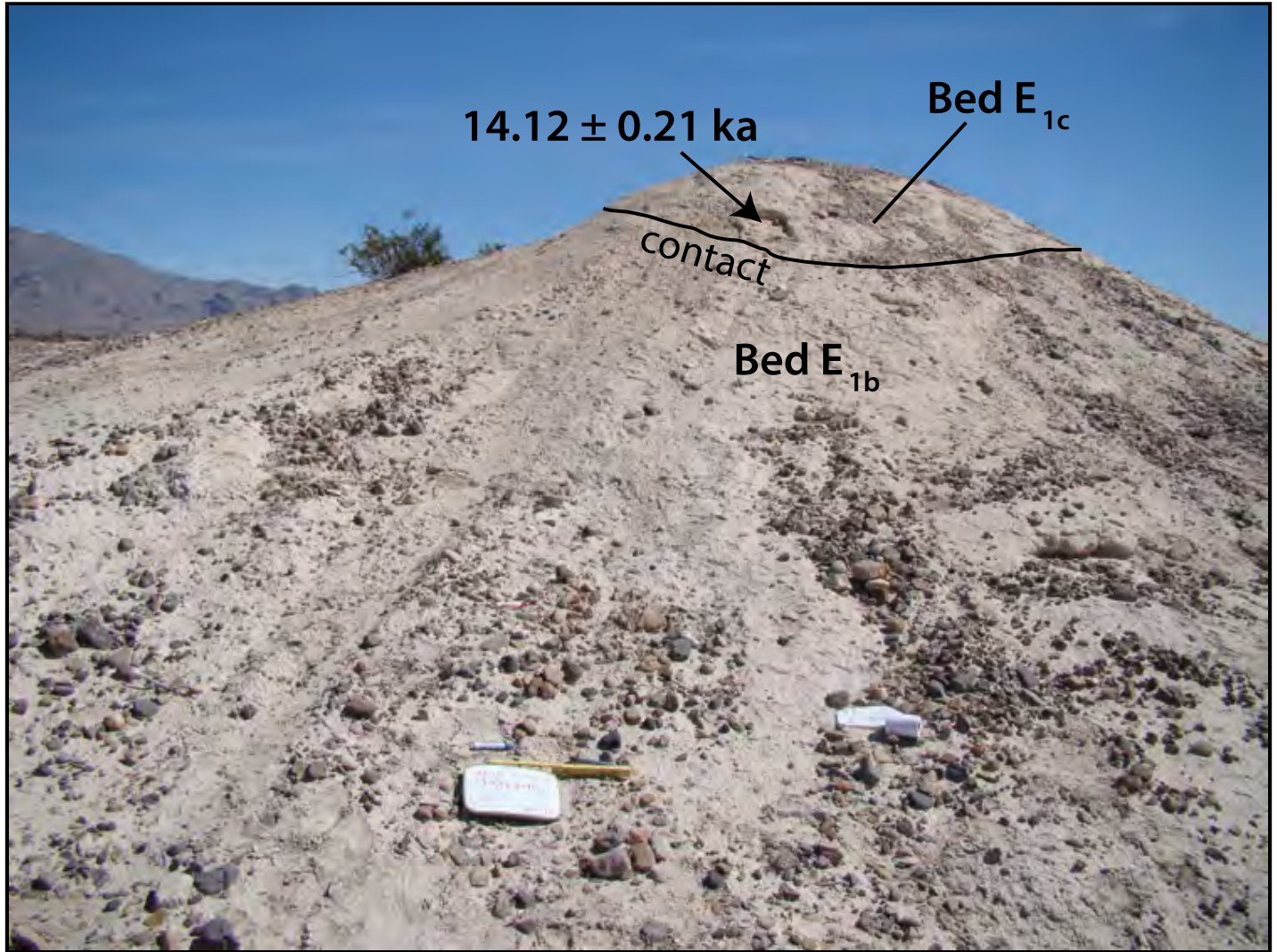


Figure 21. (a) Bed E_{1c} at site 15: 36.36917° N, 115.31560° W. The discharge interval represented by Bed E_{1c} is spatially restricted within TUSK and, so far, is rarely fossiliferous.

charge and minor ponding. The deposits of Bed E_{1d} date to between 13.69 and 13.37 ka, and consist of medium gray silt and cross-bedded sand with reworked carbonate, abundant mollusks, and interbedded black mats that are typically exposed in low relief along ‘the narrows’ (figures 1c and 22a). Bedding planes within Bed E_{1d} tend to be inclined near spring orifices. Vertebrate fossils are rare (figure 22b), but significant—of the three potential horses from TUSK, the only one distinguishable to species (*Equus scotti*) was discovered in Bed E_{1d} (Scott and Springer, 2017) (figures 22c and 22d).

Site 17: 36.34842° N, 115.28834° W (Figure 23)

The final phase of wetland development in the Las Vegas Valley occurred during the latest Pleistocene and early Holocene and is represented by Beds E_{2a-c} (collectively 12.90 to 8.53 ka). At this site, called “the islands,” we observe one of the few places in TUSK that exhibits a complete sedimentary sequence depicting the dramatic lithologic differentiation that occurred at this time as a result of climatic fluctuations. The base of the section consists of silts and sands of Beds E_{1b} and E_{1d}, which

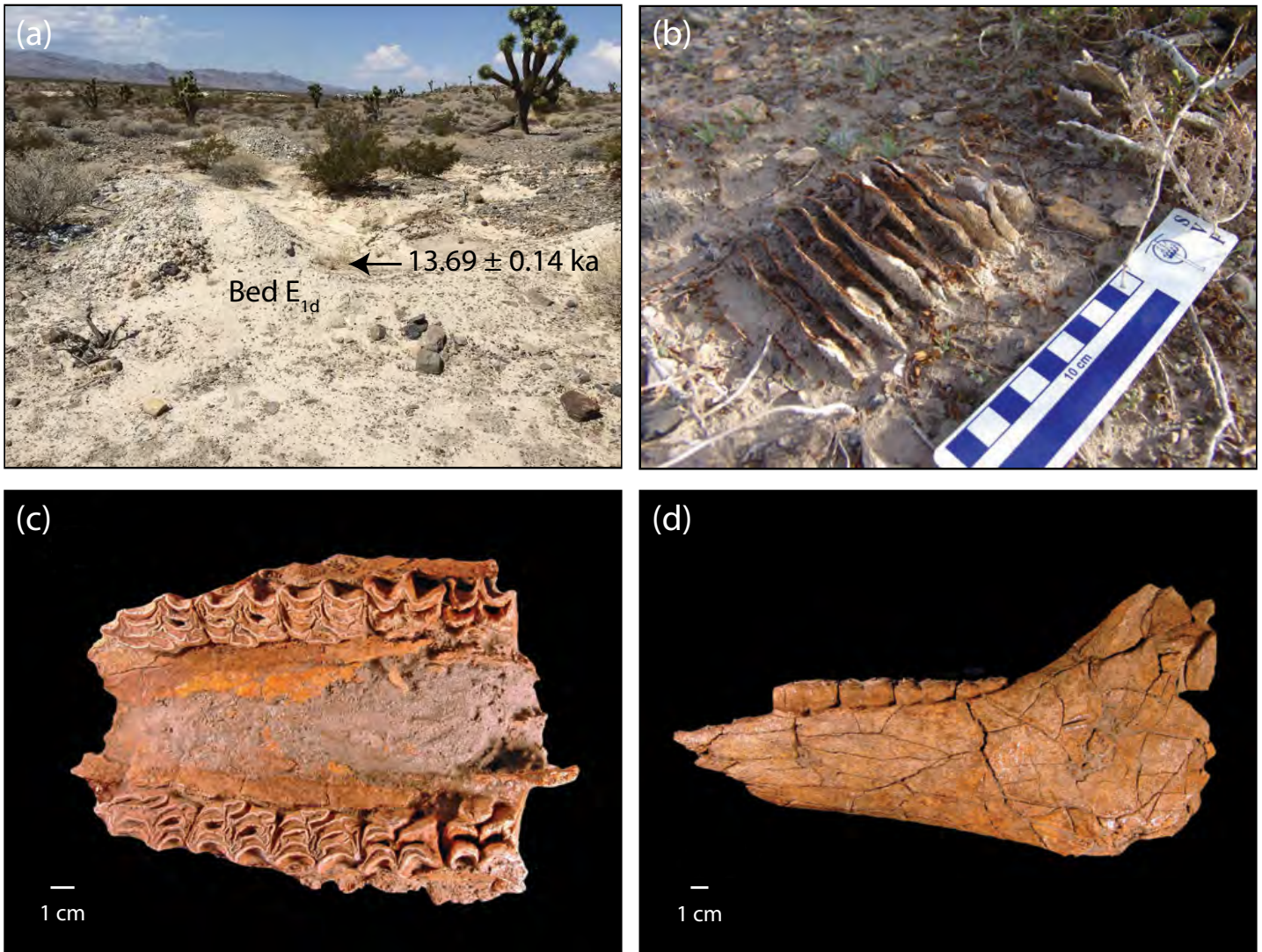


Figure 22. (a) Bed E_{1d} at site 16: 36.37807° N, 115.32807° W showing the limited relief typical of Bed E_{1d}; (b) in situ *Mammuthus* sp. tooth; (c) *Equus scotti*, occlusal view, SBCM L3160-1015; (d) *Equus scotti*, left dentary, lateral view, SBCM L3160-1016A.

represent rheocene discharge that occurred during and after the Bølling-Allerød warm period. These beds transition abruptly to olive-green silts and clays in cauldron-like bedforms, representing limnocene ponding of Bed E_{2a} during the Younger Dryas cold event. In turn, these sediments are overlain by the oxidized tan to brown silts of Bed E_{2b} that represent drier conditions and intermittent rheocene discharge that occurred during the pre-Boreal climate oscillations (figure 8). Vertebrate fossils are known from this area and likely represent the last gasp of the Pleistocene fauna in TUSK before the terminal Pleistocene extinction (~13 ka).

Site 18: 36.30489° N, 115.15128° W (Figure 24a)

This “carbonate river frozen in time” represents E₂ rheocene discharge that dominated the Las Vegas Valley during the late glacial period. This extensive groundwater-fed, braided fluvial tufa system consists of microbially mediated, ambient temperature tufas that exhibit a distinctive morphology resembling an anastomosing fluvial network dating to Bed E_{2b} time (11.22–10.63 ka) (figure 25). To our knowledge, this braided fluvial tufa system is unique in North America, and is characterized by flowing streams emanating from numerous

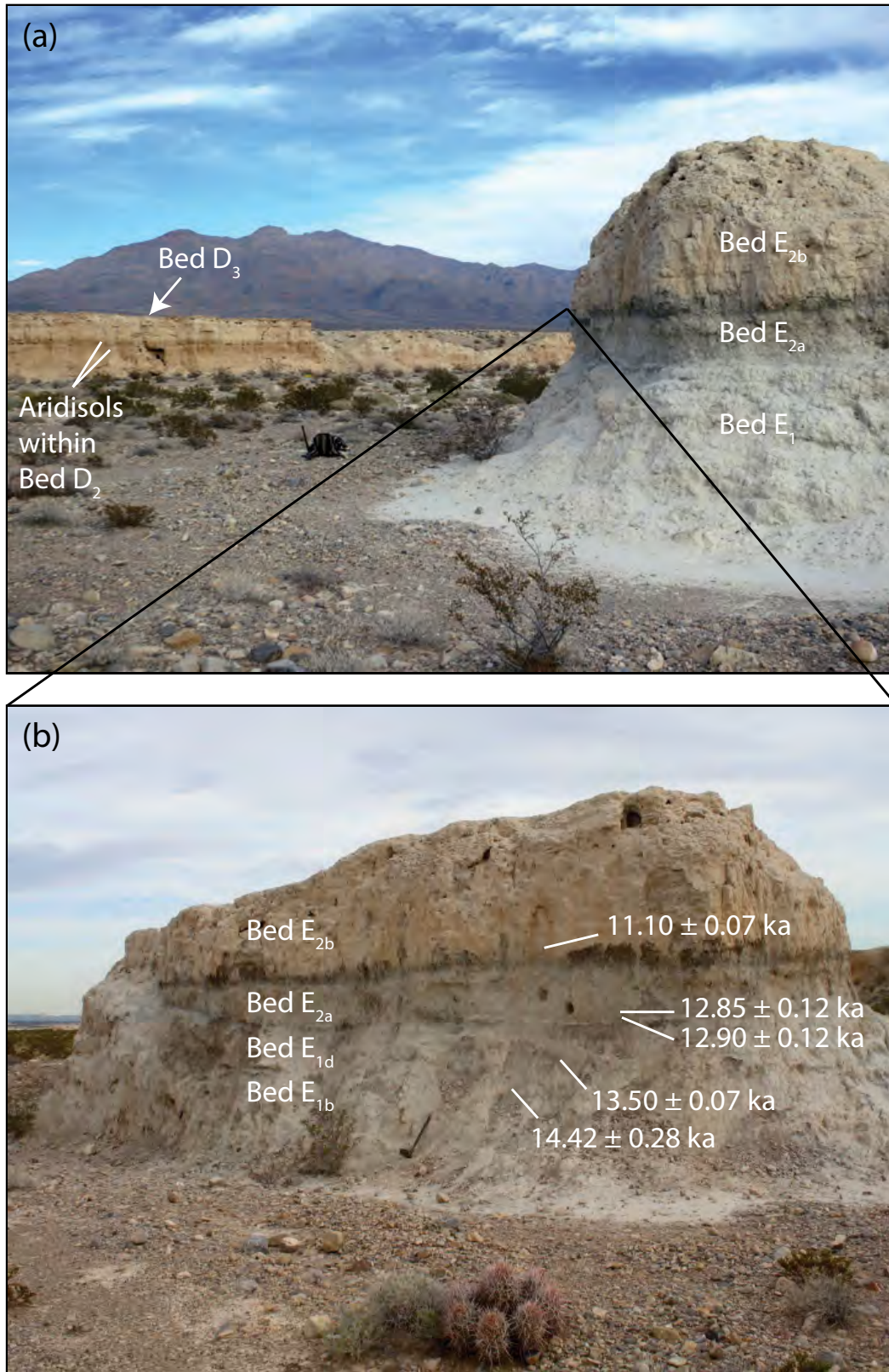


Figure 23. (a, b) Bed E_2 in the upper Las Vegas Wash at site 17: 36.34842° N, 115.28834° W. Overall, this bed ranges in age from 12.90 to 8.53 ka and consists of three distinct subunits, Beds E_{2a} , E_{2b} , and E_{2c} .

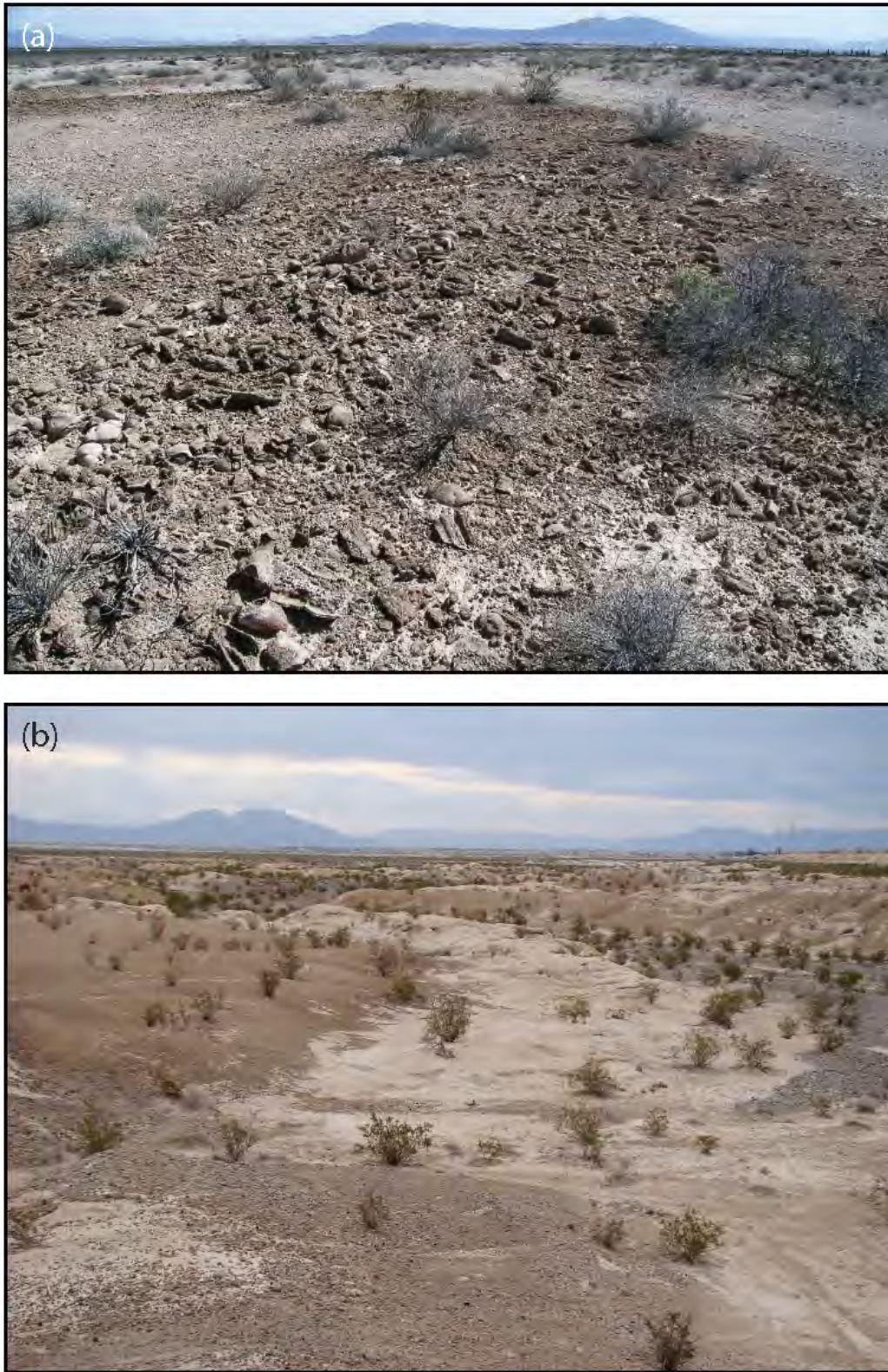


Figure 24. Examples of inset relationships in the Las Vegas Formation. (a) site 18: 36.30489° N, 115.15128° W. Bed E_{2b} with carbonate tufa channel lag mantling the highly dissected Bed D₂ topography. (b) site 19: 36.30491° N, 115.15159° W. Stream channel of Bed E_{1a} inset into the eroded topography of Bed D₂.

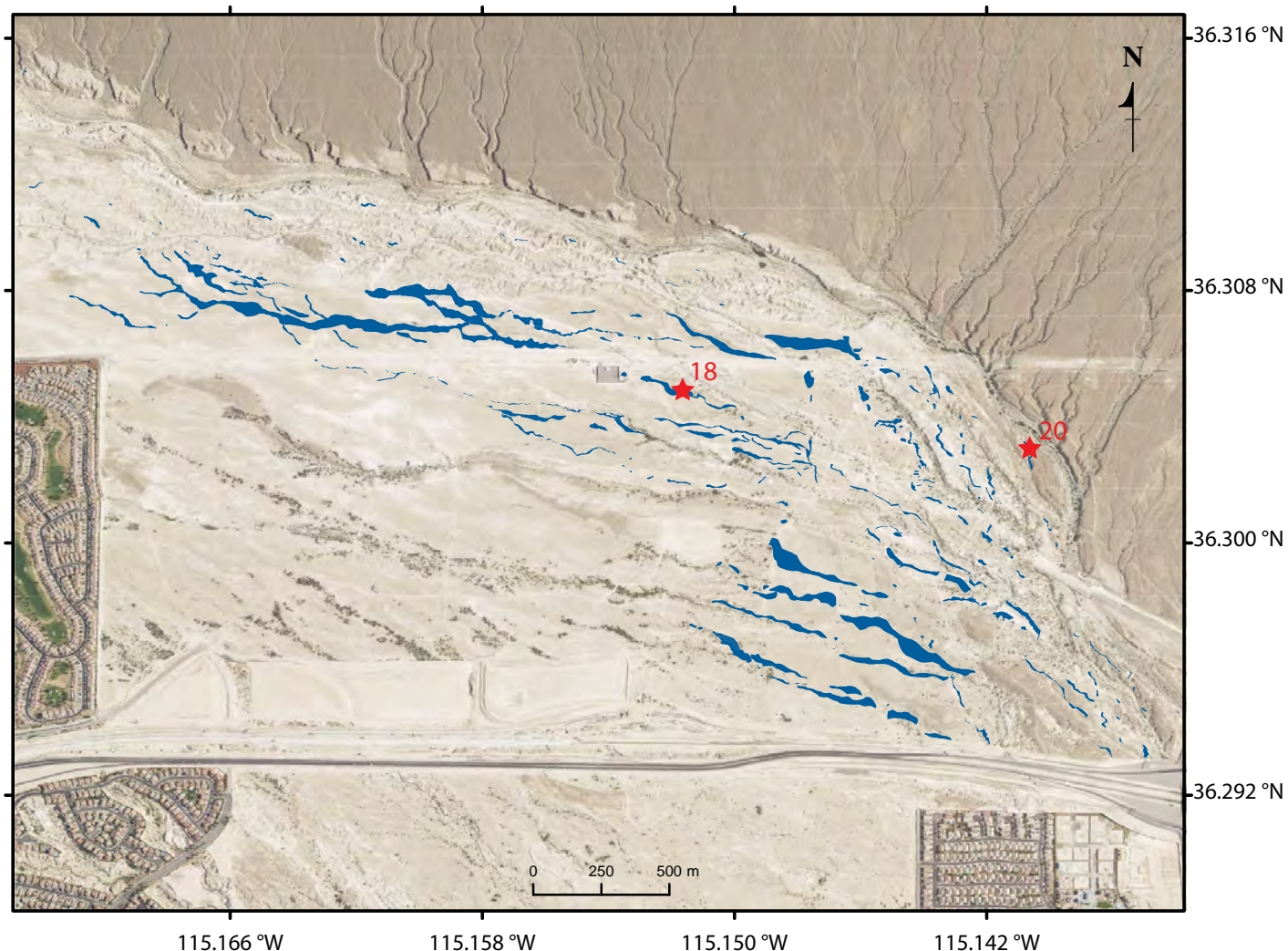


Figure 25. Aerial photograph of the mapped extent of the braided fluvial tufa system (in blue) in the upper Las Vegas Wash. To our knowledge, this is the only occurrence of this type of system in North America. Locations of tufa at sites 18 and 20 are shown in red.

point sources. Tufa associated with Bed E_{2b} is preserved at this site as surficial lag deposits that mantle the resistant carbonate topography of Bed D₂ (figure 24a). The stromatolitic tufa exposed at the surface here also occurs in situ within the host fluvial channel sediments of Bed E_{2b} and is intercalated with black mats.

**Site 19: 36.30491° N, 115.15159° W
(Figure 24b)**

This site provides another example of a river frozen in time. This stream channel of Bed E_{1a} is clearly inset into the eroded topography of Bed D₂. Here and at

many other locations in the northern portion of TUSK, the eroded surface of Bed D₂ is all that remains of extensive marsh deposits that once spanned most of the valley axis during full glacial times.

**Site 20: 36.30252° N, 115.14020° W
(Figure 26)**

Tufa that occurs in the context of the braided fluvial system exhibit many external morphologies, including phytoclasts, oncoids, cyanoliths, stromatolites, as well as resurgence features (also seen at site 18). Although braided fluvial tufas predominate, paludal and lacus-



Figure 26. Site 20: 36.30252° N, 115.14020° W. Photographs of (a) barrage tufa and (b) phytoclast tufa that formed in spring-fed channels.

trine tufas associated with pooling water behind tufa are also noted, as we observe at this site. This is a spectacular example of a barrage tufa (Springer and Stevens, 2008), with phytoclasts encasing branches, logs, and other stream-edge plants.

PARTING THOUGHTS

This field guide touches on some of the highlights of the vertebrate paleontology, stratigraphy, age control, and the response of desert wetland ecosystems to abrupt climate change that we have established for the Las Vegas Formation within Tule Springs Fossil Beds National Monument. The new monument is a treasure trove of geologic and paleontologic information and, with the aid of this interpretive guide, one can easily imagine a water-filled past, teeming with wildlife and flora on this valley floor. TUSK protects the ancient desert wetland deposits and their attendant flora and fauna for posterity. Future studies here will reveal much more about the ever-changing desert ecosystem and the animals that once called it home.

ACKNOWLEDGMENTS

We thank the Bureau of Land Management (BLM) and the National Park Service (NPS) for protecting these lands. We are especially grateful to Scott Foss and Gayle Marrs-Smith (BLM) for their long-term support of our studies and with funding through Federal Assistance Agreement L08AC13098 (to KBS). We also thank interim Superintendent of TUSK, Vincent Santucci (NPS), who got the ball rolling, as well as the first permanent Superintendent, Jon Burpee, as he moves TUSK from its infancy to fruition as a full-fledged National Park unit. Special thanks to both Vince and Jon for allowing our work to continue in TUSK with the first research permit issued (TUSK-2015-SCI-001)! We thank Gene Ellis, Harland Goldstein, Janet Slate, Greg McDonald, and Doug Sprinkel for constructive reviews of earlier versions of the field guide. We also thank Paco van Sistine and Jeremy Havens for assistance with some of the figures. This project was supported by the U.S. Geological Survey's Climate and Land Use Change Research and Development Program.

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