Title
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Flora and fauna of the Holocene Oil Canyon oil-sands from the poorly understood San Joaquin Desert Biozone

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Abstract—A thick partially-exposed outcropping of oil-sands is located in Oil Canyon ~12 km north of Coalinga, California on AERA Energy Corporation property. AERA geologists and personnel over the years have referred to the surface seep as part of the "Temblor Tar Cap." Here we report for the first time on the fossil vertebrates, insects, and plants discovered thus far at the Oil Canyon tar seep. Vertebrate remains include a partial skeleton of a relatively large bird with remnants of the wings, the articulated limb bones of a smaller bird, isolated feathers, partial skeletons of pocket mice, and a bobcat jaw. The insects include abundant carbonized three-dimensional and compressed remains of dragonflies, grasshoppers, beetles and lepidopterans (butterflies and or moths). To date, the only identifiable plant macrofossils are leaf impressions of Tucker's oak, *Quercus john-tuckeri*, leaf fragments of *Typha* (cattail), and combined carbonized compression - casts of the inflated inflorescence stems of buckwheat, possibly *Eriogonum nudum* var. *indictum*, which grows in the area today. The fossil data together with new radiocarbon age estimates and geologic context indicate the Holocene landscape and climate in the vicinity of the Oil Canyon seep at the western edge of the San Joaquin Valley between 11,320 (minimally) and 10,150 YBP was relatively wetter and cooler than today. Our preliminary findings suggest the presence of a small pond within a localized perennial wetland. Cattail grew at the margin but current evidence suggests it was not abundant. Herbaceous and shrubby groundcover would have included buckwheats growing on the surrounding slopes, with trees of *Q. john-tuckeri* growing at much lower elevation than today, closer to the depositional basin and in close proximity to the Oil Canyon drainage.

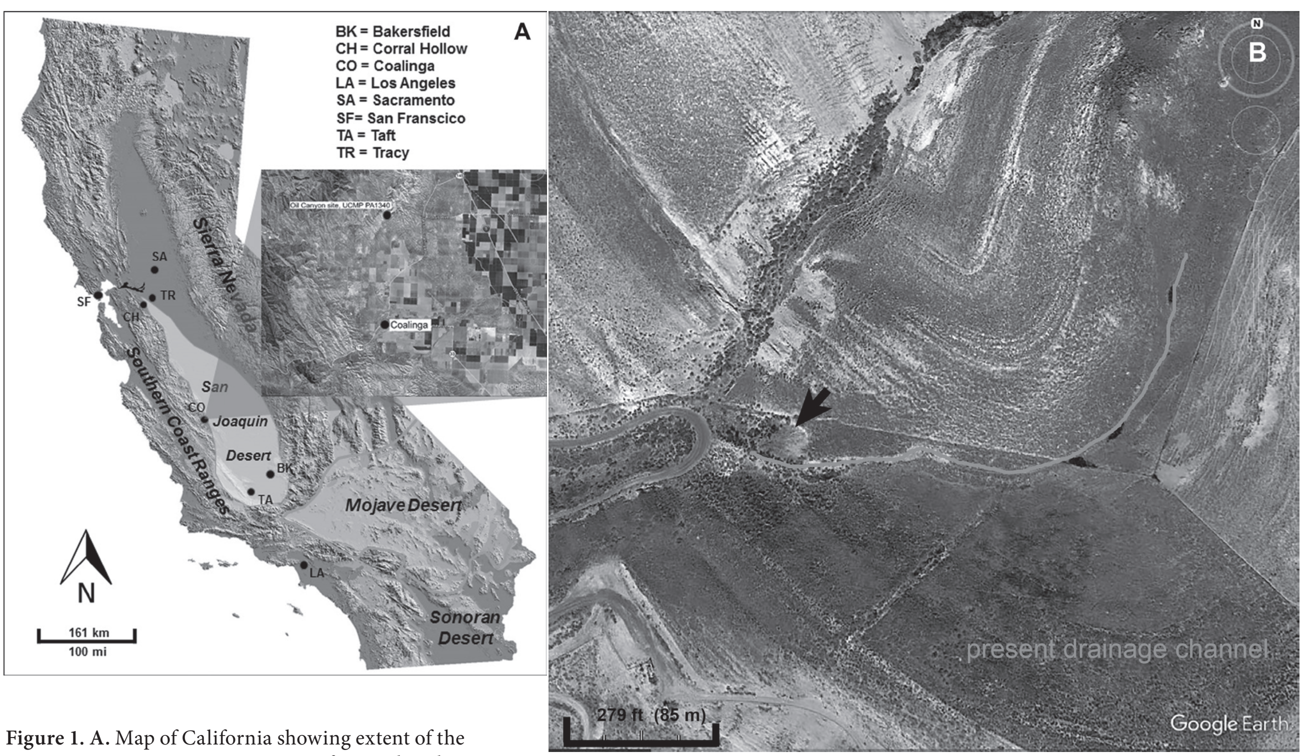

Figure 1. A. Map of California showing extent of the San Joaquin Desert Biozone, cities referenced in the text and location of the Oil Canyon site near Coalinga (outset). **B.** Google Earth satellite view of the Oil Canyon deposit (arrow) and course of the present-day drainage channel.

Introduction

The San Joaquin Desert occupying the San Joaquin Valley is the most imperiled and poorly recognized desert in California (Germano et al. 2011) (Fig. 1A). Average annual temperature from the northern limit of the desert at Corral Hollow near the city of Tracy to the southern limit between the cities of Taft and Bakersfield is 16.0°C (~61°F) to 18.5°C (~65°F) (O'Dell and Ryan, in prep). Average annual precipitation from the northern limit to the southern limit is 267 mm (~10.5 in.) to 137 mm (~5.5 in.). The most concise delineation of the San Joaquin Desert is a polygon encompassing areas of the San Joaquin Valley and South Coast Range with annual average precipitation ≤ 267 mm (O'Dell and Ryan, in prep). The San Joaquin Desert harbors a high diversity of endemic plant and animal species. Most of the land comprising the San Joaquin Desert has been converted to agriculture and much of the endemic flora and fauna is now rare and endangered (USFWS 1998; O'Dell and Ryan, in prep).

There is little fossil record, flora or fauna, of the Quaternary paleoclimate of the San Joaquin Desert. A fossil pollen study from Tulare Lake bed suggests the presence of Great Basin Desert-like flora in the San Joaquin Desert through the very late Pleistocene (Davis 1999). The McKittrick and Maricopa tar seeps provide information about the southernmost part of this area, with radiocarbon dates that range from approximately 15,000 to 5,000 years before present (YPB) depending on locality (Fox-Dobbs et al. 2014). Plant macrofossils of *Arctostaphylos glauca* (Ericaceae) and *Juniperus californica* (Cupressaceae) from one of the McKittrick asphalt seeps (Mason 1944) suggest the presence of cooler and wetter climate conditions in the San Joaquin Desert during the late Pleistocene, but floral data from these sites are limited. Discovery of the fossiliferous nature of the oil-sands deposit at Oil Canyon (OC) near Coalinga in the San Joaquin Valley is the northernmost locality yet found in the San Joaquin Desert and provides an important new source of data for understanding the paleoecosystems and paleoclimate of the San Joaquin Desert during an apparent period of rapid climate change during the early Holocene (Fig. 1A, B).

Figure 2. A. View of the stratified Oil Canyon deposit looking northeast, UCMP PA1340. **B.** Image of deposit showing the well-consolidated upper strata of the unit and the unconsolidated loose sand in the lower portion representing a decomposition sequence of the hydrocarbons from youngest at the top (10,150 YBP) to oldest at the bottom (>11,320 YBP). **C, D.** Closer views of the finely-stratified nature of the deposit. Note the fragments of white marine shale (Temblor) imbedded in the deposit (D).

Locality, age, and depositional setting

The fossiliferous nature of the OC site (UCMP PA1340) was discovered by the lead author (REO) in 2015 and brought to the attention of the co-authors. The site is located in a small, seasonal, tributary drainage to OC at an elevation of 396 m (1,299 ft.) and 12.4 km (7.7 mi.) north of the city of Coalinga (Fig. 1). It consists of an approximately 1.4 m thick and 465 m^2 exposed deposit of finely stratified sandy alluvium bound by oil and tar (bitumen matrix) (Fig. 2A–D). Excavations of approximately 10 m^3 of the matrix in 2015 yielded a diversity of plant, invertebrate, and vertebrate specimens (Figs. 3–5). The specimens consist of both three-dimensional and compressed carbonized plant and insect remains, while the vertebrate material includes partially articulated skeletons, isolated bones, and feathers. The age of the deposit has been radiocarbon dated from carbonized wood fragments to ≥11,320 YBP at the bottom of the unit and ~10,150 YBP at the top

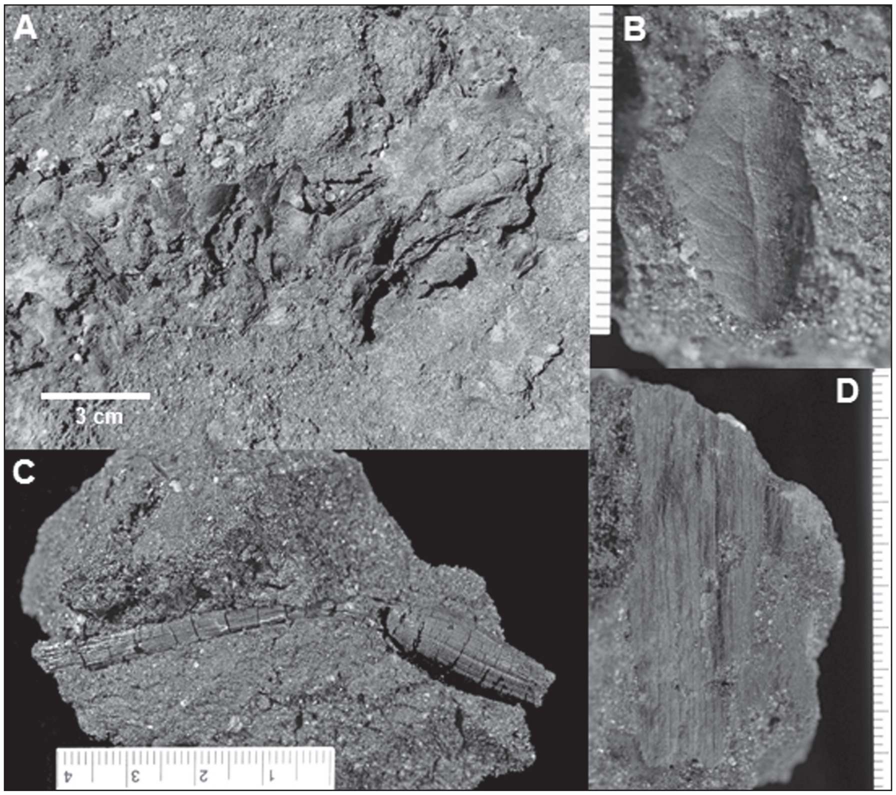

Figure 3. Oil Canyon plant megafossils. **A.** Rock surface with cluster of *Quercus john-tuckeri* leaves oriented at varying angles to the bedding plane indicative of transport prior to deposition, UCMP 401227. **B.** Detail of *Q. john-tuckeri* leaf showing venation and large tooth on upper left margin, UCMP 401210. **C.** Carbonized cast of an inflated inflorescence stem reminiscent of the buckwheat *Eriogonum nudum* var. *indictum*, UCMP 401232. **D.** Leaf fragment of *Typha* UCMP 401231. B–D: scale in mm.

(early Holocene; Beta Analytic, Miami, Florida, USA). The density and friability of the strata transitions from a hard asphalt pavement near the top (least breakdown of hydrocarbons) through moderately soft, friable oil-infused sandstone in the middle to very soft, verging on loose sand at the base due to nearly complete hydrocarbon decomposition (Fig. 2A–D). Much of the material fractures coarsely along bedding planes (Fig. 2C, D), but is fragile and highly susceptible to crumbling due to friability of the matrix. Butvar, a polyvinyl butyral resin dissolved in ethanol, was applied to most fossil specimens to stabilize them.

Oil Canyon flora and fauna

***Plants* –** Plant specimens include fragments of woody stems that are not readily identifiable to taxon, fine leaf impressions of *Quercus john-tuckeri* (Fig. 3A, B), inflated inflorescence internal stem casts of *Eriogonum nudum* var. *indictum* (Fig. 3C), and fine leaf impressions of *Typha* sp. (Fig. 3D). Leaf impressions of *Q. john-tuckeri* are very abundant throughout the strata (>10,500 YBP) except near the very top of the deposit (<10,500 YBP) where they abruptly disappear. As seen in Figure 3A, some horizons show concentrations of leaves oriented in various planes suggesting transport prior to deposition, e.g., those in Figure 3A are at relatively steep angles to the bedding plane. *Eriogonum nudum* var. *indictum* inflated inflorescence stem casts (Fig. 3C) and leaf impressions reminiscent of *Typha* (Fig. 3D) are distributed throughout the unit from the lowermost through the uppermost layers, but do not occur in large numbers. The fragmentary nature of these specimens also suggests water and wind transport prior to burial.

***Insects* –** Invertebrate specimens include a diversity of insects preserved as fine, detailed compressions-impressions, but preservation in some cases is a combination of compression and three-dimensional carbonized cast, e.g., the wings of the dragonfly specimen in Figure 4A are compressed, whereas the body is three-dimensionally preserved. The surfaces of many rock specimens show mass accumulations of grasshoppers (Orthoptera) (Fig. 4B) and dragonflies (Odonata). Other insect orders identified include Coleoptera (beetles) (Fig. 4C), Lepidoptera (butterflies and or moths) (Fig. 4D) and Hymenoptera (ants and bees). The large beetle (length >3.0 cm; >1.2 in.) in Figure 4C is most similar to the giant water scavenger beetles in the genus *Hydrophilus* (Hydrophilidae). They are typically found in shallow ponds with abundant vegetation, and in streams. The OC insects are distributed throughout the seep with the most finely preserved occurring near the top of the deposit, where the hydrocarbons are less decomposed. The OC seep is exceptional in California's oil-sands sites in the abundance, diversity, and fine-detailed preservation of the insects.

***Vertebrates* –** Twelve fossil vertebrate specimens representing a minimum of four taxa were found. All specimens are still largely embedded in sediments; identifications should be regarded as tentative pending preparation of the most diagnostic elements. The largest animal represented is *Lynx rufus*, the bobcat. The fragmentary jaw (UCMP 235585) (Fig. 5A) can be assigned to this taxon based on the size and number of preserved alveoli. Rodents are represented by five partial skeletons (UCMP 235586, 276791–276794). The most complete of these (UCMP 276792) have bisected skulls with small grooved incisors (Fig. 5B), indicating these were heteromyid rodents. Comparison of the relative proportions of the cranial bones and overall size indicates these are likely *Perognathus inornatus*, the San Joaquin pocket mouse, a species that occurs in the area today.

The most notable specimens are those of birds, which include both feather impressions (Fig. 5D, F) and articulated limb material (Fig. 5C, E). At least two taxa are present. The smaller of the two (UCMP 276788) is a passeriform and includes a complete, unbroken carpometacarpus, which was compared with a range of extant taxa. In size and morphology it is most similar to *Bombycilla cedrorum* (cedar waxwing) and *Sialia currucoides* (mountain bluebird; UCMP 119166). The element is distinctly larger than that found in any sparrows, wrens, or swallows in our comparative sample and smaller than an American robin or Brewer's blackbird. This size bracketing suggests that UCMP 276788 was a 16–20 cm bird.

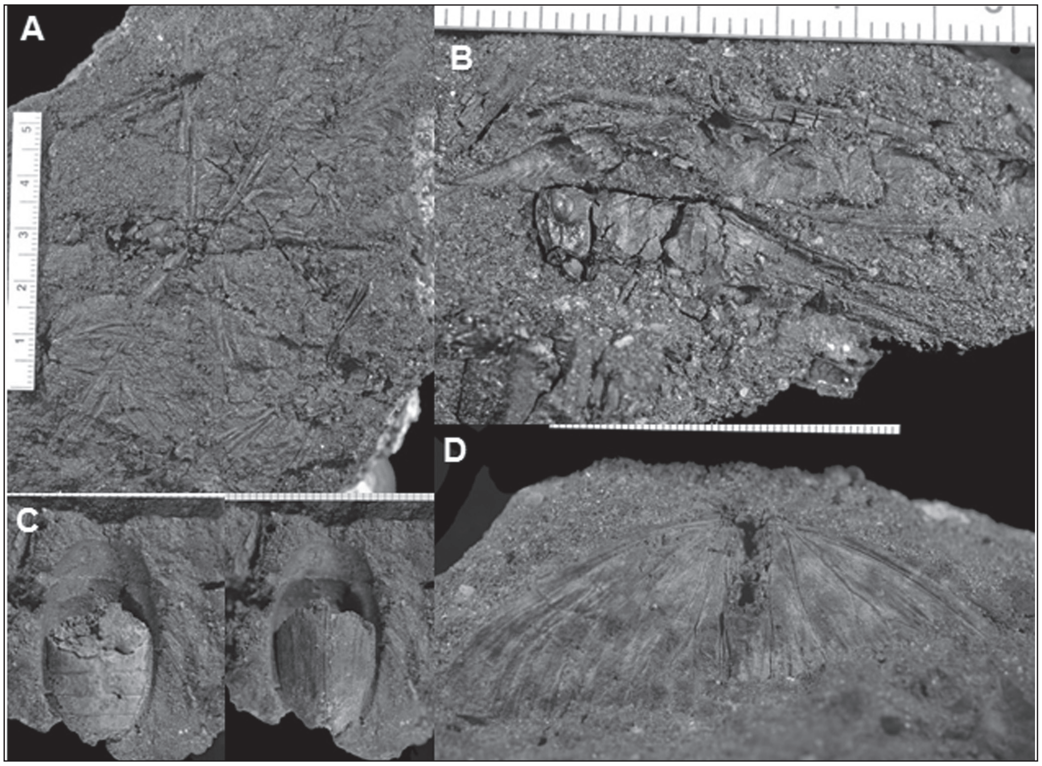

Figure 4. Oil Canyon fossil insects. **A.** Carbonized compression-cast of a large dragonfly. UCMP 401228. **B.** Carbonized cast of a grasshopper, UCMP 401233. **C.** Ventral (left) and dorsal (right) views of the impression and partial cast of the abdomen of a large beetle, cf. *Hydrophilus* sp., 401230. **D.** Compression of a relatively large lepidopteran, UCMP 401229. All scales in mm.

A second specimen, UCMP 276790, is a part and counterpart preserving bones of the hindlimb and articulated feather impressions of a bird with a tarsometatarsus approximately 50 mm in length (Fig. 5C–E). The best comparison in size is with *Corvus brachyrynychos* (American crow); it is distinctly larger than that of the American robin or scrub jays and smaller than that of the common raven.

All of these appear to represent taxa occurring in the area today. They are most notable for the varied modes of preservation and the potential for other tissues to be preserved. The preservation of the OC feathers is unusual and merits further investigation to determine if it represents one of the known modes of microbially-mediated preservation or permineralization (e.g., Davis and Briggs 1995, Briggs 2003).

Oil Canyon paleoenvironmental interpretation

The Oligocene-Miocene Temblor Formation underlies the OC seep and the small drainage (Fig. 1A, B). Adjacent and upstream of the site the Temblor strata form well-exposed slopes comprised of shale (white, diatomaceous, acidic soil) and sandstone (Fig. 6A). The OC seep consists of finely stratified alluvium in a matrix of oil and asphalt. The exposed area of the seep is ~465 m^2 and lies at the southwestern edge of the watershed area (~100 km^2) at an elevation of 396 m (1299 ft.) (Fig. 6B). The watershed's western boundary extends up to ~442 m (1450 ft.), the eastern and southern boundaries near ~475 m (1560 ft.), with the present drainage channel extending to an elevation of ~415 m (1360 ft.) (Fig. 6B). The alluvial sediments consist of sand and gravel eroded from sandstone in the eastern portion of the drainage and white Temblor marine shale fragments eroded from the northern and southern portions of the drainage. Since the deposit contains representative rock types from the entire drainage, it may be assumed that the deposit also contains plant material from species representative from throughout the small drainage during that time (Fig. 6B). Invertebrate and vertebrate fossil species are likely representative of the local fauna. Current average annual temperature at the site is about 17.6°C (63.7°F) and average annual precipitation is about 178 mm (7 in.). The dominant vegetation type of the drainage is typical of upland areas of the San Joaquin Desert and includes *Atriplex polycarpa* (Chenopodiaceae), *Eriogonum fasciculatum* var. *polifolium* (Polygonaceae), *Gutierrezia californica* (Asteraceae), and *Eastwoodia elegans* (Asteraceae). Herbaceous perennial species include *Eriogonum nudum* var. *indictum* (Polygonaceae; restricted to the marine shale), *Marah fabacea* (Cucurbitaceae), and

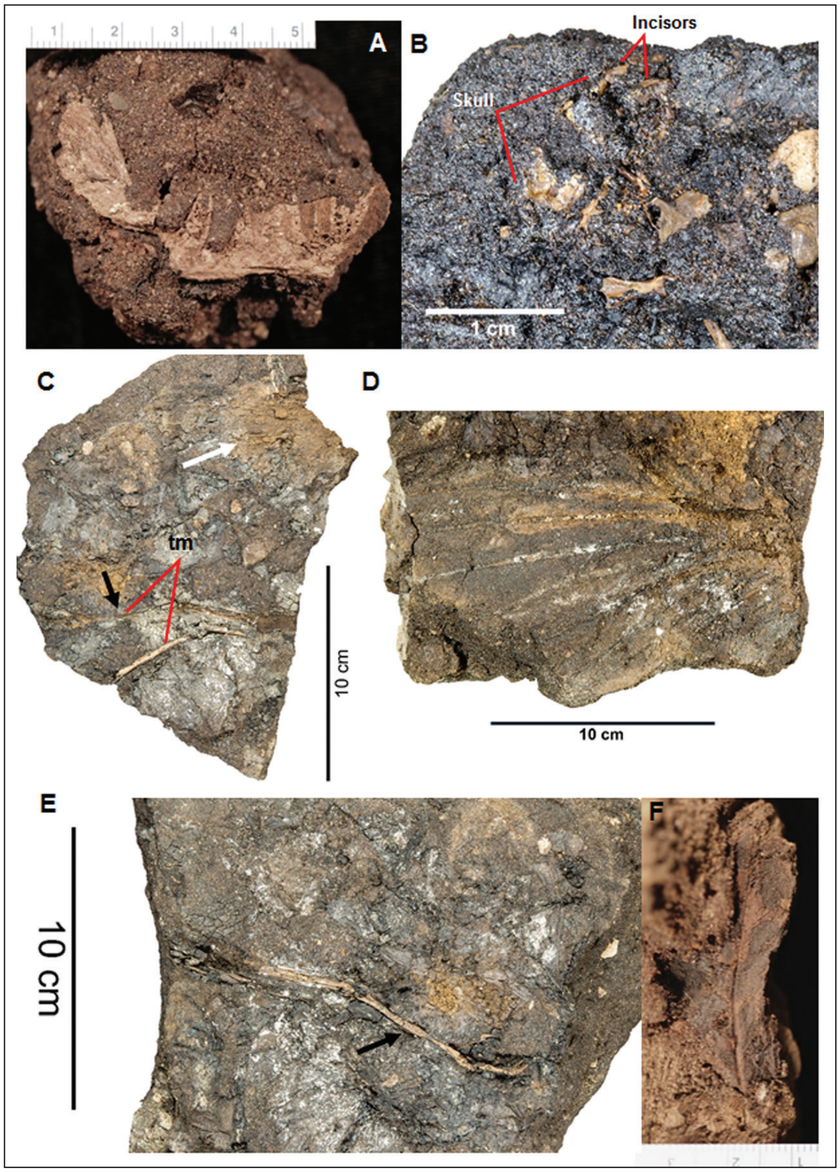

Figure 5. Oil Canyon fossil vertebrates. **A.** Lower jaw of a bobcat, *Lynx rufus,* UCMP 235585. **B.** Partial skull and associated skeletal elements preliminarily identified as a pocket mouse, *Perognathus inornatus*, UCMP 276792. **C–D.** Remains of partial legs and feathered wing or tail (white arrow in C) of medium-sized bird, UCMP 276790. Tarsometatarsals (**tm**) labeled and black arrow in C points to the counterpart of the more complete leg in D (arrow). **E**. Isolated compressed feather, UCMP 276795. A, F: scale in mm.

Poa secunda (Poaceae). The nearest *Quercus john-tuckeri* to the site occurs on Temblor shale approximately 12 km (~7.5 mi.) north-northwest and 91 m (~300 ft.) higher in elevation than the OC seep. There is no perennial water present in the drainage upstream of the deposit and no *Typha* sp. grow in the area today.

The OC seep contains fossils of two upland plant taxa, *Quercus john-tuckeri* and *Eriogonum nudum* var. *indictum*, and one obligate perennial wetland taxon, *Typha*, indicating the presence of dry upland habitat on the slopes and localized perennial wetland within the drainage bottom. We hypothesize that oil, asphalt, and water seeped to the surface in the drainage bottom not far upslope from the seep, forming a small pond where oil and asphalt were suspended on the water's surface. *Typha* would have grown on the edges of the pond providing habitat for water beetles and other aquatic insects. Terrestrial insects and small vertebrates including reptiles, birds, and rodents attracted to the water may have fallen into the pond, and become trapped in oil and asphalt on the surface. Potentially, larger vertebrates may also have become trapped, but their bodies remained within the deeper pond basin.

During flash flood events in spring and summer, sediment and upland plant material may have been washed into and through the pond, mixing with *Typha* leaves and the entrapped insects and small vertebrates, and then overflowing and accumulating as layered strata downstream of the pond. The flash flood events occurred with a frequency of once every three to four years based on the total number of distinct strata counted in the deposit. The pond overflowing to an alluvial fan-type depositional environment would explain the presence of *Typha* leaves; the presence of mass accumulations of insects (water surface accumulation); the presence of only small vertebrates (surface float); and the finely stratified nature of the deposit. The hypothesized pond basin, which may contain large vertebrate fossils, is suspected to be buried by sediment immediately upslope of the stratified OC seep. This hypothesis will be tested using augers to sample the deeper, covered portion of the basin.

Quercus john-tuckeri leaf impressions are abundant throughout the deposit, but the remains of other woody plant species that dominate at slightly cooler (15.5°C; 60°F) and wetter (279 mm; 11 in.) climates in the region are entirely absent. Those species include *Q. douglasii*, *Pinus sabiniana*, *Q. berberidifolia*, and *Arctostaphylos glauca*. Curiously, although *Juniperus californica* commonly co-occurs with *Q. john-tuckeri*, even at its warmest, driest locations, no macrofossils that may be attributed to *Juniperus* have been found in the deposit.

The abundance and distribution of *Q. john-tuckeri* throughout the stratified deposit provides clear evidence for climate change in the early Holocene at the western margin of the San Joaquin Valley, eastern edge of the central Southern Coast Ranges. Leaf impressions of the species are abundant throughout the seep, but abruptly disappear near the top of the unit. The species is currently absent from the OC watershed, with the nearest extant

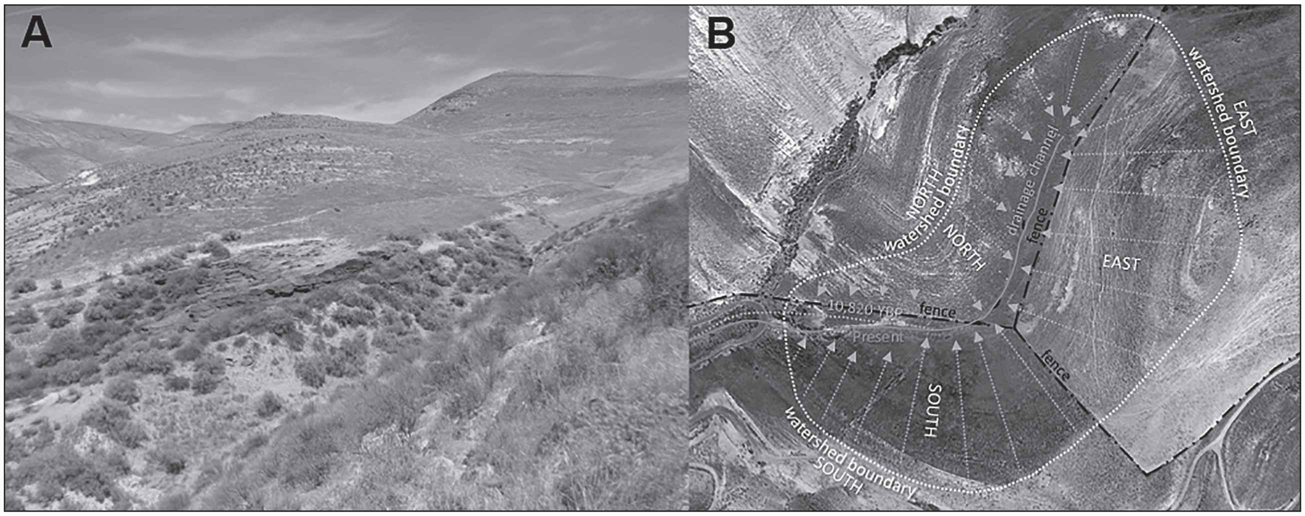

Figure 6. A. View of the Oil Canyon locality looking northeast (dark brown, center of photo) showing the small drainage upslope and current vegetation. The deposit is surrounded by *Atriplex polycarpa*. *Eriogonum nudum* var. *indictum* occurs immediately uphill from the deposit. *Eriogonum fasciculatum* var. *polifolium*, *Gutterezia californica*, and *Eastwoodia elegans* occur on the hillslope in the foreground and on the ridge in the background. **B.** Google Earth satellite view of the Oil Canyon deposit (far left edge of the dotted white polygon) and the extent of the drainage. Sandstone is located in the eastern part of the drainage and marine shale in its northern and southern portions. Dot-lined arrows indicate dominant direction of water flow and movement of sediment. Solid line indicates the position of the current drainage channel.

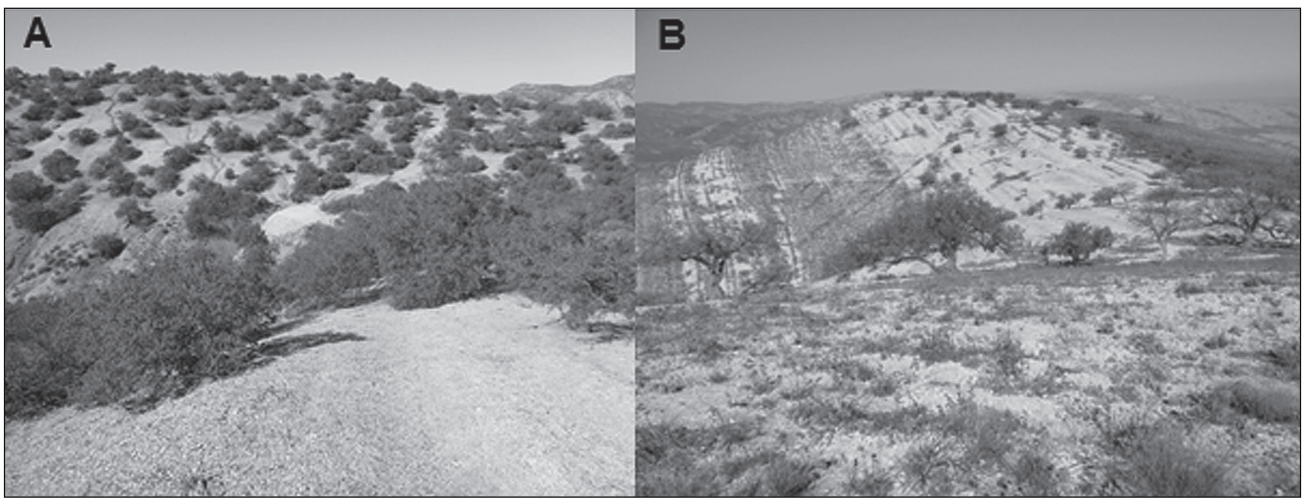

Figure 7. A. ~11,310 YBP Oil Canyon analog plant community. *Quercus john-tuckeri* is abundant. Lat. 36.388536°, Lon. -120.489775°. **B.** ~10,800 YBP Oil Canyon analog plant community. *Quercus john-tuckeri* greatly declines in abundance and disappears by 10,500 YBP as the climate becomes warmer and drier and transitions to the San Joaquin Desert. Lat. 36.358679°, Lon. -120.407082°

population located 12 km (~7.5 mi.) north-northwest and 91 m (300 ft.) higher in elevation (Figs. 7, 8). The climate at the nearest extant *Q. john-tuckeri* population and others in the region is cooler (~16.1°C; 61°F) and wetter (267 mm; ~10.5 in.) than the OC seep (~17.6°C, 64°F; ~178 mm,7 in.). Simply using the present-day OC area geographic distribution of *Q. john-tuckeri*, its temperature and precipitation requirements, and apparent population decline in the OC watershed by ~10,150 YPB, suggests the OC area climate since this time has warmed by at least 1.5°C and average annual precipitation has declined by about 50%.

Currently, the distribution of *Q. john-tuckeri* occurs just outside of the San Joaquin Desert, at its margins. The apparent rapid disappearance of *Q. john-tuckeri* post 10,500 YBP from the OC site suggests expansion of the current San Joaquin Desert climate and ecosystems into the Coalinga area by the early Holocene (Fig. 8). The early Holocene timeline for establishment of the San Joaquin Desert is also supported by the work of Raven and Axelrod (1978), with Davis' paleoclimate estimates from Tulare Lake fossil pollen data showing temperature and precipitation values approaching those of today's SJD by 7,000 YPB (see Fig. 4 in Davis, 1999).

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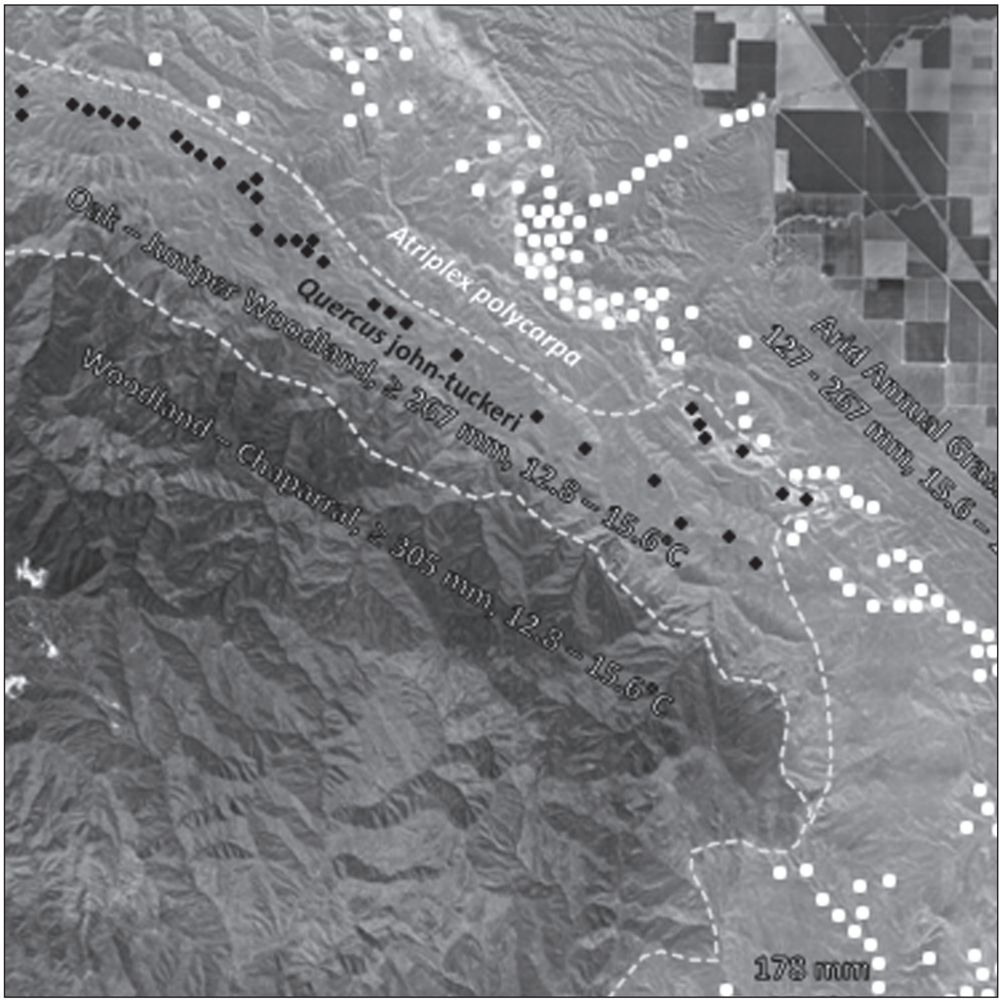

Figure 8. Google map satellite view of Oil Canyon oil seep fossil deposit ( ), and climate relative to the current distribution of *Atriplex polycarpa* (○) and *Quercus john-tuckeri* (●). The climate and vegetation of the Oak-Juniper Woodland zone is interpreted to have extended to the area of the Oil Canyon site to at least 10,500 YBP and gradually increased in elevation as the climate became warmer and drier through the early Holocene, giving way to the current San Joaquin Desert flora, represented here by *A. polycarpa*.

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ECSZ Does It

Revisiting the Eastern California Shear Zone

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