Geology of the Salton Trough

edited by

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Last Updated 2011-10-28

Note: In PDF format most of the images in this web paper can be enlarged for greater detail.

Introduction

Geologists call the area that roughly includes the Coachella and Imperial Valleys of southern California, and the western half of the Mexicali Valley and the Colorado River delta in Mexico, the Salton Trough. This region of southern California and northwestern Mexico is an area of intense geological activity. The Salton Trough is a complex transition zone between the right-lateral motion of the San Andreas transform fault system, and the northwestward progressing spreading ridge complex of the Gulf of California segment of the Eastern Pacific Rise.

The East Pacific Rise is a tectonic spreading center between the Pacific and North American plates that has jumped inland from the Pacific coast and captured a portion of the North American plate. This captured sliver of land includes all of central and southern California west of the San Andreas fault, and all of the Baja Peninsula including the northern portion of Baja California east to the delta of the Colorado River. As the East Pacific Rise separated this land mass from the North American plate it formed the Gulf of California. Spreading faster at its southern end, it has formed a long narrow wedge between the mainland of Mexico and the Baja Peninsula. The northern tip of this tectonic wedge ends on dry land at San Gorgonio Pass near Palm Springs, California. The northern portion of the wedge from the pass southeast to the mouth of the Colorado River is the Salton Trough.

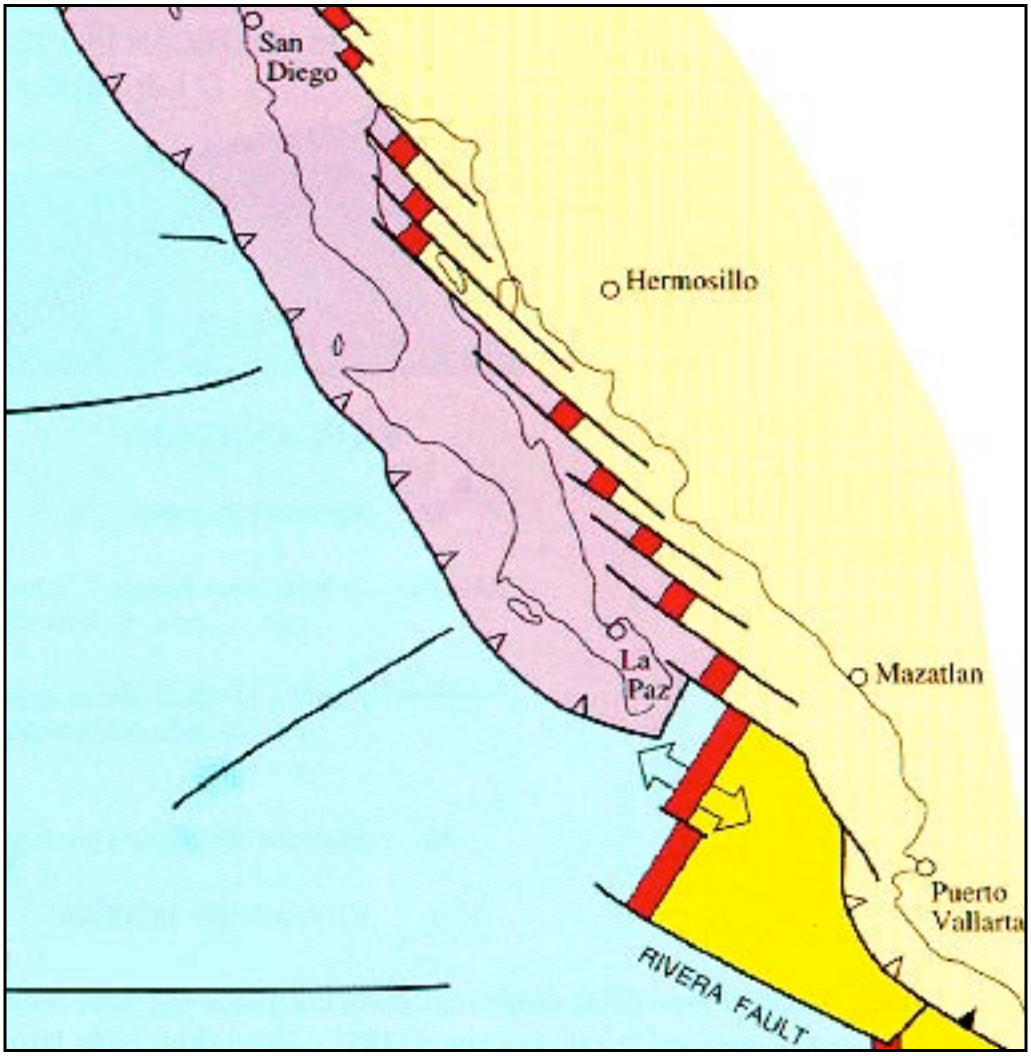
This region, at least as far north as Indio, California, 87 miles from the Mexican border, would be part of the Gulf of California today, had it not been for the sediments carried to the Salton Trough over millions of years by the Colorado River. But damming of the Colorado over the last 80 years has all but eliminated the flow of sediments to the gulf, radically changing the geologic balance between deposition and erosion in the delta of the Colorado River.

The Gulf of California, itself, is an oblique rift system with short spreading segments connected by long transform faults. Rifting in the gulf began ~12–15 million years ago when subduction ended west of the Baja California peninsula. As the East Pacific Rise approached the palaeo-trench, the subducting Farallon plate broke into a number of microplates; as subduction stalled, those microplates and the Baja California peninsula coupled to the Pacific plate, resulting in the onset of rifting. The peninsula now moves nearly completely with the Pacific plate, with ~ 48 mm/yr of spreading across the Gulf of California representing ~ 92% of Pacific–North America relative motion. (Lizarralde, et al., 2007)

3-D Visualization of the Gulf of California and Salton Trough

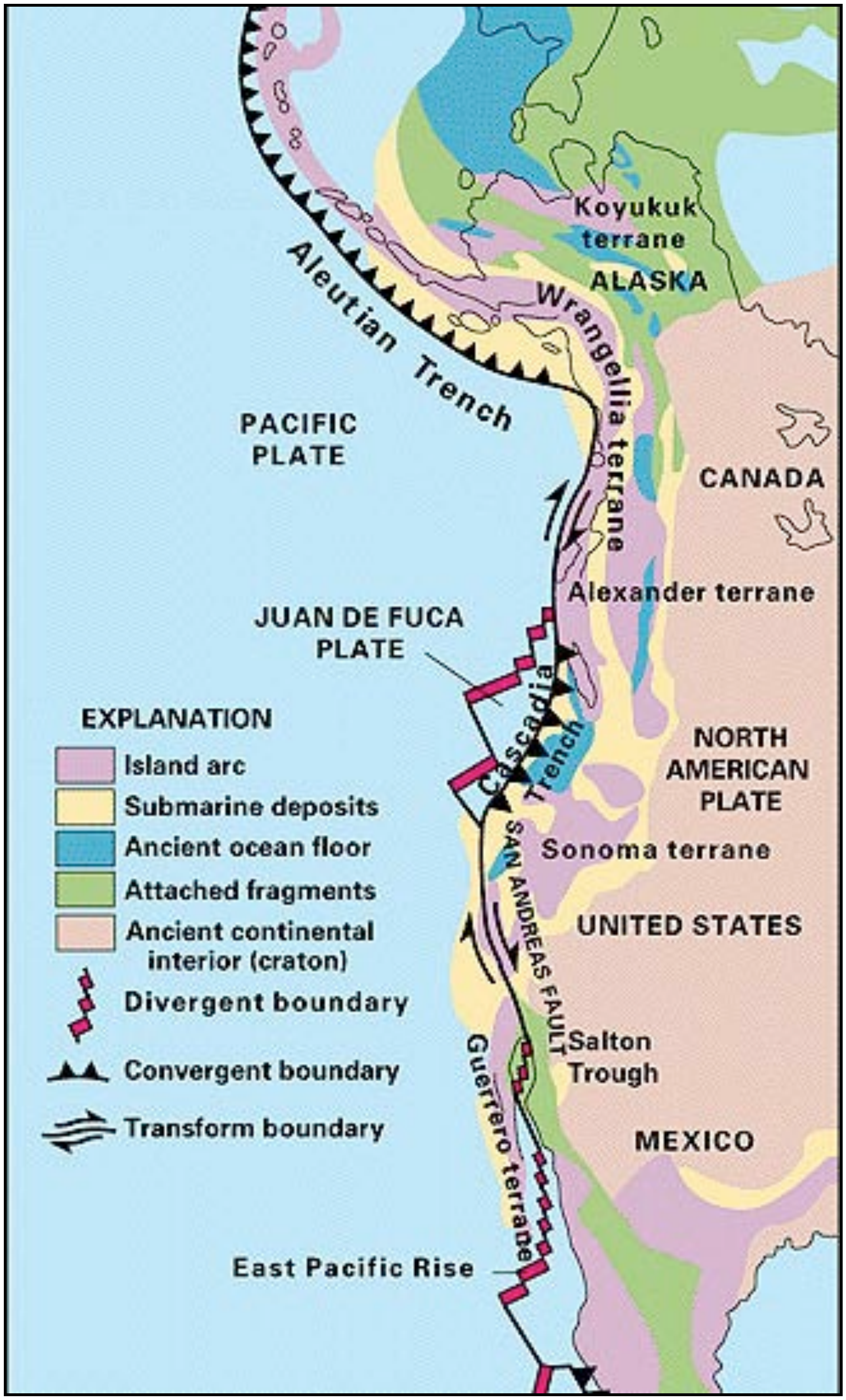
Approximately five million of years ago the East Pacific Rise, finally, split the Baja Peninsula from the mainland of Mexico. The waters of the Pacific then poured into the rift valley creating the Gulf of California. Since then, like a giant door swinging open, plate tectonic activity along the East Pacific Rise has moved the Baja Peninsula 162 miles (260 km) westward from the mainland at the southern end of the gulf. The northern “hinge” point of this tectonic system is in the Salton Trough.

(3-D map by Dave Miller)



Above is a map of the faults and spreading centers of the San Andreas fault system and East Pacific Rise that formed the Gulf of California. The San Andreas fault system is commonly referred to as the boundary on land 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 were once part of the North American.

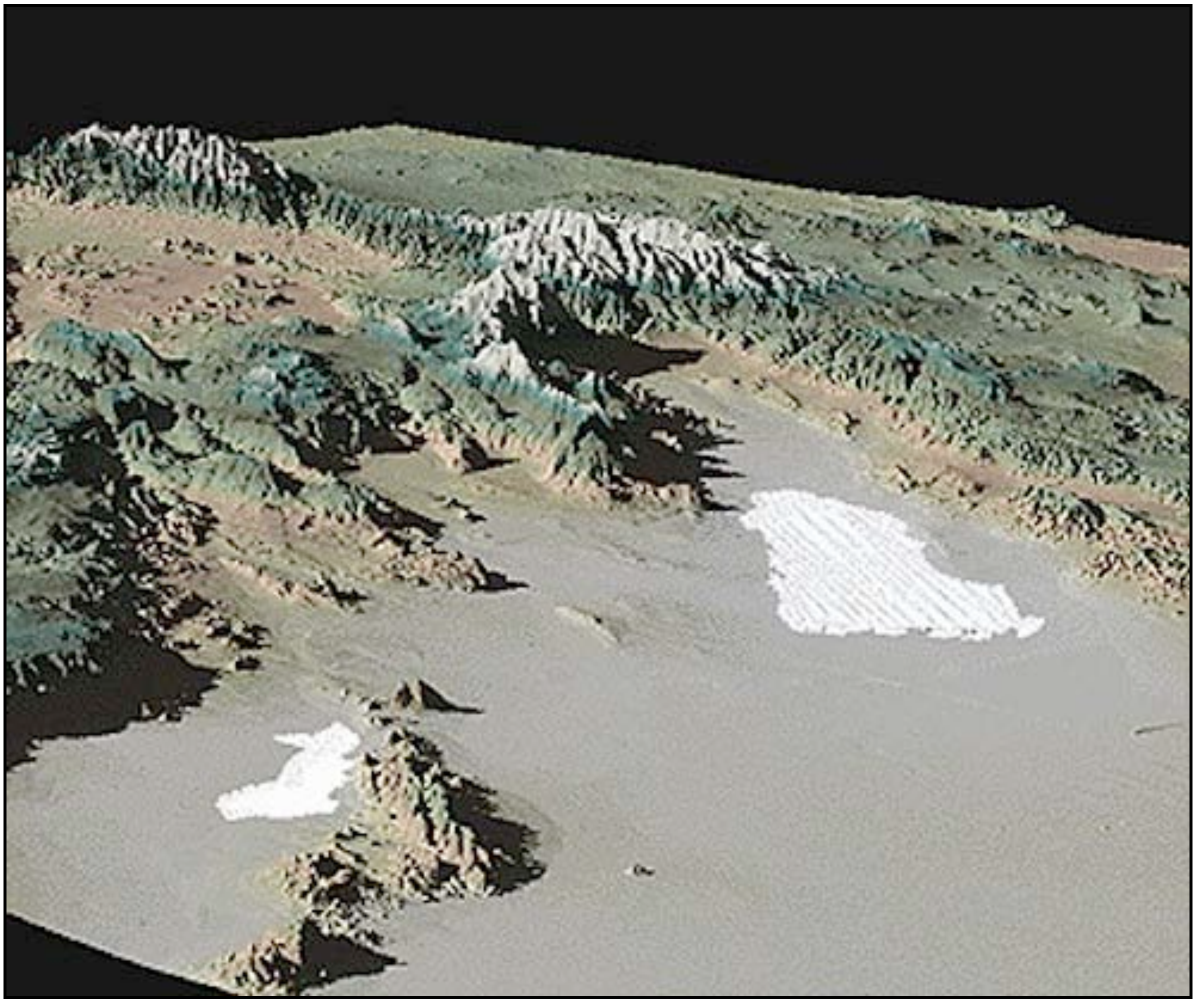
Web Reference
http://www.johnmartin.com/earthquakes/eqsafs/safs_381.htm



Western North America showing some important plate tectonics features and the mosaic of far-traveled exotic terranes plastered against the long-lived, stable interior of the continent. (Figure by Jack Cook, Woods Hole Oceanographic Institution)

Web Reference
http://pubs.usgs.gov/publications/text/dynamic.html

The Salton Trough, shown in this MODIS image acquired **February 9, 2002**, is the northern landward extension of the Gulf of California and is still undergoing active deformation and subsidence.

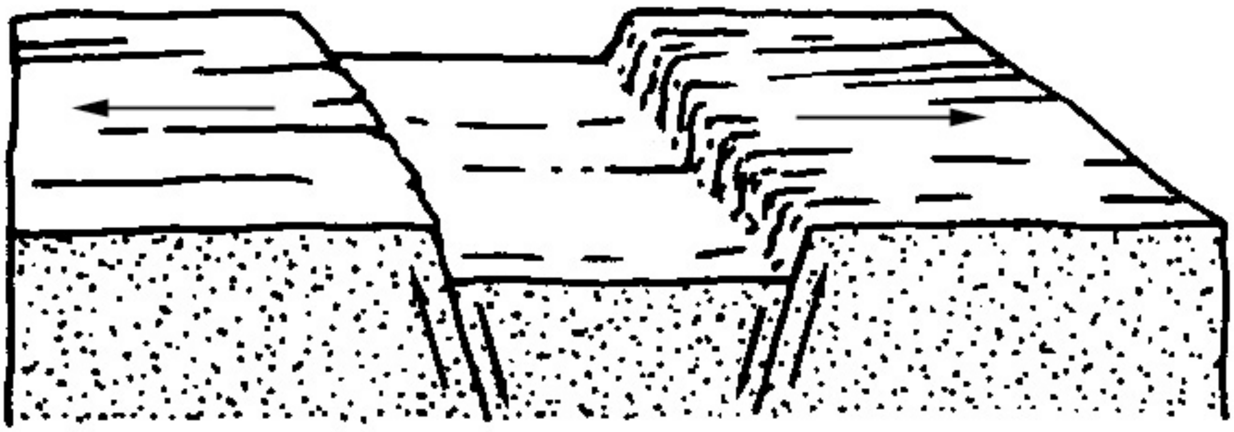


3-D Visualization of the Salton Trough looking north

The image above shows only elevation. Bright white is below sea level and includes the Salton Basin in the U.S. (right) and the Laguna Salada basin in Mexico (lower left). The mountains at the north end of the Salton Trough are the San Jacinto and San Bernardino mountains. Below and to the right of the Laguna Salada are the Sierra de los Cucapah and Sierra de Mayor mountains in Mexico.

The Colorado River may have begun filling the Salton Trough with sediments as early as five and a half million years ago. This date corresponds roughly to when the Colorado began to carve the Grand Canyon across the Kaibab plateau. The river delta rapidly spread southward across the north end of the gulf to its present position by four million years ago. Four million years later, the sediments form a natural dike between the waters of the Gulf of California and what is now the Salton Sea.

(3-D map by Dave Miller)



The Salton Trough is an example of what geologists call a graben (pictured above) which is German for "grave". A graben is a strip of land bounded on opposite sides by roughly parallel faults. Through movement of the faults, the strip of land sinks in a process called subsidence. In the case of the Salton Trough, the graben has been filled with sediments as it subsided. Although not restricted to them, grabens are characteristic of rift valleys. The Salton Trough is the northern end of a much larger rift valley formed by spreading and subsidence that runs the length of the Gulf of California.

The Colorado River delta itself is quite extensive. It covers 3325 square miles (8612 square kilometers) (Sykes, 1937), and is up to 3.5 miles (5.6 km) deep (Jenning and Thompson, 1986), containing over 10,000 cubic miles of the Colorado River's sediments from the last 2 to 3 million years. The sediments that were deposited by the river more than 2 to 3 million years ago have been shifted northwestward by movement along the San Andreas and related faults. (Winker & Kidwell, 1986)

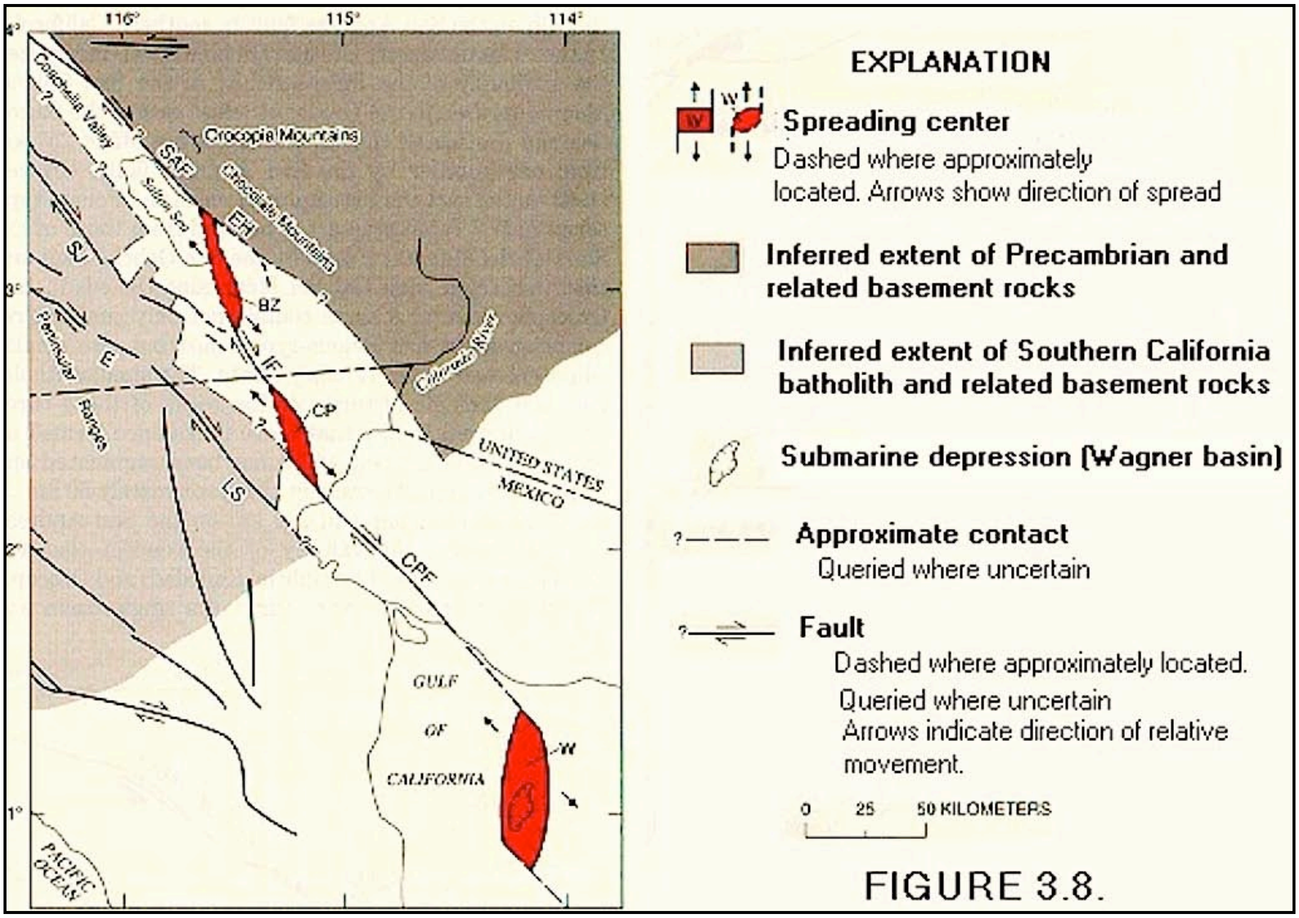


FIGURE 3.8. -Salton Trough and north end of the Gulf of California, showing major spreading centers and termination of the San Andreas fault. Spreading centers: BZ, Brawley seismic zone; CP, Cerro Prieto geothermal area; W, Wagner Basin. Major transform faults: CPF, Cerro Prieto; IF, Imperial; SAF, San Andreas. Other major faults: E, Elsinore; EH, East Highland Canal seismicity lineament; LS, Laguna Salada; SJ, San Jacinto.

As shown above in Figure 3.8 from Wallace (1990), the Salton Trough, which includes the Coachella and Imperial Valleys, widens toward the southeast, and the number of faults, and complexity of the zone, increases. The east wall of the trough is at the San Andreas fault system (see below). The west wall consists of plutonic rocks of the Peninsular Ranges including the San Jacinto, Santa Rosa, Agua Tibia, and Laguna mountains in the U.S. and the Sierra de Juarez mountains in Mexico. The fault system of the west wall includes the San Jacinto and Elsinore fault zones in the U.S., and the Laguna Salada and Sierra Juarez faults in Mexico.

Near the south end of the Salton Sea, the San Andreas appears to terminate as a transform fault at a spreading center called the Brawley seismic zone. This zone is the most northerly in a series of spreading centers distributed along the length of the Gulf of California which form part of the East Pacific Rise. The proximity of this spreading center accounts for the abundant young volcanic and geothermal features in the area, including the Cerro Prieto geothermal area in Mexico.

This geology of the San Andreas fault is based on the U.S. Geological Survey, Professional Paper 1515 titled *The San Andreas Fault System, California* edited by Dr. Robert E. Wallace and published by United States Government Printing Office, Washington in 1990 and 1991.

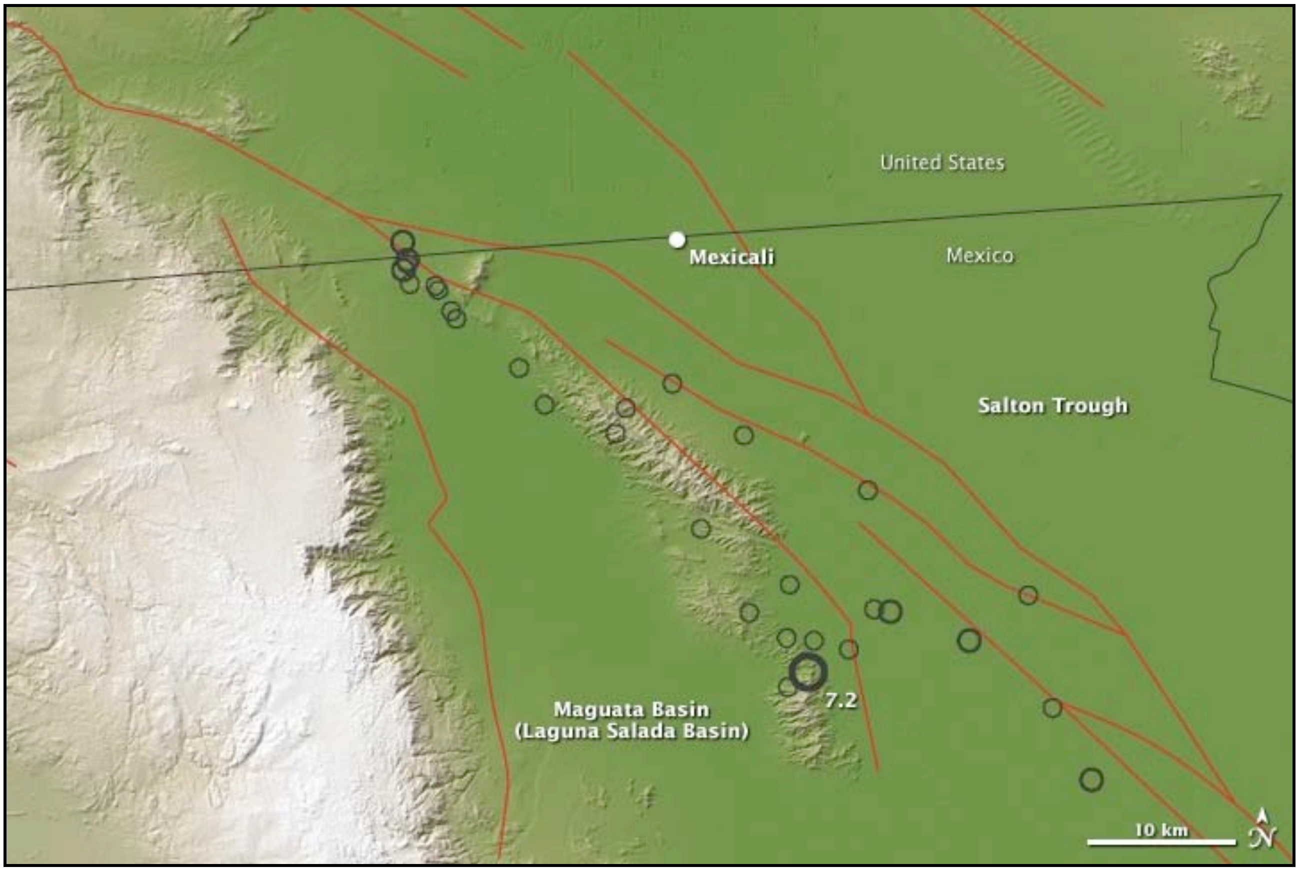
Web References

http://www.johnmartin.com/earthquakes/eqsafs/safs_361.htm

http://www.data.scec.org/

http://ceres.ca.gov/ceres/calweb/coastal/mountains.html

This image shows the approximate location of the faults and spreading centers that run through the Salton Trough.

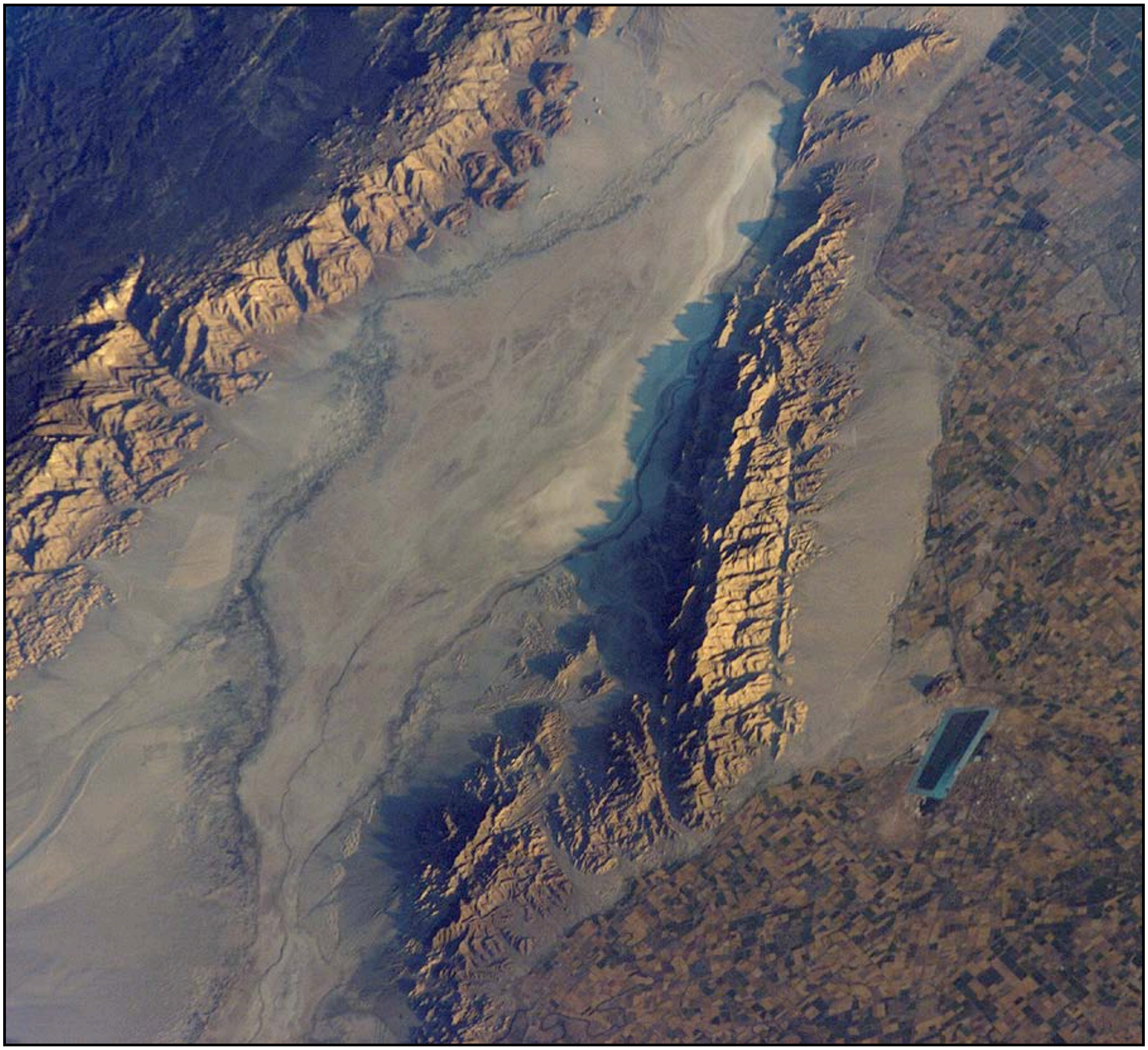


Magnitude 7.2 - Sierra El Mayor, Earthquake of 4 April 2010

The magnitude 7.2 Sierra El Mayor earthquake of Sunday April 4th 2010, occurred in northern Baja California, approximately 40 miles south of the Mexico-USA border at shallow depth along the principal plate boundary between the North American and Pacific plates. This is an area with a high level of historical seismicity, and also it has recently been seismically active, though this is the largest event to strike in this area since 1892. The 4 April earthquake appears to have been larger than the M 6.9 earthquake in 1940 or any of the early 20th century events (e.g., 1915 and 1934) in this region of northern Baja California.

Note that the quake's 7.2 epicenter is just southwest of the Cerro Prieto spreading center (see page above).

Web Reference
http://earthquake.usgs.gov/earthquakes/eqinthenews/2010/ci14607652/ - summary



Pictured above are the Sierra de los Cucapah (upper) and Sierra de Mayor (lower left) mountains running north south just right of center. The Laguna Salada basin is on the west side of the mountains and the Cerro Prieto Volcano, Lake, and geothermal area (lower right) are on the east side. The geothermal fields lie 25 miles (40 km) southwest of Mexicali, Baja California. The mountains on the west side of the Laguna Salada are the Sierra de Juarez. The basin of the Laguna Salada is a graben formed by the Laguna Salada fault on the east side and the Sierra Juarez fault on the west.

(**May 23, 2002**, ISS photograph courtesy of NASA)

In the image above the Cerro Prieto Volcano is the round dark area top left of center. The jade green wastewater surface ponds (Lake Cerro Prieto) of the Cerro Prieto geothermal field are center left. The three thermal generating plants are below and to the right of the ponds.

(**February 12, 2001**, ISS photograph courtesy of NASA)

The Cerro Prieto geothermal field generates 620 Megawatts of electric power and in the process pumps 2.6 million gallons (U.S.) (11,000 metric tons) of brine water from underground per hour that is disposed of in surface ponds. Evaporation removes most of the water quickly leaving approximately 1300 metric tons of silica waste as the residual product from this hourly production of brine. At present, there is no use for this waste silica.

The geothermal fields supply electricity to a large portion of Baja California, Mexico, including the city of Mexicali with a population of approximately 900,000. The Cerro Prieto geothermal area ranks as second largest in the world in terms of geothermal power generated.

(Photograph by Carolyn Glockhoff
courtesy of San Diego Association of Geologists)

Web Reference
http://www.sandiegogeologists.org/Geothermal2.html

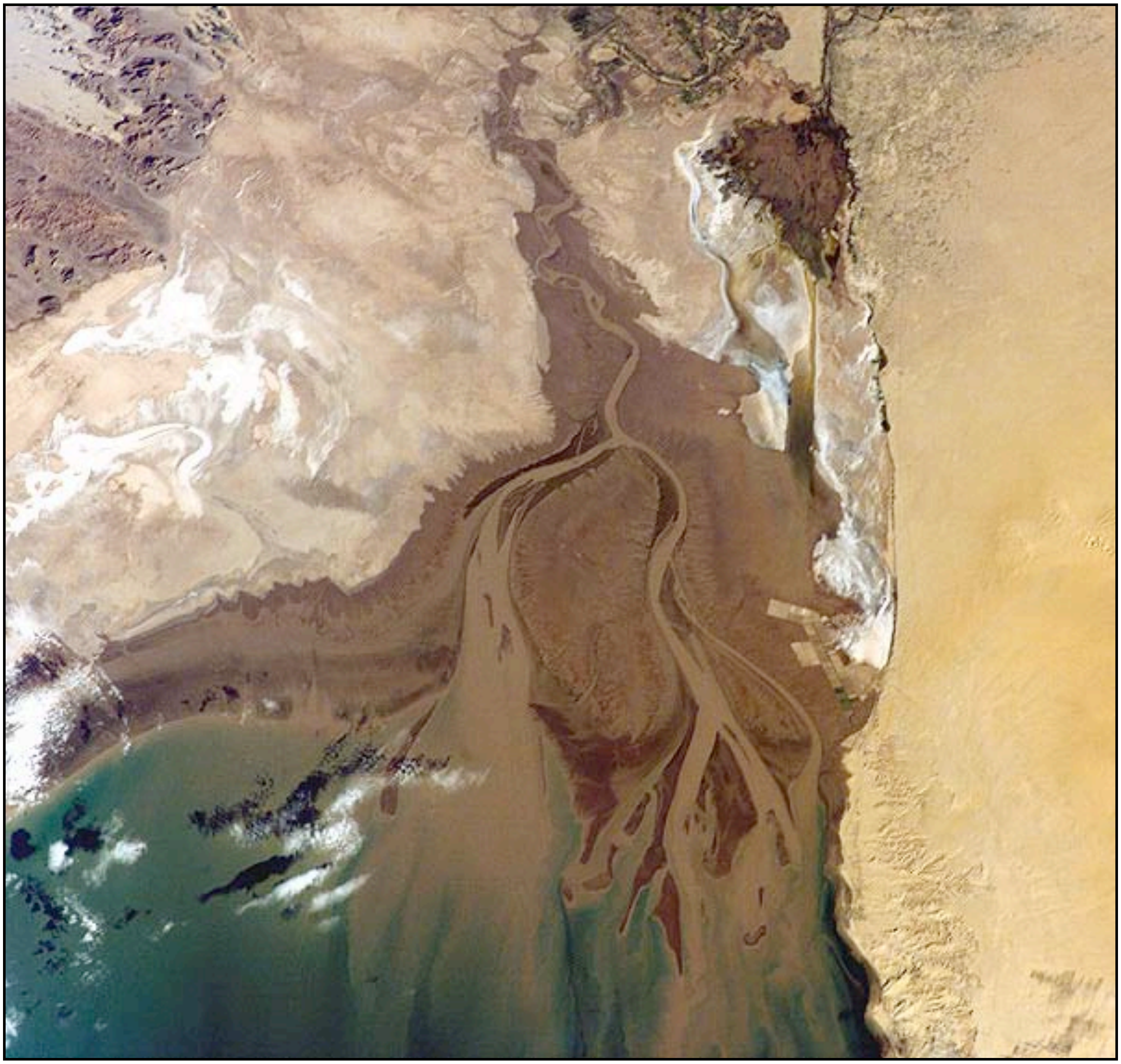
In this image taken **February 22, 2003**, the Cerro Prieto fault runs from the Cerro Prieto geothermal fields (center right) southeast to the Ciènega de Santa Clara (center left). Today the Colorado River normally runs dry in the dark purplish area (above and right of center) at the base of the Sierra de Mayor.

(ISS image courtesy of NASA)

Mouth of the Colorado River June 28, 2001

The dark area above left is the saltwater marsh the Ciènega de Santa Clara. The Cerro Prieto fault runs along the east edge of the marsh and salt flats and into the gulf. The Desierto del Altar, on the eastern side of the fault, lies on the North American plate, while the delta of the Rio Colorado and the Ciènega de Santa Clara lie on the Pacific plate. Movement along the fault is both displacement sideways, the delta is moving northwest relative to the North American plate, and subsidence, the delta region is dropping relative to the Desierto del Altar.

(ISS image courtesy of NASA)



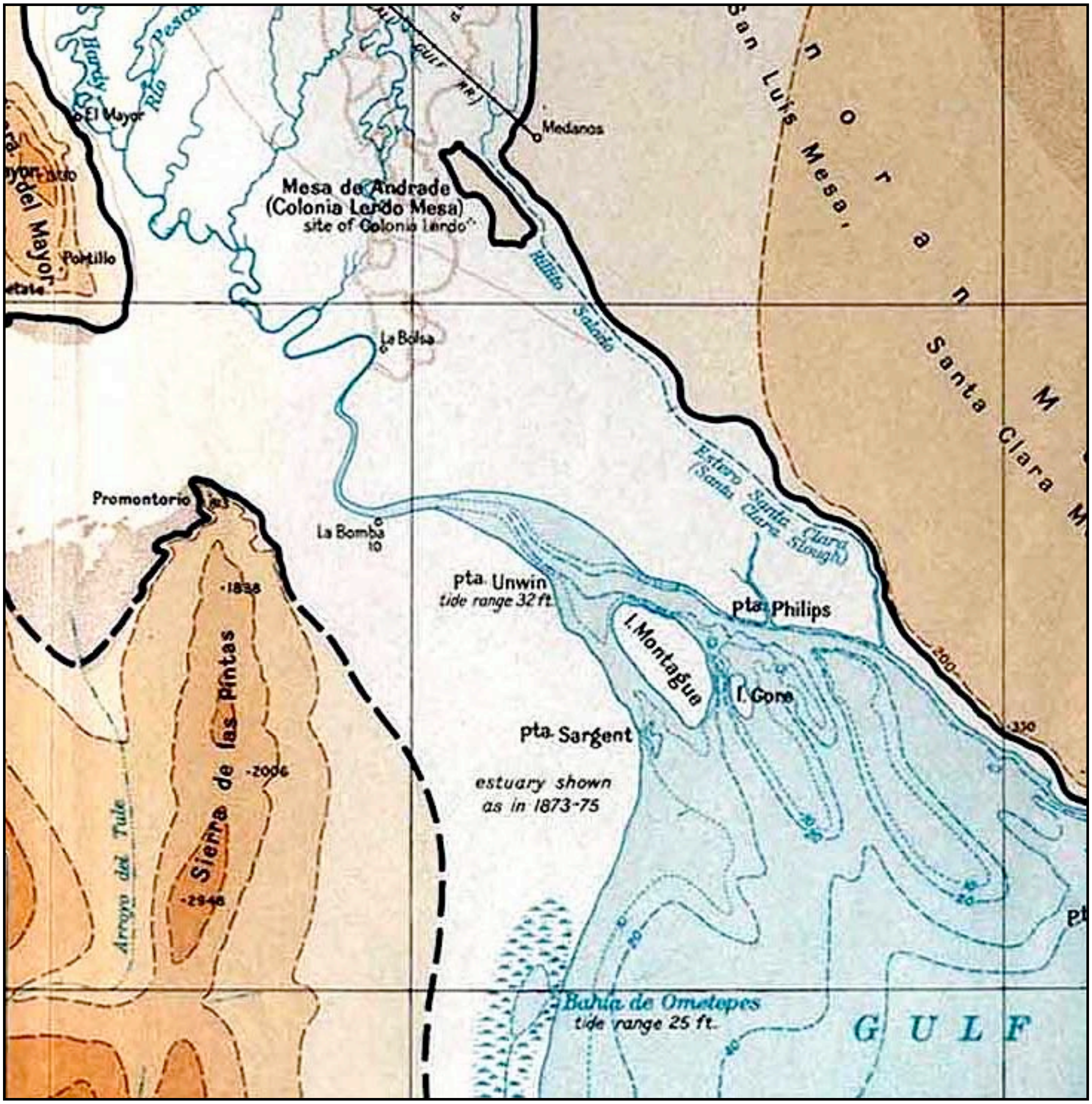
The Mouth of the Colorado River Delta April 27, 2002

The mud flats of the Colorado River delta experience one of the highest tidal ranges in the world—up to 10 meters (about 32 feet), an ebb and flow that extends the tidal estuary 34 miles (56 km) or more upriver and spread over 81,500 acres. In the past, this macro-tidal system was greatly influenced by fresh water flow from the river, but now, at its mouth, the former bed of the Colorado serves only as a channel for tidal surges. April 27, 2002, had a tidal range of ~24 feet (7.3 meters) and was the day after a full moon. Highest tide for the day was 11.81 ft (3.6 m) above mean sea level.

(ISS image courtesy of NASA)

This view of the Colorado River delta was taken from the International Space Station (ISS) on **June 2, 2004**. In the image the higher mud flats are gray colored and the intertidal zone dark brown. At the highest tides the intertidal zone extends over a much larger area and completely inundates Isla Montague as shown in the previous image.

Web Reference
http://earthobservatory.nasa.gov/IOTD/view.php?id=4610



This 1933 map of the delta shows the estuary as it was in 1873-75. Note that Isla Montague is shown but not Isla Pelícano. It does, however, show an Isla Gore which is now the southern portion of Isla Montague. Where Isla Pelícano is now is shown as a shoal at a depth of 10 feet (3 m). This gives an indication of how much the islands have changed. Note that the tidal range is given as 32 feet (9.75 m) at a point just north of Isla Montague.

(Map courtesy of the Carnegie Institution)

This image shows Isla Montague at the mouth of the Colorado River with Isla Pelícano above it on **May 17, 2002**. Since the diversion of most of the river's fresh water, the estuarine circulation is now driven by the evaporation of gulf water in the river's mouth. High evaporation rates generate dense, saline water that sinks and flows along the bottom into the upper gulf, while relatively less dense seawater flows toward the estuary near the surface.

(ISS image courtesy of NASA)

In March of 2003, geologist Karl Flessa of the University of Arizona at Tucson, shown above along one of the inlets at the river's mouth, found that the delta's salinity level is nearly twice as high as normal. The extreme salinity is believed to be endangering the clam species, *Mulinia coloradoensis*. Flessa has done extensive studies of the clam species of the delta and their historical role in the delta's ecology.

(Photograph by R. Dalton courtesy of the journal *Nature*)

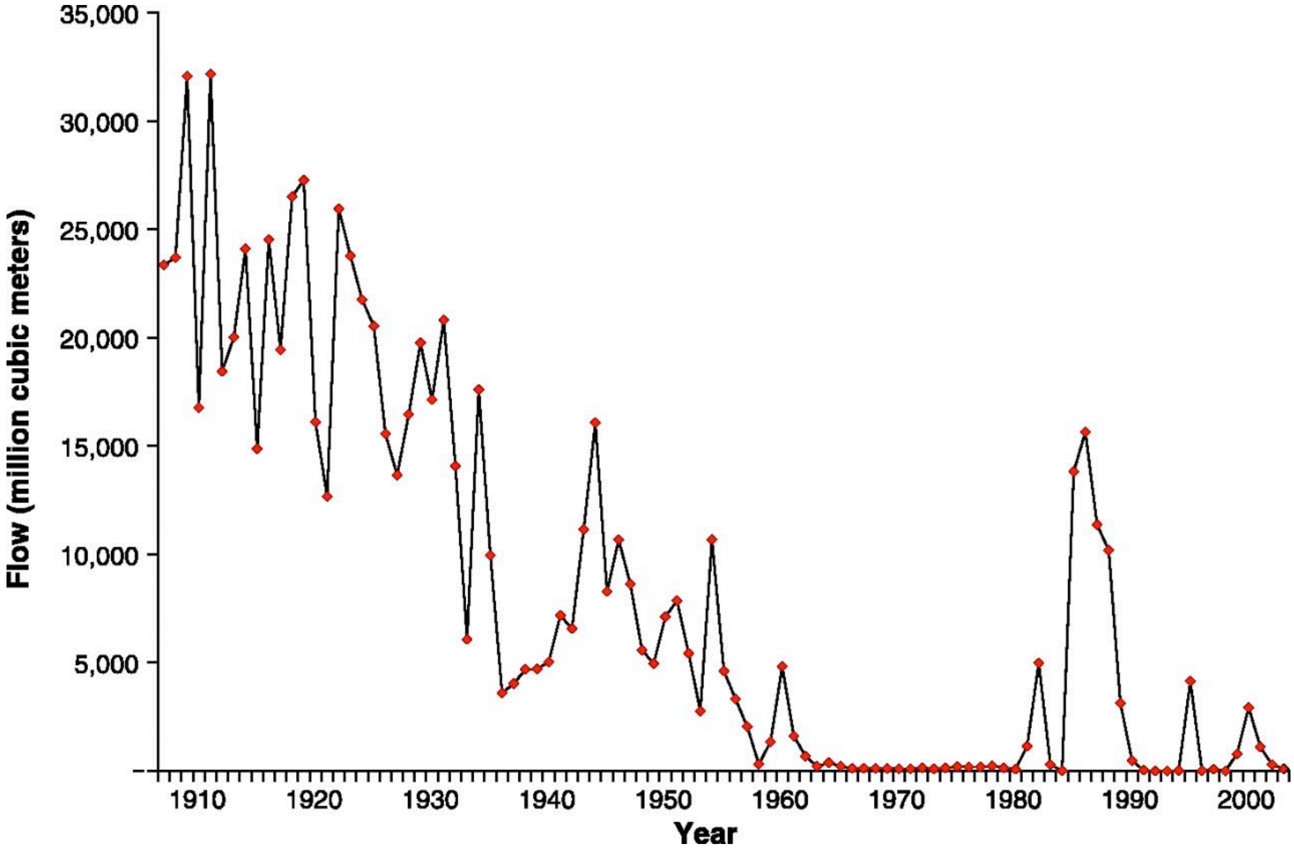
Web Reference
http://www.geo.arizona.edu/ceam/Hecold/hecolcd.htm

Isle Montague and Isla Pelícano at the mouth of the Colorado River
March 12, 2002

Upstream dams and diversion projects have trapped and diverted much of the Colorado's sediment load. The river once delivered approximately 160 million metric tons of sediment to the delta every year. The sediment load today is almost zero. Waves and tidal currents are now eroding the previously deposited fine-grained sediments.

(ISS image courtesy of NASA)

Web Reference
http://earthobservatory.nasa.gov/IOTD/view.php?id=1291



Colorado river flows below all major dams and diversions, 1905 to 2001. Data are flows of the Colorado River as measured at U.S. Geological Survey Gage 09-5222, 35 km downstream from Morelos Dam. As shown, flows reaching the Colorado River delta have dropped to near zero in most years. (Figure 1 from Gleick 2003)

The delta of the Colorado River is now in a "destructive" phase with erosion replacing deposition. This sediment reworking is responsible for the high turbidity seen in the upper gulf, as shown in this image taken in **June of 2002** and the following image. Ironically these eroded sediments are, for the present, replacing part of the nutrients that the river once delivered, thus maintaining high levels of productivity in the waters of the upper gulf even without the river's flow.

(ISS image courtesy of NASA)

MODIS True Color image of the Upper Gulf of California **November 30, 2003**
Circulation in the upper gulf is generally counter-clockwise.

(Image courtesy of NASA)

November 30, 2003, El Golfo Tidal Range 8.2 ft (2.5 m)
Highest tide of the day 4.69 ft (1.43 m) above mean sea level.

November 30th was the first quarter moon. Maximum tidal range for November 2003, was 24.8 ft (7.56 m) on the 23rd, the day of the new moon. This may explain the high turbidity of the upper gulf as caused by the high tides of the week before, during the new moon. Highest tide for the 23rd was 12.47 ft (3.80 m) above mean sea level. The 23rd also had one of the greatest tidal ranges of the year. There are no satellite images of the delta available for November 23rd. Tide information is based on tide tables from El Golfo de Santa Clara (31.6500° N, 114.5833° W) approximately 15 miles (24 km) southeast of Isla Montague.

(MODIS/Terra image courtesy of NASA)

September 18, 2003, El Golfo Tidal Range 4.36 ft (1.33 m)
Highest tide of the day 1.94 ft (0.59 m) above mean sea level.

This view shows Isla Montague and Isla Pelícano during a period of very little tidal range. A two day tide series the 18th and 19th of September had a maximum tidal range of 5.87 ft (1.79 m) and morning of the 18th saw almost no change between high and low tide. The 18th was the last quarter moon. By comparison maximum tidal range for September 2003 was 23.59 ft (7.19 m) on September 26th.

(MODIS/Terra image courtesy of NASA)

September 26, 2003, El Golfo Tidal Range 23.59 ft (7.19 m)
Highest tide of the day 11.81 ft (3.6 m) above mean sea level.

This view shows Isla Montague and Isla Pelícano completely inundated by high tide. The 26th was the day after a full moon. Maximum tidal range at El Golfo for September 2003, was on the 26th.

(MODIS/Terra image courtesy of NASA)

Sediment Loss in the Colorado River Delta

The upper Gulf of California is defined oceanographically by the mid-rift islands that separate the northern portion from the rest of the gulf. Fresh water flow into the northern gulf through the Colorado River has decreased by more than 90% since the building of the dams in the U.S.. Today, water flow is much more seasonal and sporadic than it had been earlier and sediment transport and nutrient input have been cut dramatically. Flow models suggest that low salinity surface waters extended far into the upper gulf before the dams were built. Now, and throughout most of the year, the delta is a negative (hyper saline) estuary. The tidal range in the northern gulf is huge, up to 10 meters in some of the delta channels, with measured tidal currents of 3 meters per second in the channels and 0.8 meters per second in the upper gulf itself.

Despite the decrease in Colorado River inputs, nutrient levels in the entire northern gulf remain above those levels that are thought to limit phytoplankton growth. High chlorophyll pigment concentrations and primary productivity have been measured in the upper gulf year-round. In the delta estuary, heterotrophic (bacterial) biomass and productivity are actually higher that those values for the autotrophs (algae). Based on limited samples, zooplankton densities also appear very high in the upper Gulf of California.

Currently, the loss of sediments in the Colorado River delta due to tidal currents and wave action is much greater than the accretion of sediments by river transport. The net effect is that the delta has entered a destructive phase. In the short term, however, there have been no catastrophic effects from the loss of river input on the oceanography of the northern gulf. Nutrient concentrations and productivity are high. The problems related to depletion of fish stocks and endangered species (such as the totoaba and the vaquita) in this area are the result of inadequate fisheries management, not the lack of freshwater or nutrient input. However, because nutrients captured in sediments may be contributing to the northern gulf's high productivity, and there is a net loss of sediments, the long term future of the upper gulf is uncertain.

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Geology of the Imperial Valley, California, a Monograph by Eugene Singer
http://fire.biol.wwu.edu/trent/alles/SingerImperialValley.pdf

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