

Wally Tiffel

WELCOME
Salton Sea



LPL Field Trip
Spring 2025

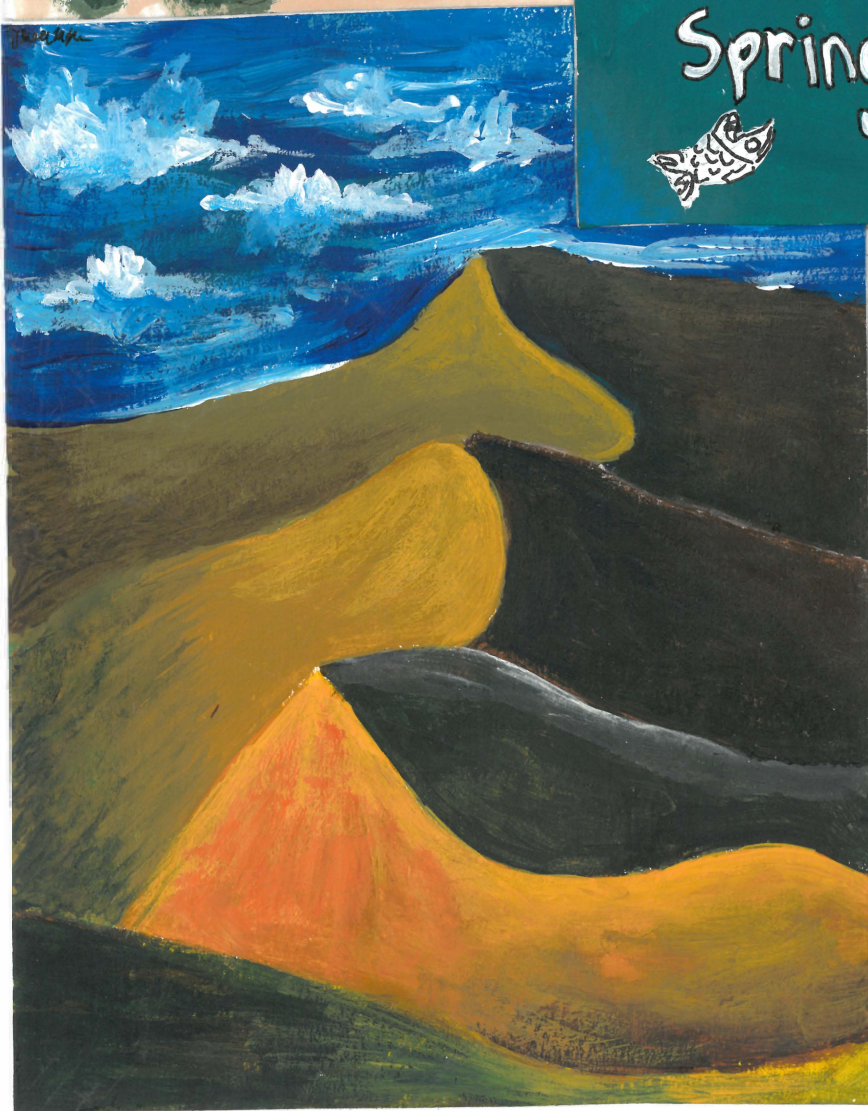


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Note from the editor: A huge thank you to the four artists—Thea McKenna (bottom left), Ruby Fulford (top left), Christina Singh (top right), and Kiki Gonglewski (bottom right)—who created the cover art for this field guide.

Letter from the editor—

As someone whose research lives in the world of distant exoplanets and escaping atmospheres, I'll be the first to admit—I'm not a geologist. But field trips like this one are one of my absolute favorite parts of grad school. There's something about getting out into the landscape, walking through it, seeing the science in real time that brings everything to life in a way no lecture or paper ever could.

Putting together this field guide has been a fun way to get familiar with the Salton Sea, a place I knew almost nothing about before this trip. From its bizarre formation to the surprising diversity of life it supports, it's a perfect example of how science doesn't stay neatly in one box—there's atmospheric science, hydrology, ecology, and yes, plenty of geology all wrapped up in this one salty, sinking basin.

I hope this guide helps you appreciate just how weird and wonderful this place is. I know I'm excited to learn more—mud pots, fish kills, birdwatching, and all.

See you in the field,
Anna :)



Land Acknowledgment

We acknowledge that the region surrounding the Salton Sea is the ancestral and unceded land of the Cahuilla, Kumeyaay, Quechan, and other Indigenous peoples who have lived in and stewarded this desert landscape since time immemorial. Their deep knowledge, resilience, and connection to the land continue to shape the ecological and cultural history of this area.

As we explore the Salton Sea and its surrounding environments, we do so with gratitude and respect for the original caretakers of this land and their ongoing presence and contributions. We recognize the importance of honoring Indigenous sovereignty and continuing to learn from Indigenous communities and perspectives in both science and stewardship.

- LPL Graduate Students

Road log for PTYS 594 Spring 2025 – All times are AZ times
Sunrise is ~6.30am and sunset at ~7pm

FRIDAY 4/4/2025

7 AM Arrive at LPL loading dock bright-eyed and bushy-tailed with full ice chests, full stomachs, coffee, and snacks.

8 AM Depart LPL for some fieldtrip excitement!
Drive north on Cherry, turn west on Speedway, enter interstate 10 westbound. After ~60 miles, transfer to interstate 8 westbound, drive 192 miles, stay awake.

Take a rest break at Gila Bend exit 115 (~10am)

Exit the 8 at #159, go north on Ogilby road for 25 miles

Turn left on CA-78, drive 16 miles and take a left on Osborne Park Road.

1PM **Lunch stop (bathrooms available)**

2 PM	Shane (ad lib)	Basin & Range formation
	Thea	Algodones dunes
	Robin	Tectonics of the Salton Trough

3PM Back onto the 78 and head west for 16 miles. Transition to CA-115 (two right turns separated by ~2 miles) and travel 16 miles. Turn right onto CA-111 in Calipatria and travel 50 miles. Left on Lincoln street immediate right on 66th Ave, turn left on CA-86 after less than a mile. Head south on CA-86 for 35 miles (after about 16 miles there's a rest stop we can visit: **Torres Martinez Travel Center – last rest stop of the day**) and turn right onto CA-78 and travel another 16 miles.

Turn left onto Split Mountain road and travel 8 miles. At this point a bridge crosses Fish Creek. Enter the wash at the bridge and drive up the wash (~1.5 miles) to Fish Creek Primitive Campground away from the new shooting range (yes, seriously) that has popped up nearby.

5:30PM **Camp (pit toilets available)**

SATURDAY 4/5/2025

8AM Head back down the wash to the bridge and then east on an unmarked road that parallels the old mining railway that's south of the wash. Travel just under 4 miles to a promising spot to see the bed of old lake Cahuilla (near the right edge of the figure below).



8.30PM Dig up some surprises in the desert
Ruby Historic Lake Cahuilla
Anna Flora & Fauna

9.00AM Drive back to the 78 along Split Mountain Road (about 8 miles) and turn right. Stay on the 78 (right at the Border Patrol checkpoint) for 32 miles.
Rest Stop just before the next turn (should be about 10AM)
Turn left onto Forester Road for 2 miles. Turn right onto Walker Road (aka O'Brien lateral) and almost immediately left onto Gentry Road, drive another 7 miles. Take a right onto Sinclair/Estelle road for 1 mile and then a left into Garst Road. Travel 1.6 miles and then turn right onto Red Hill Road (aka Schrimpf Road). Travel 1 mile and turn left onto Davis Road. Mud volcanos are on the right after ~100m.

There's an alternate site nearby if needed. Drive 6 miles further north on Davis Road until you reach CA-111. Turn left on CA-111 and immediately right into Gillespie Rd and park. Walk ~100m south to see the mud pit.

11AM **Reed Mud Volcanoes**

11.30AM Drive 15 minutes to the Rhyolite dome (map) – potentially add ~45 mins to see the other mud volcano site

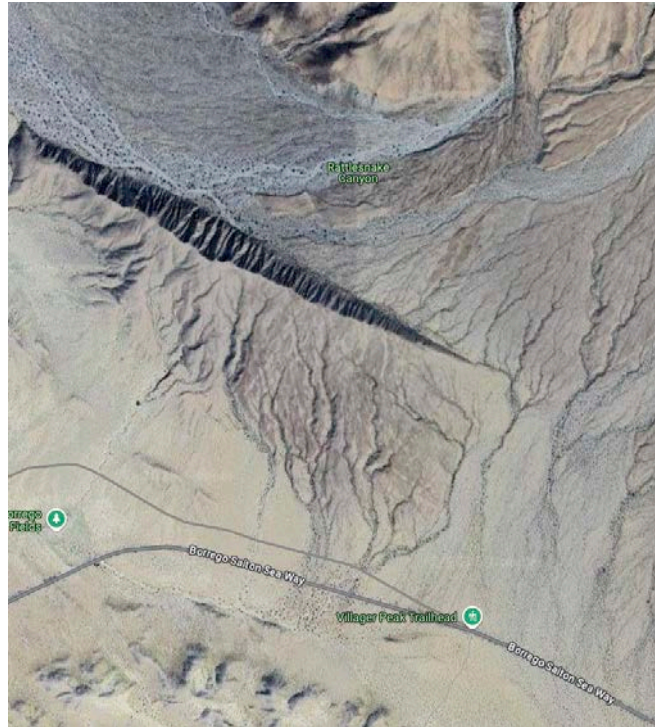


Kiki Lily Gabe	High-Silica Volcanism Formation of the Salton Sea How the Salton Sea turned into an environmental disaster
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12.30PM-ish Lunch on the shores of the Salton Sea. The beautiful Carcass Beach is nearby.

1.30PM-ish Drive to big fault. Get back to Estelle/Sinclair Rd (a half mile to the north) and go west until CA-111 and then north. We'll loop around the sea like yesterday. Optional stop at the intersection with Davis Road to see the other mud volcano. It's about 70 miles on the 111 and then 86, but we'll take a break en route at the **Torres Martinez Travel Center after 65 miles – last rest stop of the day.**

Turn right onto Borrego Salton Sea Way in "Salton City". Drive 14.6 miles to a right turn onto West Truckhaven Trail. Park the vehicles at the turnoff (no vehicles allowed I think). It's about a mile of hiking to get to the fault – which neatly severs an alluvial fan



- 4PM-ish **Robin Reprise? Tectonics of the Salton Trough**
Euibin Alluvial Fans and their interactions with tectonics
- 5.00PM-ish Drive to Clark Dry Lake. Walk back to Borrego Salton Seaway and travel another 5.6 miles west. Turn right onto Rockhouse Road/Trail. Drive ~3 miles until we find a good place to park and camp. This will probably take at least 30 minutes.
- 5.30PM **Get to Campsite (No Bathroom Facilities)**

SUNDAY 4/6/2025

8AM Drive/Walk to nearby clay dunes

Sam **Clay dunes**
Jingyu **Playas and climate change**

9AM Head back to Borrego Salton Seaway and travel east 20 miles. Turn left onto the 86 and drive 9 miles.
Stop again at the Torres Martinez Travel Center about 3 miles before the next turn (exit Black Diamond Road).
Turn left onto Coolidge Springs Road and get as close to the mountains as possible. Hike the last few 100m to the tufa/travertine deposits.

Christina **Formation of Tufa/Travertine**

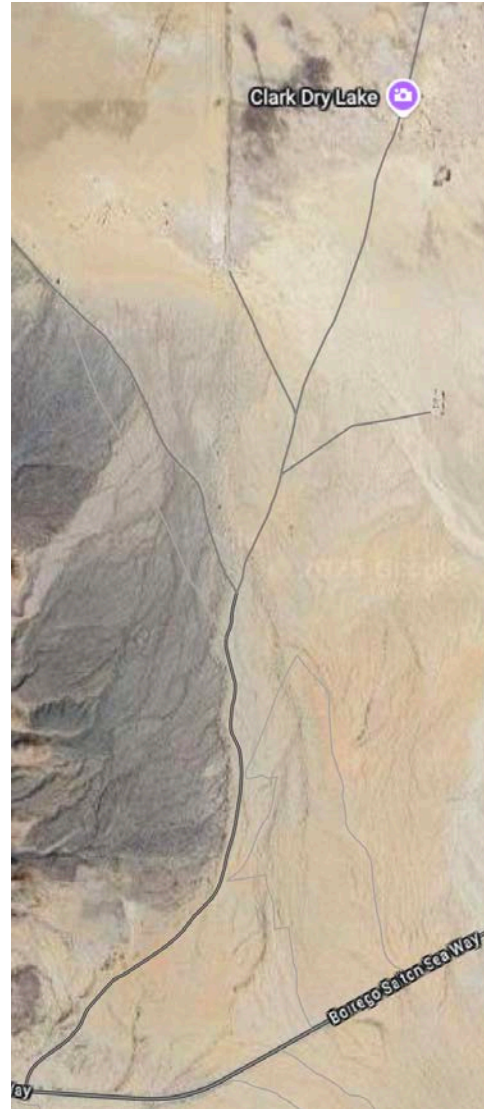
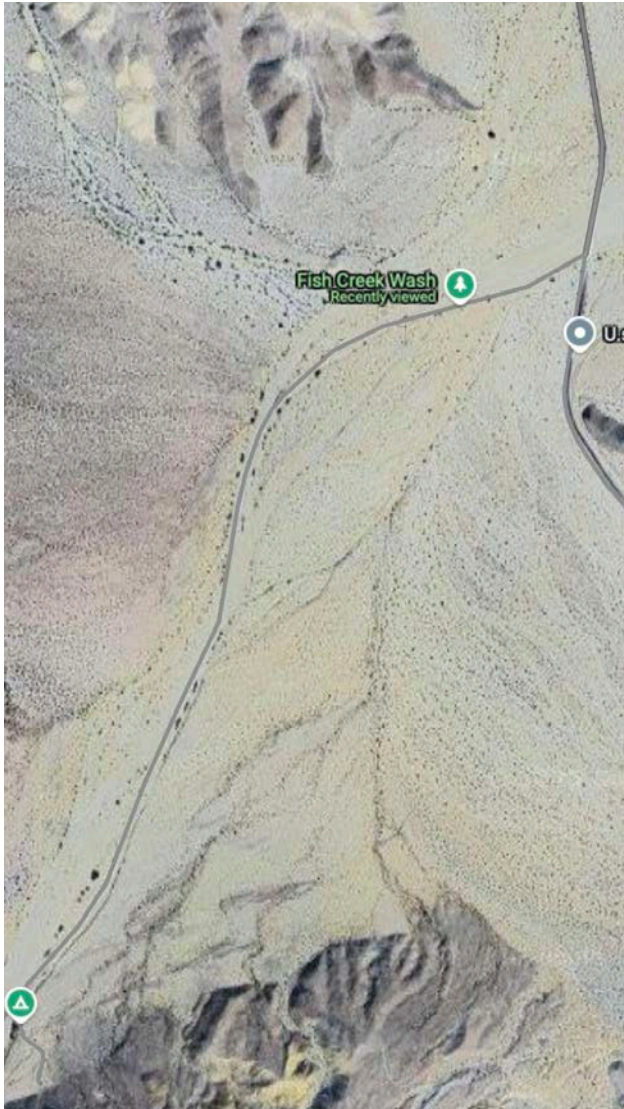
11AM Head south on the 86 for 17.5 miles. There's an unmarked turn off to the left, take this and drive a little over 2 miles. We may have to hike the last 100-200m due to sandy conditions.



11.30AM Check out dunes migrating across the road.
Nicole **Migration of dunes**
Lunch here.

1PM Start driving home. Take the 86 to the 78 (**break at Saturday's rest stop just west of Westmoreland**) to the 111 to Interstate 8 to Interstate 10 to Speedway to Cherry to Hawthorne to LPL. It'll take about 5.5 hours with stops.

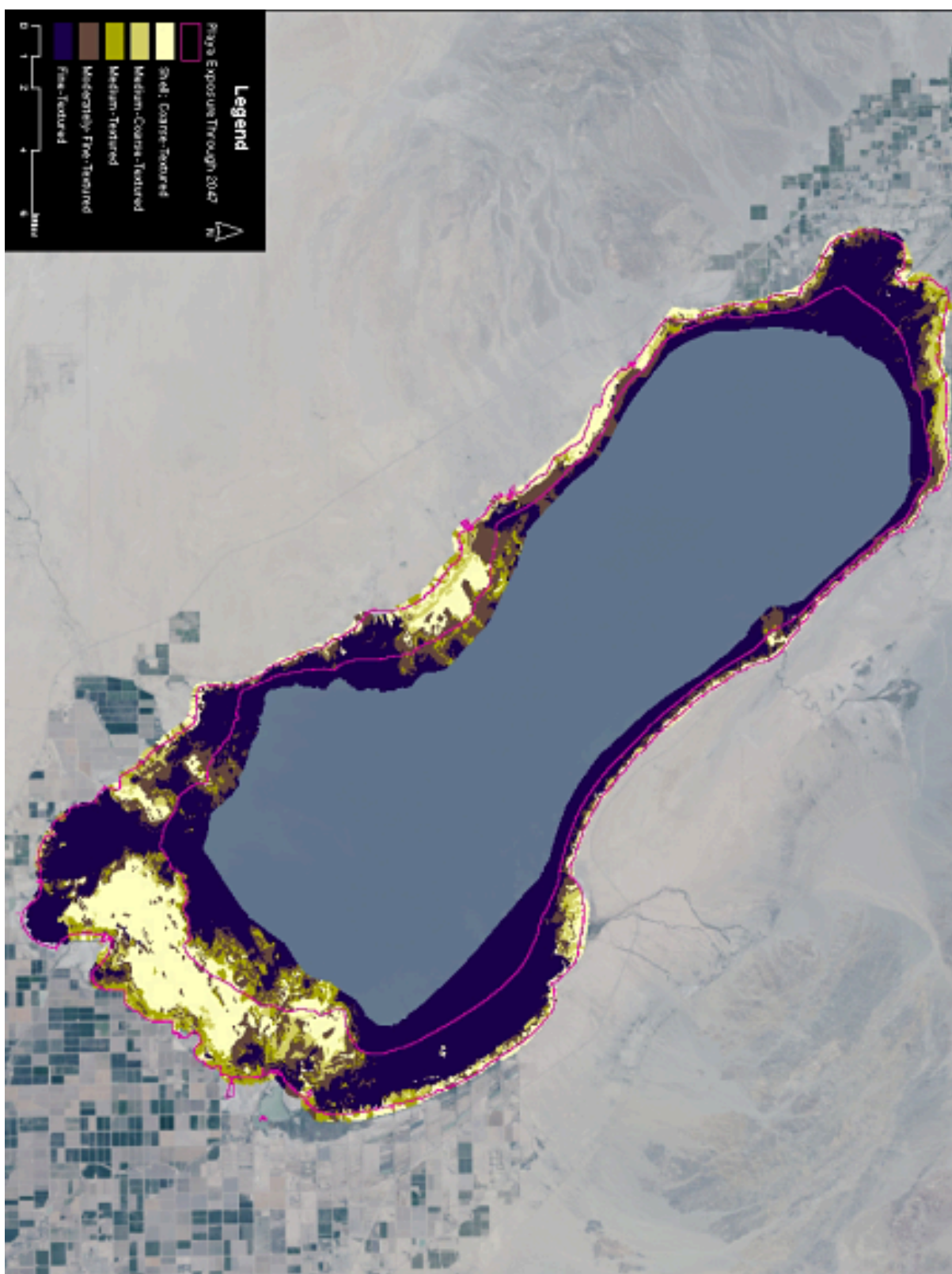
6.30PM Back at LPL



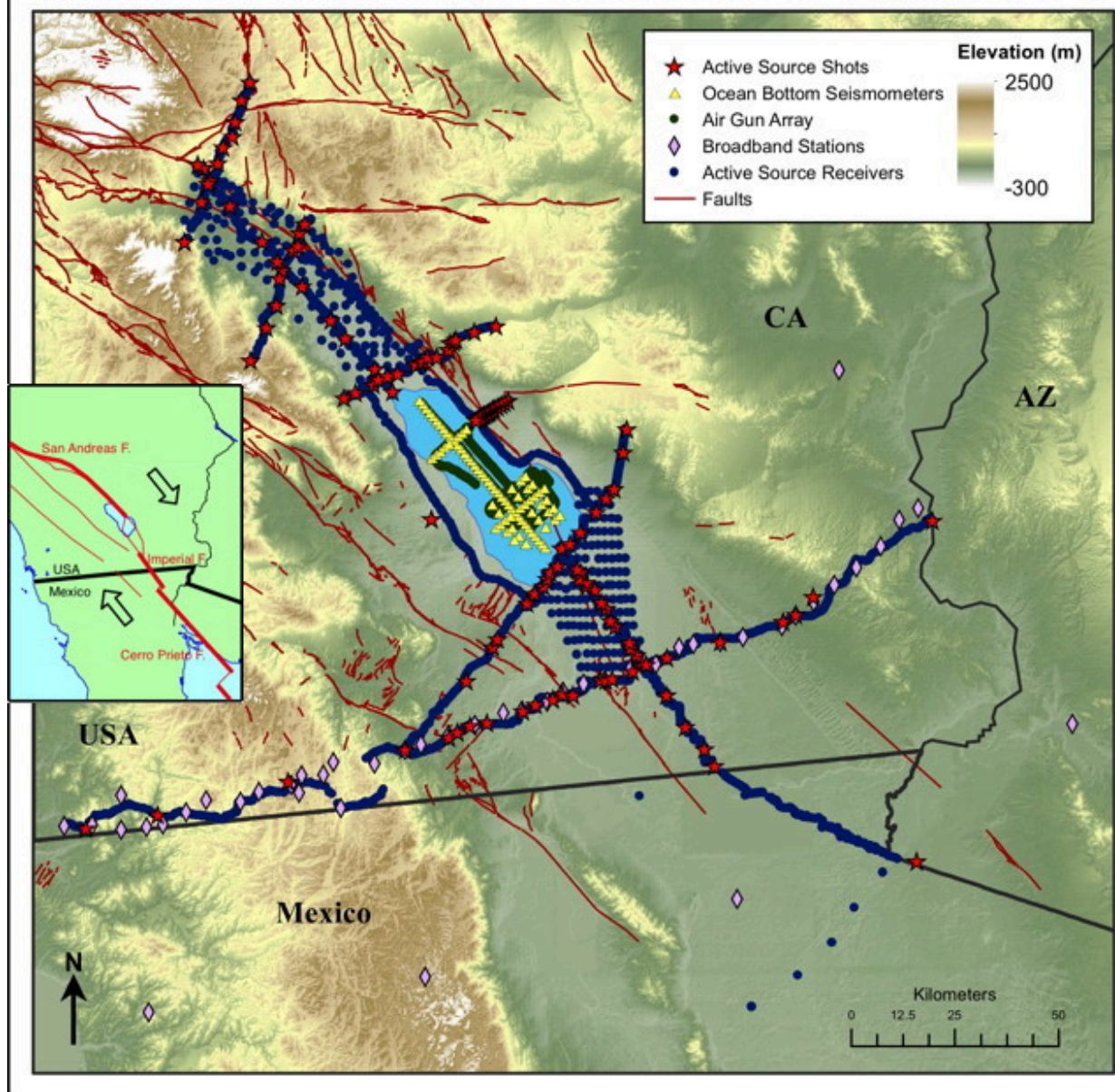
Roads leading to campsites on nights one and two.

Supplementary Maps and Figures





SALTON SEISMIC IMAGING PROJECT



Algodones Dunes

Thea McKenna

Origins, Characterization, and Evolution

The Algodones Dunes are one of the largest active dune fields in the United States, at 75 km in length and 11 km in width at its widest point [1, 2]. They source sand from a paleolake called Lake Cahuilla which is dated to be active between 3.6 ka to 360 yrs [2]. This lake was fed by the Colorado River, so the Algodones Dunes are composed of Colorado River sediment. The dune field is characterized by strong seasonal winds and conditions imposed by bounding topography/environments. There are diverse dune types, including Crescent, Linear, Zibar, and Sand Sheets (Figure 2).

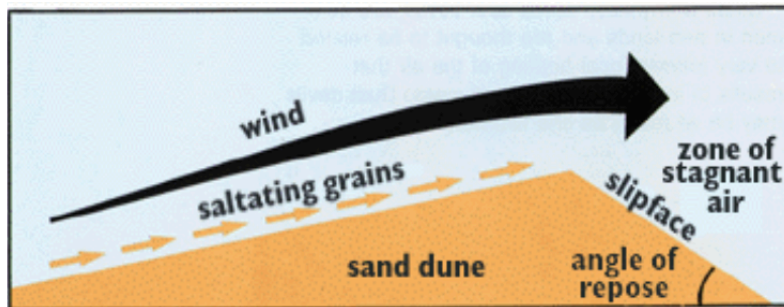


Figure 1. [Image Credit: USGS] Cartoon of a sand dune showing sand saltation, stoss and lee sides, and angle of repose. Differing wind angles lead to varying dune shapes.

Glossary: Dune Types seen at Algodones

- *Simple, Compound, Complex*: a simple dune is a single dune type, a complex dune pattern is composed of simple dune patterns spatially superimposed on each other [2]. Complex dunes are combinations of different dune types [3].
- *Linear*: long, line shaped dunes that are formed by winds along two directions.
- *Crescent/Barchan*: compound crescent dunes are the oldest at Algodones [2]. They form with dominant winds in one direction.
- *Zibar*: coarse grain sizes, often much lower and lack defined slip-faces. Found in between linear dunes in Algodones.
- *Ripples*: the coarsest materials collect at the crests, whereas in dunes, the coarsest materials are generally in the troughs [3]. Generally smaller scale features.
- *Sand sheets*: flat, undulating sandy plots surfaced by grains that may be too large for saltation [3].

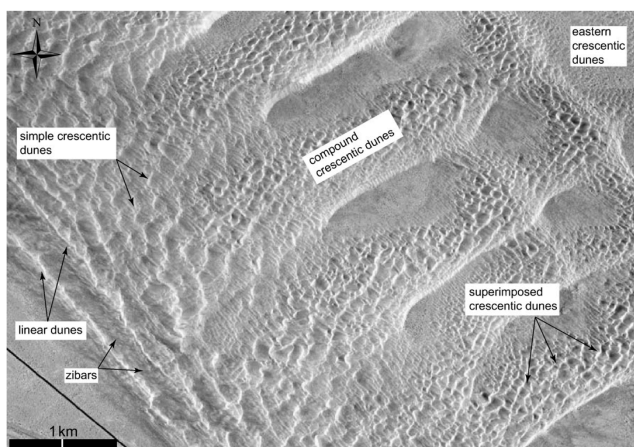


Figure 2. Picture of dune morphologies in the Algodones Dune Field from Derickson et al. 2008. Compound crescentic dunes have smaller crescentic dunes superimposed on top of them. The smaller ones are younger and form due to changes in wind direction over time. Simple crescentic, linear, and zibar dunes to the west.

Algodones Dunes

Thea McKenna

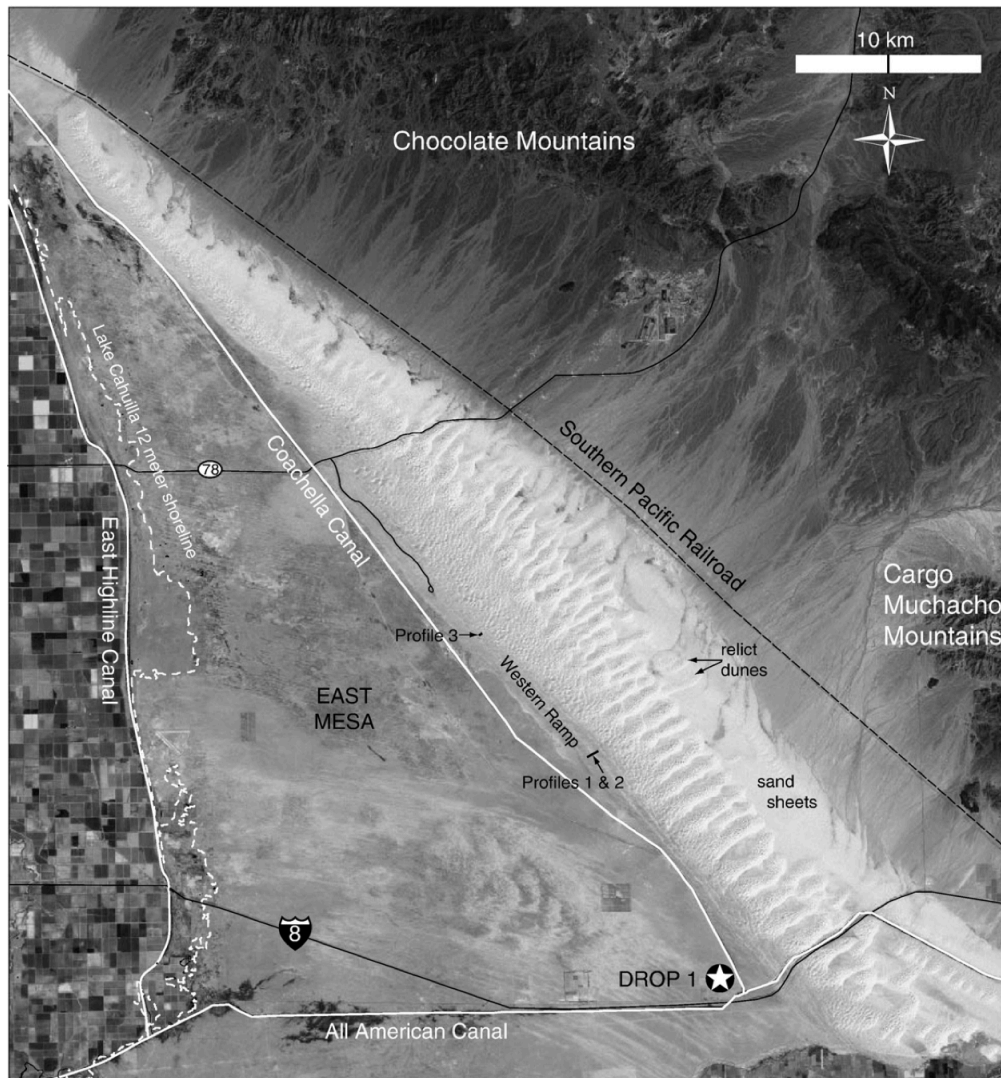


Figure 3. Map of the dune field with regional context. East of Lake Cahuilla is East Mesa, a shrub-vegetated plain with partly active dunes. The dunes are parabolic with extended linear arms. The eastern boundary has alluvial fans from the Cargo Muchacho and Chocolate Mountains. Algodones ends with the Colorado River floodplain to the south [2].

Planetary Analogs: Mars, Titan, and Tatooine

Mars has linear, ripple, and barchan dunes. Titan has linear and barchan dunes with sand made from solid hydrocarbons. Tatooine happens to have the exact geomorphology as the Algodones Dunes! (Figures 4, 5, 6).

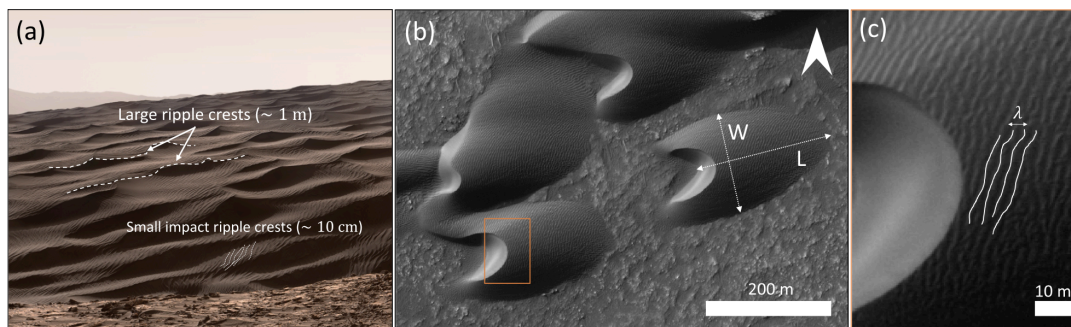


Figure 4. Barchan and ripple dunes, Namib Dune, Gale Crater [4].

Algodones Dunes

Thea McKenna

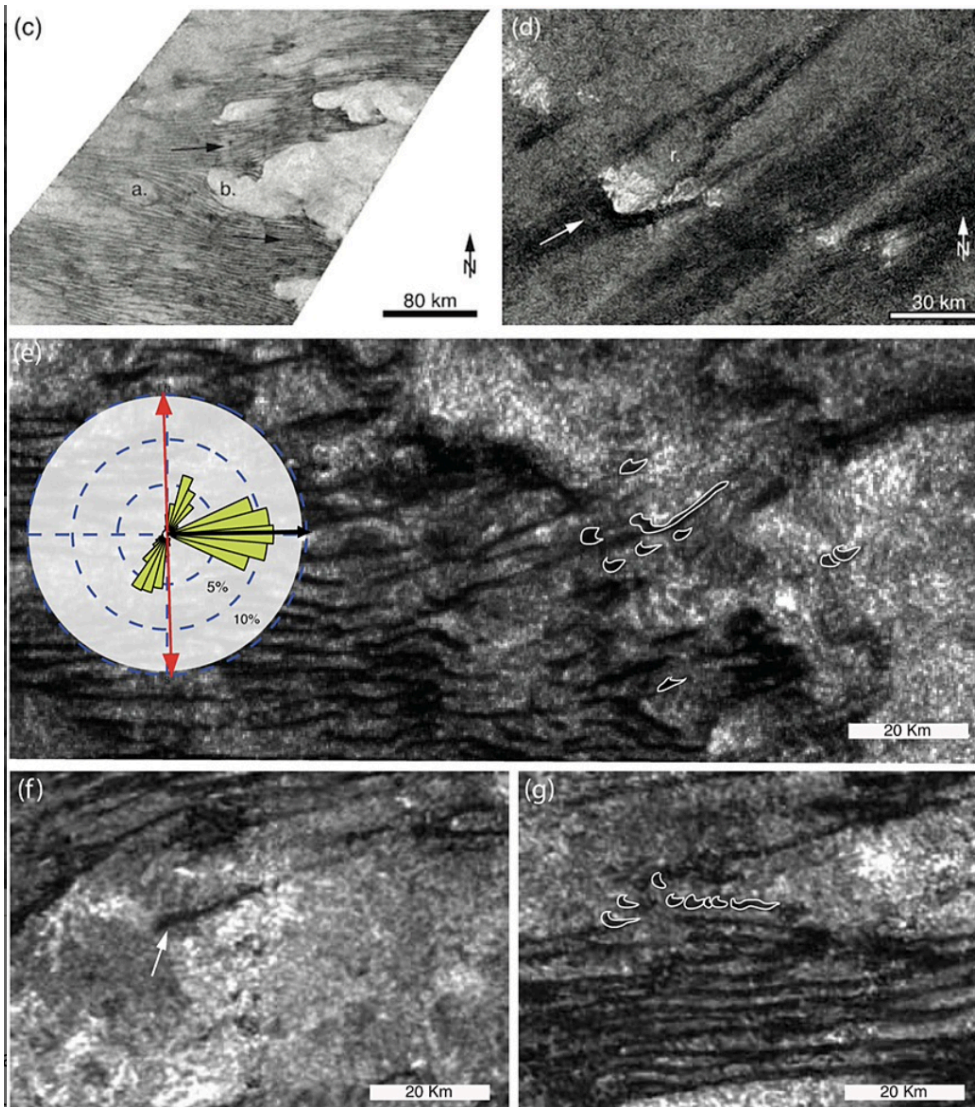


Figure 5. Dunes on Titan from Cassini Radar data [5]. Linear and barchan dunes pictured, along with topographic obstacles that obstruct flow.



Figure 6. [image credit: desertusa.com] Picture from the set of *The Return of the Jedi*.

Algodones Dunes

Thea McKenna

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Historic Lake Cahuilla

Ruby Fulford

LPL Field Trip, Spring 2025

Introduction

Lake Cahuilla refers to a series of prehistoric freshwater lakes thought to have filled the Salton trough ~6 times over the last 1100 years (Philibosian et al., 2011; Rockwell et al., 2022) and an unknown number of times before then. Well-preserved lacustrine topography from most recent fillings indicates a maximum lake elevation of ~12 m above sea level (Rockwell et al., 2022; Waters, 1983), corresponding to a surface area of over 5700 km² and a maximum depth of 95 m. Ceramics found at archeological sites associated with the 12 m shoreline do not date before the late Holocene period (Waters, 1983). The ancient shoreline is well-preserved and almost continuous around the edge of the Salton trough (Waters, 1983). Ancient shoreline features include beaches, wave-cut slopes and benches, and tufa deposits (Richard, 1980). Fig. 2 shows an example of the preserved shoreline, and Fig. 3 shows a generalized stratigraphic column.

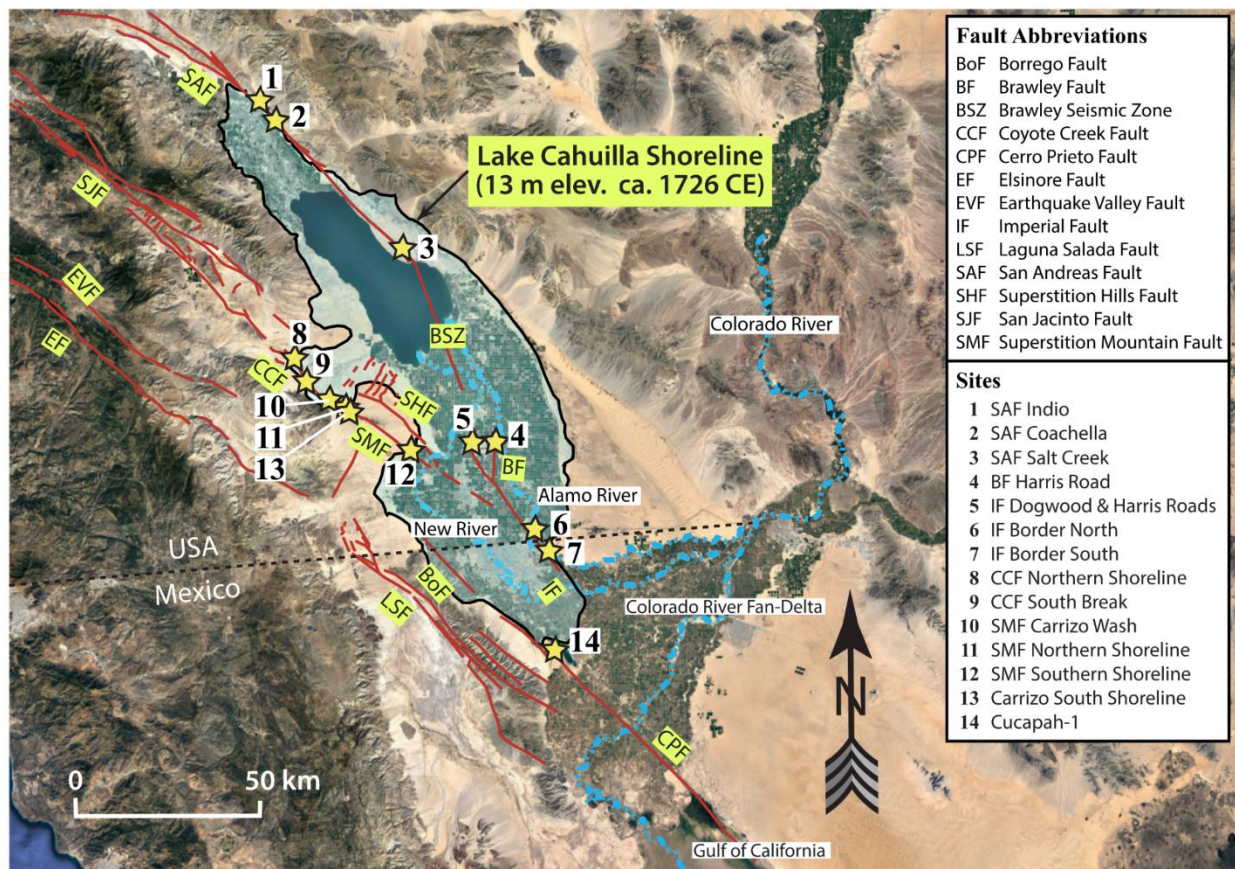


Figure 1: Map of the region around Lake Cahuilla, taken from Rockwell et al., (2022). Black outline marks the ancient shoreline of Lake Cahuilla. Blue dashed lines indicate Colorado River channels, and solid red lines indicate faults.

Formation of the ancient lake

The prevailing theory for the source of Lake Cahuilla is **diverted discharge from the Colorado river**. The depositional basin of the Salton trough is filled with fine grained Colorado River sediments (Waters, 1983). Some stratigraphic exposures show alternating lacustrine and fluvial deposits (Fig. 4) that indicate alternating periods of water flowing into the trough and the presence of a standing lake. The river diversion process is outlined below:

- The Colorado River delta likely once hosted distributary channels that continually shifted position.
- Some of these channels would have discharged down the steep, northern slope of delta into the Salton trough.
- The base-level changes involved in this process would favor rapid headcutting and channel enlargement within this alluvial terrain.
- Majority of Colorado river flow would eventually be captured and diverted into the Salton trough, creating ephemeral lakes
- Eventually, the river would redivert to flow into the gulf of California (its current destination), and the lake would evaporate.
- Process repeats when channels on delta divert toward Salton trough once again



Figure 2: Lake Cahuilla shoreline in Santa Rosa mountains (Singer, n.d.)

Wilke (1978) estimated that if the lake were to receive the entire flow of the Colorado river, it could fill to its 12 m elevation in only 12-20 years. Assuming climatic conditions similar to the present day, it would take about 60 years for the lake to evaporate between fillings (Wilke, 1978). Periods of extreme dryness in the region likely would have been long enough for lake to shrink and evaporate entirely before next filling. Unlike other paleolakes, Lake Cahuilla's highstands do not necessarily coincide with wetter periods, since its levels depend on the Colorado River and not on local climate (Rockwell et al., 2022).

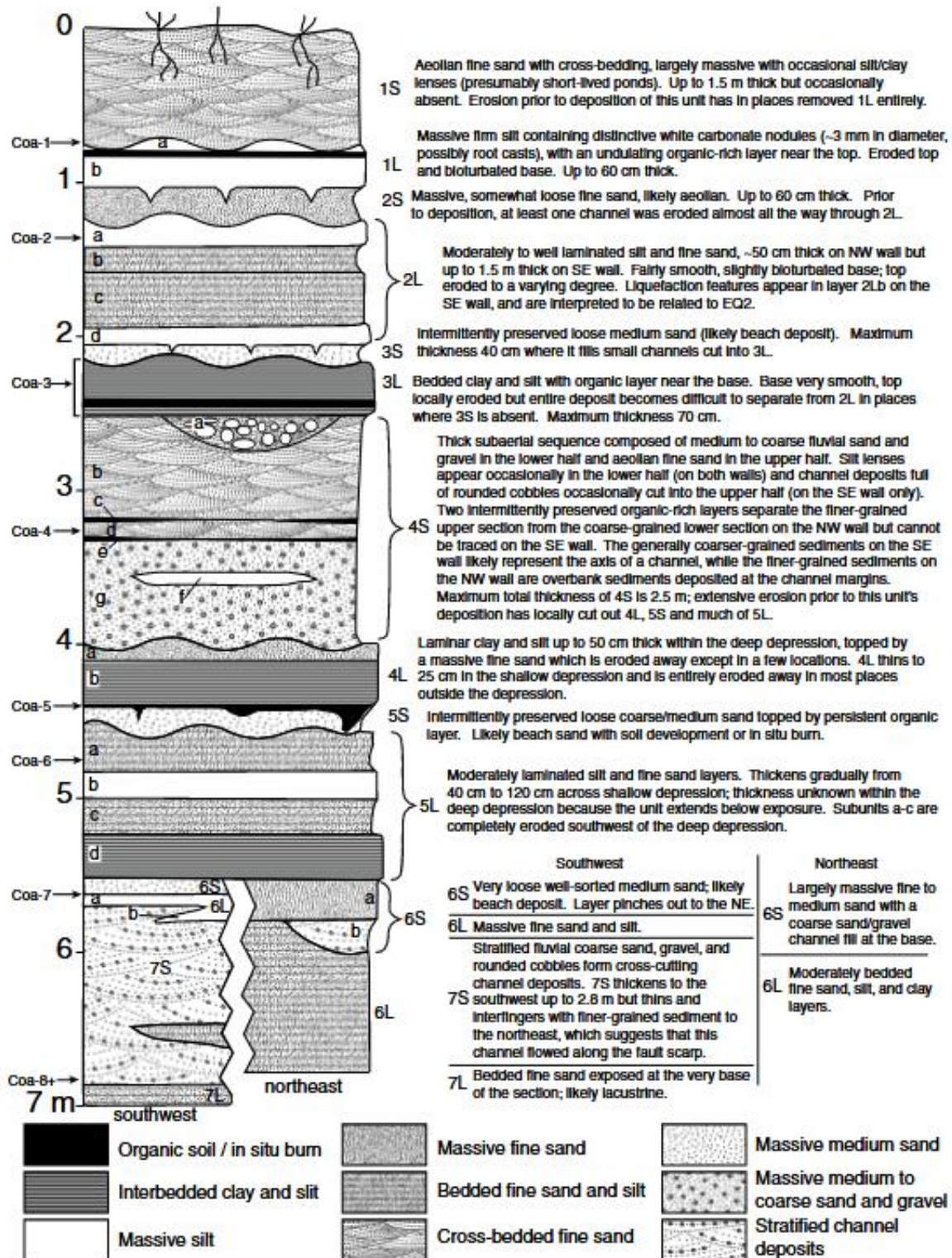


Figure 3: Stratigraphy of a trench in the Coachella region, studied by Philibosian et al. (2011). This figure shows layers associated with Lake Cahuilla's waters.

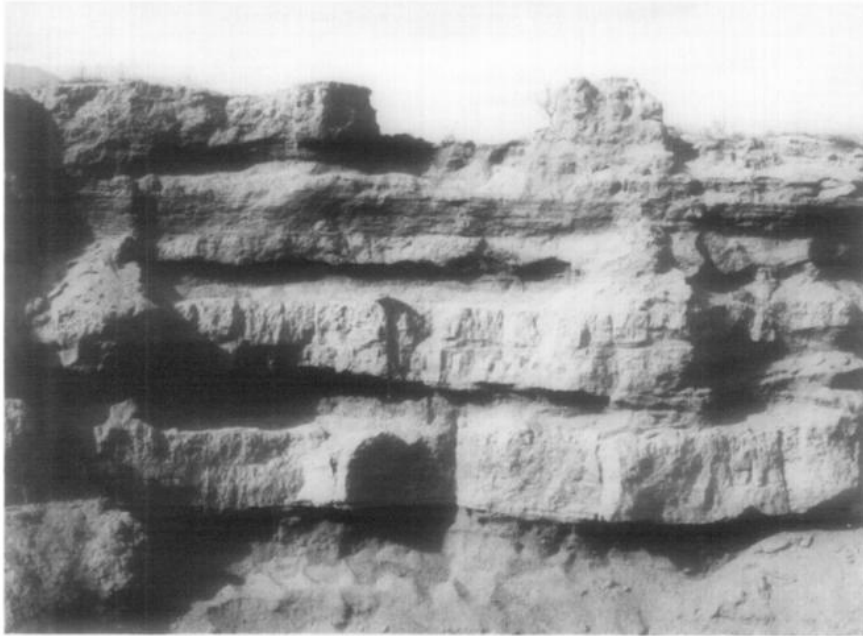


Figure 4: Stratigraphy at a study site that shows protruding lacustrine deposits alternating with undercut fluvial deposits. Photo taken from Waters, 1983.

Late Holocene timeline

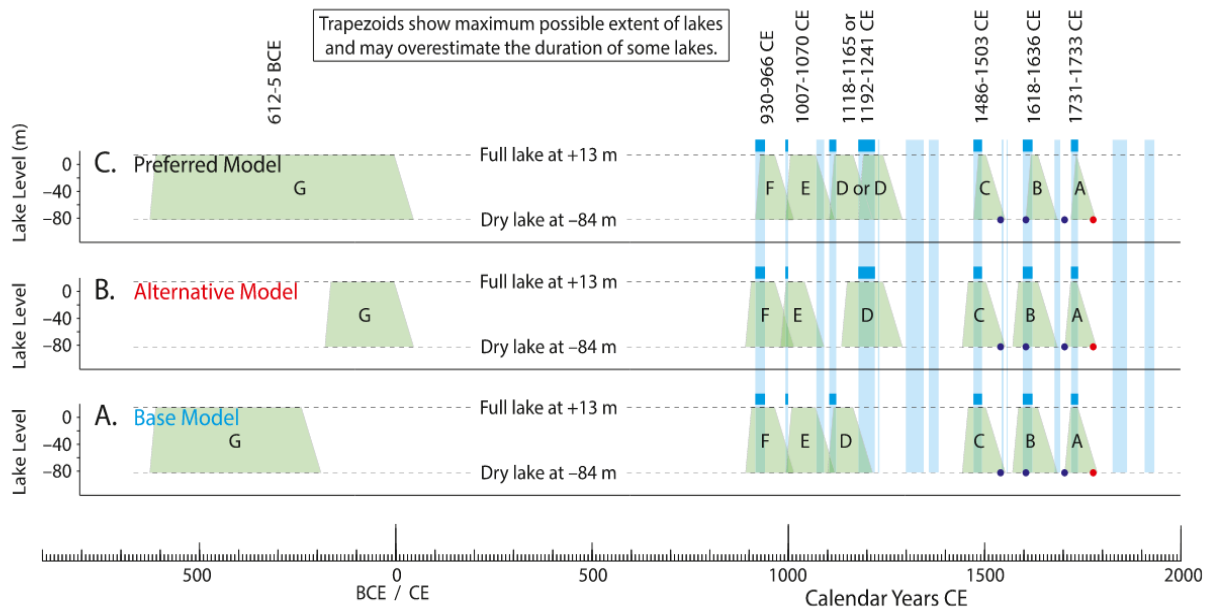


Figure 5: Lake chronology for six lake highstands over the past 1100 years and one highstand before 0 CE, taken from Rockwell et al. (2022). The bottom two chronologies result from applying two different models to radiocarbon dating data. The “Preferred Model” chronology takes dates from both models into account, and then dates are altered based on streamflow reconstruction and historical observations.

Though there is some debate in literature, the consensus seems to be that there were 6 Lake Cahuilla highstands since ~900 CE, and possibly a seventh before 0 CE (Fig. 5). Investigators have constrained the ages of these lake fillings via radiocarbon dating of samples taken from stratigraphic layers in the ancient lakebed. Samples used for recent chronologies, thought to be the most accurate, include tree stumps drowned in the last two highstands (Rockwell et al., 2018), organic mat deposits, and charcoal (Philibosian et al., 2011; Rockwell et al., 2022). Outdated chronologies (Waters, 1983) have used radiocarbon dating of shells from freshwater shellfish found in lake sediments, but these shells sequester carbon from an older reservoir, so they overestimate age (Philibosian et al., 2011; Rockwell et al., 2022). A program called OxCal is used to convert results of ^{14}C dating to calendar years based on known variations of atmospheric ^{14}C (Philibosian et al., 2011).

Recent chronologies have put the most recent filling around 1731-1733 CE. There is no evidence of any lake highstands between 0 and 800 CE. Sparse samples show evidence of a 7th late Holocene filling before 0 CE, but the date range is difficult to constrain (Rockwell et al., 2022). Richard (1980) proposed that several lake Pleistocene shorelines are preserved in the trough, with maximum altitude ranging from 31-52 m, but the absolute ages of these lakes have not been calculated.

Tectonic Setting

Several fault lines, including the San Andreas fault, run through the Lake Cahuilla region. Evidence from paleoseismic site (Fig 6.) study points to 5-7 Earthquakes in the region since 900 CE (Philibosian et al., 2011). These prehistoric earthquakes can often be dated to briefly before or a filling or evaporation of Lake Cahuilla. This association indicates that the diversion of the Colorado river into and out of the Salton trough could be triggered by seismic activity.

Archeology and Historical Records of Lake Cahuilla

Understanding the history of Lake Cahuilla requires combining geologic evidence with historical records and archeological findings. Fish traps, ceramics, and other artifacts found along the 12-meter late Holocene shoreline imply heavy use of lake resources by indigenous Patayan people during this time period (Richard, 1980). Lake fillings occurred prior to official written history of the region by

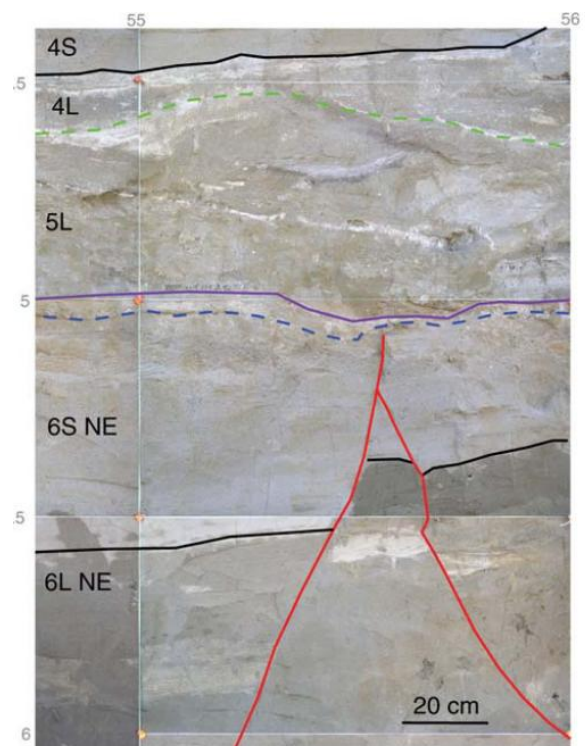


Figure 6: Fault displacement showing evidence of an Earthquake around 930 CE, taken from Philibosian et al. (2011).

European settlers, but oral accounts by indigenous people describe a history of fishing in the lake when it was full (Rockwell et al., 2022). There is also a record of indigenous people informing Spanish expeditions to what is now Yuma, AZ of a lake to the north (Philibosian et al., 2011). Historical accounts from settlers do provide evidence of minor incursions of the Colorado river into the Salton trough in the 1800s that did not result in highstands (Richard, 1980)

A partial avulsion of the Colorado river in 1905, due to river waters breaching an irrigation canal, led to two years of flooding (Rockwell et al., 2022). The flood was stopped by damming the Colorado river to revert it to its previous path, and the remaining water became known as the Salton sea (Richard, 1980). It is maintained by irrigation runoff from Imperial and Coachella valleys; it is high in salinity and contaminants from human activities.

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Flora and Fauna of the Salton Sea

PTY5 590 - Planetary Geology Field Study - Final Report

Introduction

The Salton Sea, located in southeastern California, is the state's largest inland water body. It was formed in 1905 when an engineering failure along the Colorado River caused large volumes of water to flood the Salton Basin. Since then, the lake has evolved into a complex and dynamic ecosystem that supports an extraordinary diversity of flora and fauna [1]. Despite its seemingly inhospitable environment—characterized by high salinity, extreme temperatures, and fluctuating water levels—the Salton Sea has become a vital stopover for migratory birds and an important habitat for both native and introduced species. However, the ecological health of the Salton Sea is under severe stress due to anthropogenic impacts, including agricultural runoff, increasing salinity, and habitat degradation. This report provides an in-depth exploration of the unique flora and fauna of the Salton Sea and its surroundings, while also addressing the ecological challenges that threaten its biodiversity.



Figure 1: American White Pelican (*Pelecanus erythrorhynchos*): A significant portion of the North American population of these large birds can be found at the Salton Sea, where they feed and rest during migration. Credit: National Audubon Society

Flora of the Salton Sea

Aquatic Plant Life

The vegetation around the Salton Sea is primarily characterized by desert scrubland, with plant species adapted to arid conditions and alkaline soils and by salt-tolerant species, particularly phytoplankton and algae. The lake supports extensive blooms of diatoms such as *Cyclotella choctawhatcheeana*, *Thalassionema sp.*, and *Pleurosigma ambrosianum*, which form the foundation of the aquatic food web [2]. These diatoms are well adapted to the saline conditions of the lake and thrive in its nutrient-rich waters. Filamentous green algae, such as *Cladophora*, are also found along the shoreline, often forming dense mats.

These algae provide habitat for small invertebrates and contribute to the complex interactions within the ecosystem. However, excessive nutrient input from agricultural runoff has led to algal blooms, which can cause hypoxic conditions and negatively impact fish populations. It's noteworthy that, contrary to popular belief, the region does not host a multitude of cacti and other succulents. The combination of low annual rainfall and highly alkaline soils excludes many plant species that are otherwise common in the deserts of western North America.

Terrestrial Vegetation

The surrounding desert landscape is characterized by hardy plant species adapted to arid conditions. Common species include mesquite (*Prosopis glandulosa*), saltbush (*Atriplex canescens*), and arrowweed (*Pluchea sericea*), as seen in Figure 2. These plants provide critical nesting and foraging habitat for birds, mammals, and insects. Riparian vegetation along the inflowing rivers, such as the New River and Alamo River, supports additional plant diversity, including willows (*Salix* sp.) and tamarisk (*Tamarix ramosissima*). The latter is an invasive species that has outcompeted native vegetation in many parts of the Salton Sea region.



Figure 2: Saltbush on the coast of the Salton Sea.

Fauna of the Salton Sea

Fish Populations

Despite its high salinity, the Salton Sea has historically supported robust fish populations. Early introductions of species such as the orangemouth corvina, sargo, and gulf croaker in the 1950s helped establish a thriving fishery [3]. However, rising salinity levels have increasingly stressed these populations, leading to massive die-offs (see Figure 3). The most resilient species in the Salton Sea today is the tilapia, which can tolerate extreme conditions. The desert pupfish (*Cyprinodon macularius*), a native species, is also found in the region, particularly in freshwater marshes and the mouths of rivers. This small fish can tolerate extreme environmental conditions and is often found in shallow waters of desert springs and marshes.

Bird Diversity

The Salton Sea is one of the most important avian habitats in North America, serving as a critical stopover on the Pacific Flyway. Over 380 bird species have been recorded at the lake.. Among the most iconic are the American white pelicans (*Pelecanus erythrorhynchos*), which use the sea as a key rest stop during migration. Their striking appearance and massive wingspans make them an unforgettable sight.



Figure 3: 1998 Gulf croaker die-off near Salton City. (Courtesy of Milton Friend) [1]

Burrowing owls (*Athene cunicularia*), a species experiencing population declines in other parts of the state, find a stronghold here, with the Salton Sea region hosting about half of California's population. These small owls nest in abandoned ground squirrel burrows and are active during both day and night. Another avian resident of note is the endangered Yuma Ridgway's rail (*Rallus obsoletus yumanensis*), which depends on the marshes at the southeastern edge of the Salton Sea for breeding and year-round habitat. The Western snowy plover (*Charadrius nivosus*), a near-threatened shorebird, also finds refuge here; the Salton Sea supports the greatest number of interior California snowy plovers [1]. The presence of large fish populations has historically supported large numbers of fish-eating birds, including double-crested cormorants (*Phalacrocorax auritus*) and great blue herons (*Ardea herodias*). However, frequent fish die-offs threaten these bird populations by reducing food availability.

Mammals

Mammals in the region are well-adapted to the harsh desert environment. The desert cottontail (*Sylvilagus audubonii*) is a common sight, often found in areas with sufficient vegetation cover to protect it from predators. Coyotes (*Canis latrans*) are the primary terrestrial predator in the area, playing a key ecological role by regulating populations of rodents and other small animals. Muskrats (*Ondatra zibethicus*), semi-aquatic mammals commonly associated with freshwater environments, inhabit canals and wetlands around the sea, contributing to the maintenance of marsh habitats through their feeding and burrowing behaviors.

Reptiles and amphibians

Reptiles and amphibians are also part of the Salton Sea's wildlife community. Gopher snakes (*Pituophis catenifer*) are non-venomous constrictors frequently observed in the region, often mistaken for rattlesnakes due to their similar appearance. The Western diamondback rattlesnake (*Crotalus atrox*) is a more dangerous but ecologically important resident, helping to control rodent populations. Aquatic reptiles, such as the spiny softshell turtle (*Trionyx spiniferus*), inhabit freshwater ponds and drainage channels that dot the area, demonstrating the surprising diversity of life that persists even in the most saline and arid parts of the Salton Sea basin.

Ecological Challenges and Human Impact

Salinity and Water Quality Issues

The Salton Sea has no natural outflow, meaning that water loss occurs primarily through evaporation. As a result, dissolved salts and pollutants accumulate over time, making the lake increasingly inhospitable to many species [1]. Agricultural runoff from the Imperial and Coachella Valleys carries high levels of nitrogen, phosphorus, and pesticides into the lake, fueling harmful algal blooms and eutrophication. These blooms lead to periodic oxygen depletion, resulting in fish kills and declining water quality.

Invasive Species and Habitat Loss

The introduction of non-native species, such as tilapia and tamarisk, has altered the Salton Sea ecosystem. Tamarisk outcompetes native vegetation in riparian areas, while tilapia dominate the fish community, affecting food availability for birds and other predators. Habitat loss due to receding shorelines further threatens wildlife. As water levels decline, critical wetland areas shrink, reducing nesting sites for birds and disrupting ecosystem balance.

Conservation Efforts and Future Prospects

Efforts to restore the Salton Sea have focused on maintaining water levels, reducing salinity, and improving water quality. The California Salton Sea Management Program aims to create habitat ponds and wetland restoration projects to support wildlife. Proposed solutions include:

- Diverting water from the Colorado River to stabilize water levels.
- Constructing evaporation basins to manage salinity.
- Implementing wetland filtration systems to improve water quality.

Despite these efforts, significant challenges remain. A comprehensive, long-term strategy is needed to balance ecological conservation with water demands in the region.

Conclusion

The Salton Sea is a unique yet fragile ecosystem. Its diverse flora and fauna depend on careful management to ensure their survival. Addressing issues such as salinity, habitat loss, and pollution will require coordinated efforts from conservationists, policymakers, and local communities. Without intervention, the ecological collapse of the Salton Sea could have devastating consequences for its wildlife and the broader region.

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Tectonics of the Salton Trough

Robin B. Van Auken

Overview:

The Salton Sea lies at the northern end of the Salton Trough, a low-lying region that forms the northernmost extension of the Gulf of California Rift Zone. The Salton Trough began to form ~6 million years ago due to interactions between the Pacific Plate and North American plate, along with the opening of the Gulf of California (Lonsdale, 1989; Oskin et al., 2001).

Plate motions 30 Ma - Present:

- >30 Ma (Fig. 3A):
 - The Farallon plate was subducting beneath the North American Plate (Atwater and Stock, 1998).
 - Seafloor spreading was occurring at the East Pacific Rise between the Pacific Plate and Farallon Plate, to the west of the North American Plate (Atwater and Stock, 1998).
- ~12 Ma (Fig. 3B):
 - The Pacific plate came into contact with the North American Plate (Atwater, 1970).
 - Due to the Pacific Plate's sense of motion in relation to the North American Plate, a transform boundary formed (Atwater, 1970).
 - The Farallon plate breaks up into the Juan de Fuca and the Cocos microplates (Atwater and Stock, 1998)

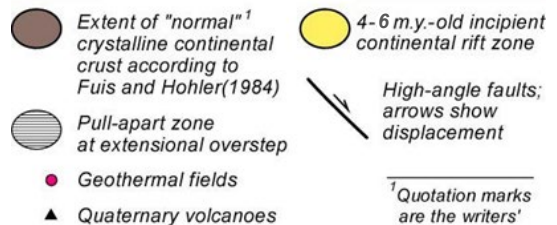
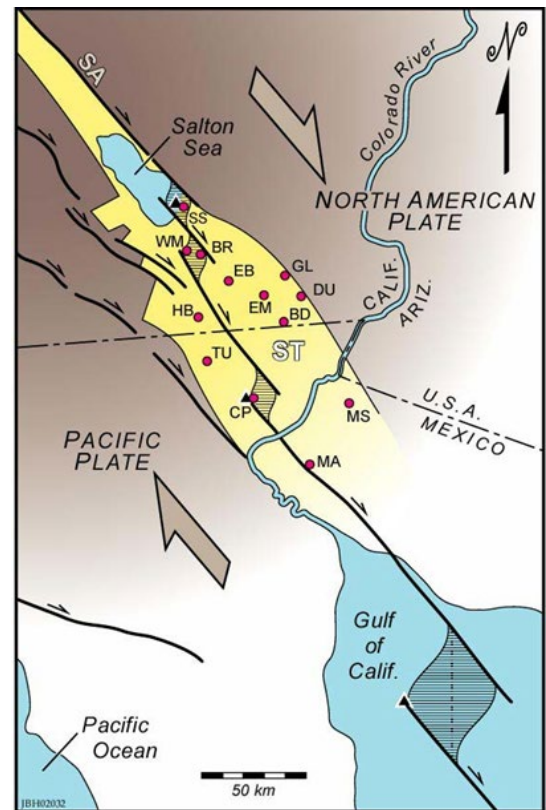


Figure 1. Location and tectonic map of the Salton Trough (ST) relative to the southeastern terminus of the San Andreas transform fault zone (SA) and the tip of the Gulf of California (Hulen et al., 2022).

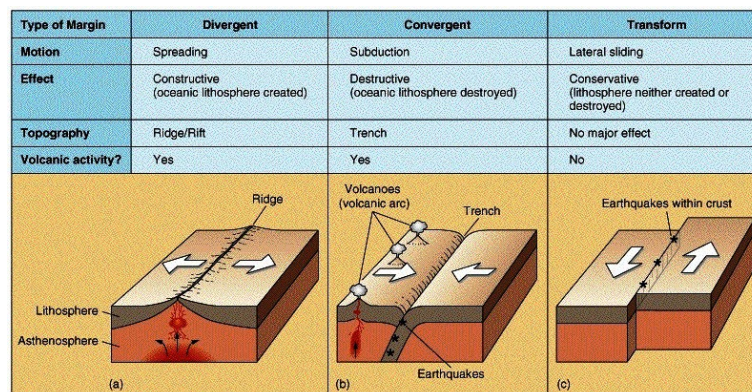


Figure 2. Types of Plate Boundaries (Duarte and Schellart, 2016).

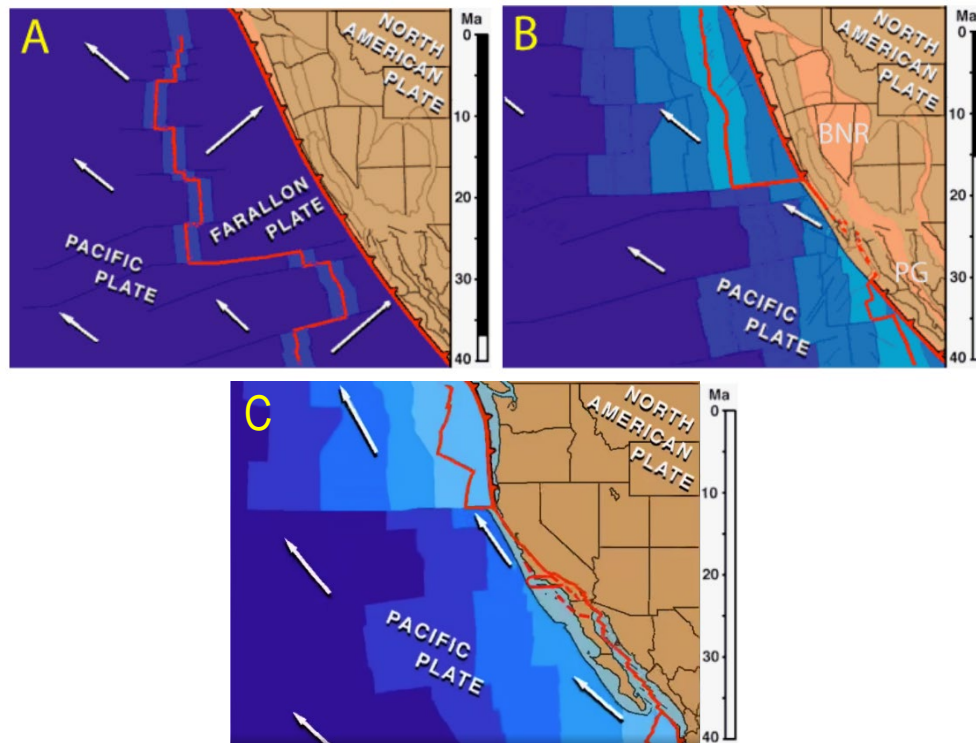


Figure 3. Tectonic History of the North America - Pacific Plate Boundary A) ~38 Ma; B) ~12 Ma; C) Present Day (Atwater and Stock, 1989)

- ~12 – 6 Ma:
 - Subduction ends beneath the entirety of what will be the Baja Peninsula, but it is still connected to the North American Plate (Van Wijk et al., 2017).
 - The Tosco-Abrejos fault to the west of the Baja Peninsula accommodates strike-slip motion (Spencer and Normark, 1979).
 - The ~20° angle between the plate boundary orientation and the direction of Pacific–North American motion produced oblique extension on the eastern side of the Baja Peninsula, forming the Gulf Extensional Province and eventually the Gulf of California (Umhoefer, 2011).
- ~6 Ma (Fig. 3C):
 - Seafloor spreading begins within the Gulf of California and the plate boundary shifts inland (Lonsdale, 1989; Umhoefer et al., 1994)
 - Salton Trough and the Gulf of California begin to form.
- Present Day (Fig. 4): The Gulf of California Rift Zone marks a transition between strike-slip motion along the San Andreas Fault to the north and seafloor spreading at the East Pacific Rise to the south. This rift system encompasses continental transtensional rifting in the north, expressed by the Salton Trough, and oceanic transtensional rifting within the Gulf of California itself.

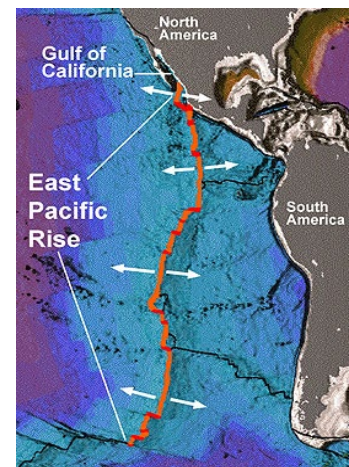


Figure 4. The Gulf of California lies at the northern end of the East Pacific Rise. Base image modified from “Age of the Ocean Floor” Poster (NOAA National Geophysical Data Center, 1996).

Tectonic Evolution of the Salton Trough:

- ~6 – 4 Ma:
 - The Brawley and Cerro Prieto Pull-Apart Basins begin to form between en-echelon transverse faults within the Salton Trough. Specifically, the Brawley Pull-Apart Basin formed between the San Andreas Fault and the Imperial Fault and the Cerro Prieto Pull-Apart Basin formed between the Imperial Fault and the Cerro Prieto Fault (Suárez-Vidal et al., 2008).
- ~2.5 Ma:
 - The Elsinore Fault formed to further accommodate strike slip motion in the region (Hull and Nicholson, 1992).
- ~1.2 Ma:
 - The San Jacinto Fault Zone formed to accommodate the complexity and transpression associated with the Big Bend (Fig. 7) of the San Andreas Fault (Morton and Matti, 1993). Lute Ridge is a fault scarp in SJFZ along Clark Fault (slip rate 10 ± 2 mm/yr) (Ryter, 2002).

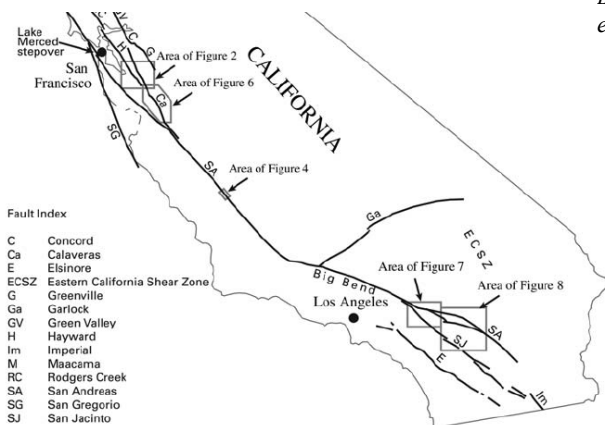


Figure 7. Faults in Southern California, as well as the Big Bend, a restraining bend in the San Andreas Fault (Graymer et al., 2007).

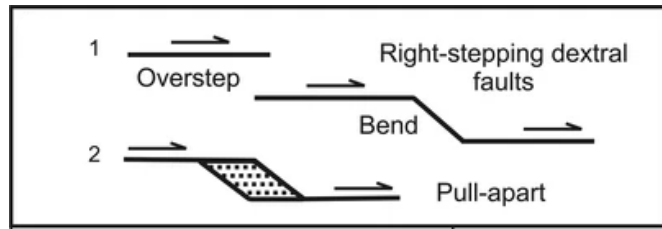


Figure 5. En echelon right-stepping dextral strike-slip faults. Pull-apart basins form at the overstep or bend (Atmaoui et al., 2006).

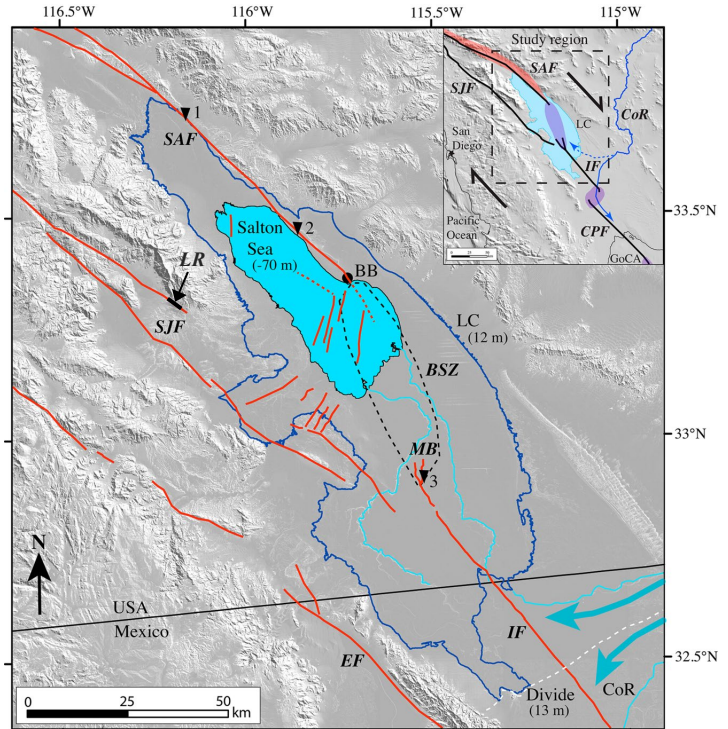


Figure 6. Fault map of the Salton Sea Area. Active faults are shown as red lines, and Lake Cahuilla (LC) high shoreline as a dark blue line. SAF—San Andreas fault; SJF—San Jacinto fault; CPF—Cerro Prieto fault; IF—Imperial fault; EF—Elsinore fault; LR—Lute Ridge; BB—Bombay Beach; BSZ—Brawley seismic zone; MB—Mesquite Basin; CoR—Colorado River; GoCA—Gulf of California (Brothers et al., 2022)

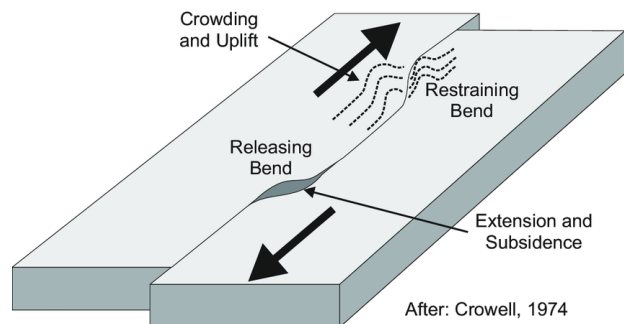


Figure 8. Sketch showing areas of convergence at restraining bends and areas of extension at releasing bends along sinuous strike-slip faults. (Crowell, 1974).

Planetary Analogs:

Subsumption (Europa):

- Plate reconstructions of Europa's ice shell revealed an area of convergence ~99 km (Kattenhorn and Prockter, 2014) to >80 km wide (Collins et al., 2022) (Fig. 9).
- Subsumption, a type of icy-plate subduction was proposed to explain the loss of material (Fig. 10).

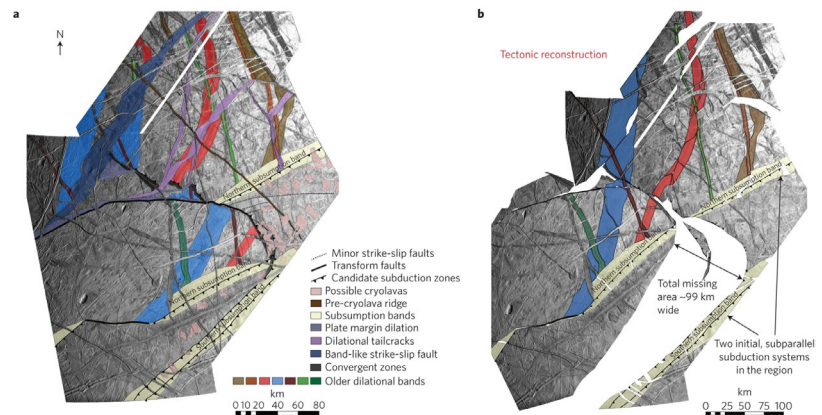


Figure 9. (a) Present day surface (b) A zone of missing surface area (white space) ~80 - 99 km wide occurs on the NW side of the southern subsumption band and is interpreted to have subducted (Kattenhorn and Prockter, 2014).

Plume Induced Subduction (Venus):

- Subduction sites have been proposed around coronae, features unique to Venus.
- Models suggest that as a mantle plume rises, it causes the overlying lithosphere to flex upward and fracture due to tension. Plume material then upwells through these fractures and spreads laterally, eventually loading the lithosphere and causing it to bend and sink, initiating a new mode of plume-driven resurfacing and localized subduction (Davaille et al., 2017) (Fig. 11).

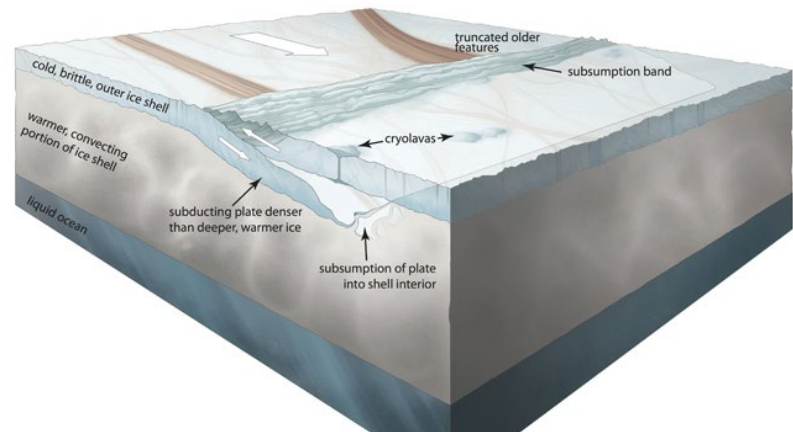


Figure 10. Recycling of surface area through the subduction of a cold, brittle, outer portion of the ice shell into its warmer interior, where it is ultimately subsumed (Kattenhorn and Prockter, 2014)

Pull-apart features (Europa):

- Astypalaea Linea is an 810 km long strike slip fault near Europa's south pole that has an estimated offset of ~42km (Kattenhorn, 2014).
- There were steps or bends along the fault, where pull-apart features have formed due to the strike-slip motion (Kattenhorn, 2004) (Fig. 12).

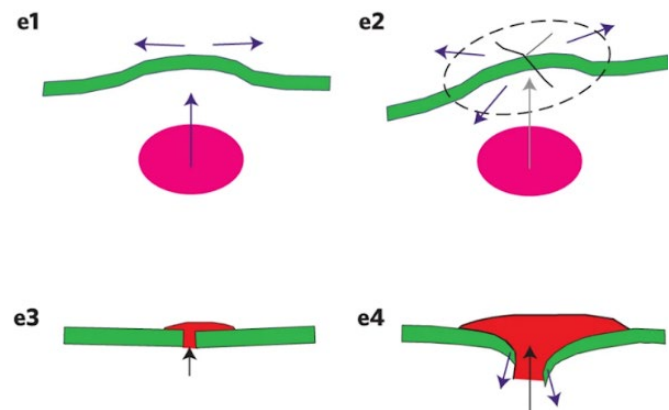


Figure 11. Schematics showing the development of plume-induced subduction (Davaille et al., 2017).

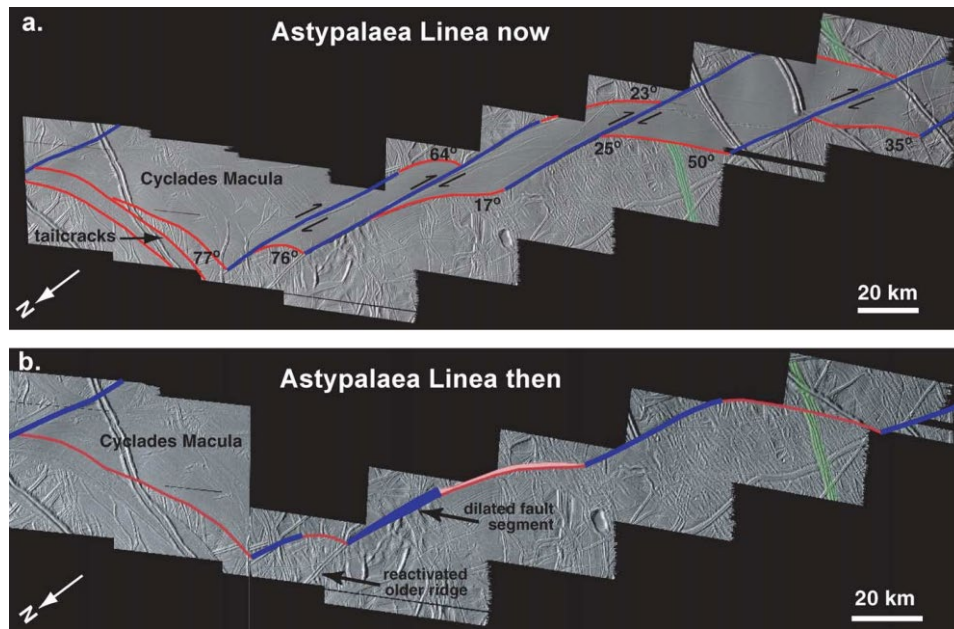


Figure 12. Astypalaea Linea is a fault that consists of several segments (blue lines) that underwent strike-slip motion and formed pull-apart features (Kattenhorn, 2004).

- The interior of these pull-apart features has filled with younger, resurfaced terrain, likely from the upwelling of warmer, mobile subsurface ice (Fig.12).

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Mud Volcanoes

Mud Volcanism in the Salton Sea

Sediments seep to the surface on the southeastern shore of the Salton Sea (Fig. 1), creating gryphons (steep-sided cones) and mud pots (Fig. 2). These oozing and bubbling features are surface expressions of subsurface activity and can provide a window into otherwise unseen processes.

Several sets of mud pots and gryphons, including those near the Davis-Schrimpf intersection, can be seen in the Salton Sea Geothermal Field. As the sea's water level has fallen, more clusters of such features have been found, lining up parallel to a local fault zone linked to the San Andreas fault zone (Onderdonk et al., 2011). These features are

examples of mud volcanism, a process in which relatively low-temperature mud is extruded onto a planetary surface (Oehler & Allen, 2010).

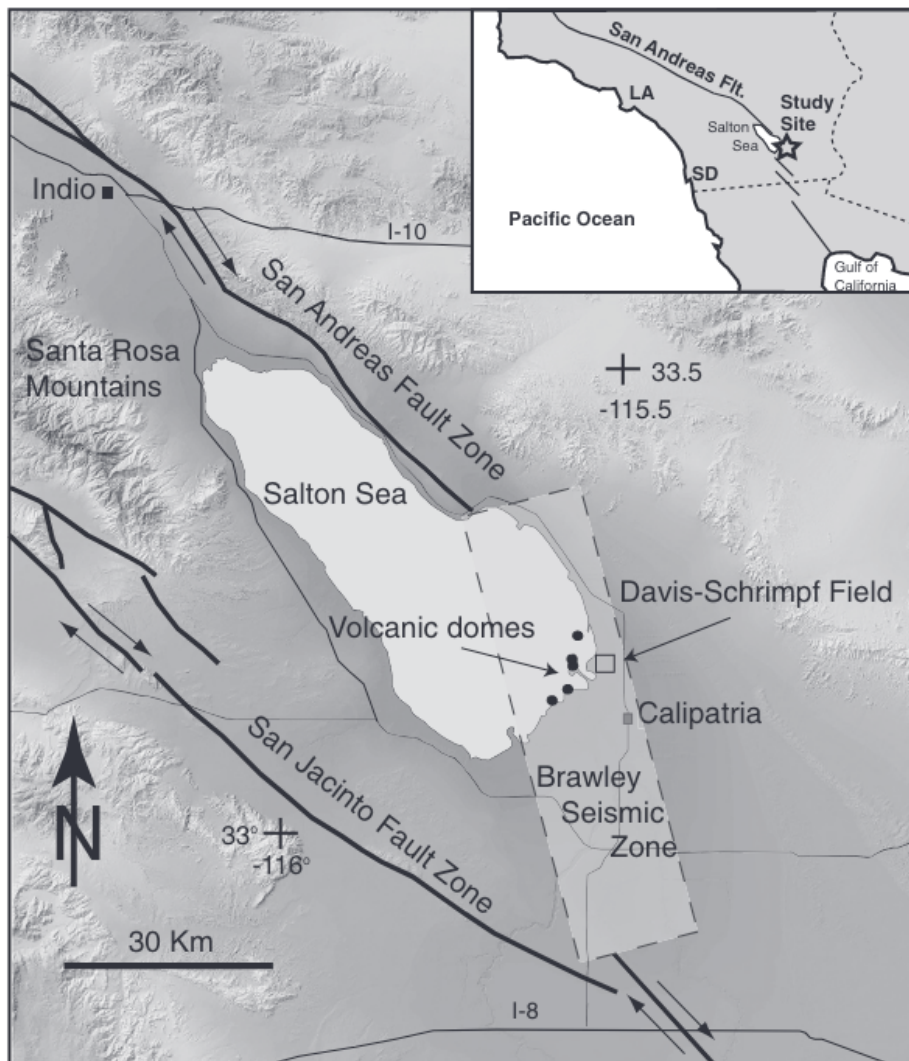


Figure 1. Map of the Salton Sea area showing the locations of major faults and the Davis-Schrimpf field. Figure from Onderdonk et al. (2011).



Figure 2. Gryphons and pools in the Salton Sea Geothermal Field. Note gas bubbles in foreground pool. Approximately 2 m-tall person for scale. Figure from Onderdonk et al. (2011).

Mud Volcano Formation Mechanisms and Rheology

When lower-density sediments containing water are covered by higher-density sediments, the lower-density sediments are pressurized and seek a path of least resistance. If a weakness in the overlying sedimentary layers is found or created (e.g., by faulting), they can follow that path upwards. This is how many, but not all, mud volcanoes form (Mazzini & Etiope, 2017).

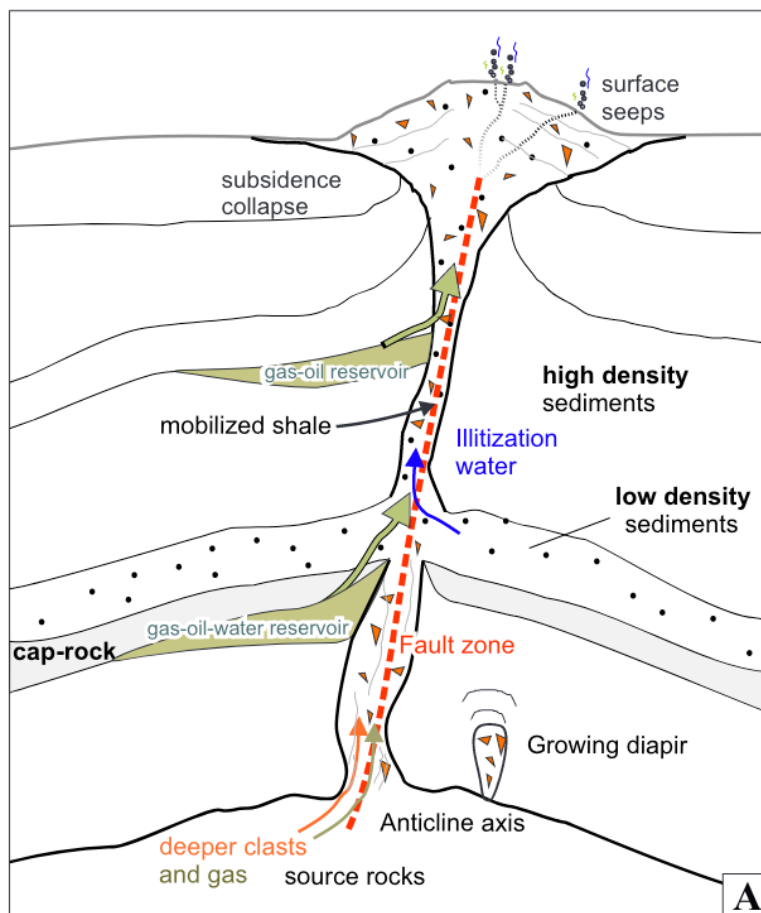


Figure 3. An example of mud volcano structure, from Mazzini & Etiope (2017).

The rheology (flow mechanics) of mud volcanoes is complex, as their mud contains solids along with liquids like water or oil and gases like carbon dioxide or methane. The size, composition, and distribution of materials, especially bubbles, in a mud volcano all affect its eruption characteristics (Mazzini & Etiope, 2017).

Often the mud acts as a non-Newtonian fluid, behaving like a solid at lower pressures but as a liquid at higher pressures. In this way, if the **yield stress** of buried mud is exceeded, it can begin to flow. This is critical to the formation of mud volcanoes.

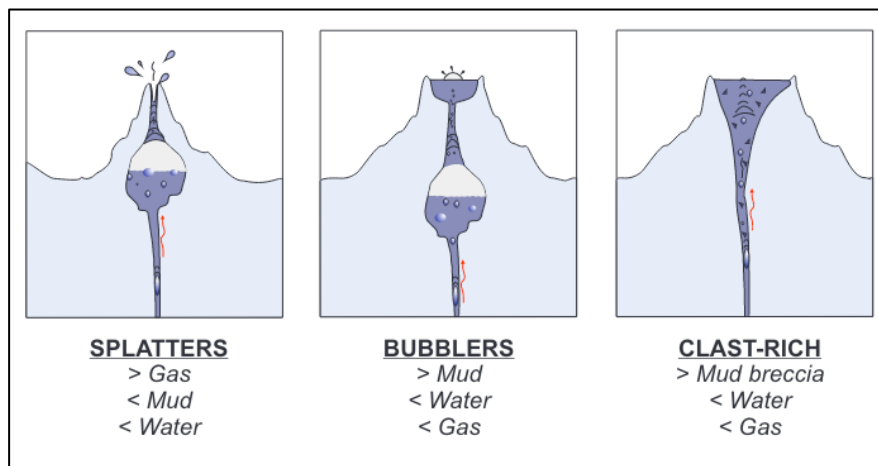


Figure 4. A simplified model of how mud composition affects eruption style, from Mazzini & Etiope (2017).

The behavior of these features is also time-dependent, sometimes episodic, and they can become dormant as conditions change. The mud volcanoes around the Salton Sea were far more active in the past, for example. Cahuilla leader Francisco Patencio recalled that in the early 20th century, near the Hell's Kitchen boat landing / restaurant / dance hall on Mullet Island, "There were acres of boiling mud springs all around. They were very hot. They boiled and hissed. No one could get close to them, for the ground was very sticky and the air was poisoned with gas. The hot gray mud piled on itself until it rose [6 meters] in the air. Then it fell, to build up once again. The steam rises from the center of the mud stacks and at the top, mud could be seen jumping and whirling. Many lives have been lost going too near them." (Oglesby, 2020; Patencio, 1971).

Mud Volcanoes on Mars?

Many cones on Mars, some pitted, look like the surface expressions of mud volcanoes on Earth, providing evidence for mud volcanism on Mars. These features could indicate the past presence of water-rich sediments (Oehler & Allen, 2010). On Earth, mud volcanoes are often associated with hydrocarbon deposits (Cartwright et al., 2007), so they could also be a good place to look for organic materials on Mars.

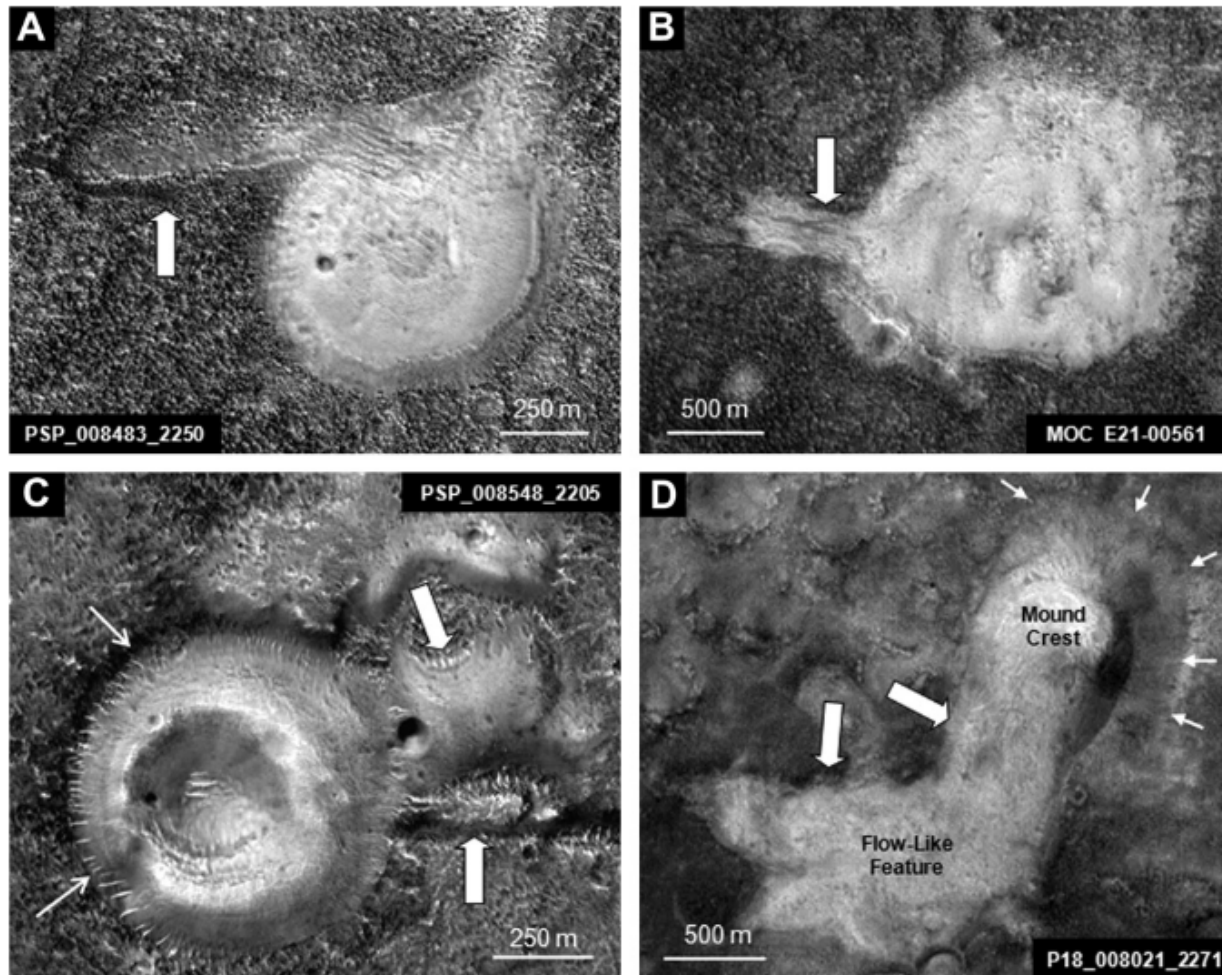


Figure 6. Mud volcano candidates with apparent flow features, in Acidalia Planitia, Mars. Figure from Oehler & Allen (2010).

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High-Silica Volcanism in the Salton Trough

Kiki Gonglewski



Figure 1: Moonset at Rock Hill

Introduction

The Salton Sea region of Southern California, located within the tectonically active Salton Trough, hosts a geologically significant example of high-silica volcanism. This activity is most notably expressed by the Salton Buttes, a cluster of five rhyolitic lava domes. These features offer insight into the interplay between tectonic extension, magmatism, geothermal activity, and volcanic hazards in a rift setting.

Geological and Tectonic Setting

- The Salton Trough is a pull-apart basin formed by the interaction of the San Andreas and San Jacinto Faults, marking the onshore extension of the Gulf of California spreading center [1, 5].
- The region is characterized by active subsidence, seafloor spreading, high heat flow, and intense geothermal activity [2].

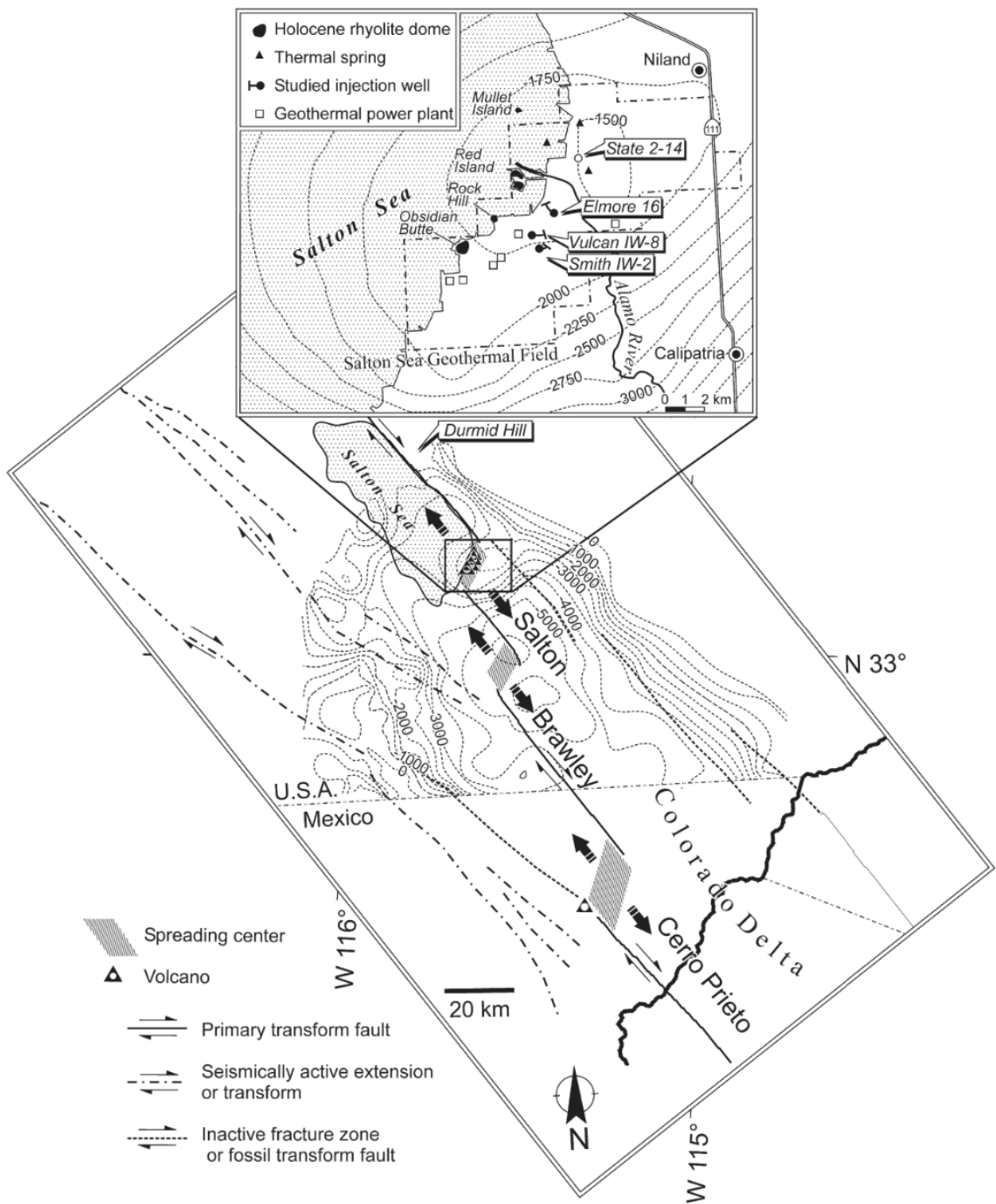


Figure 2: Map of the Salton Trough showing the location of the Salton Buttes, major faults lines and pull-apart basins. [4]

- The Salton Sea Geothermal Field (SSGF) lies within this zone and produces power for over 325,000 homes [5].

The Salton Buttes: Morphology and Composition

- The Salton Buttes's five rhyolite lava domes (as shown in Figure 3 and described in Table 1) rise 30-40 m above the terrain and span roughly 7 km in length.
- They are composed of alkaline, calcium-poor rhyolite with scarce phenocrysts of amphibole, quartz, zircon, and various feldspars [1].
- Obsidian textures are common, and Obsidian Butte has been heavily quarried .

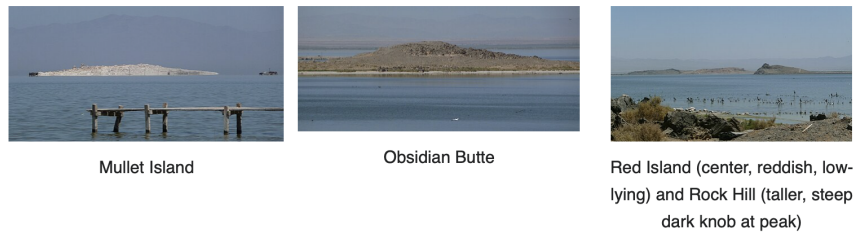


Figure 3: The Salton Buttes's five rhyolite lava domes: Mullet Island, North Red Hill, South Red Hill, Rock Hill, and Obsidian Butte [1]



Figure 4: Rock formations near Obsidian Butte, one of five Holocene rhyolite lava domes in the Salton Buttes chain. The glassy texture reflects rapid cooling of the high-silica magma.

Holocene Eruptive History

- Radiometric dating (Ar-Ar, U-Th) and paleomagnetic data confirm that all five domes erupted during the Holocene (current geological epoch starting from around 11,000 years ago), contradicting earlier Pleistocene estimates [6] as shown in Fig. 5.
- Eruption periods:
 - **Mullet Island:** poorly constrained, possibly 2300–7700 cal BP.
 - **Obsidian Butte:** $\sim 2.86 \pm 0.96$ ka.
 - **Red Hills and Rock Hill:** $\sim 2.83 \pm 0.60$ ka, paleomagnetic evidence suggests ~ 1800 BP.
- Volcanism occurred over a ~ 5400 -year window (5900 to 500 BP) [6].
- South Red Hill may have erupted through water, as indicated by pyroclastic textures.

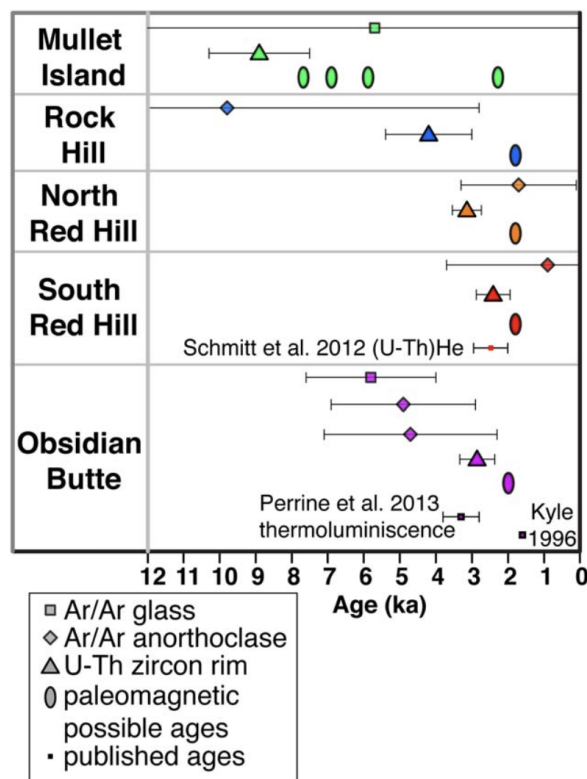


Figure 5: Summary of $^{40}\text{Ar}/^{39}\text{Ar}$ and ^{238}U – ^{230}Th age determinations for the Salton Buttes domes for Ar-Ar (2σ uncertainties) and U-Th (95% confidence intervals) dating. Also shown are paleomagnetic age constraints consistent within the uncertainty range of the radiometric dates, alongside previously published eruption ages. [6]

Buried Pleistocene Rhyolites and the Deep Magmatic System

- Drilling has revealed rhyolites at depths of 1.6–2.7 km within the SSGF in wells Smith IW-2, Vulcan IW-8, and Elmore 16 [4].
- These rhyolites are 420–479 ka in age and overprinted by hydrothermal alteration due to ambient temperatures of 200–300°C.
- Geochemical indicators suggest they were derived from the remelting of hydrothermally altered MORB-type crust.
- These buried rhyolites indicate episodic felsic magmatism that predates Holocene volcanism by over 400,000 years.

Silica Deposition in the Geothermal Field

- SEM and XRD studies of scale deposits in wells such as 68-20RD show opal-A (broad $22^\circ 2\theta$ peak) and quartz (21.5° , 26.8°) [3].
- Silica spheres coalesce into larger forms, forming strands and sheets over time.
- Tube-like silica structures may represent silicified microbial life [3].

Volcanic Hazards and Monitoring

- The USGS classifies the Salton Buttes as having “High” threat potential [5].
- The region experiences persistent seismicity, fumaroles, and geothermal activity.
- Proximity to populated areas (e.g., Calipatria, Brawley) heightens risk.
- Monitoring includes dense seismic networks, gas surveys, and geodetic tracking.

Conclusion

High-silica volcanism in the Salton Sea region represents a rare and complex intersection of active rifting, felsic magmatism, and geothermal processes. The Salton Buttes provide a Holocene surface expression of a long-lived magmatic system that includes buried rhyolites, rapid sedimentation, and intense heat flow. Their classification as a high-threat volcanic system highlights the need for continued study and monitoring.

Dome	Personality	Fun Fact
Mullet Island	Older sibling with well-guarded lore	We don't even really know when it erupted; Probably the oldest.
Obsidian Butte	The dramatic middle child who is way too popular at school	Famous for its obsidian glass texture and being extensively quarried.
North + South Red Hill	The chaotic twins	Likely erupted within ~ 100 years of each other; geologically inseparable.
Rock Hill	The overlooked wallflower	Erupted around the same time as the twins but no one ever really remembers.

Table 1: Just for fun: unofficial personality chart for the Salton Buttes domes, based on zero scientific rigor but maximum affection.

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Formation of the Salton Sea

Lily Robinthal

PTY5590, Spring 2025

Introduction

The Salton Sea is not what comes to mind when one thinks of a desert oasis. California's largest lake, located in the southern region of the state about 25 miles south of Joshua Tree National Park, has experienced significant ecological decline in the latter half of the 20th century and is now a strange dystopian wasteland haunted by the ghosts of dead fish—but this was not always the case. For the first half of the 20th century it was an important agricultural resource and eventually a thriving tourist destination. While it resides in the Salton Basin, where the ancient Lake Cahuilla would periodically come and go, the iteration of the lake as it is known in the 20th and into the 21st century is the result of a confluence of human activity and natural processes.



Figure 1. Left: Map of the Salton Sea Region (US Fish and Wildlife Service). Right: The Salton Sea from the air (Dennis R. Dimick, National Geographic)

Setting the Stage

In 1900, the Salton Basin had been dry for over two centuries. Prior to this, the region experienced periodic flooding from the Colorado River over the course of 1300 years, leading to an oscillation of the region between a fertile, thriving ecosystem and a harsh, dry wasteland [1]. Given the year-round balmy temperatures of southern California, it was with the potential for agriculture in mind that led the California Development Company to begin creating irrigation channels from the Colorado River to the basin [2]. However, large quantities of silt from the river would regularly block these channels, leading to water shortages beginning in 1902. These shortages continued through 1904, at which point the company was facing pressure from those

who depended on the irrigation system to support their crops and their livelihoods. In an attempt to alleviate this problem, the company made additional, unprotected diversions from the river into the canal. This did allow water to flow unimpeded, but with this hasty solution there was no infrastructure built to control the water now filling the canal in large volumes, or to prevent the erosion of these smaller connecting channels [2]. This may have been manageable had the river continued flowing as it had for the past two centuries—indeed, the main concern was a dearth of water, not overwhelming quantities—but the company failed to reckon with the realities of geologic time, as so many of us do.

The Flood

In 1905, as it had done many times in the course of its long life, the Colorado River began its natural cycle of overrunning its banks. This unanticipated influx of water led to a breach of the newly created connecting channel and the subsequent flooding of the valley to which it led [2]. Efforts to stem the flow and redirect the river to its original path were unsuccessful; by mid-1905 the entire volume of the Colorado River was emptying into what was rapidly becoming the Salton Sea. By 1906, all structures that had been built in an attempt to control the breach had been destroyed [2]. It took until 1907 for the flood to be stemmed and the river to be redirected on its original path to the Gulf of California [2]--and it left behind a brand new, but historically precedented, lake.



Figure 2. They took the Chevy to the Levee but the Levee was NOT dry. Attempts to stem the floodwaters sometime between 1905 and 1907. (Photo courtesy of the Salton Sea History Museum via The Imperial Valley Press.)

The Aftermath

Following the flood, the nascent sea would likely have dried up as it had in the past, due to its status as a terminal lake—it has no natural inflow and no means for water to escape except through evaporation [3]. However, the agricultural industry of the region seemed to adopt the attitude of “if life gives you lake, fill it”, and began using it as a reservoir for agricultural runoff. This allowed the sea to remain at a relatively steady level, although this runoff was its only source of inflow [3]. After being used perpetually in the manner for almost 20 years, President Coolidge designated the lake an “agricultural sump” in 1924 [4]. This constant influx of nutrients and minerals supported a diverse ecosystem of microbial life [4], as well as a population of fish that had been swept in during the initial formation flood and additional species that had been artificially introduced [3]. The sea also quickly became a haven for migrating birds, supporting more than 400 species [5]. It wasn’t long before this desert oasis began attracting human visitors as well.



Figure 3. Bird visitors enjoying the Salton Sea. (Katherine Ramos via The Desert Review)

The Heyday

The popularity of the Salton Sea as a tourist destination started off modestly, drawing a few thousand visitors per year mostly engaged in fishing [6]. Following WWII, however, lake-side communities began to spring up on its shore, and the sea started to become a hub for speedboating, waterskiing, and general beachside merriment. By the mid-1950s, The yearly visitation rate grew exponentially to 1.5 million per year [5], and it drew a wide variety of high-profile guests, including Frank Sinatra and the Beach Boys [7].

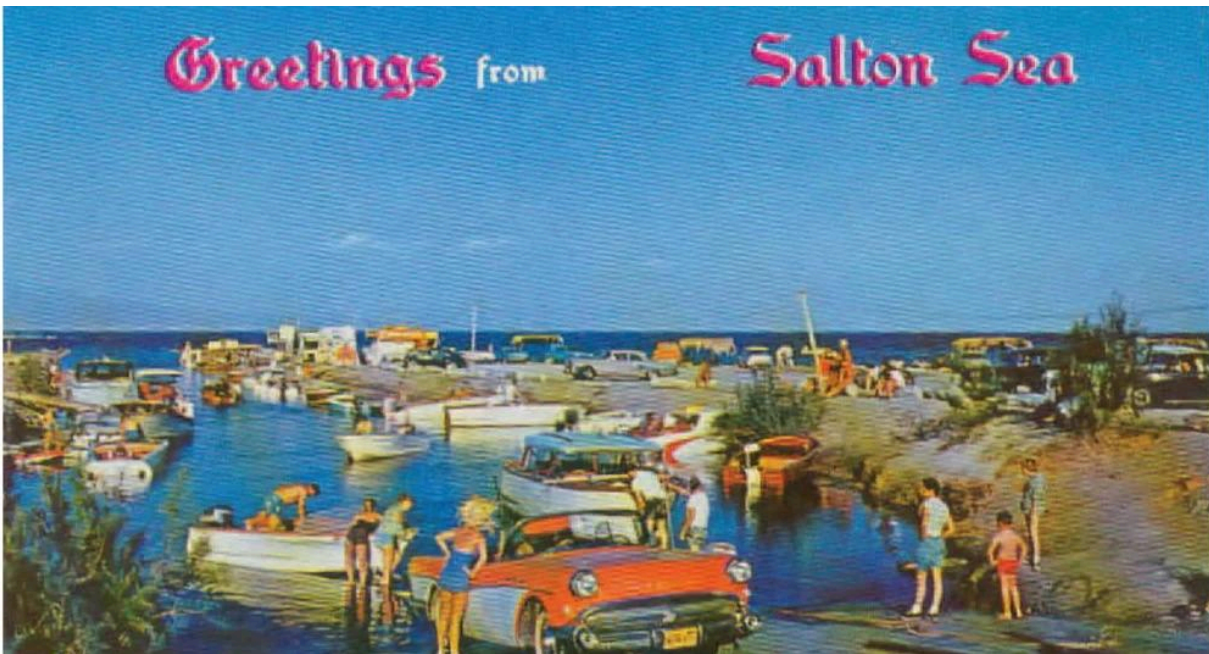


Figure 4. A vintage postcard showcasing the delights of the Salton Sea.

At the time, it seemed as though this halcyon state would last forever, but it was not to be—the Salton Sea’s doomsday clock was ticking. The agricultural runoff whose nutrients had initially jumpstarted the ecosystem also brought pollutants and minerals, which, with nowhere for them to go, led to a rapid, devastating increase in salinity and toxicity. Algae blooms and fish die-offs became more frequent [3]. But the tale of the sea’s decline is one for another time; perhaps, as we wander the fishy shore, we can hold in our mind an image of an inadvertent lake’s former glory.

Conclusion

It would be easy to misconstrue the events precipitating the formation of the Salton Sea as accidental, haphazard, the result of industrial carelessness. It would also not be a stretch to view the sea as a metaphor—one of humankind’s folly in underestimating the rhythms of the natural world, one where a sense of control is fleeting and the toxic, salty consequences of

monetizing our environment are quick to come. These are perhaps true to an extent—but it is important to emphasize that the existence of the Salton Sea is not the accidental result of human blundering, but part of a much larger cycle for which the ancient Lake Cahuilla sets a precedent [2]. Too, the sea is not an artificial aberration that should be left to languish in the desert—it remains a vitally important ecosystem for birds and other wildlife, and should be cared for as such. There is much that can be taken from the tale of the rise and fall of this saline sea—but perhaps the extent of what it can teach us lies beyond the surface level.

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How the Salton Sea Became an Environmental Disaster

After the modern Salton Sea formed in the early 20th century, it became a popular resort destination for several decades. It reached its peak popularity in the 1950s and 60s, attracting visitors for swimming, hiking, fishing, and more. Ultimately, however, the same waters that had allowed the Salton Sea to survive for decades created a new ecological disaster.

After the initial formation of the modern lake, there has been limited inflow from rivers, and what rivers do flow into it brought tons of agricultural runoff. Since the water has no outflow, any minerals, pollutants, etc. that the rivers run over accumulate in the lake over time.



Fig. 1 - Alamo River into the Salton Sea (from Fendt, 2020)

In the early days of agricultural development in the nearby Imperial Valley, the favored method of irrigation for the region's farms was through "flood irrigation." In this method, huge volumes of water are delivered by rivers or pumped in to flood farms. Some portion of the water would soak into the ground for crops to use, while the rest would run into the local watershed. Much of that water ended up in the Salton Sea, carrying all of the farm's fertilizers, pesticides, and more with it, including chemicals like DDT that have been banned since that time. The waters also picked up salt from nearby deposits, leaving the lake highly saline. As a result of the flood irrigation method, the Salton Sea was able to survive for decades at a relatively stable size.

Eventually, the region's farmers switched to a more efficient irrigation system, leaving the leftover water to be pumped further west to San Diego. This was good for the Salton Sea's environment in some ways, as it meant polluted runoff was no longer a major source of water for the lake. Unfortunately, that left the lake without much of an intake at all, and evaporation

significantly outpaced inflow. Gradually, the Salton Sea is now evaporating, shrinking in size and getting shallower as the years go on. This has been exacerbated by the recent droughts in California, leading to rapid shrinkage. As the lake evaporates, all of the minerals, fertilizers, pesticides, and more are getting more and more concentrated in the remaining water. The Salton Sea's salinity is now more than twice that of the Pacific, and there is extreme enrichment in some compounds such as nitrates that have been brought in as fertilizer. As a result, there have been huge algal blooms that have led to mass die-offs of the fish and birds that once called the lake home.



Fig. 2 - Fish dieoff after a massive algal bloom (left) and a pelican being given fluids to aid recovery from botulism during an outbreak (Cohn, 2000).

As the lake evaporates, the lakebed is gradually being exposed, revealing animal carcasses, ruins from the Sea's "golden age", and desiccated soil. Now, that soil can be picked up by wind and carried great distances. It would be hazardous enough on its own, as a new source for dust storms to form and affect the region, but that dust is also full of chemicals from the agricultural runoff that fed the lake in the first place. This has significant deleterious effects for the region's people, plants, and animals. The local population has extremely high asthma rates compared to the national average, and people with asthma deal with harsher effects due to the poor air quality. Furthermore, the freshly exposed carcasses from the lakebed as well as the animals that die due to the new environmental problems result in a terrible odor that has at times reached as far as Los Angeles.

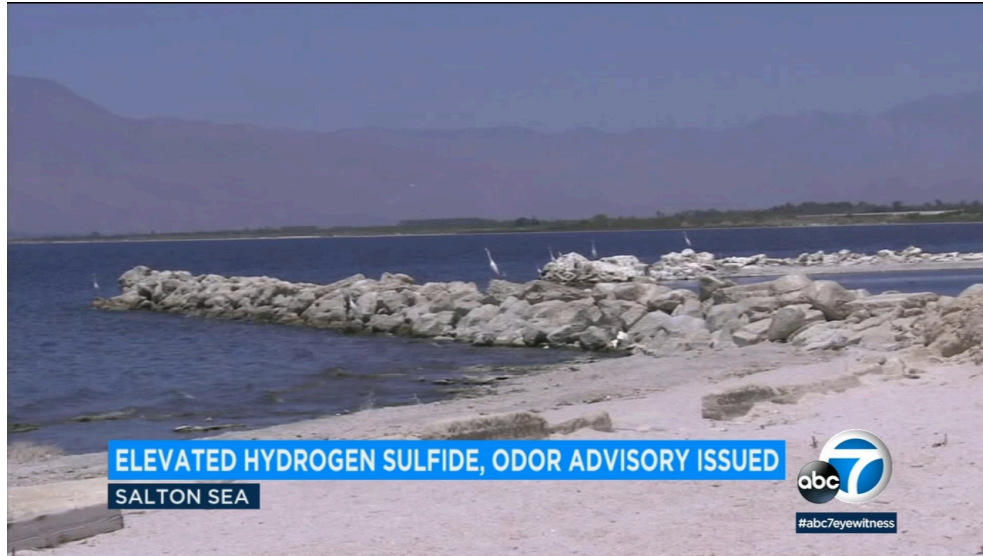


Fig. 3 - Odor warning in Coachella Valley, Aug. 2019

Today, the Salton Sea continues to shrink as the water evaporates. Despite the environmental threats, the nearby Imperial Valley is massively important as a source of fruits and vegetables for as much as $\frac{2}{3}$ of the USA's winter produce supply. Efforts have been made to reach agreements between local farmers and others who make use of water in this region (including the city of San Diego and the state government) in order to bring water back to the Salton Sea and try to rectify the disaster that has been building for the last century. However, those efforts have stalled, leaving the Salton Sea area and Imperial County with exceedingly high rates of respiratory health problems and unemployment.

There is a comparison to be made to the Aral Sea, another endorheic lake that has had its source cut off. In that case, the Aral Sea (located on the Kazakhstan-Uzbekistan border) had its source waters redirected by the Soviet government in the 1960s. Since then, it has dramatically shrunk, with only a tiny sliver of highly saline lake left today. The rest of the former lakebed has become a desert, leading to massive die-offs of local fauna and a humanitarian disaster. As with the Salton Sea, there are some efforts to try to at least stop the problem from getting worse, but these are huge ecological problems that are very difficult to solve.

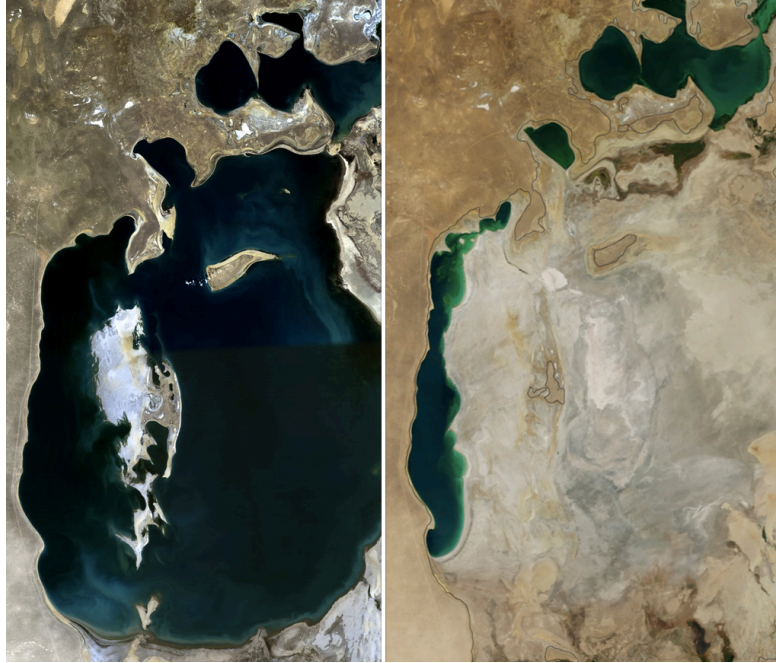


Fig. 4 - Aral Sea in 1989 (left) and 2014 (right)

Planetary Analog

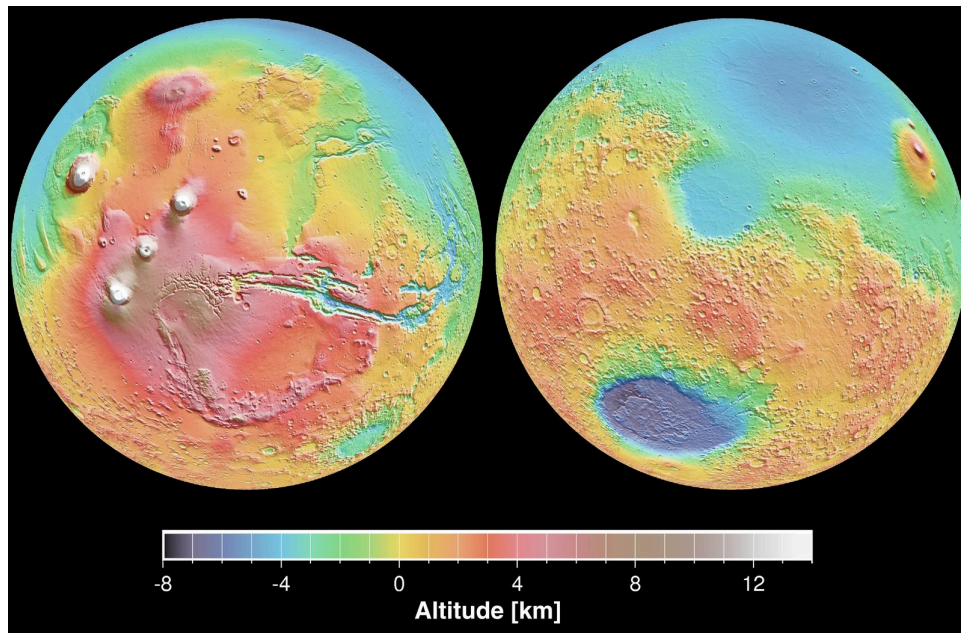


Fig. 5 - Mars Topography (from JPL)

As the era of Martian water came to an end, water would have been left to evaporate in basins and low-lying areas. As there were no pesticides, fertilizers, etc. (or a living environment), this would have been less of an issue than at the Salton Sea. Still, these waters would have been gradually enriched in various minerals that had been transported by flowing water. Deposits of minerals in places such as Hellas could inform understanding of the region's watershed structure and the ancient topography, if it differed from the modern topography.

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Alluvial Fans and their Interactions with Tectonics

Euibin Kim

Alluvial fans are cone-shaped accumulations of coarse sediment (alluvium) deposited at the transition from confined flow in a canyon to unconfined flow in a basin. As the slope shallows and the flows spread out, the flows slow down and deposit much of the sediment that they were able to transport in the canyon [1].



Figure 1. Alluvial fan forming in the Badwater Basin in Death Valley

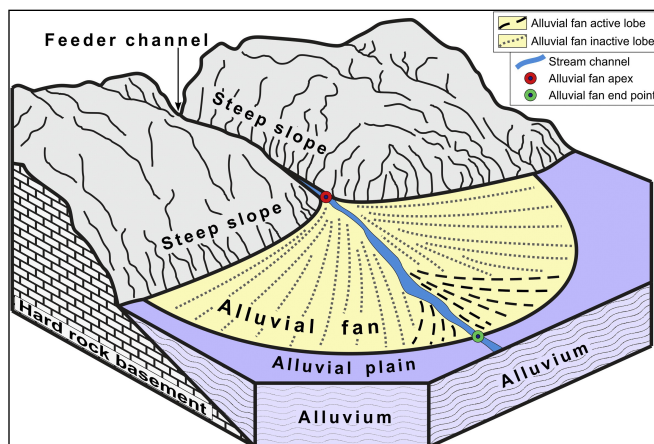
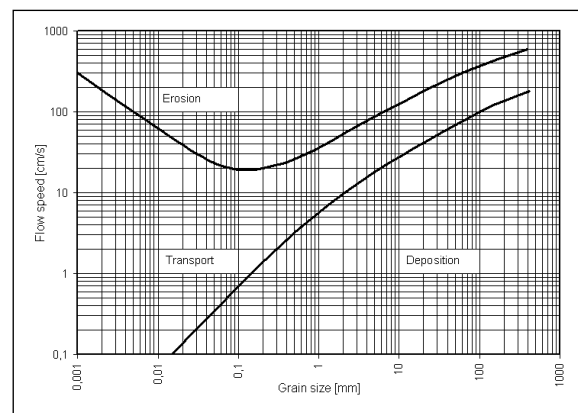


Figure 3. A Hjulstrom chart, describing transport, deposition, and erosion in streaming water [1].

Figure 2. A schematic representation of a typical active alluvial fan at a mountain front [2].



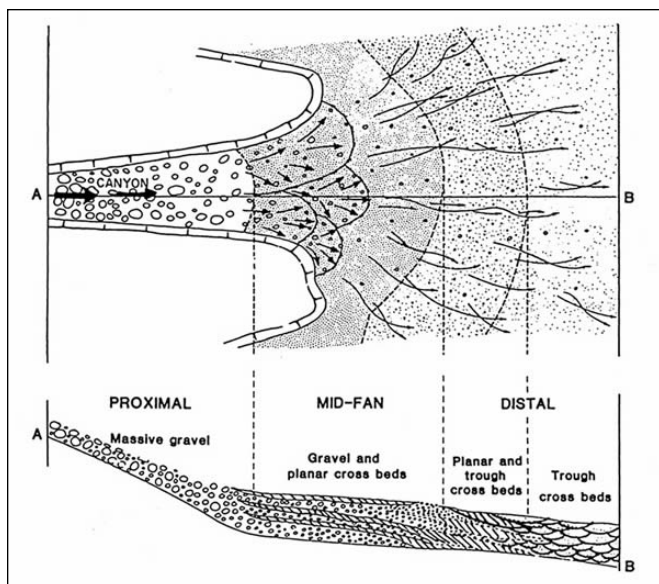


Figure 4. Schematic illustration of grain-size distribution and sedimentary structures across an alluvial fan. The **proximal fan** (nearest the apex) is characterized by steep slopes and deposition of coarse gravels from high-energy flows. The **mid-fan** region shows intermediate slopes with sands and gravels. The **distal fan** region, with the gentlest slope consists primarily of finer sediments (fine sand, silt, clay) [3].

Figure 5. Types of alluvial fan: **Debris-flow** dominated, **sheetflood**, and **stream-channel** types. The processes of deposition on an alluvial fan is determined by the availability of water, the amount/type of sediment being carried from the feeder canyon, and the gradient on the fan surface [4].

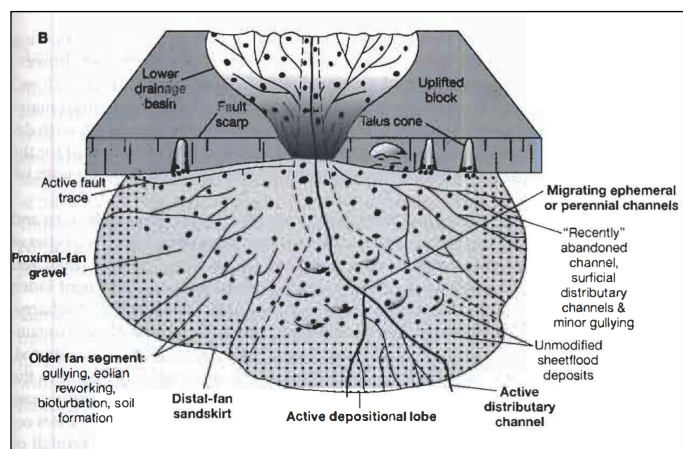
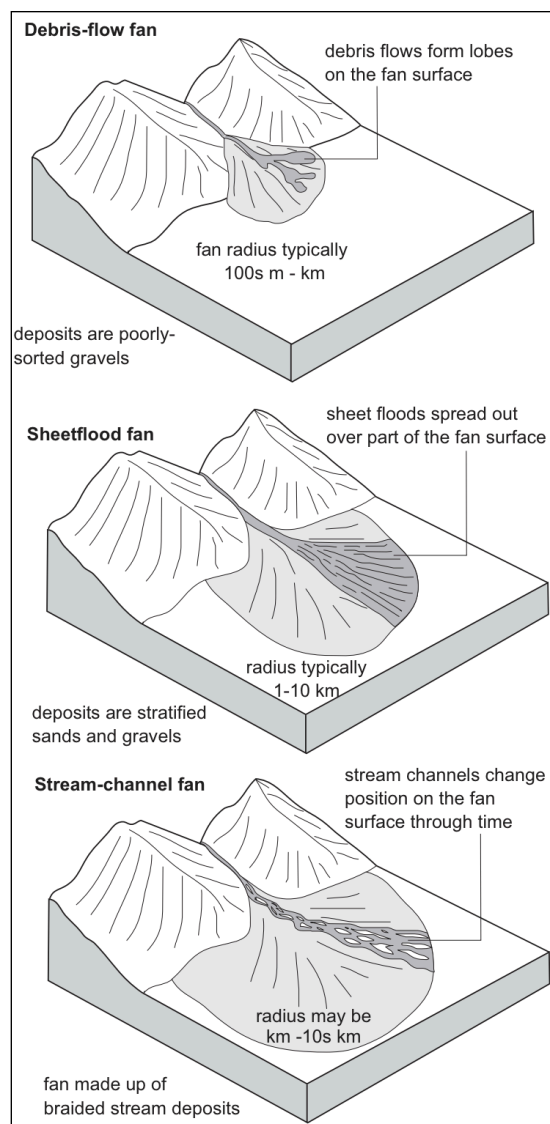


Figure 6. Another schematic diagram illustrating the depositional features of stream-flow dominated alluvial fans. See how stream channels change position through **avulsion** (abandonment of a river channel and the formation of a new channel) [5].



Which kind of fan is formed is controlled by **climate**, **tectonics**, and **lithology** in the area feeding the flow onto the fan.

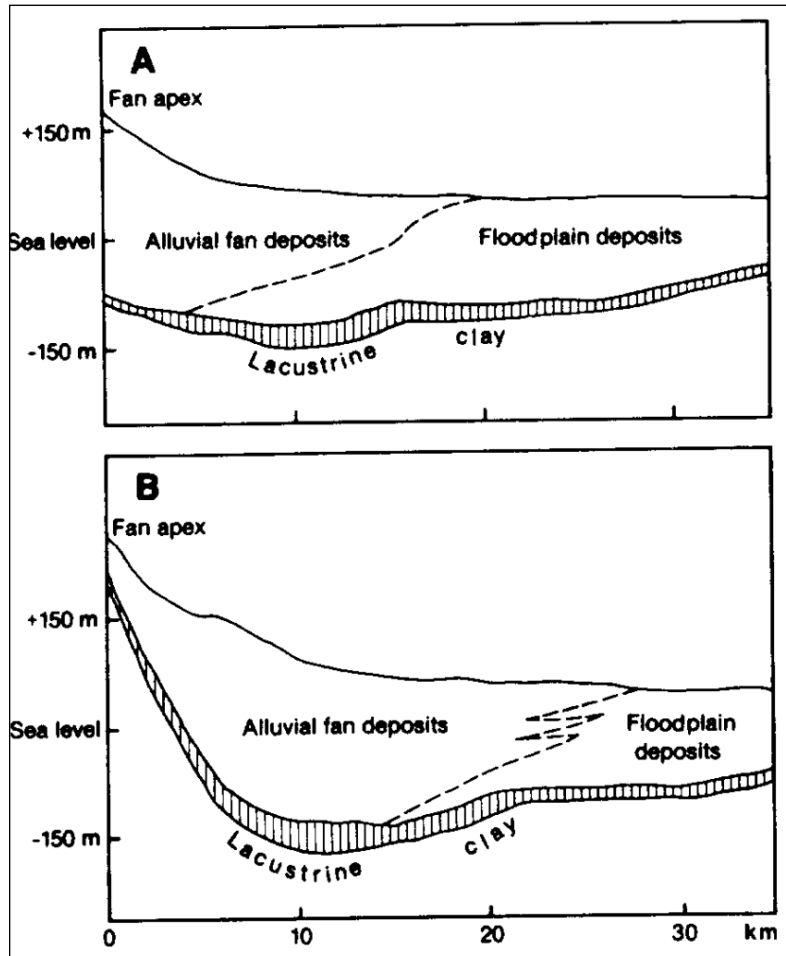


Figure 7. Longitudinal cross-sections of fan deposits. Bull (1972) identified three basic types of fan deposits. 1) **wedge-shaped** (Fig. 7-A. thickest near the mountain front and the thinnest part away from it), indicating major uplift in the mountains prior to fan deposition. 2) **lens-shaped** (Fig. 7-B. thin both near the mountain front and far away), reflecting uplift that has continued during fan deposition. 3) **wedge-shaped** thin next to the mountain front and thick away from it, indicating the cessation of tectonic activity [6].

Figure 8. Illustration showing how alluvial fan development is influenced by tectonic uplift based on the rate of uplift through fan development. If tectonic uplift during deposition is greater than the flow of the stream depositing the sediment, the fan's deposition will form closer to the mountain range. If the uplift is not as significant, it results in a more spread out, flatter fan [7].

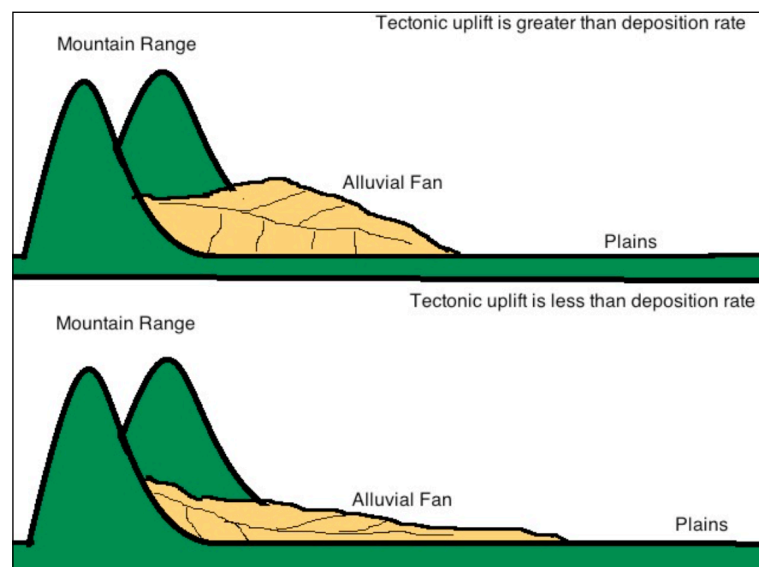




Figure 9. Google Earth imagery of alluvial fans near the Salton Sea area. The sharp, linear feature crossing the fans shows the strike-slip fault. Lateral motion along the fault has displaced drainage channels, creating **beheaded stream channels**. Continuous tectonic uplift associated with fault activity changes local slopes, causing stream channels to shift and/or abandon their original paths.

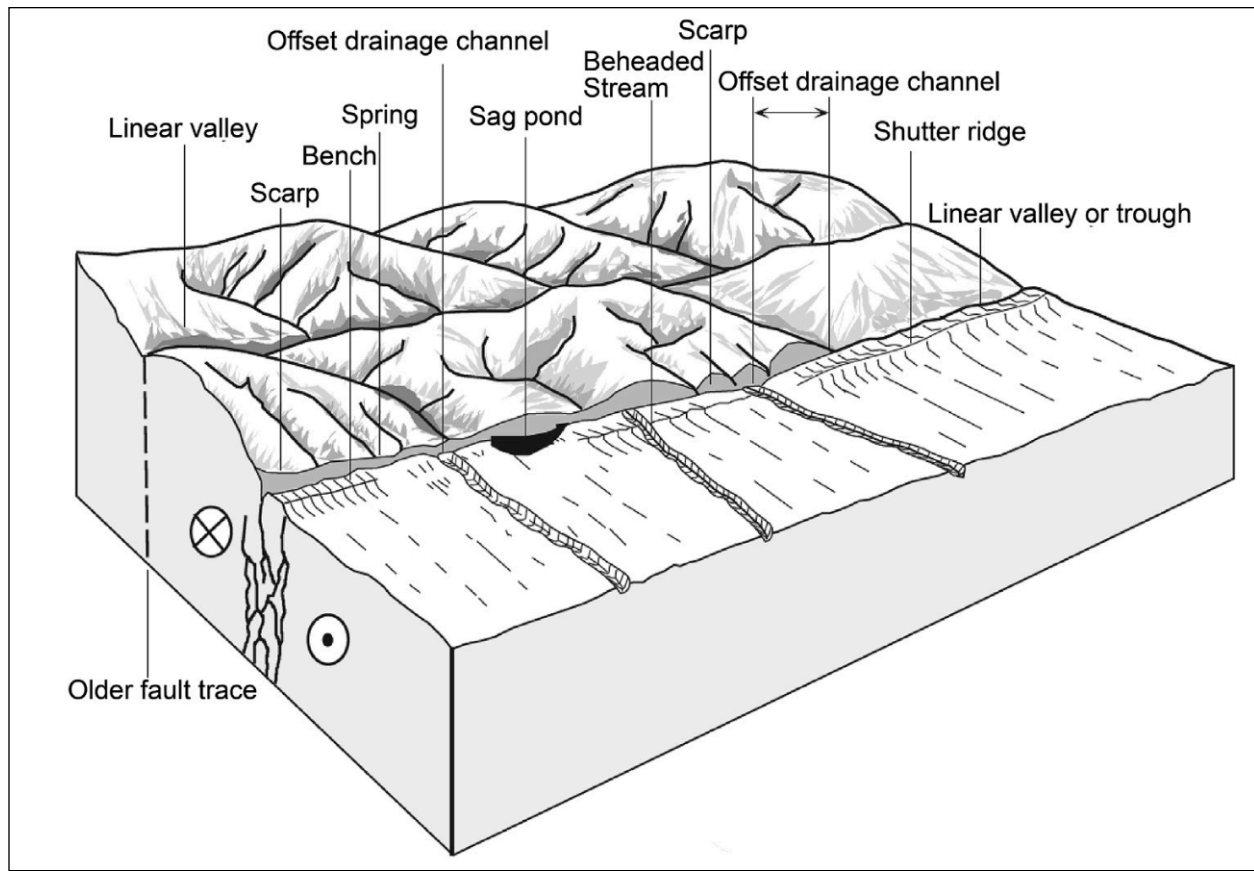


Figure 10. A schematic diagram showing linear offset geomorphic features of strike-slip faults, such as offset drainage channels and beheaded streams [8].

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Clay Dunes of Clark Dry Lake

Sam Nasreldine

- **What Are Clay Dunes?** Clay dunes are aeolian depositional features that broadly resemble “flipped” barchan dunes and are dominated by clay (typically 15–20, but sometimes up to 77 weight percent).
- **Occurrence:** They occur along the ancient shoreline of Lake Cahuilla containing the Salton Sea and in coastal lagoons, sabkha margins, and along margins of Pleistocene lakes worldwide.
- **Local Geological Context:** Clark Dry Lake’s dunes show a distinctive, streamlined shape with a cracked, hardened surface over a layered core of sand-sized silt-clay aggregates, revealing repeated episodes of wind deflation and cementation (1)

Formation Processes

- **Drying Lakes:** Clay dunes form when an ephemeral lake or playa dries up, exposing fine-grained sediments.
- **Wind Erosion & Deposition:** Strong winds rip up mud curls and trigger salt efflorescence (the process where water evaporates from a porous material) that produces sand-sized clay pellets (about 0.15–0.3 mm in diameter), which are then transported to shores.
- **Layer Accretion:** Each dry season, these clay pellets accumulate into a ridge that parallels the shore, while wet-season moisture disintegrates the upper layer to form a thin, stabilizing shell.
- **Lunette Formation:** Many dunes develop as lunette dunes—crescent-shaped ridges on the leeward side—due to persistent, unidirectional winds.

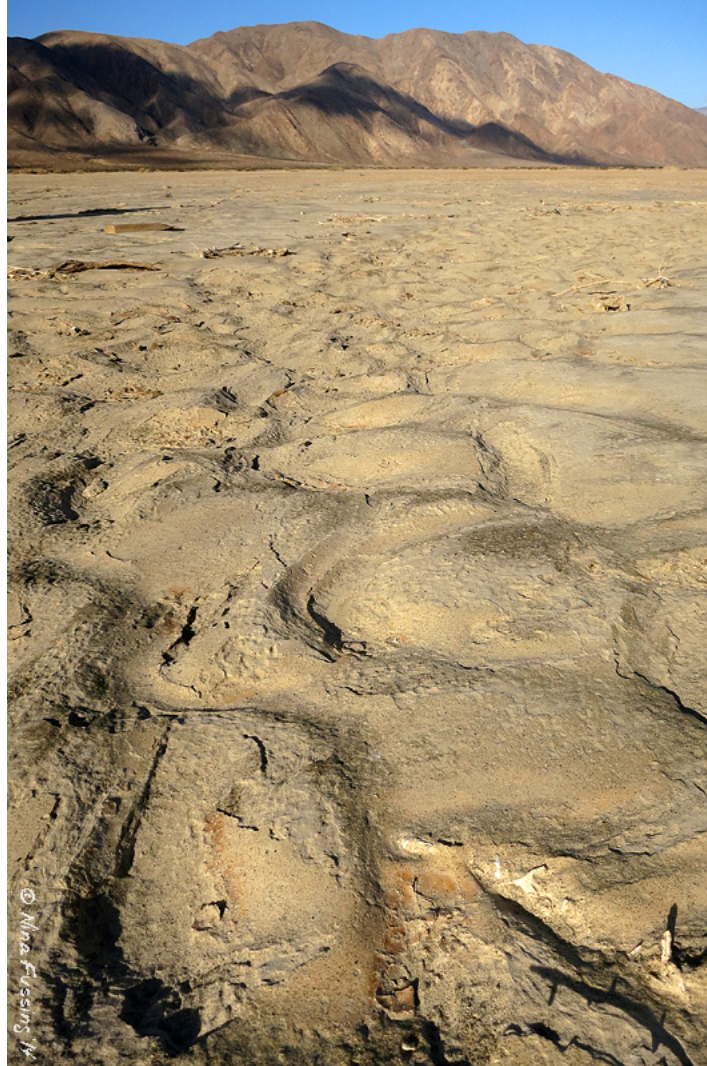


Figure 1: Clay dune feature at Clark Dry Lake.

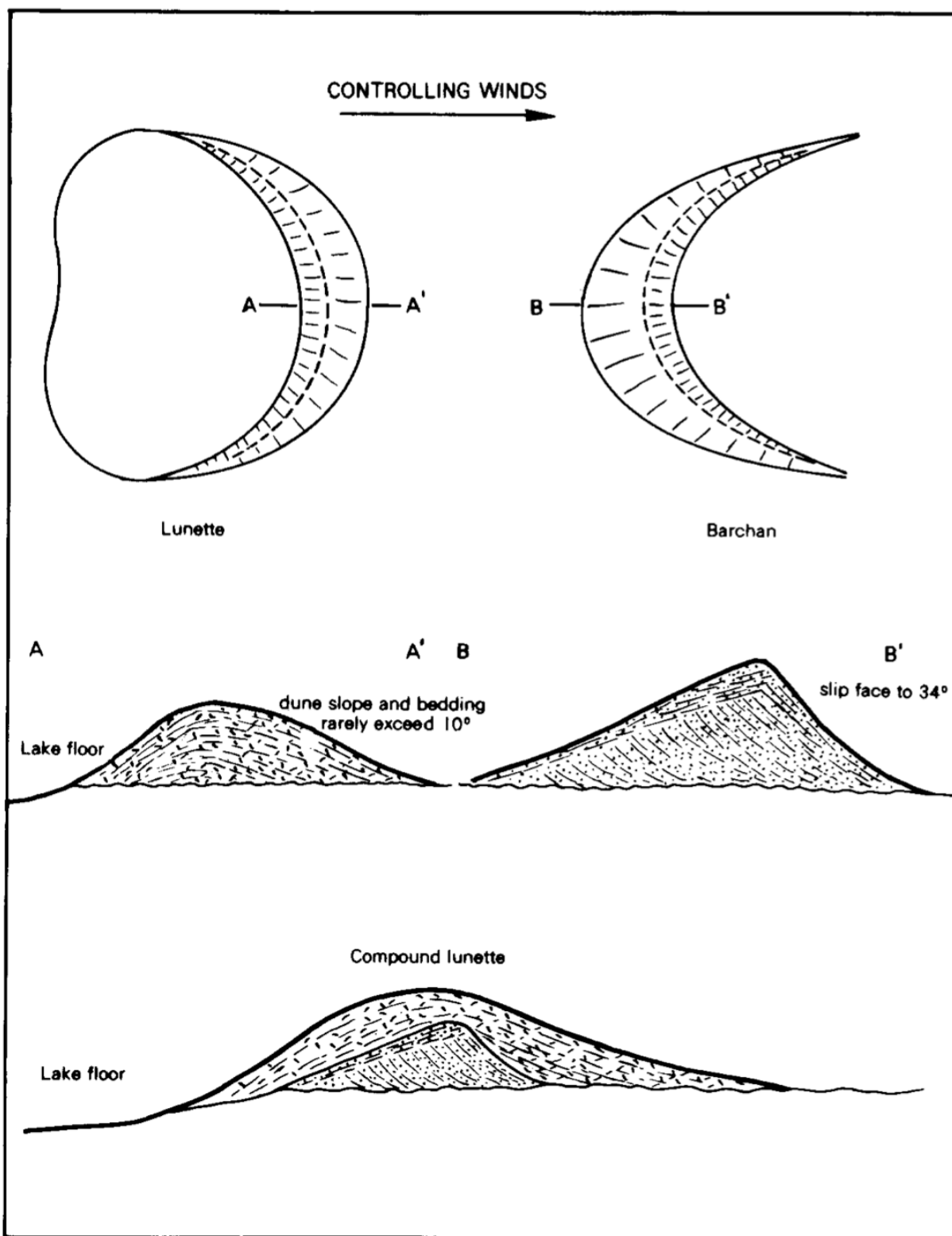


Figure 2: Plan and section characteristics of lunettes and barchans. (2)

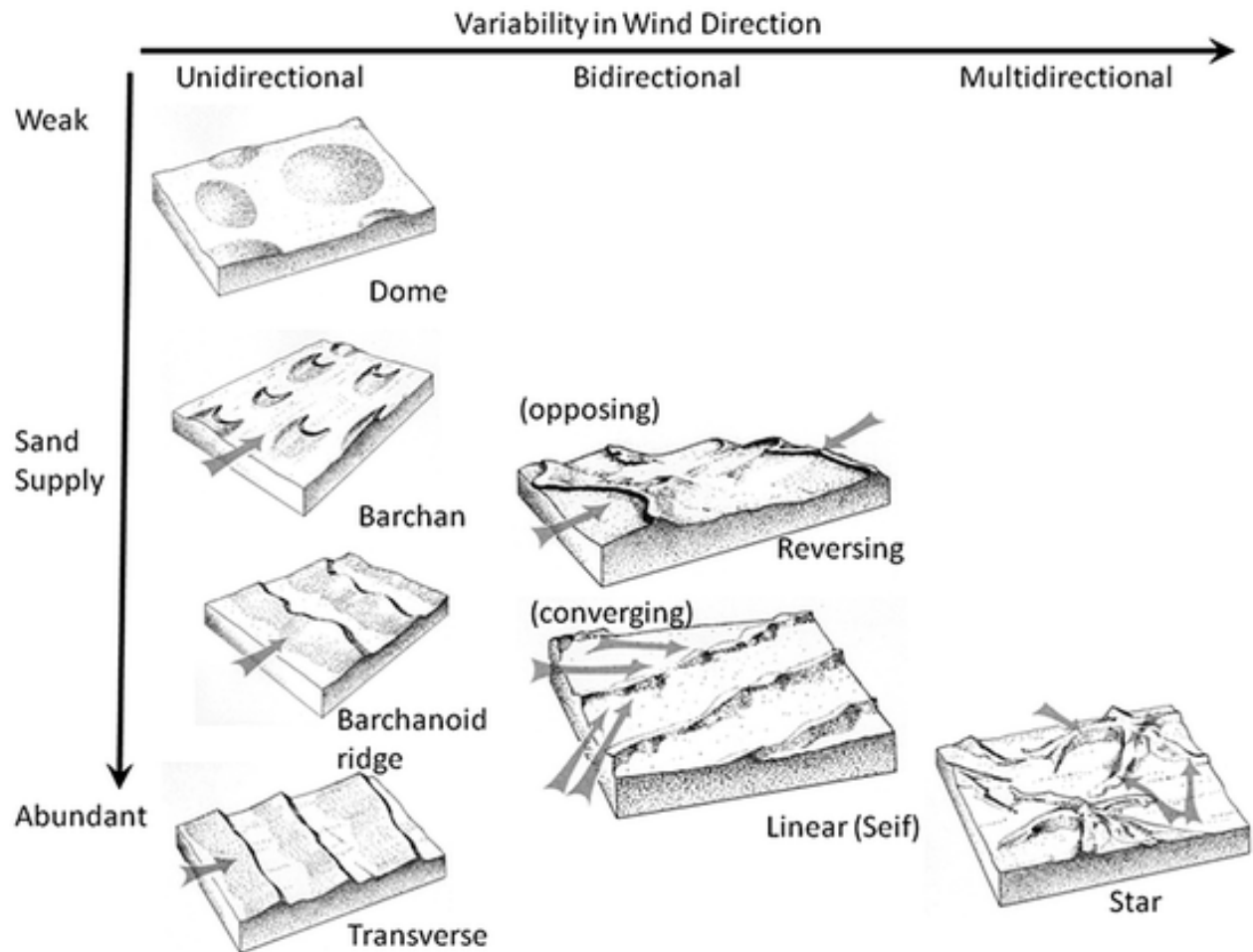


Figure 3: Major dune types. (3)

Morphology & Appearance

- **Shape & Orientation:** Clay dunes generally run parallel to the shore and may be crescent shaped with arms pointing upwind (opposite of typical sand barchans).
- **Slope & Surface:** They exhibit shallow slopes (around 15°) with a steep windward side and usually lack free slip faces; surfaces are marked by ripples and polygonal mud cracks.
- **Composition & Structure:** Composed mainly of silt and clay with minor evaporite content (carbonates, sulfates, chlorides), they show layered structures that record cycles of deposition and cementation.

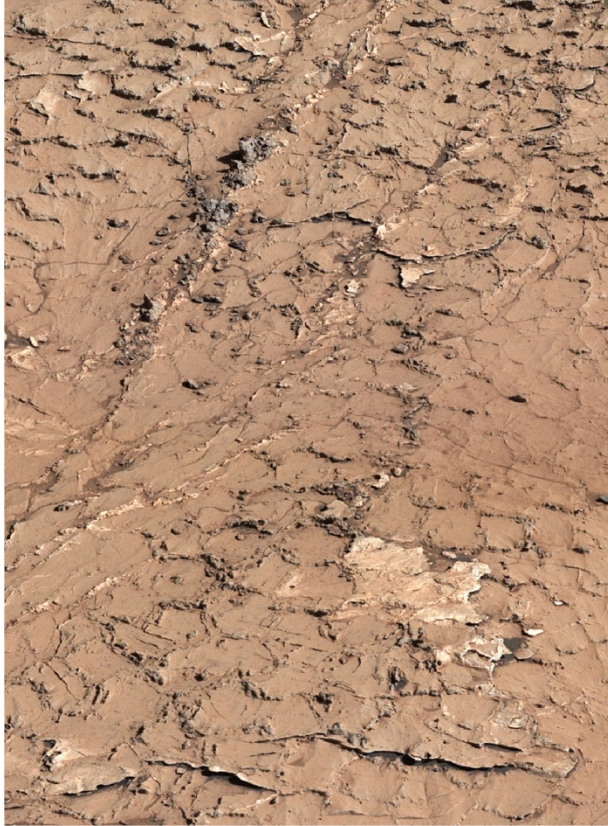


Figure 4: Hexagonal patterns reminiscent of mud cracks on Mars. (5)

Paleoenvironmental & Planetary Significance

- **Climate Archive:** Clay dunes serve as natural archives of climate and hydrologic change by preserving layers that indicate periods of lake existence and subsequent drying.
- **Formation Requirements:** Their formation requires high salinity, large seasonal fluctuations in water supply, and strong, unidirectional winds—all typical of localized arid settings.
- **Mars Analog:** Similar clay aggregates may form on Mars, potentially explaining the scarcity of sand-sized particles at Viking landing sites and offering clues about past water activity. (4)
- **Historical Merits & Limitations:** Although clay aggregates have a lower density and saltation threshold than typical sand, their formation by electrostatic forces is not fully documented, and such environments are rare and water dependent.

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PTYS 590

Playas and Climate Change

1. What are playas?

Playas are basins or depressions that formerly contained a standing surface water body, which disappear when evaporation processes exceed recharge. Playa lakes are one of the most important types of ephemeral wetlands in the arid Southwest. Although playas exist in arid regions throughout the world, the High Plains of the U.S. has the world's highest number of playas (50,000).

Usually, playas need to satisfy the following requirements:

- The basin is intracontinental, and the regional shallow groundwater system does not directly discharge into the ocean;
- The water balance of the lake (sources from precipitation, surface water flow and ground water flow minus losses from evaporation and evapotranspiration) is negative for more than half of the year, and the annual water balance should generally be negative. This ensures that the deepest part of the basin experiences dry period.
- The capillary fringe is close to the surface, and evaporation will lead to discharge of water to the surface. Evaporite minerals are usually present in the lowest part of the basin, such as carbonate minerals.



Figure 1. Photo of a playa. (Image credit: Christopher Rustay)

2. How do playas form?

- Water from precipitation or other sources flows into a dry basin or depression, forming a pond or a lake;
- Water is lost through evaporation from soil and vegetation and is gained from precipitation and catchment runoff;
- If the total amount of evaporation exceeds the total inflow, the depression will be dry again;
- Salt originally dissolved in the water will precipitate out and are left behind, building up with time;
- If a rainfall event happens, the depression will fill up with water and create temporary wetlands.

3. Geological features and hydrology

Playas have three distinct physical features (Figure 2):

- Playa floor: the flat floor of the playa that is characteristically lined by hydric soils;
- The annulus: the sloped surface at the playa margin;
- The interplaya region: the area between the annuli of different playas and includes the uplands that drain into playas.

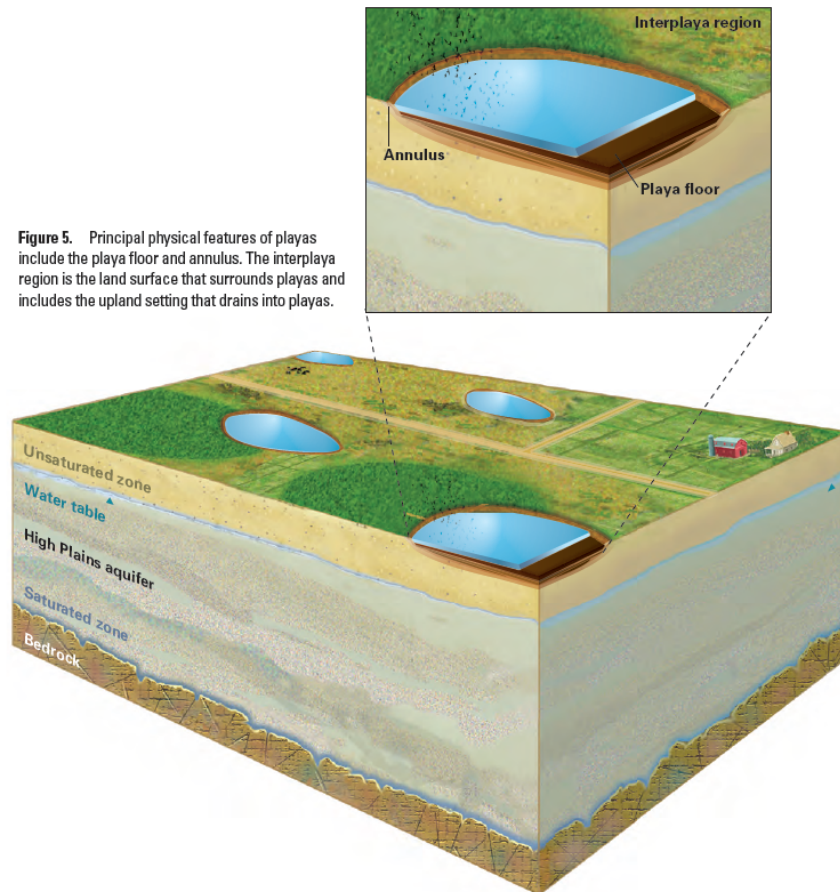


Figure 5. Principal physical features of playas include the playa floor and annulus. The interplaya region is the land surface that surrounds playas and includes the upland setting that drains into playas.

Figure 2. Geological features of playas. (Figure 5 from Gurdak & Roe, 2009)

The hydrology of playas is characterized by cycles of inundation and drying out. Once inundated, the hydroperiod of playas is variable but may last for many weeks to many months, although some may remain dry for years. The characteristic wet and dry phases of playa hydrology are a function of climate and the relatively thin permeable soils of the playa floor.

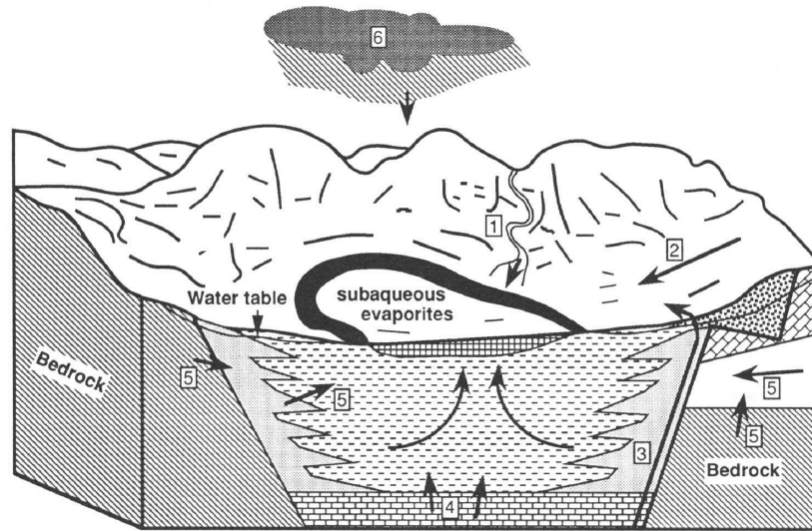


Figure 3. Diagrammatic summary of depositional environments of evaporite minerals. Salts derived from primary evaporative concentration of brines include (1) subaqueous evaporites, (2) crusts, and (3) displacive evaporites. Secondary deposits derived from the redeposition of existing evaporites include (1) intraclasts (derived from erosion of evaporites precipitated in the playa), and (2) extraclasts (derived from evaporites derived from the surrounding bedrock). Salt crust may form across the entire playa floor when there is no standing water in the basin. Gypsum dune is derived from the deflation of gypsum crystals from the playa surface and may be considered as an evaporite intra-clast deposit. (Figure 1 from Rosen, 1994)

4. Importance of playas

- Biodiversity Hotspots

Playas are the center of biodiversity, which support many animals and plants at some points in their lifecycle. In this dry landscape, playas are the main source of water for migrating waterfowl and shorebirds as well as resident prairie birds.

- Aquifer Recharge

Playas are a primary source of groundwater recharge that contribute up to 95 percent of water flowing to the aquifer. Recharge rates in playas are 10 to 1,000 times higher than under other areas. The water recharging through playas today will be available for use by the next generation since this is a continuous process.

- Water Filtration

Healthy playas are water filtration systems and this happens in two ways: first, as rainfall and runoff flow through the vegetation surrounding the playa, sediments which can carry contaminants are trapped and stopped from entering the playa; then, the soils in the clay floor beneath the playa remove nitrates and other dissolved contaminants as the water moves through it.

- Flood Water Storage

Playas can provide flood water storage and prevent property damage since they are usually at the lowest points on the landscape. Healthy playas with intact basins are the primary sites to collect

water during rainstorms, thus reducing damages to crops, roads, and property as well as reducing erosion.

- **Livestock Forage**

Grazing is an important component of the prairie landscape, and it can be used to manage the vegetation in playa buffers and basins. This can provide additional forage for livestock, especially during drought when the only moisture supporting plant life is often found within a playa, as well as providing a better wildlife habitat.

5. Impacts of climate change

- **Increased Aridity and Reduced Water Availability**

Rising global temperatures lead to increased evaporation rates, and decreased precipitation and prolonged droughts limit water inflows. This will reduce the frequency and duration of water retention in playas, and cause playas to remain dry for longer periods. Playas that once supported seasonal wetlands are becoming permanently arid, thus destructing the ecosystem.

- **Enhanced Dust Emissions and Air Quality Degradation**

When playas dry out, fine sediments become more susceptible to wind erosion, increasing airborne dust pollution. Dust storms from exposed playas can carry harmful particulates, including heavy metals and toxins, worsening air quality and causing respiratory illnesses.

- **Disruption of Hydrological and Groundwater Recharge Processes**

Playas play a crucial role in groundwater recharge, but increasing aridity reduces infiltration rates. Flash floods caused by extreme precipitation events can lead to rapid erosion, thus alter playa morphology and reduce their water retention capacity. Changes in precipitation patterns may also alter water chemistry by excessive salinity buildup.

- **Loss of Biodiversity and Habitat Alteration**

Many playas support unique wetland ecosystems that provide breeding grounds for migratory birds and other wildlife. As playas dry up more frequently, habitat loss threatens species that depend on these seasonal wetlands.

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Intro to Tufa and Travertine

Tufa and travertine are types of calcareous, lime-rich, lacustrine sedimentary deposits that form when calcium carbonate (CaCO_3) precipitates from mineralized groundwater. Precipitation is partly controlled physicochemical by CO_2 degassing which renders the dissolved calcium carbonate less soluble [1]. These deposits are useful for understanding past climatic changes as they mark lacustral intervals where paleoshorelines exist [2].

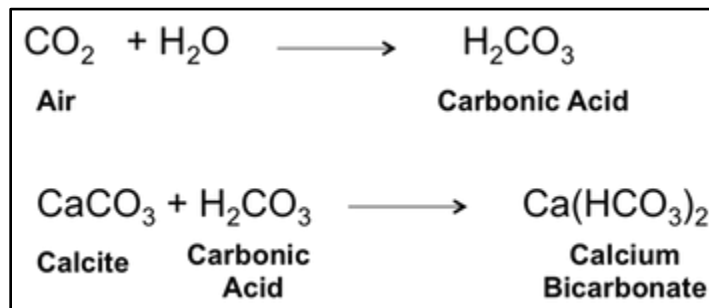


Figure 1: Chemical reaction for the precipitation of calcite as CO_2 levels decrease.

Tufa forms when small grains of CaCO_3 , precipitate from cold-to-warm (ambient temperature) mineral spring water. It lacks well-formed bedding, is very porous, and can contain plant material, insects, pollen, mollusks, and ostracods [3]. Travertine forms when the warm water in hot springs (hydrothermal freshwater environments) brings CaCO_3 to the surface. As the water cools and evaporates, the CaCO_3 precipitates, forming layers that accumulate and create travertine.



Figure 2: Tufa (left), which forms in cold-to-warm aqueous conditions. Travertine (right), which forms in warm-to-hot aqueous conditions.

Tufa and Travertine at the Salton Sea



Figure 3: Tufa deposit at the Salton Sea. The dashed red box indicates a paleoshorline.



Figure 4: Travertine Point, Salton Sea. An area characterized by tufa formations.

Tufa and Travertine Morphologies

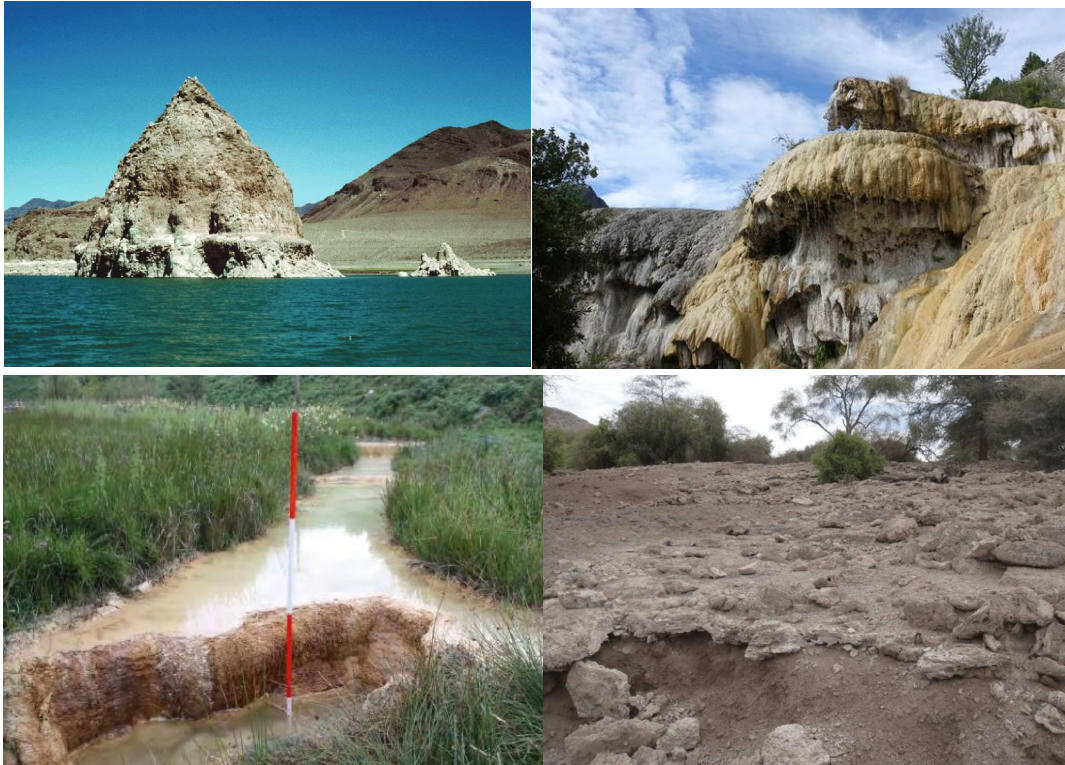


Figure 5: Cross-sectional drawings of tufa structure morphologies. (top-left) Spring mounds, (top-right) cascades, (bottom-left) barrages, (bottom-right) paludal deposits [3].



Figure 6: Travertine terraces in Yellowstone National Park.

Tufa, Travertine, and Faults!

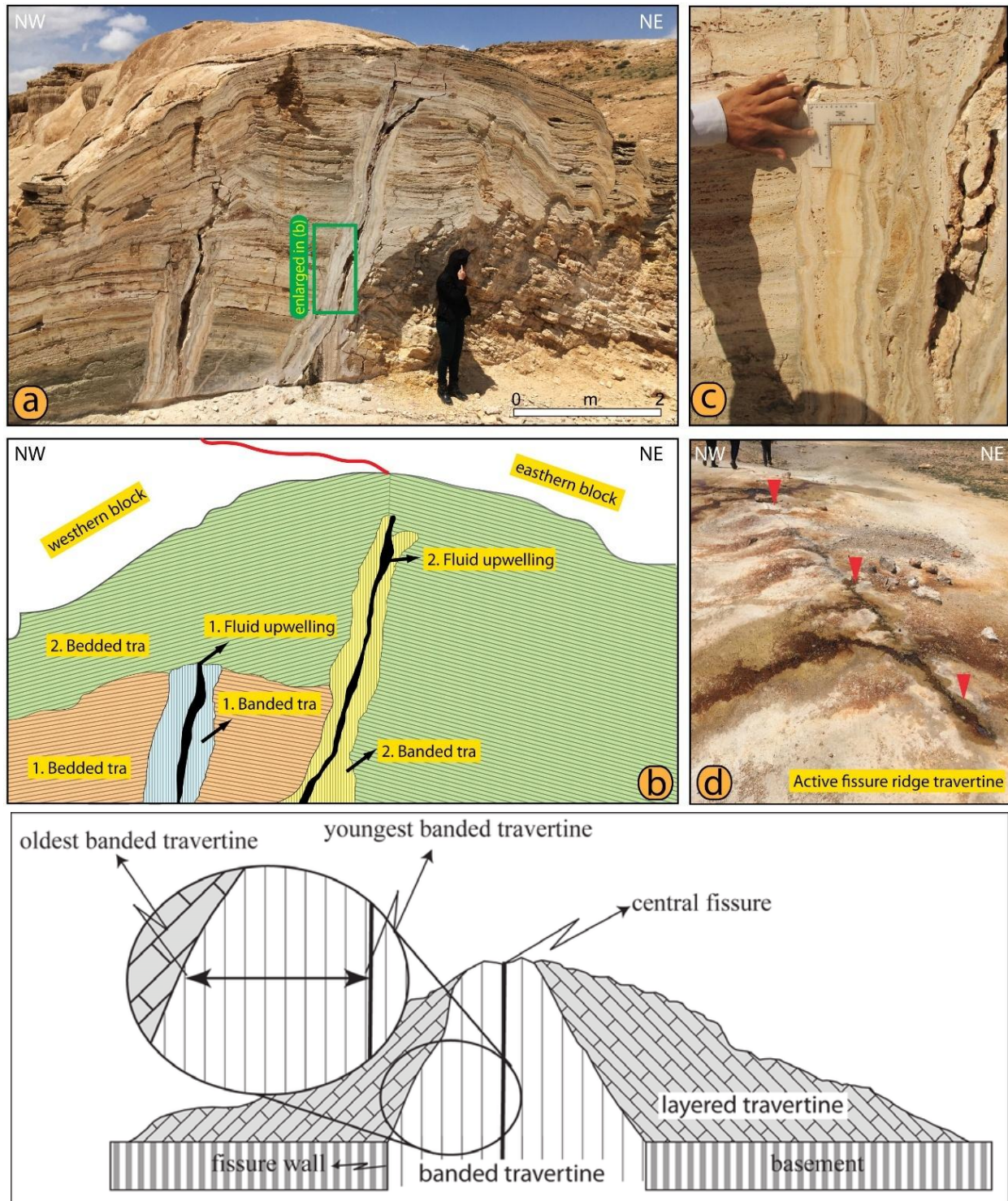


Figure 7: In tectonically active areas, elongated, ridge-like travertine deposits form along fault lines where geothermal fluids rich in calcium and bicarbonate precipitate as the fluids rise to the surface. This forms a characteristic triangular shape bulge with a central fissure [4,5].

Planetary Connection!

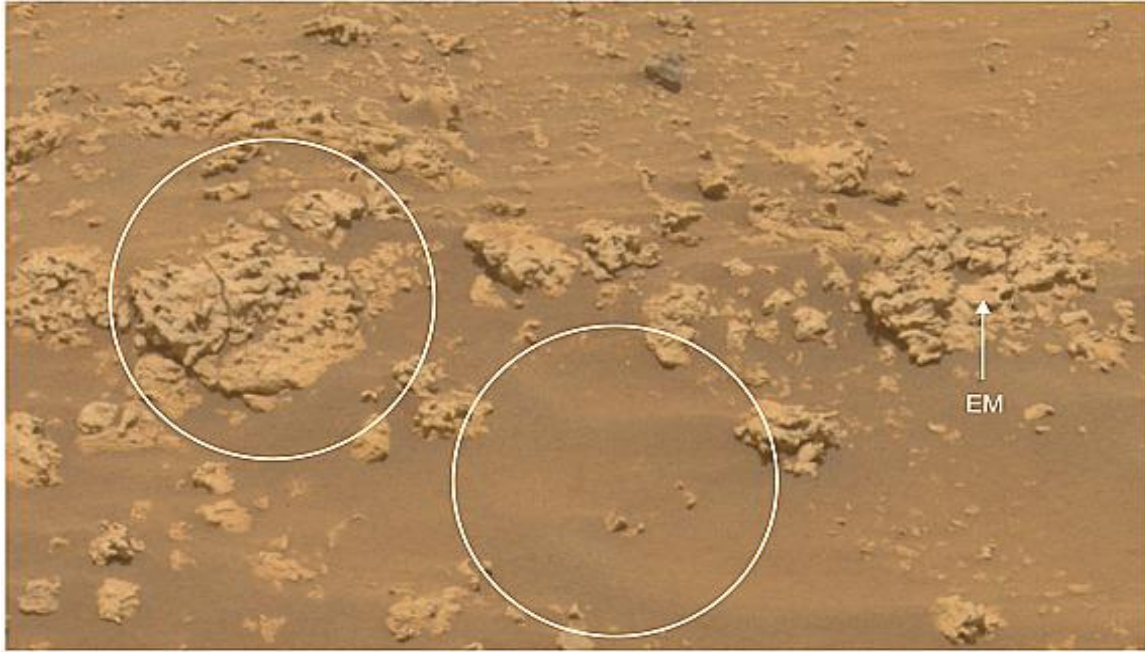


Figure 8: Silica-rich nodular outcrop, Clara Zaph4, in Gusev crater, Mars. Spectra are attributable to opaline silica. These precipitates commonly form near thermal springs or geysers in terrestrial settings; thus, their presence may be indicative of hydrothermal activity on Mars [6].

References:

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- [3] Pedley, M.H. (1978). Tufas and travertines. In: *Sedimentology. Encyclopedia of Earth Science*. Springer, Berlin, Heidelberg. https://doi.org/10.1007/3-540-31079-7_243
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- [5] Sağlam Selçuk, A., Erturaç, M. K., Üner, S., Özsayın, E., & Pons-Branchu, E. (2016). Evolution of Çamlık fissure-ridge travertines in the Başkale basin (Van, Eastern Anatolia). *Geodinamica Acta*, 29(1), 1–19. <https://doi.org/10.1080/09853111.2016.1228037>
- [6] Ruff, S. W., et al. (2011), Characteristics, distribution, origin, and significance of opaline silica observed by the Spirit rover in Gusev crater, Mars, *J. Geophys. Res.*, 116, E00F23, doi:10.1029/2010JE003767.

- The Salton Sea dune field is located east of Highway 86 and southwest of the Salton Sea (Figure 1).

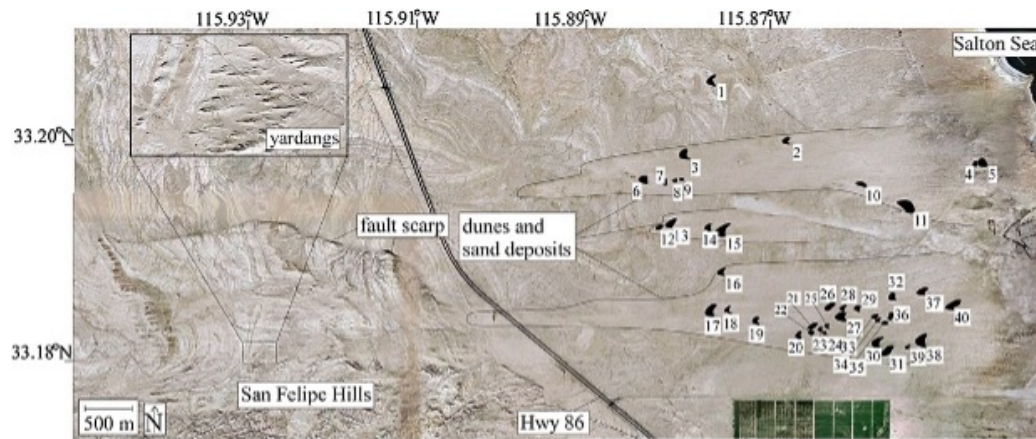


Figure 1: Location of the Salton Sea dune field from Pelletier (2013).

- The dunes in this area are primarily barchan dunes.
- Barchan dunes are crescent-shaped dunes that form in settings with limited sand supply, unidirectional wind, and low vegetation (Figure 2).
- The horns of Salton Sea dunes point towards the east, suggesting the prevailing wind is from the west and the dunes are moving eastward (Figure 3 and 4).
- In many models, dunes are treated as separate entities. Some of the dunes in this field can be considered isolated, which is useful for comparing real-world observations with simulations (Pelletier 2013).
- The mineralogy of these dunes closely resembles that of poorly consolidated Late Cenozoic strata (Pelletier 2013).
- As global temperatures rise, regions become more arid. More aridity means less moisture in the soil. This moisture sustains plants, which inhibit dune movement.
- Inactive dunes can be “reactivated.”
- The migration of dunes can impact the surrounding ecosystem (e.g., by burying plant life) and human activities (e.g., by encroaching on agricultural land, infrastructure, or residential areas).

– See Figure 5

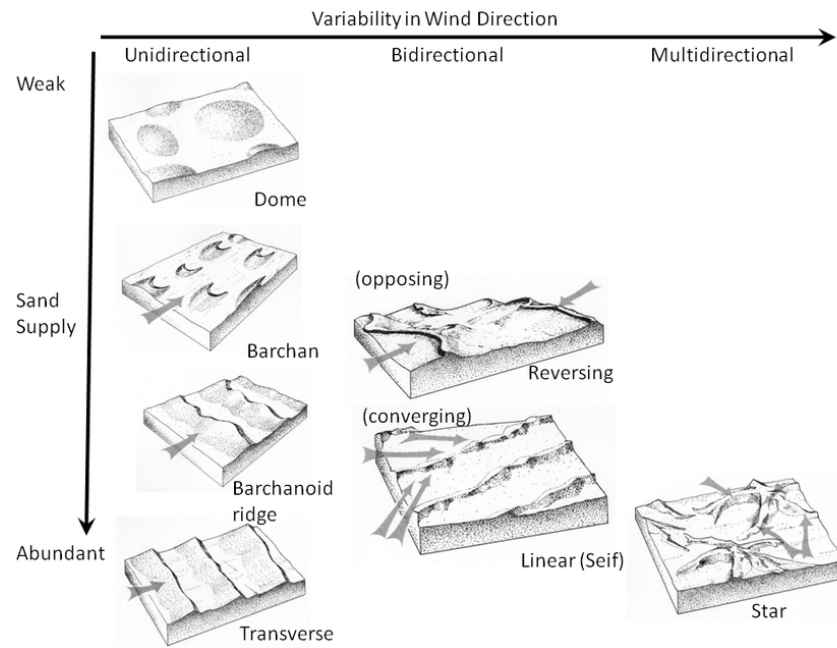


Figure 2: Sand supply and variability in wind direction influence morphology.

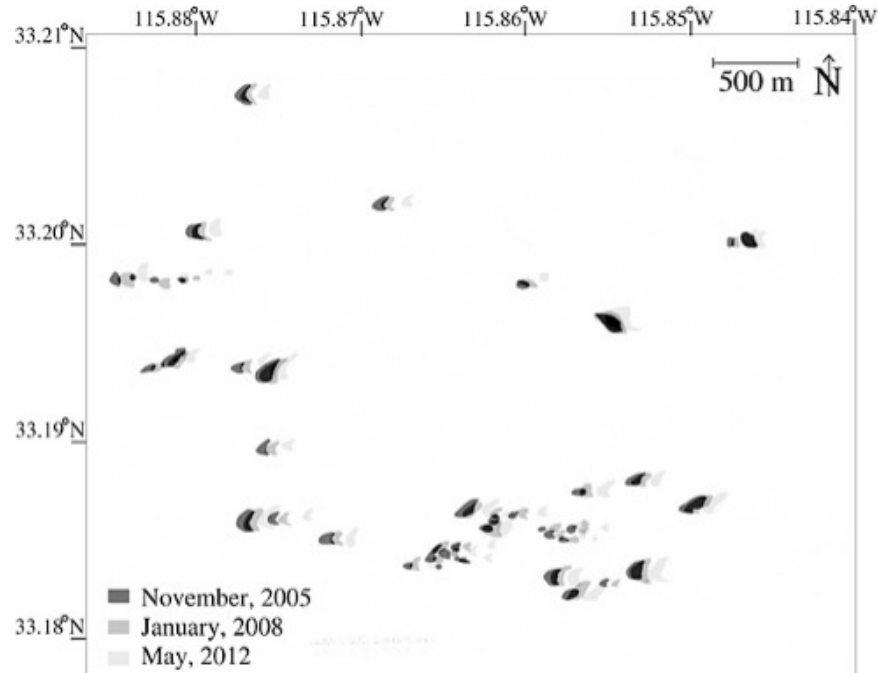


Figure 3: Pelletier (2013) tracked the migration of 40 dunes near the Salton Sea between November 2005 and May 2012 using airborne and terrestrial lidar.

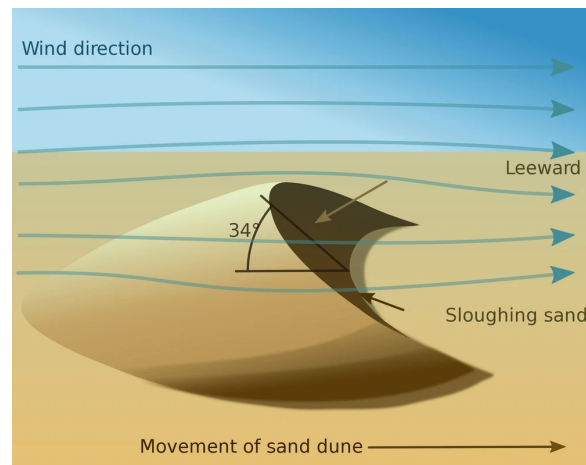


Figure 4: The horns of barchan dunes point downwind.

- In Arizona, more than one-third of Navajo Nation and Hopi Tribal lands are covered with sand dunes migrating at rates up to and exceeding 115 feet per year (Redsteer et al. 2011).

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- Pelletier, J. D. (2013), Deviations from self-similarity in barchan form and flux: The case of the Salton Sea dunes, California, *J. Geophys. Res. Earth Surf.*, 118, 2406–2420, doi:10.1002/2013JF002867.
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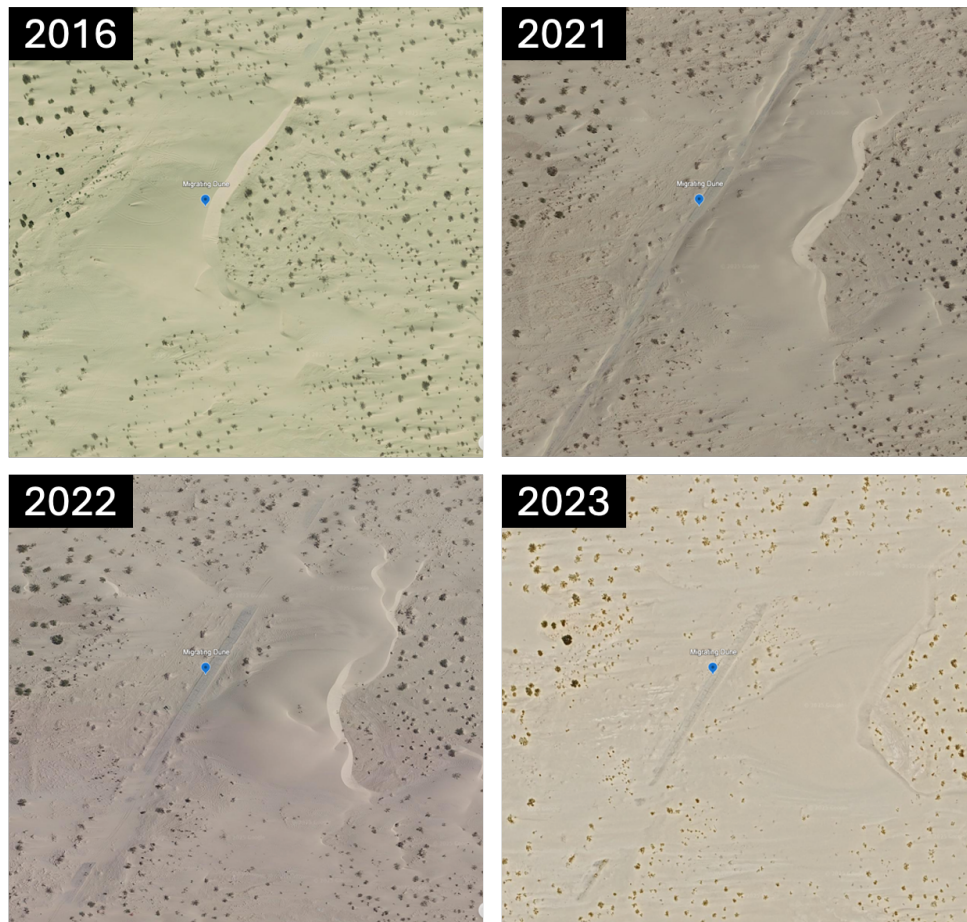


Figure 5: A migrating dune near the Salton Sea interacts with a paved road.



Scan for Geologic Resources!



John Gemperline

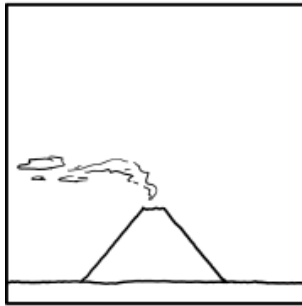
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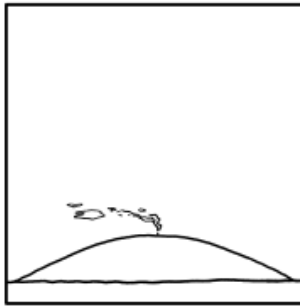
Me for the next week on the grad geology field trip:



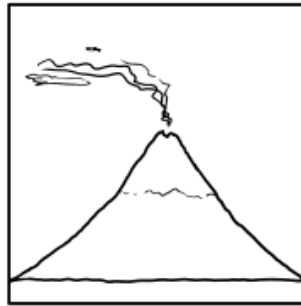
A GUIDE TO VOLCANO TYPES



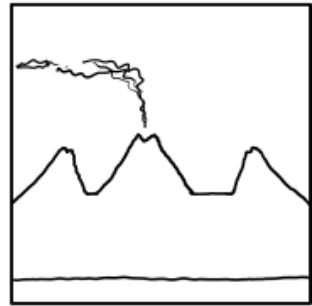
CINDER CONE



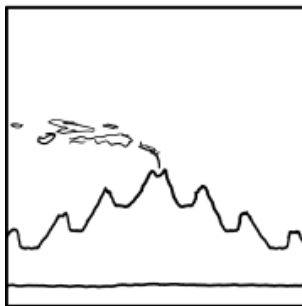
SHIELD VOLCANO



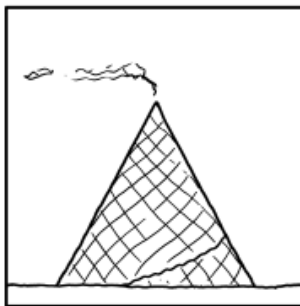
STRATOVOLCANO



SOMMA VOLCANO



METASOMMA VOLCANO



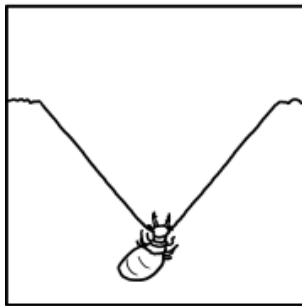
WAFFLE CONE



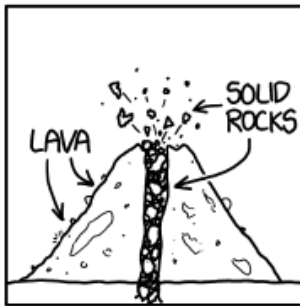
SCIENCE FAIR CONE



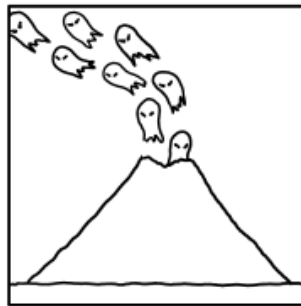
DOOT CONE



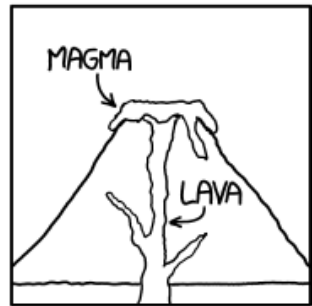
ANTLION



INVERSE VOLCANO



GHOST VENT



PEDANT'S BANE

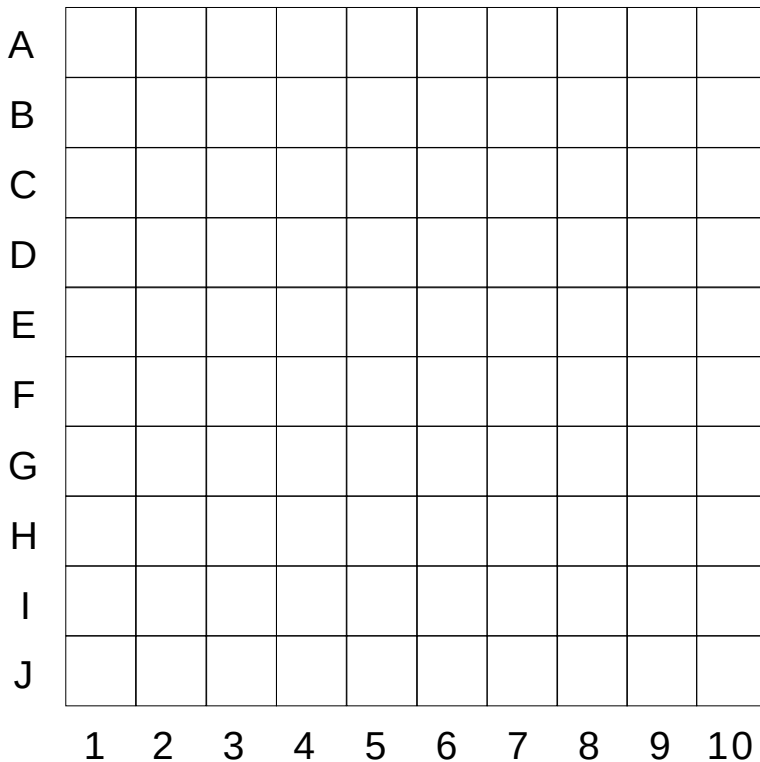
Battleship



Another fun activity from:

www.funorama.com

Defensive Grid



Put the following ships on your defensive grid by placing the appropriate letters -- horizontally, vertically or diagonally.

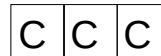
1 - Aircraft Carrier



1 - Battleship



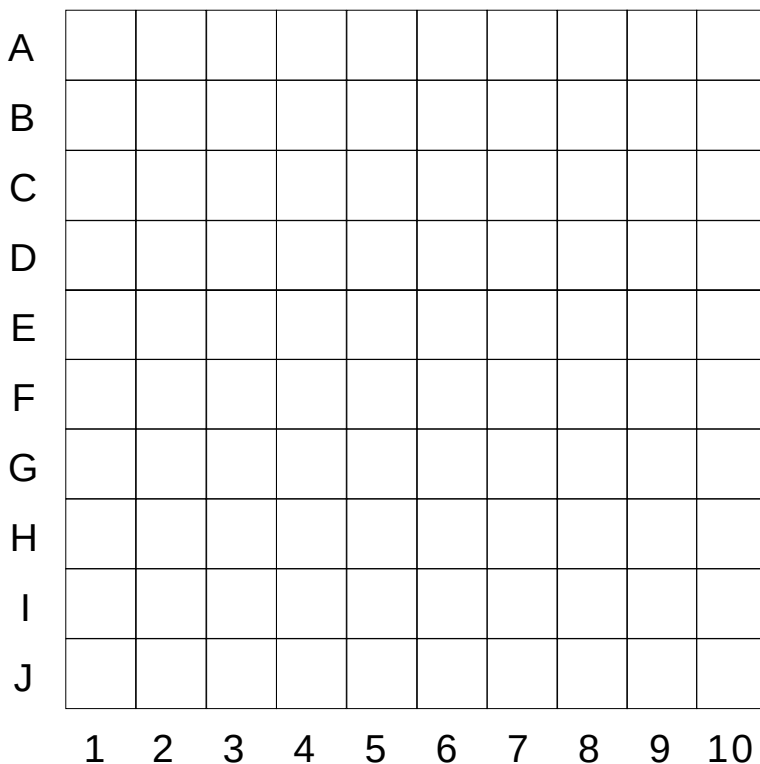
1 - Cruiser



2 - Destroyers



Offensive Grid

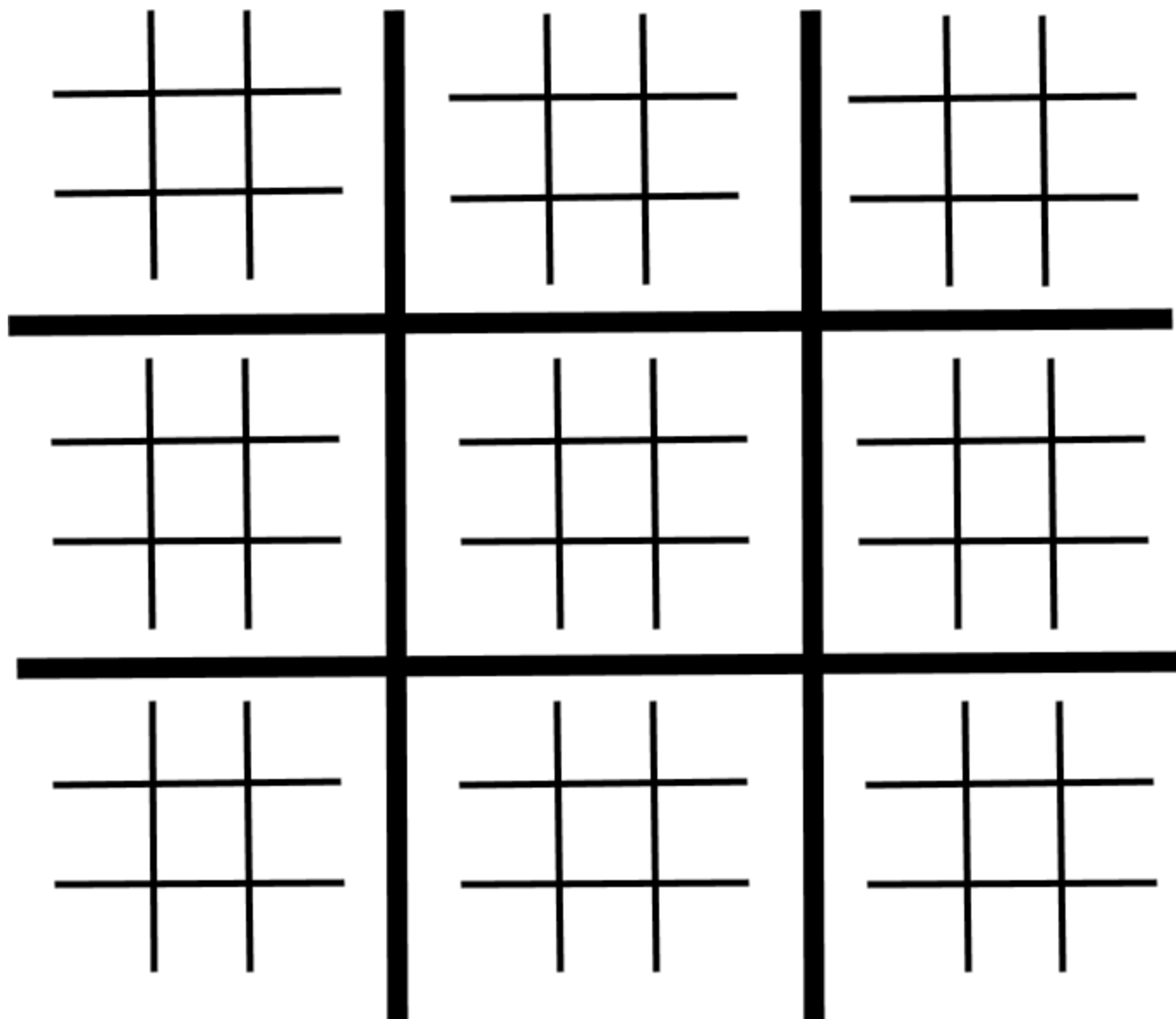


Instructions (2 Players Required):

Both players place their ships on the defensive grid according to the chart above. Whoever goes first calls out a position (i.e. G-6). The other player says either "Hit" or "Miss" depending upon whether one of his ships is in the position called out. The person calling out should mark a hit or a miss on the "offensive grid" to keep track of the shots. The other person should mark the shot on the "defensive grid". If the shot is a "Hit", the player goes again--otherwise the other player takes a turn. Once the opposing player has scored a hit on all of the spaces for a particular ship, you must call out "Hit...you sunk my Cruiser" (or whatever type of ship it was). Once a player has sunk all the opponents ships, he is declared the winner.

SUPER TIC TAC TOE

Like the normal version, but more. The board is made up of 9 sub-games within the larger supergame. Player one begins by placing an X inside one of the sub-games. The square chosen within that sub-game determines the next sub-game for player two to make their move, and so on. For example, if player one chooses the middle square in the upper-right sub-game, player two must place their move within the middle sub-game. If you win a sub-game, you win that space in the uber-game. Connect three squares in a row in the super game to win. This game can be broken. There might not be a winner. Maybe you'll have fun. You'll probably get mad at your opponent.



1

		5			7			
						9		2
7		1	2		9	6		
9	5			8		3		
	2			3	6			
		7			5		1	
			6				5	9
5	3			9				
			1	5		2	6	

2

		2		8				
	1				3	4	9	
		9		7				5
6	4					3		
					4	8		9
		5		2	7			4
	9						1	
			8	9	2			
		7	1	4			2	

3

			6	5				
7				4		9	5	2
3		5	1					4
		3					4	5
2		7					9	
4			5	2	6		7	
	7				8	5		
		4				7	2	
	9				5		6	

4

	4		3					9
		7	6		5			
		2	4			5		1
1		3						2
8					4			
2					6	9	8	
	3	1	7					
	9			2				5
	2					1	9	4

5

					1		8	2
			5	6		1		7
6	3			7	2			
			7			9	1	
		3	4		6	7		
		2					4	
	1				3		7	
	2	5		1				
		6		5		3		

6

			4			8		2
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		2				9		
9		3				1		
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7

	3		2		4	5		8
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		5			3			4
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7							1	6

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			6	5	7		8	
	6	1				4		
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	2					8	7	

10

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8	2					9	3	
	6				2			
			3	2				7
		5		9			8	2
6	1							
					8	5	9	
9		6		5				
7						8	2	3

11

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						2		7
		7	6	1				
	1	6	5	9			8	
			7					1
	9	8				6	2	
8					9		4	
2							1	8
9	6				5			2

12

					5	4		6
	6	2			9	1		
9				8	4			
	9					6		5
3		8		2				
		5			8	2	1	
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1		7	4				8	

