# The Salton Trough Rift

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## ABSTRACT

**The Salton Trough rift is manifested geomorphically as the Imperial Valley in southern California and the Mexicali Valley in northern Baja California. These valleys are major areas for agriculture, game fish, and waterfowl migration and management. Major nonrenewable resources include metallic minerals (primarily gold) and industrial minerals (primarily gypsum and aggregate). Two of the world's largest liquid-dominated geothermal energy fields are located in the rift: the Salton Sea field in California and the Cerro Prieto field in Mexico. The Salton Trough is an active continental rift, underlain by a fragmented oceanic ridge spreading system into which has been deposited the delta of the Colorado River. Deposition of the delta has significantly influenced the character of mineralization in the rift. The combination of magmatic heat sources, thick porous sediments, tectonic activity, and saline lakes has provided a unique environment for the accumulation and movement of metalliferous hydrothermal brines.**


## TECTONIC EVOLUTION OF THE GULF OF CALIFORNIA AND SALTON TROUGH

The Salton Trough (Fig. 1) is located within a unique tectonic transition zone between the divergent tectonics of the East Pacific Rise (which dominate the Gulf of California) and the strike-slip tectonics of the San Andreas fault system (which dominate California) (Fig. 2). Presently, Baja California and the portion of California west of the modern San Andreas fault system are part of the Pacific plate, moving northwest relative to the North American plate.

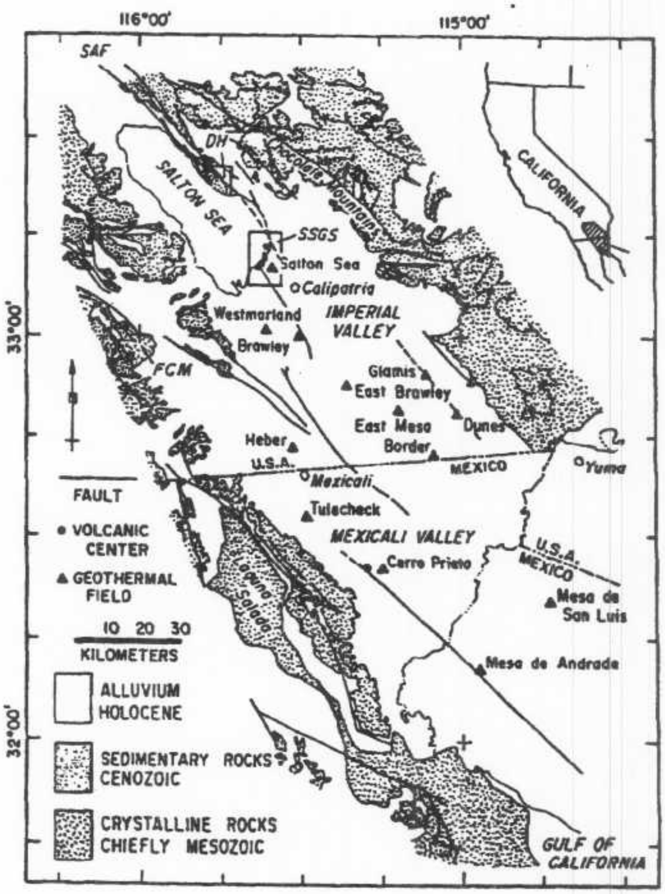


**Figure 1. Map of the Salton Trough, showing features discussed in the text. SAF=San Andreas fault, SSGS=Salton Sea Geothermal System, FCM=Fish Creek Mountains, DH=Durmid Hills.**

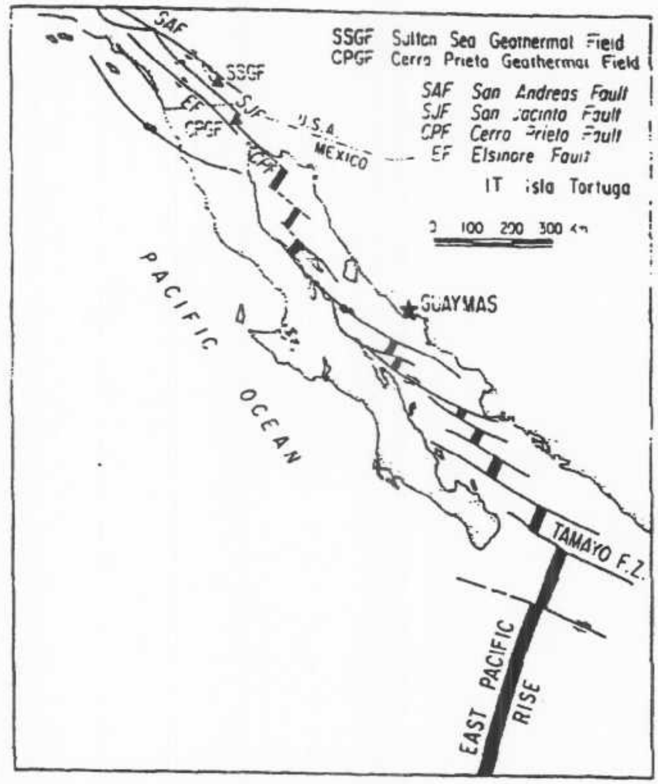


**Figure 2. Map showing plate tectonic features of Southern and Baja California.**

Comprehensive reviews of the regional Tertiary geologic evolution can be found in Elders and others (1972), Elders (1979), Fuis and others (1982) and Lonsdale (1989). Prior to the end of the Miocene, the area corresponding to the Gulf of California largely consisted of an andesitic volcanic arc overlying the zone of subduction of the Farallon plate under the North American continent. Near the end of the Miocene, the spreading center separating the western Farallon plate from the eastern Pacific plate was obliquely subducted under the North American continent. This resulted in a complex series of tectonic changes that essentially "captured" Baja California and part of southern California, rafting them away from the North American plate (Lonsdale, 1989).

The environment for formation of the modern Gulf of California and Salton Trough was set at about 12 Ma, when subduction ceased and an inland belt of east-west extension, alkali basalt volcanism, and subsidence and basin sedimentation was initiated. Marine evaporites in the Fish Creek Mountains (Fig. 1) and marine sediments in the Yuma Basin may have formed by early incursion of seawater into these proto-Gulf structures. The shear zone comprising the principal tectonic boundary between the Pacific and North American plates appears to have shifted about 250 km inland into this weakened belt by about 6 Ma, and the opening of the modern Gulf of California and Salton Trough began.

Because of the 10-20° angle between the shear zone and the relative motions of the pacific and North American plates, the Gulf of California and Salton Trough are characterized by oblique rifting that is distinct from more typical styles of continental rifting (Lonsdale, 1989). The modern tectonics are dominated by a series of *en echelon* transform faults connecting spreading center fragments (Fig. 2).

It appears that the highest intensity modern hydrothermal systems tend to occur in sediment-filled pull-apart basins (rhombochasms) overlying these spreading center fragments (e.g. Salton Sea, Cerro Prieto, Guaymas Basin) (Fig. 3). These systems exhibit high heat flow, strong gravity and magnetic anomalies, and often have surface manifestations such as Quaternary volcanoes and mud pots.

Lower intensity hydrothermal systems such as Dunes, Heber and East Mesa (figs. 1, 3), and their fossil analogs such as the Modoc

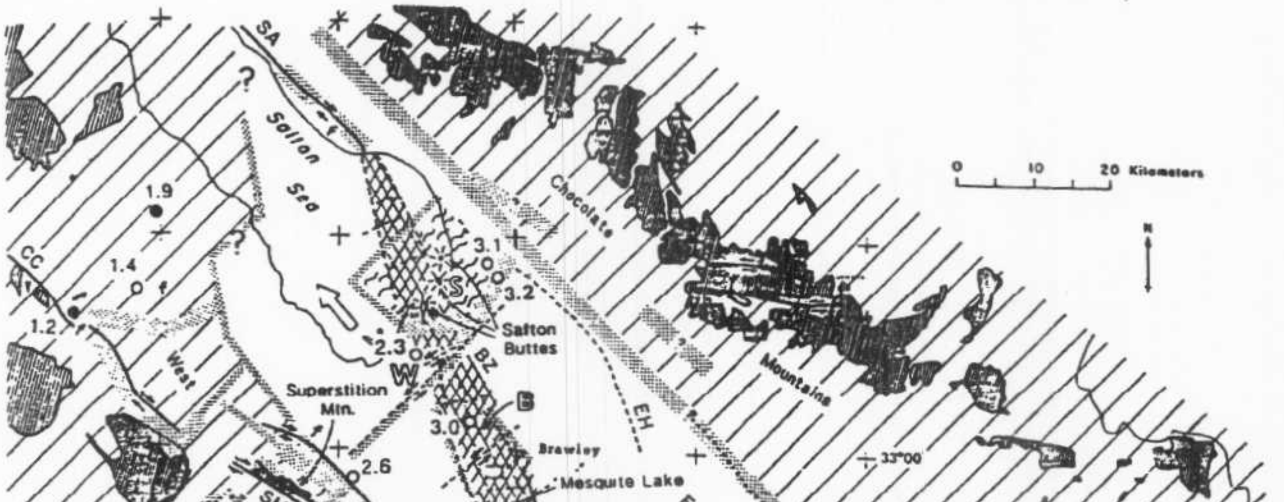


Figure 3. Structure and tectonic summary map of Salton Trough (Figure 6 from Fuis and Kohler, 1984). Circles denote wells with depths in km: open circles penetrated only Cenozoic sedimentary rocks, filled circles penetrated crystalline rocks. Outcrops of pre-Cenozoic crystalline basement are indicated by closely spaced lines; inferred extent of crystalline basement beneath Cenozoic sedimentary rocks is indicated by widely spaced lines. Zones with high (greater than 16%) gradient in depth to basement are indicated by stippled bands of different lengths. "f" refers to areas of Cenozoic folding and/or reverse faulting. Geothermal fields are indicated by block letters:S=Salton Sea, W=Westmorland, B=Brawley, H=Heber, EM=East Mesa, CP=Cerro Prieto. Seismic zones are crosshatched: BZ=Brawley seismic zone, CZ=Cerro Prieto seismic zone. Wavy lines indicate apparent basement shallowing under geothermal fields. Large open arrows indicate direction of spreading in Brawley and Cerro Prieto spreading centers.

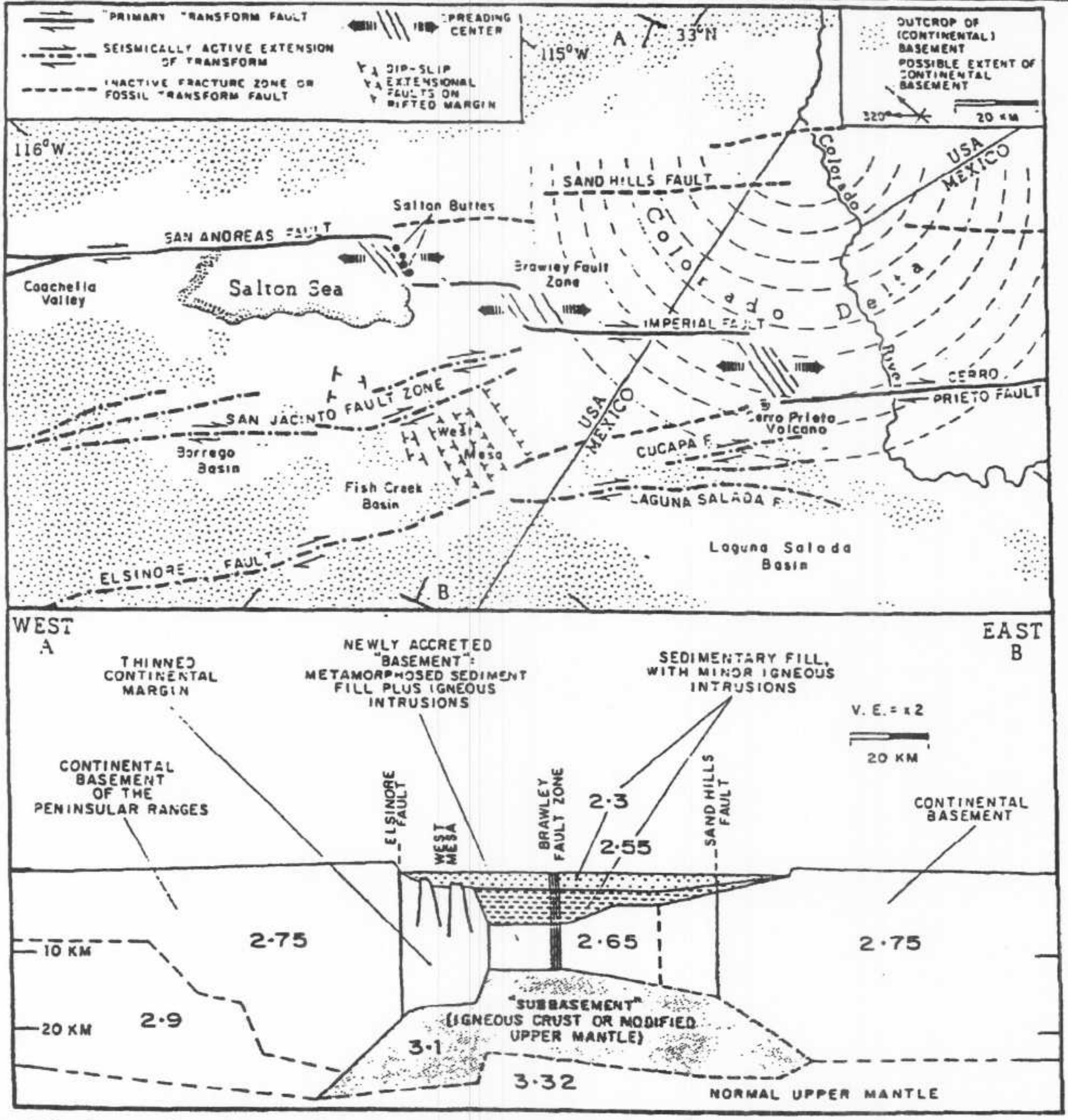


**Figure 4. Sketch map and crustal section of the Salton Trough (Fig. 6 from Lonsdale, 1989, modified from Fuis et al., 1982). Dashed boundaries in the section are controlled by gravity modeling only (not by refraction). Numbers are estimated densities (g/cm³).**

Prospect (Hillemeyer and others, 1991; Van Buskirk and McKibben, this volume) tend to occur along more rift-marginal normal and strike-slip faults, where shallow ground and lake waters are conductively heated above basement highs. In the case of Modoc, structural control along reactivated portions of an older rhombochasm may have been important. Typically these systems have little surface expression and only moderate geophysical signatures. Some are gold-bearing.

## SEDIMENTATION IN THE SALTON TROUGH

As the Salton Trough has opened, it has been filled with sediment derived from the delta of the Colorado River. The river has been building its delta from the east into the trough since about 5 Ma, and sedimentation has apparently kept pace with subsidence. Beginning about 4 Ma the delta had prograded southwestward (transaxially) across the Salton Trough (Fig. 4), so that no marine sediments younger than this are found in the now hydrologically closed northern trough (Winker and Kidwell, 1986). Since then, waters of the Colorado River have alternately flowed north and south through time, resulting in the repeated generation and desiccation of freshwater lakes (collectively termed Lake Cahuilla) in the northern

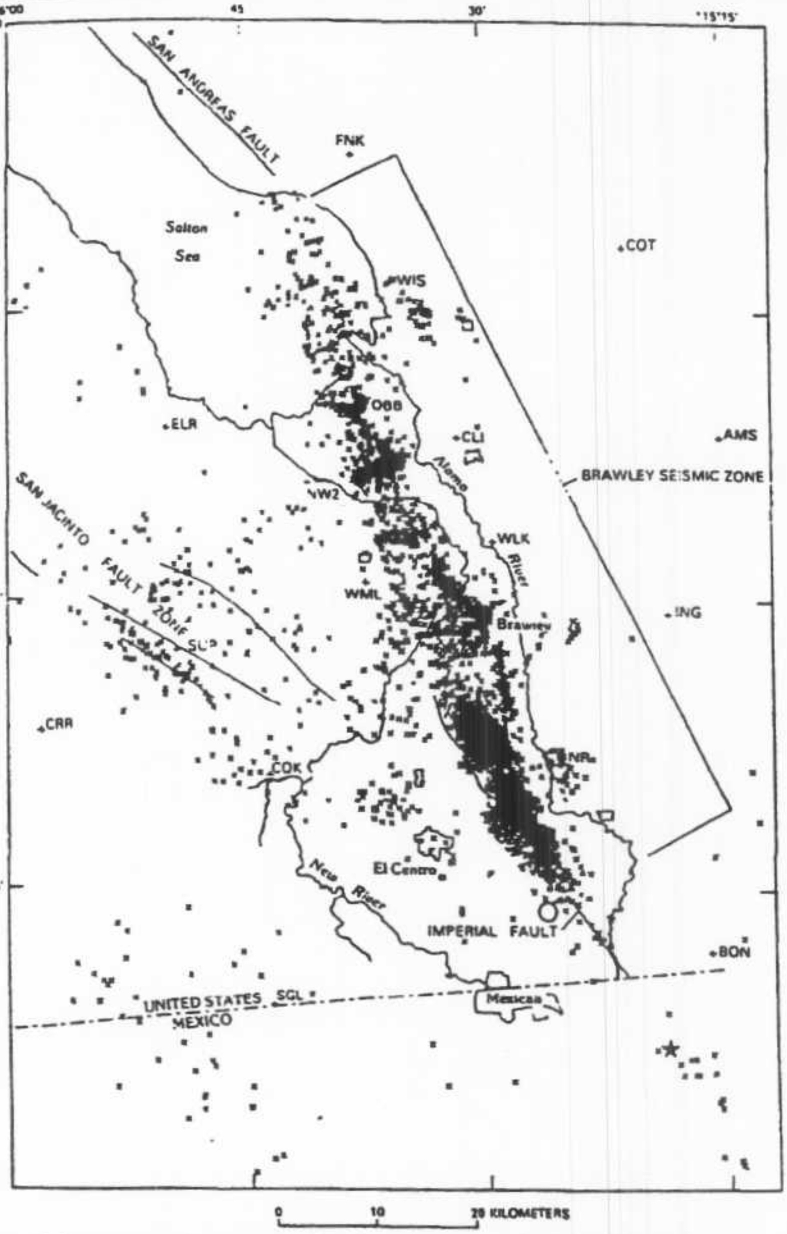


**Figure 5. Seismicity of Imperial Valley, from Johnson and Hill (1982, Figure 7). Shown are all epicenters with horizontal location errors less than 2.5 km (A- and B- quality solutions) for interval June 1973 through November 1978. Circle north of Mexicali marks instrumental epicenter of 1940 Imperial Valley earthquake , dot at left edge of 1942 Superstition Mountain earthquake ($M_L$ = 6.5), and star in lower right corner of 1979 Imperial Valley earthquake. Letters refer to station localities in southern California seismic network.**

trough. This lacustrine evaporitic environment has dominated Pliocene and Quaternary sedimentation in the northern trough, resulting in the downward percolation and accumulation of saline formation brines ("rift basinal brines") which characterize the Salton Sea and Brawley geothermal systems (McKibben and others, 1988; Osborn and others, 1988; Williams and McKibben, 1989).

Crustal spreading and accompanying subsidence continues in the central part of the trough, where sediments accumulate at rates of 2-3 mm/yr. Along the margins of the trough, equivalents of these young sediments are being uplifted near strike-slip faults. For example, in the Durmid Hills east of the Salton Sea (Fig. 1) (Babcock, 1974), movements along the San Andreas fault have exposed tightly folded but unmetamorphosed Pleistocene lacustrine evaporite sediments. These sediments are laterally equivalent to undeformed metasediments found at depths of 2 km in the Salton Sea geothermal field (Herzig and others, 1988), where they have been metamorphosed into greenschist and amphibolite facies hornfelses. This contrast in the deformation and metamorphism of stratigraphically equivalent sediments reflects the rapid and diverse tectonics of the rift.

## DEEP STRUCTURE OF THE TROUGH

Fluvial and lacustrine sediments have been penetrated in the central part of the northern trough by drilling to depths of at least 4 km. Seismic refraction measurements (Fuis and others, 1982) suggest that north of the present delta apex, about 4 km of sediments overlie about 10 km of "basement" crustal rocks, which may consist of metamorphosed post-middle Miocene sediments (Fig. 4). Because sediments may have been densified by hydrothermal metamorphism, however, seismic distinctions between metasediments and mafic intrusions related to the crustal spreading may be difficult. Dikes and sills of MORB-type basalt and diabase are encountered in several geothermal wells at depths of 2-4 km (Elders, 1979; Herzig and Elders, 1988). A high-velocity "subbasement" layer at least 10 km thick lies beneath the 14-15 km of sediments; it may be an igneous crustal layer (Fuis and others, 1982) or altered upper mantle (Nicolas, 1985).

Quaternary rhylitic domes near the Salton Sea contain xenoliths of granitic rocks, but recent Sr isotopic data and U-Pb age dates on zircons indicate ages of less than 100,000 years (Herzig and Jacobs, 1991). These are thus cognate xenoliths related to the rhyolitic domes. There is no evidence for significant amounts of older granitic continental crust underlying the central part of the Salton Trough.

## SEISMIC ACTIVITY

Five major earthquakes have occurred in the Salton Trough this century (Fig. 5) (Ellsworth, 1990). The Cerro Prieto fault ruptured in November, 1915 (magnitude 7.1), resulting in a steam eruption at Volcano Lake near the fault's northern terminus. The fault moved again in December, 1934 (magnitude 7.0). In May, 1940, the Imperical Valley earthquake (magnitude 7.1) generated a surface rupture at least 60 km long, showing a peak right-lateral offset of 7 m at the U.S.-Mexico border. This quake resulted in the discovery of the Imperial fault (Fig. 4). In October, 1979 the northern part of this fault moved again (magnitute 6.5) with 30 km of surface rupture and 1 m of strike-slip offset. The Superstition Hills fault moved in November, 1987 (magnitude 6.6), rupturing along its entire length with offset along numerous conjugate faults at its northern terminus. A distinct pattern of shallow (<7 km) microearthquake swarms, probably caused by dike intrusions, can be distinguished from deeper shocks related to regional strike-slip motions (Hill and others, 1990).

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