SALTON SEA

PTYS594A: PLANETARY GEOLOGY FIELD STUDIES

23-25 OCTOBER 2015

LUNAR AND PLANETARY LABORATORY,
UNIVERSITY OF ARIZONA

Letter from the Editor

Welcome to the 1950s themed field trip guide (look at that classy Futura typeface!), in honor of when the Salton Sea was a tourist destination, the "Riviera" of Southern California where people went to water ski, swim, and ignore the growing fear of nuclear war.

I think on this trip we'll pass on the swimming in the Salton Sea. And breathing through our noses too close to it.

However, we are catching the Salton Sea at a very opportune time. The Imperial Valley water management authorities will shut off the remaining water supply to the lake in 2018, but may do so even sooner due to the continuing drought in California. Future field trips may be able to find the legendary sunken Spanish treasure ship that ran afoul somewhere along the Colorado River delta[*], as the Salton Sea finally dries up. Or just even more dead fish.

So watch your step, and let's see some dunes, mud volcanoes, and the challenge of humans managing a landscape after some accidental flooding 110 years ago!

Margaret Landis, brand new PhD candidate[†]

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[*] Earliest accounts of the lost ship come from a man who walked out of the desert after his horse died in 1863, placing this firmly in the "lost-treasure" urban legend genre.

[†] Which means I'm still sleep deprived and if there are typos I don't want to hear about them unless they are hilarious.

Table of Contents

Cover illustration
Eva A. Landis
evalandis.tumblr.com

Road log for PTYS 594 Fall 2015 – All times are AZ times
Sunrise is ~6.50am and sunset at ~6pm

FRIDAY 10/23/2015

7 AM Arrive at LPL loading dock bright-eyed and bushy-tailed with full ice chests, full stomachs, coffee, snacks and opinions on the new Star Wars trailer.

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.
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**

2 PM

Nathan Hendler	Basin & Range formation and the Gila Graben
Sarah Sutton	Algodones dunes
Tad Komacek	Tectonics of the Salton Trough

3PM Back onto the 78 and head west for 22 miles. Turn right to stay on the 78, travel 6 miles, turn right again to stay on the 78, travel 19 miles. Turn left to stay on the 78, *there's a border patrol station here – make sure you have documents with you (and not packed in the trunk) if you're not a US citizen*. Turn left onto Split mountain road and travel 8 miles. At this point we'll have to take a left and travel a few miles on an unmarked road to the camp site.

4.30PM Dig up some surprises in the desert

Donna Viola	Historic Lake Cahuilla
Rodrigo Savage	Flora & Fauna
Jon 'The' Bapst	Mining operations of the Anza-Borrego mountains

5.30PM Camp

SATURDAY 10/24/2015

8AM Drive back to the 78 along Split Mountain Road and turn right. Stay on the 78 for 26 miles. Turn left onto Bannister Road, travel 6 miles.

Turn left onto Forester road for 1.6 miles. Turn right onto Walker Road 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 left onto Red Hill Road – follow this to the Mud Volcanoes. There's an alternate site nearby is needed (see map).

9.30AM	Sondy Springman	Mud Volcanoes (Formation mechanisms)
	Joana Voigt	Mud Volcanoes (Rheology of flows)

10.30AM Drive 20 minutes to the Rhyolite dome (map) – potentially add half an hour to see the other mud volcano site

Jean Masterson	High-Silica Volcanism
Hannah Tanquary	Formation of the Salton Sea
Michelle Thompson	How the Salton Sea turned into an environmental disaster

12PM-ish	Lunch on the shores of the Salton Sea	
	Margaret Landis	Drought and Agriculture in California

1PM-ish Drive to big-ass fault. Drive south back to the 78. Continue straight at the Border Control Checkpoint to transition to the 86. Turn left onto Borrego Salton Sea Way in “Salton City”. Drive 14.6 miles to a right turn onto West Truckhaven Trail. Drive about a mile to the nearest approach to big-ass fault. Hike ~1km north-east to the fault.

2.30PM-ish Tad Komacek Tectonics of the Salton Trough
Ali Bramson Alluvial Fans and their interactions with tectonics

3.30PM-ish Drive to Clark Dry Lake. Back to Borrego Salton Seaway and travel another 5.6 miles west. Turn right onto Rockhouse Road/Trail. Drive 4-5 miles until we find a good place to park and camp. This will probably take at least 30 minutes.

We have spare time this day so we might add a hike at some point or we’ll spend some time trying to confirm the location of the clay dunes or we’ll do Corey’s talk now instead of tomorrow.

SUNDAY 10/25/2015

8AM Drive to nearby clay dunes

Ethan Schafer Clay dunes
Corey Atwood-Stone Playas and climate change

10AM Head back to Borrego Salton Seaway and travel east 20 miles. Turn left onto the 86 and drive 9 miles. 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.

Tom McClintock Formation of Tufa/Travertine

11AM Head south on the 86 for 17.3 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.
Wei Peng 'Ben' Lew Migration of dunes

Ken Furdella Native People History
Lunch here.

1PM Start driving home. Take the 86 to the 78 to the 111 to Interstate 8 to Interstate 10 to Speedway to Cherry to Hawthorne to LPL. It’ll take about 5 hours.

6PM Back at LPL

Basin and Range

Nathanial Hendler

October 19, 2015

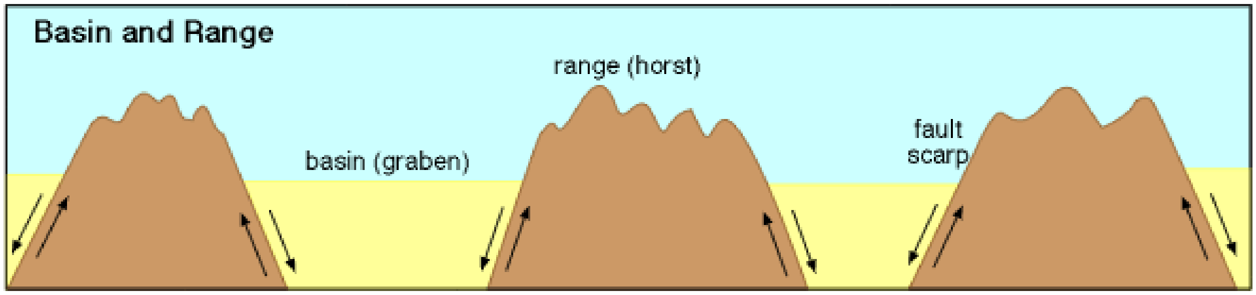


Figure 1: Source: sciforums.com

Glossary

This is where words go...

Footwall: Miners exploit faults because that's where the gold is. They would dig into faults, and the fault block that they were standing on would be called the footwall. This is important because geologist like to ask "Which way did the hanging wall move relative to the footwall" in order to watch everyone screw up their faces while they contort their hands and arms as they work out what happened. Remember, you have a 50/50 chance, so just be bold and shout out an answer without thinking about it too much. See figure 2.

Graben: A down-dropped block.

Horst: An up-dropped block.

Hangingwall: Long-term relationships can be stressful. Often these stresses result in a permanent break which divorces previously committed rock into two. It's probably your fault. Now you will have to choose sides: the side you "hang your mining lantern from" is called the hangingwall. This has nothing to do with whether or not the fault is a normal fault or a reverse fault. See figure: 2

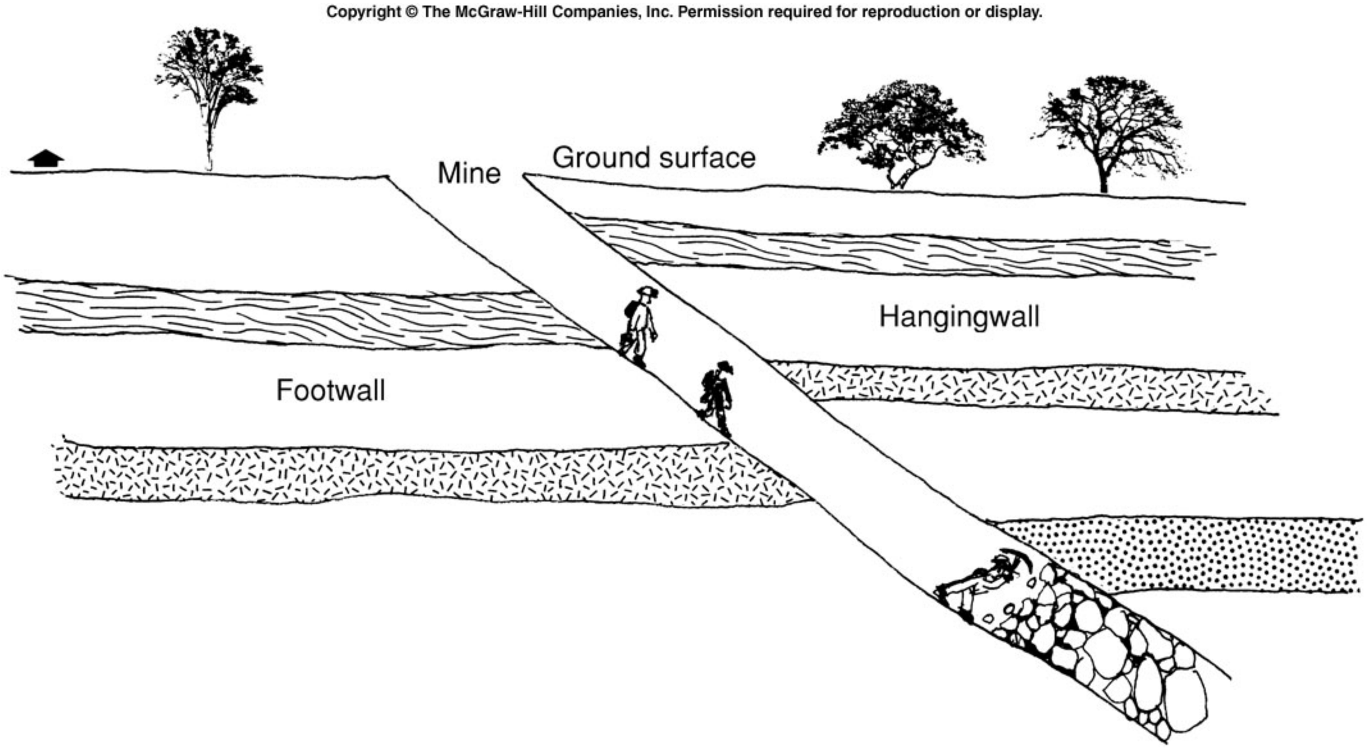


Figure 2: Source: McGraw-Hill

Metamorphic core complexes: Exposures of deep crust exhumed in association with largely amagmatic extension. They form, and are exhumed, through relatively fast transport of middle and lower continental crust to the Earth's surface. (Wikipedia)

Taphrogeny: From The Great Soviet Encyclopedia: the process of the formation of large grabens when the earths crust is stretched. In Soviet Russia, the earth stretches you!

Introduction

The Basin and Range provinces are characterized by alternating roughly parallel mountain ranges and valleys that have been created by normal faulting of continental crust due to extension. The type example of Basin and Range topography is in North America which extends from Sonora Mexico to Oregon (according to most maps) or Washington (According to the great Dr. George Davis Professor Emeritus at the University of Arizona) through the states of New Mexico, Arizona, California, Utah, Nevada, Oregon and Idaho. All of Nevada is Basin and Range.

The basin and range province of the south-west began its formation 30Ma. Overthickened crust (think Andes-like Apltiplano plateau) built by the Laramde orogeny was unstable and began to collapse and spread to the West/South-West. This created large-scale listric and block faulting. Residual heat, or heat from slab-roll back or tearing contributed to this collapse. The crust thinned to 50km to 25km (or less) and extended by 100%.

The majority of basin and range formation took place between 30 and 25 Ma. Extensional faulting continued at least until 12Ma to 4Ma.

Basins are filled with sediment (and water) as they form. Several basins in Arizona are filled with 3km or more of sediment. These basins usually start off life as closed basins, creating lakes or playas depending on how arid the environment is. The transition between a basin and a range will often contain piedmont, pediment, alluvial fans and stream piracy.

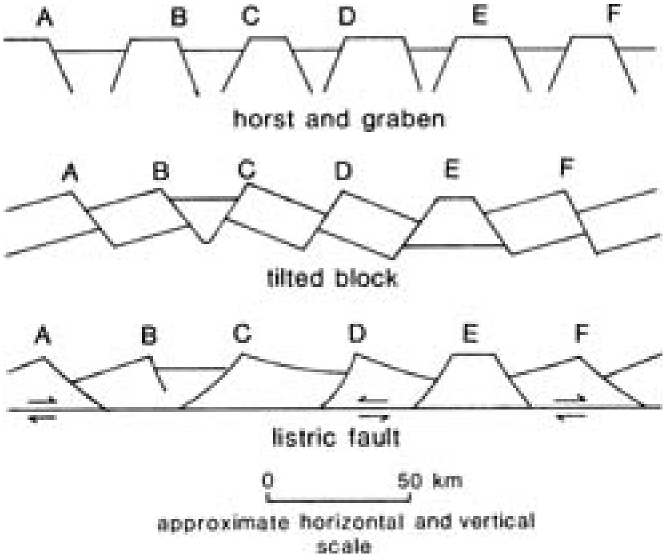


Figure 3: Example geometries of hosrt and graben. Source: J. H. Stewart, 1980

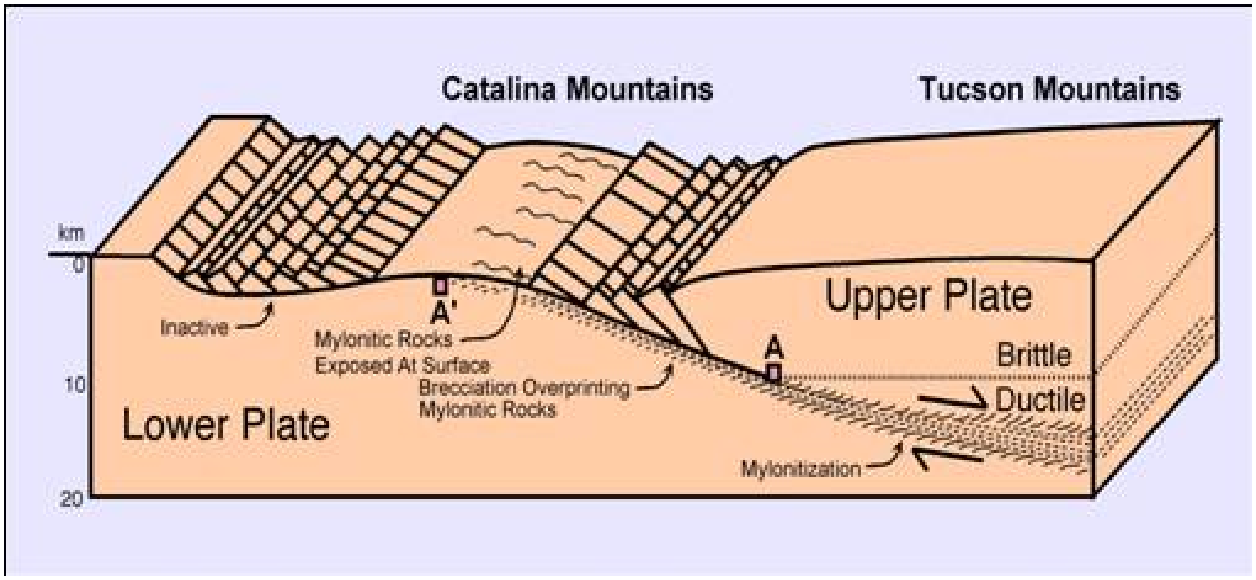


Figure 4: How metamorphic core complexes are exposed. Source: University of Arizona Geosciences

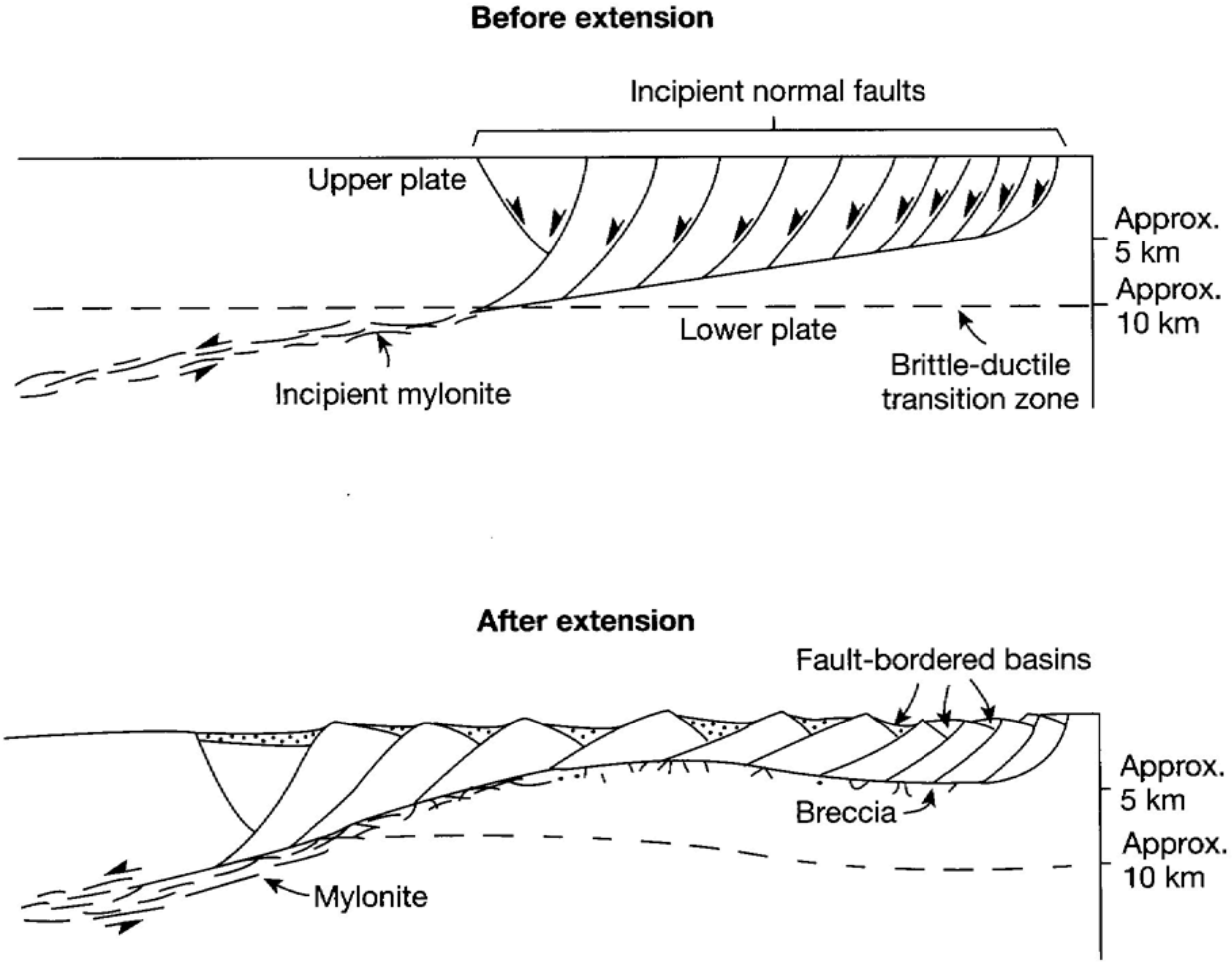


Figure 5: Source: geog.ucsb.edu

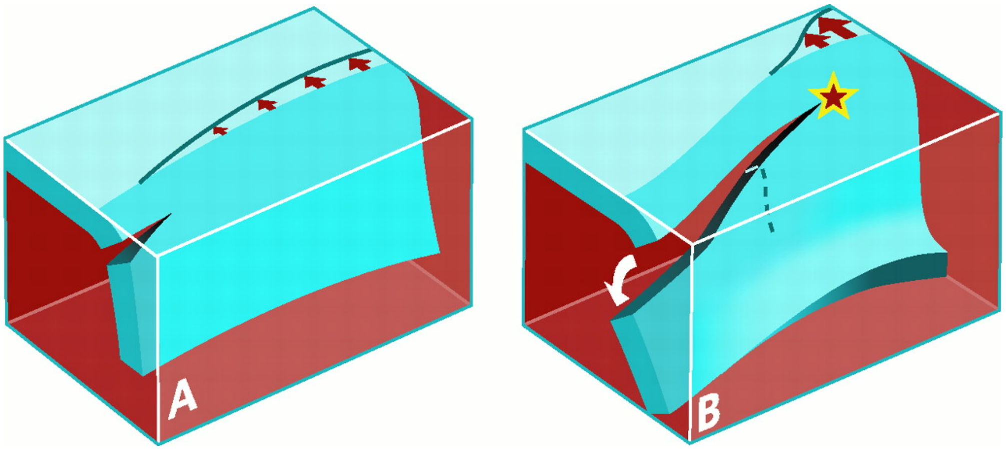


Figure 6: Source: Wortel & Spakman, 2000

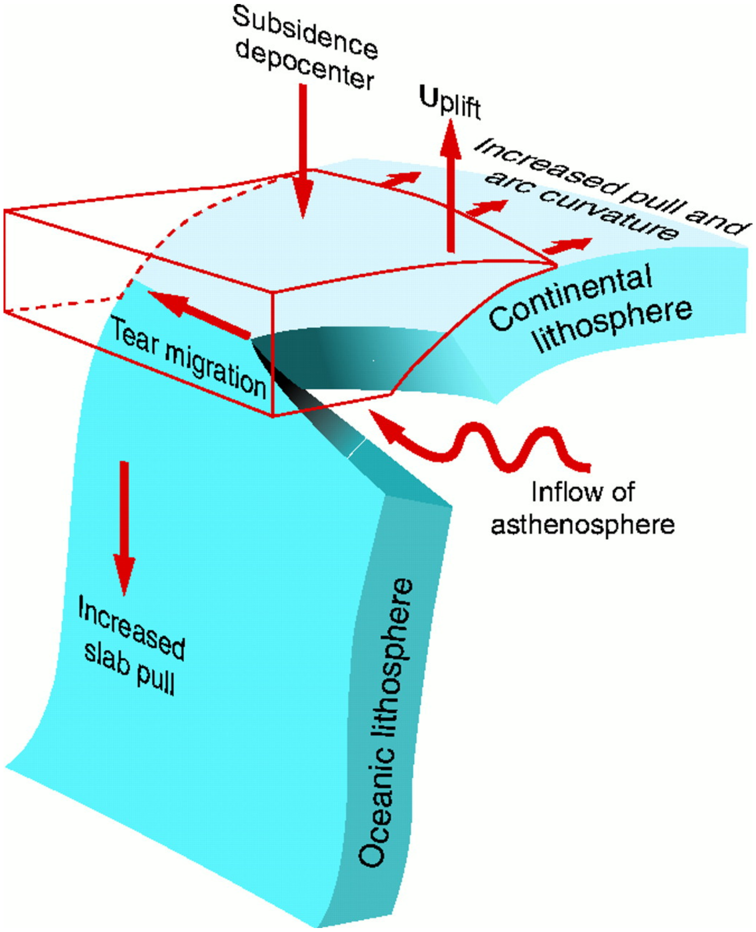


Figure 7: Source: Wortel & Spakman, 2000

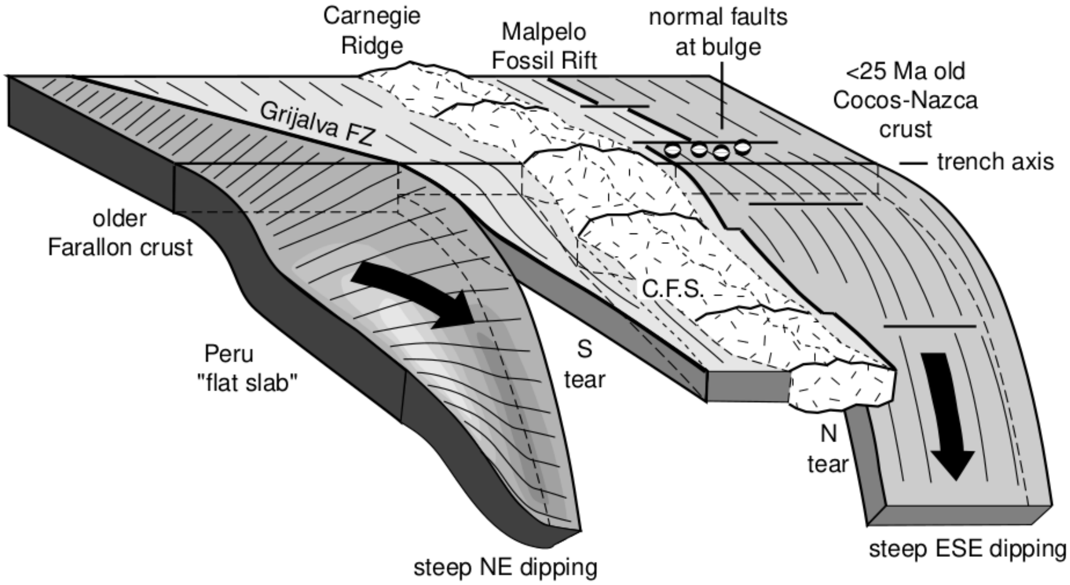


Figure 8: Example slab geometries. Source: Gutscher et al. 1999

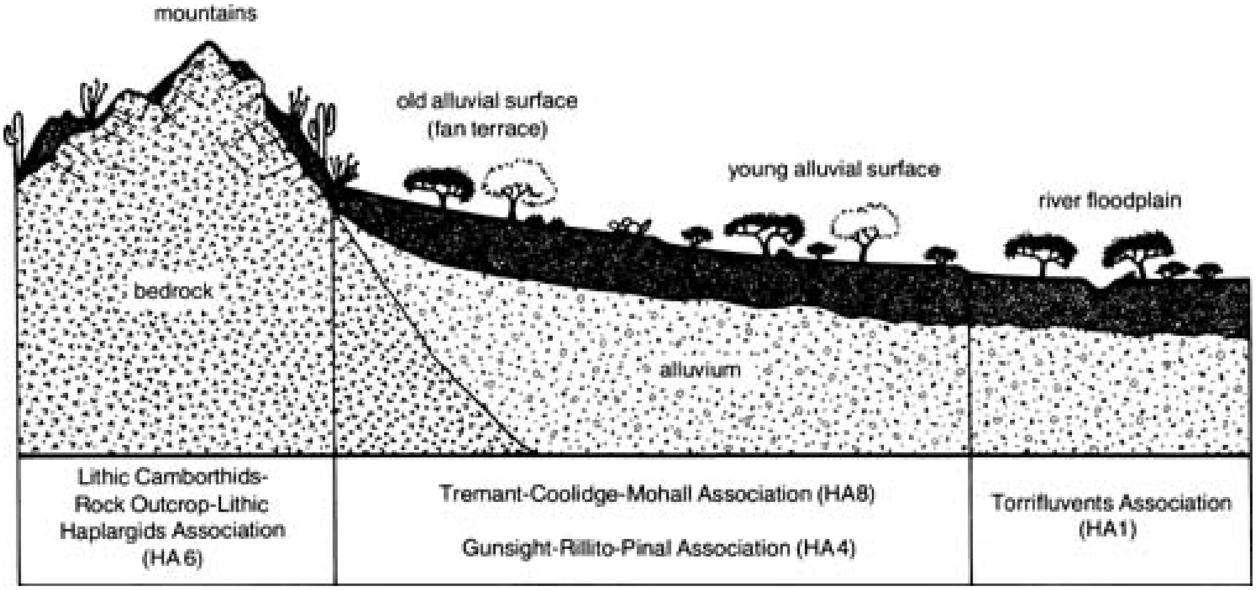


Figure 9: In Sonora and Southern Arizona, the basin and range is sometimes referred to as the "Sky Islands" because the mountain ranges rise up from the desert floor creating isolated ecosystems. Figure Source: D.M. Hendricks

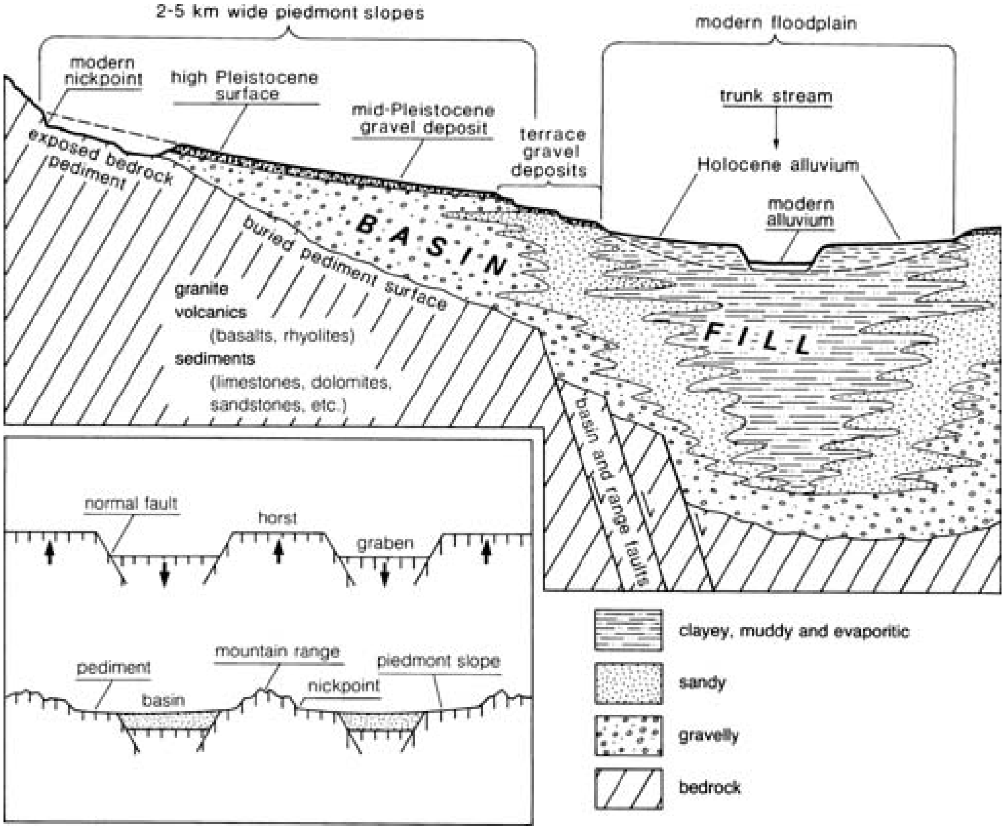
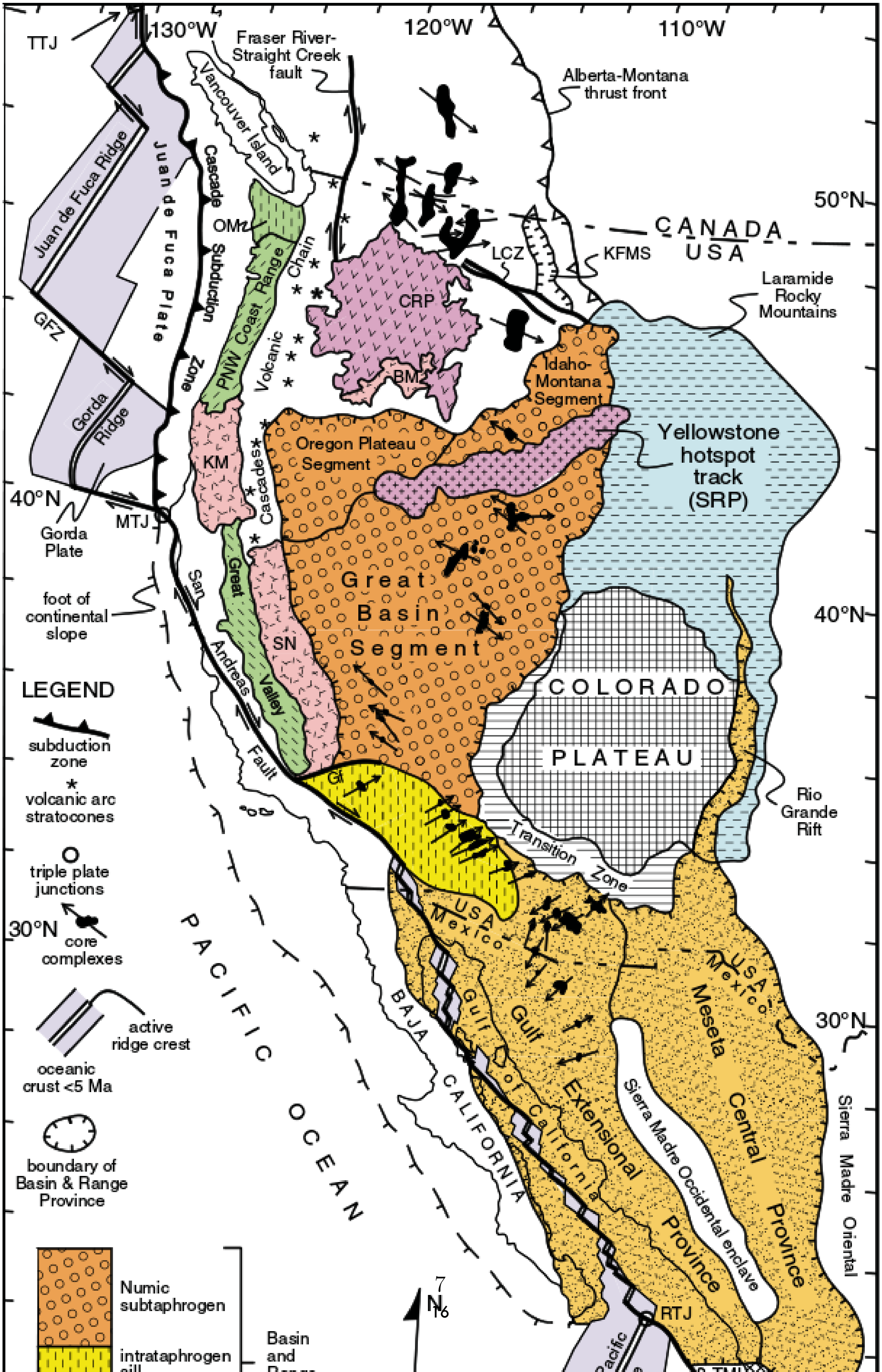


Figure 10: (cross section by R. B. Scarborough; inset after P. H. Rahn, 1966)


TTJ
130°W
120°W
110°W
Fraser River-Straight Creek fault
Alberta-Montana thrust front
Vancouver Island
Juan de Fuca Ridge
Juan de Fuca Plate
Cascade Subduction Zone
OM
PNW Coast Range
Cascade Volcanic Chain
50°N
CANADA
USA
LCZ
KFMS
Laramide Rocky Mountains
CRP
BM
Idaho-Montana Segment
GFZ
Gorda Ridge
KM
Cascades
Oregon Plateau Segment
Yellowstone hotspot track (SRP)
40°N
MTJ
Gorda Plate
Great Valley
SN
Great Basin Segment
40°N
foot of continental slope
San Andreas Fault
COLORADO PLATEAU
LEGEND
subduction zone
volcanic arc stratocones
triple plate junctions
core complexes
active ridge crest
oceanic crust <5 Ma
boundary of Basin & Range Province
Rio Grande Rift
Gf
Transition Zone
USA
Mexico
30°N
PACIFIC OCEAN
BAJA CALIFORNIA
Gulf of California
Gulf Extensional Province
Sierra Madre Occidental enclave
Meseta Central Province
30°N
Sierra Madre Oriental
Numic subtaphrogen
intrataphrogen sill
Basin and Range
N
RTJ
Pacific
TM

Algodones Dunes (aka Imperial Sand Dunes, Glamis Sand Dunes)

Description

The Algodones Dune field (or erg) is 75 km long and 8-11 km wide. It is one of the largest dune fields in the United States. Dune types include linear dunes, crescentic and compound crescentic dunes, parabolic dunes, zibars and sand sheets (Ewing et al., 2006; Derikson et al., 2008). Some of the parabolic dunes are quite large and can reach up to 80 m (200-300 feet) high (Norris & Norris, 1961). The prevailing wind directions are from the NW and N, depending on the season, resulting in a gross bedform-normal direction of ~66º (Derikson et al., 2008) (**Fig. 1**).

The dune field is divided up into sections, with much of it managed by the Bureau of Land Management. A section of the northern end is designated wilderness area. The south end crosses into Mexico. There are also several bombing ranges that border the dune field, one to the northeast (Chocolate Mountains) and two smaller ones on the west side of the north end.

Origin and Evolution

Likely sand sources are the shorelines of paleolake(s) Lake Cahuilla. Sediments derived from various levels of Lake Cahuilla are up to ~500-3,000 years old, with underlying older sediments dating from the Pleistocene (Stokes et al., 1997). Presently, no new sediment influx comes from dried Lake Cahuilla (Derikson et al., 2008). The elevated western ramp likely had dunes, but is now a deflationary feature (Stokes et al., 1997; Derikson et al., 2008). Dune patterns show complexity caused by the reworking of larger crescentic dunes as prevailing wind patterns change with season (Ewing, et al., 2006). Dune migration rates range from <1 m/yr. (Havholm & Kocurek, 1988) to 2-5 m/year (Stokes et al., 1997).

Cultural notes

The dunes are extremely popular as an off-road recreation site. Thousands of off-road vehicles visit the Imperial Dunes Recreation Area every year.

Filming location for several movies, including Return of the Jedi (**Fig. 3**).

References

Derikson, D., Kocurek, G., Ewing, R. C., Bristow, C. (2008) Origin of a complex and spatially diverse dune-field pattern, Algodones, southeastern California. *Geomorphology* 99, 1-4 186-204.

Ewing, R. C., Kocurek, G., Lake, L. W. (2006) Pattern analysis of dune-field parameters. *Earth Surface Processes and Landforms*, 31, 1176-1191.

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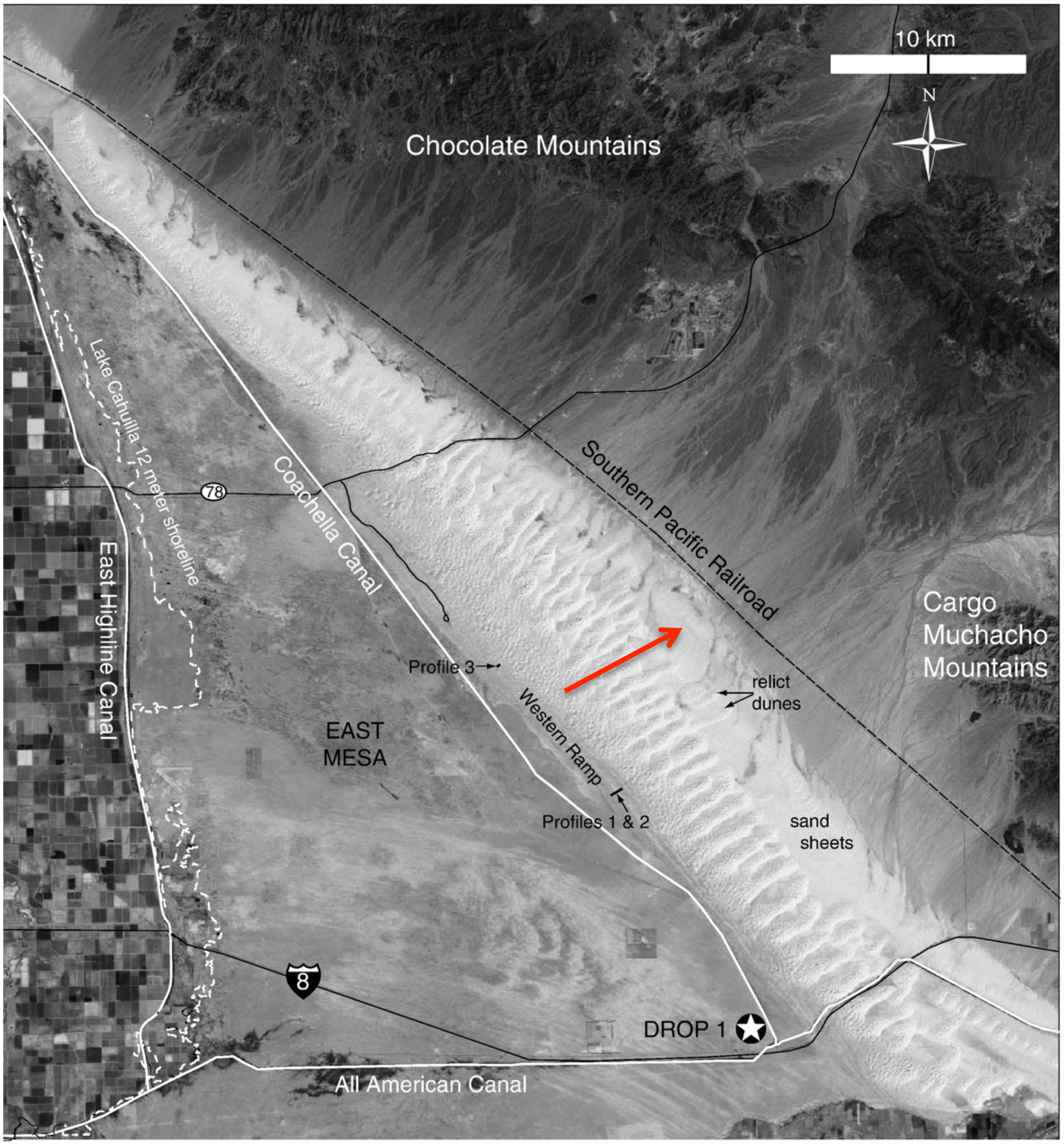

Figure 1. Aerial view of the Algodones Dunes noting, dune types. Red arrow indicates gross bedform-normal trend (after Derikson et al., 2008).

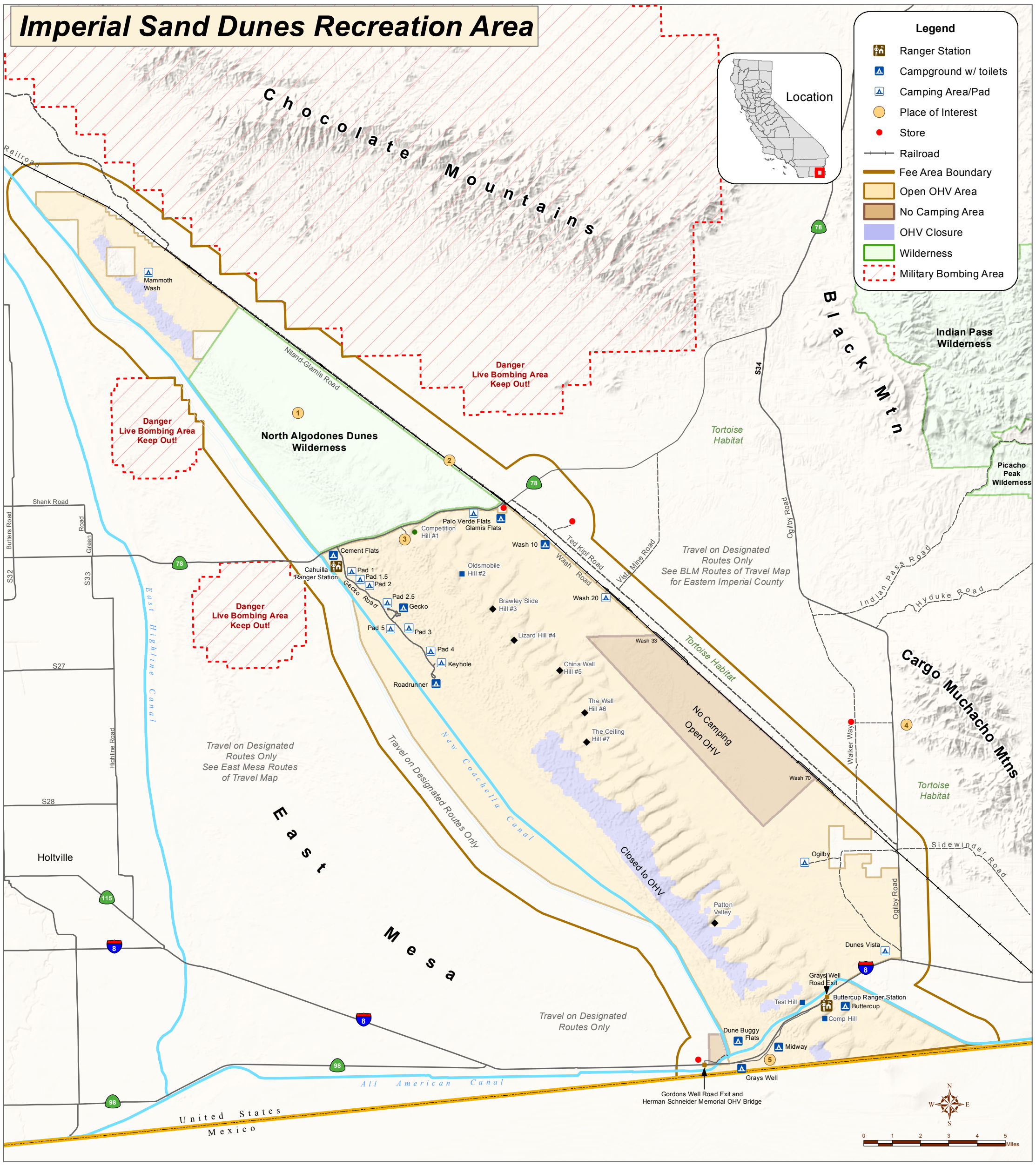

Figure 2. Map downloaded from BLM http://www.blm.gov/style/medialib/blm/ca/pdf/elcentro/maps.Par.96652.File.dat/2014_imperialdunesmap.pdf

Figure 3. Film set from Return of the Jedi. Photo from http://throughthesandglass.typepad.com/.a/6a01053614d678970c0120a59aa62e970c-pi

Submitted to Shane Byrne
Preprint typeset using LaTeX style emulateapj v. 12/16/11

TECTONICS OF THE SALTON TROUGH

Thaddeus D. Komacek

1. FIGURES

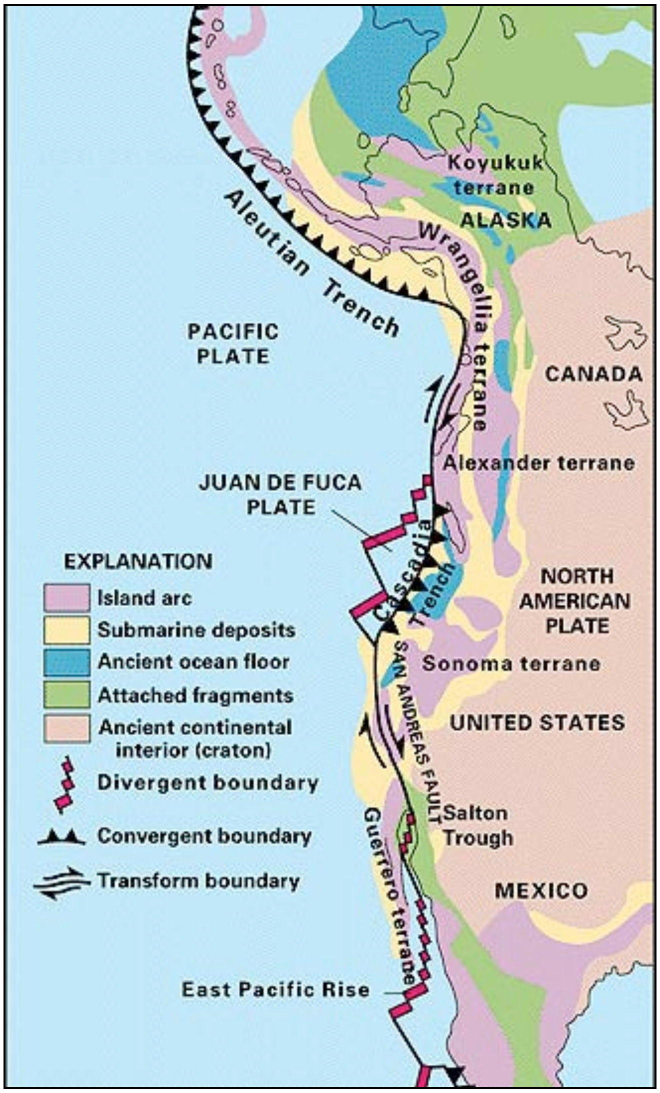

Fig. 1.— Map of boundary between Pacific and North American tectonic plates. Note the location of the Salton Trough on the San Andreas fault. Adapted from Kious & Tilling (1996).

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Belgarde, B. 2007, Master's thesis, Utah State University
Brothers, D., Driscoll, N., Kent, G., Harding, A., Babcock, J., & Baskin, R. 2009, Nature Geoscience, 2, 581
Forand, D. 2010, Master's thesis, Utah State University
Kattenhorn, S. & Prockter, L. 2014, Nature Geoscience, 7, 762
Kious, W. & Tilling, R. 1996, This Dynamic Earth (USGS)
Stock, J. 2009, Nature Geoscience, 2, 541
Watters, T., Robinson, M., Beyer, R., Banks, M., Bell, J., Pritchard, M., Hiesinger, H., van der Bogert, C., Thomas, P., Turtle, E., & Williams, N. 2010, Science, 329, 936

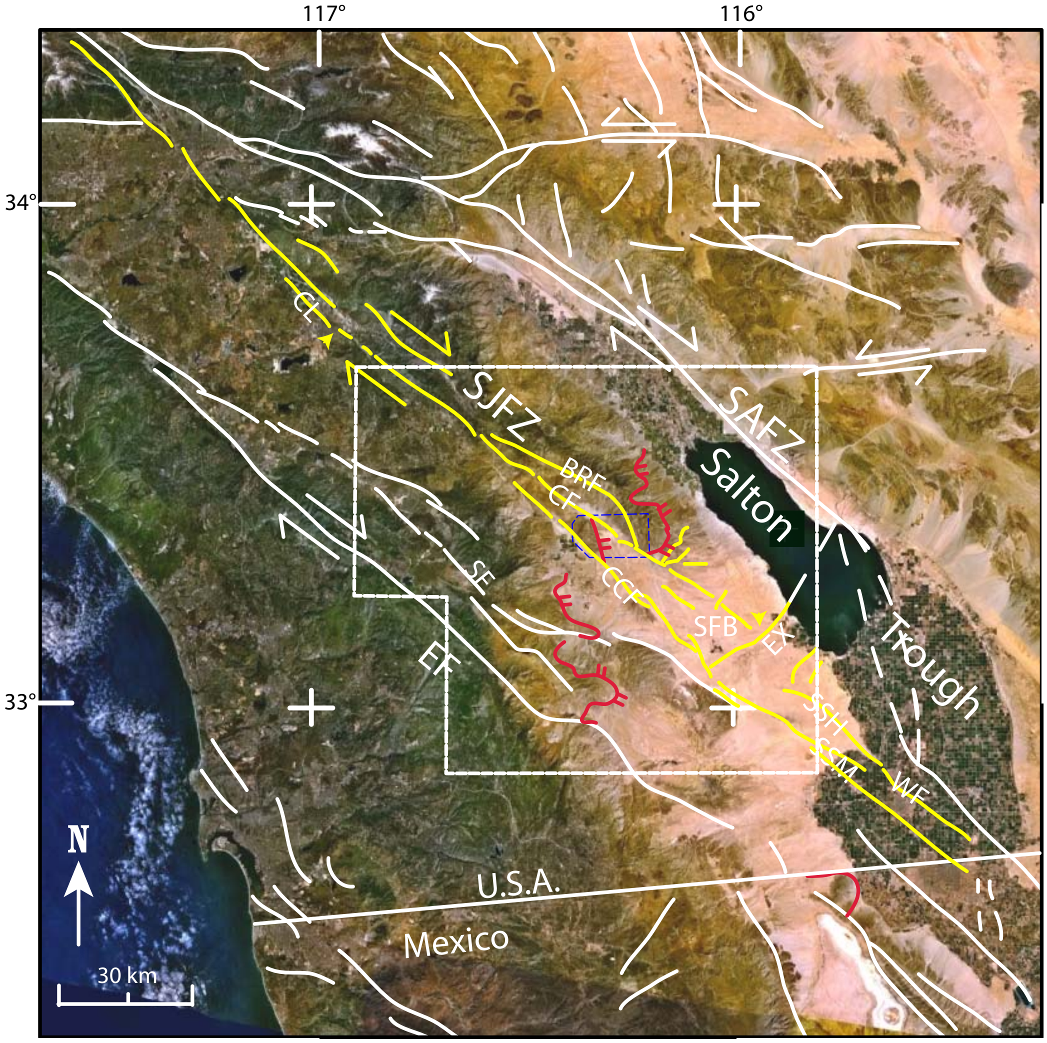


FIG. 2.— Detailed map of faults in the Salton Trough region superposed on a Landsat image, from Belgarde (2007).

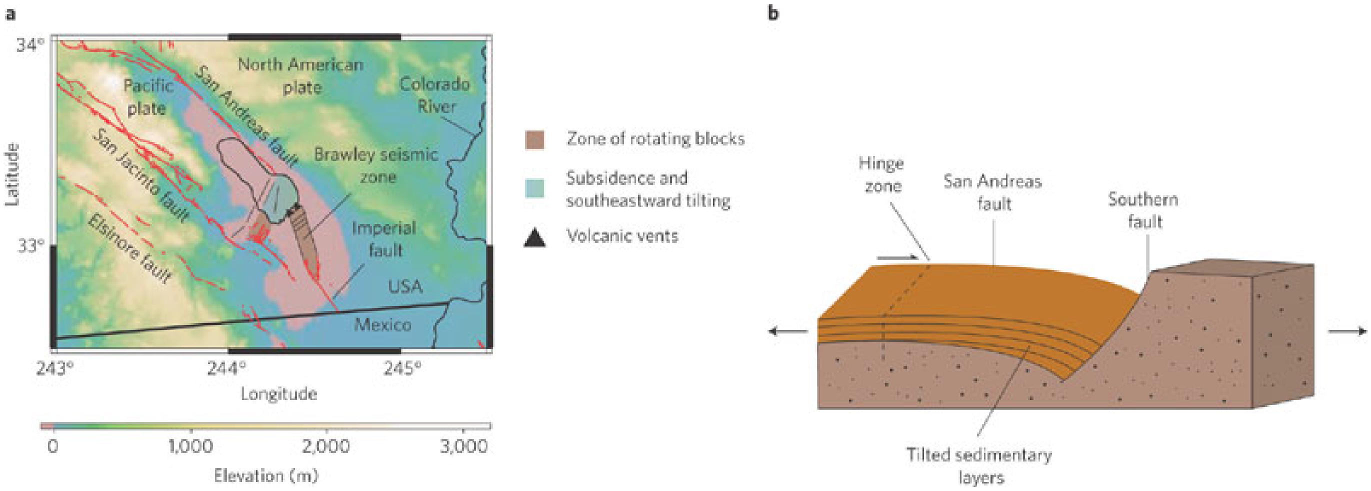


FIG. 3.— Map of tectonic regions in the Salton Trough (left) and schematic of region (right), showing the motion of the Pacific plate (left arrow) and North American plate (right-facing arrows). Adapted from Stock (2009).

Fig. 3-15.

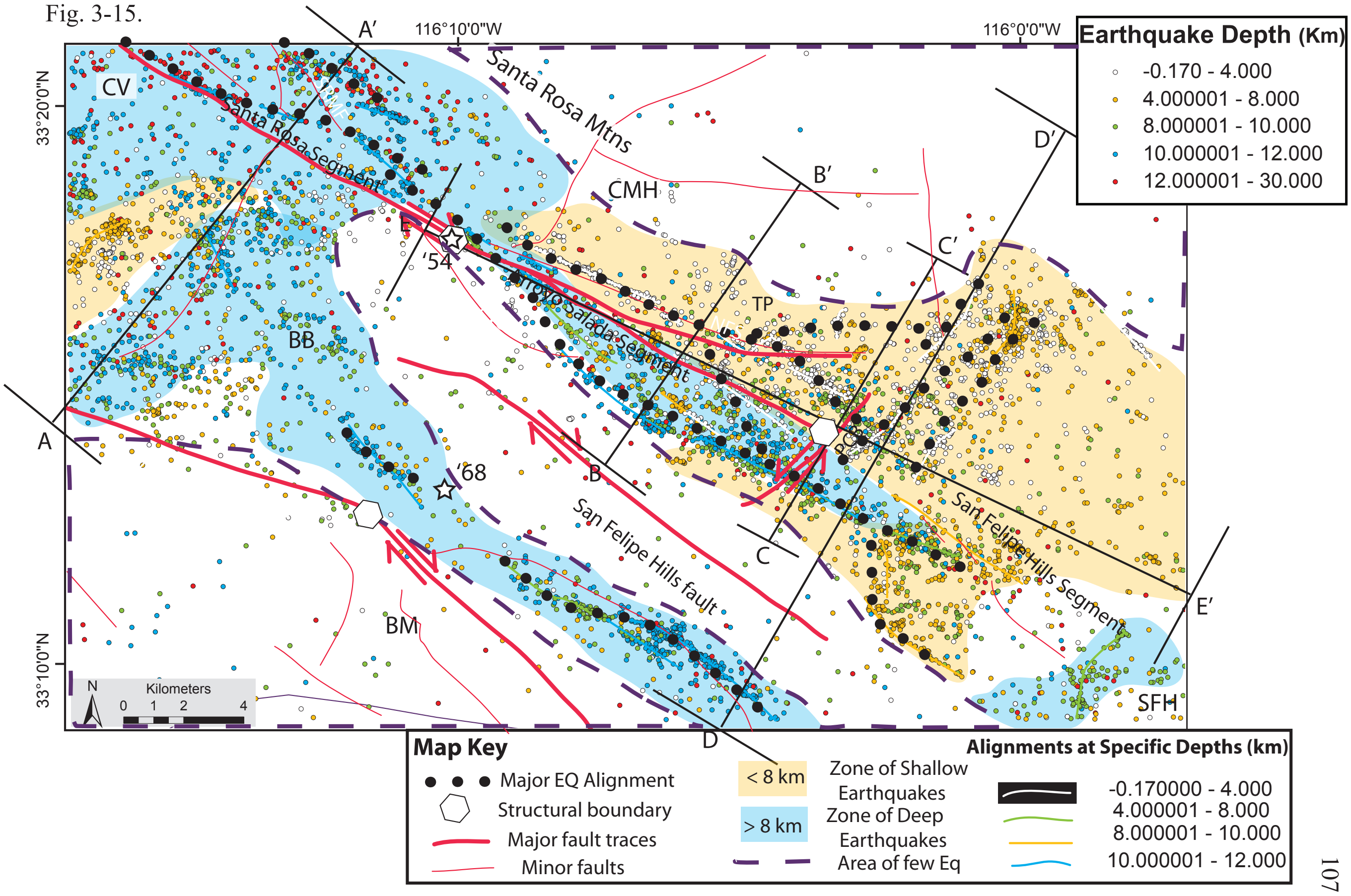


Fig. 4.— Map of earthquake locations in the Salton Trough from Belgarde (2007). Note the correlation between earthquakes and fault location.

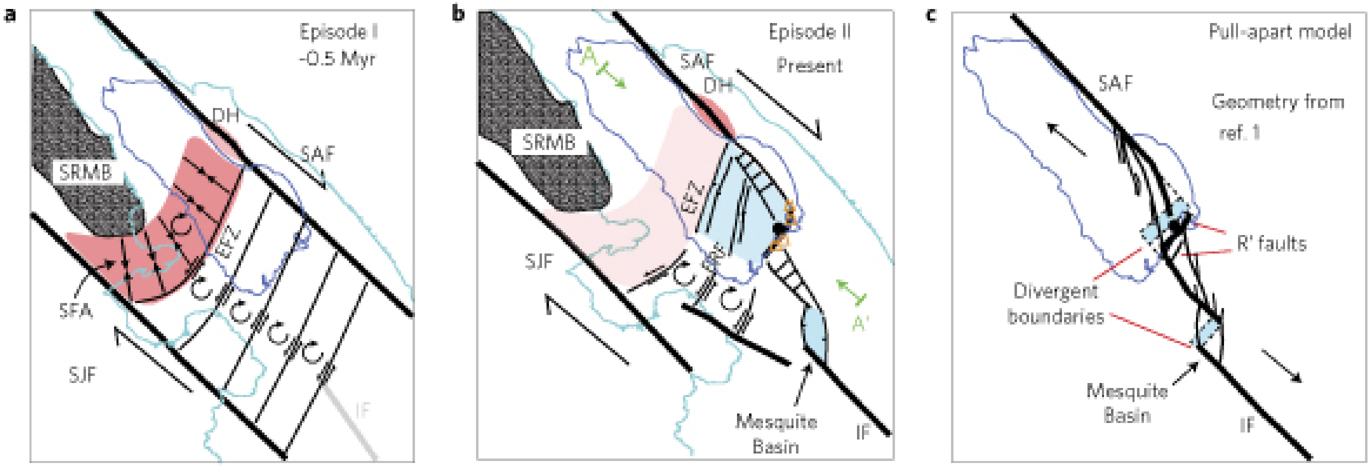


Fig. 5.— Schematic showing tectonic evolution of Salton Trough region, from Brothers et al. (2009).

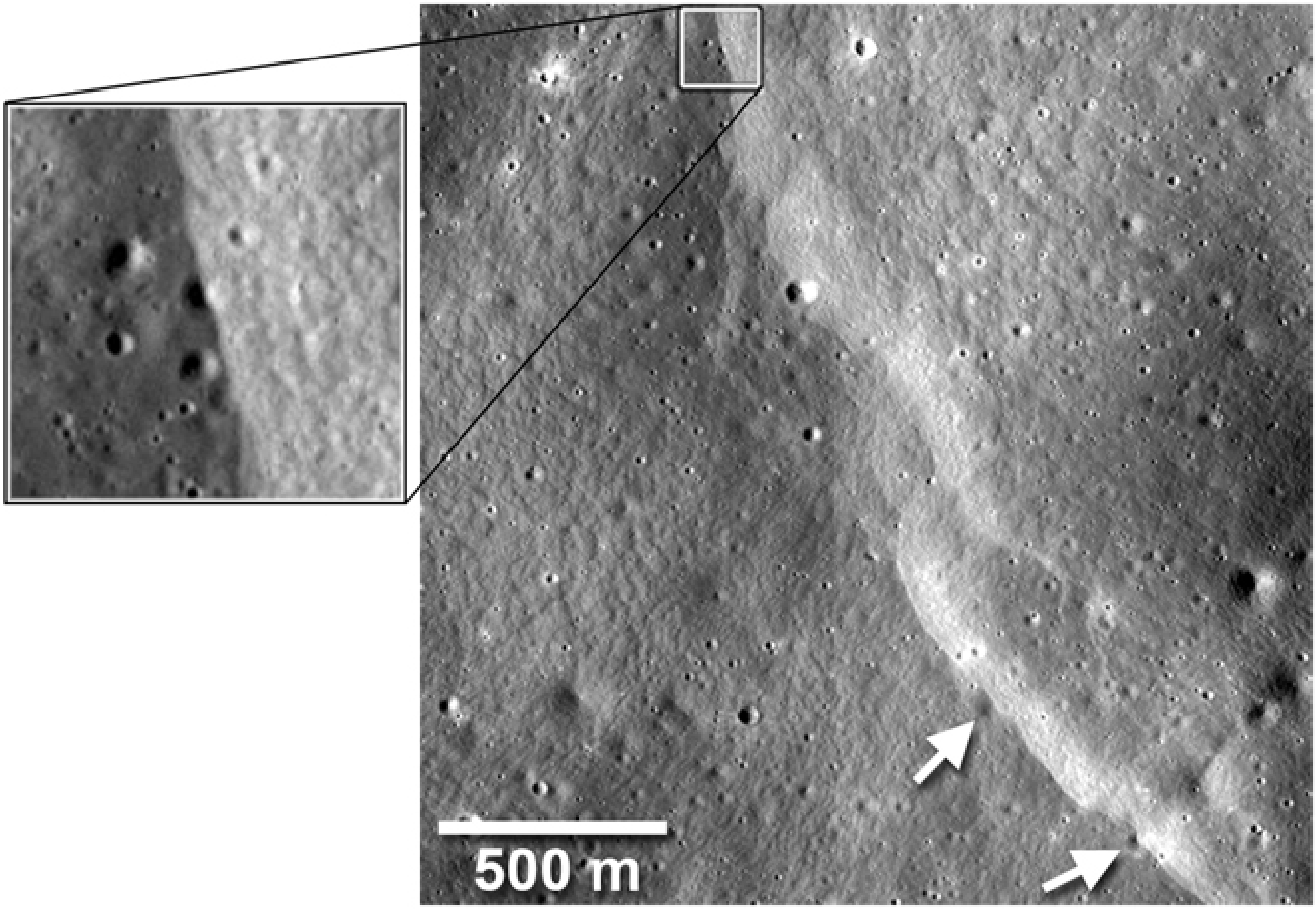


Fig. 6.— Example of thrust fault on the Moon. From NASA, Watters et al. (2010).

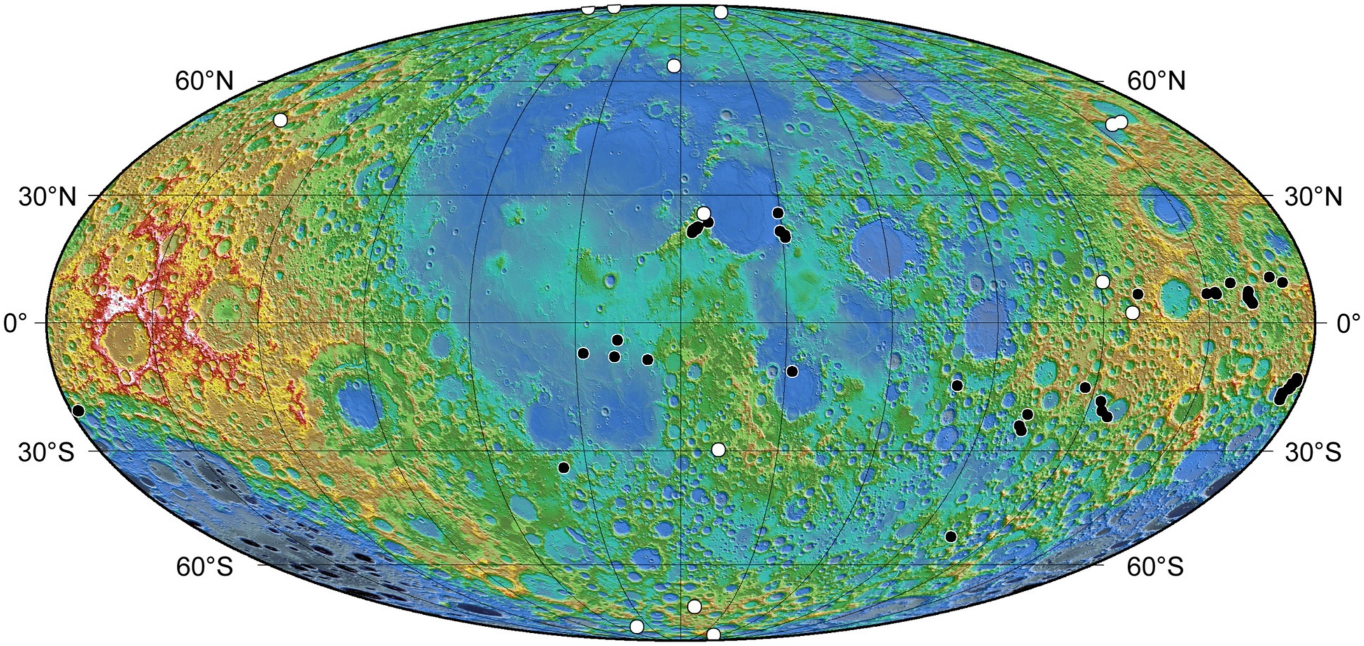


Fig. 7.— Map showing location of determined thrust faults on Moon from Watters et al. (2010).

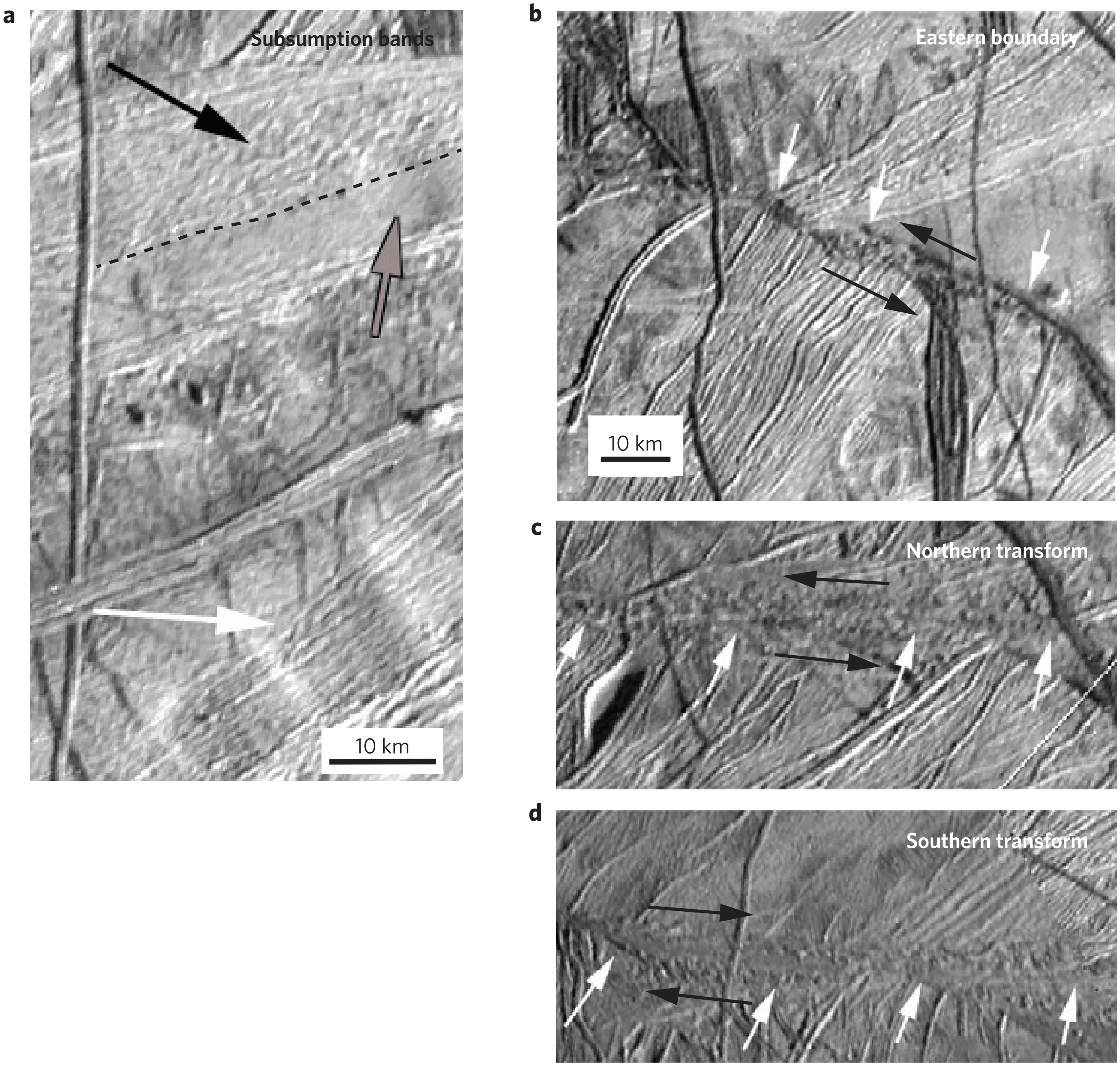


Fig. 8.— Regions of possible subduction on Europa, from Kattenhorn & Prockter (2014).

Ancient Lake Cahuilla

Donna Viola

In the past, the geographically isolated Salton Basin was periodically filled with fresh water due to changes in the course of the Colorado River: while the Colorado River often drained into the Gulf of California, fluctuations within the river delta sometimes caused the river to flow towards the north/west. Shoreline features of this ancient Lake Cahuilla have been dated back as far as 26,000 years ago, and the most recent retreat of the lake was about 300 years ago. At its largest extent, Lake Cahuilla was about six times larger than the present Salton Sea, covering an area of more than 5000 km^2. It is estimated that it would take about 20 years to fill the Salton Basin, and up to 60 years for it to recede/evaporate after the river changed course.

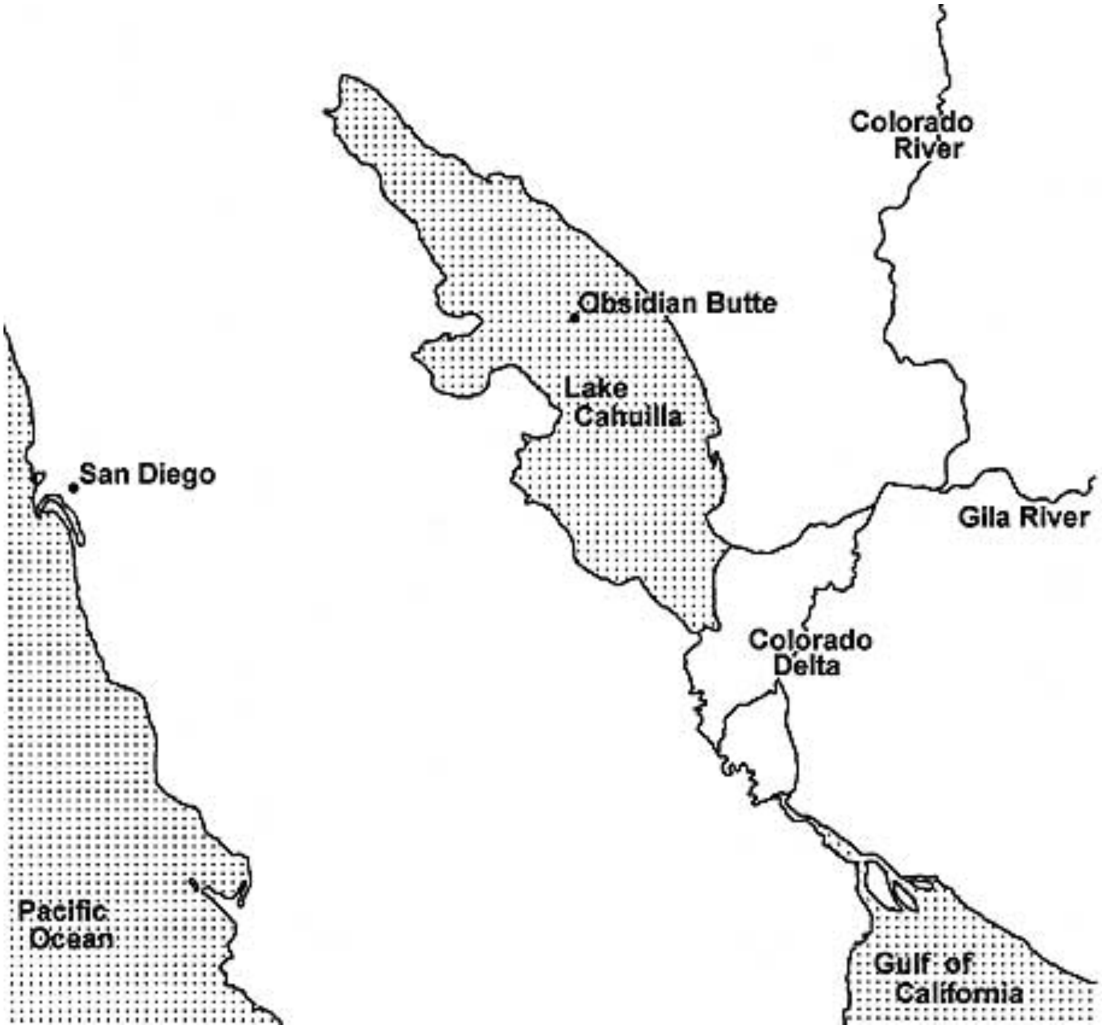


Figure 1: Map of the ancient Lake Cahuilla. Image credit: SDSU.

History of Inhabitation

Archaeological evidence of human settlements in the Lake Cahuilla area, including the Kumeyaay and Cahuilla tribes, dates back 2500 years. Most evidence indicates that the shoreline was consistently inhabited between ~900-1540, and 1600-1700. The lake was empty when the first Spanish explorations reached the region in the 16th century, and by the time Juan Batista de Anza reached the region in 1774, the last instance of Lake Cahuilla had fully retreated. However, the lake remained a prominent narrative in the oral history of the natives who lived there.

The End of Lake Cahuilla

It was once thought that the last instance of Lake Cahuilla existed continuously from about 1200-1700, but more recent evidence has suggested that the lake actually formed and retreated multiple times within that time period (Figure 3).

The final retreat of Lake Cahuilla may have happened in a step-wise fashion, as many separate shorelines can be identified. Abundant evidence of the lake's existence can still be seen today, including travertine deposits and shell fossils within beach deposits.

Today, the Salton Sea occupies just a small part of the ancient Lake Cahuilla (Figure 2).

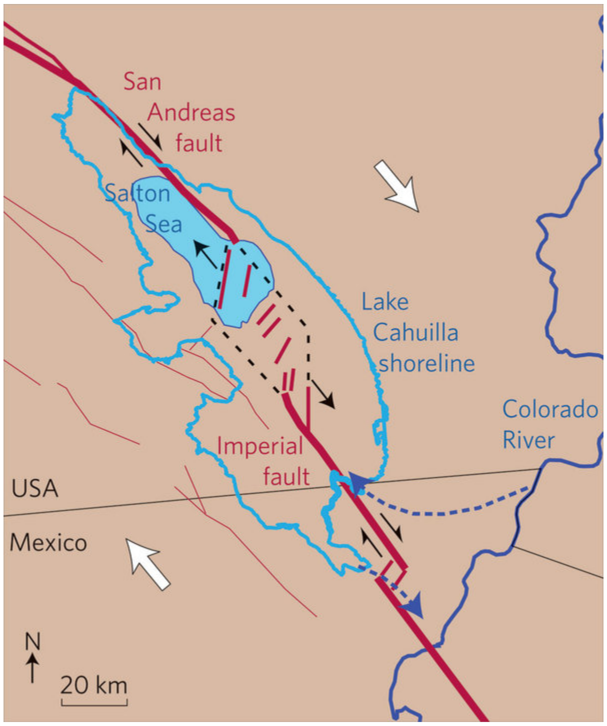


Figure 2: Map of the present Salton Sea and the ancient shoreline of Lake Cahuilla. Image credit: Hole (2011), Nat. Geos. 4:428-429.

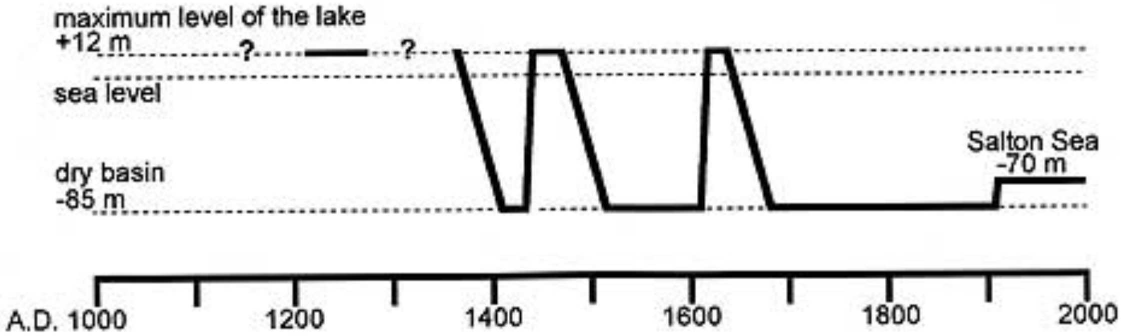
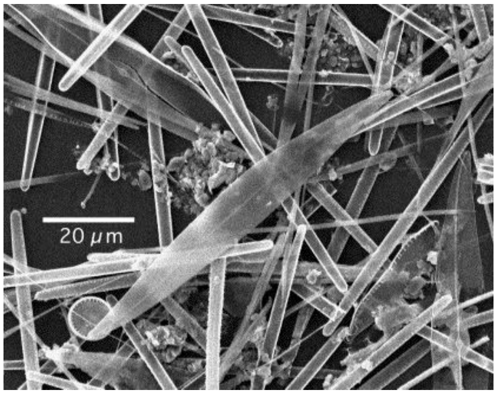


Figure 3: Tentative timeline of Lake Cahuilla and the Salton Sea. Image credit: SDSU.

Fauna	Flora
 30% of American white pelican Provides the food for several million birds every year  pupfish is resistant to levels of salt twices of sea.	 planton provide food for zooplankton and fish  Salton sea is inside the Sonoran desert.

Supplement
Fish
Due to the high salinity, very few fish species can tolerate living in the Salton Sea. Tilapia are the main fish that can tolerate the high salinity levels and pollution. Other freshwater fish species live in the rivers and canals that feed the Salton Sea, including threadfin shad, carp, red shiner, channel catfish, white catfish, largemouth bass, mosquitofish, sailfin molly, and the endangered desert pupfish.

Avian population

The Salton Sea has been termed a "crown jewel of avian biodiversity" by Dr. Milt Friend of the Salton Sea Science Office. Over 400 species have been documented at the Salton Sea. The most diverse and probably the most significant populations of bird life in the continental United States are hosted, rivaled only by Big Bend National Park in Texas.[19] It supports 30% of the remaining population of the American white pelican.[20] The Salton Sea is also a major resting stop on the Pacific Flyway. On 18 November 2006, a Ross's gull, a high Arctic bird, was sighted and photographed there.[21]
Plankton
Living planktonic diatoms are found in mid-lake water. They provide food for zooplankton and fish. A seasonal succession of the planktonic diatom flora is evident, with Thalassionema nitzschioides, Cyclotella spp. and Chaetoceros muelleridominating the summer assemblage and Pleurosigma ambrosianum and Cyclotella spp. being abundant in the winter. When mixing is heavy, as during strong wind storms, diatoms which are usually associated with other habitats (benthic, epiphytic) get mixed into the plankton. Such is the case for small benthic diatoms such as Tryblionella punctata and Nitzschia frustulum which are very abundant in plankton samples during the winter. Almost any diatom living in the Salton Sea can be found occasionally in the plankton.

Mining Operations of the Anza-Borrego Mountains

By: Jon “The Bapst” Bapst

Introduction

Mining operations in the Anza-Borrego desert have been limited to the northern regions, namely the Santa Rosa Mountains. Mining effectively began as soon as humans inhabited the region.

First Miners

The first known people to “mine” here were natives of the Cahuilla tribe. They collected “wonderstone” which, here, means a hydrothermally altered, highly silicified sedimentary rock, and likely formed in ancient hot springs. The natives gathered wonderstone from various washes around the mountains and crafted tools and arrowheads from it (for use and trade).

Figure 1. Map of southern California with the Santa Rosa Mountains outlined in red.

Figure 2. Slabs of wonderstone hot off the stove.

Early 1900’s and Gold Mining

The Santa Rosa Mountains contain no major ore-bearing deposits, either precious or base-metals. However, during the early 1900's, a prospector named Nicholas Schwartz is said to have discovered a small "blowout" or pocket of gold-bearing ore

(~$250,000 in 2010 USD). During that same time, another prospector named Butler (or possibly Buckley) stumbled on a very rich pocket somewhere in the heart of the range. Butler worked the deposit for a short time, but ill-health forced him to leave the mountains. Before he died, Butler told his tale to a long-time resident of the area named Fred Clark. The mine has never been found.

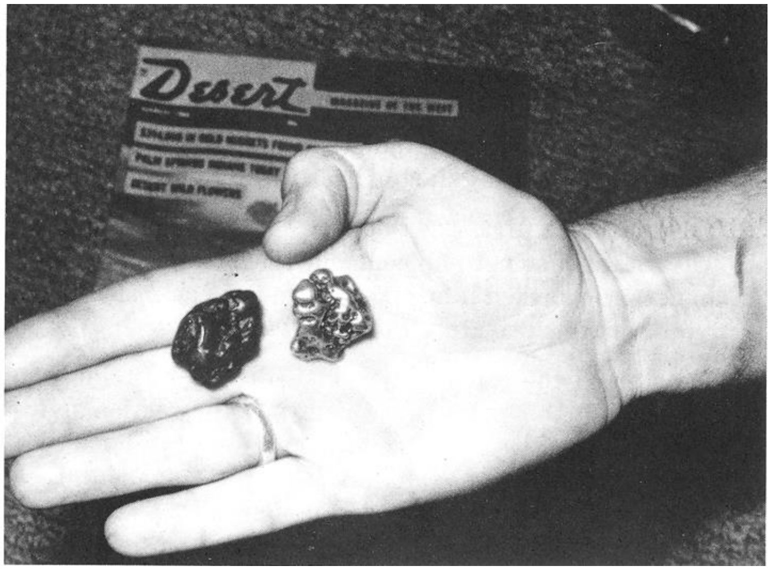


Figure 3. Black-coated "Pegleg" Smith gold nuggets have been found just south of the Santa Rosa Mountains, in the Borrego Badlands

Calcite Mining

The Calcite Mine, which dates to World War II days, is situated on the northeast slope of the Santa Rosa Mountains below Travelers Peak. It is a collection of crazily shaped sandstone configurations, evidence of wetter periods when this erosion occurred. Calcite is mined, ground into a powder and is used in the manufacturing of paint, cement, calcium carbide, metal polish and insecticides.

Mining Today

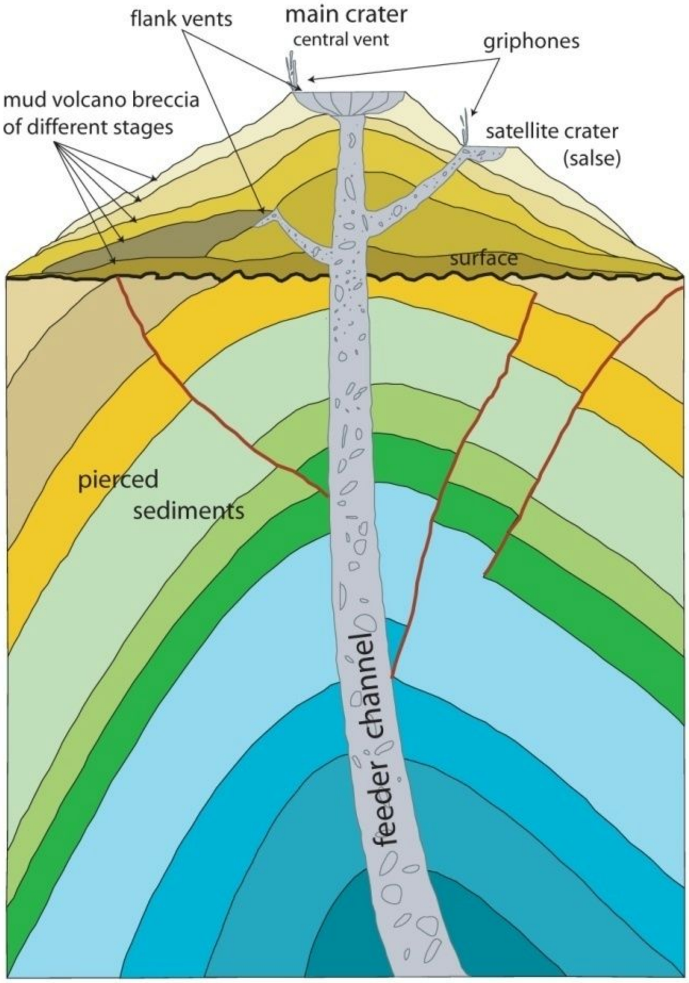
Some portions of the Santa Rosa range are off-limits to prospecting. Much of the northern part of the mountains lies within the Santa Rosa Indian Reservation, the Santa Rosa Mountains State Game Refuge, or the Anza Borrego Desert State Park. Some sections of the southern part of the range also lie within the Anza Borrego Desert State Park. More recently, the entire range has been declared a National Monument.

Figure 4. Calcite Mine Slot Canyon; Southern Santa Rosa Mountains

Mud Volcanoes: Formation & Rheology

Alessondra Springmann and Joana Voigt
October 20, 2015

Introduction



Mud volcanoes are terrestrial structures that extrude relatively low temperature slurries of gas, liquid, and rock to the surface from depths of meters to kilometers (Oehler and Allen, 2010).

Unlike traditional volcanoes, mud volcanoes are not driven by magmatic processes, and are not to be confused with geothermal features such as mudpots seen in Yellowstone park. Mud volcanoes are found where subsurface layers of fluidized sediments, like silt and clay, have been pressurized by tectonic activity. This can be due to boundaries of tectonic plates, especially at subduction zones, or due to the accumulation of hydrocarbon gases. Pressurized sediment gets forced upward and erupts onto the surface to form conical mounds of mud.

The flow of mud to the surface is related to the buoyancy of the fluid-rich or muddy sediments relative to the surrounding rocks, and occurs in weak regions such as faults, fractures, and anticlinal structures. Mud volcanoes are mostly harmless, with a notable exception in Indonesia, and may pose hazards for hydrocarbon drilling in Azerbaijan.

Terminology

- **Mud cone**: high cone shorter than 10 meters that extrudes mud and rock fragments
- **Gryphon**: steep-sided cone shorter than three meters that extrudes mud
- **Scoria cone**: cone formed by heating of mud deposits during fires
- **Salse**: water-dominated pools with gas seeps
- **Spring**: water-dominated outlets smaller than 0.5 meters

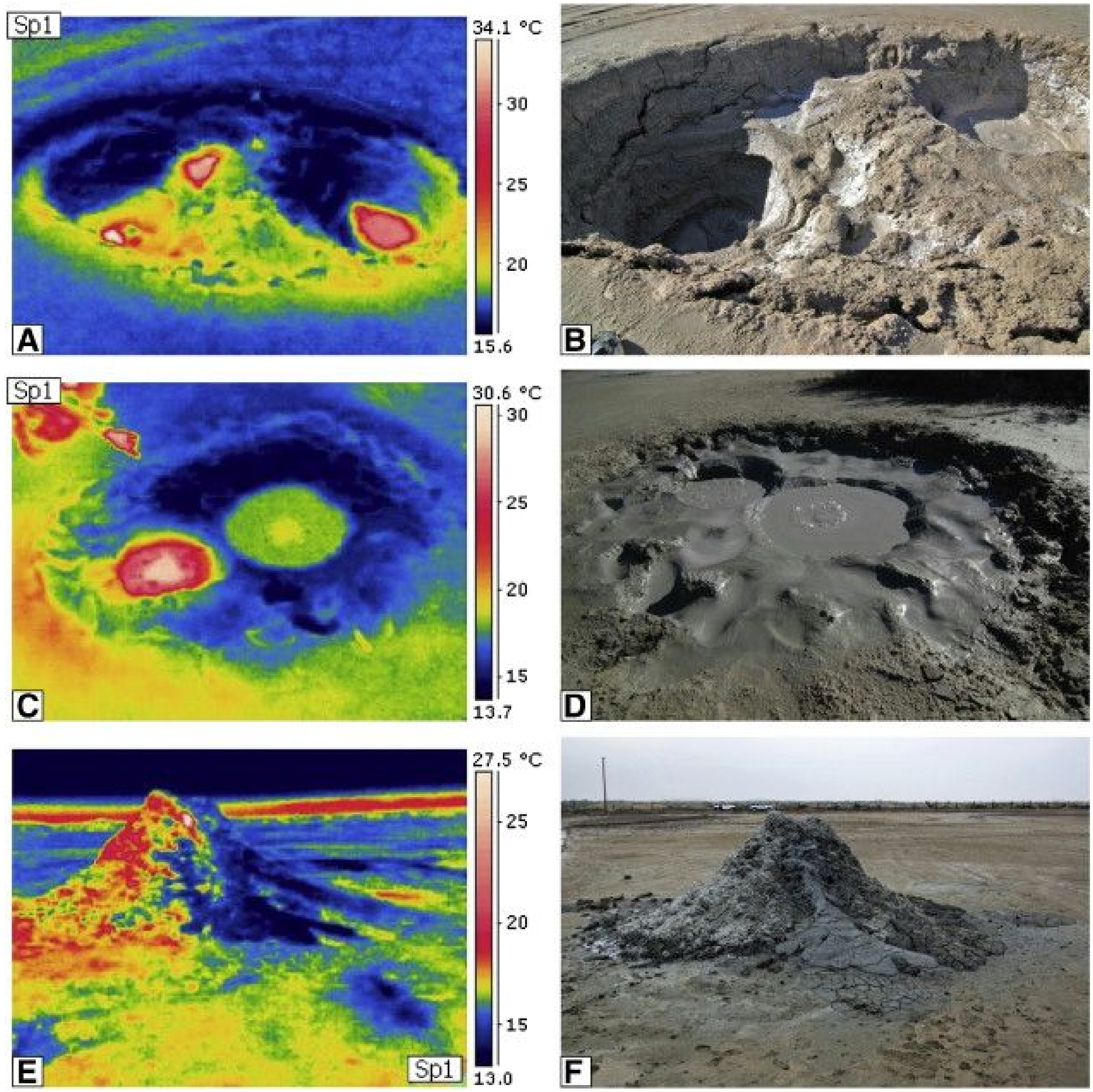
Formation

Phase transitions and differences in pressure in a sedimentary basin may be responsible for the formation of mud volcanoes as this leads to decompaction of material and gas generation. The timescale over which a sedimentary basin is periodically excited can occur over tens to thousands of years. Mud volcanoes are often associated with hydrocarbon generation, and at higher flow rates gas and sediment develop a "pseudo-liquid' state before reaching a hover velocity at which mass begins transported upward in a basin, moving as a quasi-uniform viscous mass through the sediment pile, not unlike a piston, resulting in a catastrophic eruption. Mud may be driven to the surface due to buoyancy forces arising from density contrasts between the mud and the surrounding sediment, which could result from gas expansion. Weaknesses in a rock provide a conduit for the mud slurry to travel and ultimately erupt to form gryphons and salses on the surface (Guliyev, 2007).

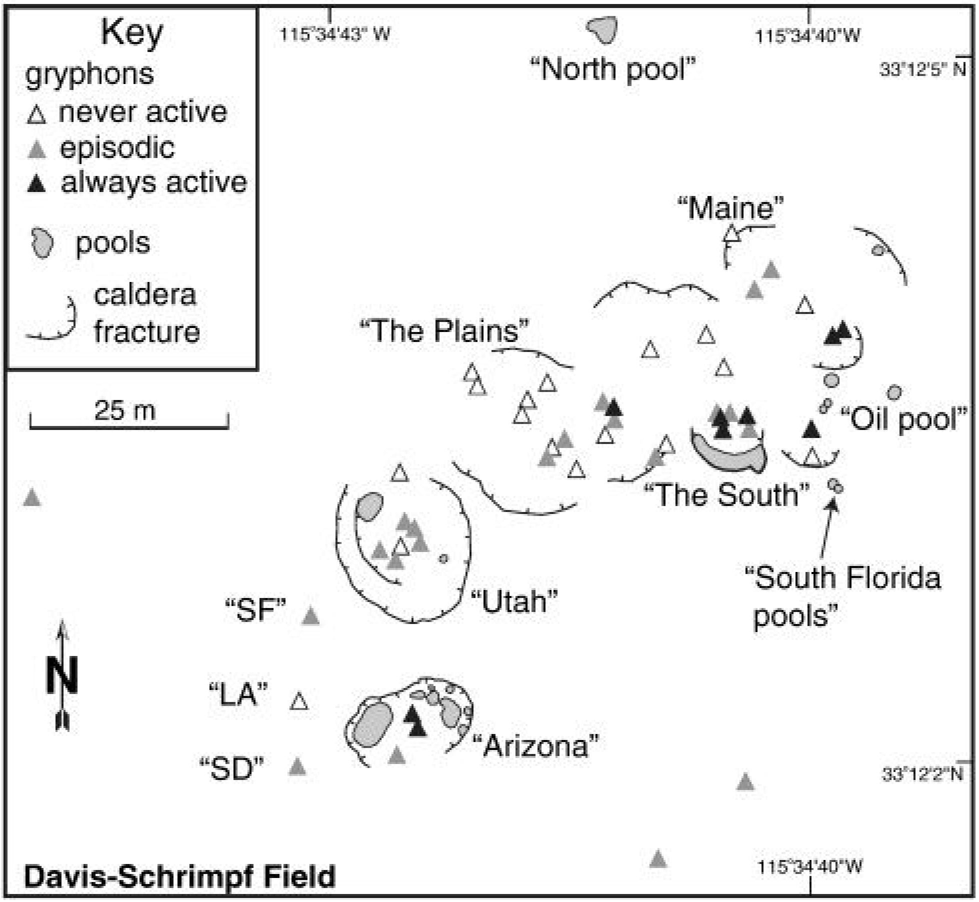
Locations

- Salton Sea
- Indonesia - Lusi
- Azerbaijan - mud volcano capital of Earth
- Almost every other continent
- Mars - Acidalia Planitia
    - Oehler and Allen (2010) provide evidence for pervasive mud volcanism in Acidalia Planitia by mapping almost 20,000 circular mounds in the region. Mud volcanoes on Mars would indicate sites that have been rich in gas, liquid, fine-grained sediments, and possibly organic materials.

The mounds shown here, located in the Southern Acidalia Planitia, range in size between 20 and 500 meters in diameter. Credit: NASA/JPL/University of Arizona



From Mazzini et al. (2011):
Infrared images (A, C, E) highlight the different temperatures of the seeping fluids even at closely spaced locations indicating a complex plumbing system in the near subsurface. (B, D) Isolated pools (ca. 1.5 m in diameter) where focused seepage of fluids occur at several locations. The images also highlight that different water levels are present at closely spaced sites. (F) Isolated gryphon (~ 2 m high) with hot mud seeping from the top of the crater and flowing along the flanks of the structure. Although the temperature of the mud is higher than 60 °C in the crater, once the gaseous phase is released to the atmosphere, the mud cools down very rapidly as it flows.



From Onderdonk et al. (2011): Map of the Davis–Schrimpf field showing seep features and caldera ring fractures.

Rheology

Rheology (inferred from Greek, where "rheo" stands for flow and "logia" for study) in general describes the deformation and flow behavior of materials, mostly in a liquid condition or soft solid form. It therefore contains sections of elasticity theory, plastic theory and fluid mechanics.
Mud volcanoes mobilize a mixture of gas, water and fine sediment from the sub-bottom of depths between few meters to several km to the surface. The eruption rates and also temperatures are lower compared to those with a magmatic origin. The rheology of mud volcanoes is complex and difficult to characterize because of the great variety of materials and conditions of the mud flows. However, it is important to get an understanding of the rheological properties in order to evaluate the conditions needed to transport the particle to the surface (Manga and Bonini, 2012) and consequently to understand the process behind the formation of this features.

In general the rheology is mostly describes as a non-Newtonain behavior by a nonlinear viscoplastic Herschel-Bulkley model (e.g. Herschel and Bulkley, 1926), with yield stresses between 4 to 8 Pa (Manga and Bonini, 2012).

This model includes time-independent power-law/flow index and yield stress behavior and therefore it could be used for rheology description of mud flows (e.g. Coussot and Piau, 1994).

$$\tau = \tau_c + K\,\gamma^n$$

Where τ is the shear stress (Pa), γ is the shear rate (1/s), τ_c is the yield stress (minimum stress needed for flow), K is the consistency (Pa) and n is the flow index. If the shear stress is smaller than the yield stress the fluid behaves as a solid, other way round the material behaves as a fluid. It should be considers that this equation is an oversimplification of rheology, however the Herschel-Bulkley model is well studied and can be used to relate the clasts to properties of the mud. Manga and Bonini (2012) for example used this relationship to calculate the size of particles on active mud volcanoes in the northern Apennines in Italy. The sizes of the particles are weight supported by yield strength of the mud and speed at which larger clasts will settle through the mud (Manga and Bonini, 2012). In their work they present a yield stress from 3.7 to 7.9 Pa that allow particles between the size of 5.7 to 12 mm to be held in place by yield stress.

The Salton Sea mud volcanoes *David-Schrimpf* are comprised of extrusional gryphons (1-2 m tall) and have a more fluid like behavior (Kopf, 2002). The eruption of mud and magmatic volcanoes is directly controlled by dynamics of gas bubbles. Tran et al. (2015) measured the rheological parameters in 4 experiments (Tab.1) and shows that the yield stress of mud magmas with sub-millimeter particles can immobilize millimeter to centimeter sized bubbles.

Magma rheology in general depends on the temperature, composition and suspended crystals and bubbles (Mader et al., 2013). In muds, the clay-sized particles interplay electrical and dissolved electrolytes and are able to flocculate (van Olphen, 1964). Particles and bubbles may orient or deform under applied shear and bulk compressional differentiation occur (Tran et al., 2015). These imply a time dependent rheology in mud volcanoes (Bekkour et al., 2005) and furthermore a spatial distribution in martial properties.

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HIGH SILICA VOLCANISM

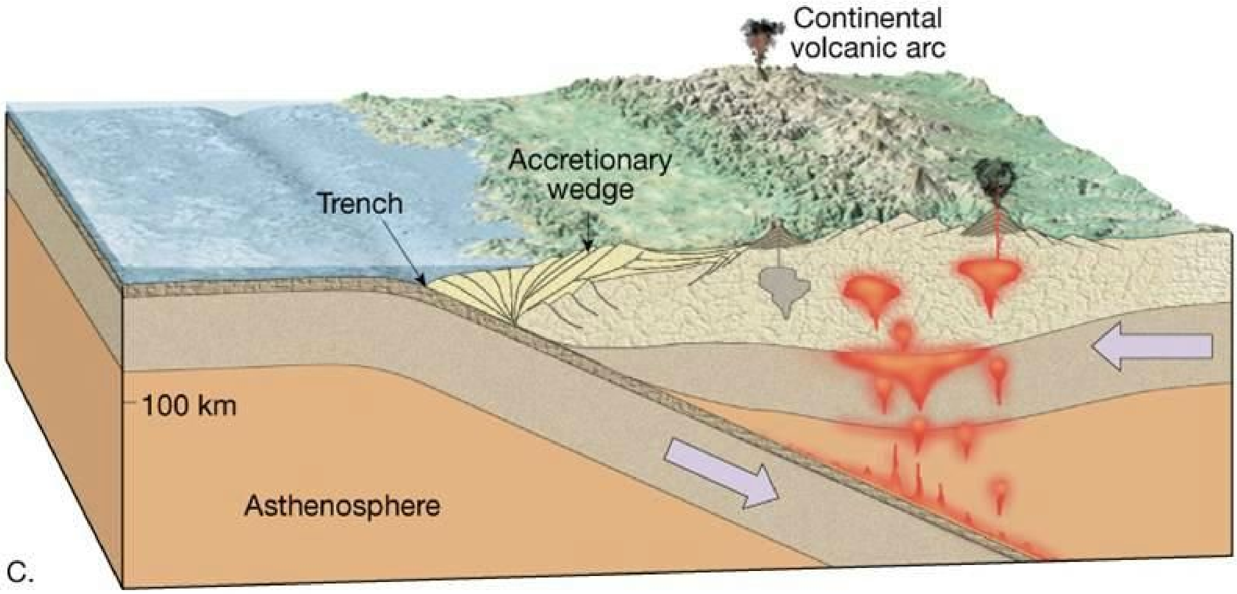
Jean Masterson

Mt. Etna - Stratovolcano in Sicily, Italy

(Image Credit: Wikicommons)

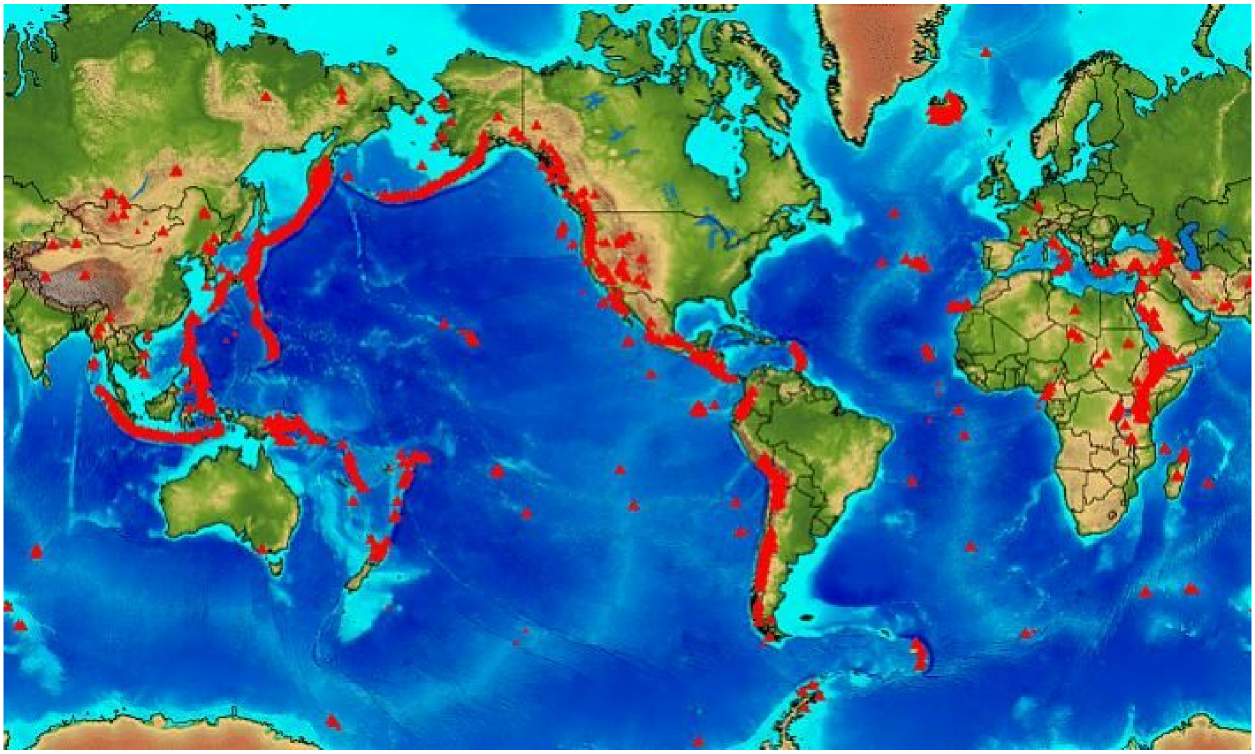
General Characteristics

- Magma is viscous due to high silica content
- Felsic lavas (dacites or rhyolites; >63% silica) tend to erupt in short, stubby flows or as domes
- More volatiles are generally trapped in high silica magma, leading to catastrophic eruptive styles (ex: Plinian-style eruptions, Pyroclastic flows)
- Volcanoes are characterized by steeper slopes than those created by mafic eruptions (~30–35°)
- Usually occur at oceanic-continental convergent boundaries



Oceanic-Continental Convergent Boundary

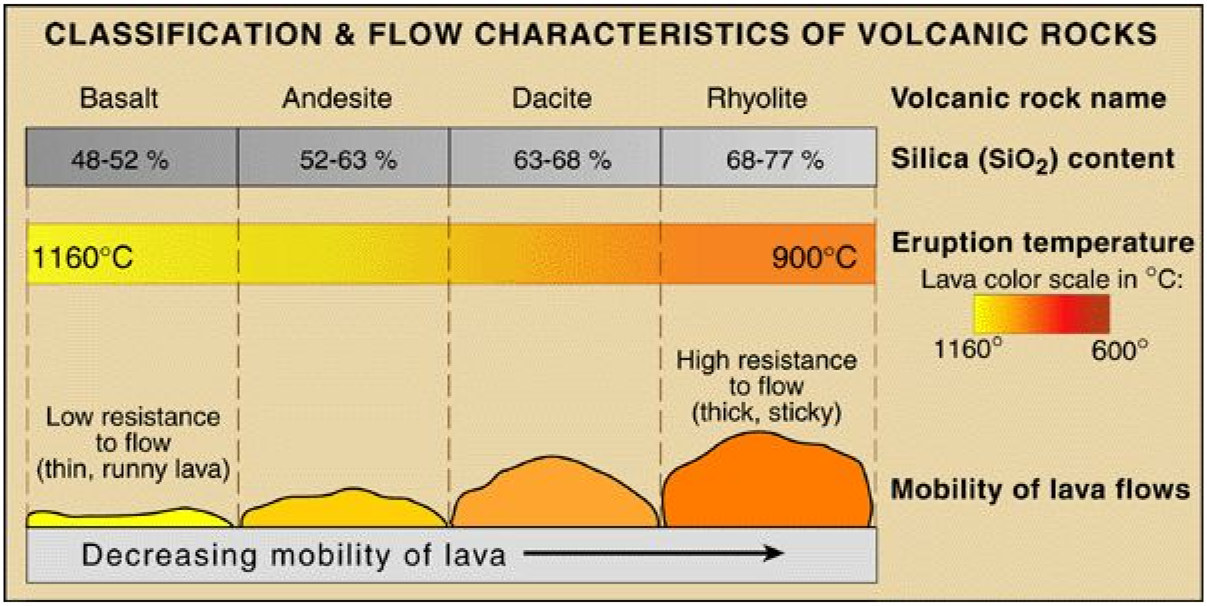
(Image Credit: https://classconnection.s3.amazonaws.com)



Ring of Fire

(Image Credit: https://engwell.wikispaces.com)

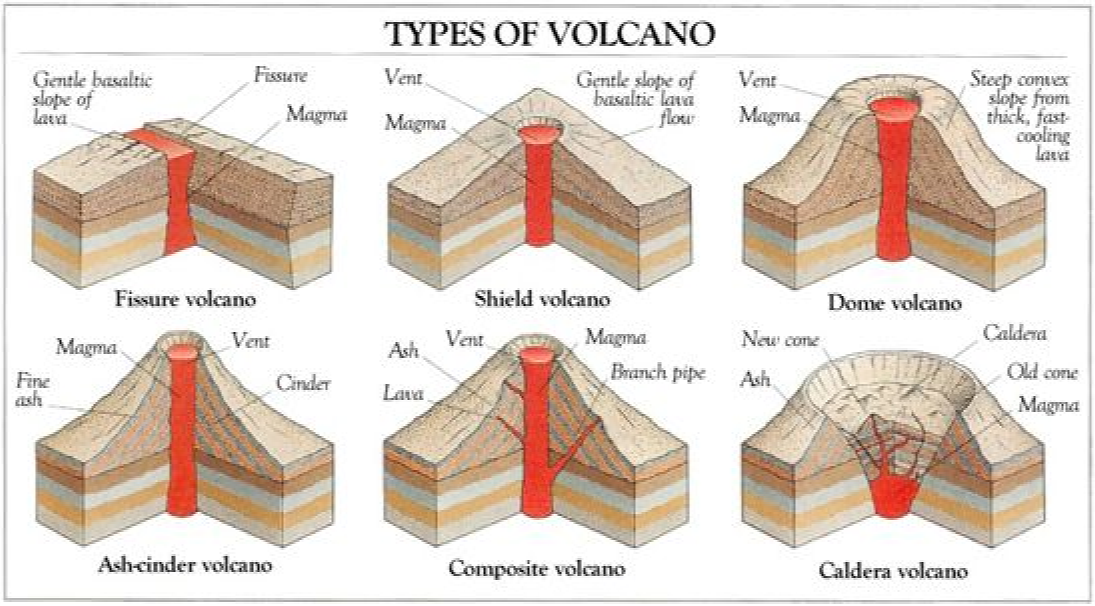
Lava Composition



(Image Credit: http://volcanoes.usgs.gov)

Specific Types of Volcanoes

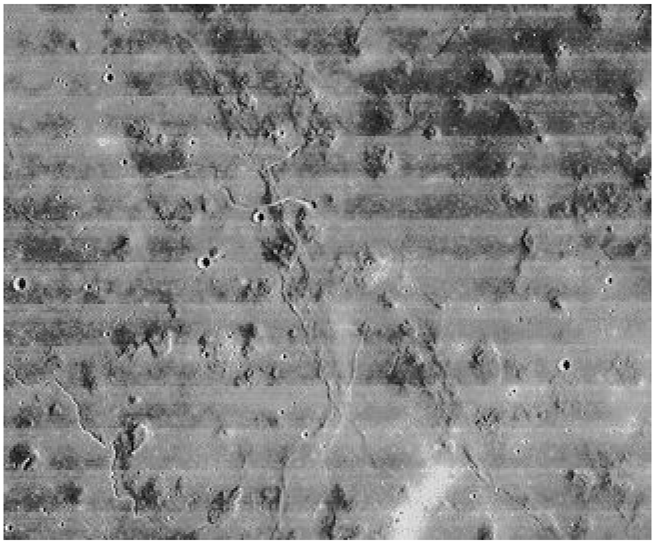
- Stratovolcanoes/Composite: Krakatoa, Vesuvius, Mount St. Helens, Mount Fuji
- Cinder Cones: Izalco, Sunset Crater



(Image Credit: http://go2add.com)

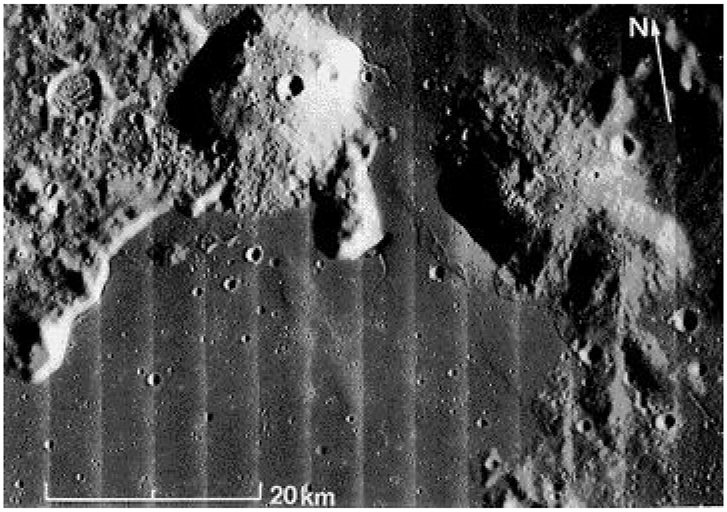
Extraterrestrial Examples

Earth's Moon:



Marius Hills - Cinder Cones

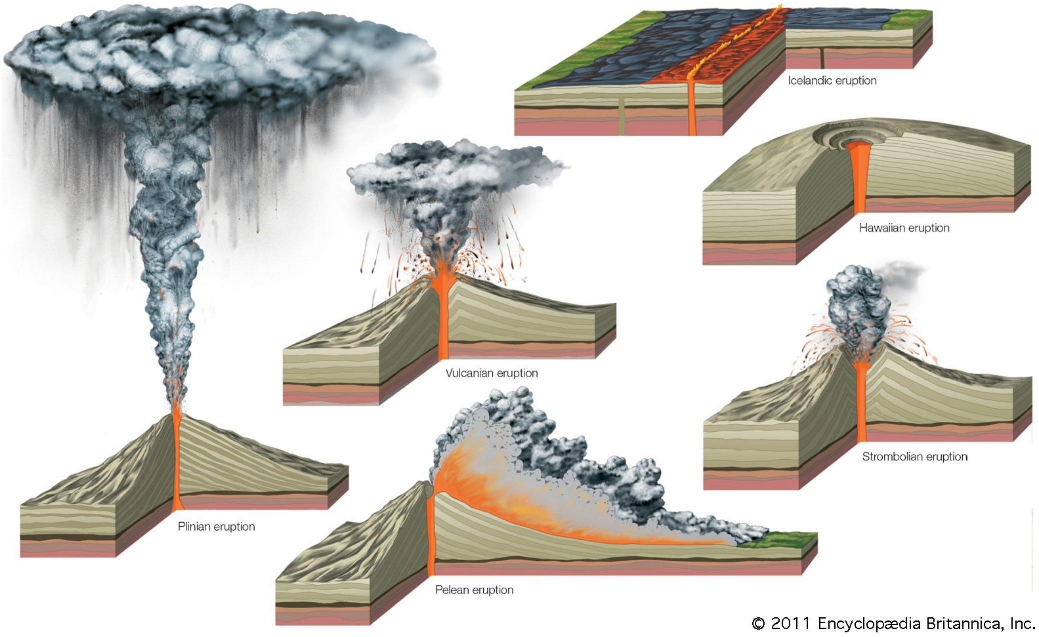
(Image Credit: Lunar Orbiter image IV-157-H2, from Wilhelms (1987))



Gruitheisen Domes - Non-Basaltic Lunar Volcanism (RARE)

(Image Credit: Lunar Orbiter image IV-157-H2, from Wilhelms (1987))

Mars:



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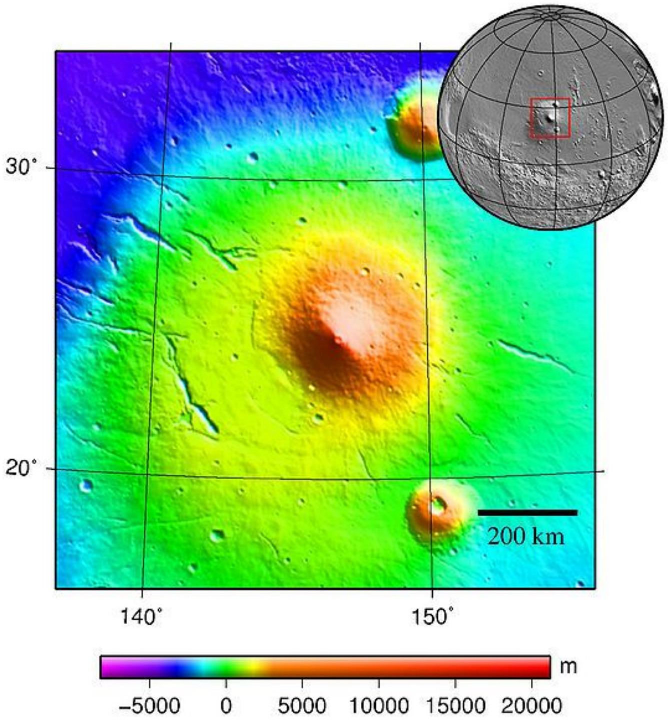
Plinian eruptions - Common of Basaltic Volcanism on Mars



Elysium Mons - Stratocone with Pyroclastics (but Basaltic!)

(Image Credit: MOLA; Wikicommons)

Michelle Thompson

How the Salton Sea turned into an Environmental Disaster

or

Should we even be here? This place is toxic AF

1.0 It wasn't always this way…

The Salton Sea is an endorheic rift lake, meaning it has no natural outlets. It receives inflow from three rivers (The Whitewater, The Alamo and The New River), as well as a significant proportion from agricultural runoff and drainage. It is very shallow, with the deepest point under <50 feet of water. The lake sits on top of ancient salt deposits that together with agricultural runoff, make it hypersaline with current salinity measurements around 44 g/L and increasing, compared to the 35 g/L in the Pacific Ocean.

The Salton Sea served as a popular resort destination in the 1950s and 1960s for boating, fishing, and other summer activities (Figure 1). Several hotels, subdivisions, and luxury resorts were in development through the later part of the 60s. It was plentiful with fish and migratory bird species.

2.0 When things start going downhill…

By the early 1970s, however, the Salton Sea began to experience serious environmental problems. Several flooding events in the 1970s halted resort development. With no outflow points, the Salton Sea is prone to experiencing rapid changes in its ecosystem. Variations in rainfall and agricultural runoff impact the water level in the Salton Sea, and as a result its salinity. It is also located in an area of exceptionally high evaporation which has only intensified as a result of the drought in California is recent years. As it is fed by agricultural runoff, the Salton Sea has been accumulating toxic pollutants from pesticide use, in particular, Se, in its lake bottom sediment for more than a century.

Figure 1: An image of the Salton Sea from the 1950s, showing the popularity of the region as a tourist destination.

3.0 From bad to much, much worse…

By the 1980s, the Salton Sea began experiencing massive fish fatalities, with thousands to tens of thousands of fish washing up dead on its shores. This likely resulted from increasing salinity levels and algal blooms. These temporary increases in algal activity make the ecosystem uninhabitable for other wildlife. Algal blooms are often caused by eutrophication (Figure 2). While it can by a natural process, in the Salton Sea eutrophication is caused by the runoff of fertilizers from surrounding farmland. This generates an enrichment in chemical nutrients (e.g., phosphates and nitrogen) in the ecosystem, leading to an overproduction of algae species. These algae consume the available oxygen in the lake and as a result, fish species die. This is only one of many water quality issues that are highlighted in Table 1.

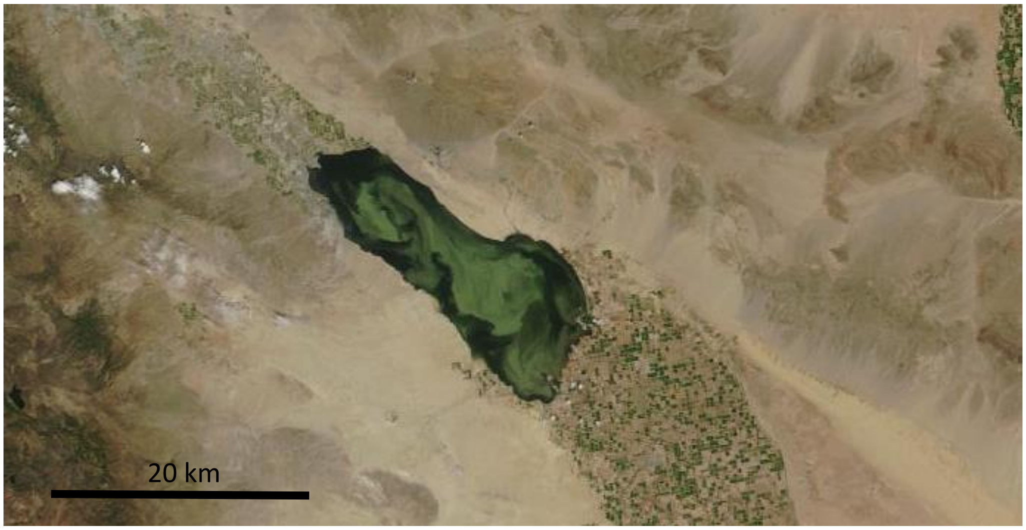


Figure 2: The satellite image of an algal bloom (seen in green) in the Salton Sea was taken with the NASA's Moderate Resolution Imaging Spectroradiometer (MODIS).

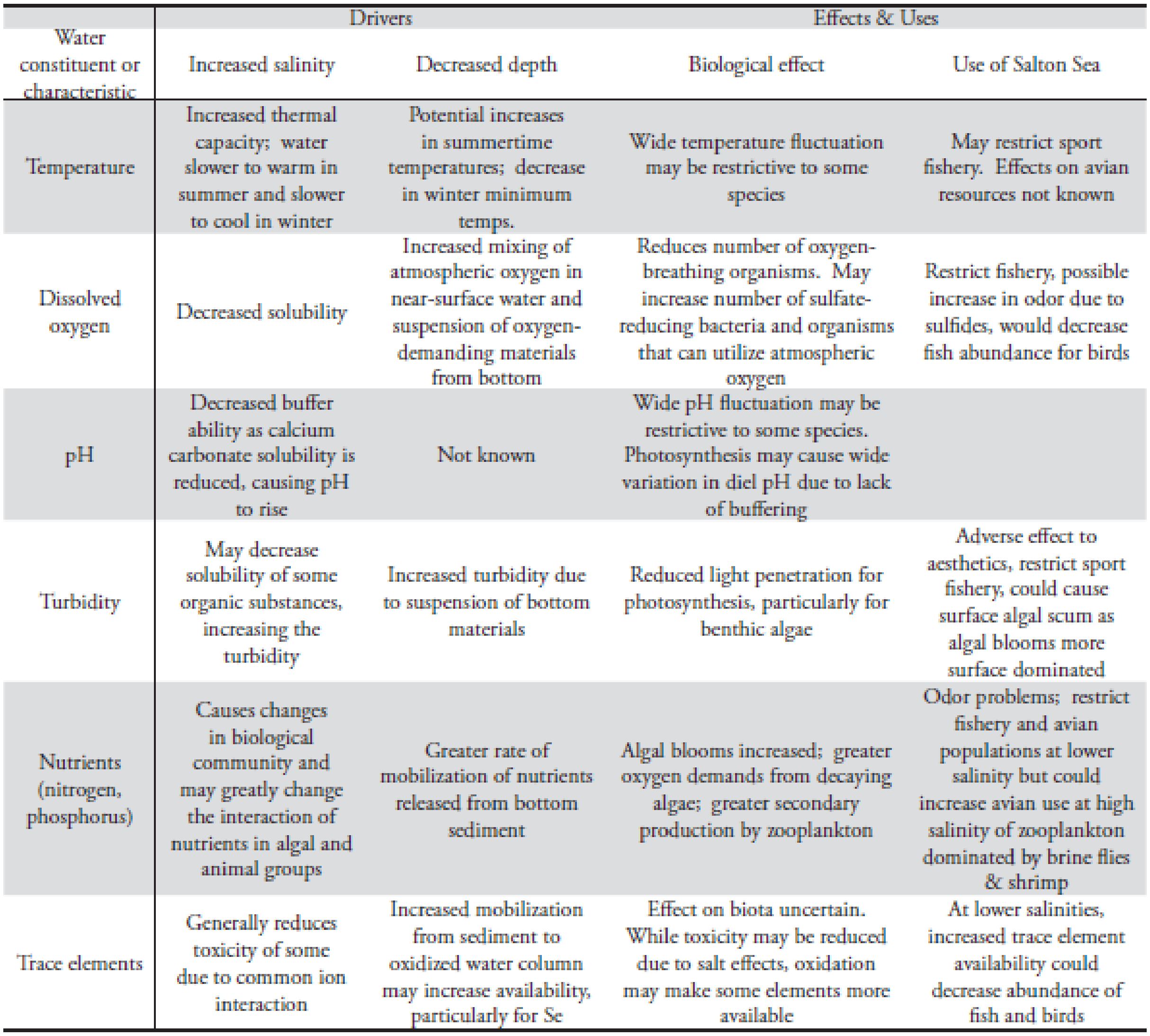
As a result of increased evaporation, many of the (toxic) lake bottom sediments are being exposed as the Sea shrinks. The Salton Sea basin exceeds the air quality standards of California for windblown dust during most of the year. This dust includes sediments and particulates from the former lake bottom, which include many toxic and poisonous components. These dust sediments and dust particulates become wind-borne and have been inhaled by inhabitants of the region. They have been linked to increased rates of asthma, especially in children and the elderly, with the Imperial Valley hosting the highest childhood asthma hospitalization rate in the state (over three times the state average).

4.0 Why Doesn't the Government do anything? Because #america

In 2003, San Diego County made a deal with the Imperial Valley in what would become the largest agricultural-to-urban water transfer in the history of the Unites States. San Diego County has virtually no fresh water supply, and as such asked the Imperial Valley to improve the efficiency of the irrigation structure on its farms and sell the 'saved water' to San Diego (in exchange for billions of dollars, of course). While this seemed mutually beneficially at first, a large proportion of the Salton Sea's inflow is from agricultural runoff, which was dramatically reduced with the passage of this new law. Recognizing this problem, the government of California enacted a 15-year plan to supply enough water to the Salton

Sea to prevent it from experiencing a rapid decline, although it still underwent a gradual reduction in size (Figure 3).

Table 1: Water quality problems associated with increased salinity and decreased depth of the Salton Sea.



Water constituent or characteristic	Drivers		Effects & Uses	
	Increased salinity	Decreased depth	Biological effect	Use of Salton Sea
Temperature	Increased thermal capacity; water slower to warm in summer and slower to cool in winter	Potential increases in summertime temperatures; decrease in winter minimum temps.	Wide temperature fluctuation may be restrictive to some species	May restrict sport fishery. Effects on avian resources not known
Dissolved oxygen	Decreased solubility	Increased mixing of atmospheric oxygen in near-surface water and suspension of oxygen-demanding materials from bottom	Reduces number of oxygen-breathing organisms. May increase number of sulfate-reducing bacteria and organisms that can utilize atmospheric oxygen	Restrict fishery, possible increase in odor due to sulfides, would decrease fish abundance for birds
pH	Decreased buffer ability as calcium carbonate solubility is reduced, causing pH to rise	Not known	Wide pH fluctuation may be restrictive to some species. Photosynthesis may cause wide variation in diel pH due to lack of buffering	
Turbidity	May decrease solubility of some organic substances, increasing the turbidity	Increased turbidity due to suspension of bottom materials	Reduced light penetration for photosynthesis, particularly for benthic algae	Adverse effect to aesthetics, restrict sport fishery, could cause surface algal scum as algal blooms more surface dominated
Nutrients (nitrogen, phosphorus)	Causes changes in biological community and may greatly change the interaction of nutrients in algal and animal groups	Greater rate of mobilization of nutrients released from bottom sediment	Algal blooms increased; greater oxygen demands from decaying algae; greater secondary production by zooplankton	Odor problems; restrict fishery and avian populations at lower salinity but could increase avian use at high salinity of zooplankton dominated by brine flies & shrimp
Trace elements	Generally reduces toxicity of some due to common ion interaction	Increased mobilization from sediment to oxidized water column may increase availability, particularly for Se	Effect on biota uncertain. While toxicity may be reduced due to salt effects, oxidation may make some elements more available	At lower salinities, increased trace element availability could decrease abundance of fish and birds

This plan to supply the Salton Sea with water expires in 2017 and, considering the recent drought conditions California has experienced, the government has called for a massive state-wide reduction in water usage. This includes water allocated for the Salton Sea, and if nothing is done, could drive water levels even lower and salinity higher.

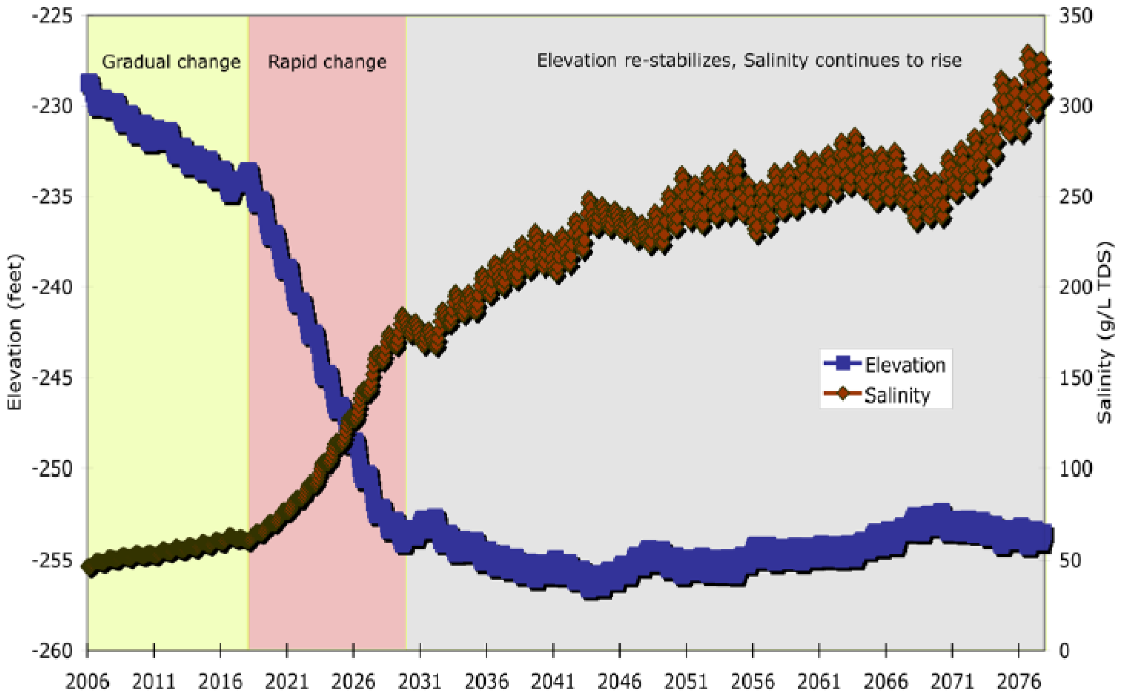


Figure 3: Projections for water and salinity levels of the Salton Sea through 2077.

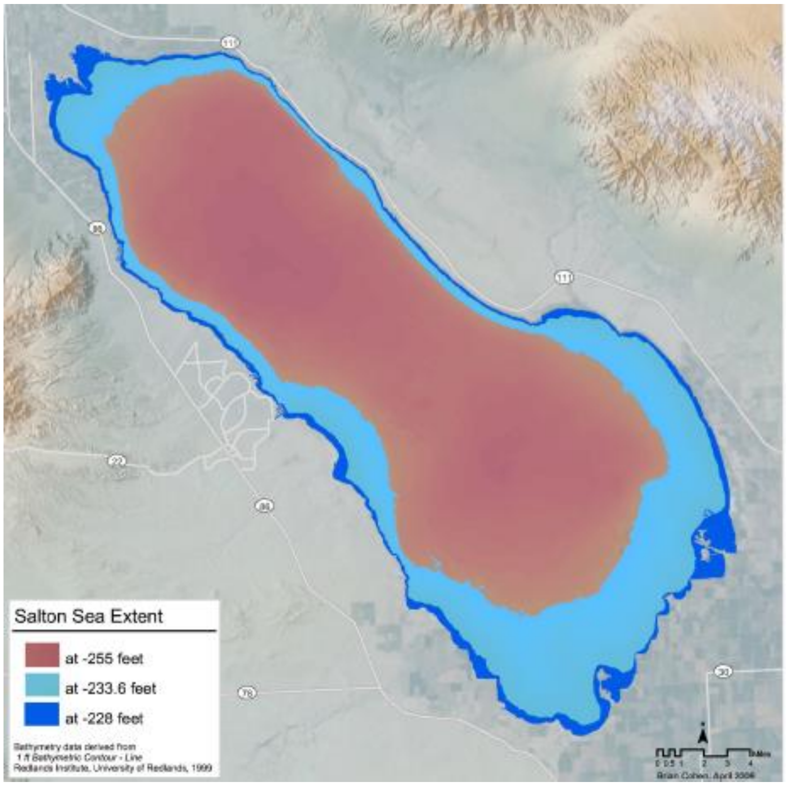


Figure 4: Current footprint of the Salton Sea and projections for newly exposed lakebed as a function of water level.

Lower water levels mean more exposed lakebed (Figure 4), and as a result, more toxic wind-born dust. California has only accepted responsibility for managing dust that is blown off the lakebed due to the water transfer, not from that exposed by “other actions”. There isn’t really an understanding of how the state will directly link specific processes to the exposure of new soil material; this will likely be very contentious.

Several groups, including the Salton Sea Authority and the Imperial Group have proposed long-term restoration plans for the Salton Sea. So far, no consensus on how to best manage the region has been reached.

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Agriculture and Drought in California

Margaret Landis

> "The Western States are nervous under the beginning change. Need is the stimulus to concept, concept to action. A half-million people moving over the country; a million more restive, ready to move; ten million more feeling the first nervousness.
> And tractors turning the multiple furrows in the vacant land." John Steinbeck, *Grapes of Wrath* (1939)

> "In California agriculture, water is seldom used only once. Applied water is often reused multiple times on the same farm or in the same region. Reuse of agricultural recoverable flows is a prominent characteristic of California agriculture." From "How Water is Used in CA: Agricultural" (http://ca.gov/drought/pdf/How-Water-Used-In-CA-Agricultural.pdf)

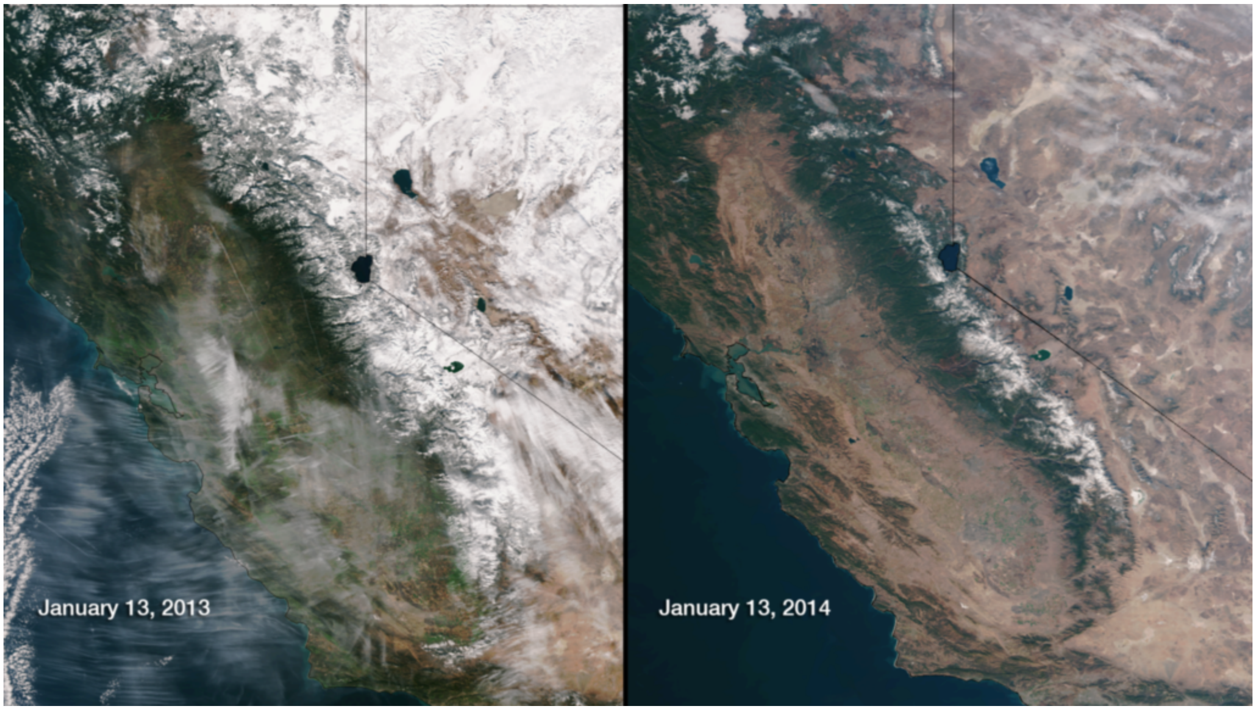


Figure 1 Two images separated by a year taken by the Suomi National Polar-orbiting Partnership (Suomi NPP) show the difference in snowpack on the Sierra Nevada Mountains in California. Snowpack is a common source of surface water in California. (Image: NOAA Environmental Visualization Laboratory)

Current water usage and issues

(source: http://ca.gov/drought/pdf/How-Water-Used-In-CA-Agricultural.pdf)

- The current distribution of water is such that 10% goes cities and human communities, 40% to agriculture, and 50% to the "environment" (e.g. rivers)
    - A lot of water is ultimately shared between the environment and agricultural sections. An example from the California state government water management

website explains, “Some rivers with stretches that are designated ‘wild and scenic’ eventually flow to the Central Valley and provide water for farms and cities.

- California agriculture irrigates more than 9 million acres, for a total of 77,900 farms.
- California is the sole producer of almonds, artichokes, dates, figs, pistachios, prunes and walnuts in the United States (see Table 1 for examples of how much money particular crops were worth in 2014).
- For two years in a row, the San Joaquin Valley farms saw no water released from the Central Valley Project. Kern County farms have had 80% of their usual water delivery cut from the State Water Project. This is due to continuing drought years (e.g. Figure 1).
- Water rights of farmers to collect from rivers and streams have been cut or eliminated by state regulators.

Table 1: Values of agricultural products from California, 2014 from the California Department of Food and Agriculture

Commodity	**Value (USD)**
Milk	9.4 billion
Almonds	5.9 billion
Grapes	5.2 billion
Cattle/Calves	3.7 billion
Strawberries	2.5 billion
Lettuce	2.0 billion
Walnuts	1.8 billion
Tomatoes	1.6 billion
Pistachios	1.6 billion
Hay	1.3 billion

Drought Mitigation

- Water released from reservoirs can also be used to control the salinity downstream (also see Michelle’s Salton Sea handout for a discussion of the effects of high salinity in a body of water, or the dead fish we will see/have seen, Figure 3 for a map of the Salton Sea watershed)
- Cutbacks to water that is allocated for “environment” and increased groundwater pumping are two potential solutions to make up for deficits in water availability
    - Implementation of precision irrigation techniques has been increased in recent years
- Another conservation strategy is to cut production. However, for 2015, UC Davis economists estimated that farmers allowed 564,000 acres to lie fallow, a loss of revenue of about $856 million (reported in “How Water is Used in CA: Agricultural”).
- State Water Efficiency and Enhancement Program (SWEEP), a grant program for farmers implementing irrigation systems that reduce water and energy use and cut greenhouse gas emissions.
- Programs are in place to assist farmers in getting irrigations systems that are more efficient (water and energy) and that reduce greenhouse gas emissions.

Figure 2 Map of the San Joaquin Valley, where a majority of the focus on water management in the California drought is placed due to heavy agricultural land usage. (public domain)

Current drought and effects

(from the 16 October 2015 weekly Drought Update, http://ca.gov/drought/pdf/Weekly-Drought-Update.pdf)

- 2,502 wells are in critical or dry condition, affecting over 10,000 residents
- As of 1 October 2015, U.S. Bureau of Reclamation estimated that the Central Valley Project had 200,000 acre-feet less than what was stored at the beginning of 2015 (e.g. area in Figure 2).
- 159 wildfires occurred in the week of 9-16 October alone. Since January 2015, there have been 7,254 wildfires across the state according to CAL FIRE and the US Forest Service.
- On October 15th, only one reservoir in California was at 90% average capacity (Millerton Lake). Four others were close to 50% (Don Pedro, Lake Oroville, Lake Perris, Lake Shasta), and the remaining seven in California were significantly lower than 50% capacity.

Will the El Nino year make a difference?

(http://ca.gov/Drought/pdf/Drought_ENSO_handout.pdf)

It's a toss up. There are only three cases of El Nino years with droughts on record, and each year either had the drought worsen, improve, or not be changed.

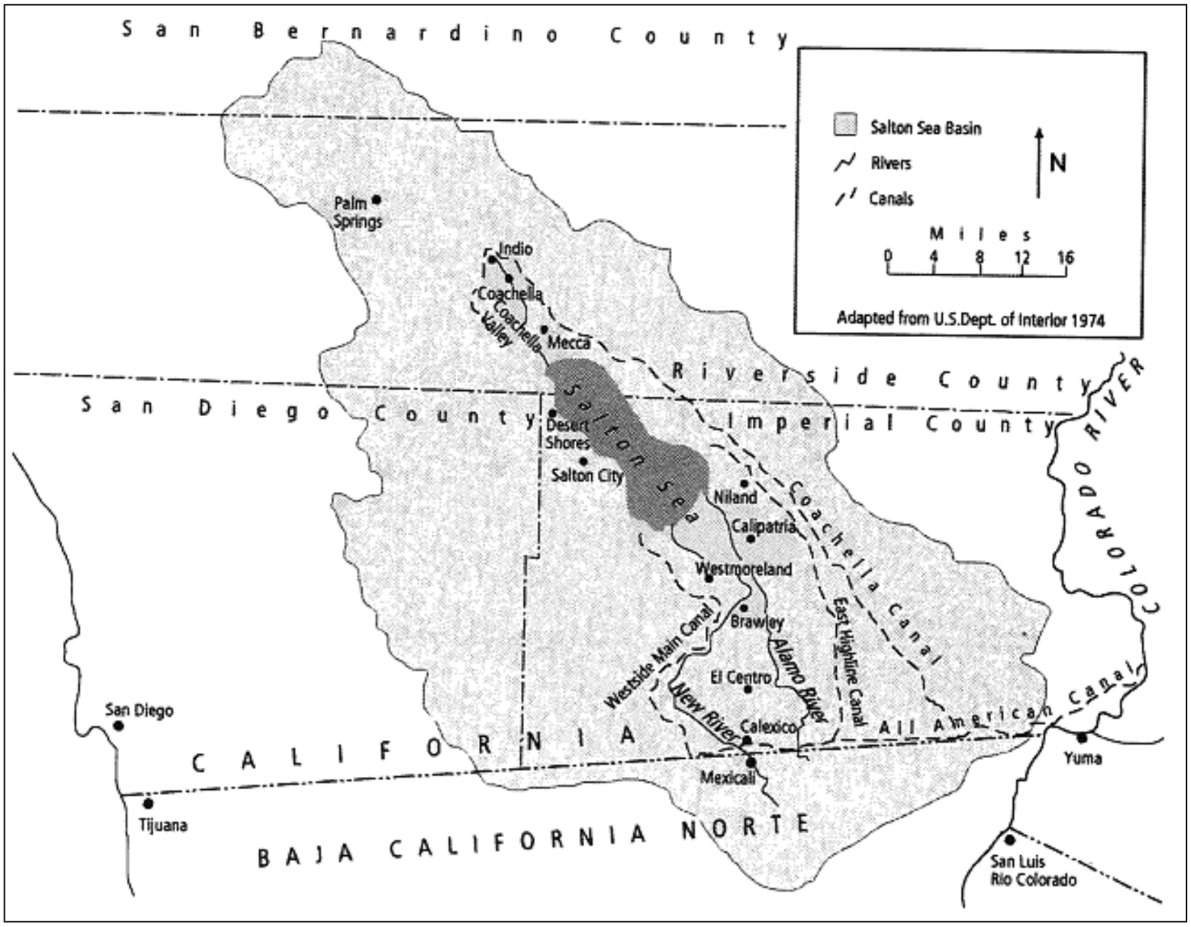


Figure 3 Map of the Salton Sea watershed, from the California Environmental Projection Agency Colorado River Basin Regional Water Quality Control Board website.

Take home points

- Agriculture is a major economic driver in California, especially the Central Valley (Table 1, Figure 2).
- Managing water resources, as per usual, is a balance between economic and human demands and an acceptable level of damage to the environment.

Alluvial fans and their interactions with tectonics

Ali Bramson

The Basics:
Alluvial fan = the accumulation of fan or cone-shaped river or stream deposits ("alluvium") on a sloping surface.

Alluvial fans are the result of sediment deposited into a fan-shaped (conical) heap of material when a stream emerges from a narrow or confined space into a wide, open area on land. This debouch-ery (lolz) occurs because when the stream flow spreads out, it also slows down, dropping sediment out of the fluid.

Word of the day: de·bouch diˈbouCH,-ˈbo͞oSH/ *verb*
emerge from a narrow or confined space into a wide, open area.
"the soldiers debouched from their jeeps and dispersed among the trees"

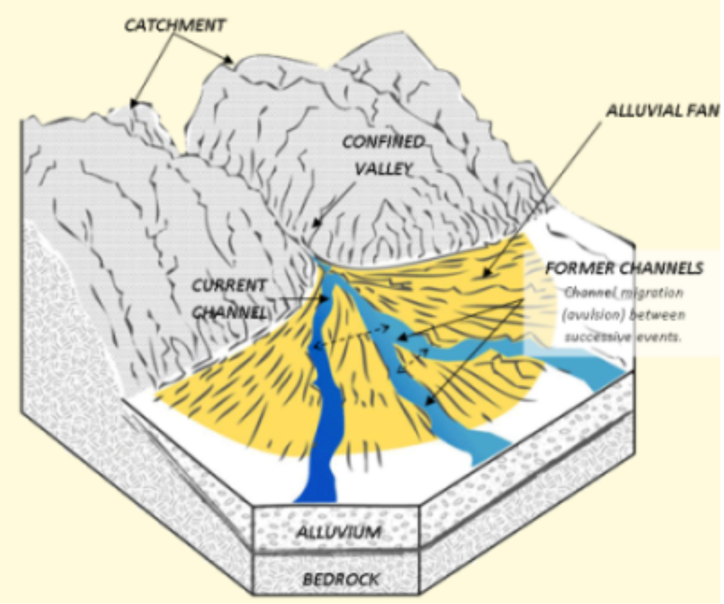


Fig.1: Schematic of an alluvial fan system [http://www.orc.govt.nz/]

Fig. 2: Small alluvial fan in Death Valley, CA [http://pages.uoregon.edu/millerm/fan.html]

Factors that influence alluvial fan formation:

a. Climate: Climate affects the magnitude and frequency of the fluvial processes involved in fan formation, such as rainfall intensity, storm frequency, total precipitation, etc. [Chapter 1, The Alluvial Fan Problem, Scott A. Lecce]

b. Tectonics: Alluvial fans can form without tectonism, but they are especially prominent in regions of uplift, as it provides a continual supply of fresh debris from steep drainage basins (Beaty, 1970). Bull 1977 found that the Basin and Range Province (which is tectonically active) has numerous alluvial fans, while south-central Arizona (which is tectonically stable) has pediments rather than alluvial fans. Pediments are gently sloping (~degrees) bedrock surfaces caused by erosion (usually sheets of running water from intense rainfall events) often at the foot of mountains.

The rate of stream channel downcutting is related to the rate of tectonic uplift, which affects the "locus of deposition" and thickness of the alluvial fan (Bull, 1972).

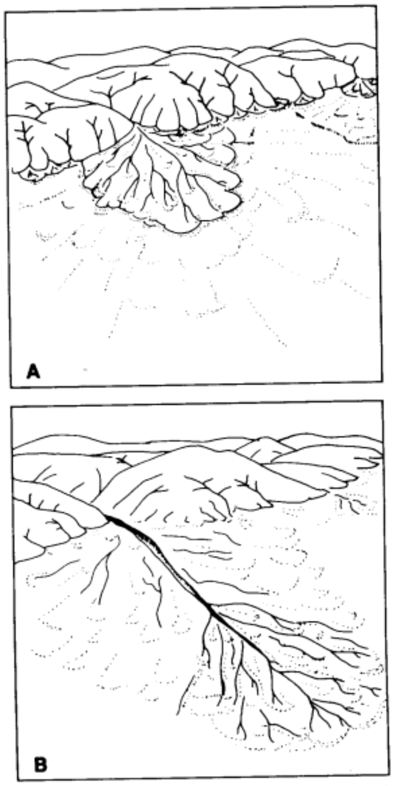


Figure 1.1. Two phases in the development of alluvial fans under the influence of tectonic uplift (A) Area of deposition adjacent to the mountain front; (B) Area of deposition shifted downfan due to stream channel entrenchment. (Reproduced by permission from Bull, 1968)

Figure 1.1A from Lecce 1990 reproduced from Bull 1968: Rate of uplift is greater than the rate of downcutting by the stream channel = deposition adjacent to the mountain front. Continued tectonic uplift leads to thick alluvial fan deposits forming.

Figure 1.1B from Bull 1968: Rate of downcutting at mountain front is more than the rate of uplift of the mountain. The fan is entrenched and the locus of deposition is downslope. This can occur when the rate of uplift is decreasing.

Radial profiles of alluvial fans are concave (Blissenbach 1954) but this can vary between a smooth, exponential curve to a series of distinct, straight (or concave) segments with progressively lower gradients downslope. This is called a "segmented fan". You can get segmented fans from either changing the stream channel slope- due to tectonic uplift, climate change or change in the topography of the base (Bull 1971).

This happens if you

a. have rapid, intermittent uplift (such that the stream gradient steepens so the next fan segment that forms is upslope of the previous deposit).

Or, if

b. the rate of tectonic uplift decreases (or stream incision increases) you can get a fan segment with a smaller gradient.

In case (a), the fan segments are steeper and younger in the upfan direction. In case (b), the fan segments downfan are younger and gentler (Lecce 1990).

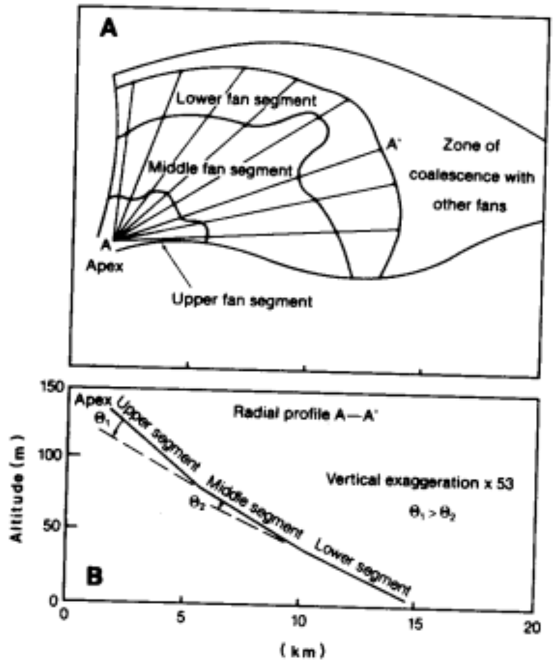
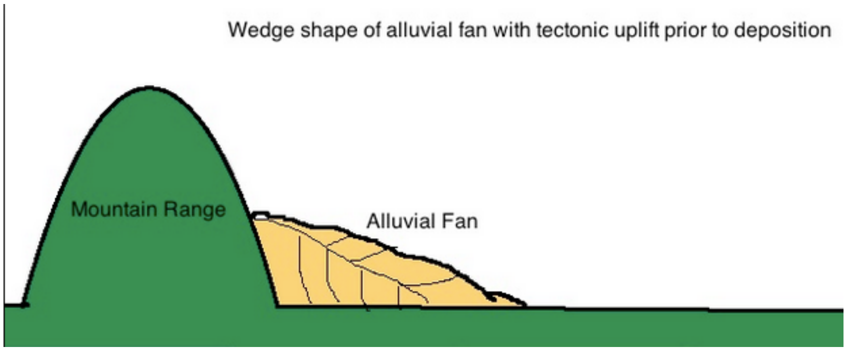


Figure 1.7. Segmentation of the Tumey Gulch fan, western Fresno County, California. (A) The segment boundaries are more strongly concentric than the contours, showing that fan segments are depositional forms rather than purely tectonic features. Each of the eight radial profiles has three straight line segments (B). (From Bull, 1964b)

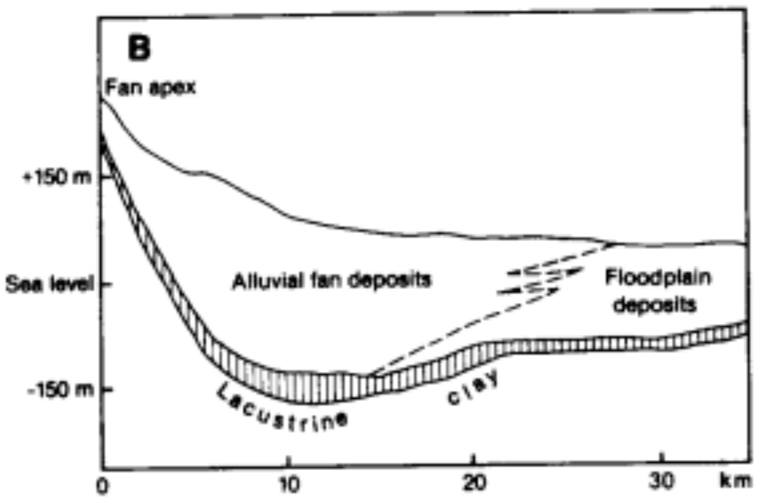
Bull 1972 described three types of fan deposits from their cross-sections along radial profiles and their tectonic interpretation:

1. Wedge-shaped and thickest near mountain front = major uplift in mountains before fan deposition



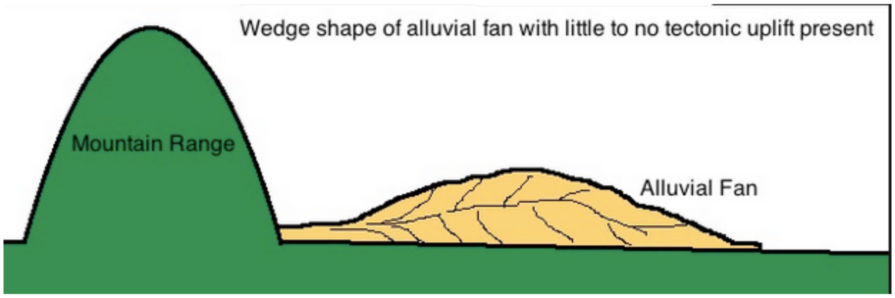
[Wikipedia]

2. Lens-shaped fan that is thin both near mountain front and far away = continuous tectonics during fan deposition



mountain front; (B) Fan deposits that are lenticular in shape. (Reproduced by permission from Bull, 1972 after Magleby and Klein, 1965, Plates 4 and 5)

3. Wedge-shaped deposit that is thin near mountain and thick away from it = ending of tectonic activity such that erosion redistributed material away from the mountain



[Wikipedia]

Tectonics also affect the coarseness of material deposited: in tectonically active basin margins, Heward (1978) found a coarsening and thickening the deposit. Galloway and Hobday (1983) found a fining and thinning of deposits upwards from the retreat of a fan and/or the source area relief (aka less tectonic activity at the basin margins).

Bahrami 2013 measured morphometric properties of alluvial fans: area, slope, length of base, wide/length ratio, radius, sweep angle, entrenchment, valley floor width-to-height ratio and strata dips of anticline limbs. Comparing these features to the margins of the tectonically active Zagros Mountain range, he found the sweep angle, base length, and entrenchment are directly proportional to the strata dips. He also found a poor relationship between catchment characteristics (slope and area) and other fan parameters, suggesting the complexities of the hydrologic systems dominate. Tectonically active fronts had highly entrenched fans with high sweep angles and long bases. Besides tectonic control on fan development, Bahrami 2013 found "fan head entrenchment and negative accumulation spaces" can be attributed to smaller sediment loads and drier climates.

Bull 1964 found the following relationship:
$\text{Area}_{\text{fan}} = c\ \text{Area}_{\text{drainage}}\ n$

n = log-log slope of the relationship (~ 1 on Earth); c is a constant which varies and is related to how much fan spreads out

In the context of this trip: Alluvial fans at Clark Dry Lake…image looking from south of Villager Peak [http://tchester.org/bd/places/clark_valley.html]

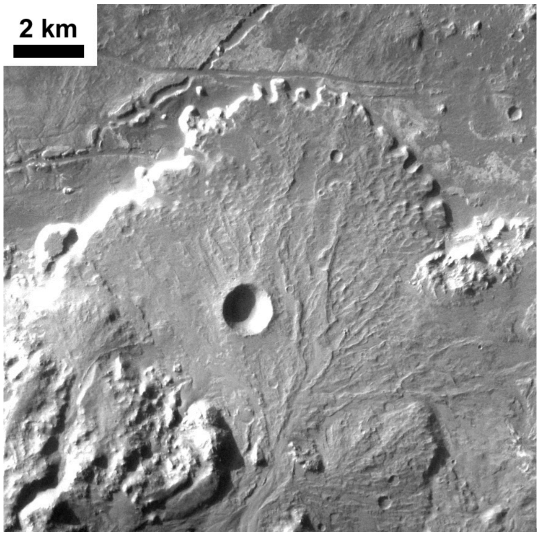
The Anza-Borrego Desert State Park (which includes Clark Dry Lake) visitor center (not sure if we're going by here) is also on an alluvial fan endearingly named Hellhole Alluvial Fan. You can hike for 2 miles on Hellhole Alluvial fan on the Hellhole Canyon trail.

View from Hellhole Alluvial Fan on the Hellhole Canyon hike [http://www.hikemasters.com/2010/03/hellhole-canyon-anza-borrego-desert.html]

Within the park are several alluvial fans at the boundaries between faulted blocks and valleys, depositional features where there has been continued uplift at mountain fronts. Within this park, they can be found along the narrow canyon openings of the Santa Rosa, San Ysidro, Vallecito, Tierra Blanca, and Coyote Mountains [http://www.parks.ca.gov/]. Along a lot of the mountain fronts, the alluvial fans combine into a BAJADA (another word of the day).

Bajada at the base of the Santa Rosa Mountains in Clark Valley [http://www.parks.ca.gov/].

Planetary Connections:
On Mars:



http://www.psi.edu/pgwg/images/jun09image.html: “A large alluvial fan in the southern floor of Holden crater, showing inverted (positive-relief) distributary channels that were preserved while wind stripped away fine-grained sediment between them. THEMIS visible imaging, 17 m/pixel.”

Often find alluvial fans on the slopes of large craters on Mars…crater floors can be covered in them when channels carve into the crater rims.

On Titan: Work by Jani Radebaugh has found river channels which end in deltas in the polar regions where there are methane/ethan lakes. But in the dryer mid-low latitudes, the river channels end in alluvial fans.

The fan system is generally radar-bright = >cm-sized grains derived from erosion from rainfall and fluvial processes but can alternate to radar-dark material. On Earth, this usually is related to deposition of different-sized materials, which can happen when there are changes in flow velocity, bedload characteristics in the stream feeding the system, or changes in location of active fan formation [Radebaugh et al. 2013].

Figure 1. SAR-bright fans (triangular deposits) north of Xanadu terminate channels from the west. Leilah Flucus, Ta, 10/26/04, 51°N, 80°W.

A 120 km fan in Elivagar Flumina at 20°N, 77°W from Radebaugh et al. 2013

Grains are likely water ice or solid organic chunks ~2 cm (Le Gall A. et al. (2010). Spectroscopy finds evidence for water ice, suggesting transport and erosion of the water-ice-rich bedrock may lead to the formation of the fans. Channels are also found in cohesive, organic sedimentary materials on Titan, which could provide the organic material [Radebaugh et al. 2013].

Clay Dunes

Ethan Schaefer

Note: Except where indicated otherwise, all material is sourced from the review by J. M. Bowler (1973) in *Earth-Science Reviews*, *9*, 315-338.

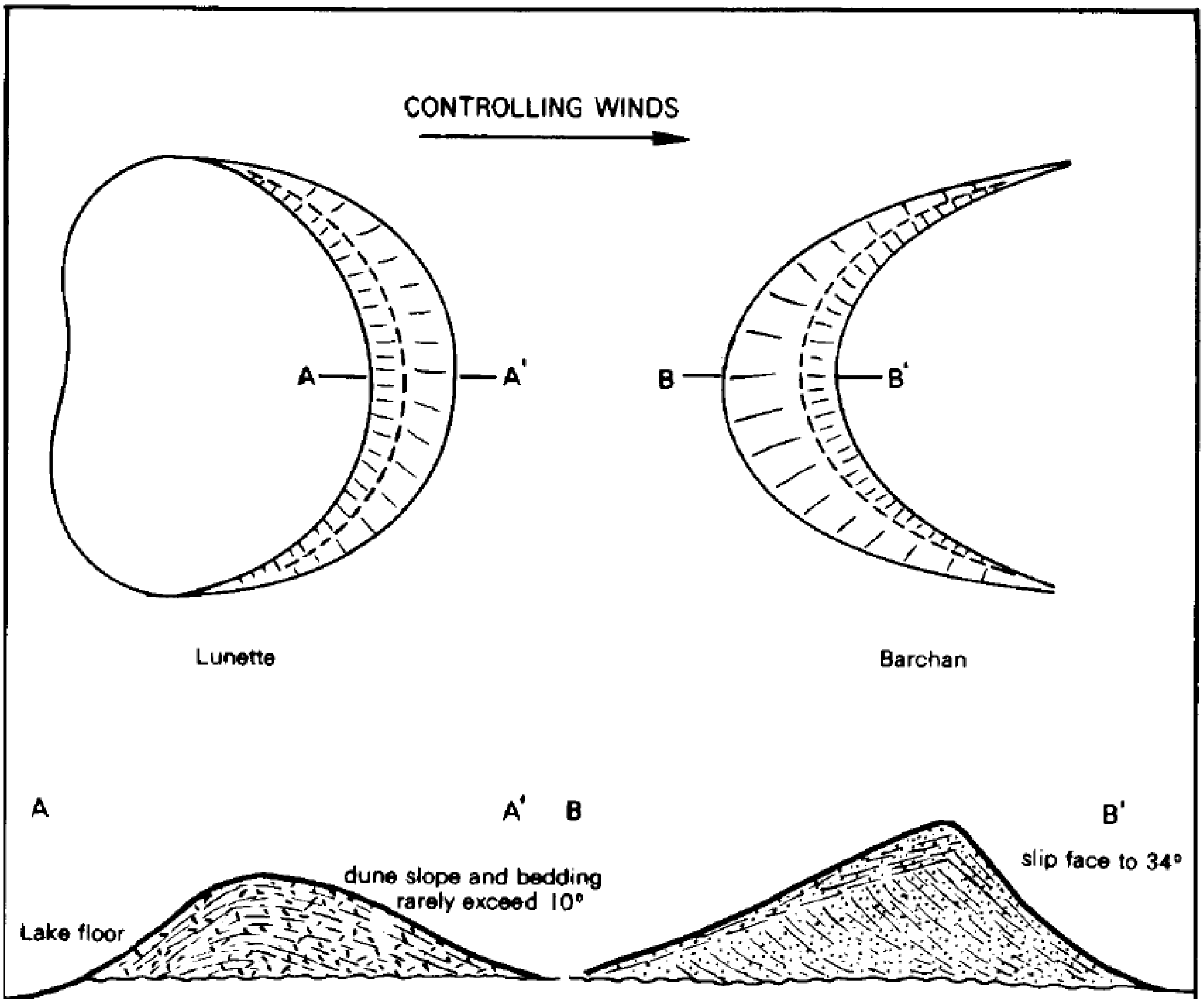
<u>What they are:</u>

- aeolian depositional features
- broadly resemble "flipped" barchan (sand) dunes
- composed of sufficient clay (≥15-20 wt%, up to 77 wt%) that this component dominates formation and morphology
    - lesser amounts of evaporites: carbonates, sulfates, chlorides
- occurrence: coastal lagoons (Texas (Coffey, 1909), Senegal), sabkha margins (Algeria); on margins of Pleistocene lakes throughout southern Australia (inactive), Wilcox Playa in Cochise County, AZ

Clay dune lunette on margin of 1-km lake basin, New South Wales, Australia.

<u>How they (typically) form</u>:

- seasonal drying of salt flat → sand-sized clay pellets
    - ripping-up of mud curls and efflorescence of salt
    - typical diameter: 0.15-0.3 mm
- pellets are saltated by wind to vegetated shore
- pellets accumulate into a ridge that parallels the shore
- a new layer up to a few cm thick is added each dry season
- during wet season, rain and/or adsorption/absorption of atmospheric water vapor disintegrates the uppermost pellets to form a shell a few mm thick
    - stabilizes dune (prevents migration, deflation)
    - if annual accumulation is thinner than this shell, lamination → diffuse banding
        - confusing relict!
    - in southern Australia, now inactive clay dunes are sometimes cored by lunate sand dunes ("compound lunettes"), interpreted to have formed from beach sands under wetter conditions

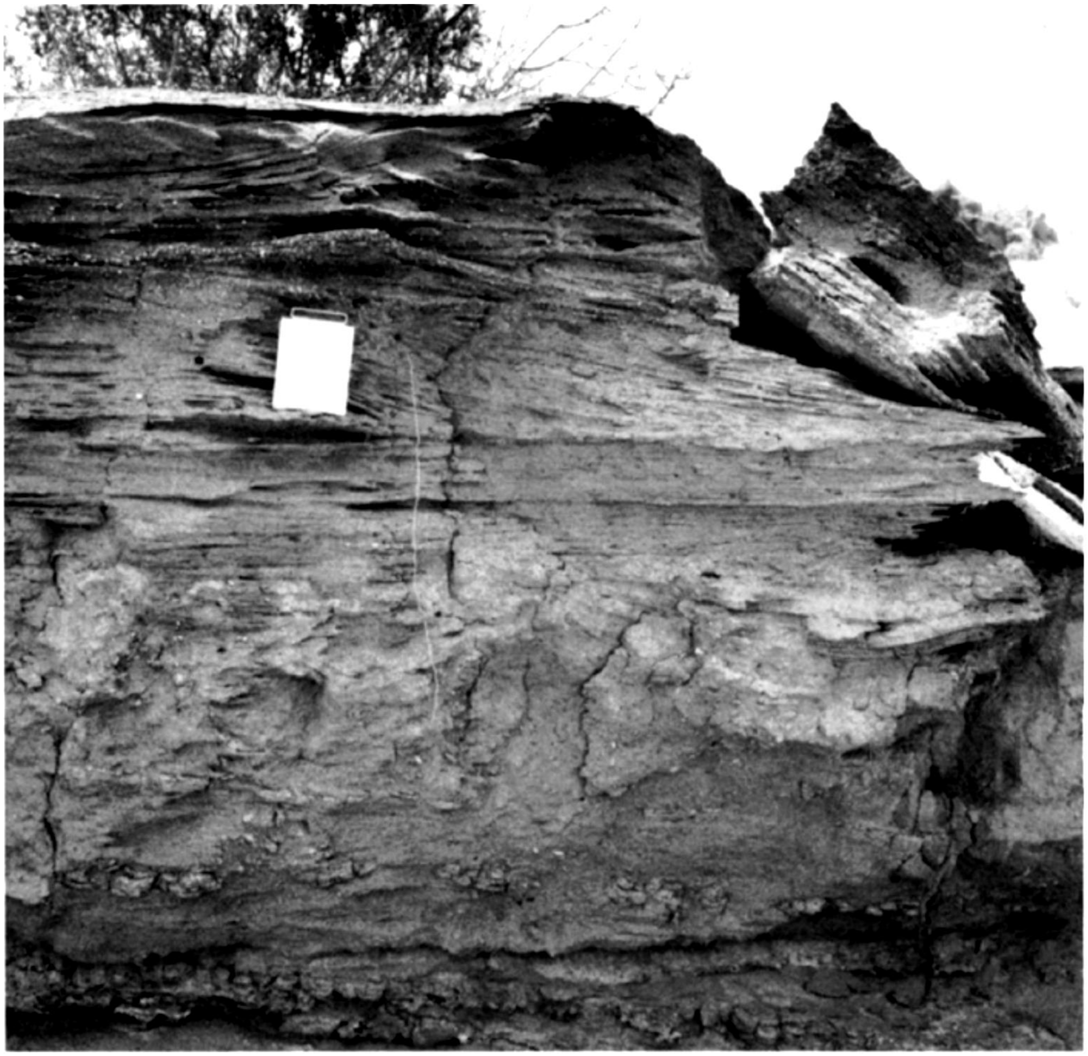


<u>What they look like</u>:

- parallel to shore
  - may be crescent-shaped, with arms pointed upwind (opposite of barchans)
  - "lunette" (Hills, 1940)
- shallow slopes (typically ≤15°), with steepest slope windward (opposite of barchans)
  - "pellets rarely form thick mobile accumulations" → no slip faces
    - exception: "long droughts and periods of exceptional aeolian activity"
- size controlled by areal extent of source salt flats (height: <1 m – >30 m)
- mantled by ripples ≤5 cm thick, made of clay pellets

Paleo(micro)climate value:

- high salinity prevents lake bed vegetation, enables efflorescence
- large seasonal fluctuations in water supply required for sufficient mud pellet production; periodic saline floods may prevent vegetation of dunes
- high evaporation rates to expose mud, cause efflorescence, and do so quickly enough to give wind time to transport and accumulate pellets
- strong, unidirectional winds during dry season to efficiently transport pellets
- requirements are often met only locally



Greeley (1979): Silt-clay dune in Clark Dry Lake, California with cross-stratification. Plate is ~7 cm long. Photograph from Ron Papson, 1977.
Greeley (1985): Silt-clay dune at Rogers Lake playa, California. Plate is ~8 cm long.

Planetary connection (and local relevance):

- Ron Greeley (1979) suggested that silt-clay aggregates could be an important component of surface sediment on Mars.
- (Historical) merits
    - aggregates have lower density → lower saltation wind threshold
    - lower wind speeds address "kamikaze" grain concern raised by Carl Sagan and co-workers (1977)
    - explain paucity of sand-sized particles at Viking landing sites despite the frequent occurrence of aeolian bedforms on Mars
    - provide a mechanism for ending dust storms (aggregation by electrostatic attraction)
- Difficulties
    - aggregate formation by electrostatic attraction was not documented in nature
    - known clay dune environments on Earth are very specific, localized, uncommon, and require significant volumes of water

Playas

Corey Atwood-Stone

Clark Dry Lake - http://annemckinnell.com/2013/02/11/clark-dry-lake-anza-borrego-state-park-california/

Playas are dry ephemeral lakes – often with evaporite minerals and clay surfaces
They form with a variety of surface morphologies

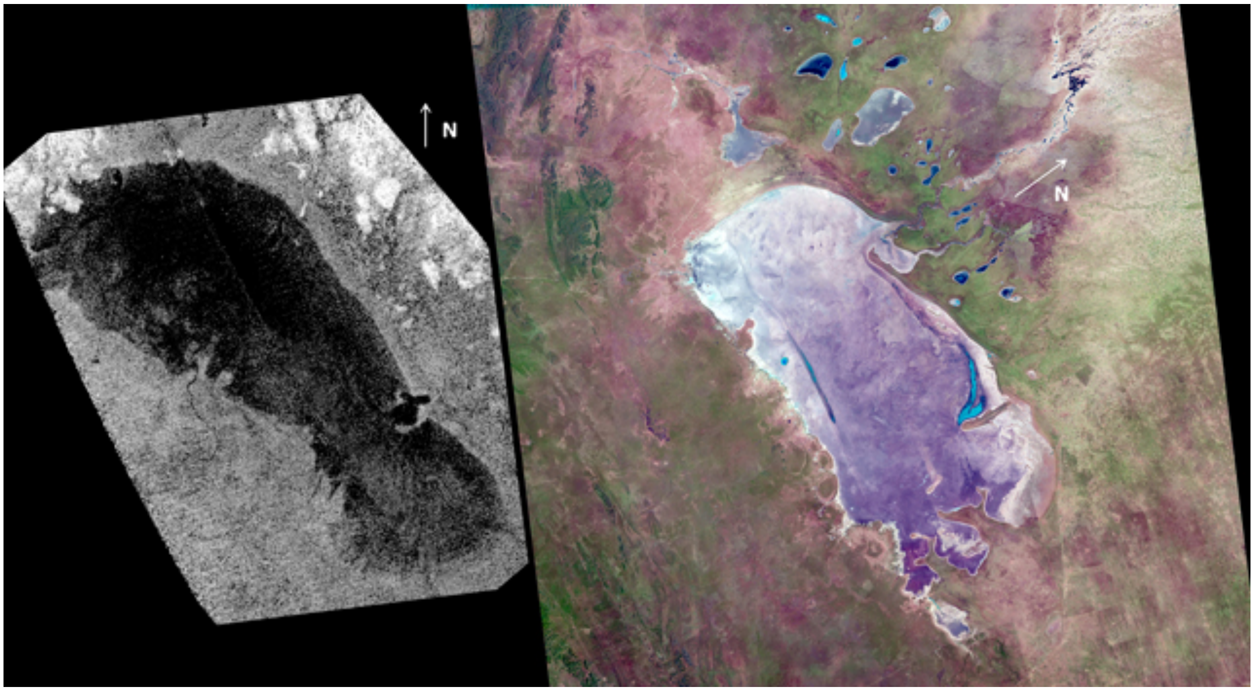
Clark Dry Lake mudcracks
http://russbishop.photoshelter.com/

Racetrack Playa – Hard Clay Surface

Evaporite surfaces on playas in Death Valley

Planetary Connection

Ontario Lacus in the southern hemisphere of Titan may be a playa.



Left is Ontario Lacus – Right is Etosha Pan, a playa in Namibia
http://www.jpl.nasa.gov/news/news.php?release=2012-108

Channels etched into lakebed suggest that Ontario Lacus drains and refills
Observed SW shoreline to retreat 9-11 km between 2005-2009

Tufa and Travertine: Salton Sea

Tom McClintock

Carbonates are created in two ways:

1. Evaporites: water evaporates and leaves behind precipitates
2. CO_2 degassing: Removal of CO_2 results in $CaCO_3$ precipitation

CO_2 Degassing:

- Results in increasing pH and lowered solubility
- Equilibrium of:
  $Ca^{2+} + 2HCO_3^- \leftrightarrow$
  $CaCO_3 + CO_2 + H_2O$ shifts left,
  thus $CaCO_3$ is precipitated

Maybe she's born with it. Maybe it's travertine.

Travertine is a general term sometimes used in the literature to refer to any carbonate precipitates, however this practice has changed with the classification of two types of travertines based on the source of the CO_2.

- *"Travertine"* now refers to thermogene travertine, when CO_2 originates from hydrothermal sources
- *"Tufa"* now refers to meteogene travertine, when CO_2 is atmospheric

Tufa:

- Forms at ambient temperatures
- Can host macrophytes, leads to a more porous formation

Travertine:

- Forms at higher temperatures
- Tends to not host macrophytes, and are less porous

T&T in the Salton Basin:

Above: Tufa formations and tufa columns at Mono Lake, California.

Travertine deposits at Yellowstone National Park, Wyoming.

- Formed underwater, only visible once waters receded
- A tufa slab from Travertine Point was dated to be between 1310 and 17840 years old (talk about precision)

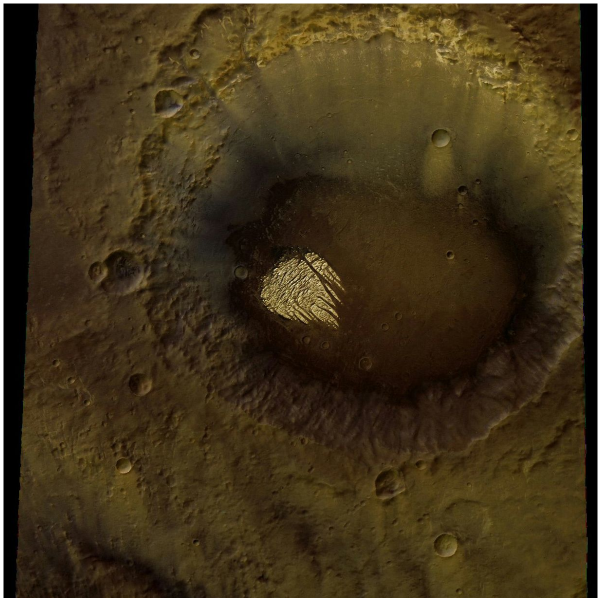
Travertine on Mars?!

Martian meteorites found in Antarctica contained carbonates similar to those found in tufa in lakes on Earth. Thus began a search on two fronts: for extremophile life capable of surviving Martian conditions, and for travertines on Mars.

Up until 2001 the "White Rock" formation in Pollack crater was a top candidate for being a carbonate deposit, however it was demonstrated by the Mars Global Surveyor that it was in fact wind-blown sediments created in a dry process.

Carbonates have been spectroscopically detected in gullies on the edges of other craters. Rather than being precipitates however, it is hypothesized that this is simply erosion of carbonate-bearing rocks exposed by the crater. Furthermore, unlike tufa and travertine, these carbonates are a mix of Mg, Fe, and Ca carbonates.

A Mausoleum in Hierapolis, Turkey, that has been submerged in Travertine after the hot springs overflowed.



"White Rock" on Mars.

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10. Wikipedia articles: Tufa, Travertine

Migration of dunes

Ben Wei Peng, Lew

1 Introduction

1.1 The formation and morphology of dunes

There are three requirements to form dunes: sediment supply, wind and obstacle. In particular, sediment supply, mostly consist of quartz, is originated from dried up lake,river seabed or the coast. Dunes can be categorized according to their shapes:

1.Barchan dunes: the simplest form with crescent shape, formed under limited sand supply with unidirectional wind
2.Longitudinal dunes:moderate sand supply with parallel to fairly constant wind direction.
3. Parabolic dunes: Similar to Barchan dunes but with vegetation on the edge.
4. Transverse dunes: Abundant sand supply with fairly constant wind direction.
5. Star dune: radially symmetric shape, formed in areas where wind direction changes over time.

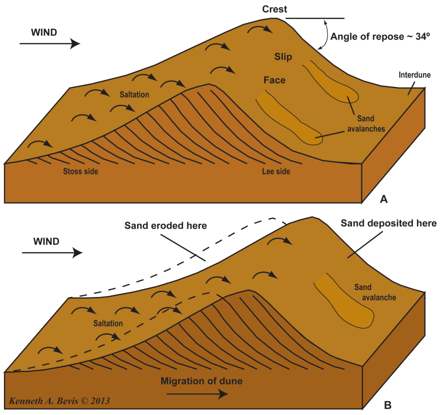
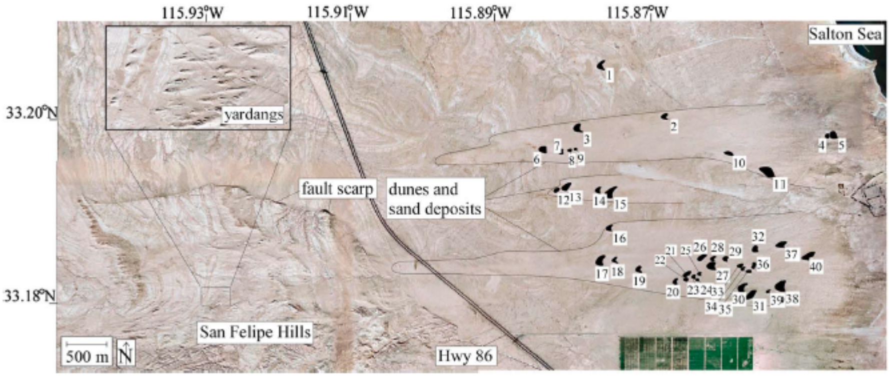


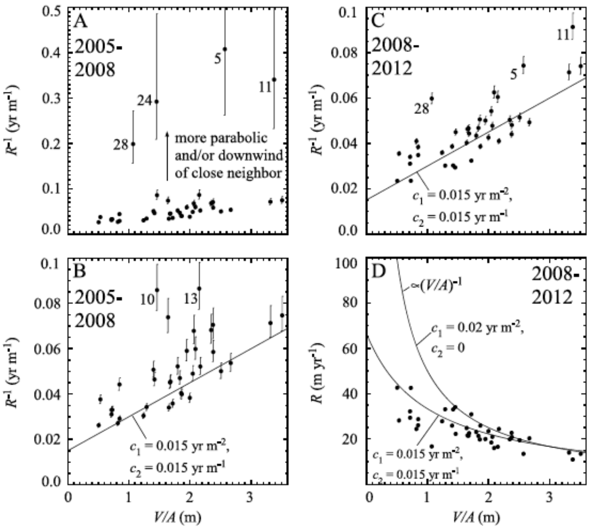
Figure 1: Structure of dune [1] and migration direction.

2 The Dunes of Salton Sea



In the following paragraph I summarized part of the result by Pelletier 2013 about migration rate of 40 isolated dunes in Salton Sea, as illustrated in figure above.

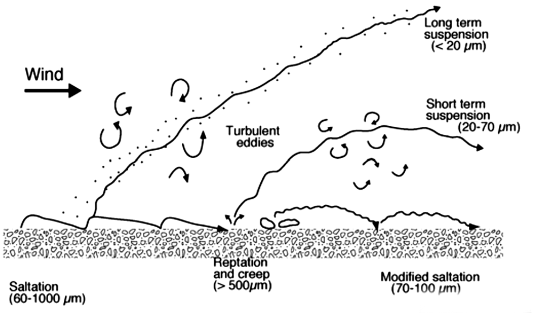
The Salton Sea dune field is about 2km long, dominated by barchans, with some transitional between barchan and dome and transitional between barchan and parabolic. The source of sand is likely originated from abrasion of the late Cenozoic sedminetary rocks on west of San Felipe Hills. The dominant wind direction is W/WSW and dunes migrate to the east with speed as large as 14m/s while the threshold to form dunes is 6m/s. Instead of showing migration rate as relationship of conventional dune heights, Pelletier showed the migration rate trend with volume/surface ratio.



3 migration of dunes

This part mainly follows the content of The Physics of Blown Sands and Desert Dunes by R.A Bagnold.

Saltation process is accounted for around 75% of sand movement while reptation is responsible for the rest 25%. The whole sand movement q is
$q = C\sqrt{\frac{d}{D}}\frac{\rho}{g}V_*'^2$ or $q = 1.5x10^{-9}(v - V_t)^3$ for 1m high from bed.
where D is the mean grain diameter(0.025cm) and C is coefficient ranges from 1.5 (uniform sand) to 2.8 (mixed sized sand).



3.1 Saltation and fluid velocity threshold

In order to initiate saltation, the impact velocity must exceed the fluid threshold velocity. Raynold's number, a dimensionless quantity is introduced predict flow pattern , equal to $\frac{V_* d}{\nu}$, where d=mean size of surface roughness, same order with grain diameter, ν is kinematic viscosity of fluid (0.14 for air).

When the Raynold's number > 3.5 (rough surface), the fluid need to reach threshold velocity to move surface grain is :
$V_z = 5.75V_* log\frac{z}{k}$ where z=height, $V_* =$ velocity gradient $=A\sqrt{\frac{\sigma\rho}{\rho}gd}$ with A =0.1 for air and grain > 0.2 mm, k= roughnes of bed, ρ=density of fluid , thus
$V_t = 5.75A\sqrt{\frac{\sigma-\rho}{\rho}}gdlog\frac{z}{k}cm/s, \sigma=$ density of grain material For smaller grain, Raynold's number < 3.5 ,the coefficient A is larger as grain is less affected by the flow and the fluid threshold velocity becomes bigger. again

3.2 Raptation

Raptation is the main process to transport large grain that cant be moved by direct wind. After large grain being collided fine grain from saltation, the initially static grain that as big as 6 times larger than impactor, , bounce up and move along in the direction of wind.

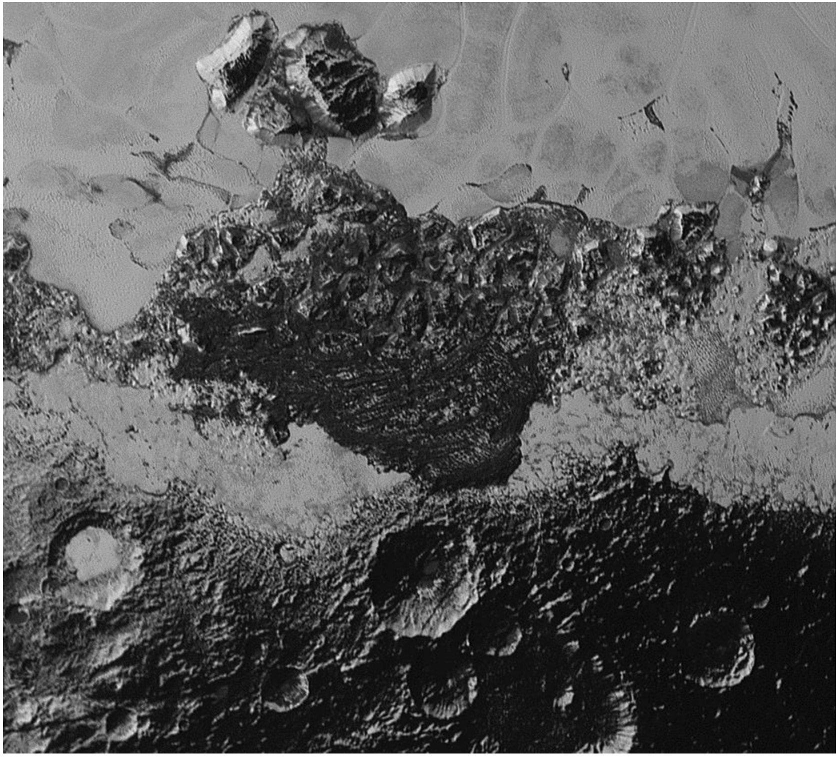
3.3 impact velocity threshold

Once saltation and reptation start, the sand grain that is hit will bounce up to a few hundred or thousand grain diameter high, reaching similar velocity as wind velocity at this level, gaining more momentum as they going down to the slope, and finally ejecting more material .Therefore, the surface velocity of air can be lower than fluid threshold afterward. The ratio of minimum impact velocity and fluid velocity thershold is around 0.82 for loose sand on the earth, known as impact threshold [Bagnold 1937, as cited in Kok 2010] However, the longer saltation trajectories on Mars accelerate grain to larger fraction of wind velocity, so the impact threshold can be as low as 10% than fluid threshold.

4 Dunes on other planets

The presence of many dunes on Mars is not expected as wind speed predicted by Ames General Circulation Model (GCM) is lower than treshold value. The sand flux calculated based on dunes by N.T Bridges provide ground calibration and mesoscale(a few hundred meters) atmospheric turbulence model correction.

In addition to Mars ,dunes have been found on Venus, titan, and possibly Pluto [6], as shown in figure below:



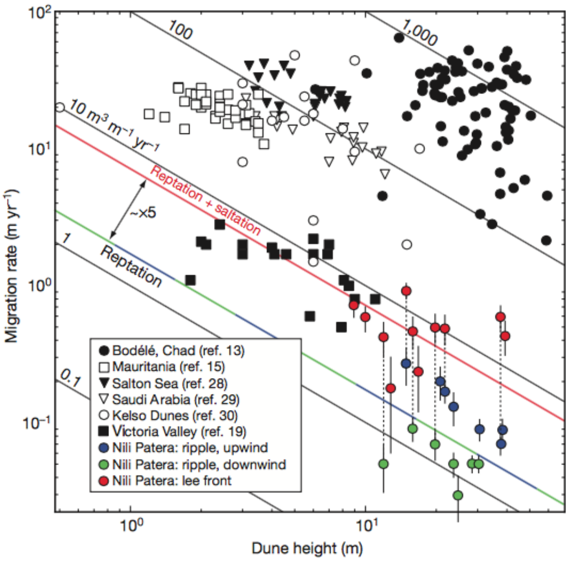


Figure 2: Plot by N.T Bridges et al Nature 2012.This plot compares the migration rate between the earth and mars(Nil Patera), based data taken by HiRISES. Black diagonal lines are isopleths of sand flux(migration rate * height) . Red and blue/green diagonal lines are mean sand fluxes derived from the lee-front advance(mainly caused by saltation) and ripple migration (mainly caused by reptation) measurements, respectively. Sand flux from lee-front advance is 4-5 times higher than ripple migration , similar as what we see on the earth.

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Kenny Furdella
PSTY 594A
19 Oct 15

Native People of Southern California

Before European Contact:

Evidence of the first human occupation of California dates back to 17,000 BCE. Like present day California, most of the native people of California lived near the coast. Most native people used the coastal resources for food and did not depend as heavily on agriculture as other native people of the time. As with most of the prehistoric people, the culture mainly consisted of hunting and gathering. One of the more famous discoveries of human remains came in 1960. Where two femurs were found on Santa Rosa Island near Santa Barbra California. The bones date back to around 13,000 BCE.

The native people who inhibited much of southern California can be seen in the figure below. Much of southern California was occupied by the Kitanemuk, but not much is known about them, but they were very similar to the native people found in Arizona and New Mexico. The primary historical sites in California are found near the coast and around the Santa Barbra area. The native people of Santa Barbra area were called the Chumash, meaning "seashell people." The primary focus of this article will be on the Chumash people.

There are signs of the Chumash people inhibiting much of the central and southern coast of California by 10,000 BCE. Their territory ranged from Morro bay to Malibu. The heart of the civilization was mainly, current day Santa Barbra. The area has vast rivers, mountain, and plains, while also offering resources from the ocean. The Chumash people used canoes to hunt aquatic life and would collect shell fish. By 2000 BCE, Santa Barbra had one of the highest population densities in Northern American. It is believe that over 15,000 individuals lived in the area, with the capital, Syuhtum, had around 800 inhabitants.

Most of the culture was based around basketry, bead manufacturing, and herbalism. The most famous arborglyphs by the Chumash people are found on the Scorpion Tree. This image depicts the counterclockwise rotation of stars around Polaris and appears to portray Ursa Major in relation to Polaris, this image is seen from the view on the Painted Rock.

Two early cultural traditions in Southern California was the La Jolla Complex and the Pauma Complex which dated from 6050 BCE to 500 AD. The La Jolla Complex is a culture that primarily focused on using coastal resources with minimal agricultural usage. Some main landmarks of the culture are hand stones and basin or slab mealing stone (picture below), stone edged tools, and shellfish. The Pauma complex is centered more on the San Luis Rey River and Valley center. Several features of the complex include knives and points, manos, and a variety of grinding tools.

Metate/mano set from the floor of Room 1, Hough's Great Kiva.

Historic Time:

By 1530s, the first exploration of Baja California begins. It was not until 1542, that Juan Rodriguez Cabrillo "discovers" California and lands in present day San Diego. Cabrillo's goal of his expedition was to map the coastline of California. The current population of San Diego at this time was thought to be 20,000 with 5 different tribes living in the area. By 1602, Sebastian Vizcaino gives San Diego its' name. It was not till the 1770s that the Spanish returned with soldiers and missionaries. The first Spanish mission built in San Diego was in 1769. By 1773, there are 76 Indians enrolled in the mission. This time period is known as the beginning of the Spanish missionaries in southern California. Much of the 19th century consist of missions in California. The first major Indian revolt happened in San Diego in 1775. The first U.S. citizens reached San Diego by walking from Baja California in 1798.

By the mid-1800s, much of the Chumash people have died from European diseases. By 1821, Mexico gains it independence from Spain and control over present day California. California becomes a U.S. territory in 1847 due to the treaty ending the Mexican-American War. California became a state September 9, 1850.

References

- www.sandiego.edu/nativeamerican/chronology
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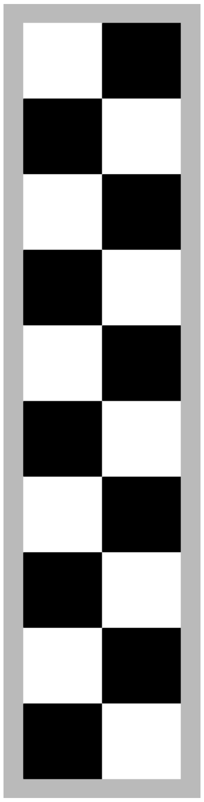
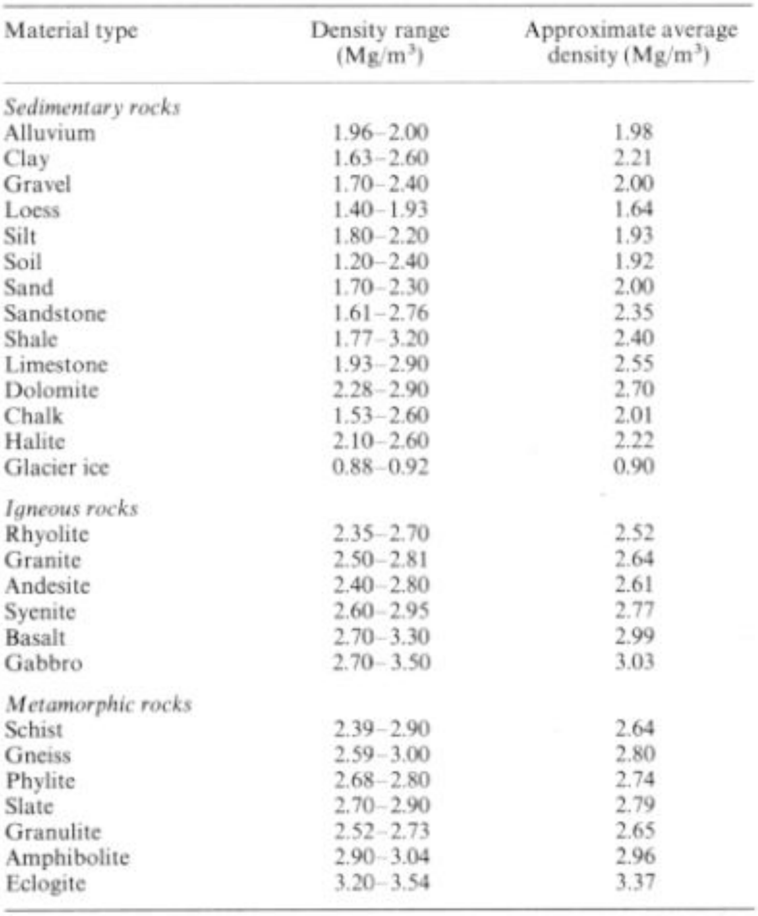
10 cm ruler



ROCK DENSITIES

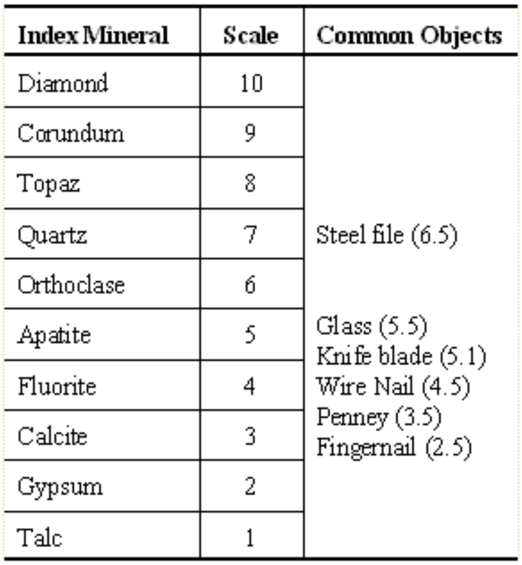


Material type	Density range (Mg/m^3)	Approximate average density (Mg/m^3)
Sedimentary rocks		
Alluvium	1.96–2.00	1.98
Clay	1.63–2.60	2.21
Gravel	1.70–2.40	2.00
Loess	1.40–1.93	1.64
Silt	1.80–2.20	1.93
Soil	1.20–2.40	1.92
Sand	1.70–2.30	2.00
Sandstone	1.61–2.76	2.35
Shale	1.77–3.20	2.40
Limestone	1.93–2.90	2.55
Dolomite	2.28–2.90	2.70
Chalk	1.53–2.60	2.01
Halite	2.10–2.60	2.22
Glacier ice	0.88–0.92	0.90
Igneous rocks		
Rhyolite	2.35–2.70	2.52
Granite	2.50–2.81	2.64
Andesite	2.40–2.80	2.61
Syenite	2.60–2.95	2.77
Basalt	2.70–3.30	2.99
Gabbro	2.70–3.50	3.03
Metamorphic rocks		
Schist	2.39–2.90	2.64
Gneiss	2.59–3.00	2.80
Phylite	2.68–2.80	2.74
Slate	2.70–2.90	2.79
Granulite	2.52–2.73	2.65
Amphibolite	2.90–3.04	2.96
Eclogite	3.20–3.54	3.37

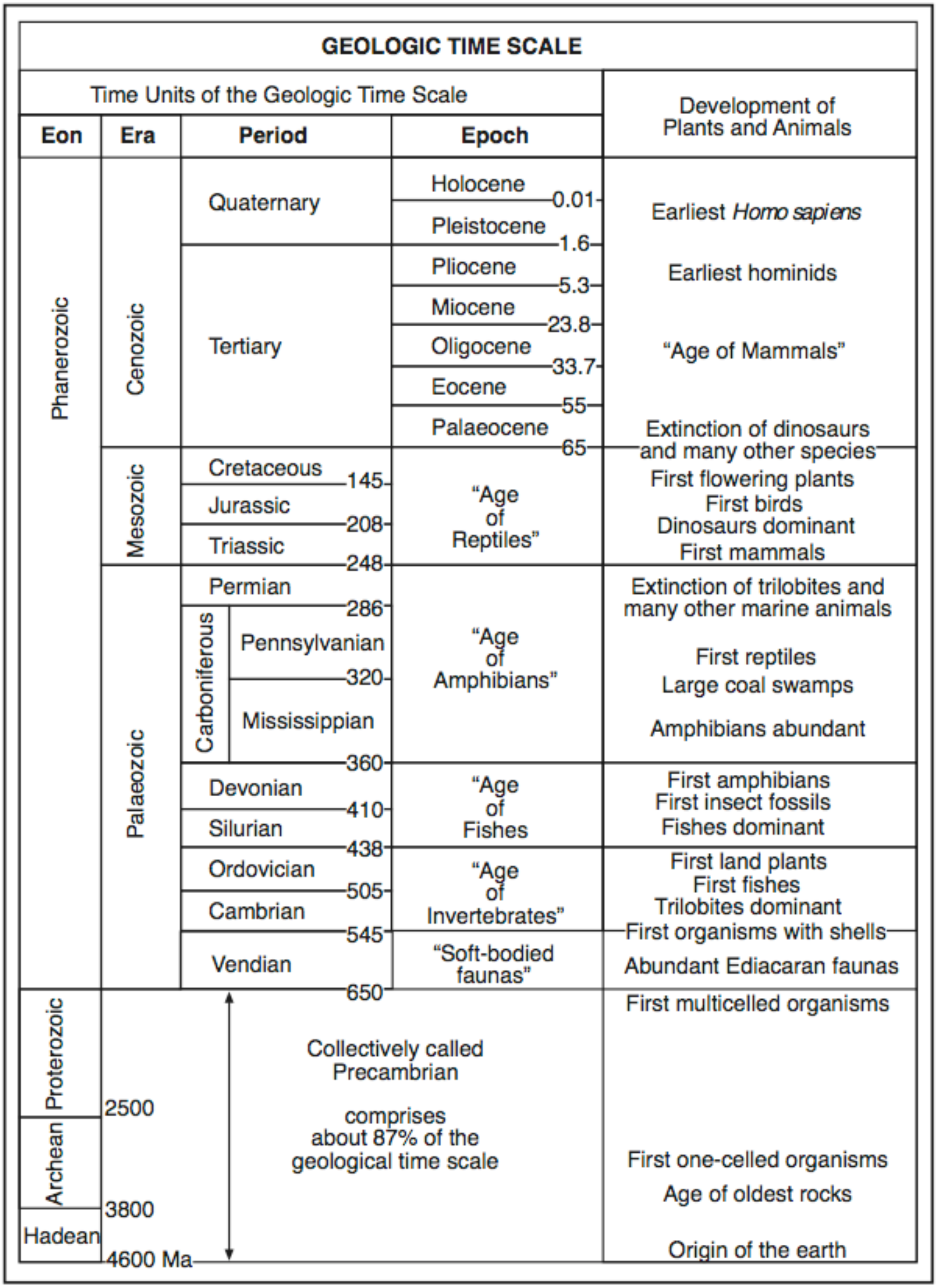
Udden-Wentworth Grain Size Scale

Size Range	**Name**
>256 mm	Boulder
64-256 mm	Cobble
4-64 mm	Pebble (occasionally subdivided)
2-4 mm	Granule
1-2 mm	Very Coarse Sand
0.5-1 mm	Coarse Sand
0.25-0.5 mm	Medium Sand
125-250 μm	Fine Sand
62.5-125 μm	Very Fine Sand
31.25-62.5 μm	Silt
15.75-31.25 μm	Clay

MOHS HARDNESS SCALE



Index Mineral	Scale	Common Objects
Diamond	10	
Corundum	9	
Topaz	8	
Quartz	7	Steel file (6.5)
Orthoclase	6	
Apatite	5	Glass (5.5) Knife blade (5.1) Wire Nail (4.5) Penney (3.5) Fingernail (2.5)
Fluorite	4	
Calcite	3	
Gypsum	2	
Talc	1	



GEOLOGIC TIME SCALE

Time Units of the Geologic Time Scale						Development of Plants and Animals
Eon	Era	Period		Epoch		
Phanerozoic	Cenozoic	Quaternary		Holocene	0.01	Earliest *Homo sapiens*
				Pleistocene	1.6	
		Tertiary		Pliocene	5.3	Earliest hominids
				Miocene	23.8	
				Oligocene	33.7	"Age of Mammals"
				Eocene	55	
				Palaeocene	65	Extinction of dinosaurs and many other species
	Mesozoic	Cretaceous		"Age of Reptiles"	145	First flowering plants
		Jurassic			208	First birds
		Triassic			248	Dinosaurs dominant First mammals
	Palaeozoic	Permian		"Age of Amphibians"	286	Extinction of trilobites and many other marine animals
		Carboniferous	Pennsylvanian		320	First reptiles Large coal swamps
			Mississippian		360	Amphibians abundant
		Devonian		"Age of Fishes"	410	First amphibians First insect fossils
		Silurian			438	Fishes dominant
		Ordovician		"Age of Invertebrates"	505	First land plants First fishes
		Cambrian			545	Trilobites dominant First organisms with shells
		Vendian		"Soft-bodied faunas"	650	Abundant Ediacaran faunas
Proterozoic		Collectively called Precambrian comprises about 87% of the geological time scale			2500	First multicelled organisms
Archean					3800	First one-celled organisms Age of oldest rocks
Hadean					4600 Ma	Origin of the earth

(From http://sci.waikato.ac.nz/evolution/geological.shtml)