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Department of Planetary Sciences**

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**Beach Processes**

**Planetary Field Geology Practicum**

**PTYS 594a**

**April 18-21, 2002**

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**PTYS 594a,**  
**PLANETARY FIELD GEOLOGY PRACTICUM**

**Itinerary, Beach Processes Field Trip 18 April-21 April 2002**

H. J. Melosh, 935 Gould/Simpson, 621-2806

We will assemble at 7:30 am on Thursday, 18 April from the LPL loading dock off Warren Street. in four 8-passanger Suburban vans. Try to be at LPL by 7:30 am to get the vans loaded. Please be sure that you have had breakfast beforehand, have ice for the coolers, etc. before we are scheduled to leave: Breakfast and ice runs just before departure have caused long delays in the past!

Our approximate itinerary is:

**Thursday, 18 April:**

- 8:00 am Distribute handouts, Depart LPL, turn right on Cherry to Speedway, then travel East on Speedway to I-10, proceed North on I-10 to I-8. Turn West on I-8 toward Gila Bend
- 10:00 am Stop at rest stop in Sentinel volcanic field.
- 1:00 pm Lunch stop West of Yuma in Algodones Dune field on I-8.
- 2:00 pm Continue West on I-8 to El Centro. Turn North on Route 86 to Brawley, continue North to Desert Shores.
- 4:00 pm Stop at Travertine Rock, where **Ingrid Daubar** will acquaint us with the story of ancient lake Chuilla and modern Salton Sea.
- 5:00 pm Return South on Route 86 to Route 78, proceed West to Anza Borrego campground.
- 6:30 pm Make camp at Anza Borrego.

**Friday, 19 April:**

- 7:30 am Break Camp, continue West on Route 78 15 miles to Route 79, turn South 22 miles to I-8. Proceed West on I-8 to San Diego. Turn South on I-5, proceed to Silver Strand Beach. We will make a stop just before the freeway entrance to hear the story of the Southern California Batholith from **Jani Radebaugh**. **Terry Hurford** has also contributed a short discussion of spheroidal weathering, as observed from space.
- 9:30 am Arrive Silver Strand beach, change into bathing suits, study near-shore currents in the surf zone using floats under supervision of **Adina Alpert**. Also observe rip currents under guidance of **Matt Chamberlin**, physics of breaking waves with **Dave O'Brien** and sand movement in the swash zone with **Joe Spitale**.
- 12:00 noon Lunch on Beach
- 1:00 pm Continued observation and discussion of heavy mineral laminae (at least in spirit) by **Jim Richardson**.
- 2:00 pm Depart Silver Strand Beach and Drive North on I-5 toward Los Angeles.
- 3:00 pm Stop at former coastal estuary, discussion of formation of spits, bars, lagoons, estuaries by **Jonathan Fortney**.
- 4:00 pm Stop at San Onofre at Echo Arch campground to observe beach cusps, the Cristianitos Fault and marine terraces under the guidance of **Peter Lanagan**.

- 5:00 pm Depart San Onofre, return South on I-5, turn East on Route 76 to Palomar Mountain campground.
- 6:30 pm Make Camp at foot of Palomar Mountain.

Saturday, 20 April:

- 8:00 am Break camp, return West on Route 76, North on I-5, then take Rte 1 at San Clemente, continue North to Palos Verdes Hills. Going is slow on this section of the coast highway, so be patient!
- 10:00 am Arrive at the Portuguese Bend Landslide, where we will hear its story from **John Keller**. We cannot actually stop on the landslide, so we will drive slowly through the slide area, then stop to the south in Point Fermin Park, where other evidence of marine erosion may be plainly seen.
- 11:00 am Continue North on Route 1. Observe the many beaches, marine terraces and wave-cut cliffs on this heavily populated stretch of shoreline.
- 12:00 noon Lunch stop on beach near Santa Monica.
- 1:00 pm Continue North on Route 1 to Oxnard, where we will follow Route 101 to Carpinteria.
- 2:00 pm Arrive at Carpinteria Beach, observe the fossil brea and active oil seeps on the beach under the direction of **Abby Wasserman**. **Gwen Bart** will acquaint us with the critters in the tide pools and **Curtis Cooper** will regale us about tides. Low tide today is at 12:25 pm, high tide is at 7:28 pm, so the tide will be coming in during our visit.
- 3:00 pm Return to Rte. 101 and proceed East towards Los Angeles. Remain on 101 at Oxnard and continue driving on the Ventura plain, over the hills at Thousand Oaks, and into the San Fernando Valley to the Whittier Narrows gap, where we will exit to the I-10 freeway traveling East. Continue on I-10 to the exit onto I-15 at San Bernardino. Whilst we traverse the dizzying concrete ribbons at this interchange, 120 feet off the ground, **Paul Withers** will describe how the trace of the San Jacinto fault passes directly underneath us in one of the most glaring examples of poor highway planning ever achieved by the California Department of Transportation. He will also describe the nature of the San Andreas fault and how it has created Cajon Canyon through which we are about to pass.
- 6:30 pm Leave I-15 at Victorville, proceed East on Route 18 to Lucerne Valley, continue East on Route 247.
- 7:30 pm Camp at the foot of the Blackhawk landslide.

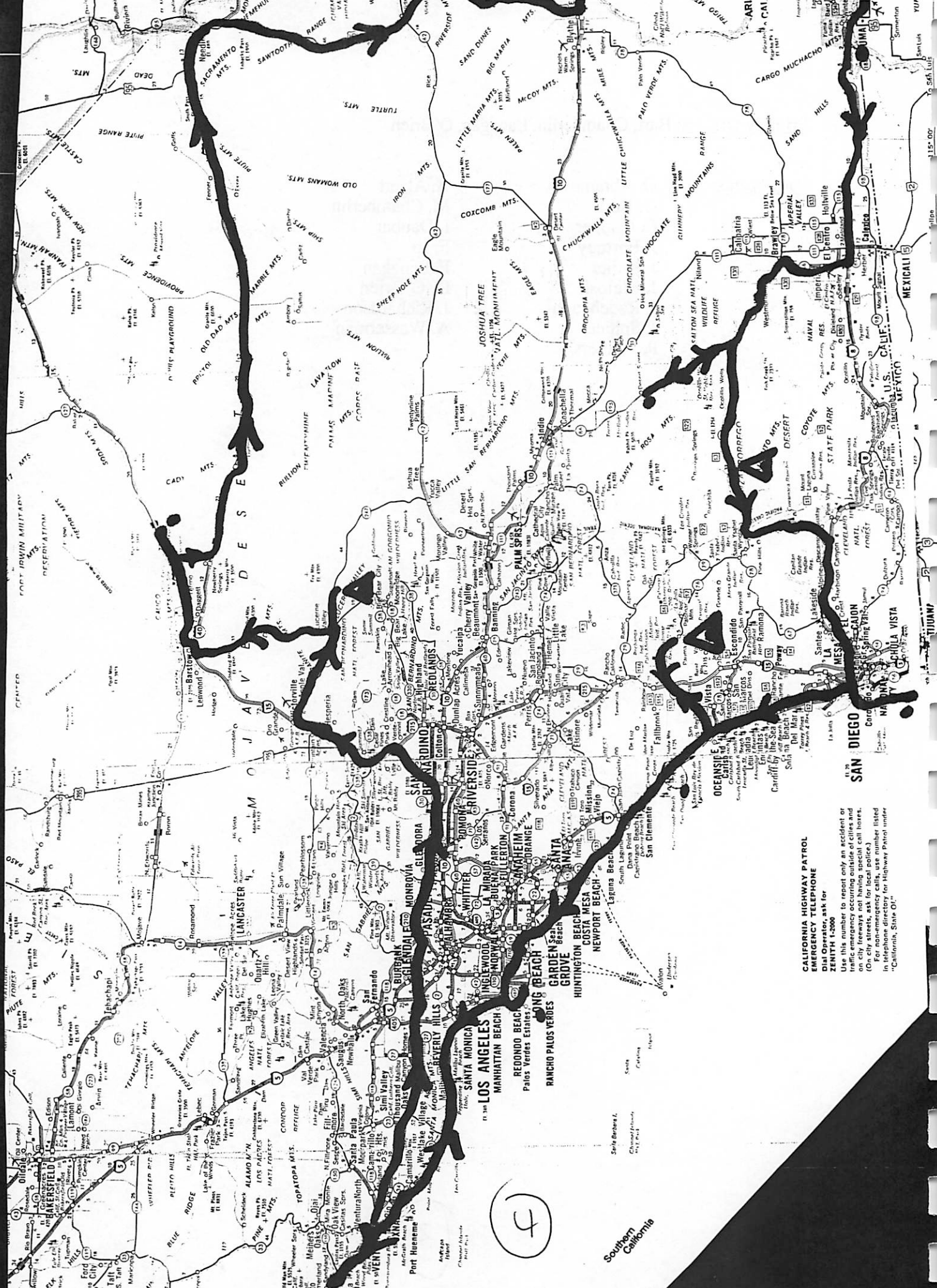
Sunday, 21 April:

- 8:00 am Break camp, return to Lucerne Valley via Rte 247, continue North 33 miles to reach I-15 at Barstow. Proceed 27 miles East to Afton Canyon exit, stop to observe the magnificent fossil beach of ancient Lake Manix. **Felipe Ip** will discuss the beach deposits and, finally, **Oleg Abramov** will relate these deposits to beaches on Mars.
- 10:00 am Return West on I-15, take the short dirt road at the Harvard exit South to I-40. Proceed East on I-40 135 miles to Route 95. Stop for lunch at an appropriate time and place. Turn South on Route 95 to reach I-10 at Blythe after 92 miles. Enter Arizona, continue 250 miles to Tucson
- 8:00 pm Arrive Tucson, unpack and clean vans, go home, tired but glorying in our new knowledge of beaches.

Primary Drivers: Bart, Chamberlin, Lanagan, O'Brien

Participants:

O. Abramov	A. Alpert
G. Bart	M. Chamberlin
C. Cooper	I. Daubar
J. Fortney	F. Ip
J. Keller	P. Lanagan
J. Melosh	D. O'Brien
J. Radebaugh	J. Richardson
J. Spitale	A. Wasserman
P. Withers	



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 Dial Operator, ask for  
**ZENITH 1-3000**  
 Use this number to report only an accident or  
 traffic emergency occurring outside of cities and  
 on city freeways not having special call boxes.  
 (O) For emergency calls use number listed  
 in telephone directory for Highway Patrol under  
 "California, State Of."

Southern  
 California

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# Lake Cahuilla: Shorelines of an Ancient Lake

## Ingrid Daubar

### Setting the scene: the Salton Trough

The Salton Trough is a low-lying area to the north of the Gulf of California. The San Andreas is only one of the faults running through it that aided in its creation. At several points in history, tectonic activity and the buildup of sediments in the Colorado River Delta acted to change the course of the river so that it emptied into the basin.

The trough is surrounded by mountains (Santa Rosa, Orocopia, Chocolate...) and by the Colorado River Delta to the south. This enclosed basin has no outlet, and therefore has been repeatedly flooded by the Colorado River before the creation of the present Salton Sea. These (pre)historic bodies of water are collectively known as Lake Cahuilla, or Lake LeConte on older maps.

### Evidence for ancient lakes

The shorelines of Lake Cahuilla are ~12-15 m above sea level, and indicate the repeated presence of a lake as large as 160 km by 56 km, and 100 m deep, or something like six times the size of the present Salton Sea. In order to fill the basin to this level, the Colorado would have had to flow into the basin for a period of 12-20 years. Once the lake reached ~12 meters above sea level, Lake Cahuilla would have spilled over at Cerro Prieto, Mexico, and drained into the Sea of Cortez. Once the Colorado stopped flowing into the basin, it would have taken ~53 years for Lake Cahuilla to dry up.

Shorelines date from the late Holocene. Evidence for this includes well-preserved shoreline features, the lack of either desert varnish or desert pavement on the beaches, and carbon dating of fossils, bones, and archeological items. Four separate lake periods can be distinguished, the last of which occurred between 1640 and 1690 A.D.

The oral history of local native americans also give clues to the lake's history. Although spanish explorers found only a dry playa when they arrived in the 1600s, the legends they heard told of a large body of water in the area and the tribes' movements when the water level fell and rose. Fish traps, or rows of pits used for fishing, are archeological evidence of the movements of native people along the falling water level.

Prominent travertine, or tufa, deposits mark the water level in several areas. Tufa is calcium carbonate,  $\text{CaCO}_3$ , which is precipitated from alkaline water. When such water is saturated with carbonate ions, release of  $\text{CO}_2$  will cause precipitation of calcium carbonate. Algae can take up  $\text{CO}_2$ , or wave agitation can release it. This light-colored precipitate stands out against the dark red desert-weathered rocks which remained above the water level.

Other evidence includes wave-cut shore cliffs, long barrier beaches, baymouth bars, spits and tombolos. Steep boulder beaches and thick tufa deposits can be found on the western side of the basin. In some places, the beach line is marked with a fossil-filled ridge of sand several feet high.

### Remote sensing.

Shorelines are visible in aerial photographs. Sandy Lake Cahuilla deposits can be identified in SEASAT images by their smoothness on the scale of radar wavelengths

(Sabins *et al.* 1980). Topography can be used to give an estimate of the extent of the ancient lake, given an indication of the water level. One study recorded GPS data at geological and archeological shoreline features (Buckles & Krantz 2000), finding the shoreline was 11.9 m above sea level, consistent with other work.

Lake Cahuilla  
when it was full  
to the 12-m  
shorelines  
(Waters 1983) →

Travertine deposits  
near Travertine Rock  
(Waters 1983)  
↓

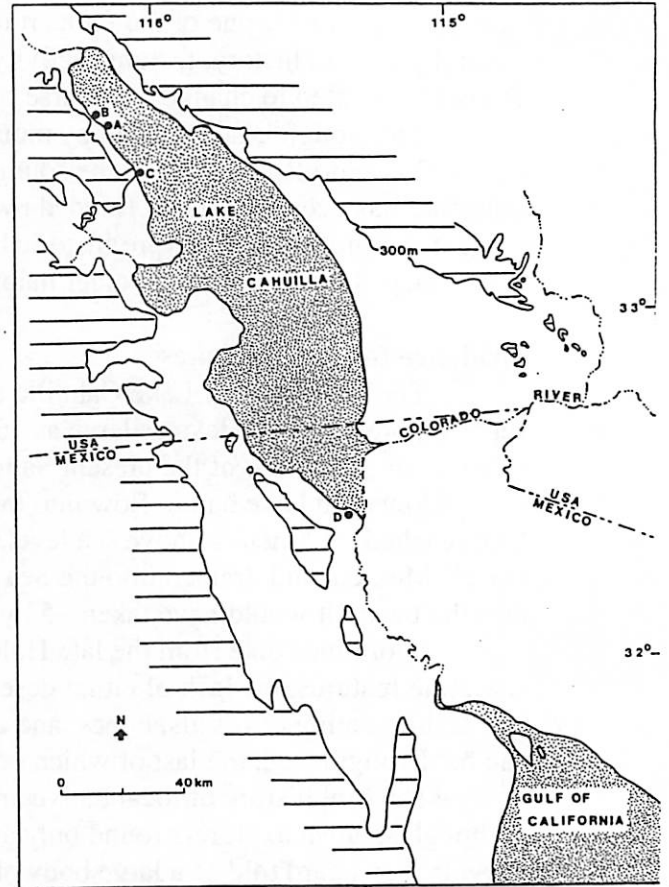


FIG. 3. Late Holocene paleogeography of the Salton Trough showing lake Cahuilla at 12-m altitude (A) Radiocarbon locality A; (B) Radiocarbon locality B; (C) Radiocarbon locality C; (D) Cerro Prieto

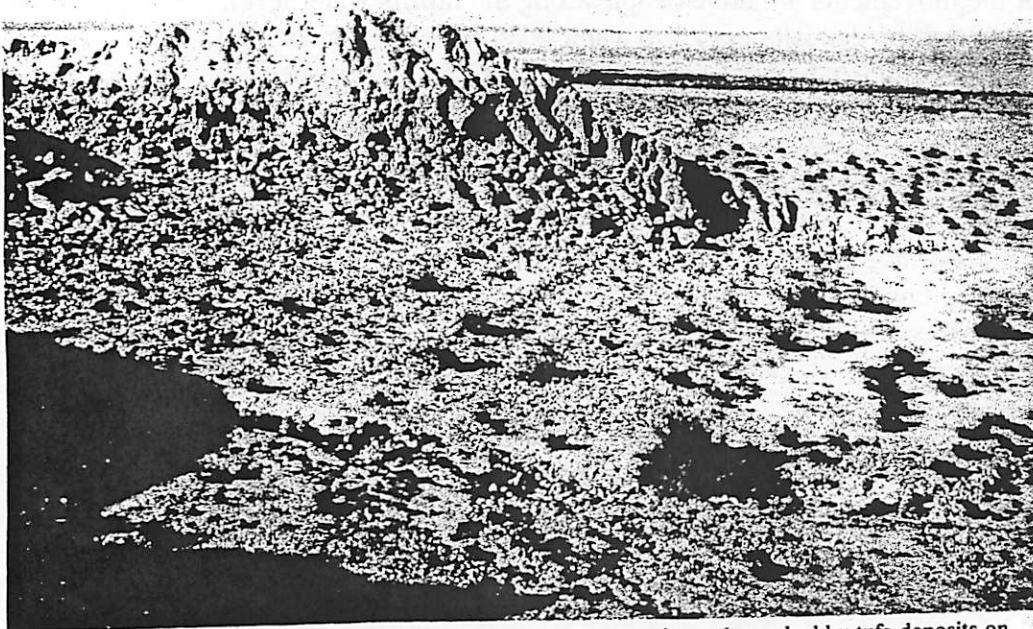


FIG. 1. Late Holocene 12-m shoreline of Lake Cahuilla conspicuously marked by tufa deposits on outcrops that protruded into the ancient lake. Photograph looking east across the Salton Trough from Travertine Point toward the Salton Sea.

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## What can we see today?

(Since I'm not sure where Jay is taking us, I've listed details about a few sites, and hopefully we'll hit one of these.)

① Near the northeast shore of the Salton Sea, a *shist shingle barrier beach* forms a prominent ridge. The beach is 3.5 km long and extends east towards the Orocopia mountains. The *headland* here is marked by a 40-ft contour on a topo map. When the water was at its highest level, *longshore drift* created a broad sandy *barrier beach* along this contour. It initially developed as a *spit* or *bar* extending east from a headland, isolating a shallow *lagoon* of water. Sediment from this lagoon can be seen upslope from the highest beach. The size of this beach indicates fairly persistent, intense wave action and shore currents. It also takes a lot of wave energy to bring the shist *pebbles* all the way from the Orocopia mountains and organize them into the *imbricate* structure seen.

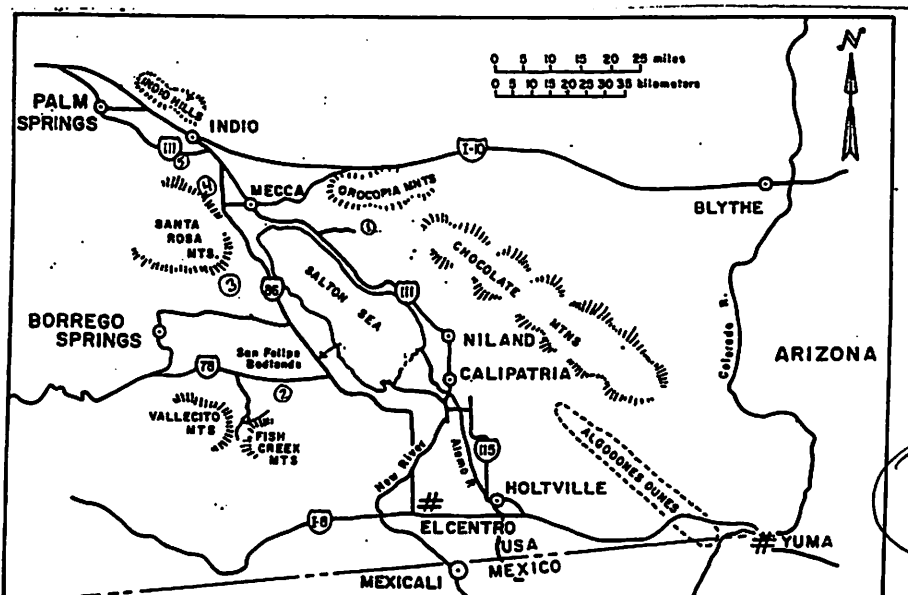
② A few km west of highway 86, north of the junction with route 78, are the San Felipe Badlands. These were carved by Lake Cahuilla out of the soft clays and silts of the Palm Spring formation. Wave-cut cliffs, some of which are 10-12 meters high, are most prominent on the eastern and northern sides of the badlands. These cliffs can also be seen driving north on 86 past the badlands.

③ Travertine Rock is just west of 86 on the northwest side of Salton, near Desert Shores. This rock marks the high-water line with a highly visible layer of tufa. The layer is also seen on the nearby Santa Rosa Mountains. Travertine Rock was an island when Lake Cahuilla was at its highest, and as the water fell, became a *tombolo* and then a *headland*. Near the intersection with Lakeview road, there is a broad sandspit extending more than a km from Clay Point. Sandy beaches, baymouth bars, and old beachlines can also be seen.

④ At the base of the Santa Rosa Mountains, the shoreline is marked by a wave-cut notch. The notch itself looks fairly fresh. Below lies a slope of rounded talus boulders made of granite porphyry. These rocks are covered with tufa, unlike the desert varnish above. Fish traps are also located here, two rows of ~ 40 pits, each ~1 m deep.

⑤ Eight km southwest of Indio, there is a 6 km long trench that was dug to control flooding. It also exposed interbedded lacustrine and fluvial sediments. Lacustrine sediments are "ripple-laminated" and made of very fine sand and silt. Freshwater shellfish fossils are contained within this layer. The fluvial layers, on the other hand, are made of coarse sand and some gravel, and have no fossils. The repeating layers indicate a cycle of rapid filling of the basin followed by tranquil deposition in Lake Cahuilla.

(see picture next page)



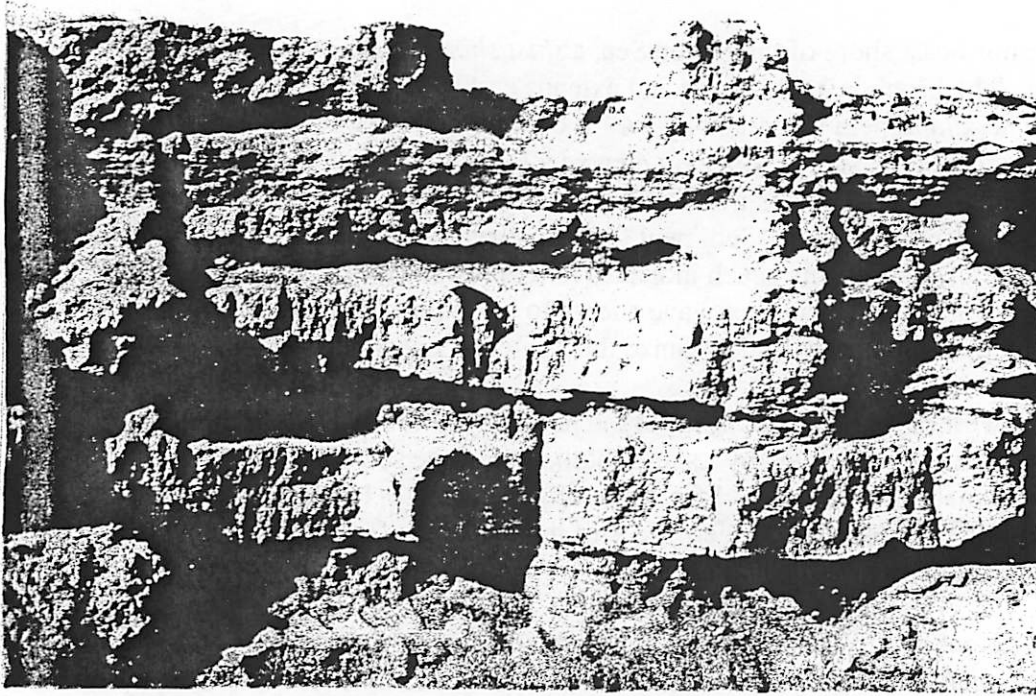


FIG. 5. Deposits of lacustral intervals 1-4 at locality A. Fluvial deposits are undercut and lacustrine deposits protrude. Shovel (center) rests on deposits of lacustral interval 2.

Interbedded lacustrine & fluvial sediments.  
(Waters 1983)

Depth of water  
in Lake Cahuilla  
over time  
(Waters 1983)

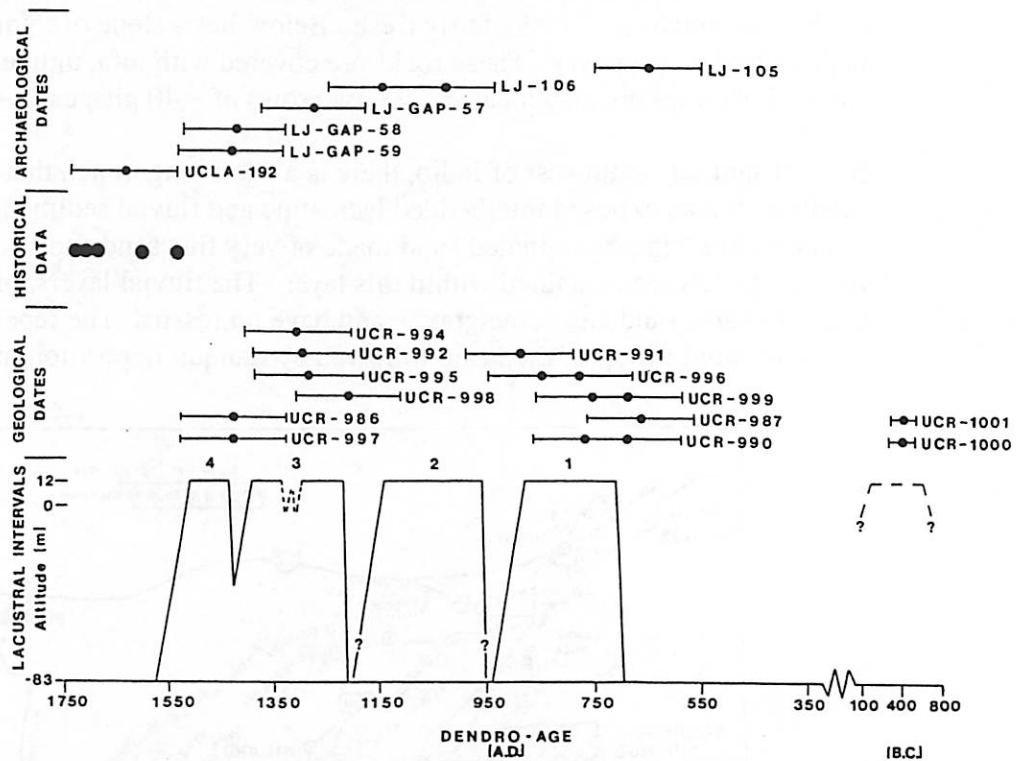


FIG. 6. Late Holocene lacustrine chronology of Lake Cahuilla. The trapezoidal-shaped outlines represent the lacustral intervals. The right line of the trapezoid represents the initial filling of Lake Cahuilla from -83 to +12 m. The top horizontal line represents the amount of time the lake stood at 12-m altitude. The left line of the trapezoid represents the recession of the lake from 12 to -83 m (complete desiccation). Solid lines represent firm chronologic placement of the lacustral interval; dashed lines represent tentative chronologic placement or duration of a lacustral interval. The large solid dots represent the time of Spanish reports on the position of the Colorado River.

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## TERMINOLOGY

unless otherwise noted, definitions are from the Dictionary of Coastal Terminology in *Coastal Engineering Manual*, ed. Szuwalski & Morang, Engineer Manual 1110-2-1100, U.S. Army Corps of Engineers, Washington, DC.  
<http://bigfoot.wes.army.mil/cem1001.html>

**alluvium** – Soil (sand, mud, or similar detrital material) deposited by streams, or the deposits formed

**bar** – A submerged or emerged embankment of sand, gravel, or other unconsolidated material built on the sea floor in shallow water by waves and currents

**barrier beach** – A bar essentially parallel to the shore, the crest of which is above normal high water level.

**baymouth bar** – A bar extending partly or entirely across the mouth of a bay, sealing the bay off from the open ocean

**colluvium** – The mixture of soil and unconsolidated rock fragments deposited on, or at the foot of, a slope. (Oxford)

**fluvial** – Of or pertaining to rivers; produced by the action of a river or stream (e.g., fluvial sediment)

**headland** – (1) A comparatively high promontory with either a cliff or steep face extending out into a body of water, such as a sea or lake. (2) The section of rip current which has widened out seaward of the breakers, also called head of rip. (3) Seaward end of breakwater or dam.

**imbricate** – a sedimentary structure characterized by a slanting, overlapping pattern in which gravel, pebbles, or grains are all inclined in the same direction, with their long axes at an angle to the dominant bedding plane. (Harcourt Dictionary of Science & Technology)

**lacustrine** – tranquil lake environment as opposed to large ocean or flowing water in a river, etc.

**lagoon** – A shallow body of water, like a pond or sound, partly or completely separated from the sea by a barrier island or reef. Sometimes connected to the sea via an inlet.

**longshore drift** – Movement of (beach) sediments approximately parallel to the coastline

**pebble** – Beach material usually well-rounded and between about 4 mm to 64 mm diameter.

**sheet flow** – Sediment grains under high shear stress moving as a layer that extends from the bed surface to some distance below (on the order of a few cm). Grains are transported in the direction of fluid flow.

**shingle** – 1) Loosely and commonly, any beach material coarser than ordinary gravel, especially any having flat or flattish pebbles. 2) Strictly and accurately, beach material of smooth, well-rounded pebbles that are roughly the same size. The spaces between pebbles are not filled with finer materials. Shingle often gives out a musical sound when stepped on.

**shoreline** – The intersection of a specified plane of water with the shore or beach (e.g., the high water shoreline would be the intersection of the plane of mean high water with the shore or beach).

**spit** – A small point of land or a narrow shoal projecting into a body of water from the shore

**tombolo** – A bar or spit that connects or "ties" an island to the mainland or to another island

## The Salton Sea today: “an aquarium that nobody has cleaned.”

The Salton Sea was created when an irrigation project went awry. A canal system was built around the turn of the century to irrigate the growing agriculture in the Salton Trough. The Colorado River was still undammed and therefore unpredictable. The silt-clogged canals were practically empty in 1905, just before the fatal flood broke through. Almost the entire river was re-routed by the flood into the Salton Trough. A salt works and the Southern Pacific railway line were flooded, and remain at the bottom of the Salton Sea. Channels (the New River and the Alamo River) were cut to handle the water, and the canals dried up. These rivers experienced such a large flux of water, they were as wide as 0.4 km in some places, and 15 m deep. Waterfalls worked their way backwards toward the source – in the New River, a waterfall migrated all the way to the Mexican border (80 km!) in less than two years.

The Colorado River continued to flow into the trough for 16 months, while several attempts to dam it failed. By that time, the Salton Sea had formed, even larger than it is today. Originally it was fresh water, but salinity increased due to evaporation and addition of irrigation water used to leach salts out of the surrounding soil.

Today the Salton Sea is the largest lake in California, although it is still much smaller than Lake Cahuilla. It reaches approximately 55 km by 22 km, but is less than 15 m deep. The surface is 71 m below sea level, and rising. Increasing the surface area will lead to increasing evaporation, and eventually the lake will stabilize somewhere near its current level. Unfortunately, the rising water level has already flooded nearby recreation areas, docks, and fields.

Not only has the surrounding environment become inhospitable, the lake itself has become rather disgusting, if not yet dangerous. Additions of sewage and fertilizer runoff, along with pollution from Mexican streams, do nothing to improve the already salty (25% more than the ocean) water. Algae “choke” the lake, changing the color of the lake from brown to red to green when they bloom. The shallow water is easily stirred up by winds sweeping across the surface, releasing ammonia and hydrogen sulfide. This mixing aids in the depletion of oxygen, creating what one author called a “parasitic microbial haven” (Kaiser 1999).

Fish and birds have been dying off in the hundreds of thousands within the past ten years. In 1992 alone, 150,000 “eared grebes” died of unknown causes, and botulism killed off 10% of white pelicans in the west and more than 1,000 endangered brown pelicans. Officials have issued health warnings about dangerous levels of selenium and bacteria in the fish. This has effectively destroyed the sport-fishing industry, begun in the 1950s when “wildlife managers” stocked the Sea with large open-ocean fish. These have mostly died out, leaving only the *tilapia*, an African species used in irrigation ditches to eat weeds. These too will soon die off if the current progress of the lake is left unchecked.

### Options:

- Dilute with fresh water to reduce salinity.
  - But where will it come from? Colorado River? Nevada? ha!
  - Will cause flooding
- Pump water out to reduce salinity.
  - But where – the Gulf of California? – the Pacific? – who wants that nasty stuff?
  - Initially leads to lower water levels and *increased* salinity
- “Evaporation ponds” separate very saline water with dikes, then remove precipitated salts.
  - Expensive, complex, unsightly
- Remove salts before they are added to the Sea.
  - Difficult, expensive, and would only slow increasing salinity
- Leave it alone, to disappear naturally like its predecessors.
  - Death warrant for agriculture, tourism

### Planetary Connection

- Putative shorelines on Mars (See Oleg’s handout, “Beaches on Mars”)
- General detection, dating of past water on Mars
- Life in very briny, “extreme” environments
- Environmental responsibility, sociopolitical (ok, just our planet, for now) issues

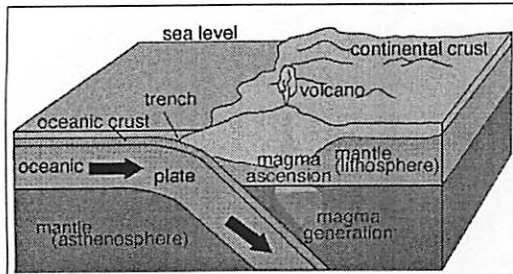
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- Norris *et al.* (1979) “Geomorphology of the Salton Basin, California: Selected observations,” In *Geological Excursions in the Southern California Area* (ed. P.L. Abbott) Dept. Geol. Sci. San Diego State University, San Diego, CA.
- Sabins *et al.* (1980) Seasat radar image of San Andreas Fault, California. *Amer. Assoc. Petrol. Geologists Bull.* **64**, no. 5, 610-628
- Singer E. “Geology of the Imperial Valley California; a Monograph by Eugene Singer.”  
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- Waters M.R. (1983) Late Holocene lacustrine chronology and archaeology of ancient Lake Cahuilla, California. *Quaternary Research* **19**, 373-387.

# The Southern California Batholith

Jani "P.O." Radebaugh

From 90 to 105 million years ago, two enormous sister bodies of igneous rock were emplaced intrusively, the Sierra Nevada Batholith (north-central California) and the Southern California Batholith (So. California-Baja). These giant **batholiths** (many combined bodies of igneous rock cooled underground) cover 14,500 km<sup>2</sup>, and the largest of the two is the Southern California Batholith.

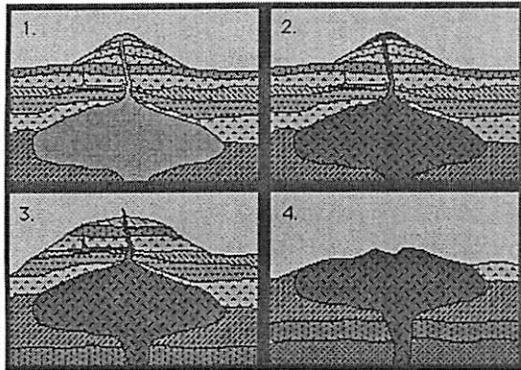


Magma is generated at subduction zones where dense oceanic plates are pushed under lighter continental plates.

## ORIGIN

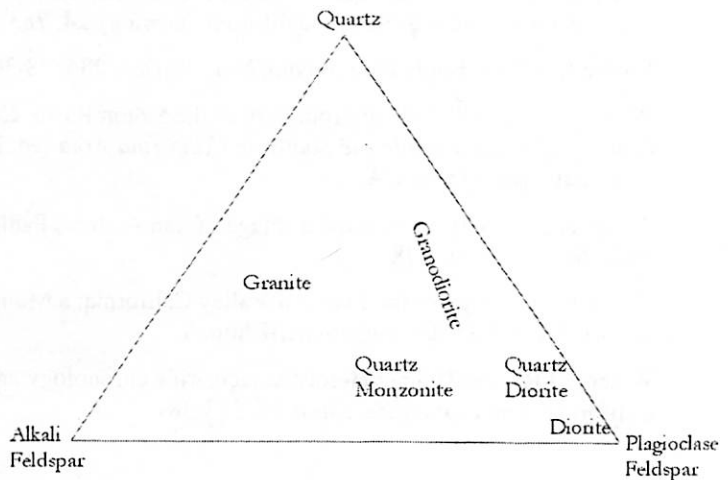
Formation of the Southern California Batholith is related to the subduction of the

Pacific Plate underneath the North American Plate during the Mesozoic. The subducting plate carried with it ocean water that then rose into the hot mantle, depressing its melting temperature. The molten mantle material rose up and incorporated some crustal rocks into the melt before it cooled and solidified high in the crust. More compression and crustal thickening during the Mesozoic (50 million years ago) resulted in uplift and erosion of the upper crust, and exposure of the batholith, allowing scientists to scramble on, analyze, and pick apart the intrusions.



## COMPOSITION

More than 90% of the rocks in the Southern California Batholith are of five main igneous types: *diorite*, *quartz diorite*, *granodiorite*, *quartz monzonite* and *granite* (all **silica-rich**, or with SiO<sub>2</sub> >60 wt%). Their isotopic signatures suggest that the plutons (smaller, geochemically homogeneous masses of igneous intrusive rock) were formed by partial melting of a recently subducted basaltic crustal slab at the base of thickened arc crust together with components of older crustal material.

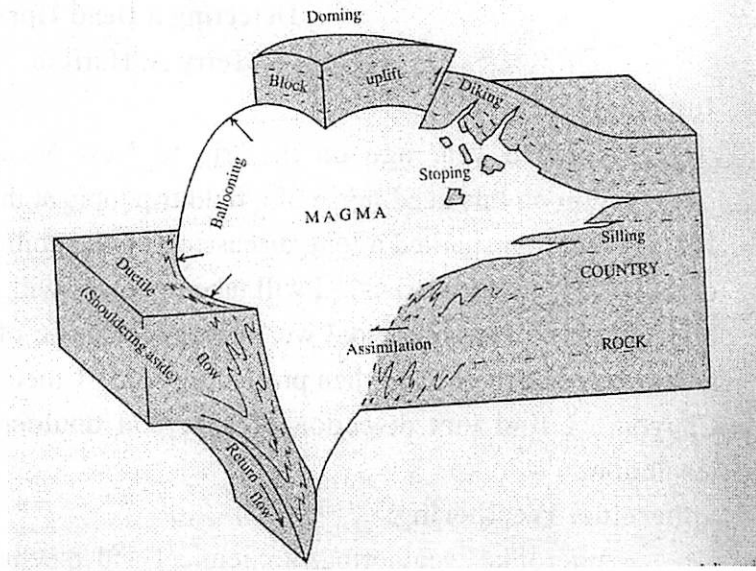




## JOURNEY

Much controversy has surrounded the rise and emplacement of these often several kilometers wide magma bodies. We usually just see the upper portion of a chilled magma body, it is rare to see the base of a pluton. How do **diapirs** (bulbous masses of rising molten rock) rise through many kilometers of thick, dense crust? There must be 1) a density contrast between the hot, molten diapir and the cooler crustal rocks such that the diapir is bouyant relative to its surroundings and 2)

enough magma overpressure so that the confining pressure can be overcome, allowing the magma to rise. These viscous magmas must rise slowly through the crust, sometimes just centimeters per year, and must thermally soften surrounding rocks, **shouldering** them aside. Rising plutons can also **assimilate** surrounding crustal rocks by **stopping**, or downward collapse of roof rocks or by melting and scraping them from the side walls. An alternative model is that of smaller rising packets of magma in the form of **dikes** (a vertical sheet intrusion of igneous rock). This is not as common with silicic magmas (granite) as with mafic magmas (basalt) because their high viscosity and low melting temperature makes it difficult for the magma to rise through small cracks without chilling (unless they do it *very* quickly!!). There is, however, a large silicic dike swarm in a portion of the Southern California Batholith.



## PLUTONS ON PLANETS?

Plate tectonics has resulted in the generation and emplacement of this particular batholith, and we do not see evidence for plate tectonics on other planets. There is certainly evidence of magma generation on other planets, though, so there are likely large bodies of cooled magma that never erupted. These are probably mafic in composition, however, since evolved (silica-rich) magmas are thought to be primarily a result of plate tectonics. The exposure of the Southern California Batholith is also a result of plate interactions and erosion, so we would certainly have a tougher time of seeing exposures of batholiths on another planet. Perhaps we can only see them outcropping in the walls of an impact crater or a patera!

## References/Further Reading:

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## Remote Sensing of Spheroidal Weathering

### Detecting a Dead Horse

Terry A. Hurford

#### Introduction:

About a year ago on the trip to New Mexico (2001) Ross Beyer gave a presentation on this dead-horse of a field trip topic at the Texas Canyon rest area on I-10. His presentation sparked a long discussion on the ability to detect spheroidal weathering on other planets (if it exists). I will take my own swing at the horse with this handout by briefly going over spheroidal weathering (for those of you who can't remember Ross' talk or weren't there) and then presenting some 1 meter per pixel aerial photos of Texas Canyon. I find that detection of spherical boulders is quiet difficult even at this resolution.

#### Spheroidal Weathering:

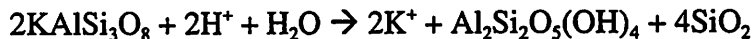
Spheroidal weathering, a chemical and mechanical weathering process erodes rock into rounded morphologies. Water in the Earth's atmosphere dissolves some carbon dioxide, then when it falls to the ground as rain it will dissolve more carbon dioxide from decaying plants. This water with carbon dioxide dissolved into it produces a weak carbonic acid, which ionizes into hydrogen and bicarbonate ions. The hydrogen ions easily break down minerals because of their small ionic radius.

#### Formation of carbonic acid

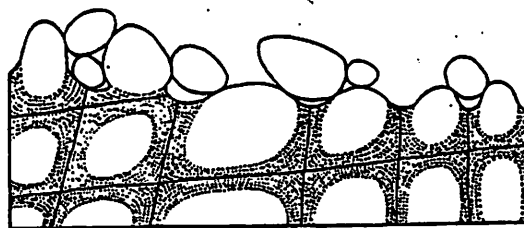


Spheroidal weathering of feldspar is one example of a reaction with carbonic acid and a mineral. The hydrogen ion can decompose potassium feldspar (orthoclase) producing potassium ions, Kaolinite and Silica. The products after decomposition are weaker clays, which are easily removed.

#### Chemical alteration of feldspar



This reaction accounts for the chemical weathering of the rock but the shape of the weathering must still be explained. The shape has to do with how the acid attacks the rock. The acid can only attack the parts of the rock it can reach, namely at the surface and in joints that penetrate to the interior. Edges and corners have a higher surface area than flat faces, thus the chemical weathering works more efficiently to attack these areas causing them to become more rounded with time. (see figures on next page)



Stages in the development of egg-shaped boulders from rectangular joint blocks. (After W. M. Davis.)

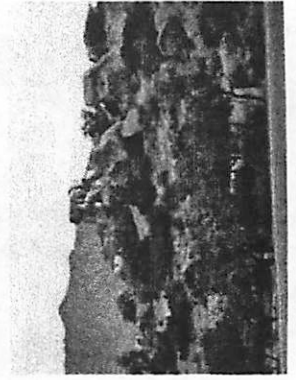
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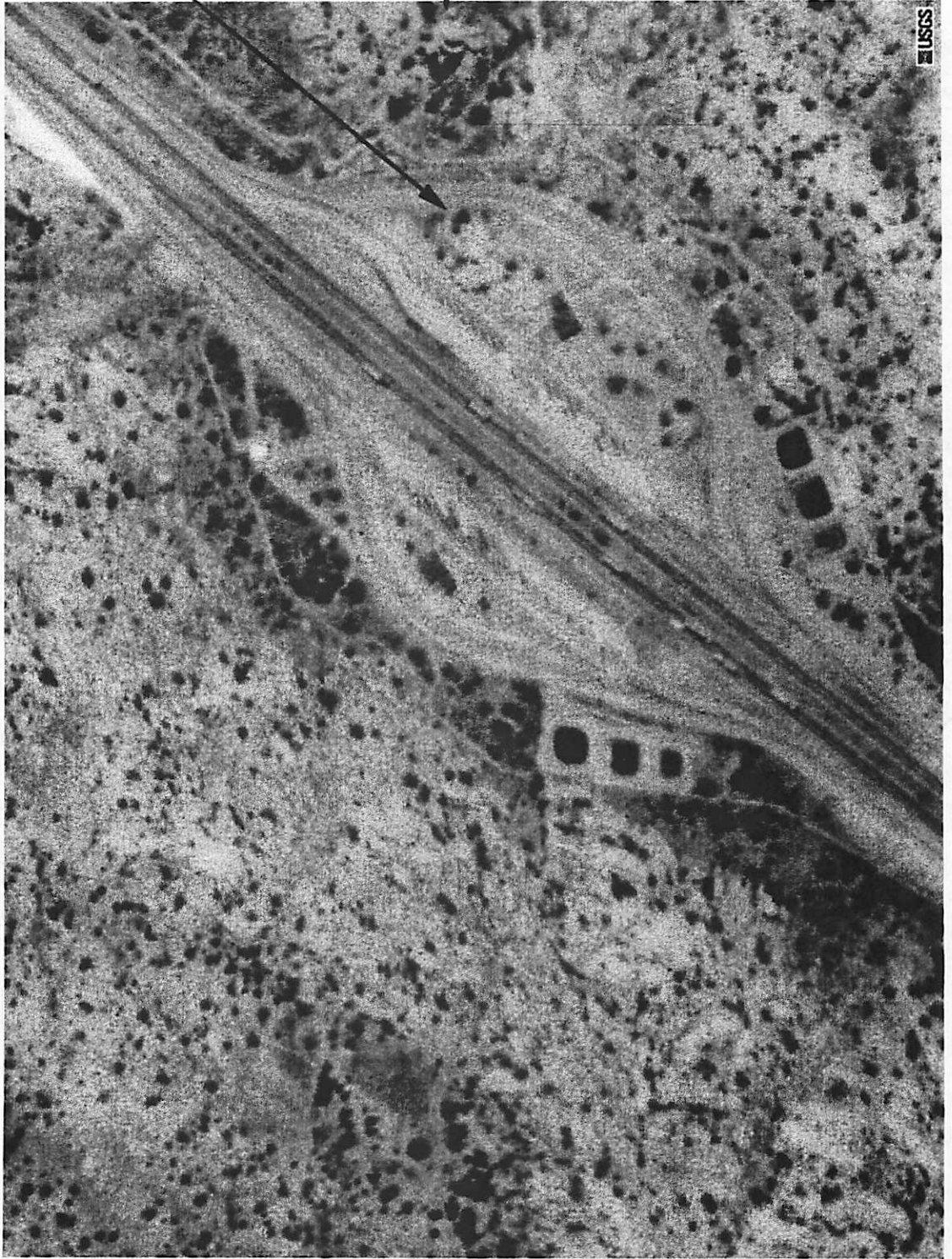
A.



B.



C.



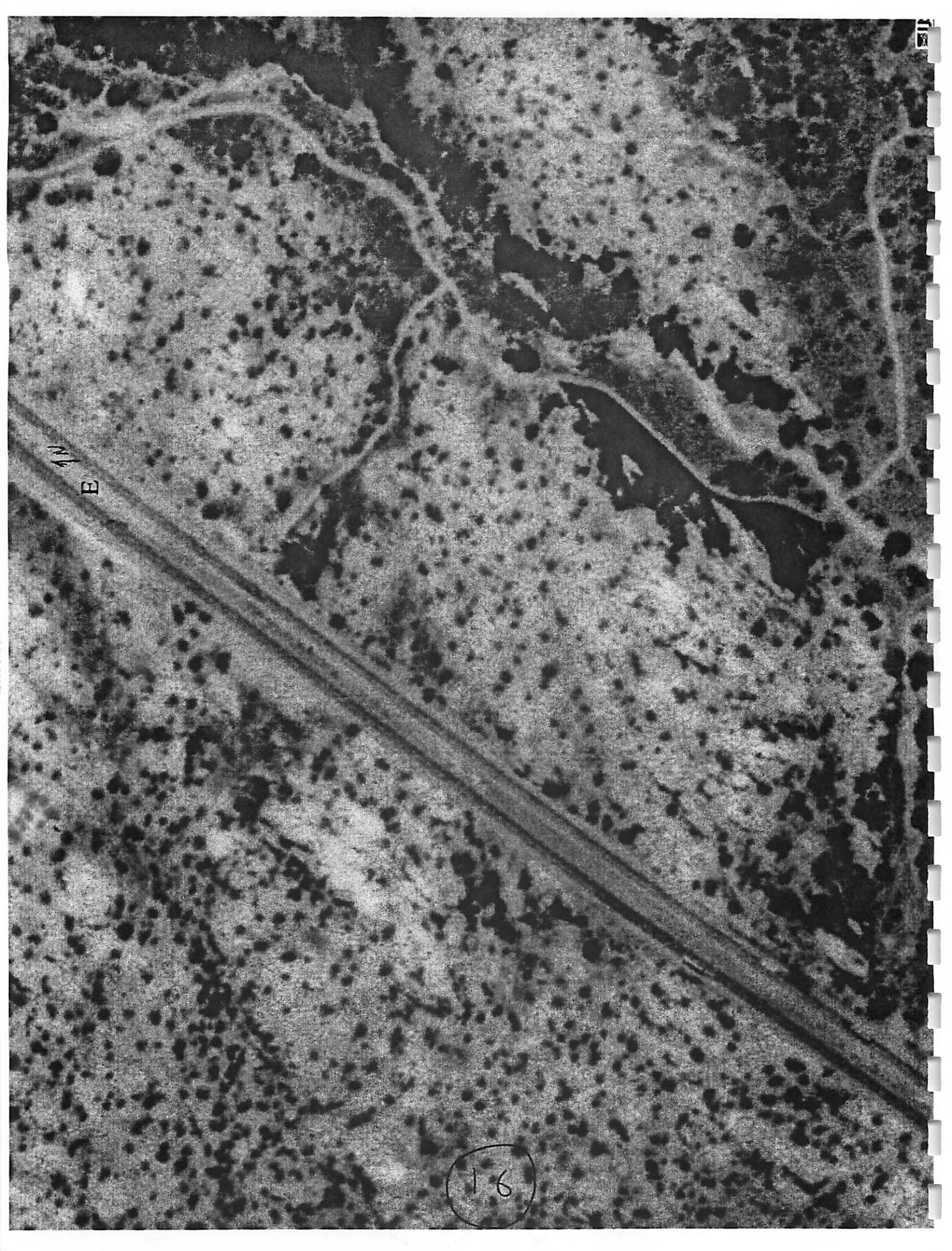
USGS

N



D.

15



E ↖

16



D



E

17

2-1

## Remote Sensing:

The first aerial photo shows the Texas Canyon rest area on I-10. Picture A, to the right, is the rock complex that we sat on while listening to Ross talk a year ago. The arrow points to its location in the USGS 1 meter per pixel aerial photo. People who have visited the rest area could probably tell that the gray blob at the end of the arrow was a boulder complex but without the first-hand experience it is impossible to tell. That area doesn't look very special. In fact the only boulder complex that stands out in the aerial photo is the complex shown in picture B. Picture C is a shot of the landscape to the southeast. I can tell you from my trip there last weekend, the pools of water to the south have boulders along their southern edge. Also on the north side of the rest stop is a large hill, shown in picture D, which isn't recognizable.

The second aerial photo is also from Texas Canyon (just southwest of the rest area). Can you find some boulders? The obvious ones line up in rows as defined by the original joints in the stone from which they were weathered.

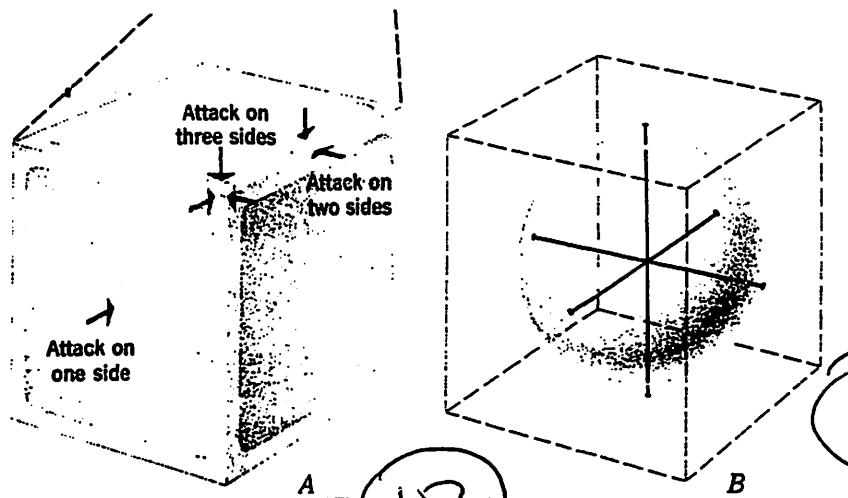
Finally aerial photos marked F and G are pictures of boulders along I-8. Between Boulder Oaks and Pine Valley on I-8 you might see boulders along the right side of the highway. From my memory (I am sure that if Fred were there, he would make an old joke at this point) on I-8 there are hills of nothing but boulders. If these pictures are of the area I remember then you can't see most of the boulders. Instead you are seeing only a few in a field of many. If you spot boulders on I-8 during the trip be sure to get a GPS reading for me and a picture or two. We can look up the aerial photos for the next field trip!

## Conclusion:

Boulders can be seen at 1 meter per pixel resolution however for every few you find there are dozen that aren't being seen. Also prior knowledge of what to look for makes finding boulders easier. Without the experience of being at Texas Canyon I may not have thought any of the features seen were boulders. MGS has a resolution of 1.4 meters per pixel. It could see these bigger complexes but mainly the boulders would go undetected. As Laz says, "Wait until HIRISE!" If there are boulders on Mars then HIRISE will be able to see them.

### Geometry of spheroidal weathering.

A. Solutions that occupy joints separating nearly cubic blocks of rock attack corners, edges, and sides at rates that decline in that order, because the numbers of corresponding surfaces are 3, 2, and 1. Corners become rounded; eventually the blocks are reduced to spheres.



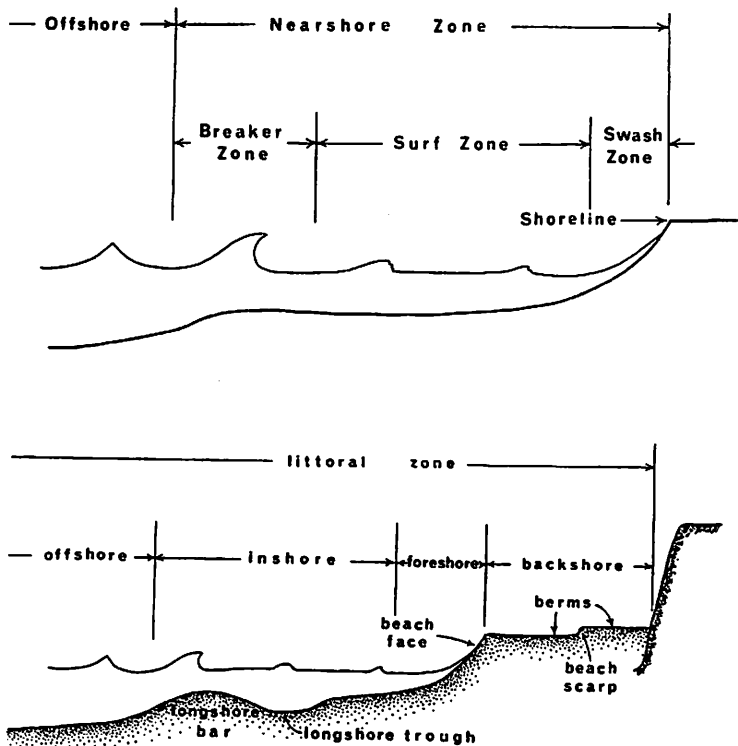
B. Energy of attack has now become distributed uniformly over the whole surface, so that no further change of form can occur.

# Longshore Currents

Adina Alpert

## Definition

Longshore currents are unidirectional nearshore currents that move parallel to the shore within the surf zone, shoreward of the breakers [see Fig. 1].



**Figure 1**

**Breaker Zone** – Here, waves steepen to the point where they become unstable and break

**Surf Zone** – Breaking waves generate turbulence that throws sediment into suspension and creates a bore wave that transports this sediment landward in this zone.

**Swash Zone** – In this zone, rapid, very shallow swash moves up the beach, followed almost immediately by a backwash flow down the beach.

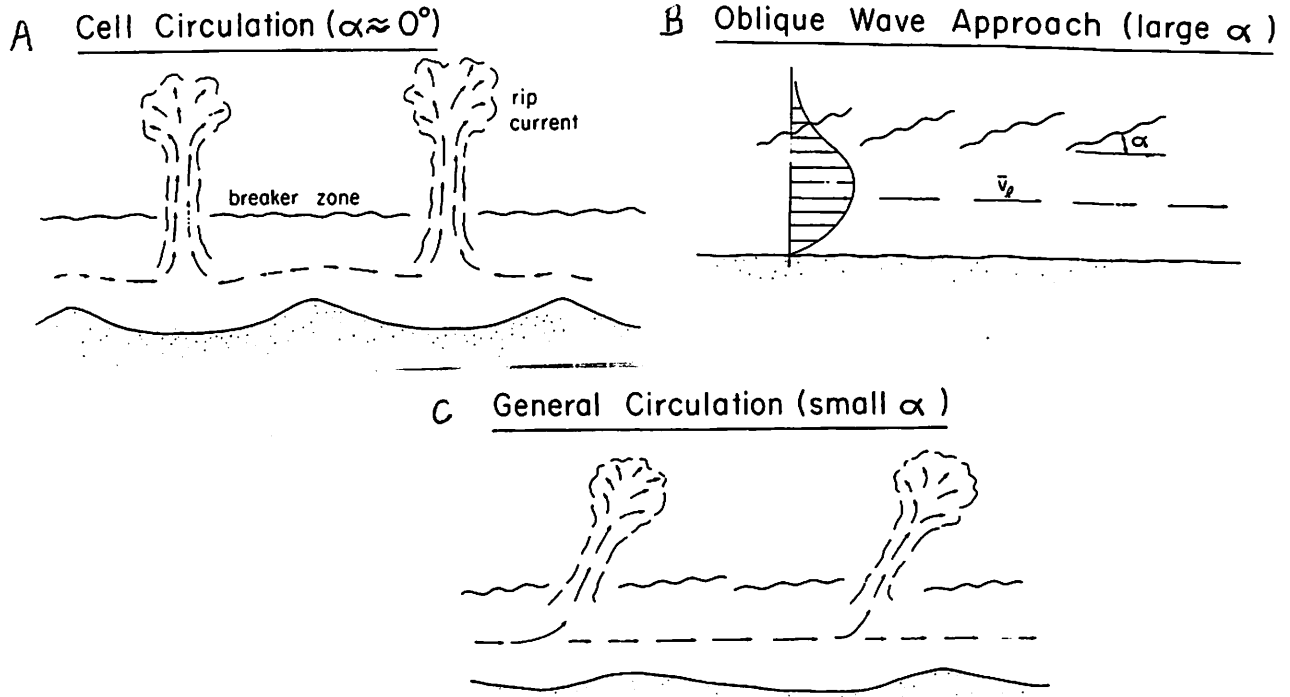
## Generation of Longshore Currents

There are two wave-induced systems that cause these currents to form:

- a cell-circulation system involving rip currents [Fig. 2A]
- a system with oblique wave approach to the shoreline [Fig. 2B]

In the general case, both of these systems play a role in causing the local longshore current, and the resulting circulation is illustrated in Fig. 2C. The longshore currents we will see are likely to be of this form.

Figure 2



**Cell Circulation**

Cell circulation occurs where there are lateral variations in breaker height. These variations are caused by the excess flow of momentum due to the presence of waves, or *radiation stress*. Radiation stress can be caused by (1) wave *refraction* [Fig. 3] and/or *diffraction* [Fig. 4] concentrating wave energy in some places and dissipating it in others, or (2) *edge waves* (resulting from a resonance between waves approaching the shore and waves reflected from it, and travel perpendicular to the shore) interfering with the incoming breakers [Fig. 5]. Longshore currents flow “downhill” from areas of greatest wave heights to areas of lower waves where the converging longshore currents turn seaward to form a rip current. This system causes divergent longshore current flow.

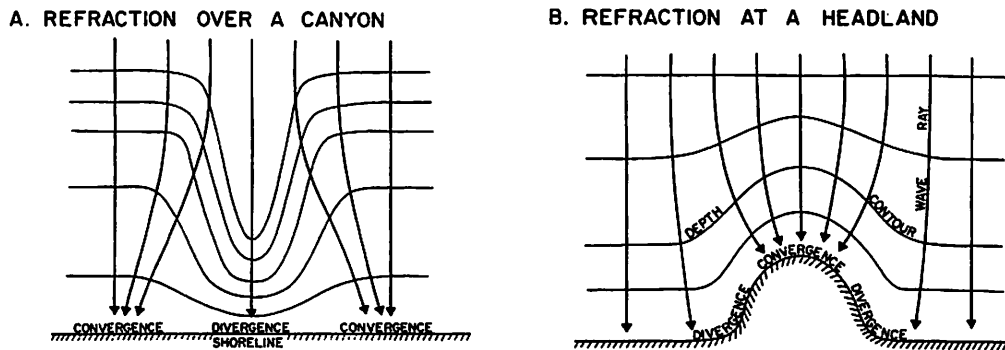


Figure 3



Figure 4

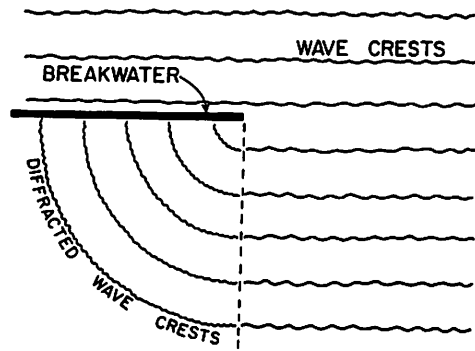
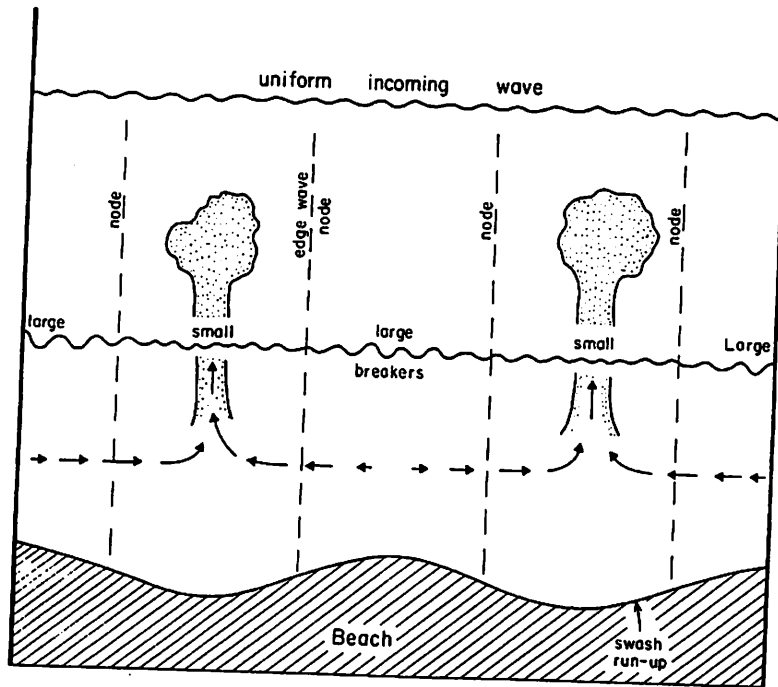


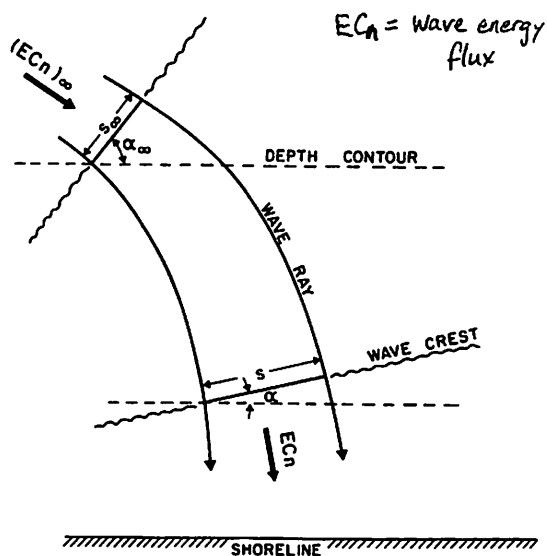
Figure 5



*Oblique Wave Approach*

When waves approach the shore at an angle to the shoreline, they usually refract due to the decrease in depth within the nearshore zone [Fig. 6]. Refraction steers the wave such that it becomes more parallel to the shore. If the offshore slope is very high, some refraction will occur but not enough to make the wave completely parallel to the shore before breaking. The waves will then arrive at the shore at an angle,  $\alpha$ , and deflect the nearshore water circulation. This deflection is due to the longshore component of the radiation stress of the obliquely breaking waves. The result of this system is a longshore current which has the same direction of motion along the whole beach.

Figure 6



### Observing the Longshore Current

Put on your bathing suit, slap on some sunblock, and let's head into the surf!

We'll be placing some neutrally-buoyant containers, marked by a dive flag, out in the surf. With any luck, this monstrosity will be picked up by the longshore current and visually mark the current flow for us.

Spread out in the surf zone in a line parallel to the shore, with spacing TBD but probably 10's of meters between people. When the flag passes your position, raise your arm high up in the air. We'll leave a couple of people onshore with stopwatches to record the times as the flag passes each position. Then, from the data, we'll attempt to perform the complicated calculation of current velocity:  $v_c = d/t$ . Use the space below to write down numbers and calculate velocity.

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## Rip currents

### **Introduction**

Rip currents are strong offshore currents through the surf zone that develop periodically to return water that has been pushed shoreward by wave action. They usually develop adjacent a beach environment though they have been observed off rocky shorelines. Rips form jets that flow seaward. Current velocity in a rip typically reach the order of 1 m/s.

The term 'rip current' was first coined by Shepherd 1936. Of course lifesavers (Australian and Californian) were already quite familiar with the phenomena - rip currents being a major factor in many beach drownings (remember to swim parallel to the shore \*not\* against the current if you are ever in a rip).

A look through literature shows that there are many numerical models of rip current systems. Most of these models emulate a rip current created by one of a number of possible mechanisms.

Rip current deposits can be identified in the geological record. While they do not form extensive deposits, they do form characteristic sets of cross beds amongst other near shore deposits.

Figure 1: Well developed rips currents regularly spaced along a beach, Sand City, California, (Thornton)



### **General Characteristics**

Rip currents are usually transient in nature, making them hard to measure in the field (Smith 1995). Currents tend to pulse at intervals. Each pulse carries 'agitated' near-shore water back out to sea. This water carries suspended sediment and is well aerated, so the current appears as a cloudy plume flowing off shore through the surf zone when viewed from above (or in acoustic or electrical soundings).

Not all rip currents pulsate. Brander 2001 report in situ current measurements in rip and feeder channels. The results show no surges, instead the flow is relatively steady. The only significant variation in currents occurred over the order of hours (induced by tides) and days (evolution of the beach bathymetry).

In most places along a beach, wave forcing across a bar creates onshore flow (as observed when an object thrown into the sea floats back to the shore). This wave forced current inshore is balanced by rip currents that return water through the gaps in the offshore bar. These gaps in the bar can be periodic along the length of the beach. On the shoreward side of the bar, feeder currents flow parallel to the beach. These feeder currents then turn and flow through the break in the bar as the rip current.

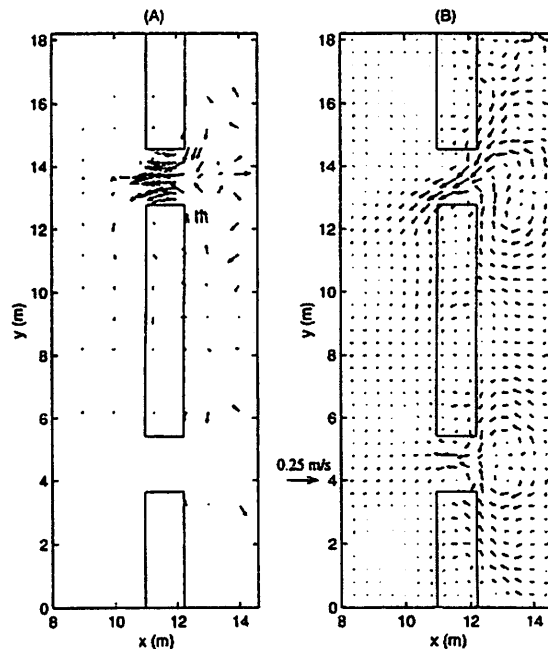
## Modeling/ Rip Formation Mechanisms

Here are some of the proposed rip formation mechanisms, taken from the introduction of Murray 2001.

- Rips develop in a region where the waves arriving at the shore are weakened, e.g. by refraction (Shepard 1950). Murray however argues that while the wave energy may vary spatially, patterns do not last for a long time and unlikely to shape rip development.
- An instability develops in an established long-shore current which then turns offshore to become a rip current (Allen 1996). Murray argues that these currents would not necessarily organize themselves into narrow jets.
- The bathymetry of the near-shore, in particular the presence of a bar with breaks or gaps along its length, can develop rip currents as waves carry water over the bar into the near-shore area (e.g. Haas 1998). The waves that break over the bar effectively raise the average water level. Waves are not breaking in the gaps in the bar so these regions will have a lower water level. Pressure gradients then drive feeder currents towards the gap through which the rip current flows seaward (as shown in Figure 2).
- Murray 2001 presents a model that allows interactions between the rip current and the incoming waves to dissipate the wave energy. Energy from the wave goes into the eddies.. This allows the rip current to be self-organizing and not require a predetermined bathymetry to establish a rip.

Almost certainly all the above mechanisms will apply in different situations. The wave/current interaction model by Murray provides a way that rip could initiate themselves on a planar beach. Once a rip has started and begun to affect the bathymetry, there will be a feedback that can continue to drive and concentrate the rip current through the channel.

Figure 2: Time averaged velocity vectors from observations and modeling (Haas 1998). The general features of a rip are shown here: the narrow rip current, the feeder currents and the head. Diagrams also show flow away from the point on the shore adjacent to gap in the bar. Haas explained that the waves that pass through the gap in the bar have more energy when they arrive at the shore. This forms a highpoint in the water surface and the water flows away from this region.



## Geological Records

A rip currents do not cover large areas so it would be expected that they could be hard to find in the geological record. Unless Huygens lands in a rip current on Titan, perhaps the only chance we have of finding any evidence of rips anywhere other than Earth is to find deposits on Mars. A good question to ask is how do you identify a rip current deposit?

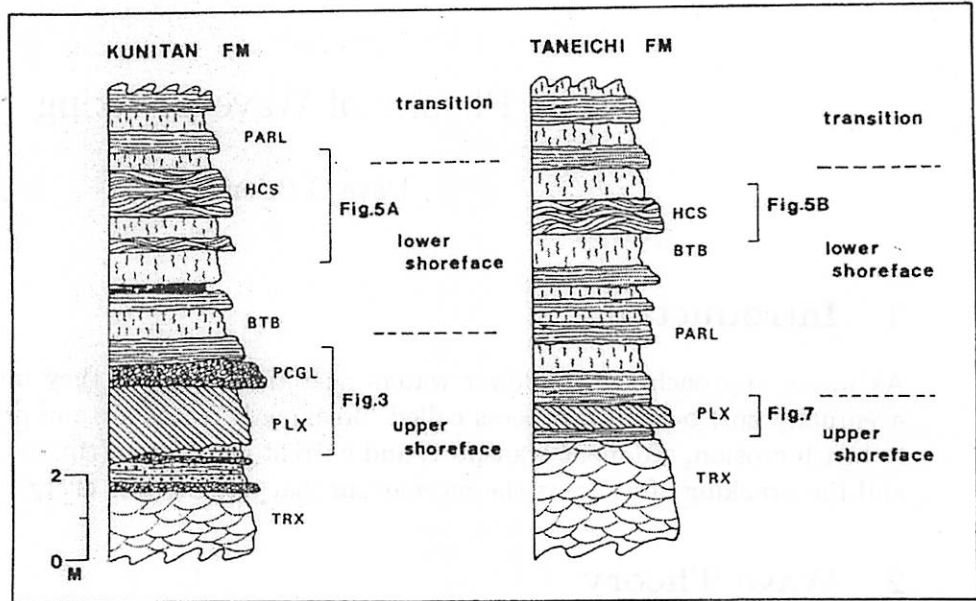
Some characteristics of rip current deposits (Yagishita 1994) are...

- sandy deposit free of mud,
- cross bedding facing one direction (no herringbones - dual directions - that you would see in tidal currents),
- direction of flow is perpendicular to paleoshore line and long shore deposits,
- under- and overlain by other shallow water deposits,
- single, planar, flat base to the deposit (not sculpted as by wave action),
- size is 10's of metres long and ~ metres thick.

In order for a deposit to be preserved a single deep channel has to be formed that can then be buried by other deposits

Figure 3: Geological sections of rock formations that include rip current deposits. Both sections show a deepening environment.

Key: PLX – planar cross-bedding; HCS hummocky cross-stratification; BTB bioturbated sandstone bed; TRX trough cross-bedding; PARL parallel lamination; PCGL pebbly conglomerate (Yagishita 1994).



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- Thornton, E., Rip currents: a field experiment and a numerical model, <http://www.oc.nps.navy.mil/~thornton/ripex/ripex.htm>
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# The Physics of Wave Breaking

Dave O'Brien

## 1 Introduction

As waves approach the shallower waters near the shoreline, they increase in height and eventually curl over in a process called 'breaking.' Waves are the primary energy source in beach erosion, sediment transport, and current generation (rip and longshore currents), and the breaking of waves is the mechanism that releases this energy.

## 2 Wave Theory

Water waves are gravity waves (i.e. waves along an interface where the restoring force is gravity). In the near-shore region, the wavelength  $\lambda$  of the wave is smaller than the depth  $h$  of the water, and the wave is referred to as a 'shallow water wave.' The propagation speed  $c$  of such a wave is wavelength-independent, and is given by

$$c = \sqrt{gh} \quad (1)$$

Note that while the wave travels significant distances along the surface of the water, the water itself undergoes an oscillatory motion but does not experience a net translation (at least in the idealized case where the amplitude of the wave is small and there is no friction between the water and the seafloor). The motion of water in a wave can be described by the displacement field

$$\xi = \eta_m \frac{\cosh(\kappa y)}{\sinh(\kappa h)} \cos(\kappa x - \omega t) \quad (2)$$

$$\eta = \eta_m \frac{\sinh(\kappa y)}{\sinh(\kappa h)} \sin(\kappa x - \omega t) \quad (3)$$

where  $\eta_m$  is the vertical amplitude of the wave at the surface,  $\omega$  is its angular frequency, and  $\kappa$  is the wavenumber  $2\pi/\lambda$ . These equations describe ellipses given by

$$\frac{\xi^2}{a^2} + \frac{\eta^2}{b^2} = 1 \quad (4)$$

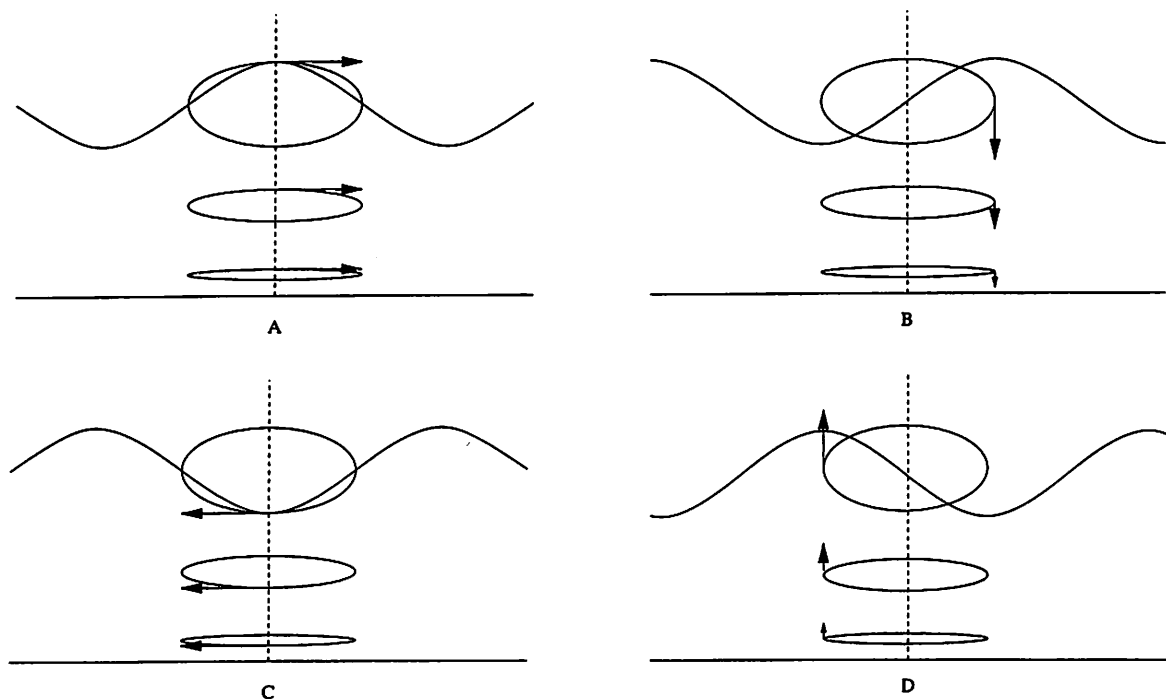
where the major and minor semi-axes  $a$  and  $b$ , simplified for the shallow water case (where the depth is much less than the wavelength), are

$$a = \eta_m \frac{\cosh(\kappa y)}{\sinh(\kappa h)} \approx \frac{\eta_m}{\kappa h} \quad (5)$$

$$b = \eta_m \frac{\sinh(\kappa y)}{\sinh(\kappa h)} \approx \eta_m \frac{y}{h} \quad (6)$$

26

The following figure shows the motion described by the above equations. The figure shows four stages of a wave's passing, seen from a fixed position (the dashed line). The ellipses show the motion of a given 'particle' of water with time. Since the paths are closed, there is no net translation of water. The arrows show the direction and relative magnitude of the water particle's velocity. Equations 5 and 6 show that the horizontal displacement is independent of depth, such that the 'displacement ellipses' all have the same horizontal dimension. The vertical displacement decreases with depth, such that the 'displacement ellipses' become flatter with depth (vertical velocity goes to zero at the seafloor). Note that at the wave's peak (A), the water is moving forward, while at the trough (C), it is moving backwards.



### 3 The Breaking Process

As a wave approaches the shoreline and the water depth  $h$  decreases, the wave speed given by Equation 1 decreases. The period of the arriving waves must remain the same, or else the law of conservation of waves would be violated (O'Brien, *pers. comm.*) Therefore, the wavelength of the waves approaching the shoreline must decrease, and the wavefronts become 'thinner.' The average energy density of a wave (energy per horizontal surface area of the wave) is given by

$$\bar{E} = \frac{1}{2} \rho g \eta_m^2 \quad (7)$$

The total energy of a wave is therefore proportional to  $\bar{E}\lambda$ . Since this energy must be conserved, the amplitude of the wave  $\eta_m$  must increase as the wave approaches the shore and  $\lambda$  decreases.

Breaking of waves occurs because the assumption that there is no friction between the water and the seafloor is not valid in any real situation. While there is little resistance to

the forward motion of water at the crest of a wave, the seafloor provides significant resistance to the backward movement of water in the trough of a wave. Hence, as a wave approaches the shore, the top of the wave moves faster than the rest of the wave, and the wave 'curls' over, causing it to break. This results in a net transport of water towards the shoreline, and drives a number of important beach processes.

In summary, as a wave approaches the shoreline it becomes thinner and taller. Friction between the seafloor and the water slows the return of water to the sea, while the crests of waves charge forwards. This causes waves to break and crash near the shore.

#### 4 Relation to Other Beach Processes

The process of wave breaking deposits a large amount of energy near the shore, and this energy drives erosion, sediment transport, and the formation of rip and longshore currents, among other beach processes. So as not to scoop other fieldtrippers, I'll just glaze over some of these processes here and let them elaborate in their talks.

Waves deposit a large amount of energy at shorelines, and can result in significant erosion and sediment production. Waves generally approach the shore at a non-right angle and lead to a 'swash' of water onto the shore. The backwash of water from the shore, however, generally occurs at an angle perpendicular to the shore. The difference between the 'swash' and 'backwash' angles leads to a net transport of sediment along the shoreline called 'beach drift.' The process of wave breaking causes a net transport of water towards the shoreline, and this water must be returned to the sea. This results in the formation of rip currents and longshore currents.

#### 5 References:

- [1] Elmore, W. C. and Heald, M. A. *Physics of Waves*. Dover, New York (1969).
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# Grain movement on the beach

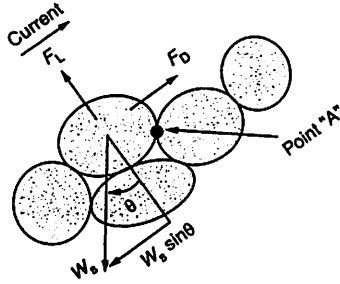
Joe Spitale

29

1. Offshore

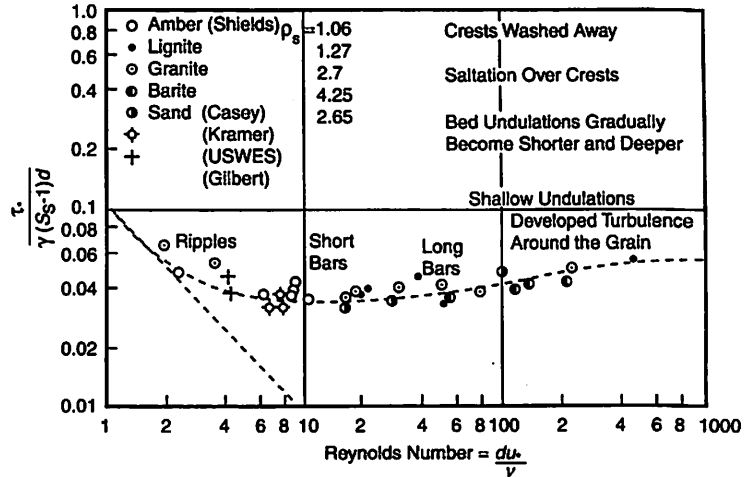
Steady flow

- grains generally begin to roll before being lifted



==> shields parameter  
bed shear stress / submerged weight

- shields curve



shields param > 0.03 --> grains might move

shields param > 0.1 --> movement certain

For moving grains, bedforms depend on Re:

- Re < 10 --> ripples
- 10 < Re < 100 --> dunes
- Re > 100 --> sheet flow

- Breaking waves mobilize additional material --> unsteady flow

- Ripples

Saltation of larger grains

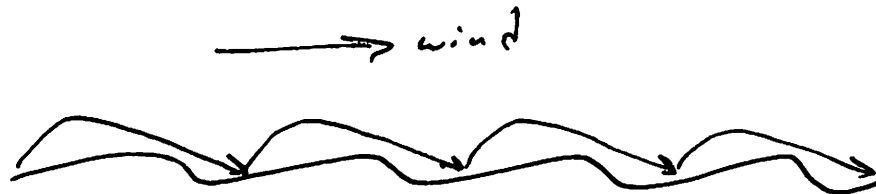
Vortex form after crest of ripple, excavating sediment

- Dunes

## 2. Onshore

Ripples

Formed by saltation



Desert dunes

Grains saltate up windward face, shear off crest by enhanced wind, fall onto slip face.



Dunes grow by eating smaller dunes, which overtake them

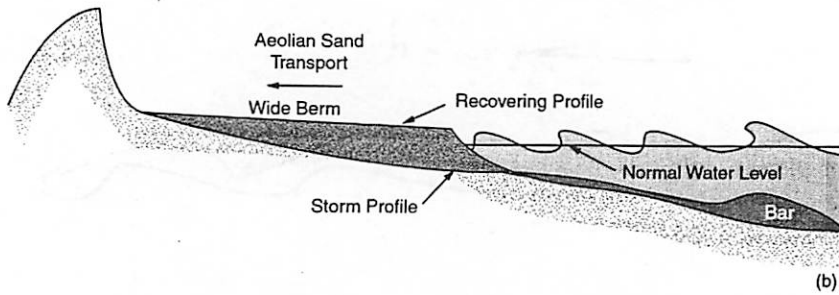
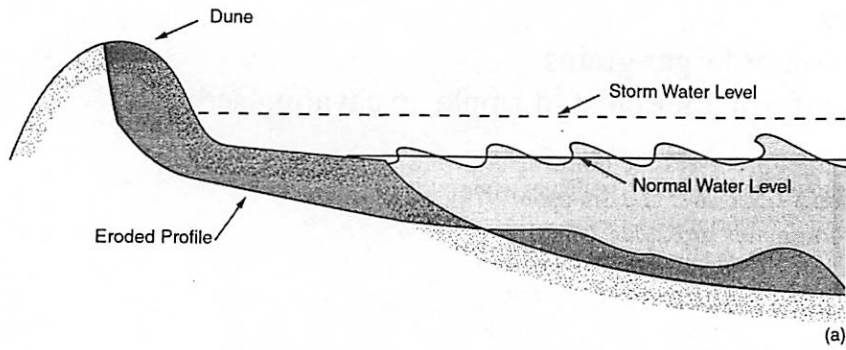
Beach dunes

Lifecycle:

- 1) Storms erode dunes, moving sand to offshore bar
- 2) Sand transported back to beach during normal wave conditions
- 3) Landward beach sand dryer, more easily lifted
- 4) Winds tend to be landward, blowing sand across the dune to be trapped by dune vegetation.

==> dune recovery facilitated by:

- strong onshore winds
- wide beach
- dune vegetation



#### References

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2. Dean, R. G and Dalrymple, R. A. *Coastal processes with engineering applications* Cambridge University Press, 2002

# Beach Placer Deposits (Heavy-Mineral Laminae)

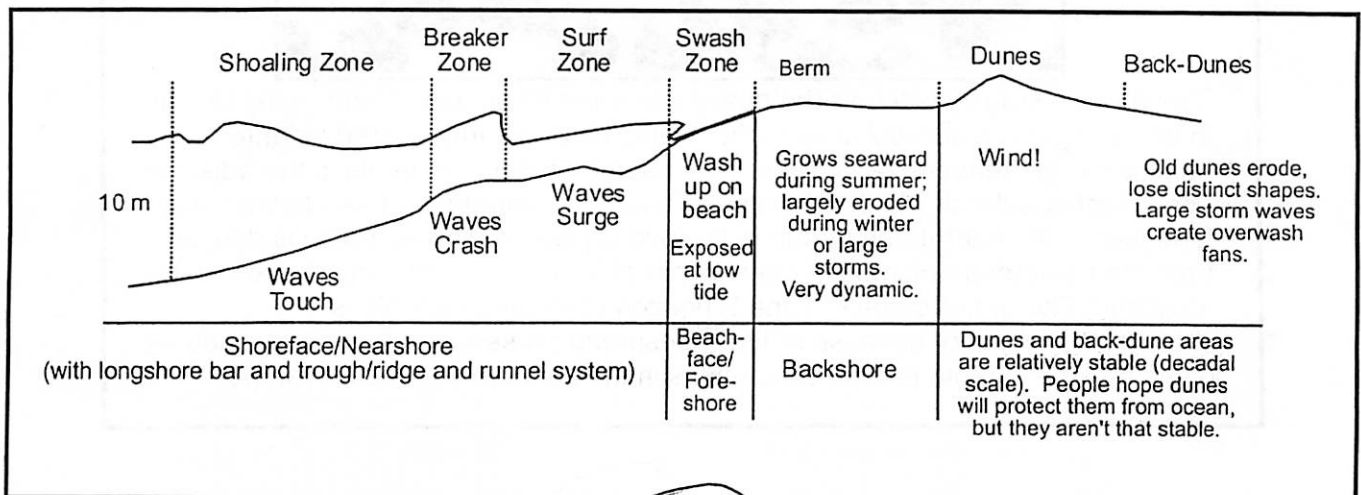
James Richardson  
Spring 2002 PTYS Field Trip



(left) A mining class examines heavy-mineral concentrations (the dark streaks in the sand) on a beach near Geewal, South Africa. (right) Heavy-mineral lamination near the base of marine terraces on Fisherman's Beach, Australia. Note that in each case, the laminae occur in the high-tide portions of the beach "swash zone."

## Introduction

A common, but not often recognized feature of beaches along the California coast are heavy mineral laminae: dark streaks in the sand near the high-tide section of beach "swash zones" (the portion of the beach where the water is washing up and down a smooth, gently sloping surface). These concentrations of heavy mineral grains are the result of a complex sedimentation process, in which the swash zone acts as a sorting "mill," working on the raw material, or "pulp," supplied to it by the erosion of marine rock outcrops in the vicinity of the beach.

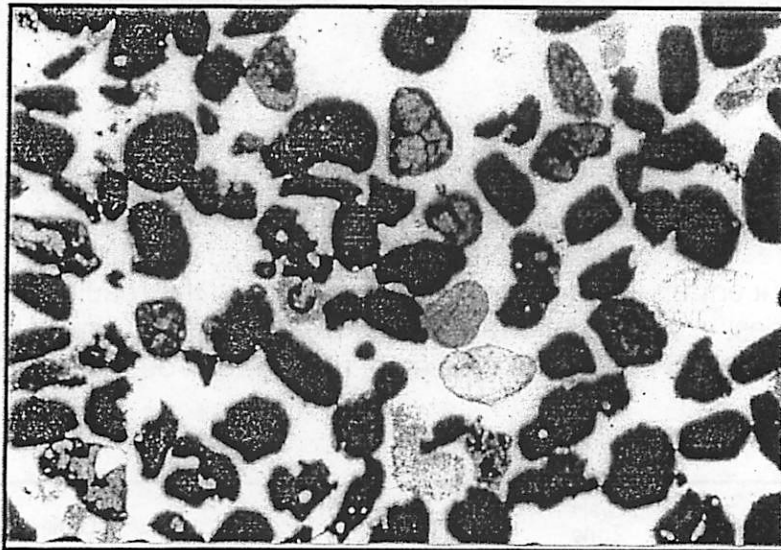


## Deposit Types and Sources

Heavy mineral lamination grains occur in a variety of types, but must share one common feature: a noticeable (but *not* extreme) difference in grain size and density when compared with the more common beach "sand" (whether it be quartz, shell, or otherwise) found in the local area. The mineral grains must necessarily be small enough to be easily transported by the action of waves and local ocean currents (along with the sand grains), while hearty enough to withstand further breakdown by chemical and mechanical weathering over short time scales. The source region for a heavy-mineral lamination will generally be some nearby marine or beach-front rock outcrop, away from which a steady supply of small grains is carried and delivered to the sandy beach swash zone – supplying pulp for the sorting mill.

Common heavy-minerals found in beach placer deposits along the California coast include:

- Magnetite ( $\text{FeFe}_2\text{O}_4$ , ferrous and ferric iron oxide) – Iron ore
- Ilmenite ( $\text{FeTiO}_3$ , iron titanate) – Titanium ore
- Chromite ( $\text{FeCr}_2\text{O}_4$ , ferrous chromic oxide) – Chromium ore
- Garnet ( $[\text{Ca,Fe,Mg}]_3[\text{Al,Fe,Cr}]_2\text{Si}_3\text{O}_{12}$ ) – common tetrahedral silicates
- Quartz ( $\text{SiO}_2$ ) – framework silicate (common sand)
- Zircon ( $\text{ZrSiO}_4$ , zirconium silicate)
- Gold (Au) -- *very little*



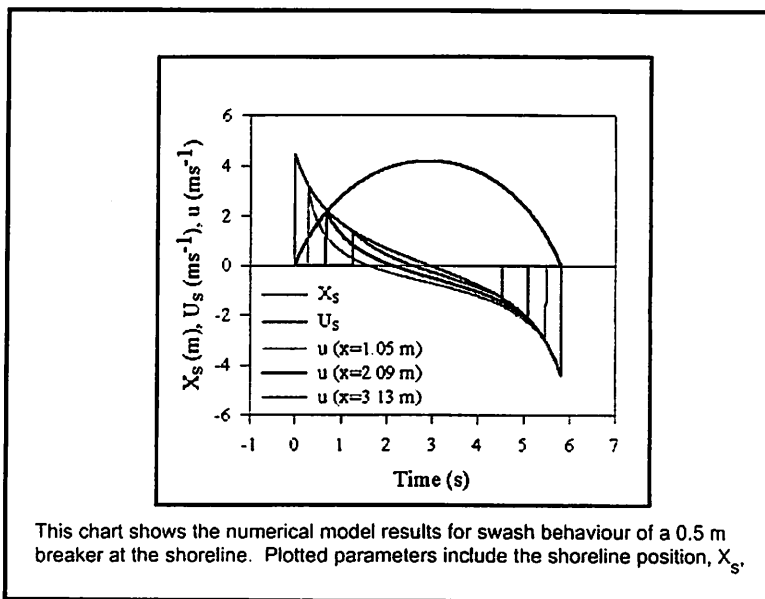
This photomicrograph shows the heavy mineral fraction from Fishermans Beach in thin section in plane-polarised light. Hematite and partly altered siderite dominates the heavy-mineral suite. The source of these minerals is the adjacent Long Reef headland, which consists of Triassic claystones and sandstones that form part of the Narrabeen Group in the Sydney Basin. The hematite is derived from the numerous outcrops of lateritic, podzolic paleosols that occur around the headland. The upper surface of the B horizon of these paleosols is characteristically red, because of the widespread presence of ferric iron oxide as hematite. The siderite is from concretions in the sandstones and claystones.

## The Sorting Process (Four Interacting Mechanisms)

Once the mixture of common "sand" and heavy-mineral grains is supplied to the beach swash zone, suspended in an incoming wave, an interacting mixture of four basic sorting mechanisms must be present in order for the heavy-mineral grains to be preferentially laid down on the surface of the zone while the common sand is preferentially carried away again. These four mechanism are:

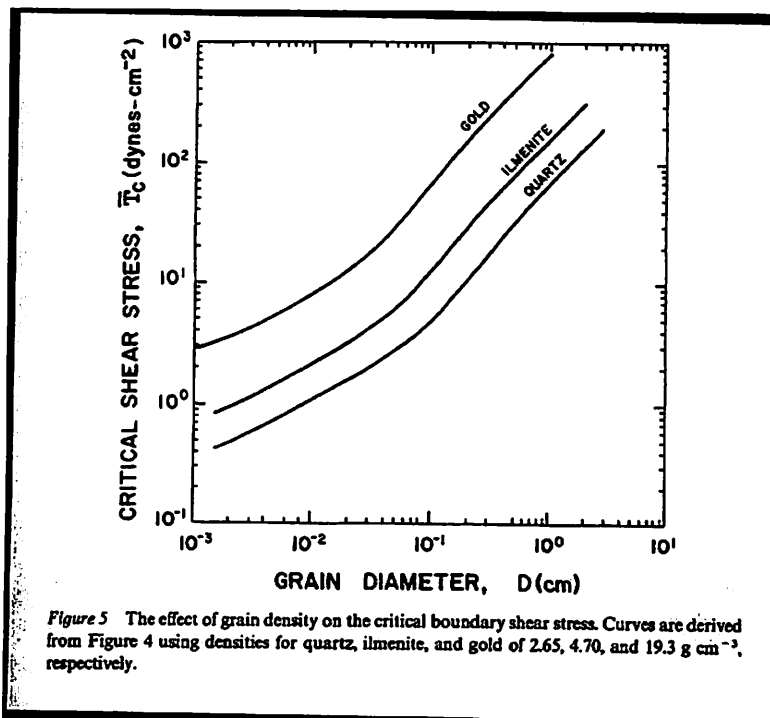
### (1) Settling of Grains

Grains of differing sizes, densities, and shapes fall through a fluid at differing velocities, thereby sorting themselves as the fluid moves over a bed – the smaller, less dense grains being carried along further than their larger, heavier counterparts. As an additional complication, the figure at right shows wave velocity as a function of time for one wave advance-retreat cycle, at various locations in the swash zone (positions 0 to 4 m on the semi-circle). The lower portions of the swash zone (0-1 m) experiences the largest range of velocities, generally high enough *NOT* to allow the settling of grains and sorting. The upper portions of the swash zone (3-4 m) experiences the lowest range of velocities, and is the primary region where grain settling can occur. In other words, the grains spend less time over the high velocity areas as they do over the low velocity areas, and thus all settling (regardless of size) tends to occur in the upper portions of the swash zone.

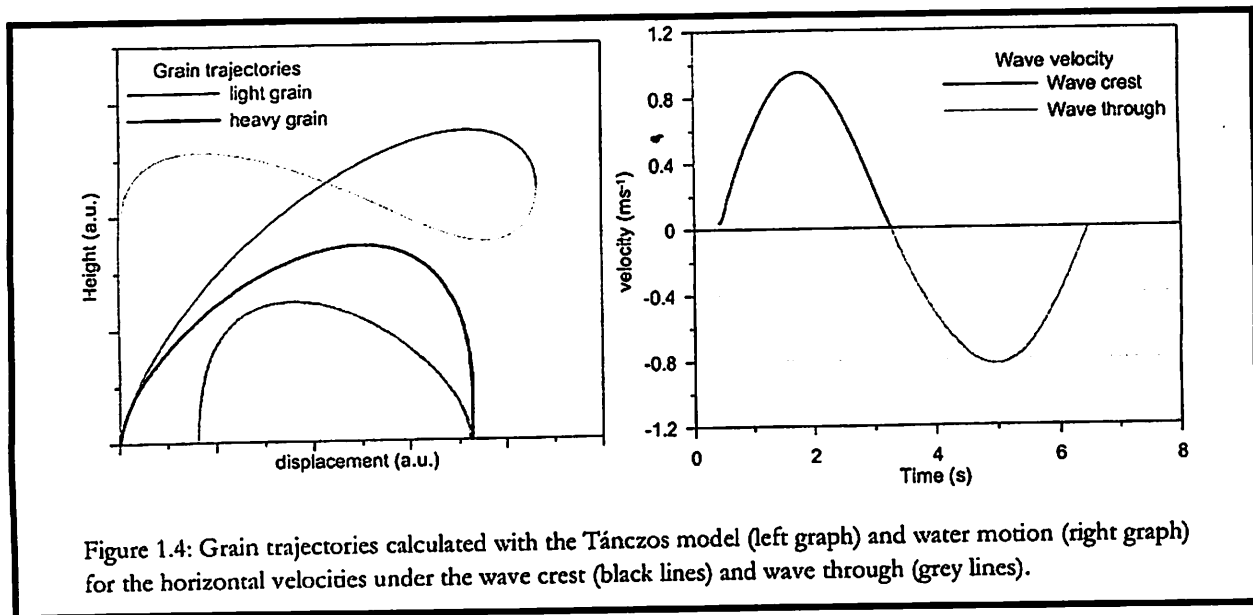


### (2) Entrainment of Grains ("Plucking")

Entrainment is the dislocation (or lifting) of grains from a granular bed and their initial movement, due to a superimposed fluid flow over the bed. The turbulent fluid flow over the bed produces a shearing stress upon those bed surface grains which are protruding into the flow. The probability of a grain being plucked from the bed becomes a function of the fluid's density and mean velocity, and the grain's density, size, shape, and the frictional forces holding the grain in place. Placed in terms of a shearing stress per unit area on the exposed grains, a Critical Shearing Stress (plotted at right) can be



experimentally quantified for grains of similar size (diameter) and density. As shown in this plot, even for similar grain sizes, sorting can occur under a particular flow condition (a particular applied shear stress) when the applied stress is above the critical shear stress for the less dense grains, but below the critical shear stress for the more dense grains. This causes the lighter grains to be preferentially plucked from the bed and removed by the fluid flow, leaving their heavier counterparts behind (and concentrating them there).



### (3) Differential Transport of Grains

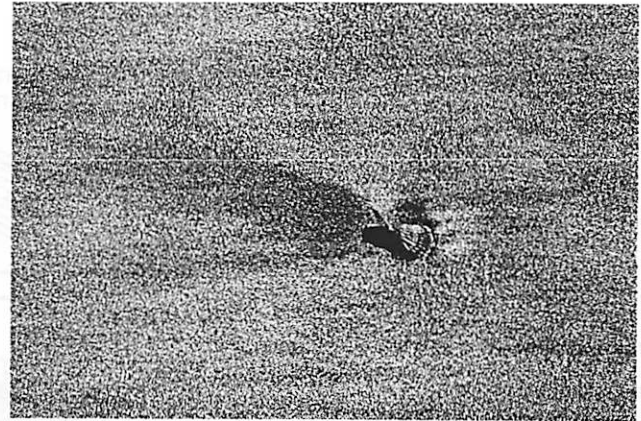
This sorting mode is, in essence, a combination of the first two methods, in that under similar fluid flow and grains size conditions, the lighter grains will tend to travel farther horizontally while settling and also have a higher chance of being re-entrained into the fluid once they have settled in a particular spot. The result is that the lighter grains will have a higher transport rate in a particular flow as compared to the heavier grains. This is illustrated in the above diagram for a sinusoidally oscillating fluid flow (wave motion over a smooth, flat surface). In the diagram at left, both grains are plucked from bed in the lower-left corner of the diagram at the same time as the flow is travelling to the right. The lighter grain is carried higher above the bottom, does not re-settle again, and is carried off the diagram to the left. The heavier grain travels closer to the bottom, re-settles during the lull in fluid flow, is re-entrained during the subsequent back-flow, but re-settles again as the flow again slows down. In a swash zone, this cycle is enhanced, such that those heavier grains which are transported to the upper portions of the swash zone have less chance of being carried away again – and will thus concentrate to form a laminate deposit.

### (4) Shearing of Grains

This is perhaps the oddest of the four sorting methods. Theoretical and experimental data has shown that when a bed of cohesionless particles is subjected to a fluid flow shearing force, grain interactions will produce a reaction force perpendicular to the plane of shearing such that the granular mass will expand toward its free surface – called a “dispersive pressure.” These dispersive pressures will be greatest on the larger and denser grains, and thus create a



differential sorting effect. Over time, the larger and denser grains will migrate toward the free surface to be concentrated there under a form of vertical fractionation. In addition to the above three methods, this method is thought to also be important in beach swash zones.



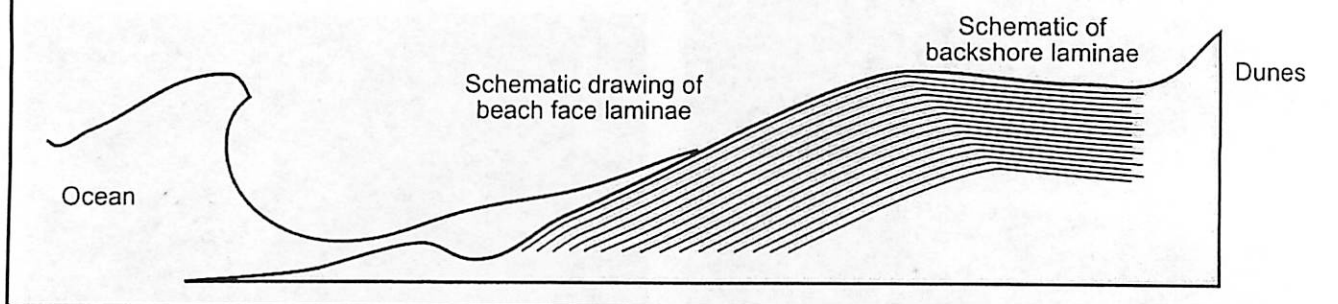
### **Fragility of Swash Zone Sorting**

As implied in the previous descriptions, the swash zone sorting process which concentrates the more dense heavy mineral grains on the surface as compared to the less dense sand grains is very sensitive to conditions – especially the differences in density and mean diameters between the grain types, and fluid flow conditions in different locations within the zone itself. The above photographs illustrate this sensitivity, showing two different mussels exposed on a beach in different locations within the same swash zone (Geewal Beach in South Africa). The mussel on the left is located in the upper, heavy mineral concentration portion of the swash zone, but the turbulent wake left behind the mussel when the waves retreat prevent proper sorting and produces a sorting “shadow “ – devoid of heavy mineral concentration. The mussel on the right is located in the lower, high-velocity portion of the swash zone, where sorting does not normally occur, but in this case the protruding mussel produces a low velocity zone in its wake, and allows sorting to occur in a zone where it normally does not. These photographs illustrate the fragility of swash zone sorting processes, even when a heavy mineral grain supply exists in the area of the beach.

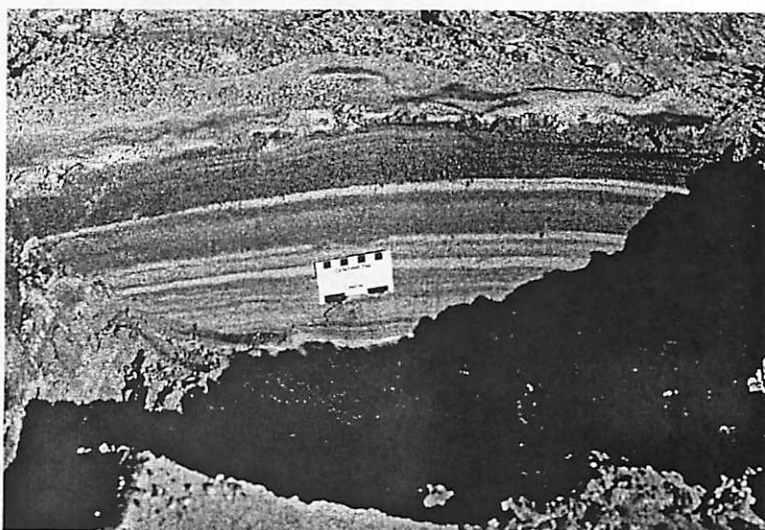
### **Long Term Heavy Mineral Laminae Deposits**

Heavy mineral deposits on beaches tend to be seasonal entities, enjoying a period of deposition and beach berm growth during the summer months of relatively gentle surf (see the below figure), but often being destroyed again during the winter months of relatively strong surf and storm conditions. Even during the summer months of berm growth, swash zone heavy mineral deposition tends to wax and wane in strength, depending upon the availability of source material (influenced by off-shore current conditions) and the effects of gentle storms abnormal tides. Thus, as the berm grows over the summer, these episodic periods of heavy mineral deposition tends to produce a varied and layered berm structure.

The net result of this is that the beach face is characterized by distinctive parallel laminae that dip gently (2-3°) seaward and are relatively continuous. Laminae may be defined by heavy mineral concentrations, shell debris, etc. These laminae are diagnostic of the swash zone!



The photograph at right shows a trench dug through heavy mineral deposits on a beach in South Africa. The darkest bands represent periods of Ilmenite lamination, the next lightest bands represent periods of garnet lamination, and the lightest bands represent periods of no heavy mineral concentration.



More permanent retention of beach swash zone heavy mineral laminations requires some means of berm preservation, such as an overall period of net sand deposition on the beach in question, regional uplift, or sea-level dropping. Although ancient beach swash zone placer deposits are generally rather small (and of low economic value) when compared to other forms of placer deposits, many such deposits are still mined around the world for their mineral ore contents. Perhaps the most significant beach placer deposit in the United States was in the Nome district of Alaska, in which gold was discovered on the beaches in 1899, helping to spark the Alaskan gold rush (in the addition to the finds at Dawson).

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- Koomans, R.L. (2000). Sand in Motion, Effect of Density and Grain Size. Ph.D. Dissertation, Groningen University.
- Hughes, M.G., Keene, J.B., & Joseph, R., (2000). Hydraulic Sorting of Heavy Mineral Grains by Swash on Medium-Sand Beach, *Journal of Sedimentary Research*, 70(5), 1002-1012.
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- Field trip of "The Honours Class of 1998 - at Broken Hill Mine, Aggenelys, South Africa": <http://www.uct.ac.za/depts/geolsci/dlr/hon98ft.html>
- Nome, the End of the Iditarod Trail: <http://www.alaskan.com/docs/nome.html>

## Spits, Bars, Lagoons, and Estuaries

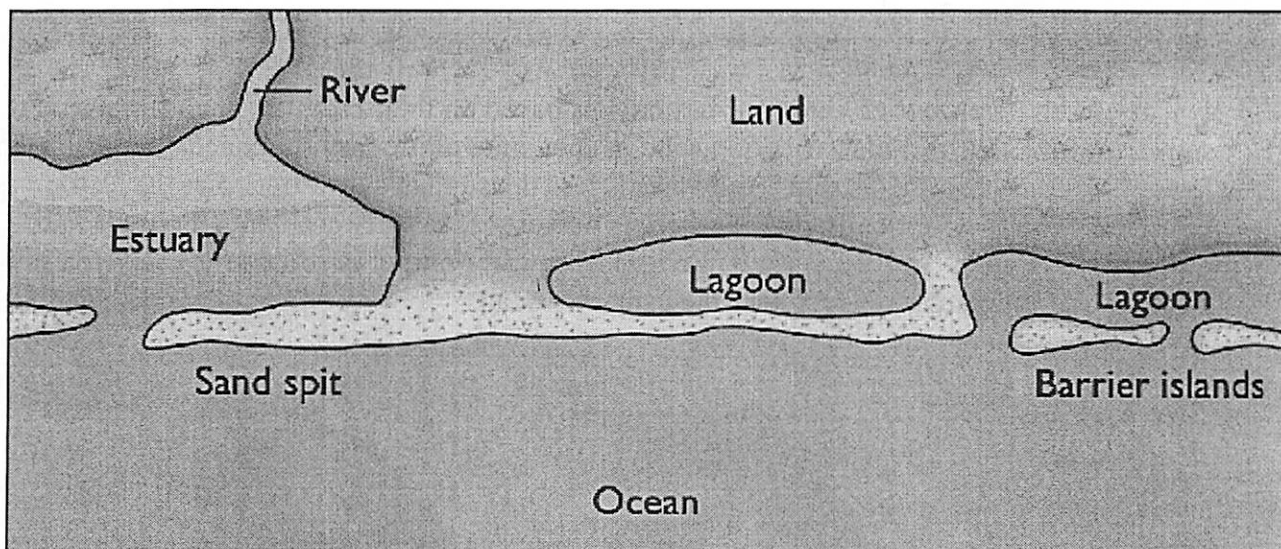
Jonathan Fortney

**Estuary:** A semi-enclosed coastal body of water in which ocean water is significantly diluted by fresh water from land runoff.

**Lagoon:** A shallow stretch of seawater partly or completely separated from the open ocean by an elongate narrow strip of land such as a reef or barrier island

**Spit:** A small point or narrow embankment of land commonly consisting of sand deposited by longshore currents and having one end attached to the mainland and the other terminating in open water.

**Bar:** A ridge of sediment buildup, usually parallel to the shore. There can sometimes be many parallel rows. (You know, a sand bar!)



Lagoons are coastal bodies of water that have only weak interaction with the ocean and have little or no freshwater source. Because lagoons are characteristically shallow, they are strongly influenced by precipitation and evaporation, which results in fluctuating water temperature and salinity. If evaporation dominates, the salinity can become very high. Circulation is mostly dominated by wind. Lagoons can also be fragile ecosystems susceptible to pollution effects from municipal, industrial and agricultural runoff.

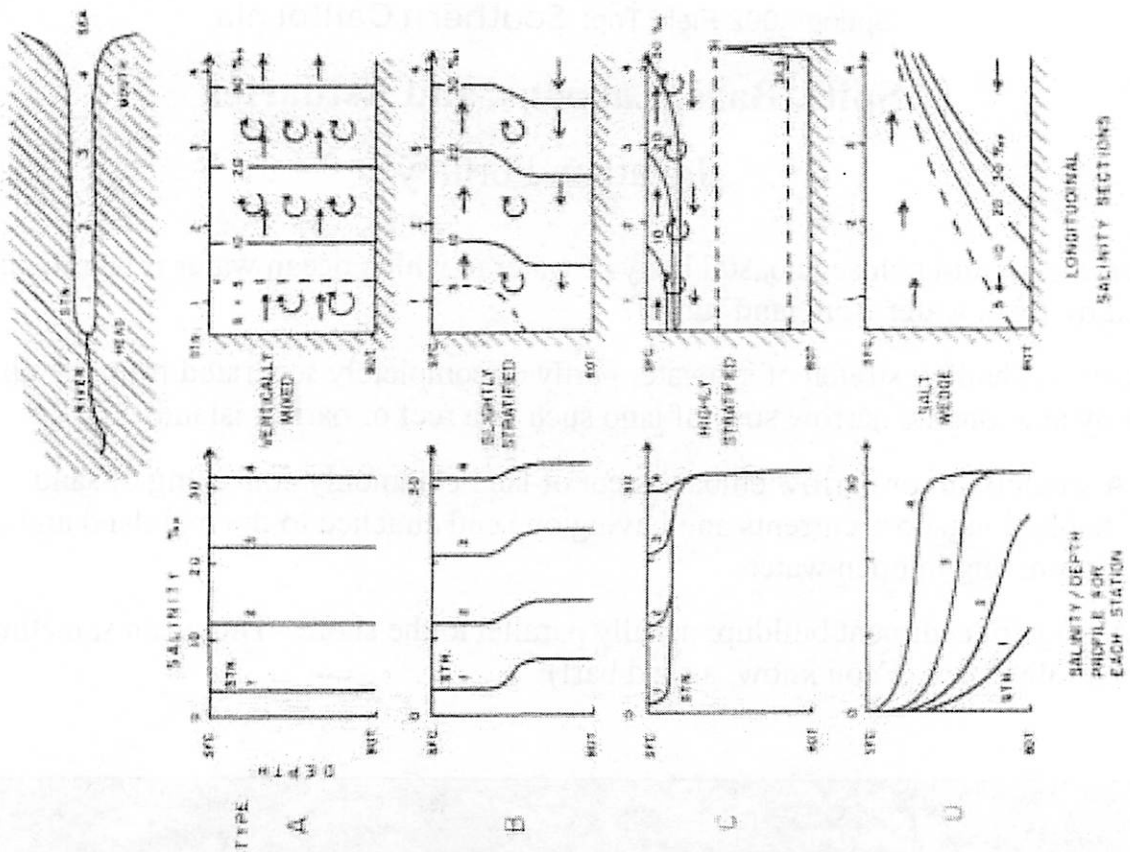
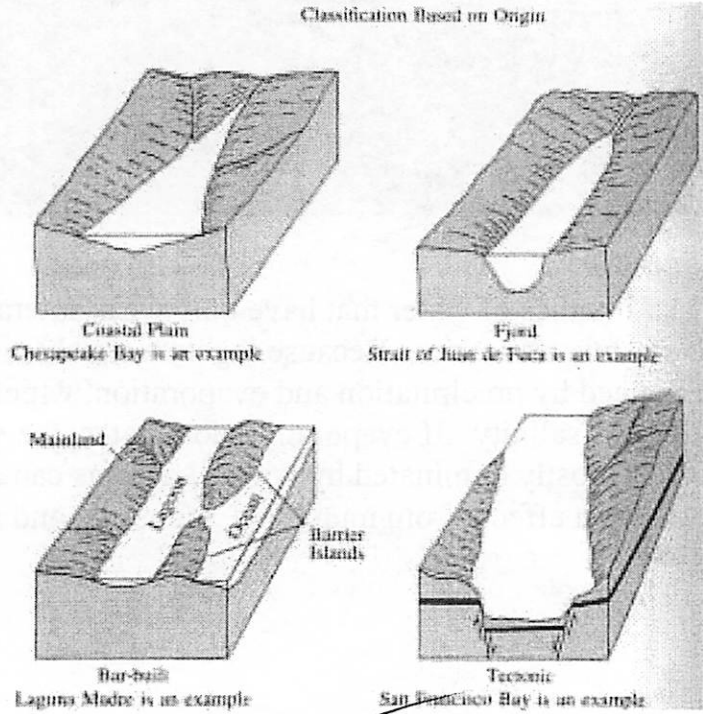
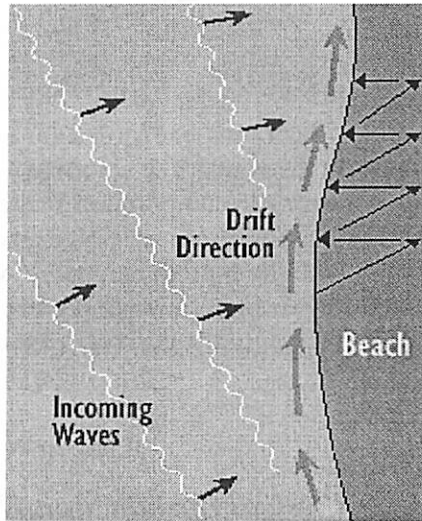


FIG. 8.2. Typical salinity/depth profiles (left) and longitudinal salinity sections (right) in estuaries (schematic).

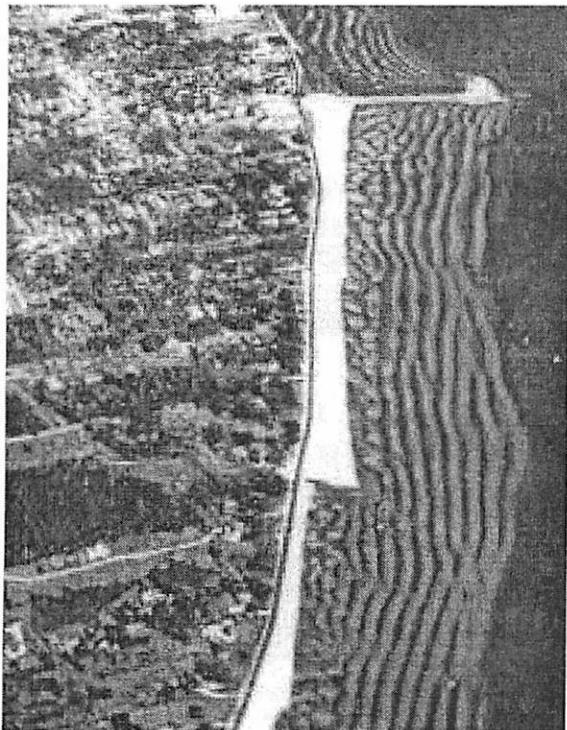
Estuaries can be classified into four basic types based on their circulation and salinity stratification. This is a classification scheme, not an evolutionary sequence. An important factor in estuary profiles is that freshwater is less dense than salt water. For the shallowest estuaries (type A—vertically mixed) there is no vertical salinity gradient. Types B and C are progressive deeper. In type D (Salt Wedge) freshwater output is so large it keeps the saltwater from having much of an effect near the estuary's head.



Spits form as sediment is swept down a shore



Bars

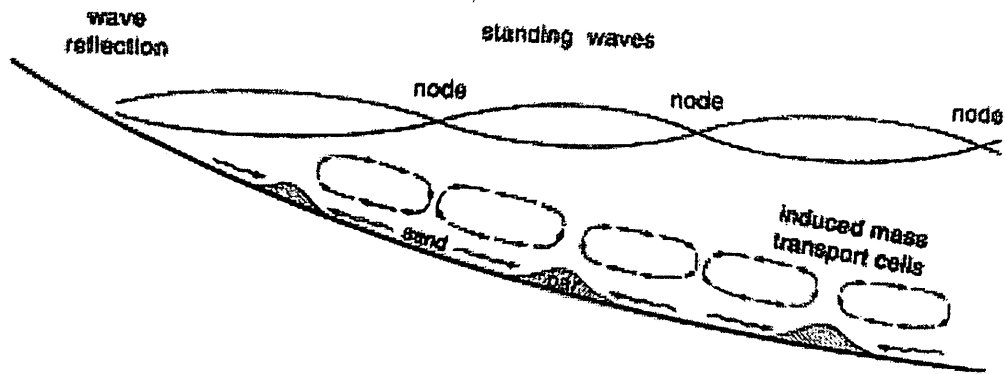


Bar formation is studied through wave-pool experiments (usually quite idealized) and modeling efforts.

Near shore, breaking waves create bars and troughs. A trough is excavated by turbulence from breaking waves, with the eroded sand moving offshore to form the bar.

Bars are often absent in steep beaches, but very shallow beaches can have several bars. This is perhaps due to multiple waves breaking, reforming, and breaking again closer to shore.

Not all bars are found in wave breaking areas! They can be farther out from shore. Below is a possible mode of bar formation for bars that do not form in the wave breaking area:



**Figure 7-27** Schematic diagram illustrating bar formation associated with standing waves due to wave reflection from the beach. The standing waves form an envelope of surface-amplitude variations, with zero amplitudes at the nodes and maximum amplitudes at the antinodes. The mass transport of water associated with the standing waves forms a series of cells, with the bottom current flowing from node to antinode positions. Sediment carried by the mass-transport currents can be expected to accumulate as bars at the antinodes where the currents converge.

#### Sources for more information:

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Komar, Paul D. *Beach Processes and Sedimentation*, Simon & Schuster, 1998.  
Thurman, Harold V. *Essentials of Oceanography*, Merrill Publishing Co., 1987.

#### Wetland areas in the San Diego area:

- Santa Margarita
- San Luis Rey
- Buena Vista Lagoon
- Agua Hedionda Lagoon
- Batiquitos Lagoon
- San Elijo Lagoon Ecological Reserve
- San Dieguito River Valley
- Los Peñasquitos Marsh Natural Preserve and Lagoon
- Mission Bay
- Famosa Slough
- South San Diego Bay National Wildlife Refuge
- San Diego National Wildlife Refuge
- Sweetwater Marsh National Wildlife Refuge and Chula Vista Nature Center
- Tijuana River National Estuarine Research Reserve
- Tijuana Slough National Wildlife Refuge

18)

## BEACH CUSPS

Jeff Johnson, PTYS 594A, Fall 1994



① Definition: Uniformly spaced, arcuate scallops in sediment that form at the shoreward edge of the episodically exposed portion of a beach known as the swash zone (Werner and Fink, 1993).

② Features:

➤ Form over period of hours to days on oceanic and lacustrine beaches in any type of beach sediment (boulders/cobbles to fine sands), and can be centimeter to meter-scale in size and spacing.

➤ Require near-normal incident waves of small amplitude, but with long crests lengths and "regular" (non-storm waves).

➤ Development favored on steep beach faces under surging, non-breaking wave conditions.

➤ Spacing of cusps depends on wave heights and swash distance (distance from wave break to highest point of swash).

➤ Offshore bays and deltas correspond to onshore ridges and cusps, respectively.

➤ Ridges (horns) of cusps show coarser sediments than embayments between ridges. Ridges are thus sites of accretion while bays are more erosional. Swash runoff is deflected by the ridges into the bays and flows seaward as runoff.

③ Models of formation mechanisms:

➔ Standing wave model (Komar, Guza): Combination of *edge waves* and normal incident incoming waves produces sinusoidal variations in swash front, leading to development of cusps and ridges onshore.

➤ Edge waves: Generally standing waves with crests normal to the shoreline and wavelengths parallel to the shoreline; they are opposite in orientation to the

incoming waves. Edge wave oscillations best observed as a "run-up" on the sloping beach face. Their height is greatest at the shore and decreases rapidly (within one wavelength) from the shore. Where edge waves are in phase with normal waves, the swash reaches highest on beach face; where out of phase, swash is lowest. Predicts that cusp spacing is equal to:

$$\lambda = (\sin\beta/\pi)gT^2$$

where T is the incidence wave period, g is gravitational acceleration (REM: for Mars, g is 3.7 m/s<sup>2</sup>), and  $\beta$  is the slope of the beach.

**Problem:** Edge waves are have not been observed unambiguously with beach cusp formation.

→ **Self-organization model (Werner):** Incipient topographic depressions in beach ("bottom morphology") are amplified by attracting and accelerating water flow, enhancing erosion.

**Problem:** Leads to same predictions for spacing and formation of cusps as edge wave model. But the conditions necessary for self-organized model (coupling between alongshore surface gradients and flow) are incompatible with the those required for the standing wave model (gradients in sea surface arising from wave patterns), at least according to Werner and Fink (1993).

→ **Experiments in N. Carolina (Werner):** Wakefield (1994) reported on experiments done in N. Carolina, where existing beach cusps were bulldozed and observations were made of the beach morphology and swash flow until the cusps returned, some 12 hours later, which was faster than expected. Also, the spacing of the cusps was irregular, varying up to 30%, which is not predicted by either model. Thus the current results are inconclusive; further experiments were reportedly performed a few weeks ago.

④ **References:**

*CRC Handbook of Coastal Processes and Erosion*, P.D. Komar, editor, CRC Press, Inc., Boca Raton, Florida, 1983.

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Ritter, D.F., *Process Geomorphology*, Wm. C. Brown Publishers, Dubuque, Iowa, 1986;

Wakefield, J., "Dozer duck dominates the nearshore scene this summer," *Eos Trans.*, Aug. 9, 1994, vol. 75, no. 32, 369-370

Werner, B.T. and Fink, T.M., *Science*, 260, 968-971, 1993

⑤ **Best quotes:**

Bob Guza (Scripps): "This beach isn't big enough for the both of us."

Bob Holman (OSU): "The work ahead, while necessary and potentially very rewarding, is enough to make any experimentalist shudder."



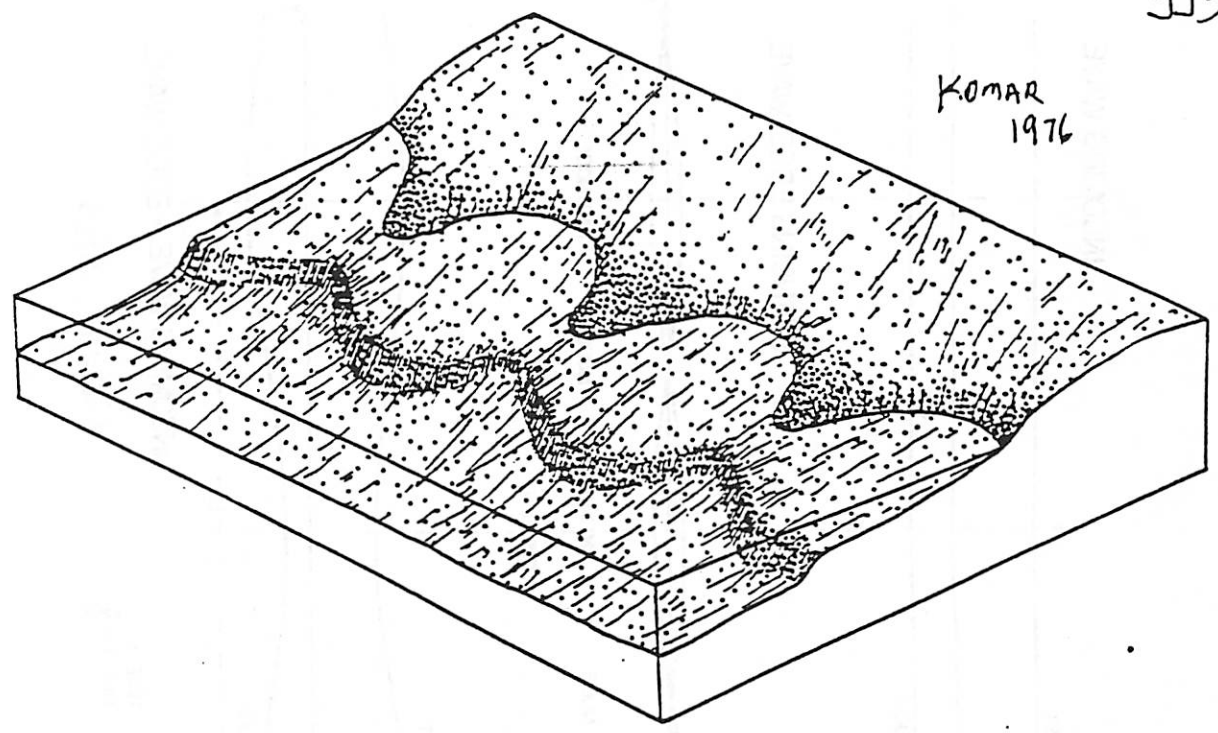
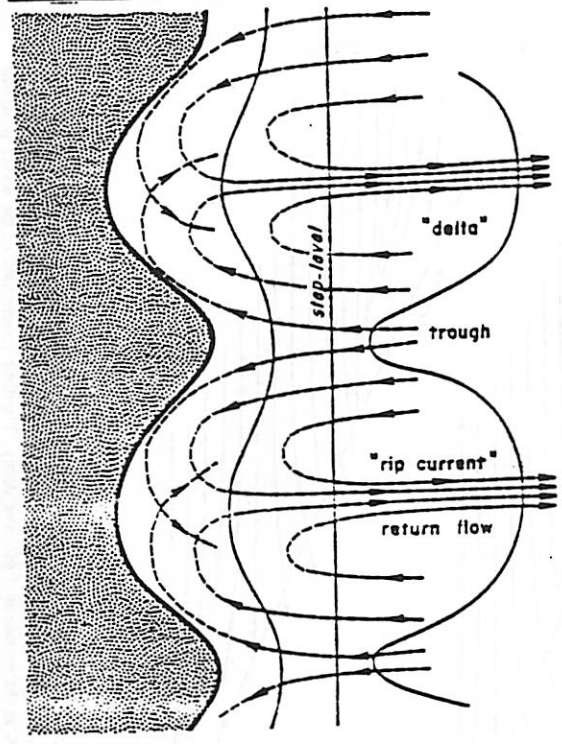


Figure 10-14 Beach cusps and associated underwater "deltas" offshore from the embayments. [After Timmermans (1935) and Kuenen (1948)]

PLAN VIEW



PROFILE

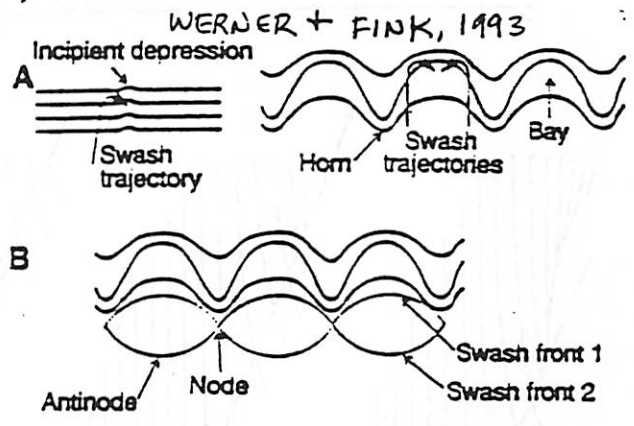
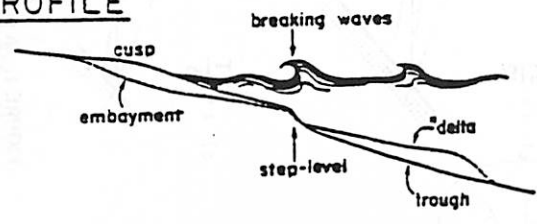


Fig. 1. Self-organization and standing wave models. Seaward is down. Bold lines are beach contours. (A) (Left) Deflection of swash flow by incipient topographic depression causing further erosion; (right) swash zone circulation in equilibrium with beach cusps (6). (B) Alignment of beach cusps and sinusoidal variation in the swash front caused by subharmonic edge waves shown at two consecutive swash cycles as broken and solid lines (3). Nodes in the swash excursion align with cusp horns.

Figure 10-17 Wave swash motions around cusps and within embayments. [After Bagnold (1940)] -KOMAR, 1976

Mode 0 Edge Wave

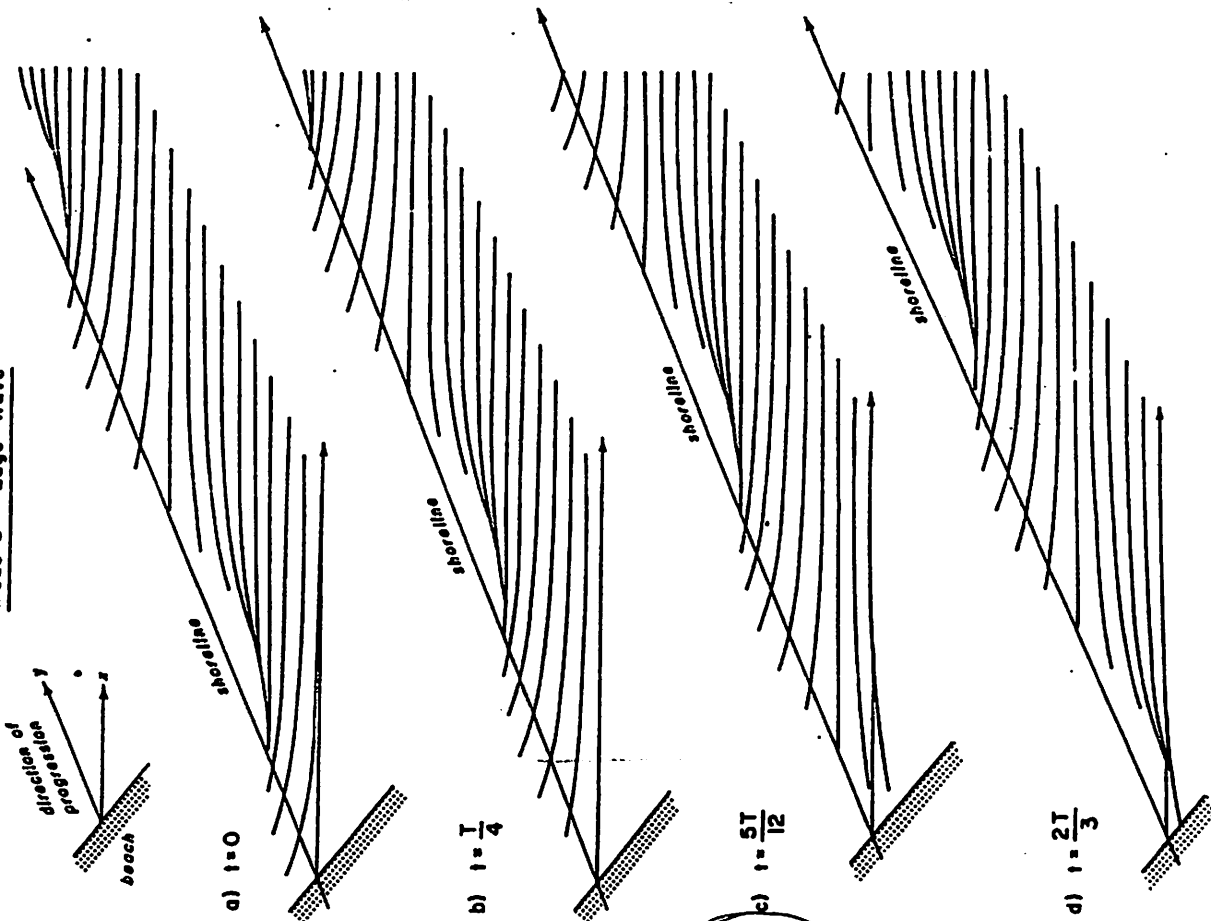
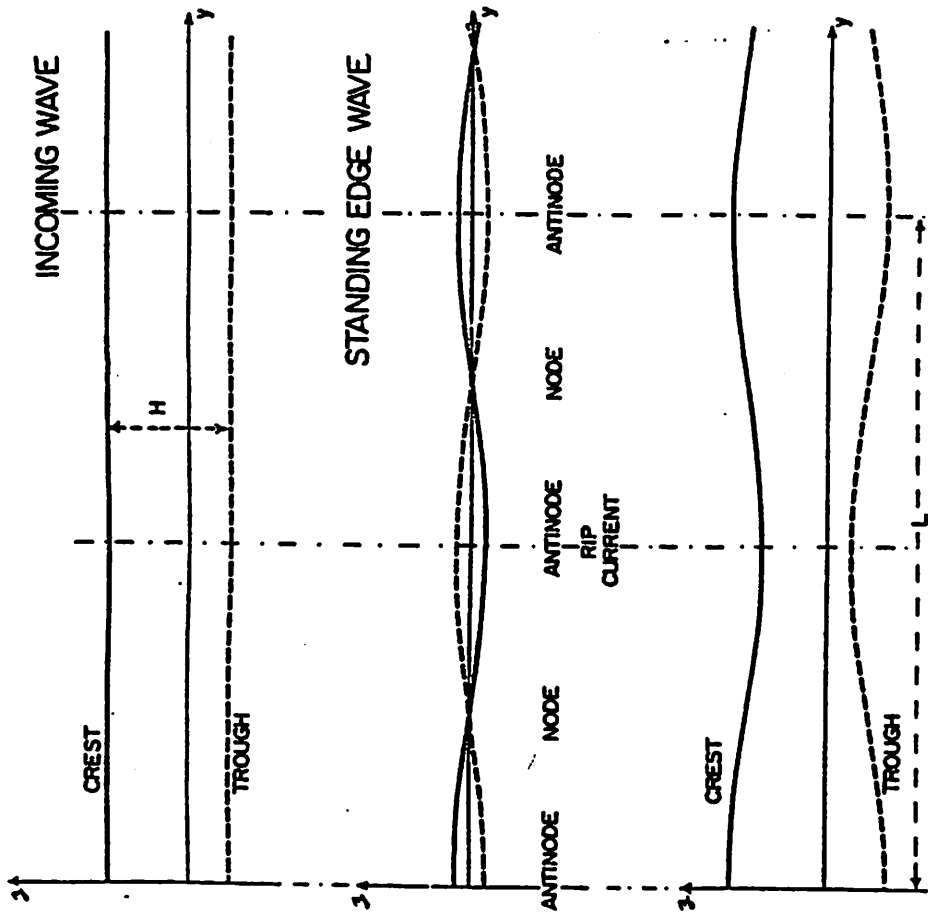


FIGURE 1. A progressive, mode 0, edge wave viewed obliquely from offshore. Seaward is to the right, the shoreline to the left. The shoreline slants away to the upper right. The sinusoidal longshore structure is clearly visible as well as the exponential offshore decay. The time progression of the waves is shown by the four figures, each later in time than the one above it.

JOHNSON, BEYER & CUSPS



INCOMING WAVE + EDGE WAVE

KOMAR, 1983

— TIME  $t$   
 - - - TIME  $t + \frac{T}{2}$

47 (21)

46

## Marine Terraces – Peter Lanagan

### 1) Definition of marine terraces

- a. An exterior platform on a building useful to amphibious troops as a sniper position
- b. A wave cut platform (i.e. a planar deposit of eroded material deposited aqueously that slopes gently seaward) that has been uplifted (Bates and Jackson, 1984)

### 2) Formation

- a. Erosion at bottom of cliff due to wave action
- b. Material eroded from cliff distributed into a gently sloping deposit in water
- c. Rate of erosion strongly dependent on competence of material in cliff, not energy of waves (Benumof et al., 2000)
- d. Marine regression occurs due to
  1. global senility
  2. sea level drop due to Ice Ages
  3. tectonic uplift
- e. Wave erosion continues downslope of old terrace

### 3) Degradation

- a. Diffusion due to subareal erosion (Anderson, 1999)
- b. Overland flow may incise stream channels into terrace and transport material seaward (Anderson, 1999)
- c. Generic mass wasting

### 4) Why do we care about marine terraces?

- a. Provides constraints on tectonic history of region local to coast
  1. constrain paleo-sea level due to ice ages using  $\delta^{18}\text{O}$  (Anderson et al., 1999)
  2. for instantaneous case: height of terrace = (uplift) – (change of sea level)
- b. Methods for dating marine terraces
  1. geologic formation uncensored personal ads (O'Brien, 2001)
  2. uranium series dating (Flint, 1971)
    - use daughters of uranium isotopes in shells for dating
    - fills in gap between radiocarbon and K-Ar dating
    - measures disequilibrium between parent and daughter isotopes
    - resulting age is the time since the system has been closed
    - complication: system doesn't necessarily remain closed due to circulation of marine waters or groundwater
    - OK for corals, less good for mollusks
  3. amino acid racemization (Cooper, 2000)

- L-amino acids (which make up proteins in living organisms) change to D-amino acids after the organism dies
- 4. electron spin resonance (Cooper, 2000)
  - determine number of electrons trapped in lattice due to exposure to high frequency EM radiation
  - useful for dating tooth enamel, shells, corals , calcite
- 5. fossils (although sometimes tough to find good index fossils)

## 5) Planetary connection

### a. Mars

1. Head et al. (1999) suggested marine terraces marked shoreline of northern ocean
2. Disputed by Withers and Neumann (2001) who suggest these features are more likely wrinkle ridges

### b. Titan

1. An ocean of hydrocarbons eroding icy hydrocarbons?
2. How strong are waves on Titan?

### c. Earth (duh!)

## 6) References

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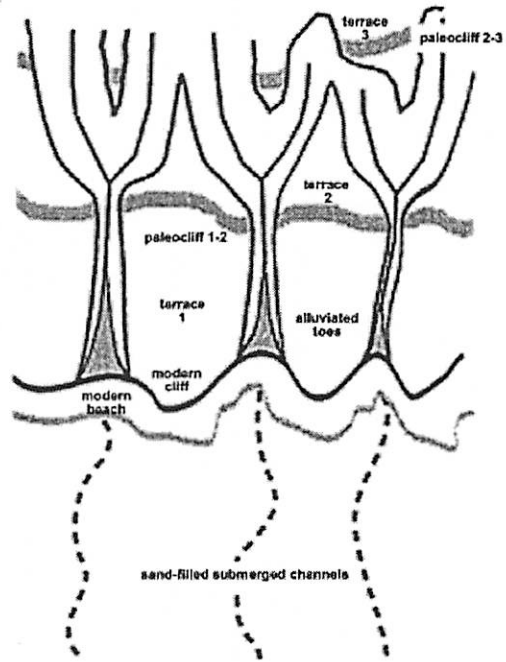
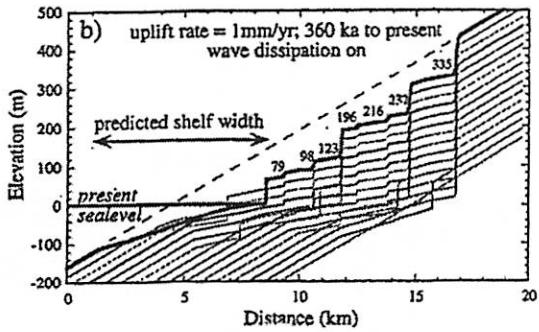
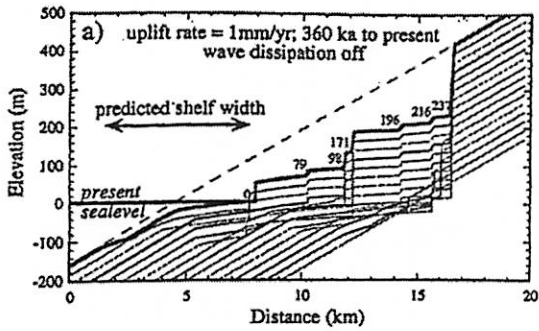
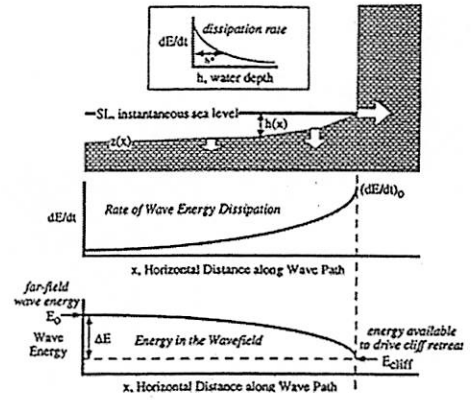
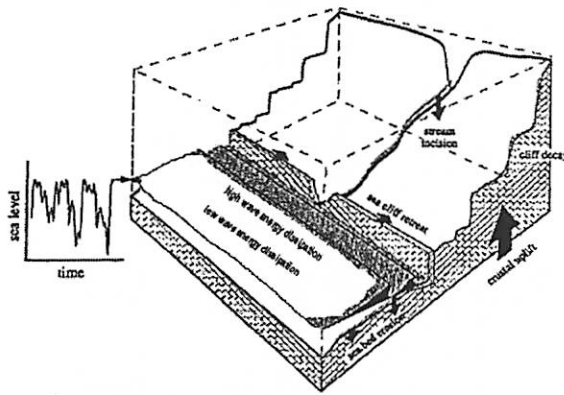
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O'Brien, D.P. Cleavage, Mohs Hardness Scale, and Bonding: A Guide for Rock Lovers. University of Arizona Press: Tucson. 2001.

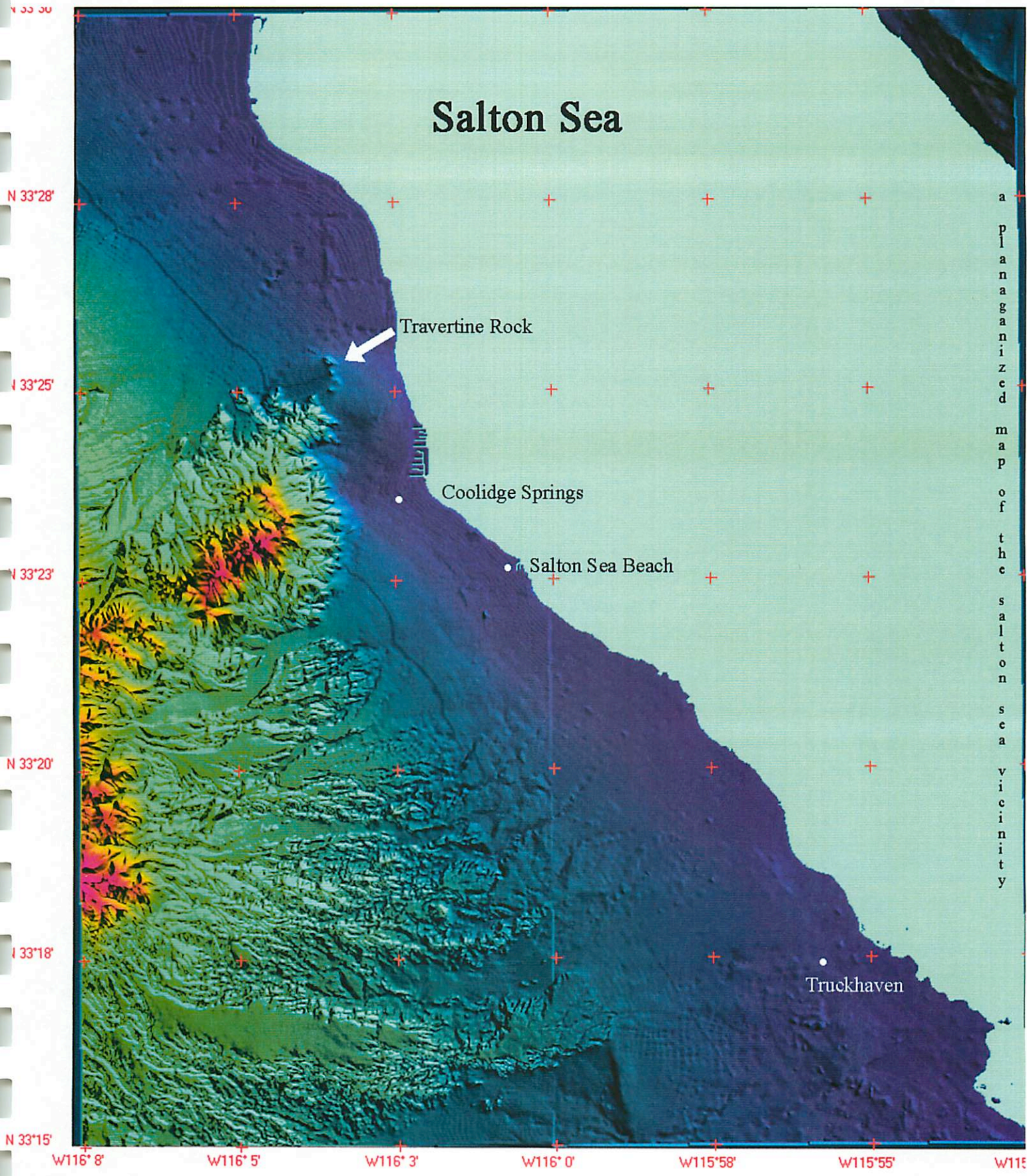
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All figures from Anderson (1999)

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# Salton Sea



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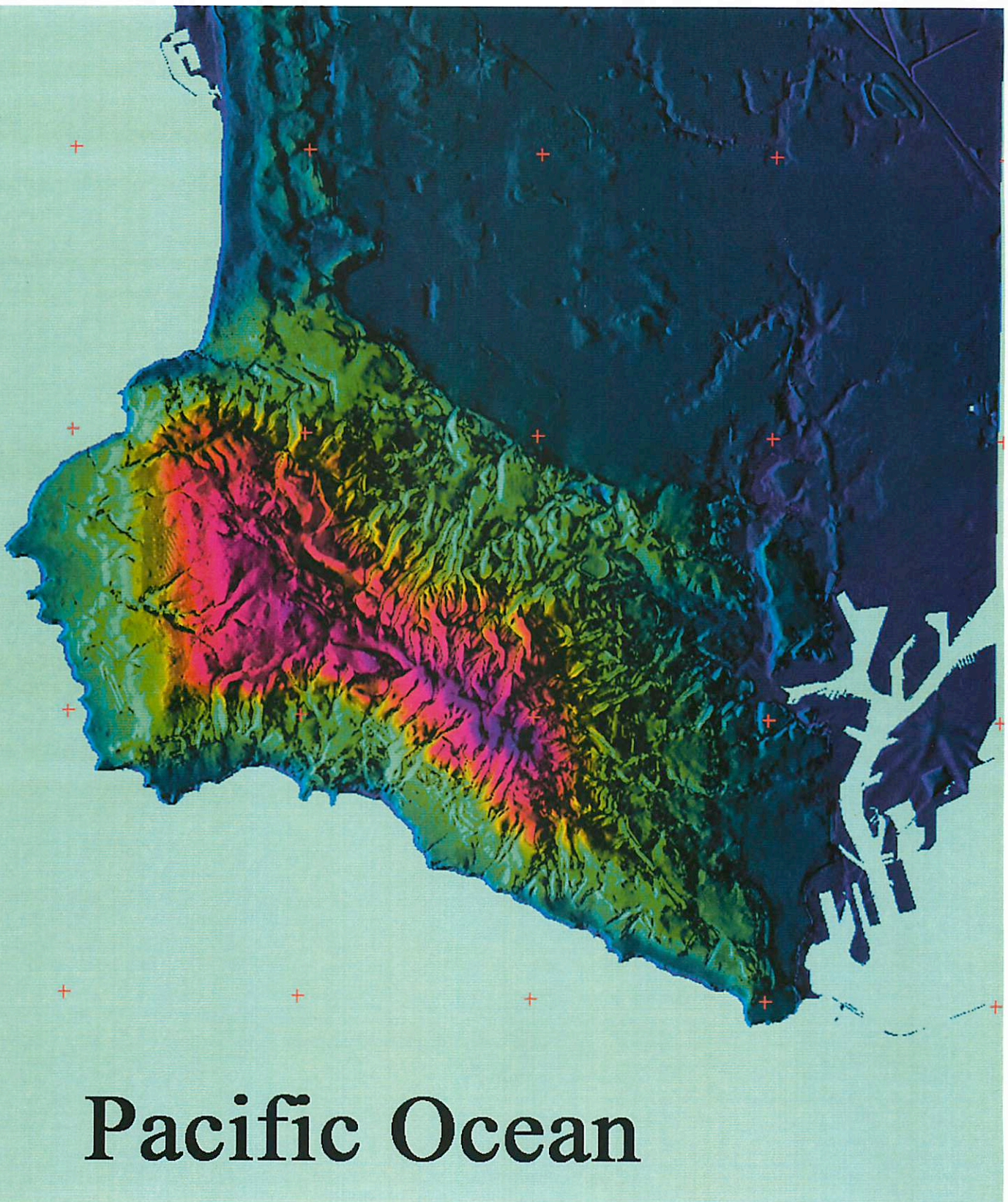
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a p l a n a g a n i z e d m a p o f t h e v i c i n i t y o f s a n d i e g o

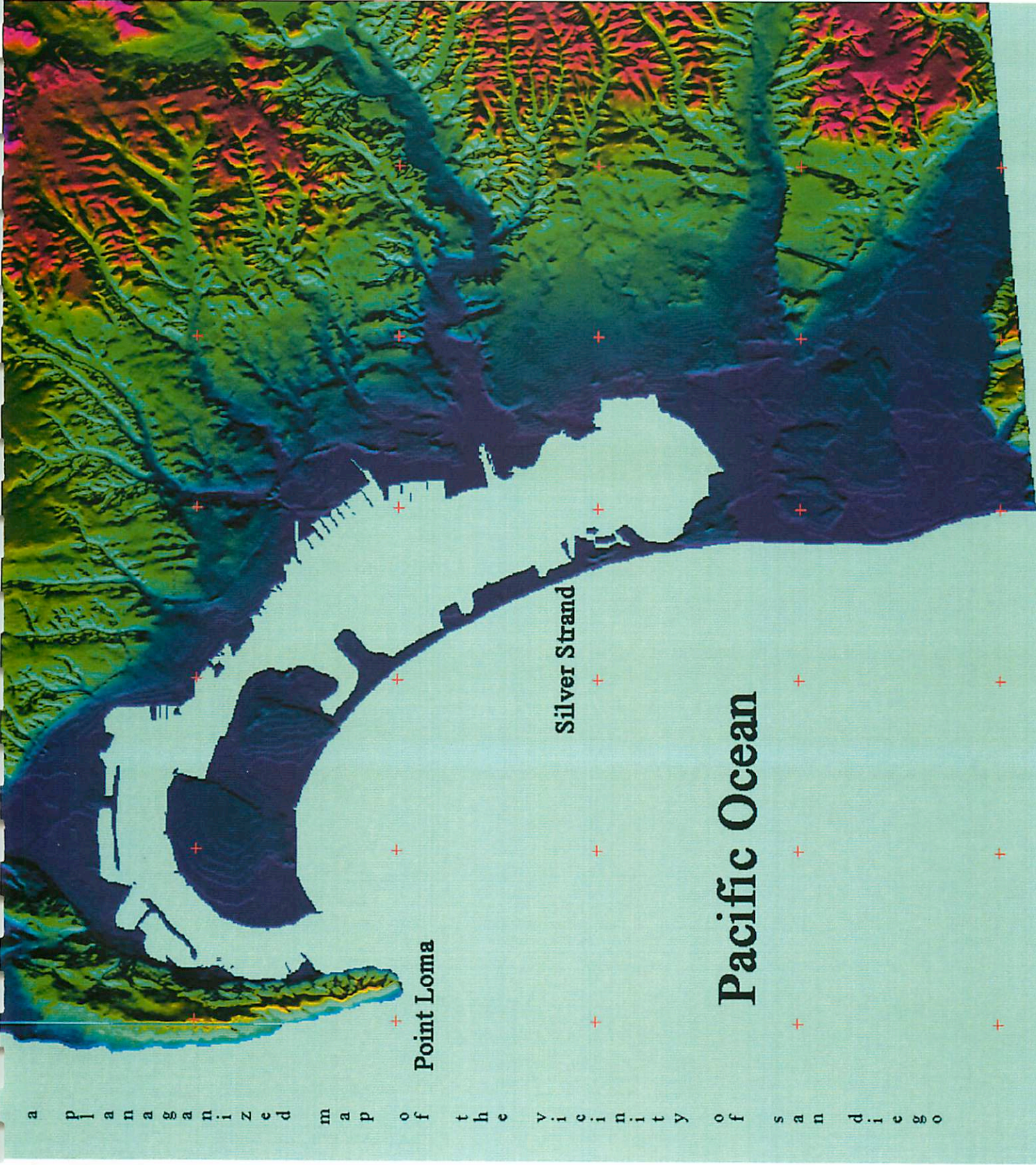
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## Portuguese Bend Landslide, Palos Verdes, California

LPL Fieldtrip – Spring, 2002

Presented by John Keller

On Friday, August 17, 1956, several cracks appeared in a storm culvert nearby a cut-and-fill construction effort to extend Crenshaw Boulevard on the Palos Verdes Peninsula. Things in the Portuguese Bend area have gone downhill ever since!

### Geologic Context:

The Palos Verdes Peninsula was uplifted out of the Pacific Ocean around 1.5 million years ago. The formation is an elevated block of marine sediments atop a metamorphic basement. Of most importance to the landslide is the Altamira Shale (also referred to as “P.V. stone”), a Miocene formation deposited 8-15 million years ago consisting primarily of cherty shale (composed primarily of diatomaceous sediments) and tuffaceous sediments associated with submarine volcanism. The Portuguese Bend Landslide is situated in an area with evidence of extensive ancient landslides dating back at least 37,000 years. Figures 1-3 below provide context for both the general stratigraphy of the Peninsula and the location of the Portuguese Bend Landslide (labeled PBL in Figure 3).

### Cross Section through the Palos Verdes Hills

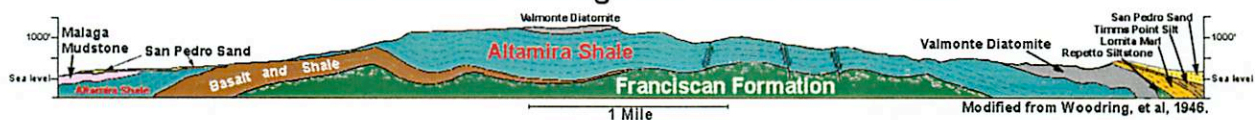


Figure 1 (Modified from Woodring, et al, 1946)



Figure 2

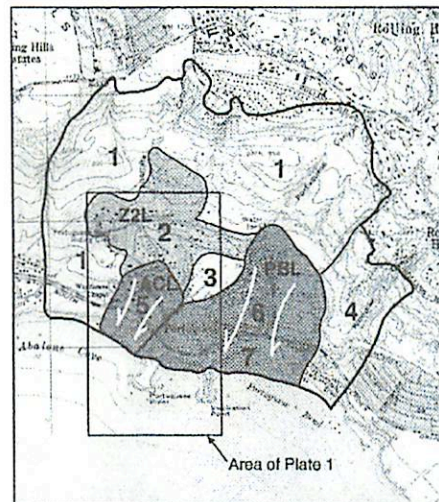


Figure 3

### Active Slide Details:

Several details regarding the recent active slide are provided below:

- The active slide has been an ongoing process since 1956 when evidence of recent mass wasting first began. The active slide involves an area of ~270 acres and is occurring in the southeastern section of the ancient slide area.
- The thickest section of the movement is around 250 feet thick in the southeastern section of the slide area and decreases in thickness towards the outer edges of the slide.
- The active slide area has moved over 600 feet since 1956. The rate of movement is not constant throughout the slide. In 1960, Merriam provided measurements of subsidence over a 600 day period of

12 feet at the head of the slide and 5 feet at a location central to the slide, with upward movement at the southeast corner of the slide of 4 feet over a 388 day period.

- Figure 4 shows an example of surface cracks found throughout the area, evidence of tensional forces and ground movement. Figure 5 shows stable land in the foreground and the landslide region in the background; the deformed curb had been straightened just two years prior.



Figure 4



Figure 5

#### **Mechanism of Recent Sliding:**

The Portuguese Bend Landslide is particularly noteworthy because land movement has continued continuously since 1956. Several factors influence the mechanics of this flow:

- Subsurface data in the area suggest that the slide area consists of a syncline descending southward towards the ocean. As mentioned above, the region consists of cherty shales along with silty shale, thin-bedded sandstone, thin limestone beds, and sandy tuff (Meriam). One layer in particular, labeled the “Portuguese tuff,” is almost 50 feet thick. This and other thinner layers have been altered into a bentonite-like clay that becomes very plastic when wet. It is believed that these layers provide the failure surface as blocks of material shear over these surfaces of low shearing strength. Data from drill holes have shown that the failure surface slopes 6-7 degrees towards the south and increases in slope towards the head of the landslide. Figures 6 & 7 provide a cartoon cross section of this model.

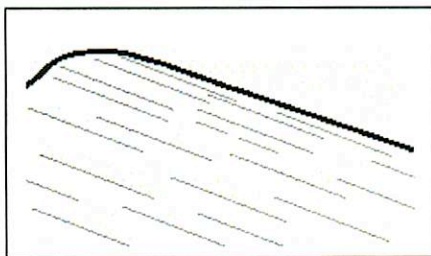


Figure 6

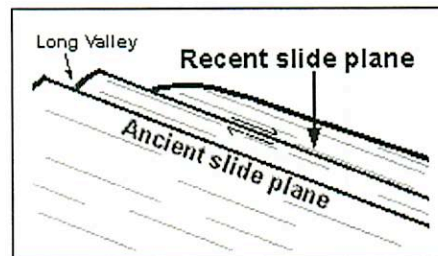


Figure 7

- Sediments are continually removed by beach processes at the toe of the landslide. This removes mass that may otherwise stabilize the mass flow of the slide.
- Degree of groundwater saturation plays an important role in the flow. Merriam describes that from 1956-1960 the rate of movement was shown to vary seasonally with rainfall, with the greatest movement occurring in the rainier winter and spring and movement slowing during the drier summer and fall seasons. There is a 1-2 month lagtime between the onset of winter rains and periods of greatest movement.

### **Possible Causes of Recent Sliding:**

The cause of the onset of failure in 1956 has been controversial. Just three possibilities discussed in the literature are presented below. One or a combination of these may have been responsible for starting the mass wasting process in this area:

- Construction of the Crenshaw Boulevard extension to connect Crest Road to Palos Verdes Drive South began in summer of 1956. This project involved the extensive cut-and-fill operations. Initial onset of the active landslide may have been influenced by this construction.
- Climate variations in rainfall may have been responsible. Although rainfall for the winter prior to failure was only slightly above average, it came at the end of a several-year dry spell in which deep cracks had been formed through dessication. Infiltration of water through cracks to reach the bentonite-like clay beds described above may have helped trigger mass movement in the area.
- Human impact may have also been a factor. Around 150 homes in the area had septic tanks and cesspools that probably contributed at least 32,000 gallons of water per day to the area. This additional water may have contributed to decreasing the shearing strength of the clay layers.

### **Stabilization Attempts:**

Two primary stabilization attempts have been made:

- In 1957, twenty-five 4 foot diameter by 20 foot long concrete caissons were inserted 10 feet into the ground in an attempt to pin the landslide to more stable rock layers underneath. While initial measurements showed slowing, these turned out to be due to seasonal variations. Flow rates continued, and even accelerated, following this control attempt. Reiter describes that these caissons were pulled from the underlying rock layers and incorporated into the slide.
- An attempt was made in 1961 to reduce erosion at the toe of the landslide when 5000 cubic yards of basalt boulders and additional earth fill were placed along the eastern part of the shoreline. The effects of this abatement effort were not measured.

### **References:**

Ehlig, Perry, "The Portuguese Bend Landslide Stabilization Project," Geology of the Palos Verdes Peninsula and San Pedro Bay, 1987, ed. Peter Fischer, p. 2-17.

Merriam, Richard, "Portuguese Bend Landslide, Palos Verdes Hills, California," Journal of Geology, 68, 1960, pp. 140-153.

Norris, Robert and Robert Webb, Geology of California, John Wiley & Sons, 1990, pp. 346-348.

Reiter, Martin, The Palos Verdes Peninsula, 1984, Kendall/Hunt Publishing, pp 26-33.

Woodring, W.P., and Bramlette, M.N, and Kew, W.S.W., "Geology and paleontology of Palos Verdes Hills, California," 1946, United States Geological Survey, Professional Paper 207, p. 145.

All figures except Figure 2 taken from the CSU Long Beach Virtual Field Geology website:  
[http://seis.natsci.csulb.edu/VIRTUAL\\_FIELD/vfmain.htm](http://seis.natsci.csulb.edu/VIRTUAL_FIELD/vfmain.htm)

Figure 2 taken from Technical Review of Geological and Geotechnical Data from Abalone Cove Landslide prepared by Cotton, Shires, and Associates for the City of Rancho Palos Verdes, 2001:  
[http://www.palosverdes.com/rpv/planning/content/Geological\\_data\\_Abalone\\_cove.htm](http://www.palosverdes.com/rpv/planning/content/Geological_data_Abalone_cove.htm)

# Organic Deposits on Carpinteria Beach

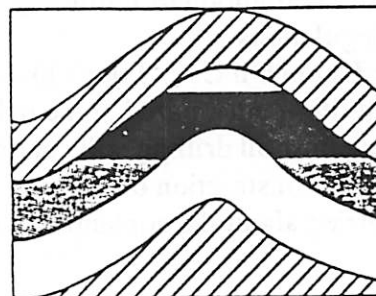
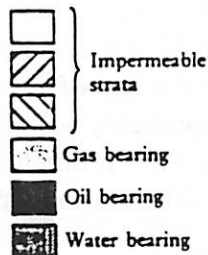
## Abigail Wasserman

### What you see on the beach

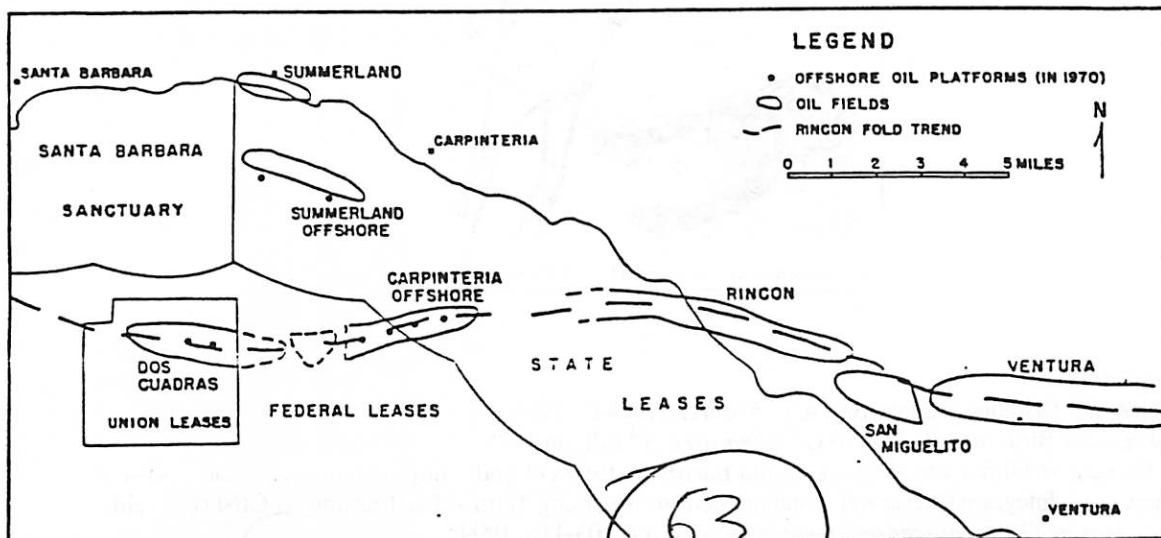
What you see on the beach is raw petroleum coming up from underground to form a tar pit or seep. Petroleum forms when deposited organic material (plant and animal remains) breaks down in an anoxic environment, such as when buried in ocean floor sediment. Instead of breaking down easily into  $\text{CO}$  and  $\text{H}_2\text{O}$ , as the debris would with oxygen present, the organic material instead slowly forms into more stable hydrocarbon compounds such as cyclopentane ( $\text{C}_5\text{H}_{12}$ ) and cyclohexane ( $\text{C}_6\text{H}_{12}$ ). Which compounds form depends on the amount of oxygen in the original debris as well as depending strongly on the temperature.

### Why it's there

The Carpinteria oil field is part of a large anticlinal system that is extensively faulted. Rising oil has collected under an impermeable rock layer forming a pond under the anticline. The faults allow the oil to ascend to the surface, both into water and on land. Carpinteria beach is on the edge of the anticline, but the majority of the oil wells are drilled into the fold axis of the rock in order to access the middle of the reservoir.



(a) Anticlinal trap



## History

The Carpinteria offshore oil field was discovered in 1964 and has produced over 100 million gallons of oil as of 1999. The seeps, of course, have been present and used for much longer. Indigenous peoples caulked boats with natural tar, and companies in the late 1800s excavated the tar and asphalt for roofing and paving. Before excavation, the seeps and pits of the Carpinteria area contained many fossils similar to those in the La Brea tar pits in Los Angeles.

The offshore oil companies claim that they are reducing the petroleum pollution of the waters and beaches by pumping down the reservoir so that less oil rises up the faults. However, the environmental impact of oil spills and well blowouts most likely outweighs any good derived from the pumping.

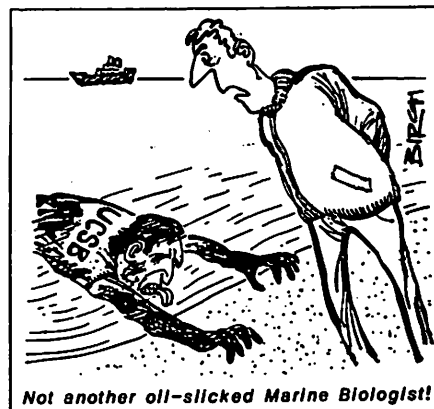
### *The 1969 Santa Barbara Blowout*

On January 29, 1969, a Union Oil Co. platform stationed six miles off the coast suffered a blowout. Oil workers had drilled a well down 3500 feet, and riggers were retrieving pipe in order to replace a drill bit when the mud and water used to maintain pressure became extremely low. The pressure of natural gas and oil underneath caused a blowout of the well. The hole was successfully capped, but the pressure differential was so high that it caused five new breaks in an east-west fault on the ocean floor. These new breaks continued to pour out oil for at least a month afterwards. 200,000 gallons of crude oil were released, soiling 35 miles of coastline. Thousands of birds, as well as seals and dolphins, died from the oil.

This disaster began the tradition of Earth Day, as well as calling attention to the need for stricter drilling regulations.

From the president of the Union Oil Co.: "I don't like to call it a disaster, because there has been no loss of human life. I am amazed at the publicity for the loss of a few birds."

The fight for and against oil drilling still continues, and probably will continue for a long time. Debate over the construction of two new oil rigs in 1985 prompted this cartoon, where UCSB worried about the contamination of its nearby marine-study preserve.



### References:

Blakeslee. Oil Disquiet at Santa Barbara. *Nature*, 315, 449, 1985.

Krauskopf and Bird. *Introduction to Geochemistry*. 3<sup>rd</sup> Edition 1995.

Santa Barbara Wildlife Care Network. Santa Barbara's 1969 Oil Spill. <http://www.silcom.com/~sbwcn/>

Whitney, et al. Integrated Reservoir Management for the Long Term – The Carpinteria Offshore Field.

*Marine Georesources and Geotechnology*, 17, 103-116, 1999.

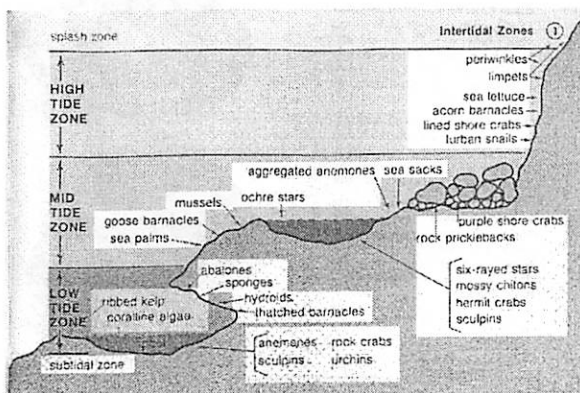
(64)

## Intertidal Life in Southern California

-- Gwen Bart --

### *Importance of Marine Biology*

Marine life represents a vast source of human wealth. The ocean is the source of many kinds of food and medicine, and also of tourism. Ocean organisms produce much of the oxygen we breathe and may help regulate the Earth's climate. Shorelines are often shaped and protected by marine life. However, these same organisms can cause many problems for humans, including direct attack; erosion of piers, walls, boat hulls, and other structures; clogging pipes; and interference with other sea based activities.



### *Properties of the Intertidal Zone*

- The intertidal zone is the area on the shoreline that gets alternately exposed to air and submerged in water due to tides.
- Animals and plants that live here are regularly exposed to huge changes in temperature and salinity, and (most obviously) water!
- Water Loss
- Battle for Space
- Vertical Zonation

↑ The intertidal zones and common occupants of those zones.

### *Planetary Connection*

Earth is a planet. Oh, you meant connection to planets BESIDES Earth. Okay. Well, it has been proposed that there may have been oceans on Mars in the past, and there may be a liquid water ocean on Europa at the present. If these or other planets were to have harbored life in these oceans, then it would be marine life. By knowing the characteristics of the life we do know about, then we as planetary scientists can competently begin to put limits on where this same type of life might occur on other planets.

**References:** Three great books:

- Pacific Intertidal Life* by Ron Russo and Pam Olhausen, Nature Study Guild, 1981.  
*Marine Biology* by Peter Castro and Michael E. Huber, Mosby-Year Book, 1992.  
*Channel Islands National Park* by Susan Lamb, Southwest Parks and Monuments Association, 2000.

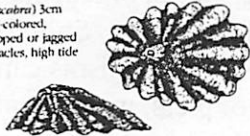
*LPL Field Trip*  
-- April 2002

**1 Limpets — snails**

Limpets are mollusks with flat or conical, one-piece shells. Some live high in the intertidal zone on rocks; others live in tidal pools on algae and kelp. When the tide rises, they creep about within a range of up to two meters grazing — scraping tiny algae from rocks with rasping tongues called radulae. As tide falls they usually feel their way back to habitual resting spots, often in crevices protected from the full force of the waves, where their shells have worn snug

depressions in the rock. A limpet may use the same resting spot for its entire life or perhaps ten to fifteen years. An alarmed limpet contracts its foot muscles to grip the surface. It's like a suction cup without a handle. Because its streamlined form offers a low profile to both surf and predators. Dislodged limpets can't right themselves, and are soon eaten or tumbled helplessly in the surf. Most species have separate sexes and release eggs or sperm into open water

**Rough Limpet** (*Collisella scabra*) 3cm long with pronounced, light-colored, radiating ribs, strongly scalloped or jagged margin. Abundant with barnacles, high tide zone. Oregon to Mexico.



**Shield Limpet** (*Collisella pelta*) Shell 3-4cm long, with fine, irregular, radial ribbing; some with scattered white dots and rays. Flexible Sea Palm provides limpet with food and protection from waves. High tide zone. Aleutian Islands to Mexico

**Ribbed Limpet** (*Collisella digitata*) Shell 2cm long, often with broad ribs, apex near front edge, mixed large and fine white dots, often pitted by parasitic fungus, tops often eroded. High tide zone. Aleutian Islands to Mexico. Most abundant north of Monterey.



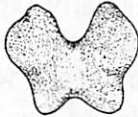
**Owl Limpet** (*Lottia gigantea*) Shell to 10cm long, light brown and white, top often eroded, apex far forward. Defends home territory by bulldozing intruders off. On undersides of rocks, high to mid tide zones, Cape Flattery to Mexico.

**14 Chitons**

Chitons or sea cradles are sluggish mollusks that creep along the under-sides of rocks on broad feet. Most have eight exposed, overlapping plates on their backs. However, two species have plates that are partially or completely covered by a thick, fleshy layer called a mantle or girdle. The flexibility of these plates allows a chiton to fit snugly into a crevice or depression, where its low profile helps it hang on. When dislodged, it rolls into a ball or "sea cradle" to protect its soft undersides from predators. Tufts of gills are hidden in a groove between the body tissues and the plates.

Although generally eyeless, some chitons have light-sensitive receptors that penetrate the plates. Like other mollusks, chitons generally use their scraping tongues or radulae to graze on thin films of algae and diatoms that coat the rocks. Some feed on

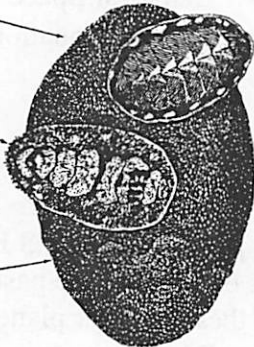
seaweed debris and dead animals. One species eats small worms and crustaceans. Like limpets, chitons frequently have homing spots where they rest when not feeding. Fertilized eggs attached to rocks and seaweed. About 100 species occur on the Pacific coast. The backs of some chitons are exquisitely camouflaged with as many as 26 species of hydroids, bryozoans and algae. Enemies include crabs, fish, and anemones. Remnant plates, known as butterfly shells, wash up on beaches.



**Lined Chiton** (*Tonicella lineata*) 2.5cm long. Pink to lavender with red, white, and blue wavy lines on plates. Girdle is smooth, leathery. Colorful. Usually on coralline algae, in pools or exposed on rocks. Mid to low tide zones, Alaska to San Diego.

**Rough Chiton** (*Nuttallina californica*) To 5cm long with brown and white spines scattered on the girdle. Plates are dull brown, streaked with white, often eroded. More sedentary than other chitons. Some individuals may stay in permanent homing spot such as deep depression that traps seaweed debris and protects them from surf and enemies. These eat less. May live to 25 years. Mid to high tide zones, Puget Sound to Mexico.

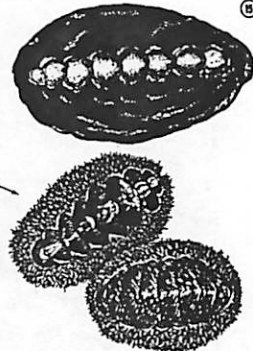
**Gumboot** (*Cryptochiton stelleri*) To 33cm long, world's largest chiton. Plates completely covered with brick-red, gritty girdle. Often found with a pea crab and scale worm living harmlessly in grooves on underside. More easily dislodged because of high profile. Mid to low tide zones, Alaska to Channel Islands.



**Black Chiton** (*Katharina tinticata*) 7-12cm long, black. Thick girdle covers white plates except for exposed sections on the upper back. Lays eggs in July along central California coast. Mid tide zone, Alaska to Point Conception, sporadic to Mexico.

**Mossy Chiton** (*Mopalia ciliata*) 3-6cm long. Scattered, branching bristles on dark girdle. Greenish overall. Most of each plate is exposed. Prominent notch at end of girdle. Mid to low tide zones, Alaska to Mexico.

**Woody Chiton** (*Mopalia lignosa*) 5-7cm long. Girdle has thick, recurved bristles. Plates are green-grey with brown lines radiating from their peaks. Mid to low tide zones, Alaska to Pt. Conception.



**Mussels**

Mussels are related to other two-shelled mollusks: clams, oysters, and scallops. Most mussels attach themselves to rocks by secreting a viscous liquid which quickly hardens in sea water to form fibrous threads called byssus. A mussel lives upside down in its shell with the head nearest the point of attachment. To eat, it opens the shell and, with tiny hairs called cilia, makes a water current which brings oxygen to the gills and microscopic plankton to be trapped in a layer of mucus and passed to the mouth by other cilia. Pea crabs often live inside mussel shells subsisting on organic debris drawn in by the current. Other animals live between clustered mussel shells. One study revealed a 711 individual sponges, crabs, worms, marine pill bugs, seals, sea cucumbers, and other small animals of 22 different species living amid mussels in an area of 30 square centimeters. Mussels release eggs and sperm into open water. Their natural enemies are primarily sea stars and people. CAUTION: From late May through October, mussels feed on microorganisms that make them poisonous to people who eat them.

**California Mussel** (*Mytilus californianus*) To 20cm long and often eroded at tip showing bands of white, blue, and black. In dense colonies on exposed outer rocks where waves break. Mid to high tide zone. Alaska to Mexico.



**15 Snails**

Most snails bear little resemblance to their more squat, sure-footed relatives: limpets, abalone and chitons. Snails have less streamlined shells, and are more easily dislodged, but because they can right themselves faster, snails are less likely to be eaten for having lost their footing. Besides, a snail can withdraw completely into its shell behind a trap-door-like, horny plate, called an operculum, which protects it from predators and water loss. A snail has a distinct head, displays plume-like gills and eyes on tentacles which can be withdrawn in case of a threat. It can extract calcium carbonate from sea water and deposit it through a membranous mantle onto the edge of the shell's opening so that the shell grows larger. The deposit is made unevenly so that the shell grows into a compact spiral rather than a long, cumbersome tube. Thick muscle tissue forms the boneless snail foot. Its adhesive ability comes from this,

elongated depressions in the sole, which act as suckers. Snails travel by advancing a portion of the foot, then pulling the remainder after it in a looping motion. Most intertidal snails scrape thin films of algae from rocks or from the shells of other animals. Some eat seaweed. One species captures plankton in a mucous net. A few species use raspy tongues to grind holes through mussel shells, then inject a muscle-relaxing chemical. When the mussel's open, use spines or teeth on the edges of their shells to pry open barnacles or mussels. Snail eggs are fertilized internally, and are usually attached underwater to rocks, shells, seaweed and are occasionally placed in sand. Some snails possess both male and female organs. Snails are often intermediate hosts for parasitic worms. Snail enemies include shorebirds, fish, lobsters, crabs, other snails, and people.

**Black Turban Snail** (*Tegula funebrata*) Shell to 2.5cm long, broad, thick, purple-black to black, top often eroded. Older specimens have two teeth on inside bottom edge of shell. Feeds on algae on rocks. May live to 25 years. Abundant high to mid tide zones, British Columbia to Mexico.

**Brown Turban Snail** (*Tegula brunnea*) Shell to 3.5cm long, broad, thick, brown to orange-brown, top often eroded. Older specimens have one tooth on inside bottom edge of shell. Feeds on algae. Not abundant. Often with black turban snails. Mid tide zone, Cape Arago to Channel Islands. Horned slipper shell snails are often stacked on top of both kinds of turban snails.

**Leafy Hornmouth** (*Cerastodoma foliatum*) Shell to 8cm long, marked with spiral ridges and at least three prominent, wing-like erect extensions of shell. Brown and white to creamy white. A tooth-like projection on lip of shell may be used to attack barnacles and Serpulid snails. Low tide zone, Sitka to Pt. Conception. Uncommon south of Pacific Grove. A similar species, *C. nitidum*, is common in southern California.



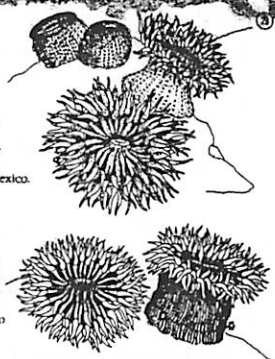


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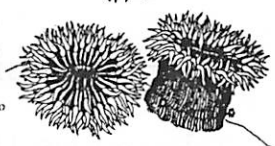
**Giant Green Anemone** (*Anthopleura xanthogrammica*) To 17cm wide at the oral disc, column olive green to brown, tentacles and disc emerald green. Column has irregular tubercles or bumps. Sand and shell fragments may stick to column, but seldom produce a solid coating. When food is scarce, white specimens living in dark caves lose weight more rapidly than those with algae in their tissues. Does not tolerate polluted water. A sea spider and ventrifer snail feed on the tissues of this anemone. Low tide pools and rocks, Sitka to Panama.



**Aggregated Anemone** (*Anthopleura elegantissima*) To 5cm wide. Olive green; tentacles often banded and tipped with white, pink or purple. Tubercles sticky, round. Column is almost always covered with sand and shell pieces, which may conserve moisture and prevent sun damage during exposure. Reproduces mostly by dividing, hence members of aggregation are often of the same sex. In dense masses on exposed rocks, mid tide zones, Alaska to Mexico.



**Brooding Anemone** (*Epiactis prolifera*) To 5cm wide and high, brown to greenish-brown. Some specimens red, pink or dull green. White lines radiate near base and on the oral disc. Tentacles same color as body. Young develop around the base of the column. When 5mm tall, they move away from adult to locate their own spaces. Low to mid tide zones on sheltered sides of rocks, Alaska to southern California.



32 **Sea Stars**

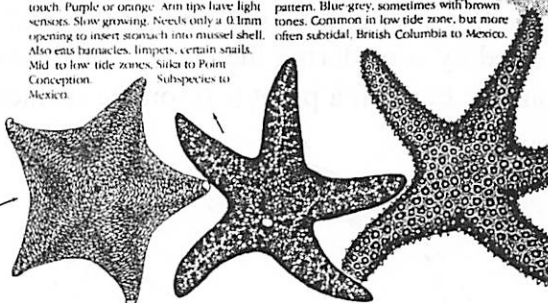
Sea stars are echinoderms with knobby spines on their backs. Their skin also has soft fuzzy clumps of oxygen-absorbing tissue, and tiny pincers which preserve the breathing ability of the skin and prevent suffocation by routinely cutting up the larvae of barnacles, sponges, and hydroids seeking attachment there. Hold an Ochre Star gently against your arm. When you remove it you'll feel pincers tugging at your hair. Just off center on the star's back is a small strainer for taking water into its internal hydraulic system which operates hundreds of flexible, elastic tubes on its underside, called tube feet. Each foot is tipped with a tiny suction

cup, which helps a star to hang on tight when a wave hits. Whichever way stars go is "forward." Having neither heads nor tails, they change direction without turning around. Tube feet can pry open clams or mussels just far enough for the star to insert its inside-out stomach into the shell and digest the victim. When finished, a star retracts its stomach and moves on. Some species have free swimming larvae, others brood eggs until they hatch into little stars. Stars can usually regenerate lost arms. In some species severed arm tips can regenerate whole new animals. Sea stars' greatest enemies are human curio collectors

**Bat Star** (*Patria miniatia*) To 10cm across, webbed between arms, scaly. Color variable: solid or mottled red, orange, brown, yellow, green or purple. Eats sea stars, tunicates, and algae. Worm lives in arm grooves. Low tide zone, but more often subtidal. Sitka to San Diego. Some to Mexico.

**Ochre Star** (*Pisaster ochraceus*) To 30cm across. Rows of white tipped spines resemble pentagons near center. Harsh to touch. Purple or orange. Arm tips have light sensors. Slow growing. Needs only a 0.1mm opening to insert stomach into mussel shell. Also eats barnacles, limpets, certain snails. Mid to low tide zones, Sitka to Point Conception. Subspecies to Mexico.

**Knobby Star** (*Pisaster giganteus*) To 40cm across. Large, club-shaped spines surrounded at base by blue rings, glowing pattern. Blue grey, sometimes with brown tones. Common in low tide zone, but more often subtidal. British Columbia to Mexico.



33 **Sea Urchins**

Sea urchins are echinoderms with roundish, fragile calcium carbonate shells called tests. They're covered with hundreds of formidable-looking spines capable of wounding careless handlers. The spines rotate on ball-and-socket joints which are seen as round knobs on old shell fragments or empty tests after the spines have broken off. The spines are used for defense and for trapping bits of seaweed. In between them there are many long tube feet like those of sea stars. Besides gripping the surface, these tube feet can also absorb oxygen and pass bits of food around to the urchin's mouth, a white, bony organ on the underside (called Aristotle's lantern) which can scrape algae from rocks and pilings. Like sea stars, urchins have tiny pincers nestled among the spines which keep their bodies clear of barnacles, sponges, tunicates, etc., by destroying their larvae. Feet and pincers can

be regenerated. Empty tests may show minor shell cracks which have healed over, but major shell repairs are impossible. Urchins grow by depositing new calcium on the outer shell surface while absorbing it on the inside. They release sperm and eggs into open water during winter and spring months and sometimes in response to the injury of one member of a group. Urchins are efficient grazers, sometimes leaving insufficient algae behind for abalone, limpets, snails and other grazers. They often burrow into reef rock, apparently by a combination of rubbing spines, plucking tube feet and water erosion. The burrows become chambers which protect urchins from wave action and enemies, and trap edible bits of seaweed, etc. They may grow too big to leave these burrows. Urchin enemies include sea stars, otters, crabs, sheephead fish, people and pollution.

**Green Urchin** (*Strongylocentrotus droebachiensis*) Body to 8cm not including spines, crowded green spines. Greenish overall with some red and brown tones near top. Abundant in low tide zone, and on pilings north of Puget Sound.

**Purple Urchin** (*Strongylocentrotus purpuratus*) Body to 10cm across, red to purple. Spines short in intertidal specimens but to 6cm in subtidal specimens. Often burrows into reef rocks by hundreds. Greenish young often confused with *S. droebachiensis*. Spawns in spring. Often harbours isopods and worms on undersides. Primary enemies are sun stars and sea otters. Thrives amid strong wave action; less common in sheltered places. Low tide zones, Alaska to Cedros Island, Mexico.

**Giant Red Urchin** (*Strongylocentrotus franciscanus*) Body to 12cm, spines to 5cm long. Usually white red; young also have red spines. Does not burrow. Spawns in early spring. Pincers have three jaws, each with a poison gland. Flaworms inhabit stomach. Abundant intertidally in quiet areas as well as rough water in the north. Mostly subtidal in the south. Low-tide-zone pools, Alaska to Mexico.



34 **Barnacles**

Barnacles are crustaceans, with jointed legs and shells of connected overlapping plates. Instead of crawling after food, they glue themselves to rocks, ships, pilings, abalones, even whales, and wait for food to wash by. When under water, or even when a wave washes over, they reach out with leathery barbed legs to strain out plankton and absorb oxygen. Most individuals have both sexes (hermaphrodites). Fertilized eggs hatch into larvae, then leave the parents' shells and spend their youth swimming. After several molts, they settle down to a sedentary adulthood, held permanently by one of the strongest known natural adhesives. Enemies include worms, snails, sea stars, fish like sheephead, certain shorebirds, and oil spills. Some are parasites inside crabs or on other animals.



**Acorn Barnacle** (*Balanus glandula*) Shell 2cm or less wide, white, volcano-shaped (although those growing in crowded conditions are columnar, reaching 2cm high). Habitats vary from exposed shoreline to protected bays. Inner hinged plates seal off the animal when exposed by low tides. In colonies, high to mid tide zones, Aleutian Islands to Mexico.

**Brown Buckshot Barnacle** (*Chthamalus dalli*) Shell about 8mm wide, half as high, brownish. When inner plates close a cross-shaped form appears. Found in the highest part of high tide zone. Our smallest barnacle. Alaska to San Diego. *C. fissus* is common. San Francisco to Mexico.

**Thatched Barnacle** (*Balanus tintinnus*) Shell to about 5cm wide at base, dirty pink. Plates have strong ridges and furrows. Usually settles under ledges and rocks, but occasionally in tight groups where shape is more columnar. Low tide zone. Bering Sea to Morro Bay, Monterey.

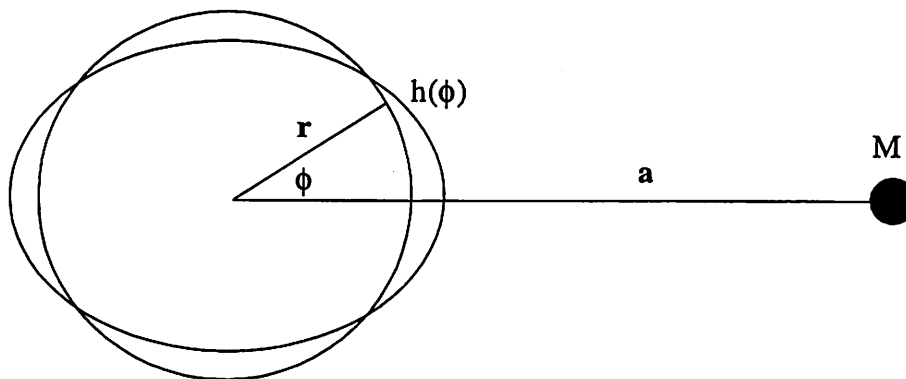
**Goose Barnacle** (*Pollicipes polymernus*) Body to 10cm high including fleshy neck. Plates small, white, many, on top of grey-green scaly or wrinkled neck. In tight clusters with necks hidden. Dorsal along barbed feet turn to face incoming wave, then turn around to strain again as wave recedes. Once believed to hitch into the gese associated with mussel beds. Mid tide zone and outer exposed rocks. British Columbia to Mexico.



# Tides

## 1. Basic Concepts

Tides are caused by the nonuniform gravitational field exerted by the Moon and the Sun over the surface of the Earth. Coincidentally (and uniquely in the solar system), the tidal pull of the two bodies on the Earth are comparable in magnitude: the tidal effect of the Sun is slightly less than half the tidal effect of the Moon. The basic effect can be derived by considering the gravitational potential of a perturbing mass  $M$  at a distance  $a$  from the Earth at a point  $(r, \phi)$  on the surface.



In the above figure,  $h(\phi)$  represents the equipotential surface of a hydrostatic body under the perturbing potential of  $M$ ; i.e., how the surface of the Earth would look if it were made entirely of liquid water. It thus represents a first approximation for the tidal response of the Earth to the Moon and the Sun. The quadratic term of the potential expansion creates the tides:

$$g_r = \frac{GMr}{a^3} (3\cos^2(\phi) - 1) \quad g_\phi = \frac{-3GMr}{a^3} \cos(\phi)\sin(\phi)$$

Using this simplified hydrostatic model of the Earth's surface, the result for  $h(\phi)$  is

$$h(\phi) = h_0 \left( \frac{3}{2} \cos^2(\phi) - \frac{1}{2} \right), \quad h_0 = \frac{Mr^4}{M_{Earth} a^3}$$

Here,  $M$  is the mass of the perturbing body (either the Moon or the Sun),  $r$  is the radius of the Earth, and  $a$  is the distance between the center of the Earth and the perturbing mass. For the Moon,  $h_{0,Lunar} = 36$  cm and for the Sun,  $h_{0,Solar} = 16$  cm. When the Moon is at 1<sup>st</sup> or 3<sup>rd</sup> quarter, the effects of the Sun and the Moon partially cancel, resulting in the low *neap tides*. On the other hand, at new and full Moon, the tidal effects of the Moon and the Sun add, causing the unusually high *spring tides*.

The figures for  $h_0$  are order-of-magnitude estimates for the tidal elongation of

the Earth. I will introduce other factors in determining the height of oceanic waves in the next section.

## 2. Other Factors

The height of surface waves over a body of water is determined by a variety of factors. The effects of the Sun and the Moon are important factors in producing tides, but other effects are quite significant, which lead to drastic variations in tidal effects across the Earth's surface. For example, the above analysis has neglected the self-gravity of the ocean. Furthermore, it has assumed the unrealistic case of a water surface without continents. The shapes of the ocean play an important role in determining tidal properties. Local topography also is crucial for determining tides. For example, in mid-ocean, the tidal range is observed to be generally less than a meter, in accordance with the figures for  $h_0$  for the Moon and the Sun. Waves breaking on beaches are often (but now always) much higher than a meter in height.

Also, the effect of resonance can greatly enhance the tidal effect of the Moon because it is a periodic force. Forcing with an amplitude of about 12 hours can cause large amplitude, resonant oscillations. This forcing is often associated with a phase lag of a quarter of a tidal period (3 hours). In this case, the high tide will not occur precisely when the Moon is overhead.

The full effects causing tides are particularly difficult to model, and numerical simulations of tides continue to reveal systematic discrepancies with the observations. For example, models have not yet been able to take into account the energy transfer to the internal waves and shelf effects, including trapping, refraction, and dissipation of tidal waves in shallow water [Marchuk and Kagan 1984].

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## The San Andreas Fault System – Paul Withers

Wallace RE, The San Andreas Fault System, California, USGS Professional Paper 1515, 1990 (helpfully pirated at <http://www.johnmartin.com/earthquakes/eqsafs/INDEX.HTM>)  
Schultz SS and Wallace RE, The San Andreas Fault, USGS General Interest Publication, 1989 (<http://pubs.usgs.gov/gip/earthq3/index.html>) [useful images]

Tectonically speaking, rocky planets are a ductile asthenosphere overlain by a brittle lithosphere. The behaviour of the lithosphere has an immense influence on both the heat budget and surface geology of the planet. Earth's lithosphere currently supports plate tectonics, Venus has stagnant lid convection, the Moon is a one plate planet, and Martian tectonics are a mystery. Europa is covered with faults and evidence of plate motion.

Large, light, rigid caps of lithosphere float around on the convection currents of the mantle/asthenosphere. At their boundaries, they either converge, diverge, or slide past each other. Here in California, the oceanic Pacific plate slides past the continental North American plate. The messiness of the Pacific-North American boundary is primarily due to the subduction of the oceanic Farallon plate beneath continental North America. This plate once underlay part of the Pacific Ocean east of the Juan de Fuca ridge and East Pacific Rise. Only small remnants remain; most has been swallowed to influence Arizona's volcanic history (see fieldtrips passim ad nauseam). The San Andreas fault system was formed 30 My ago when parts of the Pacific plate began subducting as well. "The San Andreas fault system, a complex of faults that display predominantly large-scale strike slip, is part of an even more complex system of faults, isolated segments of the East Pacific Rise, and scraps of plates lying east of the East Pacific Rise that collectively separate the North American plate from the Pacific plate." The bend in the fault north of LA is characterized by significant north-south compression.

"The San Andreas fault system is considered to lie principally within a belt about 100 km wide by 1,300 km long." Current speeds between the North American and Pacific plates are 30 – 40 mm/yr, with a somewhat lower average speed causing 300 – 500 km strike-slip movement in total. "The modern San Andreas fault apparently did not come into being in southern California until the opening of the Gulf of California during Pliocene time, about 4 Ma, since which time Baja California has moved 260 km away from mainland Mexico. The San Andreas fault is commonly referred to as the boundary between the Pacific and North American plates, which is true in the sense that the rocks on the west side of the fault are moving somewhat in concert with the Pacific plate, although those rocks actually are displaced fragments that once were part of the North American plate" "The modern trace of the San Andreas fault in central California probably had only minor slip until about 12.5-10 Ma and probably was not the strand of dominant slip before 7.5-5 Ma."

"Deformation occurring at the times of large strike-slip earthquakes is concentrated within a few tens of kilometers of the surface fault rupture, indicating that earthquake fault slip is largely confined to the upper 10 to 15 km of the crust." The quakes are shallow, unlike those in subduction zones.

Seismicity is not uniformly distributed along the fault system. The central regions creep aseismically, some have lots of small quakes, and some have infrequent but large quakes. This behaviour is correlated with the local geological setting. CO<sub>2</sub> lubrication,

increased pore pressure, and decreased frictional strength may be permitting the gradual creep.

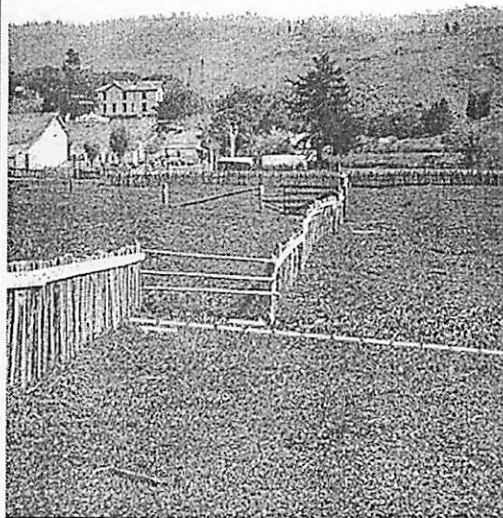
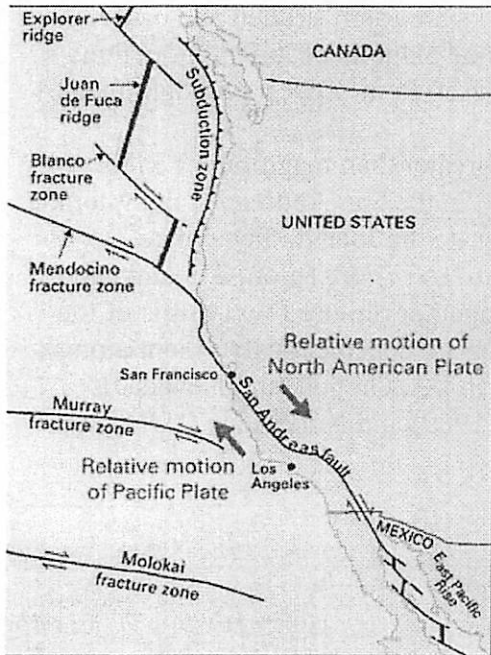
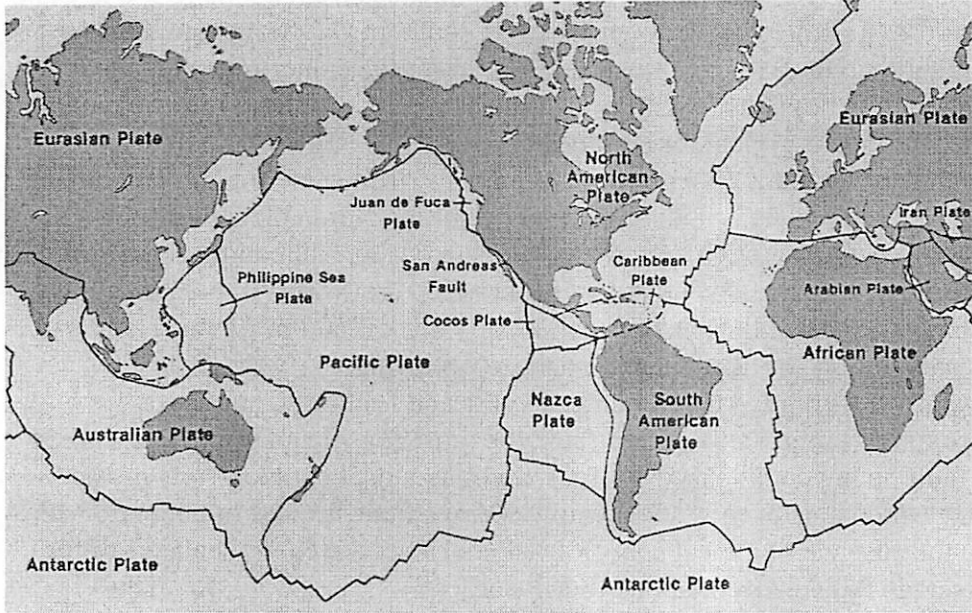
“The crust along the San Andreas fault system thickens from about 16 km at Cape Mendocino, in northern California, to about 30 km in southern California and thus is significantly thinner than the average thickness (36 km) for the conterminous United States. Lithospheric thickness (20-60 km) is also substantially less along most of the San Andreas fault system than is typical for continental areas (60-170 km). The lithosphere is thinnest at both ends of the fault system, at the Mendocino triple junction on the north, where the North American plate is sliding off the edge of the Gorda plate as it moves northward, and in the Salton Trough on the south, where onshore spreading centers of the East Pacific Rise are generating new crust in a rift between the North American and Pacific plates. In contrast, the lithosphere is abnormally thick (250 km) in the Transverse Ranges, where "subduction" of lithospheric mantle is occurring.”

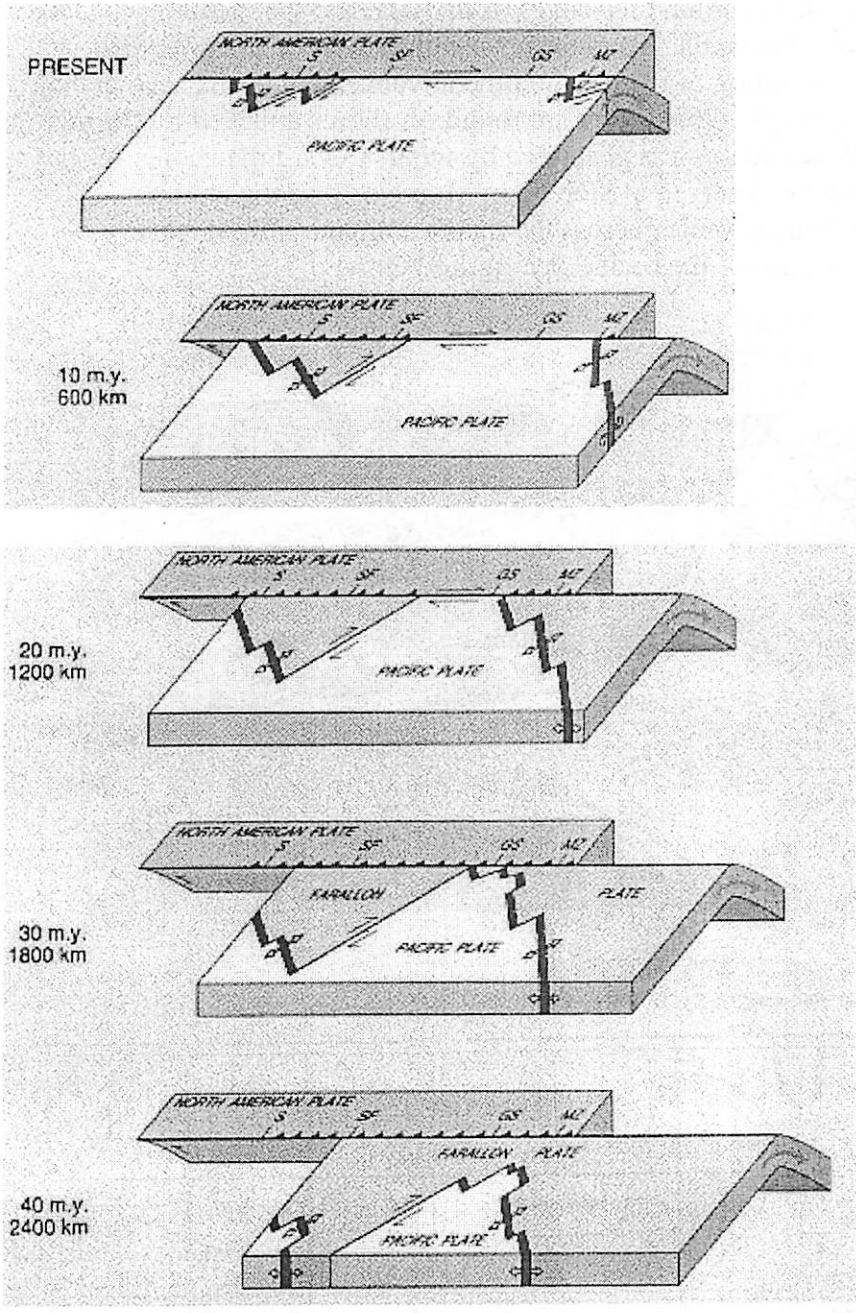
“From what we currently know of crustal stress and heat flow, neither is influenced by proximity to the San Andreas fault, the most conspicuous and best studied plate-boundary fault on the continents.” There is a problematical paradox: “(1) in-place and laboratory measurements of rock stress imply average fault stresses of about 50 MPa or more, and (2) the absence of a local heat-flow anomaly and the energy balance of the fault imply an average fault stress of about 15 MPa or less.”

“The San Andreas fault is marked in the landscape by a series of linear valleys and mountain fronts, aligned lakes and bays, elongate ridges, and disrupted or offset stream channels.” In the shear zone itself, sheared rocks are easily eroded and cause a valley-like shape. “Along its entire length, the fault zone exhibits peculiar, anomalous drainage patterns.” Shifted fences are also cool (9ft offset, Point Reyes, photographed by Gilbert)

Since 1800, there have been about 20 quakes greater than magnitude 7 in the California-Nevada region. Half of these have occurred in the San Andreas fault system, a quarter in the Basin and Range province, and a quarter on the Juan de Fuca plate boundary. “Except for the two largest events, the great 1857 (Fort Tejon, 2 deaths) and 1906 (San Francisco, 2000 deaths) earthquakes that together ruptured two-thirds of the total length of the San Andreas fault, large earthquakes are conspicuously absent along the master fault itself.” The 1906 earthquake was felt in LA, Oregon, and Nevada. It spawned Reid’s elastic rebound theory. Loma Prieta (1989) and Northridge (1994) both killed 60ish people and cost several \$B or more.

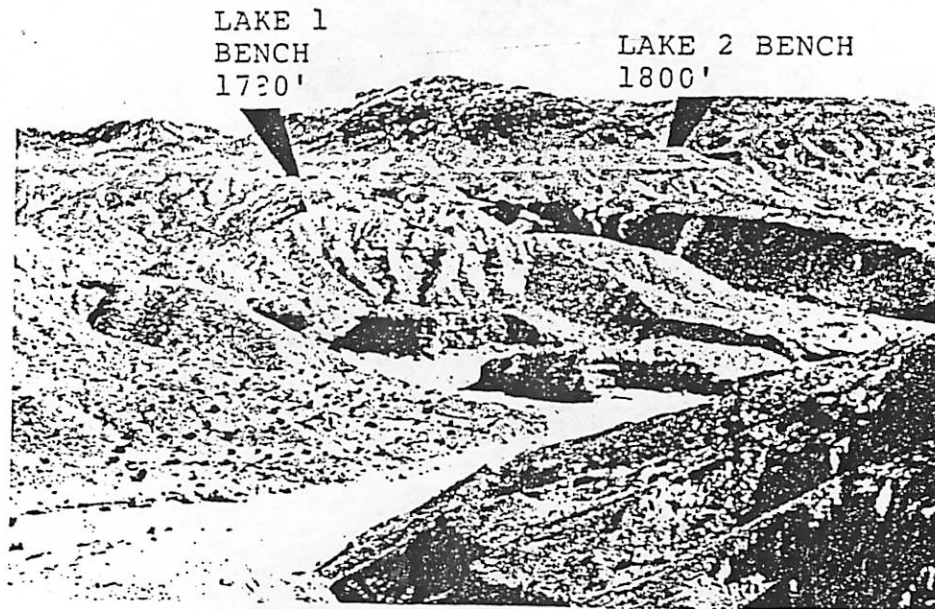






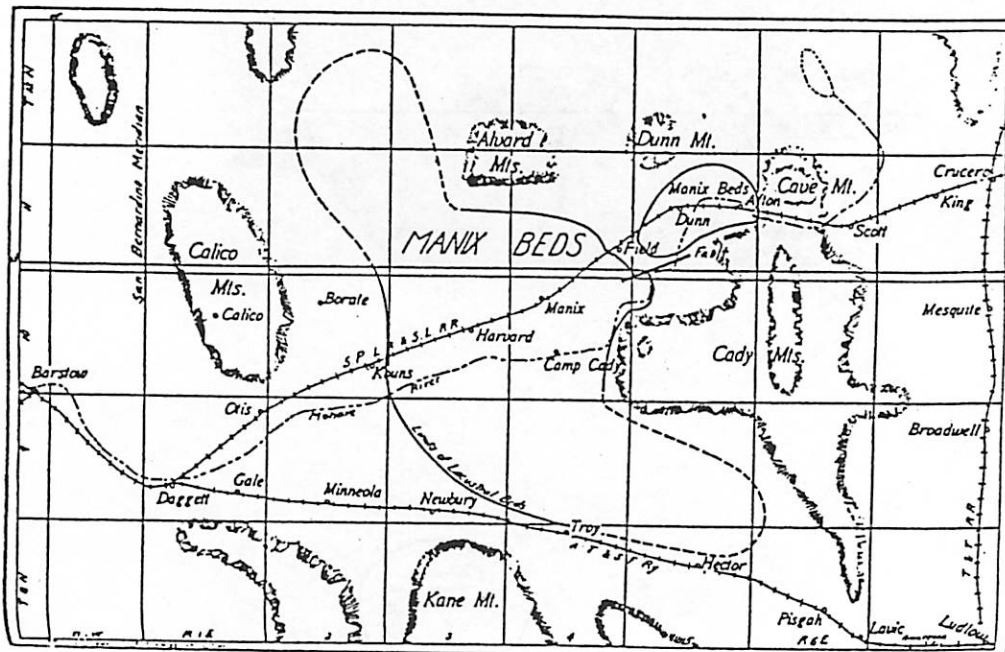
Manix Lake Gravel Bars  
Felipe Ip

As Manix lake filled during one of the glacial stages, the surrounding rivers were forced to deposit their sediment in deltas around the edges of the lake and the center of the lake received only clay deposits. Above the lake deposits is another set of river deposits marking the draining or evaporation of the lake and the advancement of the surrounding rivers into the center of the playa. Gravel bars are found on shores attacked by the high energy of large waves. Waves action was generated by winds toward the shores. Some of the gravel beach bars can be observed at Stop #2 in Map No. 1 on the next page. Two well-developed wave-cut benches occur across the major drainage from the beach bar and elsewhere around the margin of the basin. See figure below.



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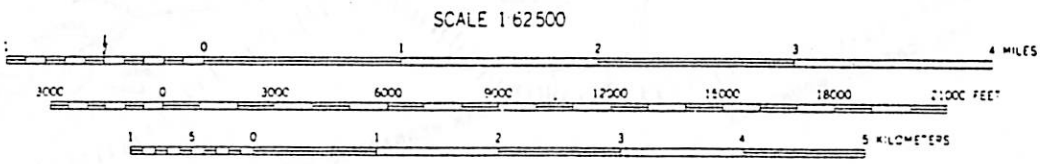
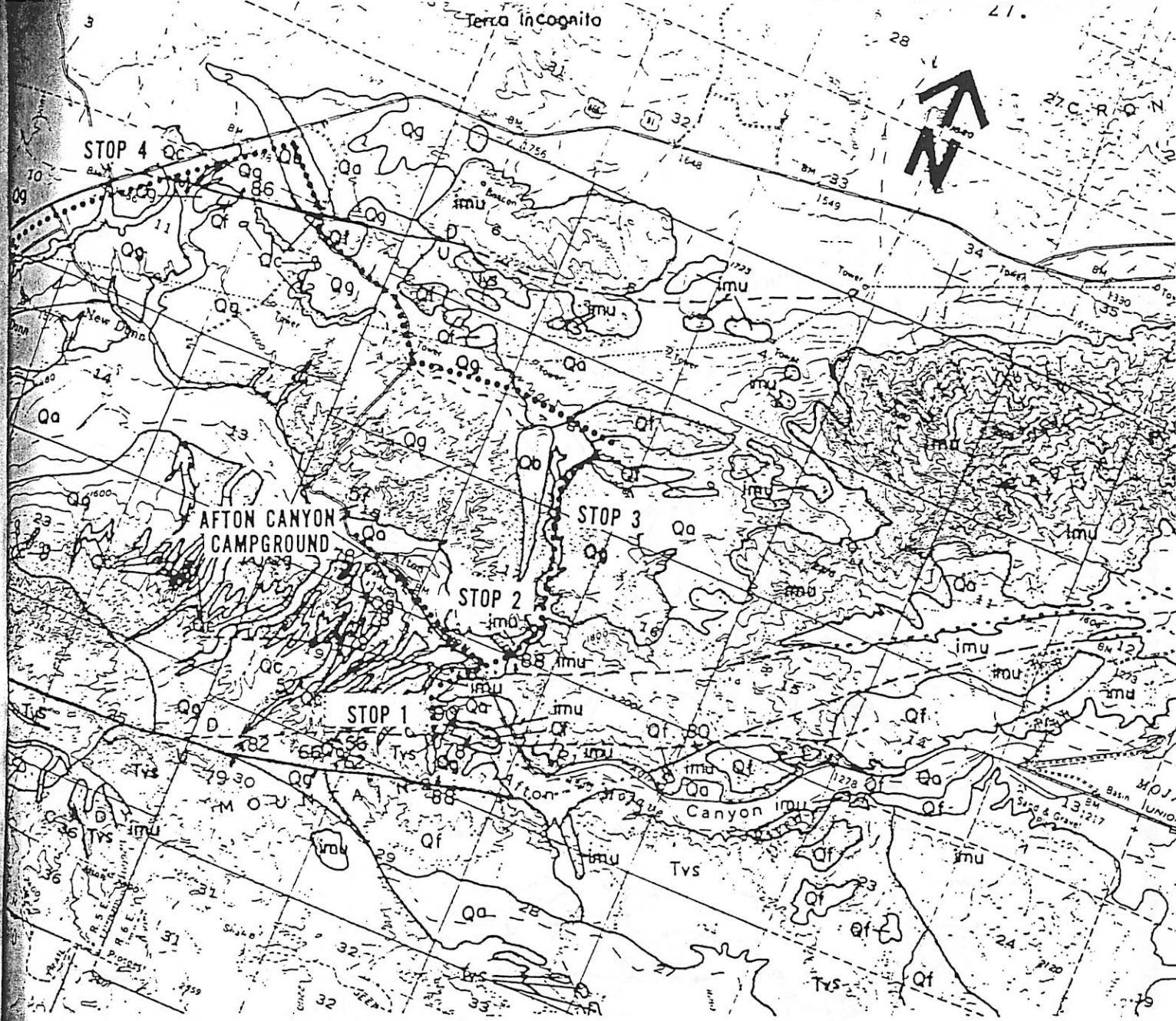
[BUWALDA] VOL. 7, PL. 22



(From Buwalda, 1914)

74





..... ROUTE  
 STOP #

**1.**  
**GENERALIZED**  
**GEOLOGIC MAP**  
**MANIX FAULT ZONE**

Topographic base: parts of Alvord Mtn, Cave Mtn, Newberry, and Cady Mtns Quads.  
 Geology modified from Southern Pacific Co 1958 Areal Economic Geologic mapping.

75

Ref: Keaton and Keaton, 1977

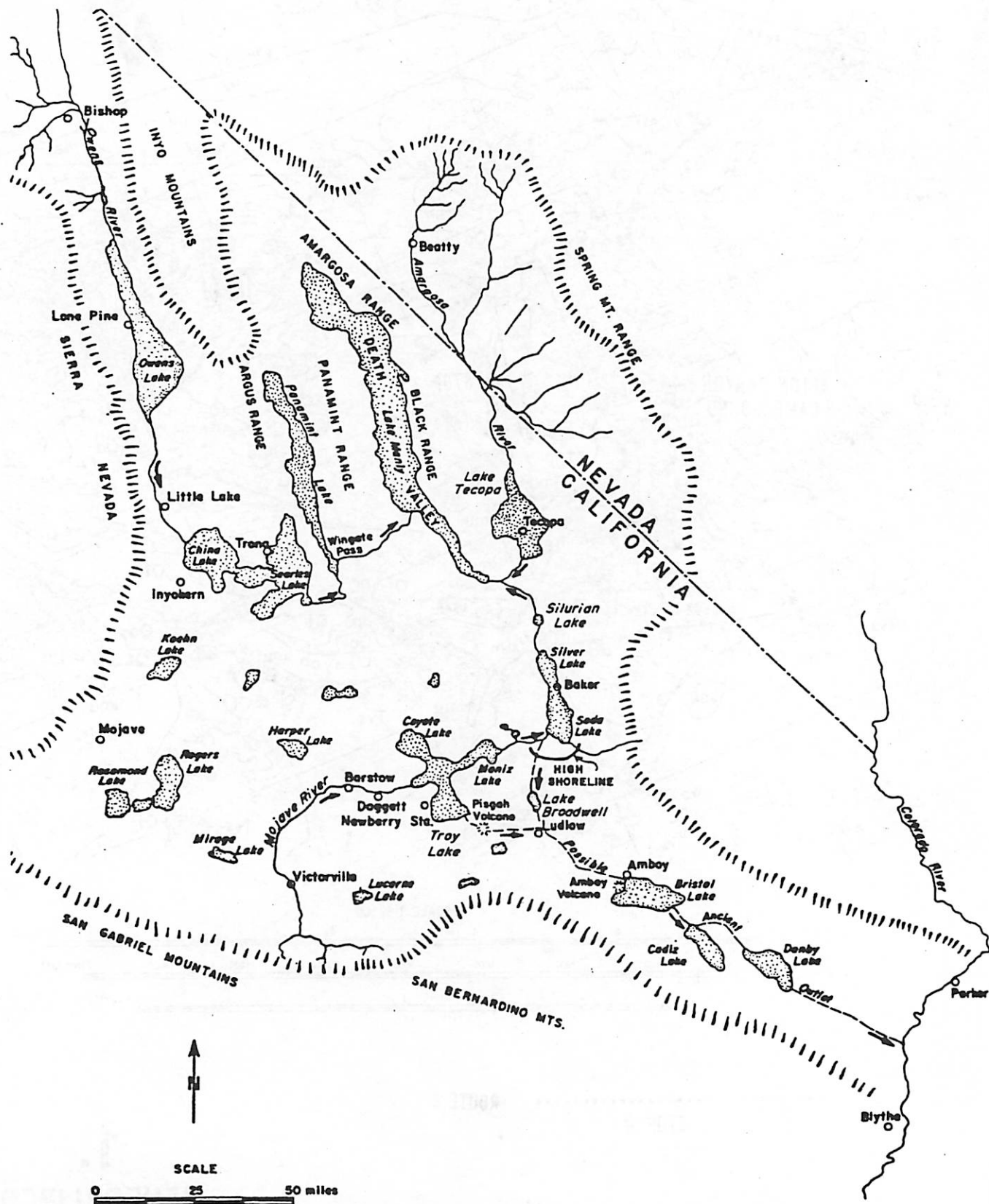


Figure 2. Pleistocene drainage in the Mojave Desert (modified from Blackwelder, 1954).

Figure 2. (76)

# **Beaches on Mars – Was There An Ocean in the Northern Plains?**

Oleg Abramov

## **Introduction**

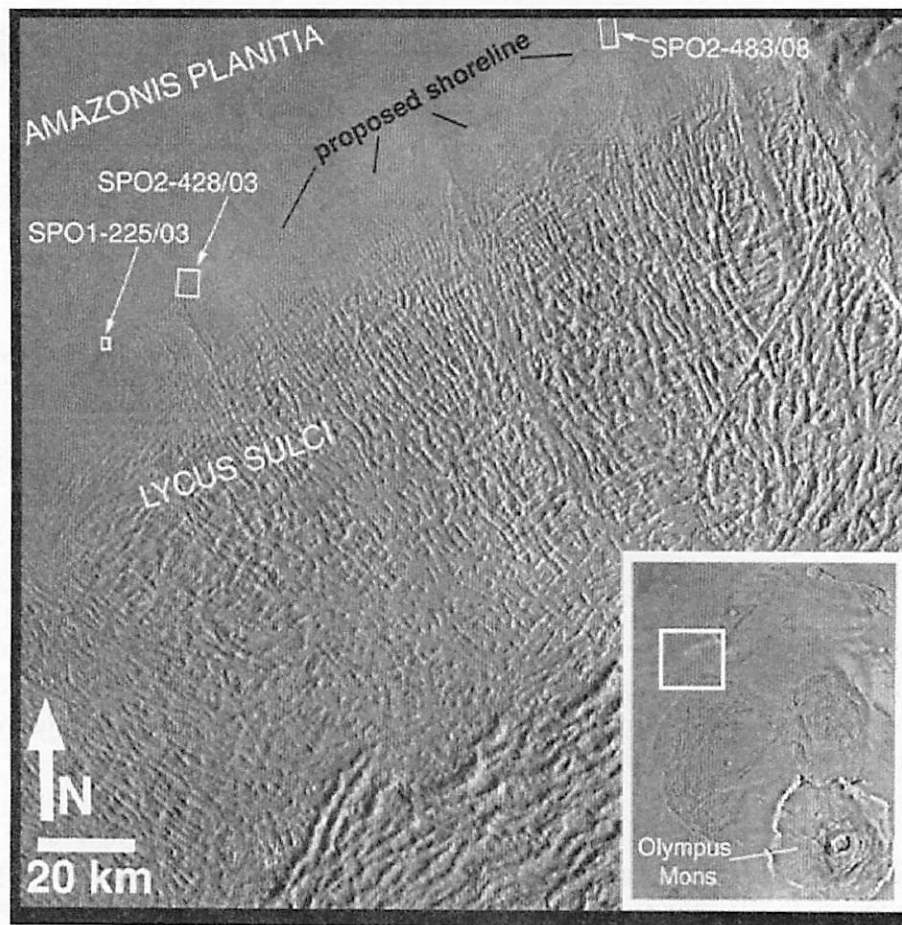
In 1971, images from the Mariner 9 spacecraft revealed fluvial erosional features including channels and valley networks, indicating that at some point in its history, Mars had a significant amount of liquid water on its surface. As the years went on, more evidence of Mars' warmer and wetter past was uncovered. There is evidence of catastrophic floods, large amounts of subsurface ice, and widespread fluvial erosion. Also, new images taken by the Mars Orbiter Camera (MOC) on the Mars Global Surveyor spacecraft show evidence of very recent seepage of ground water from crater and valley slopes in the southern hemisphere.

While it is clear that fluvial processes played an important role in the martian history, there are varying estimates of the quantity of water on Mars. By some estimates, there is enough water for Mars to have had a large ocean, while other estimates indicate that there was only enough water to form small seas and lakes.

Presented below are several lines of evidence that point to the existence of a large northern ocean on Mars during the Hesperian Epoch. The ocean hypothesis is very important, because the existence of a large body of liquid water in the martian past would have a tremendous impact on ancient martian climate and also have implications for the possibility of past life on the planet.

## **Morphological evidence from images (listed from least to most controversial):**

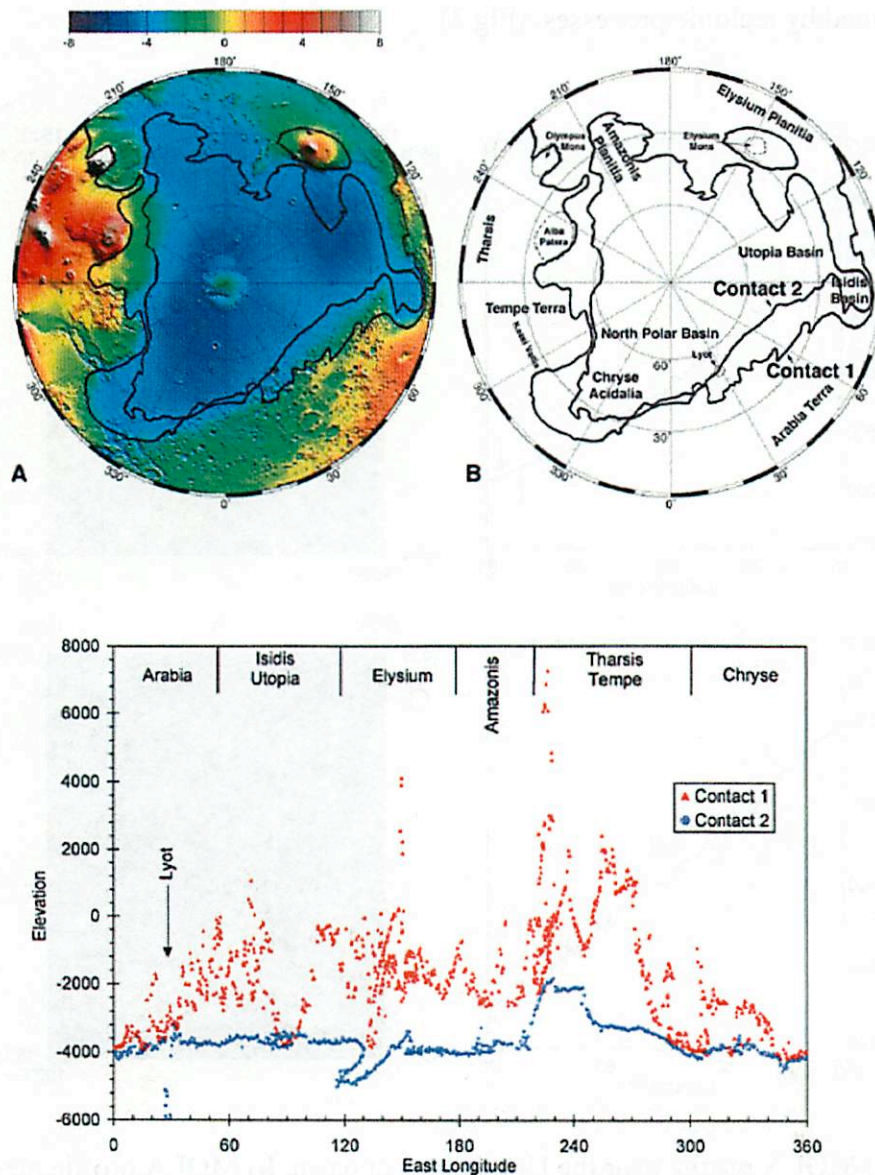
- There is a large area in the Northern hemisphere of Mars that lies below the gravitational equipotential surface ("areoid").
- Most outflow channels and many valley networks terminate near the northern plains boundary. There is little or no evidence of channel cutting far into the plains.
- Potential coastlines have been identified in Viking and MOC images (Fig 1).
- Potential island landforms have been identified. The hypothesis holds that that waves would crash these "islands" and rip off large chunks of rock, creating steep cliffs and stair-stepped terraces in the rock.



**Figure 1.** MOC image of Lycus Sulci/Amazonis Planitia boundary. The proposed coastline is a cliff that faces toward the smooth plains. It was suggested that this might be the kind of cliff that forms from erosion by waves as they break against a coastline. From Malin Space Science Systems.

#### **Evidence from Mars Orbiter Laser Altimeter (MOLA) data**

- One of the shorelines proposed by Parker *et al.* lies close to an equipotential line (Fig 2).
- The topography is smoother at all measured scales ( a few hundred meters to several tens of kilometers ) below the proposed coastline than above it.
- The volume enclosed by the proposed shoreline is consistent with estimates of available water on Mars.
- Polygonally fractured terrain correlates to the deeper regions of the northern plains, indicating standing bodies of water.
- A range of terraces parallel the proposed shoreline at many locations.

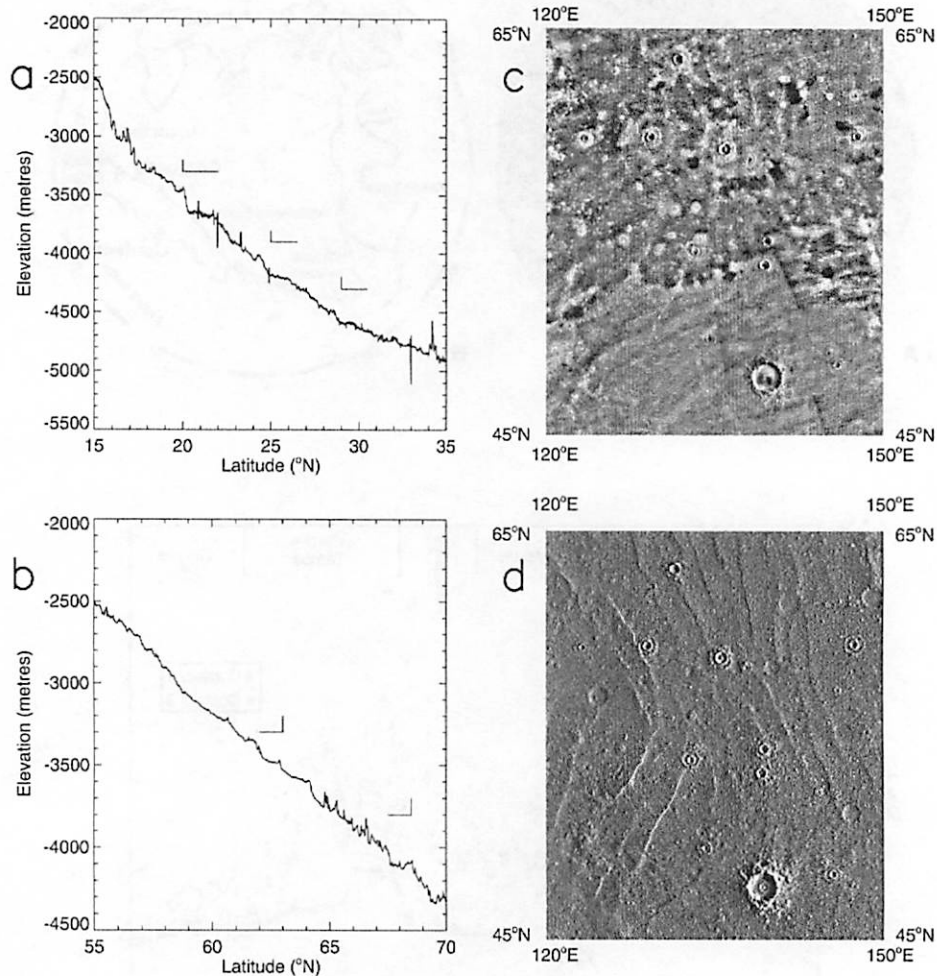


**Figure 2.** a) MOLA topography of the northern hemisphere of Mars. Black lines indicate positions of possible coastlines suggested by Parker *et al* 1993. b) Major features of the northern hemisphere. c) Elevation in meters as a function of longitude for the two proposed coastlines. From Head *et al.* 1999.

### Evidence against the Martian ocean

- Many of the common coastal landforms on Earth – such as beaches or coastal dune fields – have not been unambiguously identified in high-resolution MOC images.
- High-resolution MOLA relief maps show that the northern plains are not featureless, but contain terraces and ridges. Withers and Neumann (1999) pointed out that many features that have previously been interpreted to be shorelines appear to be wrinkle

ridges formed by tectonic processes. (Fig 3).



**Figure 3.** a) MOLA profile near the Utopia impact basin. b) MOLA profile near the Alba Patera volcano. c) Viking photomosaic near the Utopia impact basin. d) Shaded relief MOLA map of the same region. From Withers and Neumann, 2001.

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