Geology of the Imperial Valley California

A Monograph
by Eugene Singer

The Imperial Valley is located about 150 miles southeast of Los Angeles. It is a section of a much larger geologic structure -- the Salton Trough -- which is about 1,000 miles in length. The structure extends from San Gorgonio Pass southeast to the Mexican border, including the Gulf of California and beyond the tip of the Baja California Peninsula. The surrounding mountains are largely faulted blocks of the Southern California batholith of Mesozoic age, overlain by fragments of an earlier metamorphic complex. The valley basin consists of a sedimentary fill of sands and gravels ranging up to 15,000 feet in thickness. The layers slope gently down-valley, and contain several important aquifers. The valley is laced with major members of the San Andreas Fault system. Minor to moderate earthquake events are common, but severe shocks have not been experienced in recorded history. The entire trough, including the Gulf is an extension of the East Pacific Rise, a zone of separation in Earth's crust. Deep sea submergence instruments have observed many phenomena of crustal formation. The axis of the Rise, hence of the Salton Valley as well, is a great transform fault that is having the effect of separating an enormous slab of North America, consisting of the Baja Peninsula and coastal California away from the mainland, with movement to the northwest and out to sea as a terranne.

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CHAPTER 1
THE SAN JACINTO AND THE SANTA ROSA MOUNTAINS

FROM THE SIERRA NEVADA MOUNTAINS of Central California to the southern tip of Baja California, a single massive block of granitic rocks extends over a distance of 1,500 miles. This block represents two huge magma bodies that were intruded simultaneously during Mesozoic time, about 100 million years ago. Known as the Southern California batholith and the Sierra Nevada batholith,[1] these granitic rocks consitute the core of many mountain ranges in western North America. The combined bodies underlie an area exceeding 40,000 square miles, with the southern California batholith being the larger of the two masses.

Even so, these two batholiths are members of a greater batholithic system that comprise the core rocks of mountain ranges that extend more than 4,000 miles along the coastal margins of North and South America from Alaska to Chile. Radiometric dating has assigned an estimated date of origin at 90 to 105 million years ago, or middle to late Cretaceous time. This places the intrusion as associated with a major mountain-building episode when North and South America were pushed westward on their plates.

The Genesis of the Mountains

Formation of a mass of molten rock as large as these batholiths is not a random event. It is a process associated with subduction zones and plate movement. The two Mesozoic batholiths of California are a case in point.

In Late Jurassic time, about 150 million years ago, as part of a vast crustal disturbance, the westward-moving American plates began to override the Pacific plate, forcing the oceanic plate downward into the crust as a subduction zone. Under increasing depth and pressure, the descending crustal materials were converted into a molten magma. Before the end of the Jurassic, about 100 million years ago, the magma began to move slowly upward into the crust just beneath the surface. In so doing, it absorbed and converted the sedimentary rock overburden by heat and pressure into a complex new series of metamorphic rocks. The mahogany-colored rocks visible today on the lower mountain slopes from Palm Springs to Palm Desert are metamorphic rock remnants of that time and process.

During mid-Cenozoic time, some 50 million years ago, under continued pressure of the westward moving plates, the leading edge began to crumple, initiating a mountain-building episode. The crust was under enormous stress, and the rocks ruptured along vertical faults. Mountain blocks began to rise in a series of steps, with long periods of erosion between episodes of uplift. This period of mountain building reached its climax within the past few million years.

Today, like the tips of an iceberg, the mountain ranges of southern California and Baja California are the exposed protrusions of this one mass. The largest of these are the Peninsular Ranges, which extend from the Santa Ana Mountains, near Riverside, to the tip of Baja California, a distance of nearly 1,000 miles. The west coast of mainland Mexico from the Gulf of Tehuantepec to the Los Angeles basin also includes numerous extensive mountain ranges of the same rock types.

Erosion kept pace with uplift, and most of the overlying metamorphic layer was stripped away. Remnants of these very old rocks remain today in exposures in the upper elevations of the Santa Rosa Mountains and along the base of the San Jacinto Mountains.

The Southern California Batholith

The batholith is a massive intrusion of several types of granitic rock, successively injected into the crust as a series of plutons.[2] The plutons represent multiple injections over a period that may have been as long as 10 million years. The batholithic mass contains many high-silica related rock types, but more than 90 percent of the mass consists of five igneous rocks: *diorite, quartz diorite, granodiorite, quartz monzonite and granite*. All occur as large bodies, derived from the separate plutons. Of these, light-colored diorite and granodiorite are most important to the Salton Valley, comprising the core rocks of both the Santa Rosa and San Jacinto Mountains. In contrast, the granitic rocks in the desert mountains to the east, e.g. the Little San Bernardino Mountains are chiefly granodiorite and quartz monzonite which are higher in feldspar and alumina and lower in silica than the rocks of the main body as represented by the San Jacinto Mountaisn. Notwithstanding these local variations, the batholith as a whole is remarkably homogeneous, consisting almost entirely of the lighter igneous rock types. The darker ultra-mafic rock series are rare, and alkaline types such as syenite are almost non-existent.

The Peninsular Ranges of California

The geomorphic unit, nearly 1000 miles in length, is known collectively as the Peninsular Ranges. The San Jacinto and Santa Rosa Mountains are ranges within this major mountain system.

The individual ranges of the Peninsular Ranges are gigantic fault blocks, most of which are tilted to the west, toward the sea. The bedrock core in all ranges of the system is the Mesozoic granitic rock complex of the southern California batholith. The blocks are discrete mountain ranges, separated by valleys, all defined by faults which lie generally parallel to the boundary system, and all are oriented northwest-southeast. Each of the blocks has had its own distinctive landscape evolution depending on the nature and magnitude of the fault movements that created it.

In their uplift, the mountain blocks tilted west. With few exceptions, the highest elevations in the individual ranges are located close to the eastern scarp, while the western side slopes gradually. Hence, the common geomorphic feature of most of the ranges is a western subdued upland surface with gentle relief, and a steep eroded eastern scarp descending abruptly to the valley floor. This describes the mountains which form the western margin of the Salton Valley the Santa Rosa Mountains and the San Jacinto Mountains.

The mechanism for this is not completely understood. The most current perception is that the entire region is underlain by a massive detachment fault.[3] Under persistent stress, the separated mass breaks into blocks which then rotate along normal faults to accommodate the tensional strain. The tilt of the mountain blocks is dramatically evident to travelers crossing the mountains by the east-west highways. The approaches to the mountains from the east entails slower travel over steep mountain grades. On the other hand, travelers entering the mountains from the west drive up gradual slopes that are hardly noticeable.

There are several nearby examples of this, such as the spectacular climb by Highway 74, from Palm Desert. The highway climbs Seven Level Grade up the face of the Santa Rosa Mountains, then descends over a gradual slope to Anza Valley. Another example is Highway 243 from Banning to Idyllwild.

As a topographic unit the western margin of the Peninsular Ranges is inland several miles from the sea. The main structure continues beneath a sloping seacoast plain and under the sea as a broad submerged continental borderland whose geology closely resembles the landward portion.

The islands of Catalina, San Nicholas and Santa Barbara are the exposed tops of elevated blocks of this same structure. The blocks are separated by deep troughs aligned northwest-southeast. There are many submerged near-vertical fault scarps that define the margins of these blocks. As a result, the submarine topography off the coast of Southern California consists of elevated blocks exposed as islands separated by downthrown blocks of deep-water canyons. The submarine geology of the Gulf of California appears to be very similar, and even on a grander scale with extremely deep basins within the narrow Gulf.

Baja California

An important section of the Peninsular Ranges is the peninsula of Baja California. This elongated structure is as long as the State of California but only a third as wide. The northern half is mountainous with peaks that rise to elevations of over 10,000 feet. These ranges are a continuation of the Peninsular Ranges of southern California. Most of the rocks in these mountains are diorite to granite in composition, with limited exposures of an older metamorphic rock cover. In contrast, the southern half of the peninsula is lower in relief, and for the most part is a large area of sedimentary rocks and lava flows of Miocene age, about 25 million years ago. The southernmost tip of the peninsula is made up of the batholithic rocks once again. Important batholithic block ranges in Baja California which are similar to the mountains of the Salton Valley are the Sierra de Juarez and Sierra San Padre Martyr.

The San Jacinto Mountains

On a map, the San Jacinto Mountains are right triangular in outline. The northern margin is along San Gorgonio Pass, the east face looks down on Palm Springs and the diagonal is San Jacinto Valley. The highest peak is Mount San Jacinto, at 10,831 feet.

The Range is really a single mountain block uplifted along faults, with movement occurring through the Pleistocene. The major fault that created the block is the San Jacinto fault, slicing northwest-southeast along the topographic diagonal of the mountain mass. Branches of this fault zone also define several linear valleys in the upland areas, ranging in elevation from 1,500 feet to 4,000 feet.

Defining the north face (and, therefore, the southern margin of San Gorgonio Pass) is the South Pass fault. This fault is deeply buried in alluvium and has no surface trace.

The east face is an extension of the north-south trending Palm Canyon fault. The fault trace is hidden and buried in alluvium but inferred to exist along the mountain front in the city of Palm Springs. The fault becomes more evident where the scarp extends south into Palm Canyon for about ten miles.

The southern front of the San Jacinto Mountains is especially conspicuous. At the City of Palm Springs the rise is to 4,000 feet within one horizontal mile. Mount San Jacinto is 10,000 feet higher than the valley floor, less than seven horizontal miles distant. This scarp is one of the great mountain scarps of the world, exceeding in vertical relief the better-known east face of the Grand Tetons in Wyoming.

For one thousand feet above the valley floor, the frontal scarp rises abruptly. At that point, there is a considerable reduction in the angle of the slope. This indicates two recent episodes of movement, elevating a block which had been previously uplifted and eroded.

Evidence of recent uplift of the mountains is the boldness of the scarp along the range and its small amount of erosion. The front is notched by few deep canyons, and these have at their mouths only small alluvial fans.

The core of the San Jacinto Mountains consists of granitic rocks of the southern California batholith. Appearing in the lower elevations, extending into Palm Canyon and as spurs along the mountain base are fragments of older metamorphic rocks, known as the Palm Canyon Complex. Similar remnants of metamorphic rocks are very common in the Santa Rosa Mountains.

These older rocks are of uncertain age. That they were once sedimentary rocks is very likely, but metamorphism has obliterated the fossil record. It is thought the rocks are probably of early Paleozoic time, variously 250 to as much as 600 million years old.

The metamorphic series is massively banded, gray in color where fresh but mahogany or rust colored where weathered. Well-developed foliation planes of interbedded and contorted layers of schist and white recrystallized limestone, often injected by bands of granitic rock are common.

The banded structure of these old rocks is very striking to the eye. The layers are oriented north-south, and dip or tilt to the east about 35 degrees.

The layered structure of the mahogany colored metamorphic rocks is conspicuous along the San Jacinto front at Palm Springs from almost any vantage point, and particularly at the Indian trading post in Palm Canyon. The large flat rock boulders have been weathered loose along their banding planes, and are seen as gigantic scales or plates on the mountain side . Viewed from the north end of the city, the profile of the mountain face in outline is a remarkable straight-edge inclined 35 degrees.

The rocks of the San Jacinto Mountains are best seen closeup from the aerial tramway. Between the lower station at 2,600 feet elevation and the top at 8,500 feet, one may see both of the important rock types. The darker metamorphic rock is abundant as the trip begins. As the tram begins its steepest ascent, the car passes the vertical faces of the younger light-colored granitic rocks.

As a consequence of uplift of the massive block as well as tectonic forces, the rocks of Mount San Jacinto are highly fractured. There are two joint planes, nearly vertical and at right angles to each other. This is evident as the tram approaches its upper station.

The upper station area is situated on an excellent exposure of quartz diorite. The rock is coarse granular, whitish in color with a liberal sprinkling of dark mineral crystals.

Quartz diorite is abundant in the higher elevations of many of the mountain ranges of the southern California batholith. A fresh fragment at the upper tram station, for example, is identical to a sample picked up at the base of El Capitan in Yosemite Valley, some 400 miles north.

In sharp contrast to the dry valley floor, the San Jacinto Mountains are well-watered. Their high elevations trap the eastward flow of Pacific storms in the winter months. Average precipitation at Idyllwild, for example, is 26 inches per year. The summit snow pack is 40 to 50 inches.

Chino Canyon

Chino Canyon is located north of Palm Springs. The canyon is important as a source of domestic water, and for being the site of the aerial tramway. It is easily accessible by a steeply graded paved road from Highway 111. The road to Chino Canyon leaves the highway at 730 feet elevation, climbing to the lower tram station at 2,600 feet.

The drive up the road reveals much of the local geology. The dynamics of stream erosion and alluvial deposition are well shown. Also to be seen at close hand are the metamorphic and granitic rocks that comprise the bulk of the San Jacinto Mountains.

The Chino fan is the largest and best developed alluvial fan in the San Jacinto Mountains. On approaching the city of Palm Springs along Highway 111, the traveler sees the fan in profile, sloping distinctly toward the valley floor. The highway curves over the fan, cresting at 760' elevation at the flood control channel before sloping gently down to the city.

This large alluvial fan has its apex at 1,800 feet deep in the canyon, and its base rests on the valley floor at 500 feet elevation. The toe of the fan is about eight miles in radial width. The horizontal distance from apex to toe is about four miles. The Chino Canyon fan, then, is a very conspicuous feature in the landscape.

Chino Canyon is a typical V-shaped desert canyon which has been cut into the ancient metamorphic and igneous rocks. Exposed in the lower elevations are the metamorphic rocks. White crystallized limestone (marble) appearing as broad light-colored bands against the darker background rocks are very prominent in the area.

The alluvium comprising both the fan and the canyon floor is unconsolidated sand, gravel and boulders of granitic material. The source of this material is the diorite bedrock exposed at the higher elevations where the streams are most active.

Notwithstanding the great size of its fan, Chino Canyon has a very small watershed area. It is a complex set of small, but extremely steep side canyons. The fan and the desert floor deposits are the result of countless flash floods in these canyons over a long time span. Each flood has the momentum of the steep gradients of the canyons, and rock materials from sand to large boulders the size of automobiles are moved downstream. When the main stream flow reaches the apex of the fan, it randomly selects a course down the face of the fan until it reaches the desert floor where it splays out and ends by evaporation and by soaking into the sand.

This random deposition pattern has resulted in an interfingering nature of the sediments. Alluvial deposits typically consist of poorly sorted sands and gravels with intermixed boulders and cobbles along with layers and lenses of silt and clay. Size and frequency of the boulders decreases in the downstream direction, whereas the amount of sand increases.

The nature of stream deposition on a fan can be seen as one travels over the fan on Highway 111. Surface materials randomly consisting of huge boulders mixed with sand are characteristic of flash flood deposition. The materials in the topographically steeper areas near the mountain front are quite large, while deposits in the flatter areas farthest from the canyon mouth are the finest grained.

This is readily evidenced by contrasting the boulder and cobble strewn alluvial fan deposits along Highway 111 with the noticeably finer grained surface materials two or three miles east on the valley floor.

During Pleistocene time, up to two million years ago, increased stream flow plus uplift of the mountain mass gave the streams feeding into Chino Canyon their steep gradient and enhanced erosional capability. Resistant ridges of rock at high angles to the direction of stream flow hindered the down-cutting action of the streams. The dam effect caused a thin veneer of alluvial material to be laid down above the obstructions. Much of this veneer remains today as a series of terraces near the lower tram station.

As the backed-up stream water filled the alluvial material in these terraces, a line of springs developed upstream from the barrier area bringing water near to the surface. These springs support the lush growth of vegetation visible from the tram as it departs the lower station. The presence of willows, poplars, cottonwoods, various grasses and the abundance of wild grape are all indicative of shallow depths to water (zero to three feet) extending upstream from the springs.

Two collector intakes and a reservoir gather most of the spring water and feed it into the Desert Water Agency system for domestic use. It thus appears likely that the vegetation cover is now at maximum for the available ground water.

Regional faulting of the San Jacinto block probably commenced in early Tertiary time, some 50 million years ago. Periodic earthquakes along the San Jacinto fault zone suggests that it continues to the present. Periods of uplift were followed by long intervening periods of erosion of the raised landmass. As a result, a large percentage of the rock debris in Chino Canyon and its alluvial fan, then, probably represents material which has accumulated since the major uplift in Pleistocene time.

Palm Canyon

South from the City of Palm Springs, Palm Canyon extends as a straight gash through the San Jacinto Mountains for about ten miles. The lower reaches of the canyon have a flat, alluviated floor, with the mouth more than a mile wide.

The eastern wall of the canyon consists largely of the older Palm Canyon Complex of metamorphic rocks. This wall has a pronounced dip to the east as a result of the uplift of the later granitic intrusion that forms the west wall of the canyon.

Palm Canyon is defined by erosion along the trace of the Palm Canyon fault. The fault disappears beneath 1,000 feet of alluvium at the canyon mouth, but is inferred to continue for a few miles along the base of the mountains, generally underlying Palm Canyon Drive in the city. The hot spring, for which Palm Springs is named, is a surface manifestation of the fault, where subterranean drainage from the mountain slope finds its way back to the surface.

In the canyon proper, the fault trace is marked by a wide band of crushed and intensely weathered rock along the fault zone. This also marks the course of the stream bed. The collection of palm trees in the canyon floor is considered to be the largest natural stand of the native palm, *Washingtonia filifera* . Immediately east of the canyon mouth is Murray Hill. It lies close to the highway, and several hillside homes dot its lower slopes. Murray Hill (elevation 2,210 feet) shows very advanced weathering, with its mauve or reddish-brown bouldery slopes. The rocks are heavily fractured, creating conspicuous drainage channels that are filled with rock falls and crushed rock.

The Santa Rosa Mountains

The Santa Rosa Mountains are a companion range to the San Jacinto Mountains, and they share many important characteristics. Unlike the San Jacinto range, however, the block is tilted to the east, and the higher elevations here are set back a considerable distance from the valley. As a consequence, the Santa Rosas appear to be much lower in elevation.

The mountain mass has a well defined and linear scarp on the southwest side, above which there is a slope descending to the northeast from about 8,000 feet to 6,000 feet elevation.

The range extends from Palm Canyon southeast about 40 miles, including small units with local names, becoming progressively lower in elevation toward the Salton Sea. The range is about 15 miles wide at the north end, narrowing to fewer than 10 miles in the south.

Viewed from the resort cities of the valley, prominent on the horizon are the highest summits of the range. These are the twin peaks, Toro Peak (8,716') on the left and Santa Rosa Mountain (8,046') on the right. Otherwise, elevations are moderate, seldom exceeding 6,000 feet.

Unlike the higher San Jacinto Mountains, the low elevations of the Santa Rosa Mountains do not serve as a barrier to the eastward-moving winter storm systems. As a result, rainfall is scarce and erosion is minimal for the range as a whole. The Santa Rosas are almost waterless; there are few springs and no permanent streams. Deep Canyon has a small stream in its upper reaches that flows part of the year.

Like the San Jacinto range, the Santa Rosa Mountains are an uplifted block, with the southwest or "back" side strongly defined by the San Jacinto fault zone. At times, the high southwestern scarp is only two or three miles from the fault zone. The faults which probably define the other margins are deeply buried in alluvium, and can only be inferred.

The Santa Rosa Mountains are of the same rock types as the San Jacinto Mountains, a granitic core of Mesozoic intrusive rock surrounded and covered extensively with remnants of an early Paleozoic metamorphic series. The granitic rocks are common, often occurring as rock piles of jumbled boulders of disintegration the size of bathtubs. The metamorphic rocks are found as isolated masses in many areas throughout the upland interior in the southern section of the mountains. Lower elevations, a more arid climate and reduced erosion have preserved the metamorphic rock cover extensively in the Santa Rosa Mountains; far more so than in the adjacent San Jacinto Mountains.

North of Palm Desert, the metamorphic rocks appear as spurs at the low elevations, at times adjacent to Highway 111. From Palm Desert southeast along the mountain front, the granitic rocks extend directly to the valley floor along the highway, and are well exposed at Indian Wells.

The Santa Rosa Mountains become progressively lower in elevation and less distinct to the southeast, with subordinate hills enclosing broad interior lowlands.
Clark Valley and Borrego Valley, about 10 miles by 20 miles in area, are bounded on the northeast by the Santa Rosa Mountains, and on the south and southwest by the Vallecito Mountains and the Fish Creek Mountains. Valley elevations range between 500 and 1,000 feet. The Santa Rosa Mountains form the low hills west of the Salton Sea, and eventually become buried in the Pliocene and Pleistocene sedimentary cover.

Landslides

Landslides are relatively common in California. They are usually mudslides that occur on unstable slopes following heavy rains. As destructive as they can be, the low desert is fortunate to be at low risk from mudslides.
Rockslides, however, are a potential threat in the valley. Steep-walled canyons with loosely consolidated, closely jointed rock walls, or hillside slopes covered with loose, bouldery material present a danger when the slopes become unstable. Typically, slides occur when triggered by an external force, and earthquake shocks are a common cause.

The Martinez Landslide, in the Santa Rosa Mountains south of Indio is one of the largest in southern California. The slide is thought to have occurred near the close of the Pleistocene, a time of rapid erosion in the cool/moist climate. Because of closely-spaced vertical jointing in the granitic rocks, the canyon slopes became over-steepened and unstable. Triggered by an earthquake, rock debris became detached from 5,000 feet of the canyon wall, sliding down-slope nearly five miles to pile up on the valley floor below.

Palms To Pines Highway

The Palms to Pines Highway, Highway 74, traverses much of the interesting geology of the western mountains.
The eastern scarp of the Santa Rosa Mountains is highest and most abrupt at the northern end. Here, State Highway 74 leaves the Coachella Valley at Palm Desert and ascends the gentle slope of the alluvial fan of Dead Indian Canyon to the base of the steep eastern escarpment. At this point, the Seven Level Grade takes an auto from 1,300 feet elevation to 2,400 feet at the vista point -- a 4.5 mile drive over the switchbacks to reach a point that is fewer than three quarters of a mile from the base of the grade.

Climbing the grade, numerous roadcuts expose the metamorphic rocks of the Palm Canyon Complex. These rocks are conspicuous in appearance, and contrast sharply with the granitic rocks at the top of the grade. Look for highly deformed, sheared and contorted layers. They are thinly bedded and in various shades of white to light tan to brown, with occasional pink to greenish layers.

These hard, brittle and well-fractured rocks are also called metasedimentary rocks, since their sedimentary origin was not completely obliterated during metamorphism. The original rocks were thinly bedded as most of the layers are only inches thick. The sedimentary rocks of origin appear to have been interbedded limestones, sandstones and clays intruded in places by thin diorite sills. The beds are non-uniformly tilted. The color and the tilting are the result of the metamorphism of the sedimentary rocks as the plutons of the molten batholith punched their way up toward the surface. About 100 yards from the Dead Indian Canyon vista point, the roadcut shows for the first time the contact between the overlying metamorphic rock and the intrusive granodiorite.

From the Vista Point, one can look down upon the seven curves of the highway as it ascends the grade. Near the bottom, at about the second curve, a conspicuous horizontal line can be seen separating dark rocks (above) from lighter rocks below the line. This is the Santa Rosa detachment fault; age about 12 million years. Here, the younger (darker) granitic rocks lie over the light-colored older metasedimentary series.

Above the scarp, the change in landscape is conspicuous from mountainous to an advanced topography. For about ten miles, the road passes alternately over exposures of the metamorphic rocks and the massive diorite. Unlike the higher San Jacinto Mountains, the Santa Rosas still retain large upland exposures of the metamorphic cap rock.

Much of the interior is an extensive rolling upland area suggesting that the surface had been previously exposed to long periods of erosion before the range was uplifted. The history, then, is one of recurrent uplift, or periods of mountain building episodes with intervening long periods of quiet erosion. The most conspicuous of these old erosion surfaces is Pinyon Flat, at 4,000 feet elevation. An excellent large scale view of this old surface can be seen from Bighorn Overlook.

This view point looks down into Dead Indian Canyon, the largest of several cut by older intermittent streams in the Santa Rosa Mountains. On the east is Indio Mountain, and to the west is Haystack Mountain.

About five miles from the vista point, and approaching Bighorn Overlook, the road passes through some spectacular boulder fields showing spheroidal weathering, an advanced stage in the weathering of granitic rocks in an arid climate. The hills appear to be giant rock piles, with boulders generally the size of suitcases. The diorite is deeply weathered and brownish to mauve in color. The color is desert varnish, the result of long exposure to weathering and to sunlight for hundreds of years. The highway proceeds west over the 4,500' pass, crossing between subordinate blocks of the Santa Rosa Mountains over a gently rolling upland surface to Garner Valley and Lake Hemet.

Garner Valley

The Santa Rosa range includes several parallel northwest trending mountainous ridges, clearly fault block units, between which are sharply outlined sunken blocks. The most conspicuous of these sunken blocks is Garner Valley, lying at the base of Thomas Mountain.

Averaging a mile wide and about nine miles long, Garner Valley is an upland meadow filled with recent alluvium derived from the flanking mountains. It has a gently sloping floor, descending from about 4,750 feet at the Anza Road turnoff to 4,350 feet at Lake Hemet at the northwest end. The valley widens to about two miles here, and the flat valley floor is probably an abandoned lake bed dating back to late Pleistocene time.

Lake Hemet is a dammed reservoir occupying the lowest elevations of the valley. The lake is about 1.5 miles long, half a mile wide and 135 feet deep. The extraordinary depth is due to the dam across the deep gorge of the San Jacinto River, most of which has been excavated along the Thomas Mountain fault.

Topographically, Garner Valley owes its elongate form and position to the Thomas Mountain fault along its southwestern edge and possibly to another buried zone of faulting near its northeastern margin. Surface traces of these faults are lacking due to the alluvial fill. The valley is also aligned with the Hot Springs fault, an important member of the San Jacinto fault system, and may have originated from faulting along branches of the Hot Springs fault.

Leaving Lake Hemet, Highway 74 crosses a short 5,000 foot pass to Mountain Center, the gateway to Idyllwild. Here, the rocks are entirely the diorite of the mountain core, with surface exposures well eroded by weathering and with conspicuous slopes of grus, or decomposed granite, along the road cuts.

From Mountain Center, the highway descends a gradual slope for about 25 miles to Hemet down the canyon of the North Fork of the San Jacinto River, following the trace of a branch of the San Jacinto fault.

Joints

Evidence of acute stress during uplift is the well defined joint system in the massive crystalline rocks of the western mountains.

Joints are cracks in bedrock, and in massive granitic rocks they typically have a regular pattern. In the San Jacinto Mountains, there are two vertical joint patterns, nearly at right angles to each other. The result is a tendency toward steep cliff-like faces and columnar fracturing. One such joint face is highly visible on the face of the mountains at the entrance to Palm Canyon. The smooth, vertical face is best seen in the early morning sunlight. This represents a collapse of the steep mountain face along a major vertical joint.

The best exposure of the strong vertical joint pattern in the San Jacinto range is in Chino Canyon. Viewed from the aerial tramway about halfway to the top, the collapse of the walls has created spectacular spires of rock which seem to be reaching for the tram car passing overhead. Joints are zones of weakness, and stream runoff is quick to use joints as water channels, deepening and widening them into small gullies and canyons. When the water supply is relatively constant, as from snow melt, vegetation readily grows along the stream bed which has been worn into the joints. Several such vegetation patches appear as splashes of green along the mountain front.

As deeply buried magmas cool, they develop crack-like structures in the semi-solid slushy mass. Liquid residues find their way to these openings, filling them and subsequently becoming part of the rock mass. These are called aplite dikes, and commonly occur as thin, light-colored streamers in the massive granitic rock.

Joints, on the other hand, are the result of physical stress, and are caused by the release of pressure during earth movement. The rock mass of granite breaks under stress, particularly during uplift. Unlike a fault plane, there is no differential displacement across a joint fracture; it is a simple crack. The joint pattern may be either closely or widely-spaced. For example, the joint pattern of the San Jacinto Mountains yields blocks the size of steamer trunks, whereas blocks the size of boxcars are typical of the hills of Joshua Tree National Monument. Even these, however, contrast sharply with the massive joint system of Yosemite which result in spectacular Half Dome and the great wall of the valley, El Capitan.[4]

Open fractures permit the passage of underground water. It is likely that snow melt passing through a complex and deeply buried joint pattern is the source for Agua Caliente Spring (at Palm Springs), the only warm spring in the western Coachella Valley. The open fractures of the San Jacinto Mountains permit the storage and transfer of much water from the annual snow pack. Springs are common, and there are numerous seasonally flowing small streams. Small mountain communities like Idyllwild are sustained by water from streams and shallow wells into the joint system.

Grus

Chemical processes are the most important agents of rock weathering and destruction, even in an arid desert climate. Because most rocks are susceptible to it, the process of hydration appears to be the dominant factor in the weathering of many kinds of rocks. Hydration is the chemical alteration of a mineral, such as feldspar, into a soft, clay-like material when water molecules attach themselves to the mineral molecule, changing its composition and properties.

In the weathering of granitic rocks by hydration, feldspar is chemically altered to new hydrous forms which expand as they are formed. This expansion tends to lever the mineral crystals apart, breaking the physical bonds between the crystals. This, then, is a weathering process that physically destroys the rock by disintegration. The sandy rubble is called grus, or more commonly, decomposed granite, or simply DG.

The residue continuously breaks away from the rock surfaces. The sharp edges of fresh fractures weather first, with the eventual result of making the rocks spheroidal in shape. Grus is commonly seen in older road cuts as light-tan or yellowish coarse-grained sandy piles at the base of granitic outcrops. It is well-exposed at many road cuts along Highway 243 near Idyllwild, where much of the exposed diorite has been weathered to depths of 10 feet or more, and yields grus-covered slopes with numerous boulders of disintegration.

Desert Varnish

Rocks of the lower elevations of the Santa Rosa Mountains have a unique coloration. They commonly appear to be shades of mahogany, or reddish-brown. This is desert varnish, a coating that develops in hot, arid regions on exposed surfaces of granitic rocks that contain metallic minerals. Desert varnish is caused by the diurnal desert weathering process where there is a significant difference in day and night temperatures. Hydration of minerals rich in oxides of iron and manganese, such as biotite mica, helped by nighttime moisture will leach infinitesimal amounts of minerals from the rock surface. Daytime sunlight evaporates the moisture, redepositing the mineral as a surface stain. The cumulative effect of this is a gradual darkening of the rock surface over a period of years. Observations in Egypt show that the formation of desert varnish is extremely slow, requiring centuries for the brown coating to form. Hence, one finds desert varnish well developed only on upland surfaces or mountain sides that are not subject to disturbance.

Mountain Maturity

Those who are familiar with America's eastern mountains, such as the Catskills or the Appalachians, may compare them to the western mountains, typified by the San Jacinto and Santa Rosa Ranges. The former are low in elevation, have rounded crests and broad valleys. The local mountains, by contrast, are highstanding, canyons are V-shaped with steep sides, and peaks are jagged. The former are said to be mature mountains; the latter are young mountains.

There is a definite progression or cycle in mountain maturity, as weathering and erosion vigorously attack the high elevations of youthful ranges. In the arid Southwest, the barren slopes make this progression very distinctive to the observer. The bare, rocky flanks of the desert mountains are slashed with many entrenched arroyos, or canyons. Extending from the mouths of these boulder-strewn canyons are broad, sloping outwash fans consisting of a mixture of boulders, gravel, sand and dust -- all flushed from mountain valleys. These alluvial fans coalesce into broad alluvial aprons which slope downward in sweeping curves to the center of the basin. As mountains are worn down, their well-developed slopes are worn back a mile or more, leaving an even floor thinly veneered with gravel and slanting gently forward to an intermontane basin. With increasing age, the fans reach almost to the crests of the lower hills, as the well-worn mountain cores eventually become buried in their own debris. This sight is very widespread in the western deserts, and is very conspicuous to the air traveler. Seen from jet-height, the mountain tops of these old mountains seem to be isolated from one another by basin slopes which are covered with lighter-colored drainage channels.

CHAPTER 2
THE EASTERN MOUNTAINS

THE MOUNTAINS DEFINING the northeast margin of the Salton Valley differ significantly from the San Jacinto and Santa Rosa Mountains. Their age and the suite of rock assemblages have no counterpart in the western mountains. Regional plate motion involving the movement of the coastal section to the northwest no doubt plays an important role in these differences.

The Little San Bernardino Mountains

The mountains are an elevated and faulted block, thrust upward from a region of low relief to their present height during Pleistocene time, about two million years ago. Inland from the ridges forming the valley edge, Joshua Tree National Monument occupies most of the interior section.

Structurally, the flat upland plateau in the western section of the Little San Bernardino Mountains, including most of Joshua Tree National Monument, is a tilted block uplifted uniformly between the Mission Creek fault and the Morongo Valley fault. The northern margin of the block lies roughly parallel to Twentynine Palms Highway.

The Little San Bernardino Mountains are considerably lower in elevation than either the Santa Rosa Mountains or the San Jacinto Mountains to the west. The most striking aspect of the mountains is the uniquely flat and uniform crestline. This is apparent from any viewpoint in Palm Springs or Palm Desert. This is the western margin of an ancient desert upland; an old erosion surface averaging 4,000 feet in elevation which is discussed in the following section.

The eastern mountains are made up of the oldest rocks in the area, the Chuckwalla Complex of metamorphic rocks. This assemblage is of Precambrian age, about 1.7 billion years old.

The Chuckwalla Complex is a dark-colored metamorphic-igneous rock assemblage of quartz-diorite, gneiss, and granitic rocks, all intensely folded and faulted. It makes up the frontal slopes of the mountains visible from the valley. Excellent exposures may be seen north of Dillon Road.

These ancient rocks have been intruded by Mesozoic granitic rocks. They are extensively exposed in the interior of the range, and consist of various types of granitic rocks. The most significant of these is the White Tank Quartz Monzonite, a light brown to gray biotite-quartz monzonite found widespread in Joshua Tree National Monument. The widely spaced joint pattern weathers to huge boulders of disintegration. These rocks are generally equivalent to the core rocks of the mountains to the west.

The Little San Bernardino Mountains are more heavily mineralized than the San Jacinto and Santa Rosa ranges which lie on the opposite side of the valley. Gold was extensively mined in the late nineteenth century in the Dale District, east of Twentynine Palms. More recently, the open-pit iron deposits of the Eagle Mountains to the south supplied the furnaces of the Fontana steel mill for many years following World War II.

The Upland Areas

Topographically, the most unique feature of the Little San Bernardino Mountains is the relatively flat, rolling high desert upland surface covering most of the range. Isolated hills or small ranges are separated by valleys and basins. Local relief is about 1,000 feet with a few isolated peaks rising as much as 1,500 feet above the upland floor. The largest basin in the area is the Pinto Basin in the eastern section. This topographic feature is similar to a higher conspicuous erosion surface in the western section of the San Bernardino Mountains. This gently rolling plateau is an extensive upland area at 6,500 to 7,000 feet elevation. It is of modest relief, with several lakes, including Lake Arrowhead and Big Bear Lake.

Both upland surfaces, in turn, may be related to a lower and older comparable erosional surface southwest of the San Jacinto Mountains. The Perris Plain is about 2,500 feet elevation, and originally may have been associated with the upland summit areas of the mountains just described. All three surfaces, notwithstanding their significant differences in elevation, may be remnants of a vast ancient erosional terrain which covered much of southern California, though its age and limits cannot be precisely determined.

Morongo Valley

Morongo Valley is a wedge-shaped downthrown block between faults. The principal fault is the Morongo Valley fault which separates the San Bernardino Mountains from the Little San Bernardino Mountains. Consequently, Morongo Valley is associated with the Transverse Ranges.

Extensive exposures of the very old Chuckwalla Complex appear throughout the valley. Big Morongo, Little Morongo, Dry Morongo and Mission Creeks drain the western slopes of the San Bernardino Mountains. Morongo Valley is the principal drainage channel into the Salton Trough. The drainage system features deep canyons with clear-running streams and ridge-tops exceeding 3,000 feet. The melt water from the high elevations flows southward through the creeks as underflow in the gravels of the Coachella Aquifer.

Whitewater Canyon

Whitewater Canyon is at the eastern end of San Gorgonio Pass, and extends into the San Bernardino Mountains north for about eight miles.
It is a closed canyon with access only at its mouth. The east side of the canyon is an abrupt wall, with little vegetation. The western side is more sloping, with considerable vegetation. The closed northern end of the canyon is dominated by cliffs of bare, brown rock.

The west side of the canyon displays the darker rocks of the ancient metamorphic Chuckwalla Complex. Rocks of the east wall are the younger Miocene Coachella Fanglomerate overlain by the early Pliocene Imperial Formation.
The Whitewater River channel, containing abundant whitish boulders in its stream bed, generally lies close to the east side of the canyon.
The Colorado Aqueduct crosses the canyon near its mouth, and here for part of the year, excess water is diverted from the aqueduct for recharge of the groundwater system. The stream crosses the valley to the spreading ponds of the Coachella Aquifer.

About 1.5 miles into the canyon, the road crosses the Banning fault, considered by some to be the main strand of the San Andreas fault. The fault trace is marked by lush riparian vegetation in the stream channel, contrasting sharply with the stark canyon walls.

Whitewater Canyon is the only remaining unspoiled canyon in the Coachella Valley. Except for the fish hatchery development, a narrow dead end road is the only protrusion on the remote and scenic landscape.

Joshua Tree National Monument

Joshua Tree National Monument was established in 1936, and has recently been named a National Park. It covers an area about 20 miles wide and 60 miles in length, encompassing much of the Little San Bernardino Mountains and the Eagle Mountains, and extending into the Mojave Desert as far as Twentynine Palms highway. In topography, nature and climatic characteristics, it is an area that is intermediate between the high Mojave Desert and the low Colorado Desert. The Monument is exceedingly dry for its altitude. The average rainfall is fewer than five inches per year. Most of this precipitation falls as sudden summer rains, and flash flooding is common. The Palms Quartz Monzonite is the dominant rock type in the Monument. It is a gray to light brown, coarse-grained massive granitic rock. Scattered throughout its northwest exposures may be found zones of striking crystalline structure. Pink orthoclase feldspar crystals the size of walnuts contrast beautifully with the light tan country rock in which they are embedded. Several places in Joshua Tree National Monument are the site of gigantic rock piles, a source of pleasure and wonder to campers and picnickers. Here, spheroidal weathering of the quartz monzonite along a well-defined set of widely spaced joints has created spectacular boulders of disintegration, some the size of box cars.

The Orocopia Mountains

The Orocopia Mountains lie east of Mecca and north of the Salton Sea, with their eastern margin being determined by the San Andreas fault This range and the neighboring Chocolate Mountains are one block, tilted to the southwest. As such, the structure and lithology are nearly identical.

The core of the range is the very old Precambrian metamorphic Chuckwalla Complex, intruded by Mesozoic granitic rocks, all overlain by recent sedimentary rocks. The central section contains large exposures of the Pelona-Orocopia Schist of late-Mesozoic age, about 100 million years before the present. The schist is a sequence of metamorphosed mudstone, claystone and siltstone rocks. The steel-gray color is distinctive. These rock units lie in a belt between two major faults, the Clemens Well fault and the Orocopia thrust fault.

This rock sequence is almost perfectly duplicated in the San Gabriel Mountains, north of Los Angeles. Each lies on opposite sides of the San Andreas fault, and the inference is strong that these two segments may be parts of a single, original mountain mass now separated by 130 miles of right lateral displacement along the fault. Similarly, boulders of the distinctive Orocopia Schist are to be found in the conglomerates in the stream bed of Whitewater Canyon. This is also south of the San Andreas fault zone, again suggesting a significant amount of lateral movement between the two sides of the San Andreas fault.

The Orocopia Mountains are true desert mountains. They are bleak and inaccessible, and there are no good roads leading to their interior.

The Chocolate Mountains

The Chocolate Mountains, or "the Chocolates," as they are called locally, comprise the margin of the Salton Trough from the Orocopia Mountains south for 80 miles, gradually merging into the Colorado River valley. They are low mountains, reaching to 2,400 feet at their southern end. The range is narrow, seldom exceeding 10 miles in width. Similar to the mountains to the northeast, the core is Precambrian metamorphic basement rock thrust over Orocopia Schist, all intruded by the younger Mesozoic granitics.

The Chocolates (and the neighboring Cargo Muchacho Mountains) were very actively prospected in the late nineteenth century. Many small gold strikes were developed along the southwest, or valley margin of the ranges. None were very large, but the activity spawned a local history rich in tales of lost mines and many colorful characters of the times.

East of the mountains, near Glamis, the Mesquite Mine is active today. It is a large gold extraction operation. Access is, of course, restricted, as is any information on the operation.

The Chocolate Mountains are among the most remote mountains in America. The entire range is federally owned and is closed. It has been used for decades as a military bombing range for the Air Force and Navy. Consequently, there are no roads, and access to the interior is denied.

CHAPTER 3
SAN GORGONIO PASS

THE HEAVILY POPULATED Los Angeles basin is shielded from the continental interior by a ring of high mountains that were created primarily by uplift along faults. Historically, the mountains have been an obstacle to easy entry to the basin, except by passes created by the same faults. Three of them -- Tejon Pass, Cajon Pass and San Gorgonio Pass -- are all products of the San Andreas fault system. And of these, San Gorgonio Pass is the best possible route into the coastal basin, since it is lowest in elevation, and has the easiest grade.

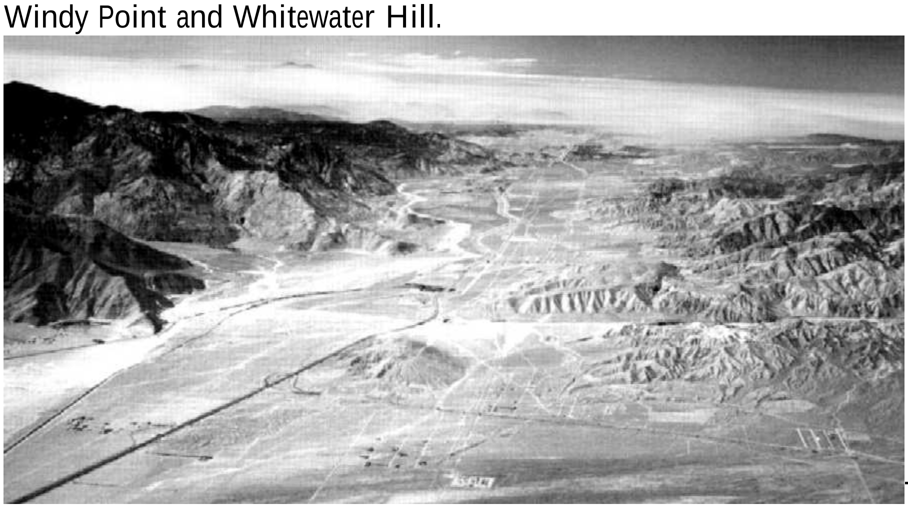
As a consequence of the high Western mountain barriers, access to the Pueblo of Los Angeles in the eighteenth and early nineteenth centuries was usually by sea or from Mexico north by the Mission Trail along the sea coast. Early travelers, approaching from the East by the Immigrant Trail, and having already breasted savage deserts enroute, saw the high peaks of the San Bernardino Mountains and the San Jacinto

Mountains loom against the sky in a seemingly unbroken line. From that distance, it was an unlikely place for a pass. Yet, the brave souls who pushed on soon noticed the welcome break between the mountains. It was the final pass leading to the Pacific coast.

As a result, the pass remained in the shadows of history for more than a century following its discovery in the early 1840s. Once the early Californians had arrived in Los Angeles, they had little interest in the desert, and even less need to visit it. There simply was no compelling reason for them to make a long, difficult journey from the bustling, growing town to the hostile desert. There was little of benefit on such a journey except . . . more desert! Local traffic was virtually nonexistent. New arrivals to southern California were prone to elect the more difficult but less hostile passes to the north. This attitude has never really been overcome; it is pervasive today. San Gorgonio Pass is the easiest Interstate artery serving the Los Angeles basin. Yet, its traffic load is only a fraction of the load carried by the more difficult passes to the north. San Gorgonio Pass lies between the San Jacinto Mountains and the San Bernardino Mountains. It is situated at the apex of the Salton Valley. The pass is a gently tilted, flat-floored upland valley oriented east-west. It is about 19 miles long, from Beaumont to Whitewater Hill, and is two to three miles wide.

The western end of the pass is somewhat elusive in definition. Already several miles wide at Beaumont, it loses its identity as it merges with the Beaumont Upland. The Beaumont Upland, which extends almost to Redlands, is an alluvial plain, or terrace-like structure built up by streams carrying sand and gravel south from the eastern San Bernardino Mountains. This old erosion surface is a flat, smooth, gently sloping plain into which broad, steep-walled, flat-floored arroyos have been cut to a depth more than 50 feet below the surface level. Interstate 10 traverses the upland surface, dipping in several places with the gullies. Also visible from the freeway, recent stream rejuvenation has incised new gullies about 10 feet below this surface.

The eastern end of the pass enters the Coachella Valley at Whitewater Canyon. It does so as a well-formed gradual slope, and is about 1.5 miles wide measured between Windy Point and Whitewater Hill.



This aerial view looks due east toward the Los Angeles Basin about 60 miles distant. Windy Point is the dark triangle center left, and Whitewater Hill is in the center of the photo. Note the marked difference between Mount San Jacinto on the left, or south wall, and the Little San Bernardino Mountain, right, making up the north wall. From lower left into the pass may be seen Highway 111, the railroad and the I-10 freeway. Also conspicuous is the notch in the foothills, right center, locating the trace of the Mission Hills fault, a branch of the San Andreas fault. A black patch at that notch marks the vegetation growth where the fault crosses Whitewater Creek.

The summit of the pass is at the west edge of the City of Beaumont, at 2,600 feet elevation. Nowhere is the pass a steep grade. From Beaumont, the pass slopes gently eastward for ten miles to Cabazon at 1,800 feet, and in another nine miles enters the Coachella Valley at 1,200 feet. The average grade is about 1.5 percent.

San Gorgonio Pass is a narrow fault trough between rugged mountain slopes, and owes its existence to complex fault activity in the area. The south wall of the pass is the granitic rock of the San Jacinto Mountains, and the north wall is the San Bernardino Mountain complex. The faults are thought to be nearly vertical and extend to a considerable depth below the surface.

While the San Bernardino Mountains include higher elevations, the north side of the pass is not as striking as the precipitous south side. This is partly because the high peaks of the San Bernardino range lie farther from their base, forfeiting the illusion of great height. It is also partly due to the low foothills which lie between the pass and the high mountains. Leading up to the foothills of the San Bernardino Mountains, the north side of the pass consists of dissected and deformed alluvial fan deposits.

The spectacular fault scarp of the San Jacinto Mountains, rising abruptly from the floor of the pass to over 10,000 feet forms the south boundary.

In the narrow fault trough between these two ranges the floor of the pass is tilted noticeably to the south. The tilt is very conspicuous to the traveler on the highway in the vicinity of Cabazon. Here, where the pass is about two miles wide, the floor to the north is at 2,500 feet elevation, while to the south, it is a 1,700 feet. This eight percent right-angle tilt is far greater than the gradient of the highway through the pass.

This asymmetrical profile is due to the more vigorous streams which originated in the San Bernardino Mountains. This resulted in greater deposition of sediment at the base of the northern ranges. The alluvial fans are well developed. At adjacent canyons they coalesce at their sides, and their toes reach to the opposite, or south side of the pass. That the San Bernardino Mountain block has been subjected to recent uplift is suggested by the presence of numerous terraces in the canyons between Banning Canyon and Whitewater Canyon. These flat terrace surfaces become progressively higher in elevation traced in the up stream direction.

The largest of these terraces, the Banning Bench, exists north of Banning. It is widespread and relatively undeformed. It extends to the mountain front, and is a smooth, gently sloping surface with low, even-topped hills formed by older streams flowing south from the flanks of San Gorgonio Peak. As a result of more recent uplift along minor branches of the San Andreas fault, newer streams are dissecting this surface. This upland surface is clearly visible across the pass from Highway 243 as the highway ascends the mountain front.

The geology of San Gorgonio Pass is complex, representing as it does a transition between two different mountain systems of southern California: the Peninsular Ranges, which include the mountains of the Salton Valley, and the transverse ranges, which are the east-west trending mountains near Los Angeles.

Nearly all the rocks exposed in the pass represent alluvial fan deposits derived from the bordering fault block mountains. These sedimentary rocks appear as a narrow band of low foothills along the north margin. Occasional exposures of the marine Imperial formation exist in thin and isolated beds, suggesting this was the most northward incursion of the ocean waters of the Gulf during Miocene time.

The body of the pass appears to be a thick fill of alluvial material of youthful age, laid down under similar conditions and contemporary with the Coachella Valley. Surface deposits consist of wind blown sand and alluvium.

The Banning Fault

The Banning fault is the principal structural feature of the pass. It brings young sedimentary rocks into contact with the ancient bedrock complex throughout its 20-mile length from Beaumont to Whitewater Canyon. The fault is unique in being oriented east-west, which is inconsistent with the prevailing NW-SE direction of the faults of the San Andreas system.

It is a vertical or steep reverse fault except for a 6-mile segment of low angle thrusting in the vicinity of Millard Canyon between Cabazon and Whitewater Canyon. This thrust fault is observed from the freeway as a series of low, brown hills and group of scarps along the north side of the pass. Here, the ancient Precambrian rocks are thrust over the much younger sediments.

The early history of the fault, and probably its hidden counterpart on the south side of the pass is one of large displacement, ofat least one vertical mile since Pliocene time, seven million years ago, with earlier displacements probably even greater. The very existence of the pass itself plus the steep and high mountain walls are clear evidence of this. In addition, well logs suggest that the gravel fill of the pass exceeds 5,000 feet in thickness, a close correlation to the fill of the Upper Coachella Valley.

The main San Andreas fault lies within the north mountains, with a prominent scarp fault-line scarp from Yucaipa to Potrero Canyon, north of Banning. There, it appears to butt into the Banning fault at an angle of about 40 degrees. While the basement rocks are severely deformed in the area of the juncture, there is no evidence that the San Andreas actually bends and merges with the Banning fault.

The zone of thrusting in the Cabazon area evidently is related to the abutment of the two fault zones, supporting the view that two distinct fault zones may be involved. The Banning fault is discontinuous, partly buried and often intertwined with other subordinate faults. As a result, identification of its main strand is complicated. In the pass, it runs east-west, which places it at about 40 degrees to the trend of the San Andreas zone. Thus, it is at least transitional between the two fault grains of southern California.

Stream Drainage

Because of the marked tilt of the floor of the pass toward the south, the course of the San Gorgonio River bed lies adjacent to the base of Mount San Jacinto. The stream is crossed by Highway 243 as the road begins its ascent. The river bed is filled with recent sands and gravels, and is usually dry.

All major stream channels flowing into the pass are from the San Bernardino Mountains. The San Gorgonio River enters near Banning, and flows along the south side of the pass. The Whitewater River drains Whitewater Canyon. These two stream channels merge and enter the Coachella Valley, becoming the principal drainage system of the valley to the Salton Sea.

Typical of desert streams, both are dry channels most of the time. Melt water flowing from higher elevations seldom reaches the floor of the pass as stream flow. The creek beds are gravelly and deep, and the water finds a ready channel underground. Because of the long, low gradient to the east, most of the underground water entering the pass eventually reaches the valley as underflow to the Coachella aquifers.

Deep fillings of gravel in most of the canyons, especially Whitewater Canyon, suggest that the stream courses were antecedent, i.e., preexisting before the present cycle of landscape development. As a result of recurring uplift, many of the existing streams are presently re-excavating channels in the canyon floors.

There are no significant streams entering the pass from the San Jacinto Mountains.

CHAPTER 4
THE HILLS

THE UNIQUE GEOLOGY of the surrounding mountains is not duplicated in the hills on the valley floor. The mountains are primarily relatively old granitic rocks; the hills are young sedimentary rocks. The mountains are discrete blocks, uplifted along faults; the hills, at times bounded by faults are all crumpled and folded portions of the valley fill.

The hills of the Coachella Valley were formed by fault activity affecting the weak rocks. All structures are associated with elements of the San Andreas fault system, and all the hills in the Salton Trough, as far south as the Superstition Hills, contain many tightly buckled small folds, evidence of intense deformation near the fault zones.

The only topographic relief indigenous to the valley is a series of low hills on the valley floor along the eastern side, the Indio Hills and Mecca Hills.

The Indio Hills

The Indio Hills are conspicuous across the valley from Palm Springs and Palm Desert. About three miles wide, they parallel Interstate 10 for about 20 miles between Desert Hot Springs and Indio, and lie about 1 to 2 miles from the foothills of the Little San Bernardino Mountains. They are conspicuous for their light tan color, their highly eroded surface, their structure being fault-controlled and their geomorphology being badlands topography.

Badlands topography is the product of sheet and flash flood erosion on sandy, poorly consolidated rocks. Torrential rains fall too fast for any great volume to sink into the ground, so there is rapid buildup of a great volume of runoff water and subsequent erosion. Badlands are typically developed in arid lands, and are usually devoid of vegetation cover.

Badlands topography is among the most intricately sculptured of landscapes, being a labyrinth of gullies separated by sharpcrested ridges. Typical of badlands topography, the arroyos or dry washes are V-shaped in cross section, with flat bottoms. These gullies have been eroded along the outcrops of weak layers. Between them, narrow ridges have developed in the more resistant strata. The bounding slopes are usually at a steep angle. The Indio Hills are low hills, generally rising about 600 feet above the valley floor at their north end, and 1,200 feet at the south end. They have typical badlands topography: soft rocks deeply eroded by intermittent stream action and gully-washing rains.

Structurally, the hills are a broad arch in the sedimentary beds uplifted along branches of the San Andreas fault. The straight southeastern face of the Indio Hills marks the trace of the Banning fault, considered to be the main San Andreas fault, and the north face is the trace of the Mission Creek fault. The hills are a wedge structure pointing to the southeast, with the two faults merging at Biskra Palms.

The northeast slopes of the Indio Hills are steep, though not more than 200-300 feet high. This is the most clearly defined fault scarp in the valley.

The most widely exposed rock formation is the young (Pleistocene age) Ocotillo Conglomerate, a coarse, gray conglomerate that grades into the valley as a pink sand and clay.

The underlying beds are the weak or incompetent fine-grained sandstones and clays of the marine Imperial Formation. The Imperial formation is conspicuous at Willis Palms along the southern base of the hills, one mile west of Thousand Palms Canyon. There, the rocks of the Imperial Formation appear as contrasting yellow-brown beds just north of the oasis.

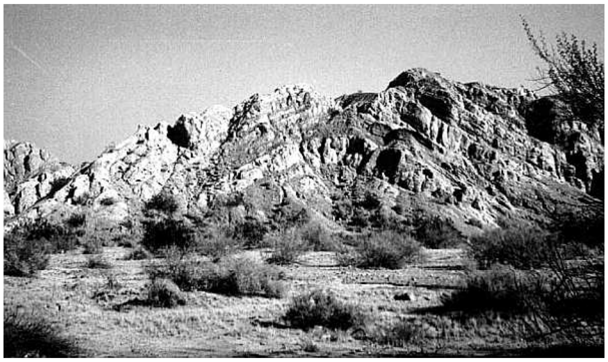
The Mecca Hills

The Mecca Hills lie along the northeast margin of the Salton Trough, from Indio to the Salton Sea. They are linear with the Indio Hills and are similar in their rock assemblage. The underlying basement is the Orocopia Schist, a hard, dark gray rock of probable Precambrian age, more than 600 million years ago. The schist rock is exposed extensively throughout the Orocopia Mountains nearby, and extends westward under the Mecca Hills.

This basement rock mass is overlain by much younger nonmarine sedimentary rocks that are typical of the valley.

The margins are defined by branches of the San Andreas fault system. The hills have little or no alluvial cover, and no vegetation. As a result, the rocks and their unique structure are extensively exposed and easily visible.

The hills have been formed since mid-Pleistocene time (as recently as one million years ago). They are strongly folded and are locally faulted, resulting in a very uneven topography. The Mecca Hills are the most distorted and crumpled hills in the valley, and are truly spectacular to see. This perfect anticline is a case in point. The Mecca Hills came into being through compression forces from movement along the San Andreas fault system. The weak sedimentary beds were shoved tightly against the bedrock complex of the Orocopia Mountains to the east. Something had to give, and the weaker sediments collapsed into folds.



Rocks on the west side of the fault were upended and wrinkled into tight folds, some of them tilted steeply to the valley. East of the fault, the sediments are compressed into a large anticlinal uplift in which the sediments are buckled and faulted into many tightly compressed folds, commonly with near-vertical bedding. All this structure is the result of right lateral drag movement on the San Andreas fault.

Geophysical studies of the subsurface in the Painted Canyon area reveal the extent of much older vertical movement along the San Andreas fault. Subsurface mapping across the fault has disclosed a near-vertical step in the basement rock of about 12,000 feet.

An excellent overview of the Mecca Hills may be seen from Highway 111, south of Mecca. The deeply incised badlands topography is evident. The straight line-up of the hills is the trace of the San Andreas fault which trends northwest across the southern margin of the hills. The frontal low hills and the streaks of red clay gouge mark its location.

Whitewater Hill

Whitewater Hill is located along the east side of Interstate 10 at the Whitewater exit. It is unique in the area because it is a dome structure resulting from recent uplift, probably associated with activity along the Garnet Hill fault.

The radial drainage pattern and the small washes suggest that deformation in the area may still be going on. Radial drainage is stream flow away from a central point in a rosette pattern, such as one might find on a dome.

Garnet Hill

Garnet Hill is located west of Interstate 10 at the Indian Avenue exit. It is about one mile long, oriented parallel to I-10, and lies between the highway and the railroad tracks. This small hill is an eroded fold in recent rocks that have been upwarped along the north side of the Garnet Hill fault, with subsequent erosion.

The hill is unique for the number of stratigraphic units exposed. Uppermost is the Cabazon Fanglomerate of late Pleistocene age. The Cabazon is a poorly sorted sandstone with boulders of gneiss and granite derived from the San Bernardino Mountains *to the east* that have been brought to the valley floor by the Whitewater River. Also lying on the surface, however, are boulders of crystallized limestone and granodiorite, rock types originating from the San Jacinto Mountains *to the west*. This striking difference suggests very recent uplift of the hill along its bounding faults.

Underlying the Cabazon Fanglomerate and appearing in scattered exposures along the south margin is the marine Imperial Formation of late Pliocene time, seven to ten million years ago. The Imperial Formation is special to the valley since it is evidence of the only incursion of the Salton Trough by the marine waters of the Gulf of California. All this happened before the Colorado River blocked the sea from the valley by its delta. This arm of the sea extended into San Gorgonio Pass, filling the area with warm marine

waters containing abundant shell fish, found today in the sandy portions of this formation.
The northwest slope of Garnet Hill faces San Gorgonio Pass. The hillside is covered with abundant granite boulders that are deeply grooved, pitted and polished by strong wind activity. Wind-polished boulders are called ventifacts. All the grooves are linear, and are oriented to the east entrance of San Gorgonio Pass. The amount and depth of the grooves in the granitic boulders suggests that the prevailing winds have been unchanged for centuries.

Edom Hill

Dominating the landscape at the northern end of the Indio Hills is a massive, symmetrical sand hill. This is Edom Hill, elevation 1,610 feet, which is easily identified not only for its size but for the communication towers at its top.
Edom Hill is bounded on the northeast by the San Andreas fault, which has separated the hill from the Indio Hills, of which it is a part, nonetheless.
Located in the track of the strong, prevailing winds from San Gorgonio Pass, Edom Hill is covered with large accumulations of wind-blown sand in the lee depressions and along its base. As a result, sightseeing tour guides are prone to claim that Edom Hill is "the largest sand dune in the world," a statement both harmless and incorrect.

The Dillon Road Piedmont

Lying between the Indio Hills and the base of the Little San Bernardino Mountains is the Dillon Road Piedmont, a narrow plain sloping steeply away from the mountain base. It extends from Desert Hot Springs to the Mecca Hills.
It is a narrow intermontane area filled with alluvium derived from the eastern mountains. Obstructed from further down-valley movement by the hills, the alluvium has collected behind the hills. Insufficient stream flow prevents the coarse alluvial debris from being washed sideways around the Indio Hills to the valley floor. The accumulated material has built up to a height several hundred feet above the valley floor.

This elevated "valley within a valley" is highly dissected by small arroyos and stream channels at right angles to Dillon Road which traverses it from Indio to Desert Hot Springs. The Dillon Road Piedmont is spectacularly visible from westbound Interstate 10 as it enters the Salton Valley.

Painted Canyon

A cross-sectional view of the uplifted and deformed sedimentary structures in the Mecca Hills is well-displayed in Painted Canyon. The canyon is reached by a short gravel road running west from State Highway 195 near the irrigation canal, east of Mecca.
The San Andreas fault crosses the road at the mouth of Painted Canyon. A minor parallel fault, the Skeleton Canyon fault defining Skeleton Canyon is about 300 yards further into the canyon. The zone between the two faults is a series of low hills of finely ground, brick-red fault gouge, or rock flour. The gouge was formed by crushing and grinding of the surfaces of the soft rock along the fault plane during movement.

The road continues into the canyon for about one mile, ending at the Painted Canyon fault, also at right angles to the road. In this traverse of the structure, the road is crossing the structural grain of the hills, and many excellent exposures of broad open folds may be seen in the canyon walls. In places, the sedimentary layers are spectacularly nearly vertical.

Warning: upon entering Painted Canyon, the gravel road narrows, eventually becoming a single track jeep trail. There are many soft sand pockets in the road to trap the unwary, and few turnarounds to help the victim. For those unwilling to play this kind of geologic Russian roulette with their car, there is an alternative. Much of this structure is also exposed along the paved road, Highway 195, as it negotiates Box Canyon between Mecca and Interstate 10.

CHAPTER 5
DESERT SAND AND THE WIND

THE TYPICAL DESERT ENVIRONMENT is characterized by deficient rainfall, clear skies, high evaporation, great range of diurnal temperatures, sparse vegetation and high seasonal winds. These are the same conditions which promote desert rock weathering, leading to the production of abundant sand, and to the movement of the sand by the winds.

The Salton Trough is filled with alluvial deposits brought to it by the intermittent streams which descend the slopes of the bordering mountains. In places, the alluvial surface is mantled with large areas of sand accumulations, the largest being the Algodones Dunes, or Sand Hills, located on the eastern margin of the Imperial Valley. Other sand bodies are scattered in the area southwest of the Salton Sea and on the floor of the Upper Coachella Valley.

In the Upper Coachella Valley, sand deposits are absent near the entrance to San Gorgonio Pass. High velocity winds descending the pass sweep the desert floor clear of its veneer of sand and fine-grained materials, depositing them farther down-valley. As a result, the Coachella Valley dune area lies along the axis of the valley between Palm Springs and Indio.

While the sand-covered surface is extensive on the valley floor, the landform expression is unimpressive. The sand is a smooth and featureless veneer with random fields of small knob dunes three to four feet in height. These modest sand forms are temporary features, subject to erosion, obliteration and eventual removal by wind action or to destruction for urban development or agricultural uses. South of Indio, around the Salton Sea the sand bodies become larger.

Deflation

In the sea of sand, the wind controls all.

Deflation describes the process by which desert sand is removed from the dry surface and transported by the wind. Sand movement is a combination of two factors acting in concert: wind velocity and grain mass. As the wind gusts, it hurls sand particles upward into the air. The finest particles are borne away by the wind. The mid-size particles become agents of the wind, bouncing across the surface, scouring each other and whatever they may strike, eventually accumulating into dunes. The heaviest, largest particles remain earthbound, forming a protective armor of large grains across the surface.

Suspension

Visually, suspension is the most conspicuous form of deflation. These are the dust clouds seen on windy days, which are sand particles in suspension in the air stream. Particle mass is so small that the velocity of the wind is sufficient to maintain the particles airborne.

Desert debris carried in aerial suspension by winds of normal speed ranges in size from desert dust to small sand grains. The smallest particles will often be carried to great heights and over great distances by the wind. Dust clouds are often seen on windy days in the desert, rising into the air from construction sites, stream beds, rural roads or freshly worked, dry fields.

In wind-borne sand movement, the lighter the grain mass and/or the greater the wind velocity, the more sand will be moved in suspension. Even a light breeze can carry the finest desert dust. Windy days, then, are often dusty days in this part of the desert. Cars, patios and anything left outdoors will be coated with a thin film of sandy dust. This also presents a health hazard. The finest particles (known as PM-10) are so small that they can pass the body's natural defense barriers and settle in the lungs. Smaller in diameter than a human hair, they can cause respiratory problems and can become very serious for someone with respiratory problems.

Saltation

Saltation is that form of wind-borne sand movement where the sand grains are unable to remain in constant aerial suspension. They are light enough to be picked up, but are too heavy to stay up. The wind is too weak to keep them permanently suspended. As a result, the wind-blown sand grains move forward on the surface in repeated pickups and long bounces. The greatest volume and weight of wind-borne sand movement is by saltation. It is a strong force of erosion, as saltating sand causes considerable abrasion of fixed objects in the path of the wind.

In saltation, the sand grains are characteristically close to the surface. Studies of wind-borne sand movement in the Coachella Valley near Garnet Hill have shown that 90 percent of the saltating grains travel within 25 inches of the ground surface.

Sand moving by saltation is often seen on windy days as sand streams swirling across a highway, and heard striking an automobile with its distinctive clicking sound. This can cause substantial and costly damage to automobile paint, glass and chrome parts. The damage is worsened by high speed driving through the sandstorm. The air flow over the car raises the suspended sand the additional height needed to sandblast the surface.

The transport capacity of the wind is enormous. The amount of material held in suspension in a desert sandstorm may amount to thousands of tons per square mile. A normal desert wind of 15 miles per hour velocity will readily transport in suspension one ounce of sand or dust, about one teaspoon, in a cube of air 10 feet on a side. Such a desert breeze extending to 1,500 feet elevation, may carry a load amounting to more than 1,000 tons of sand per square mile of area covered by the storm. That is why wind erosion is often such a problem to agricultural areas of dry farming.

Desert Pavement

The desert floor often looks more substantial than it is. The surface is usually covered with coarse grained, well-packed gravelly material that forms a crust. This is called desert pavement, and with the appearance of sandy gravel suggests a firm and solid surface. But many a motorist has bravely but unwisely left a graded road, only to quickly break through the crust of desert pavement to become helplessly mired in the soft sand beneath.

Desert pavement results from prevailing high winds from one direction. Fine particles are removed and borne away by the wind, but coarse grains and pebbles, too heavy to lift, lag behind. As the coarse materials become concentrated on the surface, they become packed into a crusty layer that protects the finer sands beneath from further wind action. Desert pavement is found everywhere in the sandy deserts. In areas of high prevailing winds, damage to this surface crust is quickly repaired by nature. Where winds tend to be moderate and variable, the formation of desert pavement can take many years to repair.

This raises an interesting environmental question regarding land use in the fragile Colorado Desert, which covers most of southern California. That is, how long can wheel tracks, for instance, be expected to remain visible on the sandy desert floor and hillsides? The most definitive answer is: a very long time. Archaeological observations in Egypt have suggested that human imprint could remain evident for more than one thousand years. More to the point, prospectors and weekend explorers venturing into the more remote areas of the mountains in the Desert Center area have reported finding tank tread marks dating back to armored training exercises early in World War II.

Ventifacts

The power of wind-laden sands as an agent of erosion is shown by the polished and grooved granite boulders, or ventifacts, on the northwest face of Garnet Hill. The sandblast effect has carved out grooves in the softer portions of the boulders, leaving the more resistant rock protruding as miniature ridges. Furrows in these boulders are as much as two to three inches deep and up to 18 inches long, all oriented in the direction of the prevailing winds from the pass area.

Blowsand

The primary source of sand in the Salton Valley is the dry alluvial plain of the Whitewater River and its principal tributary, San Gorgonio wash, as they enter the Coachella Valley. The flood plain is flat, and the surface consists of coarse sand and gravel with some small boulders. It is sparsely covered with low bushes. The relative absence of fine-grained sand and desert dust indicates active wind erosion.

Another important source of wind-borne sand is the floor and walls of San Gorgonio Pass. The arid climate, low precipitation, high heat and occasional brush fires combine to limit the amount and quality of hillside vegetation. Poorly covered or denuded hillsides are eroded of large amounts of silt and sand which find their way to the floor of San Gorgonio Pass. These loose materials do not stabilize rapidly, and are readily picked up and transported east through the pass into the valley as wind-borne sediments by the strong winds.

As the infrequent stream floods sweep down the canyons from the higher elevations, they remove erosional debris from the mountains, creating a coarse, sandy cobble-stone alluvial fan surface broken by a network of narrow, sandy washes or arroyos. The persistent southwesterly winds of the valley lift the finest particles of sand from the toe of the fan, depositing them basinward in an ever-changing field of blowsand dunes. An increasingly major cause of windblown sand is disturbance of the desert surface by human activity, principally vehicular traffic, all-terrain sports vehicles, construction equipment and farming.

Prevailing winds in the Upper Coachella Valley are from the northwest year around. During one four-year study period, it was found that 45 percent of the winds were from the northwest. More significant to the formation of sand bodies is that 89 percent of the northwesterly winds had a velocity more than 16 miles per hour, sufficient for both suspension and saltation of sand grains. Wind velocity is greatest at the exit of San Gorgonio Pass between Windy Point and Whitewater Hill. Below Windy Point, the wind spreads laterally over the valley floor, losing some of its velocity and carrying capacity as it flows down-valley. As a result, much of the sand burden is deposited in the wind channel that generally parallels the highway and the railroad from Whitewater to Indio. Deposition of the sand occurs in the lee of larger obstacles such as buildings, desert bushes and surface irregularities. Except where topography interferes, dunes and sand mounds are oriented along the northwest-southeast axis of the valley.

The Coachella Valley blowsand area covers about 70 square miles. It is estimated that about 130,000 cubic yards of sand are transported annually southeast to the central valley floor from the source of the sand, primarily the Whitewater River floodplain.

The largest blowsand accumulation is the triangular area at the mouth of the pass formed by Interstate Highway 10, State Highway 111 and Indian Avenue. This area also includes the majority of the windfarms in the valley.

The character of blowsand is very well displayed along the six major east-west roads from Vista Chino to Country Club Drive. These cross the valley from the urban areas to the Interstate 10 freeway. When an open desert area lies north of the road, the sand blows freely across the road, accumulating along curbs and flowing into property on the south.

Another area of blowsand deposition and dune formation lies in a belt north of Interstate 10 near Thousand Palms. This area of spectacular sand deposition is within the Nature Conservancy Preserve, and is the home of the endangered Coachella Valley Fringe-toed lizard.

While they are extensive, blowsand accumulations tend to be unimpressive, lacking the precise geometry of the Algodones Dunes or the barchan dunes of the Imperial Valley. This is due to the large amount of new sand constantly being added to the blowsand fields and to the irregular wind velocity.

Knob Dunes

The most widespread sandforms in the Coachella Valley are knob dunes. These dunes are elongated low mounds that form in the lee of desert shrubs. They are generally small, but can range up to five feet high and 20 feet long. Knob dunes often occur as widespread dune fields.

Knob dunes commonly stabilize around patches of mesquite, creosote bush and other large desert shrubs, changing shape and form as the plant group increases or dies out. Typically, this type of sand form increases in size and height as the bush grows more top to escape the sand, thus trapping more sand at its base. These sand drifts may locally be called mesquite hill dunes, or "boondocks," a cone of sand with a bush enclosed in it. The bush has a scraggly, leafy top with a long, deep root system through the sand,

anchoring the dune to the desert floor. Boondock fields can become extensive, and are characterized by their conical forms on a floor of desert pavement. They are common throughout the southwest. One unique field is located adjacent to Highway 111 south of the railroad bridge at the Snow Creek turnoff. From their peculiar shape, these knob dunes are sometimes called "elephant dunes." The windward surfaces are covered with luxuriant evergreen growths of ephedra, or desert tea, with protruding proboscis-like ridges forming on the lee sides.

Where the wind is both persistent and strong, living plants can survive only in the lee of some protective obstruction. The plant tops are commonly shorn even with the barrier, and new shoots are trimmed off by the windblown sand, with the plant taking the shape of the boulder protecting it.

Another form of fixed sand accumulation results from plantings for windbreaks. An example would be the line of tamarisk trees along the west side of Highway 111 at Windy Point. Another is the planting of miles of trees along the railroad line. Eucalyptus and oleanders are commonly planted as windbreaks in the fields and vineyards on the valley floor. Vegetative windbreaks help alleviate the blowsand problem, but do not eliminate it.

Sand Dunes

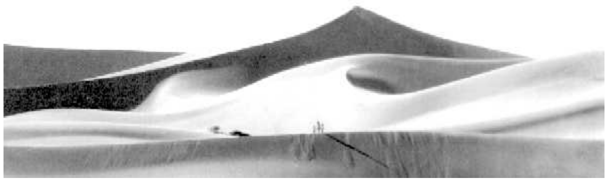
Windblown sand moving across the desert floor will take on a variety of characteristic forms, all loosely defined as sand dunes. These forms range from sand mounds around or behind an obstacle to large spectacular sand fields.

A sand dune is a curiously dynamic landform. It can form behind any impediment - a bush or a rock - or simply as a wayward product of the wind currents. The variety of dunes is staggering. Some are dwarfs only a few feet high. Others are monsters towering hundreds of feet high.

True sand dunes are accumulations of sand that take a distinctive form under different wind patterns and are relatively free to move or migrate before the wind. An important distinction is whether the dune is fixed or mobile. A fixed dune is anchored in place by a barrier. A mobile dune consists of free sand able to move at will under the influence of the wind.

The largest tract of desert dunes in North America is the Algodones Dunes, also known as the Sand Hills, in the extreme southeast corner of the Salton Valley. This spectacular field is about 40 miles in length and five miles in width, oriented in a northwest-southeast direction. Interstate 80, between Yuma and El Centro, cuts directly through the sand field, as does the All American Canal.

The sand body has an average thickness of 250 feet. The Algodones Dunes are migrating as a body slowly to the southeast at about six to 12 inches per year under the influence of the strong northwest winds of Spring and Winter.



This form of sand dune fits the popular perception of what desert sand dunes are like. They are widespread in desert areas all over the world, and are called seif dunes. A seif dune field is a longitudinal dune chain composed of a regular succession of summits, each tapering to a point, the whole looking in cross section like an Arab scimitar. (The word "seif" is Arabic for sword).

Seif dunes are propagated and take their distinctive shape from the interaction of two prevailing wind patterns, one stronger than the other, acting upon an abundant supply of sand.

The Algodones dune field is linear. The southwestern margin is a remarkably straight line lying directly over the buried but inferred trace of the Sand Hills fault, a member of the San Andreas system. This view, looking southwest clearly shows the linear margin of the dune field. Interstate 10, shown here as a gash across the dune field, was built by removing the loose sand down to the desert floor. That the field, notwithstanding its size is simply sitting on the desert floor is also evidenced by the several large clear areas which are themselves impermanent. The fault continues as the Algodones fault, which is traced from the Cargo Muchacho Mountains past Yuma into the Gran Desierto de Altar in Mexico.

As to the origin of the dune field, it is believed that fault-dammed ground water percolated to the surface along the fault to support a line of vegetation at the surface. The prevailing northwesterly winds brought abundant sand from the upper valley, eventually burying the vegetation.

The source of the sand for this massive dune field is uncertain. One speculation is that the sand was derived from the dry lake bed of ancient Lake Cahuilla. This possibility, however, fails the prevailing wind test. More likely, the source may have been the wind blown sand of the Whitewater River floodplain and the Coachella Valley. This seems to be the most plausible explanation since the dunes are located in the track of the migrating sand, and the prevailing wind is from the northwest.

Barchan Dunes

Where there is a limited supply of sand and a steady wind blowing from one direction across a flat ground surface, barchan dunes may form. Barchans are usually free-standing single dunes, and large fields of individual dunes are not uncommon. The barchan is crescent-shaped with the points downwind, like a croissant bun.

Because a barchan dune is free-standing, there are no restrictions which might affect its shape. The perfect barchan dune is an air foil, as the flow of air past this type of dune responds to the same aerodynamic laws as the airflow over an airplane wing. Barchans migrate readily, and it is not uncommon for a flat, windswept desert valley floor to contain many barchans marching downwind in the direction of their points.

A small field of barchan dunes is located near San Felipe Creek, within the abandoned Navy property on the southwest shore of the Salton Sea. The characteristic barchanoid shape is not always apparent at ground level, but is clearly visible from the air. Called the "Salton Dunes," these have their crescents open to the east, indicating a prevailing west wind. The individual barchans are 25 to 100 feet across, and are six to 30 feet high. The underlying surface is desert pavement gently sloping to the lake. Under the influence of the wind, the barchans are migrating east, or toward the lake. As the individual dunes move at different rates, some dunes are overtaking and merging with others.
Since the field is located below the high-water level of old Lake Cahuilla, it is probable that the dune field is fewer than 400 years old.

The Mineralogy of Sand

Because sand is erosional debris of other rocks, the mineral composition of dune sand at any particular location closely paralels the mineralogy of the rocks in the neighboring mountains. In the Salton Valley, these are the granitic rocks of the mountains framing the northwest margin of the valley and the many dry creek beds that drain them. Desert sand is easily recognizable under a magnifying glass. Its properties and mineral constituency, particularly the abundance of fresh feldspar and quartz are determined by the nature of the parent rocks of the surrounding mountains.

In the weathering processes of an arid climate, mechanical or physical weathering is important in rock breakdown. This is the disintegration of the rock into grains and crystals little altered from their original state.

Feldspar is the most abundant mineral constituent of desert sand, most of it being fresh and not yet chemically broken down. The combined pinkish orthoclase and gray plagioclase varieties give desert sand its typical light buff or fawn color.
Clear, colorless quartz is the next most abundant mineral, and is the most durable.
The dark grains are the ferrous minerals, and as might be expected in the detritus of granitic rocks, includes biotite mica, hornblende, epidote, apatite and others, all more or less weathered and slightly altered.

The larger quartz and feldspar grains have sharp edges, with corners only slightly rounded. Spheroidal grains, characteristic of beach sand, are absent. Most of the finer material is sharply angular. The soft mica flakes are rounded and have pitted surfaces.

The sorting action of the wind may concentrate the finely divided mica flakes on the surface of the dune. This gives the dune a glistening, often brassy appearance. This same appearance is often seen in streambeds where the sorting action of stream flow has placed the lighter mica flakes on the surface of the silt.

CHAPTER 6
DESERT PALM OASES

DESERT OASIS requires no definition. Everyone has a perception of an oasis. There is something romantic about the term, yet something mystical -- a near-sacred place where one can escape. An oasis is a life center keeping at bay an often-hostile outside world. What do people really feel when they say, "I have a condo in Palm Springs?"

An oasis is indeed a center of life in the desert. A remarkable selection of animal and plant species adapt in a balanced existence, and are able to survive in an otherwise impossible environment.

A unique creation, the desert oasis owes its existence to a source of water close enough to the surface to support plants. With a continuing water supply, the vegetal base soon supports a thriving population of birds, insects, reptiles and small animals. The oases of the California low desert have been a source of water and comfort for hundreds of years, some of them large enough to support small bands of Indians.

The Washington Fan Palm

The oases of the Salton Valley are unique for their spectacular display of America's only native palm. That the trees were native, however, was not known until 1879, when a German Botanist named Wendland first identified them. He named the tree after the father of our country -- *Washingtonia filifera*. There are dozens of these magnificent oases throughout the area, each with half a dozen to thousands of palm trees.

A paradox is that even though they are considered to be desert plants worldwide, palm trees require large quantities of water to survive. In their natural habitat of the oasis, the root system is always in contact with a source of groundwater. This has led to the saying that, "palm trees grow with their heads in the sun and their feet in water." The unique root system consists of thousands of rootlets, most no thicker than a human finger. The roots seldom reach more than 8 to 12 feet beneath the surface. Thus, if the water level in the oasis falls below that level for long, the trees begin to die.

Reaching a height of 60 feet, it is a beautiful tree with its very tall, smoothly slender trunk and a burst of fronds at its top. Each frond on a palm tree is a single leaf. The frond on the *Washingtonia* palm is a single stalk four to five feet long with a double row of sharp thorns along its length. At the end is a single leaflet, shaped like a fan, accordion-folded and with short thread-like extensions at each pleat. The fronds of mature trees may be six to eight feet in length and six feet across. If left unattended, as in their natural habitat, the trees accumulate a striking shroud, or skirt of dead fronds the entire length of the trunk

Unlike other trees, the palms do not have growth rings. Consequently, there is no way to determine their exact age. It is thought that some of the largest may be as much as 250 years old.

The Washington fan palm should not be confused with its close relative, the common Mexican fan palm, *Washingtonia robusta*. This palm is imported from Mexico, and is used extensively for landscaping in the valley, as the trees transplant easily. The two species are similar in appearance except that *W. filifera* is much taller and more slender than its sturdy Mexican cousin.

It is impossible to confuse either tree with the other local palm in the valley, the date palm. Date palms, late of the orchards, are also popular trees for landscaping in the desert.

The date palm is distinguished from its cousin, *Washingtonia* by the structure of the frond. The stem of each frond may be up to eight feet long with a double row of short, spiky leaflets arranged on two sides of the main stem from its base to its tip. It is not native to the area, being imported to the Lower Coachella Valley from the Middle East in the late nineteenth century for commercial purposes. The trees adapted well, and for many years dates have been an important farm crop in the valley. Many of the date palm orchards have given way to real estate development, but a number remain along side roads around Indio. Some are untended, and await the bulldozer, but many are still in active production. A neatly trimmed date orchard is a stunning visual experience.

The Desert Oasis Environment

Virtually all the oases occur in the hills along the eastern side of the Coachella Valley. They are much less common in the western mountains, being small and scattered in isolated canyons of the San Jacinto Mountains and in the Borrego Valley area. The exception is Palm Canyon located near Palm Springs.

The palm oasis does not occur at random. Many local desert plants such as encilia, burrobush and creosote bush are widespread on the barren desert floor. These plants have adapted to an existence of surviving for months with little or no water. But palms need a constant source of water.

So, the sight of palms is an unfailing sign of a water supply. The water quality may not necessarily be very good, as the trees are tolerant of water with high alkali content. An indicator of this condition are patches of white precipitates on the surface of the moist ground around the trees.

An oasis environment requires a source of ground water and a way for the water to reach the surface. Two circumstances -- fault dammed ground waters on the eastern margin of the valley, and water flow in jointed rocks of the canyons of the west mountains -- account

for the existence of the palm oases in the Coachella Valley.
The palm oases on the eastern side of the valley owe their existence to branches of the San Andreas fault system which has a profound influence on the area's hydrology. It is an abrupt barrier to ground water depths and movement, and to water temperature variations on either side of the fault. It also contributes to the surface occurrence of water and the existence of hot springs and palm oases along the hills between Desert Hot Springs and the Salton Sea.

In the Coachella Valley, the major source of natural ground water is drainage from the eastern flanks of the San Bernardino Mountains. Greater precipitation at the higher elevations and a large watershed area combine to provide a constant source of inflow to the underground aquifers. Four streams, Mission Creek, Dry Morongo, Big Morongo and Little Morongo Creeks provide the flow channels of porous alluvium from the mountain canyons to the aquifers of the valley.

The natural movement of water in an aquifer is downward and toward the valley center. This flow path is temporarily blocked by structural traps caused by the faults. The water is diverted upward under hydrostatic pressure, thereby opening flow routes between the deep subsurface and the surface.

In this manner, water, finding its way to the surface along the faults, emerges as springs or seeps which support the palm oases along the valley margins and in the canyons. On the valley floor, preferential vegetation defines the traces of the faults on the alluvial surface. This can be traced back to earthquakes of the distant past. At the time of rupture, the fault plane, or contact surface between the two rock walls was under sufficient compression force that the movement of the walls had a grinding and crushing effect. Being pressed tightly together, yet moving past each other, the contact zone was reduced to a fine, clay-like, hard compacted material called fault gouge. This gouge, then, acts as an aquiclude, or barrier to water flow.

Many of the oases are located along the base of the low hills across the valley from Palm Springs and Palm Desert. With damming of water on the uphill, or north side of the fault, the oases then occur along the bottom slopes of the ridges or hillside scarps. This places the trace of the San Andreas fault in front of the trees. Willis Palms is a good example of this.
The oases of the eastern hills involve two faults. Two Bunch Palms, Thousand Palms, Pushawalla Palms and Macomber Palms are all located along the trace of the Mission Creek fault. Along the San Andreas fault will be found Seven Palms, Willis Palms and Hidden Palms Oases. The two faults meet and merge at Biskra Palms, north of Bermuda Dunes.

The oases on the west side of the valley, from Palm Springs to Borrego Springs are another matter. Here, the faults are deeply buried in the alluvium and are not an impediment to the flow of ground waters. Hence, there is no seepage to the surface along faults.

Some Easily Accessible Oases

A few oases are easily accessible by car. The best of these are Palm Canyon near Palm Springs, and Thousand Palms oasis, near the town of Thousand Palms across the valley. Many others may be reached by hiking trails from one to several miles. Depending on distance and ruggedness of terrain, the hike could be quite strenuous.

An excellent field trip is a visit to Thousand Palms Oasis. This large stand of trees and ponds is easily accessible by paved road. It is a preserve of the California Nature Conservancy, and the small museum and trails offer an excellent opportunity to observe and experience a desert oasis first hand. Another local oasis is Willis Palms. This oasis may be reached from Ramon Road about four miles east of Thousand Palms. The palms are easily visible at the base of the hills.

An interesting one is Dos Palmas oasis, located close to the northeast shore of the Salton Sea. [1] One of the largest oases in the valley, Dos Palmas is a large grouping of fan palms encircling cool water pools fed by springs along the San Andreas fault. Dos Palmas is reached by a dirt road from the community of North Shore in the Lower Coachella Valley. The water supply is abundant, forming a series of ponds that support a wide variety of wildlife in their natural habitat.

Dos Palmas oasis is of great historic significance. Before its discovery by the early pioneers, Dos Palmas oasis was inhabited for centuries by the Cahuilla Indians. In the 1860's, it was a stop on the stagecoach line taking the old Bradshaw Trail between Los Angeles and La Paz, Arizona. Since it was the only reliable source of water between Indio and the Colorado River, Dos Palmas soon became a key jumping-off stop for the freight roads that lead to the gold fields along the river.

Palm Canyon

A different hydrology is found in the rocks of the San Jacinto Mountains and Santa Rosa Mountains. They are broken by a complex set of vertical joints, or cracks which appear to extend to considerable depth. Rain water falling on the high slopes percolates downward into and through the joint system, eventually reaching the alluviated valley floor.

In the canyons, many of which are deeply eroded fault zones, the water finds a ready channel, flowing near to the surface, which becomes a water source for the palm trees. A case of this occurrence is Palm Canyon, near Palm Springs. This canyon extends into the San Jacinto Mountains for more than ten miles in a straight line following the trace of the Palm Canyon fault. The lower reaches of the canyon contain more than 2,500 trees, the largest stand of native Washington fan palms in the desert.

CHAPTER 7
ANCIENT LAKE CAHUILLA

FOR THREE MILLION YEARS, at least through all the years of the Pleistocene glacial age, the Colorado River worked to build its delta. By then, the delta had reached the western shore of the Gulf of California (the Sea of Cortez) creating a massive dam which excluded the sea from the northern reaches of the Gulf. Meandering at random across the ever-growing fan-shaped mass, the river changed its course constantly. For a while, the course would shift to the north, and the stream flowed into the isolated Salton basin, filling it with a large freshwater lake. Eventually, a river shift to the south to the Gulf of California would abandon the inland lake to evaporation and extinction.
As a result, the Salton basin has had a long history of alternately being occupied by a fresh water lake and being a dry, empty desert basin, all according to the random river flow, and the balance between inflow and evaporative loss. A lake would exist only when it was replenished by the river, a cycle that repeated itself countless times over hundreds of thousands of years.

There is abundant evidence that the basin was occupied by multiple lakes during this period. Wave-cut shorelines at various elevations are still preserved on the hillsides of the east and west margins of the present lake, the Salton Sea, showing that the basin was occupied intermittently as recently as a few hundred years ago. The last of the Pleistocene lakes to occupy the basin was Lake Cahuilla, identified on older maps as Lake Leconte.

Lake Cahuilla

Lake Cahuilla was possibly one of the largest lakes of the past. It was a huge freshwater body covering over 2,000 square miles to a depth of more than 300 feet. The lake was almost 100 miles long by 35 miles across at its widest point, extending from the delta in Mexico north to the vicinity of Indio. It was six times the size of the present Salton Sea. This ancient freshwater lake completely filled the Salton Basin to overflowing behind the natural delta-dam.

The muddy water of the Colorado River flowed into Lake Cahuilla for centuries. The rich soil of the Imperial and lower Coachella Valleys was built up from river silt deposited on the floor of the old lake. The thick accumulation of lakebed deposits is evidence of a long period of deposition. The shoreline of the old lake is still visible at the base of the surrounding mountains. It averages about 40 feet above sea level, but varies from 25 to 50 feet elevation. The variability of elevation is thought to be due to subsidence of the basin floor.

Radiocarbon age-dating of charcoal and fish bones found interstratified in the lagoonal silts behind gravel bars suggests that the lake existed since before the year 1200. Further evidence discloses that about 900 years ago, while Lake Cahuilla was a young, vigorous freshwater lake, the Cahuilla Indians, generally thought to be connected to the Aztecs by language, appeared from the northeast. With the first Spanish explorations in the 16th century, they found no lake in the Salton Basin. This suggests that Lake Cahuilla had evaporated completely by 1600, or about 400 years ago. Yet, these early Spanish records allude to Indian legends of the existence of a large body of water to the west. The Indians now living in the Coachella Valley have distinct legends to the effect that at some time in the past the valley was occupied by a large body of water.

Prof. Blake in his 1854 exploration report notes that the Indians told him of a time when a great body of water existed in which there were many fish and of the manner in which the water disappeared 'poco a poco' (little by little) until the lake became dry.

The Indians now living in the desert put this event as far back as the lives of four or five very old men. (The year 1900 less four or five times 60 years would place the approximate time of its end at about the year 1600.)

Lake Cahuilla's end must have been rapid when it came. The lake had been sustained for centuries as the net inflow of river water balanced the loss by evaporation. But again, the river changed its course. Possibly there was an ancient flood caused by a surplus of melt water, or perhaps the river's own natural levees became so high to be unstable. Whatever the cause, the river changed its course to flow once again south into the Gulf of California, and the lake was abandoned.

When fresh river water was no longer supplied, evaporation became the dominant factor. The lake quickly wasted away, leaving beach deposits, travertine deposits, wave-cut cliffs, sand bars and other shoreline features as proof of its existence. In its final stages, the lake level appeared to have retreated in steps, as more than a dozen separate shorelines still appear in aerial photos of the western shore and the Coachella Canal between Niland and Mecca.

So it was that Lake Cahuilla disappeared, leaving a playa, a flat, extensive salt-encrusted mud flat, desolate and without vegetation. Typical of playas, the lake bed was a dry, smooth hard packed surface. When supplied with a little water from an infrequent rain, or perhaps some random inflow via the New River, the playa would temporarily become a huge pond, sometimes miles across but filled with only a few inches to a foot of water.

Lake Cahuilla left abundant evidence of its existence. Foremost among these is the old shoreline representing the high water level of the old lake. This is evident from Indio to Cerro Prieto in Mexico at a height of about 40 feet above sea level. Where the shore abutted the bedrock of the mountain slopes, it left a whitish encrustation, called travertine. The travertine deposits destroyed or covered the original desert varnish.

The travertine appears as a showy light-colored deposit along the base of the Santa Rosa Mountains, from La Quinta for several miles southeast along the shore of the present Salton Sea. In places, the travertine is several feet thick on the rock face. The sharp contrast of the light colored travertine against the reddish brown desert varnish causes the old shoreline to be highly visible from a considerable distance.

Travertine, or tufa, is a freshwater lime deposit. It is derived from fresh waters that have a high concentration of calcium carbonate, $CaCO_3$, the material of sea shells. Freshwater algae use carbon dioxide in photosynthesis precipitating the lime. This usually occurs in shallow water where algae can grow in abundance on resistant rock surfaces.

Travertine Rock is a vivid

reminder of old Lake Cahuilla. It is along Highway 86, near Desert Shores, on the northwest shore of the sea. Travertine Rock was a small islet of bedrock that projected above the lake's high water line. Below this line, the boulders are heavily crusted with pale brown travertine, from a few inches to three feet thick and appearing sponge-like.

Travertine Rock is connected to the Santa Rosa Mountain mass by a conspicuous saddle, or tombolo, rising 150 feet. Successive Lake Cahuilla shorelines were once visible on the saddle, but they have been destroyed by recent cultivation of the land.

Shell fossils from a brackish water environment are abundant on the valley floor. They are arranged in linear accumulations parallel to the old shoreline. As the shorelines retreated, enormous numbers of Pleistocene gastropods and pelecypods (mollusks) became stranded, leaving their shells in windrows that stretch for miles. These beaches and their shells are most pronounced along the northwest and eastern margins of the Salton Sea. They may be reached by several side roads west from Highway 86, in some places less than a quarter of a mile from the main highway.

Wave-cut shore lines and sand and gravel bars are found near Niland. These are left from the ancient beaches and strand lines. In most places, the beach line has a sand ridge a few feet high, covered with abundant well-preserved freshwater shells.

Fish Traps

West of Valerie Jean, and along the lower mountain slope, is a valuable archeological site.
These are stone structures considered to be ancient Indian fish traps. There are three rows of shallow pits excavated in the talus slope. Each row has about 40 circular pits 10 feet in diameter and three feet deep. This photo, taken in 1929 clearly shows the circular pits as well as the stratified levels of the retreating shoreline.
These artifacts are thought to have been used by the Cahuilla Indians for fishing purposes, as they lie just below the high-water mark of Lake Cahuilla. The arrangement of the pits suggests they might have been constructed to keep up with the receding shoreline. With the high evaporation rate in the arid climate, each row of traps was probably used for only a few seasons before it was replaced. So, the traps are likely to be about 400 years old.

CHAPTER 8
THE SALTON SEA

For at least four centuries, the Salton Sea existed only as a dry, forbidding desert. This changed as the twentieth century opened, and the lake became a sump for discharged irrigation drainage water. But slowly, in the last half of the century the Sea is has increased in economic value as a recreational resource, with facilities for boating, hunting, fishing and camping.

In addition, the Salton Sea has assumed importance in its own right, serving as a winter refuge for many species of migratory birds. One of North America's major bird migration corridors runs from Alaska and the Yukon down the west coast into California. This pathway is used by waterfowl traveling from their summer breeding sites in the north to wintering areas in the wetlands of California's Central Valley, once the winter home to an estimated 20 percent of North American waterfowl. But farms have increasingly encroached upon and absorbed the natural bird refuge areas sharply curtailing this ecological use. The ever-diminishing wetlands of the Central Valley, centered north and south of Sacramento, have been replaced to a large extent by the Salton Sea as a wintering area. Now, helped by thousands of acres of farming and irrigation, the Salton Sea provides food and winter homes for hundreds of thousands of waterfowl during the winter months.

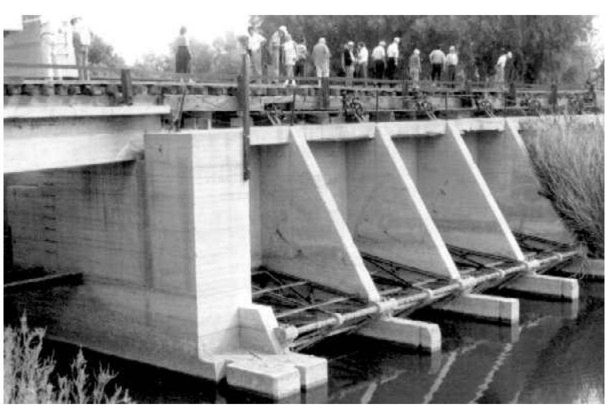
The Alamo Canal

The Salton Sea is a newcomer to the area. How and why it came into being is a fascinating story.

As the nineteenth century approached its close, the Salton Basin contained no water. It was an arid, inhospitable desert, offering no apparent benefit and only hardship to travelers. But records of early military surveys had already commented on the potential fertility of the soil if water could be found.

The surveys determined that a canal would be practical from the Colorado River to the desert. The route would begin near Yuma, where, nearing its delta, the river flowed gently through a wide floodplain with low hills on either side. At this point, the river is about 130 feet above sea level, or 200 feet higher in elevation than the Imperial Valley floor, some thirty miles to the west. The gravity gradient would be about six feet per mile, within acceptable limits for a canal. Imaginative developers planned and schemed for years seeking solutions to the engineering and financial problems involved.

The problem was finding a way to cross the formidable Algodones Dunes that lay astride the route. Neither technology nor funds were available to construct a canal across the dune field. The problem was finessed by selecting a route which began with the canal intake in the United States, circling the dunes south into Mexico following the Alamo River channel, then turning north back into the United States' Imperial Valley. In exchange for the transit rights, the Mexican government was to receive a share of the water for development of its Mexicali Valley.



A syndicate seized the opportunity, and the California Development Company was formed in 1898 to build the Alamo Canal. As the new century opened, the project was begun with the intake near Yuma. The Hanlon Heading works were well built. They were used until 1942 and still exist.

In contrast, the canal was not so carefully built. It was a hastily constructed, somewhat primitive earthen ditch, dug by manual labor. or, "mules and muscle." This century-old photograph graphically portrays the immensity of the job in the desert heat. Here, at least thirty mule teams and drags scoop out the sandy soil to make the canal. Yet, in spite of all this work, a critical omission in the design was a lack of engineering works to control the variable water flow, or the means to cut it off in an emergency.

Initially, the Alamo Canal did accomplish its mission. The new canal opened the valley to agriculture in 1901. Expansion was rapid. By 1902, there were 1,000 people in the valley. The homesteaders brought 100,000 acres of barren desert land under cultivation watered by 400 miles of ditches branching from the canal.

The California Development Company named it the "Imperial Valley", selecting this exotic name to promote land sales and to sell water. This was essential to development, since the company controlled only the *water rights*; the land itself was federal land that was to be homesteaded by individuals to establish ownership.

The entire project was a private enterprise with severe limitations, mainly the insecure arrangement with Mexico. The company lacked heavy political backing, and was without federal patronage. It was strictly on its own since the American government firmly stated it would have no jurisdiction over a canal that passed over Mexican sovereign territory. When *banditos*, for instance, threatened the peace, it was necessary for farmer posses to organize for the pursuit into Mexico to protect the canal.

By 1904, it became clear that the canal grade was too low to maintain a flow rate sufficient to keep the channel clear of mud. There were few dredging facilities, the canal silted up badly, and the water flow was greatly reduced. Deprived of a reliable water supply for their crops, the farmers grew restive and vocal.

To solve the problem of a silted-up canal, the company, in 1904, resolved to relocate the canal intake to a point farther downstream, four miles south of the border. While this shortened the length of the canal, thus increasing the gradient, the entire canal route was now entirely within Mexico. It was a questionable political decision.

It was also a poor engineering decision, since both the intake and the main ditch were now on the surface of the delta. It ignored the fact that the only practical place where the river could be diverted was at Hanlon Heading. At the new diversion, there were no natural confining hills, nor was there a permanent river channel. All the company knew or wanted to hear was that the immediate problems would be solved. So, the new ditch was dug on the flat surface of the delta in the fine, deltaic silt and sand.

Flooding was a known problem, but it was ignored. The stage was now set for disaster. This was a time before the high dams upstream were built to control the flow of the Colorado River, and the unpredictable river still carried its load of silt and mud for final deposit on the delta. The developers had paid little heed to the latent strength of the river and its potential for flood. They ignored the 1891 flood just a few years previous, and particularly the massive flooding that took place in 1862.

The Great Flood

It happened in the Spring of 1905. Violent winter storms from the Pacific caused a heavy winter snowpack to accumulate in the Rocky Mountains, and spring runoff was greater than normal. The swollen Colorado River went on a rampage. There were enormous flash floods in January and February, and the mighty river went over its banks. Seeking a better outlet across the delta, the river began scouring a new channel following the canal route and greatly enlarging it.

Notwithstanding the strength and volume of the river at flood, the swollen stream breached its banks after it had left the confines of its valley. Once on the floodplain, the stream might have been expected to lose much of its strength as it spread laterally, reducing its capability to cut a new flood channel. One must consider, then, the possibility of a second contributing factor to have helped cause a flood of this magnitude. A likely candidate would be a coincidental tidal bore from the Gulf of California, where the tidal surges are among the world's highest. The new high dams which have reduced river flow to virtually nil have also eliminated the problems of tidal bore today. But it was a different situation then.

The bore of the Colorado River would have been caused by the conflict that arose when the incoming tide encountered the large volume of river water flowing into the Gulf in those years before the high dams. This created a tidal flood with a high abrupt front. The average bore was more than twenty feet in height, and the maximum, in Spring full moon periods was measured to have been nearly thirty two feet. The sea always won, of course, checking the flow of the oncoming river water and sending a great wall of water back upstream. This scenario, the combined effects of river flood and tidal bore, seems to be a plausible explanation for the great flood of 1906.

The river surged into the Salton basin. At the intake below Yuma, the floodwaters cut a channel half a mile wide and forty feet deep. At the outlet near the town of Imperial, a waterfall 28 feet high and 1,000 feet wide was formed in the New River.
In July of that year, 87 percent of the total river flow was through the canal system. By October, virtually the entire Colorado River was flowing into the Imperial Valley. The primary inflow was via the New River and the Alamo River, through channels that remain today.

The development company had neither the funds nor the political resources to fight the river, and the government was trapped in the jurisdictional web. The only hope was the Southern Pacific Railroad, which by that time was busy moving its tracks to higher ground. They were to move 60 miles of track two more times before the river was controlled.
When the company went bankrupt, the Southern Pacific was forced to take action to protect its traffic interests, hoping that Congress would find a way later to share the cost burden. Meanwhile, farmers watched helplessly as their land was flooded. Many became discouraged and left the valley.

The railroad mustered all its resources to do battle with the river. Levees, dams, trestles and dikes were constructed, only to be repeatedly breached or washed away. Every gondola car in the west was brought in to transport rock for the levees. Here, a gondola car drops its load of earth and rock into the water during the construction of a levee.

In the following Spring, 1906, more flooding wiped out most of the works that had been built with so much effort. By that time, the new lake in the Salton Sink was 40 miles long by 12 miles wide, and the water level was rising 8 inches per day.

The struggle peaked in the Spring of 1907. In one massive effort, the Southern Pacific Railroad finally built a lasting trestle across the river, as thousands of tons of rock were dumped into the stream bed to close the break. Following the expenditure of millions of 1906 dollars and construction of miles of new levees along its banks, the river was finally brought under control.

The railroad never recovered any of its costs from the government.

The Salton Sea is the legacy of this mighty dual struggle between nature creating it, and man containing it. When the flooding was stopped, the lake's shoreline reached as far north as Mecca.

The Salton Sea Today

The lake now has a surface area of about 350 square miles, and an average depth of about 20 feet. Water temperature varies from the mid-50s in winter to above 90 degrees F. in mid-summer. The bottom of the lake is 271 feet below sea level, making it the second lowest (after Death Valley) spot in the country. The lake level is balanced between loss by evaporation and inflow of waste water from the surrounding lands.

When the lake was formed in 1906-07, the surface level was at minus 195 feet, with the lake 80 feet deep and covering more than 400 square miles. Cut off from its source in 1907, it began to shrink, and, by 1925 had reached -250 feet, its lowest and shallowest level. In the late 1930s, the sea began to rise again to about -232 feet with the increasing use of irrigation water. During the 1980s, however, the lake level began to rise again, to about -228 feet. This was due to a higher than normal supply of irrigation drainage water, causing inflow to exceed evaporation.

Normally, the seasonal variation in the lake level is about one foot, being highest in April and lowest in October. The area of the Salton Sea surface is very sensitive to the elevation of the lake level. Located in a flat playa basin, a change of even one foot in water depth significantly affects the surface area. This is important to the local farmers, as the surrounding farm land is nearly flat, and a minor change in lake level will either expose or submerge a large area. In recent years, the rise in water level did, in fact, cause the loss of hundreds of acres of Imperial Valley farmlands, with subsequent lawsuits on the cause and the liability.

Not all the inundation of croplands at the south end of the Salton Sea, however, is necessarily due to rising water level caused by the inflow of additional water to the lake. Part of the cause may be subsidence, or the sinking of the land surface. Since 1972, precise geodetic surveys suggest that the land surface of the Imperial Valley is sinking at an average rate of one-half inch per year relative to the surrounding bedrock hills. This subsidence is caused by a combination of compaction of the sediments and to deepening of the trough. Thick prisms of sediment become thinner as water is squeezed from them, as they compact under their weight, and as the earth's crust below sags under the accumulating load.

As a result, crustal subsidence steepens the grade of the streams, canals and drains, thus increasing the storage capacity of the basin.

The Salinity Problem

The Salton Sea began as a freshwater lake since it was derived from waters of the Colorado River. But it was born into a saline environment that is common in many desert areas, and the salinity of the water increased as soluble salts were leached from sedimentary formations. The problem has been exacerbated as more lands have been brought under cultivation. All new farmland must be leached before they are of beneficial use.

The Salton Sea, only eighty years old, is already two-thirds as salty as ocean water.

Table 9.1 Salinity of the Salton Sea
(parts per thousand)

	Salton Sea	Ocean Water
Chloride	9.0	19.0
Sulfate	4.1	2.6
Sodium	6.2	10.6
Magnesium	0.6	1.3
All Others	1.0	1.0
TOTAL	20.9	34.5

While sodium chloride is the dominant component, it is a lower percentage than in sea water. As the lake shrank in size under natural evaporation during the early years of this century, the Salton Sea reached a salinity of 35 parts per thousand by 1917, and to 43 parts per thousand in 1934, a few years before the All-American Canal became operational.

Evaporation from open water surfaces in the valley, chiefly in summer extremes of continuous 100^0-plus days, is about six feet per year. The surface area of the Sea is about 350 square miles, suggesting an enormous potential water loss. It is estimated that the evaporative loss from the Salton Sea -- therefore, an equal amount of replacing inflow -- is about 1.3 million acre-feet of water per year. This is nearly one-third of the total Colorado River water imported for irrigation.

Other Problems of the Sea

An enormous amount of waste water finds its way to the Salton Sea each year. Most of the runoff water is irrigation drainage and leach water from the fields, but it also includes tail water, rain water and operational discharge. The Imperial Valley is the principal source since it is larger in area than the combined Coachella and Mexicali Valleys.

As important as it is, the amount of water reaching the Salton Sea is far less of a problem than its salt content. The lake receives a constant inflow of soluble salts from irrigation drainage from surrounding farmlands. Part of the salt is leached from the soil, and part is due to the fact the river water itself is highly saline.

The farmlands must be periodically leached by flooding to remove the soluble salts. Field drainage water from soil leaching practices has a salinity of 6 parts per thousand. This may be compared with California health standards for drinking water of 0.5 parts per thousand as average, and 1.0 as the maximum allowable. Each increment of salt adds to the salt load of the sea, and there is no way to get rid of it.

The salinity problem is one key issue of many that are important to conservationists. The argument correctly states this water is irretrievably lost when it reaches the Salton Sea. The sea has been made into a salt lake, and any fresh water that reaches it becomes unfit for further consumptive use.

Another potentially serious set of problems has overtaken the Salton Sea in recent years. Agricultural development of the Mexicali Valley has greatly increased the amount of salt-laden leach water draining to the Sea. Equally significant, the population explosion of the urban Mexicali area to about one million people has not coincided with an effective infrastructure. Consequently, the New River has become virtually an open sewer draining the Mexicali area across the Imperial Valley to the lake, exposing a pollution threat to the American communities and to the Sea itself.

The Salton Sea would long since have evaporated into a playa flat if it was not resupplied with irrigation drainage water. The variables, evaporation and inflow, are constantly at work to lower or to raise the water level. It tends to be self-regulating, as greater inflow increases the lake's surface area, which promotes greater evaporation . . . and vice versa. A natural balance is struck between the two.

Thus, drainage water maintains the lake level. Yet, diversion of Colorado River water either to other users or reduction by conservation would cause the lake to shrink in size, increasing its salinity. In so doing, the uses to which the lake is now being put would be impaired or destroyed.

The conservation alternatives are unclear. The Salton Sea serves a dual purpose. On one hand, the lake is a sump receiving drainage water and getting saltier every year, and on the other hand, the Sea has new values for recreational use and as a bird sanctuary and wintering area. But these issues are peripheral to the central problem of the best way to use this priceless natural resource.

So we circle back to the unique property of water in not being destroyed in use. This is true, in the scientific sense. Yet, here we see how an enormous amount of water is rendered unfit for further consumptive use.

It is difficult to picture the future of the Salton Sea in other than gloomy terms. Lacking neither circulation nor natural drainage, its destiny may be to become an American Dead Sea.

CHAPTER 9
THE GULF OF CALIFORNIA

SEVEN MILLION YEARS AGO, in Pliocene time, the Baja California peninsula did not exist, nor did the Gulf of California, known in Mexico as the Sea of Cortez. Their mutual evolution and geologic history not only make a fascinating story, but one that has had a profound effect upon the Salton Valley.

The Gulf of California and the Salton Trough are components of a single geologic structure that averages less than 100 miles in width yet is more than 1,000 miles long. In this context, the Salton Trough is considered the landward extension of the Gulf.

This point becomes clear when one considers that the Salton Valley exists only because the Colorado River delta is a natural earthen dam that completely excludes the waters of the Gulf. If it was not for that dam, the Valley would be submerged as far north as Indio.

So, any study of the valley's physical history and environment must include the Gulf. More so than usual, in fact, since this area is one of earth's most dynamic and changing regions, and the long term future of the valley has many speculations of wonder.

Geology of the Gulf

Briefly stated, the Gulf of California is an elongated depressed block along a zone of major, roughly parallel faults. It is a complex fault zone in which total relief, i.e., the elevation difference between the sea floor of the Gulf relative to the mountains of Baja California to the west and the Sierra Madre of mainland Mexico to the east is greater than 10,000 feet.

The San Andreas fault is considered a major element of this fault zone. The fault presently disappears beneath the alluvium of the Imperial Valley, but is thought to continue southeastward into the Gulf, merging into the East Pacific Rise along the Gulf's axis.

The general structure of the Gulf is very well observed in this satellite composite photo. It is linear in direction, with the landward portion, the Salton Valley comprising a triangular area in the north. Clearly visible is the Colorado River delta, the Mexicali Valley and the Imperial Valley represented by dark tan color, the Salton Sea's conspicuous gourd-shaped area and the Coachella Valley at the apex. One may also interpolate the East Pacific Rise as the axis of the Gulf translating into the San Andreas Fault Zone beneath the delta.

The northern one fourth of the Gulf is shallow; at no place greater then 600 feet deep. Here, the Colorado River delta has contributed greatly toward filling the north end with fine sand and silt, making the sea floor much shallower than it is in the south. The sea bottom of the Gulf grades upward to the north, gradually and eventually mergeing into the marshlands of the delta. This character of the Gulf is observed at the beaches of San Felipe, 120 miles south of Mexicali.

The basement rocks under the north end of the Gulf are covered by as much as 25,000 to 30,000 feet of these deltaic sediments. This enormous volume of silt suggests the amount of erosional debris taken from the Colorado Plateau to the Gulf by the Colorado River over several million years.

Further south, the east side of the Gulf floor slopes gently from the mainland Mexico coast to an irregular escarpment near the center of the Gulf. Between the 25th and 26th parallels of latitude, one section of this escarpment is a great submarine cliff nearly 6,000 feet high.

Much of the south half is occupied by a remarkable depression in the sea floor, extending 250 miles southeastward from a point east of tiny Isla Tortuga. It widens into enormous proportions in places. The enclosing contour of this depression is 5,400 feet below sea level. This great submerged basin is occupied by three separate basins. The deepest basin, 10,740 feet, lies in the center of the Gulf between the 25th and 26th parallels.

Between 30 and 40 islands varying in size are found in the Gulf. Some islands, while very small in area, tower to surprising elevations with great ocean deeps close offshore. Many islands are elongated, with shorelines generally parallel to the axis of the Gulf, suggesting their origin as uplifted blocks along faults.

Isla Angel de la Guarda, the second largest island, is unique. It is at the 29th parallel, in the upper half of the Gulf. This 45-mile long island lies about ten miles offshore from Baja California, yet is separated from it by a long, narrow and deep submarine trough which averages 4,000 feet deep. The deepest portion is more than 5,000 feet below sea level. (This island is conspicuous in the satellite photograph at the top of this page.) Considering that the island lies only a few miles offshore from the peninsula proper, the extreme depth of the intervening basin suggests significant vertical displacement along faults on the sea bottom.

The several broad, deep basins in the Gulf are probably wedge-shaped blocks, or grabens, bounded by faults. The most convincing evidence of this is that the deep basins are true closed depressions, with elongated steep sides, rather than open-ended submarine valleys. Volcanic activity in the Gulf area was intense in Miocene time, about 25 million years ago. Extensive basalt flows are found in the southern part of Baja California. Volcanoes were active through the Pleistocene, and have continued active to the present. Isla Tortuga is a very young volcano in the Gulf. Las Tres Virgenes and Isla Coronada have been active in historic times, as well.

A Hypothesis as to the Origin of the Gulf of California

The Baja peninsula, including most of southwestern California is an elongated slab of the North American continent that has been sheared from the mainland and moved to its present position.

The postulated movement of the peninsula may be retraced backward in time and in direction. Looking back to the Cretaceous, the peninsula is brought into a likely former position with the mainland. In this arrangement, the Sierra Madre del Sur appears to continue without break from mainland Mexico into Baja California.

In Pliocene time, about seven million years ago, a zone of separation developed on the East Pacific Rise. The future Baja California peninsula and a piece of future California were sheared from mainland Mexico along a lateral fault, possibly the ancestral San Andreas fault which was then, as now, oriented northwest-southeast. During this early period of development, movement was right lateral, with the sheared-off slab moving northwest, but always in close contact with the mainland.[1]

The northwest movement seems to have been repeated slippage along the principal members of the San Andreas fault system -- the Elsinore fault, the San Jacinto fault, and the main San Andreas strand itself.

About four million years ago, the San Andreas fault proceeded to play a key role in the next phase, the opening of the mouth of the Gulf of California. While the Baja California peninsula continued to move to the northwest as a whole, its southern end began to rotate westward, opening a seaway between the new peninsula and the mainland. This movement is thought to have been caused by torsional stress. That is, while the primary movement continued to be northwest, the northern end of the Baja California peninsula became locked against the mainland, causing the southern end to rotate westward, creating the seaway that was to become the Gulf of California.

As the Gulf continued to open, Baja California moved out to sea while the Peninsular Ranges of California remained attached to the mainland block. Movement along the San Andreas fault system was vigorous, and the San Jacinto fault became the most active member. At this time, the San Jacinto Mountains and the Santa Rosa Mountains were sharply compressed and uplifted.

Like a massive lever, the rotation caused intense compression forces at the north end, near the fulcrum. The squeezing effect helped to raise the Transverse Ranges of the Los Angeles basin (the Santa Monica, San Gabriel and San Bernardino Mountains), orienting them east-west, as opposed to the northwest-southeast direction of other major ranges of central and southern California.

Coincident with these forces, there were stresses that formed the offshore basins, such as the Santa Barbara Channel and the underwater grabens off the southern California coastline.

It thus appears that the East Pacific Rise extends well into the Gulf of California and sea floor spreading is widening the Gulf. Tensional thinning at the spreading center between the North American plate and the Pacific plate is further supported by the existence of a large intrusion of magma beneath the sediments of the Salton Sea. The result is regional metamorphism of the sedimentary fill beneath the Salton Sea, resulting in high heat flow and the geothermal activity and volcanism in the Imperial Valley.

CHAPTER 10
VOLCANIC ACTIVITY IN THE IMPERIAL VALLEY

VOLCANIC ACTIVITY in Southern California is not something one thinks about very much. With earthquakes carrying such a high priority in our concerns for public safety, the thought that other geologic phenomena are present hardly matters. Perhaps it is just as well, for while the valley contains a remarkable selection of volcanic wonders, they are subdued and seem to present no danger.

Why this is so goes back to the same forces that drive the earthquake question: the dynamic earth on which we live. If one accepts the fact that the Salton Trough is a part of the Gulf of California, and, therefore, the landward extension of the East Pacific Rise, and if this is the cause of our frequent earthquakes, then it does make sense that incipient volcanism may be present, as well.

This might become more clear if we describe the East Pacific Rise as a tear in earth's crust, and that sea floor spreading is opening the gap as a zipper would separate an opening in a garment, in this case from south to north. Off the west coast of Central America, deep submergence vessels, most notably the *Alvin* of the U.S. Navy, have extensivly observed and documented startling undersea volcanism, including smoking vents, ore formation and pillowy lava formations.

Progressing north to the Imperial Valley, geophysical evidence suggests that the crust is very thin and that a large mass of super-heated rock exists just below the surface. All this is characteristic of a zone of sea floor spreading where new crust is being formed as molten material is brought to the surface of the earth. As the combined Gulf of California/Salton Trough structure is a transition zone between continental crust and oceanic crust, it follows that some magmatic intrusion and regional metamorphism is going on with concurrent volcanic activity. But surprisingly, it is limited. Possibly the great thickness of recent sediments in the basin act as a thermal barrier, confining the incipient volcanic activity and insulating the surface from its effects.

Even so, the limited volcanism present in the valley includes a variety of phenomena, from hot springs to recent volcanic eruptions.

The Heat Source

Volcanic activity of any type requires a heat source close to the surface. Geophysical studies of seismic activity, of heat flow in the earth, and of magnetic anomalies in the area around the south end of the Salton Sea all suggest that active igneous and metamorphic processes are now going on associated with an intrusive mass that lies below the sedimentary cover.

The intrusion under the Salton Sea is thought to be a pluton, an arm or protrusion from a deeply buried molten magma. This intrusion is parallel to the axis of the Salton Trough. It is about 20 miles long by four miles wide, and is at least one to two miles thick. It lies within the upper 10,000 feet of the crust, and possibly as close as 4,000 feet from the surface. It is centered beneath the community of Niland, at the southeast shore of the Sea.

This pluton is acting upon the sedimentary fill, altering the rocks into a low grade metamorphic series under low-temperature/low-pressure metamorphism. Associated with the metamorphism of the rocks, chemical analysis of hot brines brought to the surface by deep thermal wells in the Imperial Valley and Mexico show that active ore formation is probably taking place around the pluton. This involves the concentration of sulfides of iron, lead, zinc and copper.

Hot Springs

The Hot springs within the valley were known and used by Indians for centuries. The first commercial development in the area dates from the turn of the century, when a therapeutic spa was opened in the foothills of the Chocolate Mountains near Bombay Beach, on the east shore of the Salton Sea. This spring is still in use, and is unusual for its high water temperature, ranging from 135 to 180 degrees Fahrenheit.

With few exceptions, the hot springs are concentrated in a linear pattern along the eastern side of the valley. The line of springs extends from Desert Hot Springs into Mexico, and the arrangement strongly suggests that the warm waters are reaching the surface using fractures of the San Andreas fault system as conduits.

There are some exceptions. At a natural spring at Miracle Hill, east of Desert Hot Springs, warm water rises to the surface along the Miracle Hill fault, a north branch of the Mission Creek fault. The hot spring in the City of Palm Springs is another exception. The warm springs in the Coachella Valley are largely confined to the city of Desert Hot Springs and its immediate vicinity. Desert Hot Springs is on the Mission Creek upland, an alluviated surface created by the coalescing alluvial fans from the east base of the San Bernardino Mountains merging with the western Little San Bernardino Mountains. The upland is a sandy plain sloping to the southeast toward the valley center.

There are more than 50 wells in a rough linear pattern from the city center southwest, following the Mission Creek fault trace. The wells deliver thermal waters at an average temperature of about 120° F. with some wells as high as 200° F. Temperature is highest in the wells located in the city, consistently decreasing southward. Desert Hot Springs waters are high in calcium and magnesium salts, primarily the sulfates, and are alkaline.

Well depths are between 20 to 340 feet into three aquifers, with the lowest being the best producer.

As there is no evidence of recent volcanic activity in the area, it is assumed that the hot waters are cool meteoric water that has traveled downward in the aquifers, there to become heated, then rising from depth along lines of fractured and faulted rocks.

Beliefs regarding the therapeutic value of natural hot springs have been popular for centuries. Since the days of the Roman Empire, mineralized hot springs have been a mecca for people afflicted with a variety of disorders. Exploiting these disabilities, zealous promoters have often used vivid imagination to lure prospective bathers. For example, early in this century the hot springs near Bombay Beach were claimed to be "veritable fountains of youth offering comfort and health-giving properties to the bathers . . .finding relief from arthritis and rheumatism." In recent years, the popularity of mineral spas has waned, as the medicinal values of the waters have been largely discounted, but the natural springs have retained some popularity as outdoor hot baths.

There are many warm springs in The San Jacinto Mountains. These are situated along the San Jacinto fault zone from Gilman Hot Springs, in Hemet Valley, south to Borrego Valley.

Agua Caliente Spring (Palm Springs)

The area that is now downtown Palm Springs has been a center of human activity for centuries. Agua Caliente Spring, located on the present Spa Hotel property, was important to the early Indians. For many years before western man came to this valley, the spring was an oasis of palm trees, saltgrass and other vegetation in profusion. It was a natural water source in an otherwise hostile environment, and the Agua Caliente Indians still attach great cultural significance to the spring.

The spring has had a long history of various mineral bath operations using the water. For more than a century, bath houses have been built on or around the spring for commercial purposes. This old photo shows the spring and the bath house in 1880.

In its natural state, and before construction of the current hotel buildings, the spring flowed from a low mound that rose a few feet above the ground surface. In its natural development, located in the central part of the spring mound, the orifice deposits are light-gray highly permeable fine sand. This appears to extend to depth, and is the vertical conduit through which the spring water rises to the surface. Surrounding the orifice, and making up the bulk of the mound is an impermeable mass of fine-grained clay-like material.

Prevented from lateral migration by the clay, the spring water rises through the washed-sand conduit of its own making. Flowing water brings sandy material to the surface, where the fine silty material is washed to the margins of the mound while the sandy material remains in the orifice. The structure of the spring, then, is a sandy permeable flow channel surrounded by a silty, clay-like, nonpermeable confining chimney.

It is probable that the spring is very old, and has slowly extended this structure upward for centuries, with the rate of building equal to the rate of deposition of alluvium on the valley floor.

Agua Caliente Spring water is of unusually high quality. It differs markedly in chemical quality from the groundwater pumped from nearby city water wells. It is a sodium bicarbonate type, with low dissolved solids and is very soft. It has a high pH, or slightly alkaline, and is high in sodium and fluorine. Natural groundwater, pumped by the local water company for domestic water, is of the calcium bicarbonate type, has low dissolved solids and is soft to moderately hard. These differences suggest that the spring water rises in its natural conduit from a depth substantially greater than the depth of the domestic water wells.

Emission temperature of the spring water is about 107 degrees Fahrenheit, and the flow rate is about 25 gallons per minute.

The circumstance of the spring is its association with the Palm Canyon fault and the unusually thick 1,000 foot sequence of sedimentary beds at the mouth of Palm Canyon.

West of the fault are the high San Jacinto Mountains, with substantial precipitation at the upper elevations. The granitic rock mass is intricately fractured, and water readily flows in the fractures. This rainwater seepage appears to follow a parabolic path under gravity and convection. It flows vertically in the rock fractures to great depth, is heated in contact with a deeply buried heat source, then, being hindered from flowing laterally by the buried fault, rises to the surface along the fault plane. It ultimately finds its way to the valley floor by the sandy vertical conduit the spring itself has made in the coarse alluvium.

Geothermal Resources

There are several experimental geothermal developments in the Imperial Valley, extending from the south shore of the Salton Sea into Mexico. The Salton Sea geothermal field is the largest and the hottest of the several fields in the Salton Valley, and has the longest history of development.

Across the Mexican border lies the Cerro Prieto geothermal field near Cerro Prieto Volcano. It is a large field and is economically productive. The geothermal waters are the result of a complex subsurface heat transfer system. Convection within the mantle is a continuously renewable source of heat. The heat is transferred by conduction through the thinned crust. Surface waters migrating downward are heated, then dissolve chemical compounds from the rocks undergoing metamorphism, and rise by convection through the water-saturated sediments to the surface.

The potential for the development of geothermal energy resources was first recognized in the mid-1920s. However, it was not until 1961 that the first commercial well in the Imperial Valley was drilled. It reached a depth of more than 4,700 feet.

The energy crunch of the 1970s spurred renewed interest in commercial development, and several wells were drilled to depths of 5,000 to 8,000 feet.

In the Salton Sea geothermal field, typical brines are produced at wellhead temperatures up to 600^{0}F. During extraction, the high temperatures and reduced pressure in the drill holes cause the superheated water to flash into steam, thus bringing in a mixture of steam and hot water at the wellhead.

The steam/water solution is highly charged with chemical salts, principally sodium chloride, calcium chloride and several metallic compounds. A unique characteristic of the brine is the high concentration of dissolved rare elements, including Lithium and Potassium. The brine is slightly caustic, and severe corrosion and scaling problems complicate the production of clean turbine steam. Although the resource is large, technical problems and cost factors associated with processing the hot brines are a continuing constraint to large-scale commercial development.

Important unresolved secondary problems inhibiting commercial development are (1) a means of disposing of the spent brines without contaminating the surface or the ground water systems, and (2) a source of a large quantity of fresh water for coolant.

By contrast, the wells of the Cerro Prieto development just over the border in Mexico are producing relatively clean steam, and commercially important quantities of geothermal energy are generated. The natural resource is extensive and valuable. The technical problems can be solved, with the principal question being the economic viability of large-scale commercial development. The opportunity is not being overlooked, as the steam resources are estimated to be adequate for the power requirements of a population of four million people indefinitely.

Volcanoes

Volcanoes? In the Imperial Valley? At the south end of the Salton Sea, southwest of Mullet Island, are five small volcanic domes. They are oriented along a northeast trend, or perpendicular to the trace of the San Andreas fault system. The domes rise 100 to 150 feet above the valley floor, and collectively are known as

Obsidian Butte. They are extruded into the Quaternary alluvium and are thought to be fewer than 20,000 years old.

Their composition is rhyolite and pumice, with subordinate obsidian.

Obsidian is volcanic glass. It is a volcanic rock that forms when the lava is cooled very rapidly. Mineral crystals do not have time to form in the molten lava, and the noncrystalline mass becomes a glass when it is subject to sudden cooling. Obsidian is often found associated with pumice, often in layers as at Obsidian Butte.

Pumice is the hardened residue of volcanic froth, or very liquid rock highly charged with gases. If the gas content is high, then the bubbles "frozen" in place upon hardening can give some buoyancy to the rock. It is commonly thought that pumice rock floats on water. Sometimes it does; usually not. Pumice boulders, because they are light and easily handled, are used extensively for landscaping.

The Cerro Prieto volcano, 15 miles south of Mexicali, is a rhyolite dome that is the product of a single eruptive cycle in the late Pleistocene.

The marked lack of erosion of the cone attests to its youthful age. Young volcanoes at Cerro Prieto are apparently part of the same suite of volcanic activity, all being associated with the East Pacific Rise.

Carbon Dioxide

From 1933 to 1954, carbon dioxide was produced from a small field near Niland. The gas was recovered from pockets 200 to 700 feet deep and was converted to dry ice for refrigeration, with much of the output supplied to the railroad for icing of refrigerator cars. The project was abandoned in 1954, a victim of refrigeration technology.

The rising water level of the lake in the early 1980s has since flooded the area, and nothing remains except a few timbers sticking out of the water.

Mud Pots

Mud pots were once a popular sight near Mullet Island. The island, originally an arm of land extending into the sea, was also submerged by the rising water.

The mud field was a dark-colored mass of lacustrine silt mud. Large bubbles of steam, some the size of a football, formed and burst, spattering wet mud into the air. Principal gasses ejected by the field were steam, carbon dioxide and hydrogen sulfide. Similar to other volcanic phenomena, the mud pots are the result of surface waters percolating downward through the sedimentary layers to the proximity of the magma body. The heated water then rises to the surface, flashing to steam as the confining pressure is reduced.

CHAPTER 11
WATER: A DESERT IMPERATIVE

The Historical Setting

ONE WONDERS HOW the twentieth century will be viewed by future local historians. A pragmatic view would say it was a period of progress measured in growth and development for the greater use of man. An environmental perception might claim that the urbanization of the desert was at the expense of the natural beauty, and

particularly the waste of our most precious natural asset -- water. Conflicting views, to be sure, but both should at least agree these have been years of profound change.
Southern California is a desert. A visitor from another land sees a bustling economy as twenty million people compete for space in a megalopolis that stretches unbroken from Santa Barbara to the Mexican border. The cities are green with lush landscaping, and are surrounded by rich farms that produce much of the nation's agricultural needs. But beneath it all, it's still a desert.

Rainfall averages three to thirteen inches a year, all of it in a three-month period of winter. There are no free-flowing rivers, notwithstanding several dusty, dry stream beds that serve to channel runoff from winter rains in the mountains. So how do we explain the paradox here? If there is no water locally available, simply bring it in from somewhere else. That's what canals are for.
Recognizing the problems, energetic and innovative water development projects evolved over the course of the century, culminating in the Central Valley Project which brings water 600 miles across deserts and over mountain ranges into Southern California. Overcoming huge financial and technological challenges, these water projects represent the most massive and impressive engineering accomplishment in the world.

The history of any community in the American West is essentially a history of its water supply. The deserts of Southern California were no exception. Located in the extreme southwest portion of the country, the climate went to extremes to deny the intrusion of western man. The desert could support its unique ecosystem of plant and animal life, and scattered small bands of Indians lived in harmony with nature. But the high summer temperatures, the hot, drying winds, and a lack of reliable water holes combined to thwart adventurism for decades.

The Conquistadors

The recorded history of the Salton Valley really begins with the post-Columbian Conquistadors. The early years of the sixteenth century were the glory years of Spain, with the mastery of Mexico and a large part of Central and South America. Gold beyond their dreams flowed to Spain from the treasuries of the conquered Indians.
The Indians paid a terrible price for the benefits of Spanish rule. This was the time of the inquisition in Spain, a period of savage cruelty which translated directly to the submission of the "pagan" Indians. It may be debated as to which of their new masters treated them the worst, the Spanish soldiers on the military expeditions or the Jesuits who "civilized them. This was the environment in which the Spaniards began to look north from their recent ascendancy over the Aztecs and the conquest of Tenochtitlan, or what was to become Mexico City.

Don Antonio de Mendoza was the first Viceroy of Mexico. He was appointed by the King of Spain in 1536, slighting the power dreams of Hernando Cortez, the conqueror of Mexico. Cortez remained Captain-General, but subordinate to Mendoza. The relationship was stormy, and the resulting friction and jealousy led to Cortez' eventual downfall. Cortez' only remaining accomplishment, but a big one, was the discovery of Baja California and the exploration of the Gulf of California as far as the mouth of the Colorado River.

The lust for gold obsessed the Spaniards. With vast wealth already stolen from Mexico and the south, why not seek north, as well? They listened avidly to Indian tales of treasure in the north. There was little gold, but much silver, they were told. But the Spaniards were not interested in silver; they wanted gold. The Indians obliged, the Spaniards heard what they wanted to hear, and the rumors of much gold intensified.

Mendoza planned to undertake an expedition into the north in 1539. Francisco Vasquez de Coronado, a wealthy General, was given the task of finding the cities of great wealth. He set forth from Mexico with a long train of soldiers, priests and Indian followers, and established his base near Santa Fe, New Mexico. For months, detachments of troops chased down rumor after rumor, killing and pillaging the Indian villages in their frustration at finding no gold.

Imagine the electrifying effect a new report of gold must have had on the Conquistadors, when they heard rumors of the Seven Cities of Gold, in a land called Cibola that lay to the west "along a great river." The Spanish general, Coronado, at the end of his fortune, his health and his political support, was determined to get his hands on the reported treasure. A large party was dispatched to find it. But Cibola was just another dream, and this last effort failed, as well. But they did find the Colorado River and the Grand Canyon.

So, Coronado found nothing and accomplished nothing. Measured against his dreams and grand objectives, his was arguably the greatest failure in exploration ever recorded. Coronado returned to Mexico, broken in health and penniless.

Yet, his chronicler, Castenada, placed Coronado correctly in history. In the preface to his journal, he wrote: "While they did not find riches, they found a place in which to search." In two years, from their base in New Mexico, Coronado's parties explored the entire southwest from Kansas to the Colorado River. And there they were stopped.

The Hardship Trail

The Colorado Desert was never a serious objective of exploration parties, either the Spanish or the mountain men. The desert was so forbidding; it was simply a miserable part of a journey to somewhere else. The trail west was truly formidable, with the most grueling section being the section from Yuma to Warner's Ranch, a distance of about 150 miles. These were the beginning and the end of a trail of hardship -- crossing the Salton Basin, the portion known today as the Imperial Valley.

Yuma and Warner's Ranch, lying on the east and west boundaries of the Colorado Desert, became important central points in the opening of southern California. Always a place where travelers could rest, they later became outfitting points for prospectors and miners in the nineteenth century.

The Yuma Crossing

The eastern terminus of the Hardship Trail became known as the Yuma Crossing, since crossing the Colorado River was itself a formidable task -- at certain times of the year an impossible task. Yet, it was known to be the key to the exploration of, and later migration to southern California.

The American push westward before and after the Civil War was strongly influenced by the geography of the West. The great wagon trains of the early pioneers preferred the Oregon Trail for a good reason: it was the least hazardous choice of several hazardous routes. As the pioneers reached the Great Basin, the wagon trains were confronted by the high barrier of the Sierra Nevada Mountains of California. This barrier deflected the trail northwest around the mountains to Oregon.[1]

Deflecting the trails to pass south of the mountains was not a viable choice. Death Valley offered little in the way of a safe passage, and the raging Colorado River in its deep canyons was a formidable barrier. In fact, mountain men eventually found Yuma to be the only place below the Grand Canyon where the river could be reasonably forded.

In an important way, Yuma was key to the exploration of the Low Desert of California. It was the only site of reliable water in a land that exacted a terrible toll from the pioneers who bravely attempted to challenge it. Crossing Arizona, either via the Sonora Trail or by way of Tucson, was a nightmare of privation. The last one hundred miles of each was totally dry except for chance encounters with *tinjaras*, or mountain tanks.[2] Both trails became known as *El Camino del Diablo*, the Devil's Trail.

The trail westward from Yuma was equally dangerous. It was more than one hundred grueling miles of sand across the Salton Trough, much of it below sea level. Water holes or wells were scarce and unreliable. Carrying as much water as possible, pioneers were on the trail five to eight near-waterless days before they could rest at Warner's Ranch. This trail was later named *El Camino del Muerto*, Trail of Death, for good reason.

Yuma was the home of Indians for uncounted generations. After the Spanish conquistadors found it, the Yuma Crossing became a strategic position for military and political maneuvering since it was the gateway to coastal California. But control of the crossing was by fits and starts.

The gold-seeking expeditions of the Spanish General Coronado were the first to reach Yuma in 1540, and to gaze across the river at what would later be California. Their stay was temporary, and it was not until 1605 before the first mission and settlement came into being. This languished, however, and it was soon abandoned for several decades.

By 1700, the Spanish had determined that Baja California was not an island as originally believed. This renewed interest in the strategic value of Yuma, since it offered an overland route to the coast. The Governor of Mexico ordered the building of a new fort and mission. That effort at colonization failed, as well, but not until the first European traveled to the Salton Valley. This was Father Eusebio Francisco Kino who crossed the Colorado River with Yuma Indian guides in 1701.

For seventy more years, the peaceful Yuma Indians had the area to themselves again. Then, an alarming report came to the Spanish Governor revealing increased Russian influence coming south along the Pacific coast. To counter this move, Juan Bautista de Anza, a captain in the Spanish army, led an expedition westward in 1774. Enroute, he established another mission at Yuma.

De Anza found only desert beyond the Yuma Crossing. He reached the Salton Valley, finding some water at Buzzard's Roost (near present Calexico). He then headed northwest through the dry wash of San Felipe Creek, finding water at Harper's Well. He then found his way through Borrego Valley into the highlands of the Cahuilla Indians. De Anza's little band of soldiers and followers suffered greatly, losing all of their animals, though none of the people in the party. The wasteland was so forbidding that upon reaching San Gabriel Mission, De Anza wrote in his journal about "La Jornada de los Muertos," Journey of Death.

Meanwhile, back at the Crossing, the Yuma Indians, fretting under harsh Spanish rule, killed all the mission Spaniards in 1781. The post reverted to the desert again for decades. The first American to enter the area was probably Jedediah Smith, the Mountain Man. He and a partner left the 1826 fur traders' Rendezvous in Idaho and headed for California. He reached the Colorado River somewhere between present Yuma and Blythe. Mohave Indian guides guided them across the river and west over the deserts and the San Bernardino Mountains to the San Bernardino area. After trapping in the foothills of the San Joaquin Valley, Smith cached his furs and headed back to the 1827 Rendezvous. He then returned to get his furs, again taking the southern route. This time, however, the Indians fell upon the party of trappers as they were crossing the Colorado River. Smith lost half his men and all his supplies. Suffering hideously in the August heat, they barely made it across the desert.

The war with Mexico came next. General Kearny, in 1846 set out from Fort Leavenworth for Santa Fe and California with a large detachment of troops. By the time he reached the Yuma crossing, his depleted party was in bad shape, having lost all their horses. He crossed the desert along the international border to San Diego where he subsequently defeated the Californios. The remnants of the Mormon Battalion from Santa Fe came shortly after Kearny's crossing.

It was the discovery of gold in California in 1849 that finally resulted in a permanent settlement. The town of Yuma had its beginnings as an army post established on the river to protect the tide of gold-seekers going to California.

Warner's Ranch; the Western Terminus

West of the Salton Sea was a flat valley, lying at 3,000 feet elevation and surrounded by mountains rising to 6,000 feet. It had been the home of the Cupeno Indians ever since their gods Eagle and Coyote had led them to this peaceful place. Then. in 1795, the Spaniards arrived from San Diego. Father Juan Mariner and Captain Grijalva were looking for a suitable site for a mission. At once, they recognized the possibilities of the valley and its the fine grazing lands for the mission cattle.

The valley got its name in a typical California-Spanish way. Jonathan Trumbull Warner, "Long John", was a New Englander. He went west as a young man in 1830, to St. Louis, then an outpost town, where he became a clerk in various fur-trapping enterprises. After a year, he joined a party heading for California to purchase horses for the Louisiana Territory market. Taking the southern route, the party reached Yuma, and crossed the Colorado Desert. They left the desert by way of Vallecito and came to the valley of hot springs, then known as El Valle de San Jose.

Warner remained there. Perhaps he saw the folly of driving horses back across the desert. He was a fortunate man, for thirteen years later, in 1844, while still in his thirties, he obtained a grant of 44,000 acres in the valley from the Mexican Governor of

California. He appropriately changed his name to Juan Largo Warner to fit his new rancho. The land was called Warner's Ranch for many years, and today the principal town in the valley is Warner Springs.

Did Our Ancestors Value Water More?

The California desert did not welcome people. For many years, the hostile summer climate and lack of water discouraged all but the most intrepid and dedicated souls. The rare travelers who came were simply passing through on their way between the Spanish settlements of New Mexico and the missions of California.

As a result, little about the desert was recorded by explorers of the 18th and early 19th centuries. Westbound traffic from Yuma were faced with more than one hundred miles of dry desert before water at Warner's Ranch. Travelling only at night, ten to twelve miles, they had other, more pressing problems than scientific observations along the route. Yet, they could marvel at the wonders of the open desert while cursing its hardships.

The earliest written record of the valley, in 1815, mentions that the San Gabriel Mission was obtaining salt from Salton Sink. By 1822, Indians carrying mail and messages from San Gabriel Mission to Tucson traveled a route through San Gorgonio Pass and across Coachella Valley using the ancient Indian trails. Fragments of these trails still exist in the interior.

Other early Spaniards who left a record of the Coachella Valley were members of Captain Jose Romero's expedition which traveled through San Gorgonio Pass in 1823, establishing a mission ranch near present Beaumont. He was headed for Tucson, but lack of water and forage enroute turned him back short of reaching the Colorado River.

Romero tried again in 1824, and was successful. He crossed the valley via Agua Caliente, Toro, Dos Palmas and Salt Creek Wash.[3] He reported this route to be impractical, not knowing part of it would later become the route of a modern interstate highway.

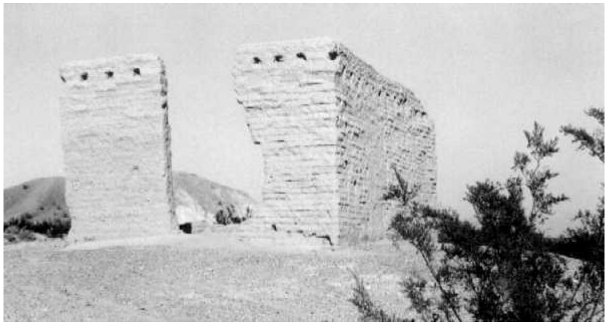
In 1849, Dr. Oliver Wozencraft explored the Colorado Desert and observed the Indians cultivating plots of land around springs and wells. He concluded the soil was very fertile, and conceived the notion of importing water for irrigation.

In 1859, he petitioned the government and received a grant of 1,600 acres in the Salton Sink conditional upon federal approval for the diversion of water from the Colorado River. He died before he could accomplish anything, but his dream persisted through others.

The 1857 expedition of Isaac Smith traveling south from central California laid out the first definitive road between Los Angeles and Yuma. Important stops were established at Caber Zones (now Cabazon) and Agua Blanca (now Whitewater).

In 1858, the Butterfield Stage Company established a passenger and express route across the driest and hottest portion of the valley. This was part of the 2,500-mile overland stage line from St. Louis, El Paso, Tucson and Yuma to San Diego and San Francisco. The route followed the old trail from Yuma east across Mexican territory to avoid the sand hills, following water holes at Carrizo and Vallecito to Warner's Ranch and the coast.

Contrary to popular perception, the stages were not pulled by wildly-galloping horses. Mules were preferred, since they were stronger and more reliable on the trail. The stage companies tried to find wells about 15 miles apart, or one day's hard journey, but springs were not always that accommodating. As a result, stage stops were as close as three miles or as far as 25 miles apart. One of these stations still exists -- the stage stop at Araz, the first stop west from Yuma. As this old photo indicates, it may not last much longer. The old adobe building is rapidly deteriorating from the effects of the elements and vandalism.



The primary building material used for the stations was adobe. The number of rooms was limited, and they were small. Meals of simple fare were available to travelers, and some offered overnight accommodations. Every station had a proprietor, or agent, and usually one or two hostlers. One of these agents was Jack Summers, who managed the Agua Caliente station. Summers and his wife thus might be considered the first Anglo residents of the future Coachella Valley.

In early 1862, gold was discovered near La Paz and Ehrenberg, along the Colorado River, north of the present location of Blythe. But access to the gold fields was a long, arduous process. To reach central Arizona, travel was forced either south through Yuma or north using the Santa Fe Trail. Business interests in Los Angeles engaged pioneer William Bradshaw to find a new, more direct route.

San Gorgonio Pass and the (as yet unnamed) Coachella Valley were, of course, a known route to the south, but it had no branch westward to central Arizona. Bradshaw's trail blazing party followed the Smith route to Sand Hole (now Palm Desert), Indian Wells and the spring at Dos Palmas. Bradshaw left the valley near present-day North Shore, striking east over an Indian trail never before trod by Anglo-Americans. Using primitive Indian maps, he followed the trail up Salt Creek Wash between the Orocopia and Chocolate Mountains, from spring-to-spring for 100 miles to the river. The Bradshaw Trail across the desert was short lived, however. Today, the portion from Dos Palmas east for 25 miles is a poorly graded dirt road, as is the western 40 miles from Chuckwalla Well and Wiley Well to the river. The central connecting portion of the trail is lost.

In spite of these brave attempts to combat the hostile environment, the virtually waterless desert remained a wasteland. Its only purpose seemingly an unpleasant way to get from one place to another.

The first geologist to visit the area was William Blake, a member of the expedition of 1853-54 by the U. S. Corps of Engineers mapping railroad routes to the Pacific. This survey found San Gorgonio Pass to be the only low-level feasible southern railroad route. Blake's work resulted in the first geologic report and maps of southern California, including the Salton Valley. Blake named it the Colorado Desert (8 years before the state of Colorado), and described the natural features both accurately and completely, a scientific work that remains remarkably valid today, more than a century later.

The military surveys of the Southwest in the 1850s and 1860s were to be prophetic in the extreme. Several of these old reports describe the dry desert soils as potentially fertile, requiring only water. They reported on the success of the Indians' primitive irrigation practices along the Colorado River and in the Coachella Valley, noting the luxuriant growth of palms and other vegetation around the natural springs in the valley.

A minor gold rush occurred when the metal was discovered near Twentynine Palms in 1873. This attracted an initial influx of miners, but it soon subsided. A few years later, the discovery of gold in the Dale District, seventeen miles to the east, brought more permanent changes to the area. The mines required large amounts of supplies. A freight wagon road was opened to Dale from Banning, 60 miles to the west, following the route of present Highway 62. It was a grueling five-day wagon trip from Banning to the mines. A second, but no less arduous supply route to the mines was also established from Mecca by way of Box Canyon.

While a few visionaries like Wozencraft could foresee the opportunities in the desert, it was thirty years after the Army surveys before these reports excited the imagination of land developers. The reason: the construction of the Southern Pacific Railroad linking Los Angeles with Yuma.

As it was throughout the west, major expansion came with the railroad. Land grants to finance construction were given to the Southern Pacific by the Federal Government. Under these grants, every odd-numbered section of land along the right-of-way was deeded to the railroad. The ingenious financing scheme allowed the railroad to sell this land, thus raising the funds for needed construction. Since the proposed route traversed the Agua Caliente Indian Reservation, the Reservation boundaries were somewhat arbitrarily redrawn into the checkerboard pattern that exists to this day.

The railroad's right of way followed the same general route and stations as the stage lines, and small communities developed from sidings along the way. Some, such as Mecca, Thermal, Coachella and Indio still exist; most do not. By 1876, the Southern Pacific Railroad had reached Indian Wells (now Indio), and was operating trains on a 4-hour schedule from Los Angeles with stage connections on to Prescott, Arizona. The final link to the eastern hookup at Yuma was completed a year later, in 1877.

A local and abundant water supply was essential to the operation of the railroad. The first local source to be tapped was Snow Creek in the San Jacinto Mountains. In 1878, the Southern Pacific Railroad piped water from this small stream to its Cabazon, Garnet and Whitewater stations.

With completion of the Southern Pacific railroad through the valley, land development was within reach, but water supply remained the key to the future. During 1885 and 1886, under the provisions of the Desert Act, prospective settlers and developers filed on a large part of the non-railroad land. Homesteaders began to move to the valley to farm in the warm climate, irrigating with water from wells, but the wells were shallow, small and unreliable producers. As a result, large scale agricultural development was inhibited.

Even the railroad had its share of water problems. Sources of natural water were so limited and unreliable en route through the valley that trains often pulled four to six water cars to keep supplied until the next reliable water stop.

In 1894, using new rotary drilling techniques, the railroad company drilled a well at Mecca (then known as Walters). They discovered an abundant supply of good quality artesian water under high pressure that burst 20 feet into the air.

It was not until 1900 that well-drilling for agricultural use in the valley was completely successful. Wells were drilled at Thermal and Coachella, and it was soon found that artesian wells could be brought in at many places below the sea level contour which crossed the valley floor near Indio.

By the turn of the century, the old artesian wells began to fail as heavy withdrawals lowered the water table to the point where the hydraulic head no longer brought water to the surface. To maintain the supply, the farmers resorted to pumping. The early pumps were driven by wind or gasoline engines, and it remained so until electricity could be brought in for the more powerful electric pumps that were required.

By 1907, there were about 300 flowing water wells between Indio and the Salton Sea. As a result, the lower Coachella Valley was rapidly put to agricultural use. Meanwhile, development had also been going on in the Upper Coachella Valley, notwithstanding the lack of artesian water due to the higher elevation. An early Palm Springs resident, moving here in 1884, was John Guthrie McCallum. He built the first waterworks for the tiny settlement. It was a hand-dug, rock-lined ditch that extended for sixteen miles from the Whitewater River across the desert to the village. It was the valley's first irrigation project, and small fruit farms began to flourish in the early 1890s. Then, a flood washed out the little canal, followed by a ten-year drought that dried up the surface sources of water upon which they all depended. As happened innumerable times throughout the West, the dwindling supplies of water brought on disputes among the settlers. Good relationships turned ugly and the conflicts soon turned to violence. Three men were killed in the fight over water rights. Without water, most of the settlers were forced to leave. Within a short time, the little village reverted to a minimum existence, not to be revived until after 1905.

In the meantime, the Imperial Valley was also being developed for agriculture. In 1901, the California Development Company commenced water diversion from the Colorado River into a hand-dug ditch that had its intake in the United States but which ran most of its length in Mexico before recrossing the border into the Imperial Valley.

The Old Plank Road

In spite of advancing development of the Salton Valley, travel from the Yuma Crossing remained a chancy and rigorous task. The Algodones Dunes were a formidable barrier to east-west travel. As a result, most travelers circled south through Mexico to avoid the dunes. Crossing the relatively lawless border resulted in frequent clashes with bandits. As the nineteenth century drew to a close, local vigilante groups maintained the peace in such matters.

The first road across the dunes, the Old Plank Road, was built in 1917-18. It was a one-lane wood plank road built in moveable 12-foot sections that were held together with steel straps. It was laid on

the surface of the loose sand, and like a railroad track, there were turnouts for passing. Shifting and blowing sand made maintenance both difficult and costly. Whenever the road became buried in sand, teams of mules were used to pull the sections out of the sand for relocation.

The old plank road was used until 1926, the only means by which motor vehicles could cross the treacherous dunes. Only one short segment of this rare historic treasure remains.

CHAPTER 12
WATER SUPPLY FOR THE THIRSTY DESERT

GEOGRAPHERS DEFINE A DESERT as having fewer than 10 inches of rainfall per year. The Salton Valley, with average precipitation about three to six inches per year, then, is a true desert.

From an economic or political point of view, however, a lack of precipitation is inadequate to define a desert environment in today's world. There is plenty of sunshine and warmth, and abundant mineral fertility in the soil. With the addition of water, the desert burgeons with life, becoming a garden.

The Salton Valley economy is based on its water resources. There are two separate economies, each equal in value. The northern section of the valley supports a winter recreational and tourism economy; the southern portion is devoted to agriculture. There are also two separate sources of water: irrigation water is imported from distant sources, while domestic water is mined from groundwater reserves.

As a result, the greening of the Salton Valley has created an environment that is both habitable and prosperous.

The water supply system of the valley is but one part of a state-wide water system that is a masterpiece of science and technology, supporting more than 25 million people and an economy that ranks in value among the world's developed countries.

California's Water Supply

Most of California's natural water supply is run-off from winter precipitation in the high mountains of the central and northern part of the State.

More than eighty percent of California's total precipitation occurs from November to April. Massive winter storms breed over the Pacific Ocean to the northwest, and batter the high mountains with heavy precipitation. Most of this falls as snow, building an enormous snowpack that accumulates through the winter. The spring melt releases the water gradually to reservoirs in the western slopes of the Sierra Nevada Mountains.

A lesser amount of water is derived from the snow melt of the high Sierras' eastern margin. This water collects in reservoirs in the Owens River Valley for use by the City of Los Angeles.

Some of the State's water supply comes from the Colorado River. This is melt water from the western slopes of the Rocky Mountains. The water is held in storage upstream in seven massive reservoirs, including Lakes Mead and Powell, for controlled release during the year. California's share of Colorado River water is taken downstream from Hoover Dam.

Over most of the State, there are extended periods during the summer months with virtually no precipitation. This is the normal and expected condition. Winter precipitation, then, is crucial to California.

California uses more water than any other state. Ninety percent of the total water supply goes to agriculture for crop irrigation. Periodically, water supplies become locally critical when the normal winter precipitation fails to occur. A shortage of water in storage at the beginning of the Spring growing season is a serious matter since normal summer precipitation is insufficient to make up the difference for agriculture's requirements over a full year growing season.

Within the State of California, more than 70 percent of the water resources are north of the latitude of San Francisco. Conversely, about 80 percent of the water is used south of that latitude, in the farmlands of central and southern California. To complete that unique paradox, we must also consider that hundreds of miles of arid land and mountain ranges lie between the water source and the water consumprion. Consequently, the allocation of water supplies is an issue of major economic and political concern within the state.

The Central Valley Project

The Central Valley Project was the first major regional water project in California. This Federal agency, whose principal storage facility is Lake Shasta, collects and distributes water from northern California sources for irrigation and consumptive use. It also provides water to meet fishery, navigation and water quality needs in the Sacramento delta area. None of this water is available to southern California.

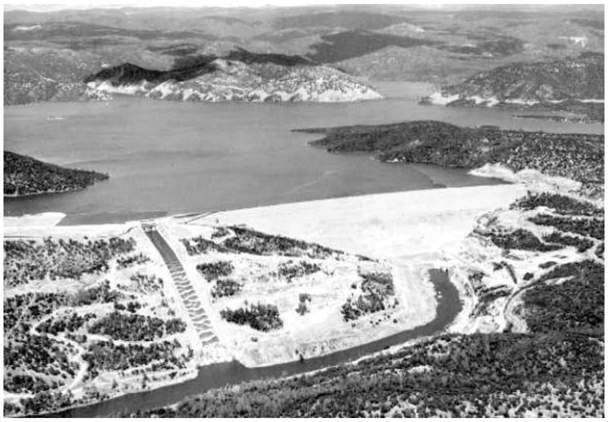
The California State Water Project

Following World War II, southern California began to grow explosively. The economic and agricultural bases expanded with the population base, and it soon became apparent that existing supplies of water could not supply projected needs. Since all water sources in the south were already fully committed, a means of redistribution of surplus northern water had to be found.

In the November, 1960 election, Proposition 1, the "California Water Plan" was approved by the electorate. This politically sensitive plan provided financing for facilities that went far to meet the emerging needs of the entire State. The project included (1) flood control in northern California, (2) irrigation water for central California, and (3) domestic water for southern California. Planned to go on line by the end of the decade, this became known as the State Water Project (SWP), the primary water system in California.

Construction began in 1963, with improvements and expansion continuing to this day. The SWP has become one of the world's most comprehensive water distribution projects. Briefly stated, the project transfers northern California water to central and southern California. If the population growth rate and the economic base continue to grow as projected through the next century, it is planned that eventually the system could be extended as far north as the Klamath River, tapping new supplies.

The project is presently in two physically separate sections. The northern section takes water from the upper Feather River in the Sierra Nevada Mountains, storing it behind Oroville Dam in Butte County. From there, the water flows south by canal to the Sacramento-San Joaquin delta. The southern section extends from the delta to reservoirs in central and southern California, the farthest one being Lake Perris in Riverside County. The two separate sections are not yet physically linked together by a canal system. Instead, the water is allowed to flow into the Sacramento River delta, finding its own way through a labyrinth of natural channels and sloughs to reach the pumping stations at the mouth of the southern section of the California Aqueduct. In so doing, much water is lost, and quality deteriorates as the fresh stream water flows through the often brackish delta, picking up pollutants and salts.



Many of the facilities in the state water system are unprecedented in size. There is the Oroville Dam, more than a mile wide at its crest and 747 feet high. The dam, with its spillway is the highest earthfill dam in the world. The leading structure in the system, however, is the California Aqueduct, 444 miles in length.

The physical plant of the total planned project is about 60 percent complete. The principal requirements not yet constructed are additional major reservoirs and the transfer facility or cross-delta canal to link the northern section with the southern extension via a concrete canal. This part of the project is known as the Peripheral Canal. A multi-billion dollar plan to proceed with this phase of construction was proposed in 1982. It quickly became a controversial political issue that reached the ballot and was rejected by a vote of the people.[1]

State water is allotted to many water agencies of southern California. The largest agency is the Metropolitan Water District (MWD), a coordinating and management body whose members are individual water agencies that serve local communities in the greater Los Angeles Metropolitan Area and most of six coastal counties from Ventura to San Diego.[2]

When the State Water Project was authorized, Coachella Valley Water District and Desert Water Agency were two of the 30 charter water agencies contracting for northern California water.[3]

However, no facilities have yet been constructed for the delivery of state water to the Coachella Valley. As part of the original project, an extension of the California Aqueduct was planned to reach the Coachella Valley, but little progress has been made. This unfulfilled portion of the project has been studied in detail for more than fifteen years, with the options narrowed to two proposed routes. One route, known as the "Desert Route", would extend from the existing California Aqueduct near Hesperia, thence by way of Lucerne Valley and Yucca Valley to the Whitewater River. A second route option, the "Pass Route", would begin at the existing aqueduct at Highland (north of San Bernardino), and would follow a route generally paralleling Interstate 10 through San Gorgonio Pass to the Whitewater River.

Both routes are feasible with nearly offsetting advantages. The desert route, by circling the mountains in open desert country would primarily be a concrete canal alternative. The pass route would be buried pipeline for most of its length.

The Desert Route is longer in length, and estimated to be more costly to construct. Traversing open desert land, it would have few stubborn legal problems, but would likely face protracted environmental impact studies.

The Pass Route is claimed to be less costly to build, and its environmental impact problems would be mitigated since it follows an established utility right-of-way. There would be complicated legal problems, principally the need to provide a water supply to several SWP contractors over whose territory the route would be built and the need for amendments to their contracts.

In 1972, the two Coachella Valley water agencies were initially allotted 61,200 acre-feet annually of state project water. Under a 1987 supplemental agreement, the two local agencies' entitlements were increased to 123,080 acre-feet annually.[4]

In the meantime, a creative alternative has been implemented. Since delivery of this water cannot be made directly to the two local water districts, the allotment is presently being met by an exchange agreement with Metropolitan Water District on a bucket-for-bucket basis, i.e. their share of state water for a like amount of MWD Colorado River water.

Colorado River Water

The Colorado River is the only major perennial river in the American Southwest. As a result, it is of immense importance to the agricultural economies of many states. Besides California, six other States (Wyoming, Colorado, Utah, New Mexico, Nevada and Arizona) plus Mexico lie within the Colorado River basin, and all press their claims to a share of the river's water.

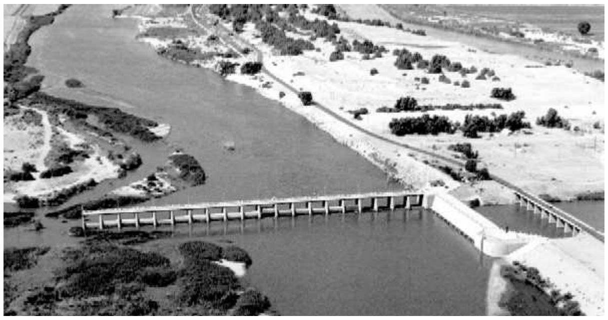
Colorado River water is so valuable that virtually all the stream flow is used. The mighty Colorado which rushes through the Grand Canyon in so spectacular a fashion is a placid stream within a hundred miles, and has virtually vanished in another hundred. During a cycle of dry years, all its water is either used or stored, and little, if any water reaches the natural outlet into the Gulf of California. Only during a cycle of wet years when all the reservoirs are filled does any of the stream reach the Gulf. During the two decades of the 1970s and 1980s, only four years saw water flowing into the Gulf.

The rapid growth of the southern California agricultural base (the Bard and Palo Verde Valleys along the river, and the Imperial and Coachella Valleys) has its roots in the abundance of water. For decades, California has dipped freely into the Colorado River. This went on because California was the first to have a water distribution system in place vis-a-vis the other States not yet having the need. Minimal upstream withdrawals left an abundance of water in the stream for downstream users. In recent years, however, two significant events greatly altered California's favorable position.

First, after many years of court litigation, a formal plan of water allocation between the lower basin states was established, with a large share to go to Arizona. Under a 1963 decision of the U.S. Supreme Court, California's entitlement was set at 4.4 million acre-feet annually, or more if available. Arizona's entitlement was established at 2.8 million acre-feet annually, and Nevada's at 0.3 million.

The second event was the completion in the late 1980s of the first phase of the massive Central Arizona Water Project. This brought the Arizona claim into reality, as the project was completed in 1992.

Within the California entitlement, several water agencies individually have claims on the Colorado River water. The largest of these is the Imperial Irrigation District. Others claiming river water are Metropolitan Water District, the Palo Verde Irrigation District (serving farmlands adjacent to the river), the Yuma Project (serving Indian lands in Bard Valley), Coachella Valley Water District and San Diego County Water Authority.



Furthermore, the Colorado River is an international river, flowing across Mexico to its outlet into the Gulf of California. By treaty, 1.5 million acre-feet annually must be available in the river at the border. This water is diverted at Morales Dam, south of Yuma, and is used to irrigate 600,000 acres of farm land in the Mexicali Valley. This photo shows Morales Dam during a period of abundant upstream water causing a near-flood situation at the dam.
Small wonder that every drop is accounted for.

The All American Canal

Two aqueduct systems bring Colorado River water into southern California, the All American Canal and the Colorado River Aqueduct.
The All American Canal, built with federal funds, was finished in 1942. The Coachella Canal branch, delayed by the war, was completed in 1948.

The All American Canal intake is above Imperial Dam, north of Yuma. As its name implies, the canal's westerly route is entirely within the border, generally parallel to Interstate 8. It crosses the Algodones Dunes and enters the Imperial Valley near the East Mesa. The water flows by gravity more than 50 miles in an earthen ditch across the desert to the valley. The total drop in elevation along this length is 185 feet. Taking advantage of the hydraulic gradient, four small generating stations along the route develop hydroelectric power.
Upon entering Imperial Valley, the first main lateral is East Highline Canal. From there, the distribution system carries water to farms as low as 222 feet below sea level.
While only about 80 miles in total length, the main All American Canal has the capacity to deliver a maximum of 4.5 million acre-feet per year to southern California.
Virtually all the water is used for irrigation, and is distributed throughout the Imperial Valley in a network of branching canals and ditches. Water is delivered to each 160-acre parcel within the half-million acres under cultivation. Of the 1,445 miles of feeder canals serving these farms, 906 miles (62 percent) are concrete-lined. There is some loss of water by infiltration in the earthen ditches, and substantial loss by evaporation from all open channels.

The Coachella Canal

The Coachella Canal is a major branch of this system. Its turnout from the main canal is about 40 miles from Imperial Dam. The water flows by gravity about 70 miles north along the east margin of the Salton Sea to Indio, generally following the sea level contour. The canal curves west around Indio and terminates at the Lake

Cahuilla reservoir at the base of the Santa Rosa Mountains.
Completed in 1954, the 500-mile distribution network within the Lower Coachella Valley is one of the world's most technologically advanced water distribution systems. It serves about 85,000 acres with metered delivery to each 40-acre parcel of farm land.

The main canal, between the turnout and the Coachella Valley, is the only open canal in the system. When the canal was first built, only the northern third, from North Shore to the Lake Cahuilla reservoir was concrete-lined. All the rest was earth-lined. In 1980, the southern third, between the turnout and Niland, was rebuilt as a concrete-lined channel. Presently, only the middle 36-mile segment, from Niland to North Shore remains an unlined ditch. Due to the nature of the rock structure and lithology, there is loss because of seepage, as evidence by the vegetation along its sides. The water district has plans to complete the lining along the remaining section. The extensive distributary and drainage subsystems consist entirely of buried pipeline to eliminate seepage and evaporative losses. There are no open ditches in the system. Because it is built entirely underground to conserve water and land, the Coachella Valley Water District delivers to farms more than 90 percent of the water it takes from the All American Canal.

The terminal reservoir, Lake Cahuilla, is located at the south end of Jefferson Street at the base of the Santa Rosa Mountains. Built in the mid-1960s, it was then the world's largest soil cement lined reservoir. It serves a dual purpose. First and foremost, it is terminal storage capacity to the Coachella Canal. Because the water must flow 160 miles by gravity through the system, it takes several days to get to Coachella Valley farms. Short-term water requirements are based on weather conditions, historic patterns, crop patterns and other factors.

As weather conditions change, more or less water may be actually needed at the farms. Lake Cahuilla's storage capacity of 1,500 acre-feet of water balances these changing short term needs. Secondly, Lake Cahuilla has been developed into a County park, ...tional facilities to the public.

completed in 1942, is owned by the Metropolitan Water
Colorado River at Lake Havasu, created by Parker Dam,

and heads across the desert and mountains in a generally southwest direction in concrete canals and tunnels.

In its statistics alone, it is an impressive engineering achievement. From the intake at Lake Havasu to the principal terminus at Lake Matthews in Riverside County, the main canal is 242 miles long. From Lake Matthews, another 430 miles of branches distribute water to Los Angeles County and parts of San Diego County. Its capacity is one billion gallons of water per day, or about 1.1 million acre-feet annually.

At the intake near Parker Dam, two powerful pumping stations lift four million tons of water a day more than 600 feet in the first of several boosts to cross the mountains. The canal then proceeds by gravity flow for 70 miles to another lift of almost 150 feet. At Eagle Mountain and near Chiriaco Summit on Interstate 10, two final pumping stations boost the water another 900 feet. The water has by now flowed 125 miles from the intake, and has been lifted by pumps almost 1,500 feet, higher than the Empire State Building in New York.

The water then continues its extraordinary journey by flowing 115 more miles by gravity to Lake Matthews, near the city of Riverside. The total journey has taken the water more than 300 miles across the State of California.

Within the Coachella Valley, the aqueduct's route takes it past Indio northwest along the margin of the Little San Bernardino Mountains. It traverses the length of the valley by tunnel, passing Desert Hot Springs and crossing Whitewater Canyon. From there, the route crosses San Gorgonio Pass and passes through the San Jacinto Mountains by tunnel. The location of this tunnel is visible from Interstate 10 near Cabazon as a large mass of gray talus at the base of the mountain.

Just before Lake Matthews, a branch diverts some of the water south to San Diego County. Along its great length, there is no diversion of water except at Whitewater Canyon where the local water agencies withdraw a portion of the water in the exchange program.

Along the route of the canal, the Metropolitan Water District operates several small power plants. One of these is located where the aqueduct crosses Whitewater Canyon. This small hydroelectric generating plant, put into operation as a joint project with Desert Water Agency in 1986, has the capacity to produce electric power equal to the needs of 500 households.

CHAPTER 13
THE COLORADO RIVER

FLOWING ALL YEAR, the Colorado River is the only major stream in the American Southwest. The river has often been called "the American Nile," sharing a number of similar characteristics, principally that of being a singular through-flowing stream in a desert whose annual flooding in its lower reaches for centuries brought new silt to its floodplain.

In the desert, even a small stream is king because there is no competition for the job. So it is that the Colorado River is the most important source of surface water for the thirsty deserts of California and the Southwest.

Discovery of the River

The discovery and early history of the Colorado is intimately connected with the exploration and subjugation of the Southwest by the Spaniards in the sixteenth and seventeenth centuries.

During the early years of the Spanish conquest, it was known that the overland route to conquer and explore the Pacific coast was across forbidding deserts. To reach the coast by sea, ships from Mexico had to undertake a long voyage south around the tip of the peninsula of Baja California. It was therefore easy to believe rumors and speculations that perhaps the peninsula might really be an island off the west coast of Mexico, and that a short cut might be found somewhere around its northern end to more easily reach the coast.

In 1539, on orders from Cortez to find a northern passage around the "island", Francisco de Ulloa sailed up the Gulf and reached its head. He did not discover the open channel to the sea he was seeking, but he did encounter fresh water flowing into the Gulf. He was convinced that a large river lay beyond, but he could not traverse the shallow and intricately branching stream channels that lay before him. Ulloa was never to see the river he suspected existed. But he was the first to sail the length of the Gulf, naming it the Sea of Cortez. It was a significant accomplishment.

The quest for gold fueled continued Spanish interest in the hostile southwest. For years, land expeditions had chased countless dreams under fearsome conditions, searching in vain for rumored quantities of gold such as had been plundered from Mexico and from Central and South American Indian civilizations.

Imagine the electrifying effect a new report of gold must have had on the Conquistadors, when they heard rumors of a land called Cibola, with Seven Cities of Gold, that lay to the west "along a great river." The Spanish general, Coronado, at the end of his fortune, his health and his political support, was determined to get his hands on the reported treasure. The search was on by land and by sea. In 1540, three vessels under command of Hernando de Alarcon again sailed up the Gulf. Alarcon discovered the Colorado River. With some expert piloting, and no doubt aided by a heavy stream flow, he got his ships over the bars and into the mouth of the river. In small boats pulled by friendly Indians, he breasted the current, exploring the stream as far north as the Gila River, near present Yuma, before turning back.

Alarcon named the river Buena Guia, the River of the Good Guide, a name used by cartographers for many years to identify the stream that flowed into the Gulf. No white man was to see as much of the river as Alarcon for more than a century, and it was more than 300 years later before anyone traveled upstream as far as he.

In the meantime, the land expedition Coronado sent from Santa Fe, of course found no gold. They did reach the Grand Canyon area, and found the upstream portion of the river.

The name, "Colorado", meaning reddish color, was first used in 1604 on a map of Arizona showing the Little Colorado River. By 1700, the name had been given to the great river itself. Early American cartographers used the name Red River on their maps for many years, but the original name endured.

The Course of the River

From numerous headwaters in Wyoming and Colorado, the Colorado River flows 1,450 miles to the Gulf of California, traversing six States and descending more than 10,000 feet. The river system drains the west slopes of the Middle Rocky Mountains and a large part of the Colorado Plateau. The drainage basin covers about 243,000 square miles, almost ten percent of the continental United States.[1]

Major tributaries are the Green River of Utah and Wyoming, the Gunnison River of Colorado, the San Juan River of New Mexico and the Little Colorado River and the Gila River of Arizona.

The Colorado has a long history of being a vigorous and exotic stream. The force of the water against the steep gradient and the generally soft composition of the rock formations in the Colorado Plateau, through which the river flows for much of its length, contributed to the river's extreme amount of erosion for thousands of years. The river carried more silt than most rivers, and it has a high concentration of dissolved minerals in its water. All this is part of a river system that for many years was considered to be one of the most dangerous and unpredictable rivers in the world.

The Colorado River is best known to most people as flowing across the Colorado Plateau through a series of spectacular gorges, including Grand Canyon. It is in the Colorado Plateau where the river has done most of its work. The steep gradient of the swiftly moving, muddy stream has carried away huge volumes of sediment for hundreds of thousands of years.

When the first Europeans discovered the Colorado, they found it to be totally unpredictable, and often a raging barrier. It was impossible to cross at flood stage, but they could practically walk across it during dry periods.

To the pioneers, the river had few redeeming attributes. So encumbered with silt, it was dismissed as "too thick to drink and too thin to plow." It was not considered a navigable stream. For a time, shallow-draft streamers operated on the river between the Gulf and Fort Mojave (now Needles). Captains never knew from one day to the next if they would be stranded on a sand bar or sheltering from a raging flood. All the boats were eventually wrecked. It was dangerous and unprofitable, and no good could be seen in the river.

Geologist John Wesley Powell, the first man to traverse the Grand Canyon by water, reported the river would never be of beneficial use. But it was tamed. By a strange turn of history, the engineer who designed Hoover Dam and selected its site was his nephew, Arthur Davis Powell.

The mighty Colorado River is now kept in check by nine major dams and reservoirs between Wyoming and southern California The reservoirs have a total gross storage capacity of 65 million acre-feet, or about seven years' supply in event of a lengthy drought. The Middle Colorado River is the site of the two largest: Glen Canyon Dam, impounding Lake Powell at 3,700 feet above sea level, and Hoover Dam, creating Lake Mead at 1,220 feet elevation.

The average gradient over the 130 miles between Powell and Hoover dams is about 19 feet per mile, which accounts for the spectacular whitewater rapids, particularly in the Grand Canyon area.

Below Hoover Dam, the flow is generally south to the head of the Gulf of California. From Hoover Dam to the Gulf, a distance of about 300 miles, the stream grade descends about 500 feet, an easy gradient of two feet per mile. The Lower Colorado River is bordered through most of its length by low mountain ranges. During this part of its journey, the river often crosses open basins, and flows generally parallel to the mountains. Depending on the distance of these ranges from the river, its valley is from 2 to 2.5 miles wide.

Flowing tributaries along the Lower Colorado are absent because of the aridity of the region. The surrounding mountains, typical of the southwest, are barren and are being buried in their own alluvium. The ranges are connected to each other by alluvial divides which form basins of interior drainage, or basins that do not drain into the Colorado River and to the sea.

At Parker, near the Riverside and San Bernardino County line, the elevation of the river is now only 350 feet. From there to Yuma, the stream crosses the Chocolate Mountains and the Trigo Mountains in a valley that is narrow but of only moderate depth.

At Winterhaven, near Yuma, the river enters the Salton Trough at an elevation of 130 feet above sea level. From there, any remaining water slowly makes its way over the wide floodplain the last 70 miles to the Gulf of California.

The river's last feature is the vast surface of its delta. It is flat, marshy and marked by many abandoned distributary channels. Tapped out by irrigation demands before it reaches the Sea of Cortez, the river no longer flows into the Gulf.

The Colorado River Delta

The work of a river is to erode high land and to carry erosional debris to the sea as mud, silt and sand. This debris becomes the building material of the river's delta.

As soon as a stream enters the sea, its velocity is abruptly checked. Most of its load of mud and silt is deposited at the mouth of the stream. The stream drops part of its load in its river bed and part along its edges, raising its elevation slightly and forming natural levees that channel the water course. It is then in a condition of unstable equilibrium, and at some favorable time, as during flood, the stream breaks through its own levee and forms another channel on the delta.

Thus, the stream meanders over the face of its delta, always only a few feet above sea level, building and extending it as the mass of the delta is gradually extended into the sea.

So it was with the Colorado River.

There is abundant evidence that the Colorado River during its long history was indeed a muddy stream. Even as this century opened, mud and silt was a problem to the early settlers. Stories are told of drawing household water from the river so muddy that the water barrel always had to be allowed to settle, leaving as much as half a barrel of silt in the bottom. Silting of the early irrigation ditches was indirectly responsible for the 1906-07 flood that created Salton Sea.

When Hoover Dam was first planned, silting was considered to be a major contingent problem. Predictions were that the dam would be silted up by 1950, (later revised to 1970). Yet, the problem never materialized. Silt, today, is largely absent. Massive desilting works at Imperial Dam, for instance, are underutilized as there is so little solid material in the river water. The reason for this is not clear, but it is believed to be the net effect of flood control measures throughout the river system that have been constructed in the past 50 years. This has changed the grade of the stream completely. The overall elevation drop from headwaters to the Gulf is the same, but a large part of the vertical drop is now absorbed by the high dams, giving each intervening river section a reduced, more controllable grade.

Not so in the past, however. For uncounted years, the Colorado was a mighty river carrying large amounts of silt to the Gulf of California. Hydrologic studies of the muddy Colorado, made before construction of the high dams showed it was discharging annually enough silt to cover one square mile to a depth of 53 feet of dry earth. That is equivalent to one cubic mile each century, cut from the great canyons of the Colorado Plateau and carried to the Gulf.

The muddy stream, with its load of silt and sand entered the east shore of the Gulf below present Yuma. The great Colorado River delta was built into the sea, ever wider and farther west into the narrow Gulf. Eventually, the river's delta reached the western shore, 50 miles from the river's mouth. Continued deposition established a massive natural earth dam across the Gulf, isolating the arm of the sea to the north as a new lake.

The abandoned lake soon evaporated in the arid desert climate leaving a barren depression below sea level. The Salton Basin was born. Its age is uncertain, but for more than one million years the massive delta-dam has been a barrier that excludes the sea from the Imperial Valley.

The delta, located entirely on the Mexican side of the border, has varied in height during its growth due to compaction of sediments and to a subsiding basement. Now, the summit is about 35 feet above sea level

The mass of the fan-shaped delta is not on the scale of the Mississippi or the Nile River deltas, but it is still large. The above-water portion is about 40 miles radius from the river mouth near Yuma west to the Sierra de los Cucapah and south to the Gulf of California. The exposed surface area is greater than 1,000 square miles, and thickness below sea level may exceed 10,000 feet.

This mass represents the work of the river over millions of years as it carved out the Grand Canyon and the other canyons of the Colorado Plateau, wearing the rocks down to sand and silt, carrying uncounted cubic miles of debris to the Gulf to build its delta.

The Colorado River delta, then, is the southernmost landform of the Salton Trough. It is a natural earthen dam that totally blocks the Gulf of California from flooding the valley.

Floods on the River

Similar to many rivers in the west, the Colorado River has a long history of highly variable stream flow. This is in part due to seasonal factors in an arid climate, but primarily to the variable winter precipitation in the high mountains and the extent and thickness of the annual snow pack.

Damaging flows were common before the construction of Hoover Dam. The largest flood on record occurred in 1884 when an estimated 250,000 to 300,000 cubic feet per second passed through Black Canyon, future site of Hoover Dam. Peak flows exceeded 200,000 c.f.s. at least three other times, but since the mid-1930s, the mighty Hoover and, later, Glen Canyon Dams have held the river in check.

Since Hoover Dam was completed in 1935, it has met all its flood control expectations. Every tourist, for 50 years has noted the white band of its high water mark on the canyon walls of Lake Mead. The height between this line and the lake level was the reserve storage capacity for any years of above-normal stream flow. Only once, and then in a test of the facilities in 1941, was water allowed to flow over the spillways.

Flooding can be anticipated, but it cannot be predicted. In 1982, weather patterns worldwide were upset as nature went on a rampage. Early in the winter of 1982-83, the National Weather Service predicted that inflow to Lake Powell would be 10 percent above normal. The abnormal snow pack that accumulated later caused this forecast to be increased to 30 percent. In June, a massive storm moved across the Upper Colorado Basin, with heavy runoff occurring over a wide area. The river swelled to more than double its normal size, and the reservoirs rapidly filled to capacity. By July, the water level of Lake Mead was 4.5 feet *above* the spillway gates of Hoover Dam.

During the flood stage, the Bureau of Reclamation was hard put to balance the release of water from the nine high dams on the river. At maximum, river flow reached 65,000 cubic feet per second, but generally was 40,000 to 45,000 c.f.s.
Flood damage was minimized due to the controls at the overflowing reservoirs. Nevertheless, developments built on the lower river flood plain required extensive sandbagging, and some flooding occurred.

The Age of the River

The origin and the age of the Colorado River are uncertain, in spite of many attempts to explain how this major drainage system evolved.
Different approaches, however, do have some threads of commonality. The sequence of events most likely goes back to the stream drainage over a vast highland area that was to become the Colorado Plateau.

Uplift of the Colorado Plateau commenced in Pliocene time, about 7 million years ago. The result was to disrupt the existing drainage pattern. The new elevation difference favored a small southwest-flowing stream, the ancestor of the present Colorado River. The rejuvenated river cut vigorously headward into the plateau, eventually capturing the older east-flowing rivers and reversing the drainage pattern.
This perception is advanced by a comparison of rocks exposed along the Lower Colorado River with rocks in the Salton Trough.

A conspicuous thick sedimentary series occurs in the canyons of the Lower Colorado River. This is the Muddy Creek Formation, a weakly consolidated buff-colored siltstone grading into sandstone. The lower layers of this formation consist of hundreds of feet of gypsum and other salts. The total assemblage is typical of sediments laid down in shallow lakes or playa flats in an arid environment.

The thickness of the beds suggests a considerable length of time had elapsed for deposition. Vertebrate fossils found in the upper layers of the Muddy Creek Formation have been age-dated to be 11.8 million years old. This places the Muddy Creek as being laid down in late Miocene time, when the river first began to empty into the sea.

Since the Colorado River has eroded into this formation, it follows that the river could only have established its present course some time after the deposition of the Muddy Creek beds. This suggests that the river is not older than perhaps 7 to 10 million years. At about the same time, a rift developed between the North American Plate and the Pacific Plate in a northwesterly direction. This allowed the ingress of the sea into a long embayment which penetrated as far as the present San Gorgonio Pass area.[2]

The Salton Trough contains an immense thickness of sedimentary rocks. All members of this series, but one, are of continental land origin. That is, erosional debris laid down as alluvial deposits. There is only one marine sedimentary series (laid down under ocean water) in the valley -- the Imperial Formation.

The Imperial Formation was deposited in a large marine embayment that covered the area of the present Salton Trough and the lower reaches of the Colorado River. The Imperial beds are also a buff-colored series of weak siltstone and sandy beds, similar to the Muddy Creek formation. They have also been age-dated to the Pliocene, 7 million years ago.

This reasoning, then, suggests that the earliest materials carried to the Gulf of California by the new-born Colorado River consisted of silt and mud derived from the Muddy Creek Formation. The Salton Trough was open to the sea at that time, and the silt and sand deposits were laid down in the marine waters of the Gulf that stretched considerably farther north than it does today.

Born about ten million years ago, then, the Colorado River discharged into the Gulf embayment, constructing its delta. As the delta continued to grow in size, deposition conditions gradually changed back again from marine to land.

The Salinity Problem

The major problem of the river today is its salinity. Ten million tons of dissolved salts are transported downstream annually. By the time the stream reaches the Imperial Dam, the water contains about *one ton* of mineral salts per acre-foot. That is one ounce of salt per gallon.

The river water averages about 750 ppm (parts per million) soluble salts, against a world average of all streams of 140 ppm. The Mississippi River is 200 ppm and the Columbia River is 90 ppm. The lowest streams in the U.S. are rivers of the southeastern states at about 55 ppm. The Colorado River today, then, is clearly a salty river, at just about the marginal limit for drinking.

The river acquires its salt from two sources. Much of it comes by solution from saline sedimentary beds that are exposed to the river and its tributaries as they flow through the canyons of the Colorado Plateau. A second source is irrigation drainage. Irrigation water leaches the upstream farmlands of their salt, and drains to the river, adding to the salt load. All this places the greatest burden of the problem on the last downstream users, the Salton Valley and the Mexicali Valley across the border.[3]

From these sources, then, the river's salt load increases progressively downstream. In addition, considerable water is lost by evaporation, increasing the concentration of dissolved salts. Salinity is a serious problem on the lower Colorado, and has the potential to become worse in future years as more water is withdrawn upstream.

CHAPTER 14
THE COACHELLA AQUIFER

THE SALTON VALLEY is a basin of interior drainage. All streams flow toward the center of the basin in a radial pattern. There are no perennial, or permanent streams on the valley floor; all streams are intermittent. Stream beds are dry except for local drainage during the winter rains or the summer flash floods.

In effect, the valley is a closed water system. Being a desert, there is little precipitation available. What does enter the valley either evaporates or is trapped in the aquifers. There is no outlet by which any surface drainage may reach the sea.

The Whitewater River, rising in Whitewater Canyon of the San Bernardino Mountains, is the principal stream channel of the valley. Its dry channel threads its way past the cities of Palm Springs, Palm Desert and Indio to the Salton Sea. Minor dry tributaries emerge from canyons in the San Jacinto and Santa Rosa Mountains to the southwest. There are few tributary canyons in the Little San Bernardino Mountains to the east, and none in the Indio and Mecca Hills.

The San Jacinto and Santa Rosa Mountains west of the valley are a lofty barrier to the winter storms coming in from the ocean. Additionally, they are asymmetrical. The mountain masses are tilted blocks with the highest elevations looking down upon the valley. While this lends itself to spectacular scenery, it also means that the greater watershed area of the mountain mass lies on the windward (western) slopes. The canyons on the east margin facing the Salton Valley are small and steep. With both the greater rainfall and the larger watershed areas on the western slopes, the amount of run-off available to the Salton Valley is limited.

By contrast, the Little San Bernardino Mountains on the eatern side of the valley are extremely arid. Being in the rain shadow of the higher mountains to the west, and considerably lower in elevation, they do not act as a barrier to the moisture-laden prevailing westerly winds. Hence, precipitation is infrequent and minor, and largely confined to summer thunderstorms.

The watershed area of the Coachella Valley includes the valley itself plus the canyons of the adjacent mountains. The valley floor covers about 450 square miles. Due to the great height and geologic youth of most of the mountains surrounding the Coachella Valley, the canyons are steep and narrow. As a result, their watershed areas are small.

Watershed Areas	
Little San Bernardino Mountains	430 Sq. Mi.
San Bernardino Mountains	296 Sq. Mi.
San Jacinto Mountains	135 Sq. Mi.
Santa Rosa Mountains	335 Sq. Mi.

While the total mountain watershed area supplying the Coachella Valley is about 1,200 square miles, the mean annual inflow is not great. Most of the watershed itself is a desert environment, and only during heavy rains and flood stage will any surface run-off reach the valley floor.

The Role Played by Faults

The principal source of natural water is drainage from the eastern slopes of the San Bernardino Mountains. Water flow is greatest from several creeks which merge in Morongo Valley. By then, the water has percolated into the gravels of the stream beds, but continues as underflow into the Coachella Valley. Its first barrier is the Mission Creek fault which generally parallels the mountain front, hence, at a near right angle to the stream direction.

The nature of faulting along these branches of the San Andreas system is that the adjoining walls are kept in close contact. During movement, the strata within the fault zone have been deformed and sheared, with the formation of accumulations of finely ground fault gouge, or rock flour along the vertical walls.

Upon encountering this impermeable fault plane, the water is deflected and most of the water is forced to flow southeast along the north face of the fault. The warm springs and wells of Desert Hot Springs are located along the northeast side of this fault. Because of the low permeability of the barrier, a difference of 150 to 250 feet in water level exists across the fault.

The Banning fault and Garnet Hill fault are parallel to the Mission Creek and are similar barriers, with water depth differentials of 100 to 300 feet on opposite sides of the fault planes. Direct evidence of the higher water table is the line of vegetation along the northeast margin of the Banning (San Andreas) fault trace which determines the axis of the valley.

Most of the faults of the valley are generally parallel to the valley axis and are nearly vertical, acting as barriers to lateral groundwater movement. As a result, the upper Coachella Valley is not a single, large groundwater basin. The finely ground and compacted gouge along the fault planes have become vertical aquicludes, restricting the lateral movement of groundwater.

The three local branches of the San Andreas system, the Mission Creek fault, Banning fault and Garnet Hill fault have thus effectively compartmentalized the Coachella Valley into four nearly separate groundwater basins. The largest of these is the Whitewater sub-basin, generally lying under the track of the Whitewater River.

Structure of the Aquifer

The subsurface geology of the Salton Valley is not well known. Only a limited amount of commercial or scientific attention has been devoted to mapping the thick sedimentary series that underlies the valley. Yet, there is convincing reasoning that the valley structure includes multiple aquifers or compartmentalized sub-basins. For descriptive purposes, then, the singular form -- the Coachella Aquifer -- is used here to describe the many.

An ideal groundwater reservoir is: (1) a permeable aquifer, (2) of great extent and significant thickness, (3) sloping downward, (4) with aquicludes to confine and channel water in the aquifer, and (5) with a recharge area in a source of reliable surface run-off. The Coachella aquifer meets all these criteria. Its shape is half a cone, with the apex at San Gorgonio Pass and the base merging into the Salton Sink. This elongated structure contains a thick sedimentary sequence with granitic bedrock defining its sides. The sediments lap against the granite margins, sloping to the central axis from both sides, thickening and more deeply buried as the trough opens to the south.

The aquifers of the valley are zones of relatively coarse-grained alluvial materials deposited during the cool, wet years of Pleistocene time, less than two million years ago. These sediments are the products of intensive erosion of the surrounding mountains during that time. The erosional debris was brought to the valley floor by the various stream channels that drained the San Bernardino, San Jacinto and Santa Rosa Mountains.

For the most part, the valley fill consists of interfingering and intermingling layers of sand and gravelly material of moderate to high permeability. These appear to be aquifers capable of holding enormous amounts of water. Layers which act as aquicludes seem to be at random. There is much mixing of the waters except where hindered by fault barriers.
The sedimentary fill of the Salton Valley is less than 4,000 feet thick at San Gorgonio Pass, increasing to nearly 20,000 feet at the south end of the Salton Sea in the Imperial Valley. The groundwater moves readily down-valley in the aquifers under gravity.
The mountain ranges and the hidden basement complex of the Salton Valley consist of ancient granitic rocks. These rocks are massive and impermeable, containing little recoverable water. Consequently, they are a no-flow boundary along the margins of the aquifers.

Recoverable water is believed to exist in quantity in the upper portion of the basin, principally the Upper Coachella Valley. The main sequence of water-bearing sediments ranges from about 700 feet thick on the east side of the valley near Desert Hot Springs to about 2,000 feet thick on the west in the Palm Springs area. This increasing thickness in a westward direction is evidence that the primary source of the sands and gravels has been the streams draining the flanks of the San Bernardino Mountains overlooking the valley.
In the deeper parts of the basin the water-bearing units are more than 3,000 feet deep. Based on economic limits of pumping, and compression of the aquifer with depth, however, the practical thickness of the aquifers is considered to be the upper 1,000 feet of the valley fill.

Natural Recharge

Surface run-off has historically been the most important source of natural inflow to the Coachella Aquifer. The accumulation of water that fills the aquifer today occurred during the hundreds of thousands of years of the glacial periods during the Pleistocene, which closed about 12,000 years ago.

Principal inflow, or deep percolation, is from the high, precipitous granitic San Bernardino Mountains by way of their southwestern canyons. Surface run-off from the snows of winter precipitation flows through several creeks adjoining Morongo Valley and merge into the Whitewater River. All these channels are underlain by highly permeable sands and gravels, permitting surface water to easily seep into the groundwater system as subsurface inflow.

Run-off from the San Jacinto Mountains is via Snow, Falls and Chino Canyons at the north end, and from Tahquitz and Palm Canyons at the south end.
The Santa Rosa Mountains are drained principally by Palm Canyon, Deep Canyon and Martinez Canyon. As these drainage basins are much drier than those of the high mountains to the north, run-off is minimal and flashy in nature.
To the east are the dry, sandy Indio and Mecca Hills and the arid Little San Bernardino Mountains. These contribute only the occasional flash flood to the valley.
Some recharge is provided by sub-surface inflow from San Gorgonio River as it enters the valley from the pass.

Because the average rainfall over the valley floor is three to five *inches* per year, and evaporation from exposed surface water bodies averages five to six *feet* per year, there is no significant recharge to the groundwater system from rainfall on the valley floor itself.

Despite occasional heavy downpours, most desert stream flow or flooding will moisten only the upper few inches of the soil cover and will soon evaporate. Wetting to a depth of 10 inches or more is required before any precipitation will enter the groundwater system by infiltration.

Natural Discharge

There is no current evidence relating to the destination of the water in the lower reaches of the valley. The structure of the valley suggests that discharge from the Coachella Aquifer is primarily as underflow to the central basin underlying the Salton Sea.

It is likely that the aquifers are dammed by the thick accumulation of the silt of the Colorado River delta. If that is the case, then the possibility is strong that a large volume of water exists under the Imperial Valley at depth. Whether it is potable or not is a matter of speculation, as the surrounding sediments are known to be highly charged with soluble salts, plus the effect of downward percolation of salt water from the lake bed.

CHAPTER 15
WATER RIGHTS

The Political Angle

THE PERMANENCE OF WATER, that it cannot be altered or destroyed, is the basis for the unique legal status of water. Water can only be *used*; it cannot be *owned* as property. Thus, the term "water rights," -- meaning an individual has the right to use any water which flows over his/her property, but not the legal right to own it. Expressing this simple principle as law has vexed an army of lawyers, the courts and legislatures to no end, with the wisdom of Solomon eluding all of them.

Traditionally, and not unexpectedly, the matter of water rights has been in sharpest focus in the American West. Water rights were exercised by the early Indian tribes when certain streams were claimed for fishing and trapping. While the application was narrow in scope then, the underlying principle was there. Water meant survival, and survival was worth fighting for. So it is today, as limited and dwindling water supplies are more and more carefully divided up.

The Quicksand of Water Rights

The earliest application of the principle of water rights came with the first water wheel. Water was diverted to flow in such a way to turn a water wheel for a useful purpose. The water was returned immediately and completely to the stream. The next user downstream did the same. Over the centuries, and countless water wheels later, this became the basis for Riparian Water Rights. Each stream-side user utilized, then returned 100% of the water to the stream.

Later in history, the diversion of stream water for crop irrigation complicated the issue. The diverted water was used, but not all was returned to the stream for reuse. Some water was retained as soil moisture, some evaporated from irrigation ditches, some was transpired to the atmosphere by the crops and some was harvested with the crops. Obviously, the upstream users enjoyed the advantage. So, it was inevitable that water rights often became a source of conflict between farmers.

In the American West, during the late nineteenth century, the conflict was between rancher and farmer -- the ranchers learned very quickly that whoever controlled a water hole had effective control over (usually vast) acreage surrounding it. The disputes intensified, often leading to lethal violence. This state of affairs did not stop with the establishment of law and order. The issues only became larger and more complex. The range wars became water wars and were moved into the courtroom, the protagonists became the states, and the hired guns became lawyers in pinstripes.

Mark Twain said it well: "Out West, God provided plenty of whiskey to drink, and just enough water to fight over."

Water rights have always been aggressively fought for, and jealously defended. Notwithstanding a long history of protracted court cases and legal maneuvering, the issues remain complex and the solutions remain ambiguous.

At first, it was different. When the nation was born and in ensuing years in the eastern United States, water law was developed with its foundation on *Riparian Water Rights.* These rights are based on three legal principles:

First, only those who own land bordering a stream or river have the right to use water from that stream. This right is inseparable from the land, and cannot be transferred apart from the land.

Second, under no circumstances can an upstream user divert or otherwise shut off the flow to a downstream user.

Third, a riparian water right is permanent; it cannot be lost or forfeited simply because it may not be used for a period of time.

In the western states, water rights are more than different; they are virtually the opposite. From the very beginning, courts supported the view that rights are based on precedents of mining law set in the late nineteenth century when the West was being settled. As first set forth in Colorado in 1876, the *Doctrine of Appropriative Rights* rests on its own set of three principles:

First, appropriation means "first come, first served". Whoever first diverts and uses an amount of stream water establishes a permanent priority, or senior right to future use of that same amount of water.[1]

Second, an appropriative water right can be separate from the land. Hence, water may be bought and sold apart from the land it flows through. Thus, the water right is a separate property right and can be transferred to another entity up or downstream. Or, the water may be diverted from its natural source to another location and used there.[2]

Third, the water must be put to "beneficial use". Should the water not be put to beneficial use, the right to the water can be lost. In short, the "use it or lose it" rule applies.

One of the ambiguities in all this is the meaning of "beneficial use." Originally, western water law was written to meet the needs of mining and agricultural interests. Consequently, beneficial use has come to be interpreted as removal of water from a stream to be used "offsite", as it were, for specific purposes.

This restrictive interpretation does not recognize any beneficial use that would require leaving some water in the stream. In other words, streams and rivers may legally be drained dry. The Colorado River is an example; most of the time, none of the water reaches the mouth of the river.

That this was never considered is not unexpected if one accepts the historical fact that the development of the American West was primarily driven by commercial interests, whether they were mining, ranching, timber or agriculture.

The question of water availability came into sharp focus at the turn of the century. Then, as now, only the Federal Government could marshall enough money to meet the high costs of large irrigation projects. Spurred by Theodore Roosevelt, Congress, in 1902 passed the Reclamation Act. The bill's intent was not merely to provide water, but also to aid a maximum number of small farmers and to frustrate speculation. Among the controls in the act was a constraint on owners of large tracts within a reclamation area, restricting each parcel only to the amount of water needed to irrigate 160 acres. Also, single ownership of adjoining multiple parcels was forbidden.

But interests and needs are changing, which appears to require a revision of priorities. Voices are being heard, asking if precious water supplies might also include the retention of flowing stream water for conservation, scenic, wildlife ecosystem protection, recreational purposes as well as for maintaining a flow adequate to protect the quality of the water in the stream.

This overlay has come to be known as the Doctrine of Public Trust. Already in California and neighboring states, a number of legal suits have been won, while many are in the courts on issues of "In-stream" water rights. The Nature Conservancy is a leading force in seeking this broader interpretation of existing water law. The Conservancy has won in-stream rights in some narrow cases, hoping to establish precedent.

Colorado River Water Rights

The first half of this century was a period of constant legal wrangling between the seven states in the Colorado Basin over Colorado River water rights.

It all began in the closing years of the nineteenth century, when military expeditions and land surveys of the southern deserts had commented on the potential for agricultural development of desert land if only a way could be found to obtain water.

Opening guns were fired with a scheme for irrigating the Imperial Valley with Colorado River water. Using Indian labor, a hand-dug ditch was built across Mexican territory from the river to the valley in 1901. Mexico allowed the California Development Company to route the canal over its territory in exchange for half the water.

By 1907, however, the canal was wiped out by the flood which created the Salton Sea. A replacement canal was needed, and the American users of the water wanted a new and better canal to be built entirely on the American side of the border to avoid problems about Mexico's control over their water supply. (Read this as: why give them half?)

For a project of that size, federal funding would be required. But there was little chance of getting Congress to approve any such project without the support of the seven states through which the Colorado River flowed. This approval was not to be forthcoming until those states' own (not yet determined) claims had been considered and satisfied.

The canal would be built virtually at the downstream limit of the river, and the successors to the California Land Development Company knew it would be risky in the extreme to invest huge sums in Imperial Valley land promotions if upstream water users could later threaten the downstream supply. A standoff ensued.

From this issue alone, a novel interpretation of water rights evolved, the *Doctrine of Appropriative Rights*. This doctrine (later upheld by the U.S. Supreme Court) held that the first to use the water also established the first right to the water, referred to as "first in time, first in right", (or, more bluntly, "first come, first served").

Thus, since California would have a major downstream dam and canal diverting a given amount of water from the river, California would have a permanent priority right to that amount of water. The upstream states would always be required to leave enough water in the stream to satisfy that downstream right.

The issues were finally resolved in 1923 with the Colorado River Compact. With only Arizona refusing to sign, the remaining six states (including California) and the federal government proceeded to ratify the Agreement. An interesting sidelight: California approved the Compact on condition that a high dam would be built on the lower Colorado River, and agreed to purchase all the power generated by the dam. This committment led to the construction of Hoover Dam.

California's priority right was set at 4.4 million acre-feet of irrigation water annually plus a discretionary right for up to half of any surplus water, if available. Since the inception of this entitlement plan, California has taken annually as much as 5.3 million acre-feet from the river.

It was not until the early 1940s that Arizona changed its water policies and ratified the old Compact. Arizona simultaneously laid claim to a substantial share of the river water. The battle was joined once again. Twenty years of litigation finally resulted in the 1963 decision of the U.S. Supreme Court which paved the way for the Central Arizona Water Project by reducing the California allotment.

In this decision, California retained the priority right to 4.4 million acre-feet for irrigation, but would be cut 900,000 acre-feet per year from other allotments. The big loser was Metropolitan Water District, giving up 600,000 acre-feet, more than half its previous entitlement. The rationale for this was that MWD was also a party to the State Water Project, hence, had access to water from sources other than the Colorado River.

Even so, Southern California water conflicts continue unabated in the courts. Among these are the still-open case of Arizona vs. California before the U.S. Supreme Court, various on-going environmental claims of water waste, and the unresolved problems of urban vs. agricultural use of the river water. The latest developing conflicts are the emerging Indian tribal claim for more river water.

The Indian claims arise from a decision of the Department of the Interior in the early 1980s to release a large portion of Bard Valley to the Quechan Indians for farming purposes. The Indians immediately filed claims for riparian water rights. In turn, the existing water purveyors, knowing that any such allotment would come from their shares, have filed suits in Federal court challenging the government decision. And so it goes.

These unresolved issues, presently moving at the glacial pace of the law are likely to become more active in the near future for two reasons. First, the early 1980s was a period of above-normal river flow, and there was plenty of water in the river. Cycles of dry years, however, will put enormous pressure on any sharing of available supplies. Second, the Central Arizona Project, and projects of the Upper Basin states are not yet fully operational, but presage a demand for increased water in the next few years.

An Overcommitted River

The fundamental document in water issues is the Colorado River Compact of 1923, a mutual agreement between the six states within the river basin. The Colorado River Compact first defined the seven-state area of the Colorado River basin as consisting of two separate basins.[3] In addition, other interim agreements have attempted to allocate the supply equitably. These include the California Limitation Act of 1929, the Seven-Party Agreement of 1931, the Mexican Water Treaty of 1945, and the U.S. Supreme Court

Decree of 1964 in Arizona vs. California. All of these agreements combine to form what is now known as "The Law of the River."

To divide up the water, the participants had to know, first, how much water was actually in the river. In the early 1920s, the river flow was highly variable. Completely dependant on seasonal precipitation, and lacking the high dams, stream flow at any one time varied from very low to raging floods. Estimating the average annual flow was difficult. Future conflicts were ensured when the *highest* estimate of stream flow was used for the allocation of water rights! The number used was 15 million acre-feet per year.

In an apparent fair cut, each basin was granted rights to 7.5 million acre-feet of water annually. Since most of the river's water was being used at the time by the Lower Basin states, notably California, the Lower Basin was granted an additional discretionary one million acre-feet a year.

The Mexican Water Treaty was a later overlay which guaranteed Mexico 1.5 million acre-feet of Colorado River water annually.[4] This water is now diverted at Morales Dam, south of Yuma. In years of low flow, any shortfall required to meet Mexican treaty rights would have to be made up in equal quantities out of the allocations to the Upper and Lower Basin states.

Put all this together, and an incredible feat of political compromise emerges. Rather than confront and resolve the issues, the decisions and agreements granted the claimants water rights which in total exceeded the amount of water in the river! It was an agreement that guaranteed its return to haunt the parties sooner or later.

Against an average annual river flow of 15 million acre-feet, 18.5 million acre-feet have been specifically allocated to the states and Mexico. The political finesse left to future courts and legislatures the obvious question: when all claims are pressed, where will the 3.5 million acre-feet shortfall come from?

At the present rate of water development projects in both the Upper and Lower Basins, it is estimated that by the turn of the century total water use will be about equal to the long-term dependable river flow.

Water Allocations

As a consequence of these agreements, the additional one million acre-feet granted to the Lower Basin states by the Compact never became available. Further, it is clear that the 7.5 million acre-feet basic allocation to the Lower Basin states can never be available when the Upper Basin states claim their 7.5 million entitlements.

The allocation of the 7.5 million acre-feet for the Lower Basin states was set by the U.S. Supreme Court at:

California	4.4 million acre-feet
Arizona	2.8 million acre-feet
Nevada	.3 million acre-feet
	7.5 million acre-feet

California's irrigation entitlement under this scheme is unique under the Doctrine of Appropriative Rights. It is a perfected, or priority entitlement that must be honored before any other water, anywhere, is withdrawn.

But the shortages do not end at the state boundary. California's Seven-Party Agreement avoided "allotments" and instead set "priorities" for the use of the water within the state. The California priorities were established in 1931 by the Seven-Party Agreement as follows:

Irrigation[5]	3.85 million acre-feet
Metro. Water Dist.	1.10 million acre-feet
San Diego	.11 million acre-feet
Other	.30 million acre-feet

First and second priorities were granted to irrigate farmlands in the Colorado River Valley, third priority is shared by Imperial and Coachella Valley irrigation needs, and fourth is Metropolitan Water District. These priorities total 5.4 million acre-feet, nearly a million more than the state's total allotment.

The third priority, by far the largest in volume, was subsequently firmed up in the 1934 Compromise Agreement which granted a perfected right of 2.6 million acre-feet to Imperial Irrigation District. Of this amount, 300,000 acre-feet is delivered to the Coachella Valley for irrigation of 80,000 acres of farm land.

The most recent court case affecting the established water allocations is a 1982 decision of the California State Supreme Court which declared that in disputes over water rights, the "Doctrine of Public Trust" must now carry equal weight in water rights with the "Doctrine of Appropriative Rights," the basic water law. This issue is being actively challenged by those who stand to lose by it. The opposing case claims that the doctrine of public trust was established to safeguard the public interest in navigation, fishing and commerce. It had never before been applied in western courts to questions of water rights.

Unresolved Issues

The allocations defined by these agreements and court decisions are under constant attack by special interest groups representing a variety of alternative uses of the river water. For example, during the 1970s, proposed mining of oil shale in the Upper Basin states would have required enormous amounts of water for processing. The problem with this proposal was the potential for pollution of the entire Colorado River, and a degraded water supply for downstream users. Also, during that same "energy crunch" period, and due to the moratorium on coastal construction, power companies were planning two nuclear power plants in the Colorado Desert that would have used river water for cooling, a proposal vigorously opposed by anti-nuclear and environmental groups.

These two issues subsequently became moot. However, new claims have emerged to replace them, e.g. Indian tribes whose reservations border on the river are now claiming riparian rights to additional water.

River water salinity is another unresolved issue. The salt content of the Colorado River increases as it flows southward. Tributary streams drain canyons in the Colorado Plateau dissolving mineral salts from the sedimentary rocks, adding them to the soluble load of the river. Irrigation drainage from upstream users adds even more.

Evaporation in the desert climate further concentrates the salts, creating a catch-22 dilemma. As the stream flow declines, the salts become more concentrated. The higher the salt level, the more water is required for leaching and irrigation of Imperial Valley farmlands.

By the time the river water reaches Yuma, its salinity is often dangerously high. Only during periods of vigorous river flow is the salt content considered to be within acceptable limits.

Water quality and pollution problems will become even more severe in future years as the Upper Basin states withdraw more river water, reducing the volume and concentrating the salts in the downstream supply.

Farm Irrigation

Agriculture is a major segment of the California economy. Most of this industry is located in Central and Southern California where water problems are most acute. As a result, water cost and availability, conservation measures and irrigation practices are key considerations to understanding some of the problems of the industry. Agribusiness is a large, powerful industry whose self-interest is often at odds with special interest groups and with government agencies on water issues.

Of the total California water entitlement, agricultural agencies claim 3.85 million acre-feet.[6]. How much water is 3.85 million acre-feet? For comparison, 3.85 million acre-feet is *nine times* the total amount of water used annually in all San Diego County.

The Imperial Valley (500,000 acres) and Lower Coachella Valley (80,000 acres) are the farmlands of the Salton Valley. Virtually all this land is below sea level, with summer temperatures consistently in excess of 100 degrees. The agricultural allotment goes to these two areas plus the Palo Verde Irrigation District and the Bard Valley Indian lands, both lying in the Colorado River valley.

Irrigation in the Imperial and Coachella Valleys requires dealing with some unique problems. Coachella Valley farmlands are primarily sandy soils with good drainage but poor ability to retain soil moisture, thereby requiring considerable water.

By contrast, Imperial Valley soils are clay-like, holding water very well but also high in soluble salts. Because the soil has its origin as playa lake beds, there is considerable stratification of the soils. Abrupt textural changes have created perched water tables 5 to 8 feet below the surface throughout the area. This prevents proper drainage, and particularly lends itself to undue concentration of salts in the upper layers of the soil.

As a rule, desert soils tend to be heavily impregnated with salts of sodium, potassium and magnesium. In rainy climates, water percolating through the soil naturally leaches and dissolves the surface minerals, working them deep into the ground. In a desert climate, on the other hand, where most or all the rainfall evaporates into the atmosphere, the salt minerals move upward with the moisture that is drawn to the surface by capillary action.

Consequently, salts that are concentrated in the desert soils of the Imperial Valley can only be removed by periodic surface flooding and leaching. This requires more water than normal irrigation practices. In the Imperial Valley, the highly saline Colorado River water makes an ideal leaching water. Thus, there is validity to the claim that the Valley's farmlands require considerably more water for irrigation than comparable acreage elsewhere.

The Water Exchange Program

There is much merit to the argument that dams and water distribution systems are prohibitively expensive and that alternatives should be explored. Among these, water exchanges and conservation programs seem to hold the most promise. One successful and amicable inter-agency agreement is the exchange program now carried out in the Coachella Valley.

While Coachella Valley Water District and Desert Water Agency have entitlements to state water from northern California, there are no distribution facilities by which the water can be delivered. Fortunately, the Colorado Aqueduct (owned by Metropolitan Water District) traverses the Coachella Valley carrying Colorado River water to coastal counties. An exchange program neatly solves the distribution problem.

An agreement with the Metropolitan Water District provides the exchange mechanism. MWD takes delivery of the agencies' state water allotment in a bucket-for-bucket trade for MWD water that can be delivered to the Coachella Valley. The river water is delivered to the valley for recharge to the Coachella Aquifer.

In practice, MWD takes title to the desert agencies' state water at the Hesperia reservoir while an offsetting equal quantity of water is released from the Colorado River Aqueduct into the Coachella Valley.

The program is a model of cooperation, and deliveries have stayed in balance since inception. All the Coachella Valley entitlements to state water have been met with an equal amount of Colorado River water. In some years, above-average river flow has resulted in diversions that presently exceed the annual entitlements. This is due to a desire to place in storage the maximum amount of water available anticipating dry years ahead. Colorado River water is diverted from the aqueduct as it crosses Whitewater Canyon Figure. The water is released into the normally dry Whitewater River channel for infiltration into the groundwater system. The stream flows adjacent to the highway bridge at Windy Point, and has become a favorite gathering place for all-terrain vehicle buffs, few of whom are aware of the fact this is Colorado River water from nearly 200 miles away.

The stream empties into a series of large spreading basins. There, the water is impounded and allowed to seep into the groundwater system of the Coachella Aquifer. The Whitewater spreading grounds consist of 19 separate ponds ranging in size from 16 to about 60 acres, totaling over 700 acres of infiltration area. The ponds lie adjacent to Highway 111, but being at eye level are difficult to see from the road. An excellent view of them can be obtained from the upper tram station.

The agreement was modified in the mid-1980s to take advantage of high flows on the river. This provides for advance delivery of water to the Coachella Valley using the Colorado Aqueduct. It allows Metropolitan Water District to bank 600,000 acre-feet of water[7] in the Coachella Aquifer against shortages along southern California's coastal plain during drought. MWD has this claim against the valley's groundwater until the banked amount is exhausted.

The exchange program is a creative solution to a severe contingent problem, and it has the happy result that both sides win.

Still, there some negative aspects to the exchange program other than as a temporary measure. The valley is entitled to a share of state water, and there is need to be certain that political or financial considerations do not postpone indefinitely the construction of an aqueduct extension into the valley. More important, these facilities are needed to prevent excessive mineralization of the groundwater from the continued addition of Colorado River water which has a higher salt content than either state Water or the water of the Coachella Aquifer.[8]

Other Solutions in Sight

Another example of managerial foresight is a plan that should, when carried out satisfy even the most die-hard conservationist. This is the current planning and land acquisition toward the eventual construction of treatment plants to convert Coachella Canal (Colorado River) water to domestic use as the Lower Coachella Valley urbanizes. It is a worthy goal, using surface water resources for current water needs, leaving the groundwater resources as a "water bank" for future emergency use.

Water conservation programs are, of course, the most expedient steps that can be taken by everyone -- the homeowner, the farmer, the developer and the government. One such program undertaken by both the Coachella Water District and the combined Desert Water Agency/City of Palm Springs is water reclamation. Reclamation facilities are becoming operational that will provide millions of gallons of treated water for the irrigation of parks, golf courses and greenbelts.

Where Do We Go From Here?

Water is not an inexhaustible resource. The water problems of the Salton Valley are only a local insight into the much larger water issues of southern California. The burgeoning population centers, with staggering projections of growth in the future require action by the people to continue with the State Water Project, if not as originally conceived then at least in terms of viable alternatives.

The ever-increasing demand for water in southern California will inevitably approach the available supply. By then, supplies from northern California through the State Water Project must be augmented or supplemented to meet the requirements in the south. To avert shortages and assure an adequate supply to meet future needs, both state and local water district government must exercise statesmanship and wisdom to meet this challenge.

The Salton Valley is fortunate to have had people of foresight and goodwill in decision-making roles of water management. Managing our water resources is not a task where solutions to problems come easy or where policy is equally acceptable to diverse groups with their own agendas.

Much has been said here about the unique property of the permanence of water. Although water itself cannot be destroyed, its usefulness and availability can be. Like any natural resource, our water resources need to be protected if our nation is to have enough undegraded water for future generations.

CHAPTER 16
THE DYNAMICS OF AN EARTHQUAKE

Earthquakes: How They Happen

Earth is not a rigid mass, unyielding and incapable of flexing to relieve its internal strains. It is remarkably flexible, though on a scale difficult to comprehend. Under gravity, the compressive forces are enormous. In the subsurface mantle, the combined effects of heat and pressure cause rocks to behave as a plastic mass, yielding ever so slowly to relieve the stress. Rocks of the more brittle crust relieve their internal stresses by rupturing and moving suddenly and violently. The break is a fault, and the energy release is an earthquake.

A fault, then, is a fracture in the earth's crust along which there has been movement of the rocks on either side. Movement along a fault releases vibration energy that we experience as an earthquake. Some fault movement is abrupt, violent and the cause of major earthquakes. Along other faults, episodes of movement may be minuscule, producing only minor tremors.

Earthquakes are remarkably closely associated together in discrete groups. Most are related to fault zones which are associated with contemporary movement of Earth's great plates, and they usually occur in well defined regions.

The Mechanism of Faulting

Many faults are a single strand, or break. The major faults of southern California are unique in being *fault zones*. A fault zone consists of many separate breaks, usually interlocking and intertwined in a braided pattern, with no one fault trace dominant. A fault zone may be a few feet to several miles wide. The San Andreas fault is such a fault zone, with movement and earthquakes occurring at various times and places on the many branches along its great length.

Direct evidence of a fault is, first, a visible crack in the earth's surface. Significant displacement will often bring two different rock types in direct contact. Other direct evidence may be a uniformly straight mountain front, offset stream channels, fence lines, curbs, roads, orchards, vineyards, vegetation patches and other linear geographic features. These indicators are present in the Coachella and Imperial valleys, fixing the location of many known recent faults and earthquakes.

The Focus

Rocks in the earth's crust rupture when they are subjected to stress. The actual site of lesion is the *focus* of the earthquake. The focus is the point on the fault plane where movement begins. Within seconds, movement proceeds rapidly away from the focus and along the fault plane.

The strain energy in the crust is converted into elastic wave energy that radiates outward. At the surface, this energy is felt at the surface in the form of an earthquake.

The Epicenter

The *epicenter* is the point on the surface directly over the focus. It is the term used in news reports to describe the geographic location of an earthquake. Since fault planes are often at an angle from vertical, an earthquake epicenter does not necessarily lie on the surface trace of the fault.

For example, the 1963 Desert Hot Springs earthquake was a very noticeable shock measuring 6.3 on the Richter Scale. The quake was the result of movement along the Mission Creek fault. While the surface trace of this fault passes directly through the city of Desert Hot Springs, the sunterranian fault plane angles to the northeast. The focus of that episode of movement was at a depth of about ten miles, fortunately placing the epicenter (the surface point directly over the focus) well to the north in the Little San Bernardino Mountains, thus sparing the city of major damage.

The epicenter is a key definition in understanding earthquakes since the epicenter is the surface area closest to the focus. As the earthquake's vibration energy radiates outward from the focus, the epicenter is, therefore, usually the site of maximum damage from the earthquake.

Measuring Earthquakes

A news flash makes a very positive statement when it says an earthquake of devastating proportions has occurred in, say, a remote area of Central China or the Middle East. Considering the limited infrastructure in such regions, how can the event be known so soon and with such certainty?

There are two reasons. First, the behavior of earthquake waves is well known, i.e., the nature of earthquake waves, how they are propagated, and how they travel through the earth. Second, there is an array of sensitive monitoring stations around the world, on alert for incoming signals that strong earth movement has occurred somewhere.

Of many instruments involved, the best known is the seismometer, which is used to determine the location and energy release of an earthquake. First developed in 1885, seismograms remain the basic record of earthquake activity. Seismometers are also supplemented by newer more sophisticated measuring devices. From their data, a seismologist can calculate not only the location of the earthquake but also its magnitude, or severity.

In its simplest form, a seismometer is a heavy weight suspended over a revolving drum firmly anchored to bedrock. The indicating device is often a stylus on the suspended weight. When shock waves in the earth reach the instrument, the drum moves with the earth since it is anchored to bedrock, whereas the weight and the stylus remain stationary because of their inertia. As the stylus traces its wavy line on the precisely timed revolving drum, it is creating the record of the distant earthquake.

When an earthquake occurs, the vibration energy propagated at the focus radiates outward as a series of wave fronts. Traveling around and through the earth at two to four miles per second, the separate wave fronts may be recorded at great distances from their source. The seismograph records three distinct types of waves that are of importance to earthquake measurement: P (primary) waves, S (secondary) waves and L (surface) waves. First to arrive are the fast-moving primary, or P waves, which have traveled through the earth in a direct line from the focus to the recording instrument. Next to arrive are the secondary, or S waves. As these energy waves arrive, they trace the familiar wavy line on the rotating drum in a distinctive pattern

The fast P waves are like sound waves, compressing ahead, expanding behind. These are the waves felt as a sharp jolt when the earthquake is nearby. The S waves are shear waves, with movement up and down similar to waves at sea. Because of this lateral shearing component, the S waves are particularly damaging to buildings.

Then come the surface waves, or L waves. These have followed the curved surface of the earth from the focus to the instrument. Since they have traveled a longer distance, they are last to arrive.

Each seismograph station measures the time difference between the first arrivals of the separate P and S waves. Since the speed of transmission through the earth is known, the distance from the earthquake focus to the instrument may be calculated. When an earthquake is nearby, the time difference is very small. With increasing distance between the focus and the instrument, the separate arrival times progressively increase due to the increasing length of the arc of the earth's surface.

To illustrate this, assume that a strong earthquake has just occurred in the Imperial Valley. About 30 seconds after the onset of the quake, the first ground vibrations reach the Seismological Laboratory at California Institute of Technology, in Pasadena. Their instruments are set in motion and begin to record the event. Half a minute later, seismometers in Berkeley, California and in Arizona start their motion. In another thirty seconds, instruments in Salt Lake City record the vibration energy. In this manner, recording stations at increasingly greater distances become aware that an earthquake has occurred somewhere.

Preliminary information from these and other stations all over the world is flashed to the National Earthquake Information Center in Golden, Colorado. Within minutes following the event, triangulation using data from multiple reporting stations pinpoints the location of the epicenter.

The great San Francisco earthquake of 1906 provided the first worldwide use of this technique to obtain a quick and precise location of earth movement. In the scientific investigation following the event, an analysis of the data revealed that Toronto (2,200 miles away) recorded the disturbance 6.5 minutes after the first shock. In turn, Edinburgh, Scotland (4,500 miles away) learned of the event in 11.0 minutes; Munich, Germany, (5,200 miles away) recorded the waves in about 12.5 minutes; Calcutta, India, 6,400 miles away, was aware of the great event in 16.6 minutes, and so on all over the world.[1]

With improvements in communications, news of an earthquake today is available in a short time, enabling public safety and disaster relief programs to be mobilized without delay. This is possible through the cooperative efforts of many earthquake watch centers. The establishment in 1966 of a worldwide network of sensitive seismic stations has enabled seismologists to monitor the thousands of earthquakes that occur each year. The network now includes more than 650 seismographic stations, all reporting data electronically regularly to the data center in Golden, Colorado. More than 60,000 seismic readings per month go into its massive computer data banks. On average, there are about 500 significant traumas per month. For each earthquake, the Center publishes research data from every observation of the earthquake from every possible recording location. Other instruments measure the way the ground surface is deforming, not only during the earthquake itself, but as on-going research into earth movements. Accurate laser surveys and tiltmeters reveal continuous crustal movement, by measuring both vertical and horizontal changes in elevation and location of benchmarks. A network of laser triangulation markers crisscrosses the Salton Trough and the Cerro Prieto section in Mexico. Periodic checking detects minute changes in the surface of the valley that may relate to potential earth movement.

Different Types of Faults

Since a fault is a break along which there has been movement, the direction and kind of movement must be considered. Rocks in the earth's crust are subject to three primary stress configurations, *tension* (pulling apart), *compression* (squeezing) and *shearing* (sideways) forces. The strong, brittle rocks rupture when subjected to these forces, producing faults and earthquakes.

Many faults are evidence of mountain-building episodes of ancient geologic time. Most of these faults are inclined at high angles to the earth's surface. Movement of adjacent blocks is largely vertical.

There are two broad classes of high angle faults. In both cases, movement of the adjacent blocks is relative, *i.e.,* one side moves up relative to the other side, and vice versa.

Normal faults are the result of tensional forces. The result is a depressed block creating a valley or basin. A *reverse fault* is the result of a compressional force that has the effect of raising uplifted blocks into mountain ranges, *strike-slip*, or *lateral faults* involve sideways movement, caused by shear forces in the crust of the earth. The adjacent blocks move horizontally, with little or no vertical movement component. This type is common in the Imperial Valley, and, indeed, to coastal California as a whole.

Strike-Slip Faults

Virtually all the great faults of Southern California are northwest-trending strike-slip faults. Of these, the San Andreas fault zone is the best known and "infamous" as the source of many destructive earthquakes of the past. The San Andreas fault zone is itself composed of a number of subordinate zones covering a wide swath that threatens hundreds of miles of coastal California.

The San Andreas is a special category of strike-slip fault called a *transform*. This involves movement at plate boundaries, where one crustal plate slides past another plate in tight contact. Movement is uniformly right lateral, i.e., looking across the fault, one perceives the other side to have moved to the right.

Consider this as it applies to the San Andreas fault. The eastern or continental side will appear to have moved south. Or, did the western, or coastal side of the fault move north? Movement is relative, and the question becomes: which side of the fault moved?

A preponderance of evidence supports the conclusion that the coastal block is moving northwest relative to the stable continental side of the fault system. That is to say, the ground west of the San Andreas fault is moving to the northwest, sliding past the relatively stationary ground east of the fault.

An interesting sidelight will illustrate this point. The City of Los Angeles is west of the San Andreas fault, while San Francisco finds itself east of the fault, on the continental block. Right lateral movement of the adjacent blocks is bringing the two cities closer together about two inches per year. Scientific wags love to point out that soon, geologically speaking, San Francisco will be another suburb of Los Angeles. How soon? About 15 million years.

There is another local example. The cities of Palm Springs and Desert Hot Springs are on opposite sides of the San Andreas Fault which bisects the valley. Here, Palm Springs is sliding northward, carried by the moving Pacific plate past Desert Hot Springs on the (relatively) stationary North American plate.

A feeling of great respect for nature and great natural forces can affect people when they can actually see evidence of one of these forces. Next time you are in Palm Springs, go north on Indian Avenue a few miles to the line of mesquite trees near the 20th Avenue intersection. These trees in the barren desert are nurtured by groundwater seeping upward along the fault plane of one of the faults in the San Andreas system. Stand in front of the trees and know you are on the Pacific plate, while the trees are on the North American plate!

How Earthquakes Happen

An earthquake results from the sudden movement of adjacent blocks within the crust. This generates an enormous release of energy. Stresses accumulate, and release when the rock masses rupture and slide past each other. The underlying source of that movement is relief from strains induced by the motions of the earth's plates. The earthquake is the surface manifestation of that energy release.

As southern California is positioned on an active plate boundary, our frequent, at times disastrous earthquakes are the result of movement between adjacent plates. Consider a right lateral, or sideways moving fault, such as the San Andreas. The mobile western side wants to move northward relative to the stable continental land mass. The two sides are in tight contact, held in place by the westward-moving American plate.
As the rocks become increasingly strained through time, elastic energy accumulates in the rock mass the same way energy may be stored in a wound-up clock spring. Eventually, the frictional bond can no longer be sustained, and the bond fails. An enormous amount of strain energy is abruptly released as the adjacent blocks suddenly and violently rupture, and slide by each other to regain equilibrium. This is known as *elastic rebound*. The physical break is the fault, and the vibration energy transmitted through the earth is what we experience as an earthquake.

CHAPTER 17
THE RICHTER SCALE

The Richter Scale is the accepted standard of the general public by which earthquakes are measured. It is a measure of the "size" of an earthquake, and is expressed in whole numbers and decimal fractions. It was the first reliable measurement system for earthquakes and is still widely used in the press. As a result, it has become a familiar part of the Southern California culture. So, in spite of the scientific community's development of newer, more sophisticated measurement tools the Richter Scale will be with us for a long time.

Quakes that make the headlines are usually 5 or higher on the scale. But what, exactly, is the scale, and what does it tell us?

Developed in 1935 by Dr. Charles Richter of the California Institute of Technology, the scale measures an earthquake's magnitude, which is closely related to the energy content. Magnitude is calculated from the seismogram of an earthquake. The amplitude, or swing distance of the largest wave is related to the computed distance to the earthquake epicenter.

The Richter Scale is often referred to as ranging from 1 to 10. This is incorrect. Because earthquakes range from the slightest tremor to cataclysmic events, no arithmetic scale, especially one limited to a range of 10 units, could possibly cover them all. The Richter Scale is logarithmic; each whole number is ten times greater than the one below it. The scale is open-ended; there are no meaningful limits. From a practical view, however, magnitudes less than 2 are of scientific interest only, and the greatest earthquakes may reach 9 on the scale.

Upon examination, the magnitude differences are striking. Take, for example, Richter magnitude 4. This size earthquake is common. It is one where the shaking is slight but noticeable, and all it usually does is rattle the dishes. A magnitude 5 (e.g., the 5.6 Palm Springs earthquake of July, 1986) is ten times more severe than the 4, and a magnitude 6 (e.g., the 5.9 Whittier earthquake of October 1, 1987) is 100 times more destructive than the magnitude 4 earthquake. As the expression goes, these things really pack a wallop! The actual amount of energy released is about 30 times greater for each step. For example, a magnitude 5.0 earthquake has 30 times the energy content of a 4.0 earthquake, and a 6.0 shock is 30x30, or 900 times greater than a magnitude 4.0 earthquake. That is why even moderate earthquakes can have so much potential for destruction.

Yet, the most significant factor affecting losses from any large earthquake is the location of the epicenter; where the quake actually occurs. Consider two equal earthquakes may occur, one in heavily populated southern California and another in the barren desert of central Nevada. While they may be of identical magnitude according to the Richter Scale, the damage and social effects will differ greatly.

Past experience with California earthquakes makes it possible to describe in a general way what might be expected should an earthquake occur in urban southern California. Using the Richter Scale as a descriptive tool, the following table suggests the effect of various levels of intensity for earthquakes in Southern California.

Expected Effects of Earthquake Intensity For Urban Southern California Earthquakes

Richter Scale	Effect at the Epicenter
1-2	Detected only by instruments; seldom felt by people.
3	Usually felt indoors, especially on upper floors; seldom felt outdoors; often not recognized as an earthquake; may be confused with passing traffic; standing cars may rock slightly.
4	Felt by everyone; many awakened if at night; dishes, windows, doors rattle; slight breakage of unstable dishware; hanging light fixtures sway; standing cars rock noticeably.
-5	Buildings creak and groan; unstable objects topple; movement may be appreciable on upper floors of tall structures; dishes and glassware broken; some cracked plaster.
5+	All sleepers awakened; many people are frightened and run outdoors; heavy furniture moves around slightly; some fallen plaster and damage to chimneys; glassware breakage is heavy.

-6 Everyone runs outdoors; excitement is general; some chimneys and walls broken; extensive damage to mobile homes; damage is minor in well-built structures, and considerable in poorly built structures.

6+ Partial collapse of ordinary substantial buildings; chimneys, stacks and monuments fall; people move unsteadily; church bells set to ringing; considerable breakage of household objects.

-7 Major damage everywhere; everyone frightened; difficult to stand; trees and bushes shake violently; poorly built structures collapse; frame houses shift off foundations; underground pipes broken.

7+ Most masonry and frame structures destroyed; landslides on steep slopes; railroad rails twisted and bent; water slops over swimming pools.

-8 Severe damage everywhere; alarm approaches panic; few masonry structures survive; bridges collapse; underground pipes completely out of service; earth slumps and slips; rails twisted badly; fissures open in the ground; objects thrown into the air.

8+ Damage near total; infrastructure and utilities lost; injuries widespread; major loss of life.

CHAPTER 18
THE SAN ANDREAS FAULT SYSTEM

The San Andreas fault is a major geologic feature of North America. Actually, the term San Andreas *fault* is a misnomer, suggesting that the fault is a single break. It is more accurately called the *San Andreas fault system,* or zone, with several major and numerous minor branches, particularly in southern California.

The San Andreas Fault

Despite its benign name (Saint Andrew), the San Andreas fault is a violent and destructive killer. Over its long history, spasms of its enormous energy have been released in countless earthquakes along its great length. These have ranged in magnitude from slight tremors to cataclysmic upheavals and rupturing of Earth's surface.
It is a well known and familiar geologic feature in western America. The remarkably straight fault trace is prominent on any California map. It looks like a knife slash from hell in a northwest-southeast direction that attempts to separate the Coast Ranges from central and southern California.

The fault ranks among the longest such structures in the world. Overland, it is a visible break that can be traced for 625 miles from Point Arena, north of San Francisco, to the Salton Sea, near the border with Mexico.

The inferred extensions of the fault are even more dramatic. Northward, the break is thought to extend under the sea another 400 miles, possibly merging into the Murray Fracture Zone on the deep sea floor. At the southern end, the fault is believed to follow the axis of the Gulf of California for almost 1,000 miles.

Because of the fault's great length, as much as 2,000 miles, movement is intermittent as to time, and random as to place. At any place along the fault, movement may be a one-time event, or movement may be recurrent over thousands of years. In any one episode, displacement may be a fraction of an inch or it may be many feet.

The surface trace of the fault first appears at Point Arena, a peninsula north of San Francisco. It takes a straight path southeastward through a series of elongated valleys to San Francisco Bay, it crosses the bay with San Francisco on the western block and the bay cities on the eastern or continental block.

In the San Francisco Bay area, the San Andreas has two major companion branches. Generally defining the east side of the Bay is the Hayward fault, and a few miles inland is the Calaveras fault. The Hayward fault presently carries a high probability forecast for an earthquake.

In an undeviating course, the trace passes San Jose and enters the Coast Ranges. It runs parallel to the Gabilan Range, passes the towns of Coalinga and Parkfield (both with vivid earthquake histories), thence it defines the elongated Temblor Range to Tejon Pass. This segment of the fault in central California is very old. Between the Bay area and the Tehachapi Mountains, rock formations appear to have been displaced as much as 160 miles. This suggests that the northern section of the fault may have originated about 30 to 40 million years ago, during Oligocene time.

The fault planes of the faults in the system are usually near vertical. In some sections, however, the fault plane is locally tilted as much as 60 degrees to the northeast. A local example of this effect is the Banning fault near Cabazon in San Gorgonio Pass. Here, the fault tilted to the point where the moving western block slid under the eastern block, a *thrust fault*.

The San Andreas fault is a shallow fault, generally extending into the earth's crust four to ten miles. Earthquakes associated with shallow faults are more destructive at the surface than those originating from deep-seated faults.

The San Andreas is an uninterrupted zone of many braided fault traces. These fractures branch and interlace in a swath two to eight miles wide along the fault's great length. With these multiple fractures creating great slices or slabs, and over countless episodes of earth movement, the rocks within the fault zone have been severely deformed, smashed and ground up. Thus weakened and broken, they become subject to rapid weathering and erosion.

So, the fault course in central California has been eroded into a series of elongated valleys for more than one hundred miles through the Coast Ranges as a shallow trench only a few miles wide. This distinctive landform was made both from erosion of the shattered and weathered rocks and from the effect of recent faulting. The valleys contain many typical fault-related features such as offset streams, ponds, and scarps. This string of continuous valleys is recognizable on any large scale road map.

In southern California, the fault is much younger. Major right-lateral movement began about 12 million years ago, or during late Miocene time.

This considerably predates the opening of the present Gulf of California which began about 5.5 million years ago. The progressively younger age of segments of the fault from north to south is consistent with ideas concerning plate movement along the west coast of North America.

The southern California segment of the San Andreas fault is described from the vicinity of Gorman, about 60 miles northwest of Los Angeles. There, it bends abruptly to the east for six miles, then resumes its original southeast heading.

This "Big Bend" area is possibly the most significant tectonic area in California today. Here, the San Andreas intersects the left-lateral Garlock fault, the only major east-west trending fault in southern California. Earthquakes are common in this area. The Fort Tejon earthquake in 1857 (magnitude 8-plus) is thought to have been at least as violent as the San Francisco earthquake 49 years later. The San Fernando earthquake of 1971 (magnitude 6.6) was also associated with this zone of intersection.

From Tejon Pass, the main trace of the San Andreas fault passes through the high desert north of Los Angeles, defining the north face of the San Gabriel Mountains. It then separates the San Gabriel Mountains from the San Bernardino Mountains, creating Cajon Pass that takes Interstate 15 out of southern California.

From the vicinity of Cajon Pass, the southern California segment of the San Andreas fault becomes very complex with no distinctive single trace as in the north. Instead, it is divided into several right-lateral elements, all somewhat parallel to each other. Principal among these are the San Jacinto and Elsinore faults. Several branches go through the San Bernardino Mountains and along the north margin of San Gorgonio Pass into the Coachella Valley. One important associated fault is the San Gabriel fault, defining the southern edge of the San Gabriel Mountains in the Los Angeles basin. This fault was probably the most active strand for thousands of years, but there is no evidence of recent activity. Another important branch in the Los Angeles area is the Newport-Inglewood fault, the source of the destructive Long Beach earthquake of 1923.

The Banning Fault

The Banning fault, a subordinate branch of the San Andreas, first appears east of Riverside, trending almost due east. It defines the north side of San Gorgonio Pass where a section is unique in being a thrust fault. This thrust is responsible for the low, brown-colored hills along the north side of Interstate 10 between Cabazon and Whitewater Canyon.

The fault has created a distinctive gash behind these hills. In crossing Whitewater Canyon, it forms a barrier to the passage of groundwater down-canyon, supporting lush riparian growth in the floor of the canyon.

The Banning fault enters the Coachella Valley near Whitewater, crossing Route 62 about 1.5 miles north of the interchange with Interstate 10. It intersects Indian Avenue one mile north of the freeway, and crosses Palm Drive at 20th Avenue, then continues to the southwest past Palm Springs.

The surface trace of the San Andreas fault is conspicuous on the valley floor by the lineup of vegetation along its north side, a result of fault-dammed groundwater flow. This prominent feature is conpicuous as viewed from the observation post at the top of the aerial tramway.

The Banning fault trace defines the southern margin of the Indio Hills, and supports several beautiful palm oases in the canyons where ground water reaches the surface as seepage along the fault trace. Similarly, the northern margin of the Indio Hills is defined by the Mission Creek fault, and here, too, may be found palm oases, principally Thousand Palms Oasis.

While the Banning fault is very well defined by surface features, its relationship to the main San Andreas fault has not been firmly established. The area in question is the complex fault geology of San Gorgonio Pass.

The Mission Creek Fault

About six miles north of the Banning fault, another branch, the Mission Creek fault, enters the Coachella Valley near the mouth of Morongo Valley. The Mission Creek fault passes directly through the town of Desert Hot Springs, and is responsible for the many warm springs in that area. It intersects Dillon Road near Wide Canyon Road, and marks the northern margin of the Indio Hills. Thousand Palms Oasis is on this fault. Locally, the Mission Creek fault is the most active branch in the system. Seismological data relating to recent earthquakes and measures from precise triangulation surveys show current persistent movement. Disrupted alluvial deposits, truncated older alluvial fans, and vegetation lines are evidence of its trace. In particular, low scarps may be seen where Indian Avenue meets Route 62, and again at Miracle Hill, east of Desert Hot Springs. The Banning fault and the Mission Creek fault join at Biskra Palms in the Indio Hills near the north end of Madison Street).

The San Andreas fault continues along the northwest shore of Salton Sea. At Salt Creek Wash, the surface trace of the great fault ends, more than 600 miles from its northern end. Current thinking is that the San Andreas fault, buried under alluvium, merges with the Imperial fault. It then continues southeastward to the Gulf of California, defining the western margin of the Gulf, finally merging into the East Pacific Rise.

The South Pass Fault

The inferred South Pass fault defines the southern margin of San Gorgonio Pass along the edge of the San Jacinto mountains. The fault has no surface trace, being deeply buried in alluvium. The principal rationale for placing a fault here is (1) the uniform straight mountain scarp, and (2) without a fault, it would be difficult to account for the pass structure. Where the fault enters the Coachella Valley, it curves to the southwest, past Windy Point to about Chino Canyon.

The San Jacinto Fault

The most seismically active fault in southern California today is the San Jacinto fault and its branches. It is also the fault that is potentially troublesome to the Salton Trough. Many earthquakes within historic time have been associated with it.
The San Jacinto fault is a major element of the San Andreas system. Separating from the San Andreas west of Cajon Pass, it takes a more southerly but generally parallel track. The trace bisects the city of San Bernardino, and passes directly under the four-level freeway interchange at Colton. Its path takes it behind the San Jacinto Mountains, passing the communities of San Jacinto and Hemet. Along the mountain front in this area, the fault has dammed groundwater channels, forcing water to the surface as hot springs.

It lies west and south of the San Jacinto Mountains, and for several miles forms the northeast edge of Borrego Valley. The fault cuts the Ocotillo Badlands near Ocotillo Wells, then enters the Imperial Valley where its trace is buried under recent lake bed sediments. The known length of the fault is approximately 180 miles.

Like the San Andreas, it is a complex system of many faults with local names. At its northwest end, following its separation from the San Andreas fault near San Bernardino, it generally has one or more well-defined breaks, especially where its trace cuts across rocks of somewhat recent age. Southeastward, it includes several zones of subparallel breaks, separating masses of bed rock into slabs ranging in width from a few feet to thousands of feet. Although they are parts of the San Jacinto fault zone, many of these subsidiary faults are themselves major features and commonly are given individual names. One important subordinate fault is the Thomas Mountain fault that forms the southwest margin of Garner Valley.

This pattern of multiple faults continues to broaden to the southeast where the San Jacinto zone enters the Salton Trough. There, at least six subordinate faults are spaced half a mile to three miles apart. This pattern continues through the Imperial Valley and into Baja California.

The major breaks in the San Jacinto fault zone dip very steeply to nearly vertical, and the entire zone appears to be a very deep-rooted feature.
There is abundant evidence of recency of movement along most of the length of the fault. In its central section, along the San Jacinto Mountains and the Santa Rosa Mountains, there are many fault scarps, elongate trenches, sag ponds, aligned canyons, and offset drainage. Many earthquakes, moderate to severe in scale, have been recorded from the City of San Jacinto south into Mexico.

The most active branch at this time is the Imperial fault, the source of many tremors and quakes in recent years, some of them very destructive. Another active branch is the Superstition Hills fault along the west side of the Imperial Valley. The very active Cerro Prieto fault on the Mexican side of the border is a member of the San Jacinto system, and is probably an extension of the Imperial fault.

The San Jacinto fault is a young, right lateral zone of seismic strain that has dominated fault movement in southern California for a least a century. Notwithstanding the notoriety of the San Andreas fault, since 1857 there have been 36 major earthquakes identified to faults in the San Jacinto system. Of these, 15 have originated along the Imperial fault in the Salton Trough.

Between 1915 and 1954, five historic large quakes, all with magnitudes between 6.0 to 6.8 on the Richter scale, occurred along this fault between the City of San Jacinto and the Salton Sea.

While presently more active than the San Andreas fault, the San Jacinto fault is much younger in age, having slipped laterally only about 15 miles, compared to nearly 200 miles of displacement along the San Andreas fault. The age of the San Jacinto fault is uncertain, but it seems probable that the fault has been active since at least early Tertiary time.

The Elsinore Fault

A brief mention of the Elsinore Fault is made here only because it is one arm of a trilateral split of the San Andreas Fault. As a geographic feature it is not associated with the Salton Valley.

The third major fault in the southland is the Elsinore fault, also a member of the San Andreas system. Its trace is parallel to the San Jacinto, and about 20 miles west. The fault originates beneath the alluvium of the Los Angeles Basin. Running southeast, it sharply defines Elsinore Valley and Lake Elsinore). Passing south of the Vallecito Mountains bordering Borrego Valley, the fault enters the Salton Trough near the Coyote Mountains in the extreme southwest corner of the Imperial Valley.

Of the three principal branches including the San Andreas and the San Jacinto faults the Elsinore fault has been considerably less active in historic time.

Movement along the San Andreas fault

The San Andreas is a right lateral fault, with the relative movement of adjacent land masses being sideways. Along the San Andreas system, movement of the western block has been consistently to the northwest. Over millions of years, the cumulative displacement amounts to several hundred miles. Or, as Armand Eardley put it, "The San Andreas marks such an important contact that rarely can it be crossed, except in recent alluvium, without passing into significantly different rocks.

Displacement, or the amount of movement along lateral faults is determined by identifying distinctive rock units found on opposite sides of a fault, but are some distance apart. One such technique is identification of rock debris in a sedimentary basin that could not possibly have come from the local mountains. The geologist then attempts to match up the sedimentary material with the appropriate source on the other side of the fault.

A local example of this occurs in Whitewater Canyon. A rock formation known as the Coachella Fanglomerate a coarse, bouldery ancient alluvial fan deposit is exposed where the Mission Creek fault crosses the canyon. Geologists have studied the boulder fragments in the Coachella Fanglomerate in detail, finding several distinctive types south of the Mission Creek fault that do not appear north of the fault. These rock fragments appear to have been derived from a source area close to the Cargo Muchacho Mountains, near the Mexican border. Such a correlation requires 130 miles of right-lateral separation within the San Andreas fault system.

Studies at many locations between Soledad Pass and the Salton Sea have established that the San Andreas fault has a total offset of at least 140 miles. As the southern section of the San Andreas fault can be dated back to the Miocene Epoch, about 12 million years ago, this suggests an average displacement of more than one inch per year.

Offset of the rocks has also been observed at many points along the length of the San Andreas fault. Older rocks appear to have been displaced more than 350 miles, while progressively younger rocks are displaced progressively fewer miles.

It is difficult to absorb the scale on which nature works! A displacement of hundreds of miles along the San Andreas fault can only be accepted when we understand that it is the result of an immense number of small steps occurring over a vast span of time.

CHAPTER 19
A ROLE CALL OF EARTHQUAKES

EARTH IS A REMARKABLY DYNAMIC BODY; far more so than ever suspected in the past, and certainly more so than any of the other planets. Within the mantle, gigantic convection cells of semi-molten material ares constantly in motion, providing the driving force to move the plates of the crust. As the plates move, they do so with immense momentum, dragging the continents with them, colliding and scraping by each other. This turmoil generates more than one million recorded earthquakes a year, or one every 30 seconds somewhere. Of these, about 3,000 per year will move the surface noticeably. About 20 per year will cause severe distortion of the surface, and if in heavily populated areas will cause human suffering and widespread property damage.
Great Earthquakes of magnitude near 8.0 seem to occur about once in 5 to 10 years somewhere, even in California.

Great Earthquakes in California's History

In southern California, while there have been many moderate earthquakes involving the San Andreas system, there has been no great earthquake in recorded history! That has not been the case in Central California!
In central California, great earthquakes of devastating proportions occurred on the San Andreas fault in 1838, 1857 and 1906. Little is known about the 1838 episode, and much is known about the 1906 disaster.

The Fort Tejon Earthquake

On January 9, 1857, a violent shock involving the San Andreas fault struck the Fort Tejon area, about 50 miles northwest of Los Angeles. The magnitude is estimated to have been over 8 on the Richter Scale, or at least equal to the San Francisco earthquake that followed fifty years later. The initial shock was so massive it was felt by people in Washington and Nevada. Ground cracks along the fault trace were observed to the north for over 100 miles, and southward at least as far as San Bernardino. Surface displacements were extreme. Between Fort Tejon and Parkfield, horizontal displacement was 30 feet. Farther south, displacements of ten feet were common. This earthquake is considered by geologists to have been potentially the most destructive in California's recorded history. But, except the collapse of scattered small buildings, damage was negligible, as the quake occurred in a sparsely settled area of open range land. An earthquake of that magnitude in populous southern California today would be devastating, no matter where the epicenter was located.

The San Francisco Earthquake

In one minute, on April 18, 1906, San Francisco learned the immense potential of earthquake destruction. Damage was widespread, and nearly 3,000 deaths were recorded. The quake was triggered by movement along the San Andreas fault. It slipped in places as much as 21 feet, with many displacements of 10 to 15 feet observed. The magnitude was 8.3 on the Richter Scale. Damage was widespread, caused in part by the earth movement, but largely by the uncontrollable fires that followed. This quake is perhaps the best known of any in history.[1]

Significant Events in Southern California

While southern California has been fortunate to have thus far escaped a great earthquake, episodes of lesser but still significant magnitude still a part of everyday life. In the past 100 years, there have been about 20 significant shocks. Two were more than 7.0 on the Richter scale. Both were in Baja California near the head of the Gulf, and both occurred more than 50 years ago. Moderate earthquakes (magnitude greater than 6.0 on the Richter scale) are not uncommon in California. On average, they happen about once every five to ten years. Their individual effect upon the social fabric is almost totally dependent upon where they occur.

The San Fernando Earthquake

On February 9, 1971, a quake of magnitude 6.4 shook the north Los Angeles community of San Fernando. This shock caused an immense amount of damage and took 58 lives, 49 of them at a hospital near the epicenter. More than 2,000 injuries were reported. Damage to public and private property and to the infrastructure was heavy, involving thousands of homes and businesses. Older, unreinforced masonry buildings collapsed. Freeway overpasses ruptured and fell; landslides and rockfalls were common. There were no foreshocks to warn of the quake, but in the following 24-hour period, 174 aftershocks of magnitude 3.0 or greater were recorded, two of them at 5.8. This earthquake was unique in that most of the earth movement was vertical. Later surveys showed that an elliptical area six miles long had risen about five feet.

The Whittier Earthquake

Whittier is a suburban community in east of Los Angeles. At 7:42 AM, October 1, 1987, the area was rocked by a shock of 5.9 magnitude. The center city was damaged, with many older store fronts collapsing. The shaking seemed to many to be nearly endless. In the following six hours there were 39 aftershocks ranging from 2.5 to 4.7 in magnitude (that is about ten minutes between shocks) before things quieted down. And it wasn't over yet; October 2nd and 3rd each had 6 to 7 aftershocks greater than 3.0 magnitude, followed on the 4th with a final convulsion of 5.3 magnitude at 3:59 AM.

The Loma Prieta Earthquake

Residents of the Bay area will always remember the evening of October 17th, 1989. At 5:04 PM, a branch of the San Andreas jolted loose under Loma Prieta mountain, sending shock waves throughout a wide area. The city of Santa Cruz was hard hit, where old masonry buildings were destroyed or badly damaged in the 20-second tremor. Fifty miles north, in the San Francisco Marina District, developed on soft landfill, damage was heavy. Gas and water mains were ruptured, a lethal combination as fires broke out just as they had 83 years earlier. The worst disaster was across the Bay in Oakland. A section of the double-decked freeway collapsed, crushing 53 cars. Though damage was localized, it was a costly natural disaster, with a price tag of 53 human lives and tens of millions of dollars in property loss.

Moderate Events in or near the Salton Valley

Imperial Earthquake

There have been 17 moderate earthquakes this this century in the Salton Valley. The one of greatest magnitude happened on 10 May 1940. Tis was the Imperial earthquake which involved the Imperial fault. It measured 6.7 on the Richter Scale. The epicenter was located ten miles southeast of El Centro. Nine deaths were caused, and structural damage was heavy and extensive in the agricultural towns in the Imperial Valley. The fault, previously undiscovered, had been concealed by alluvium. The quake caused a horizontal surface displacement of many feet, and the surface trace was marked by a low scarp indicating minor vertical displacement.

There were many offsets in roads, fences and orchards. The brand new All American Canal was broken and offset 14 feet, and many feeder canals were breached. Horizontal displacement of the right lateral fault was three feet at the town of Imperial, increasing to over 13 feet at Calexico.

Today, some 50 years later, continuing creep or offset along the Imperial fault may still be observed where the fault crosses Highway 80, east of El Centro.

Westmoreland Earthquake

This earthquake happened on 26 April 1981. The epicenter was located about five miles due north of the town of Westmoreland, near the southwest shore of the Salton Sea. The main shock was magnitude 5.6, with many foreshocks and aftershocks, all in swarm-like patterns. Damage was not significant.

A major earthquake on one fault can trigger sympathetic movement along nearby faults. This quake, of 6.5 magnitude, occurred on the Coyote Creek fault, a member of the San Jacinto system. Surface movement was later found along portions of the traces of the Banning fault, the Mission Creek fault and the Superstition Hills faults.

The Palm Springs Earthquake.

The first warning on 2 July, 1986 was one foreshock of 3.1 intensity. Then, without warning, on 8 July, two successive quakes struck. At 2:20 AM, a shock of 5.6 hit, followed four minutes later by a second at 4.4 on the Richter Scale. It was felt in Los Angeles, Las Vegas and San Diego. The epicenter was 12 miles northeast of the city, between the Banning fault and the Garnet Hill fault, with lateral displacement about 2 to 2.5 inches along both faults.

What made this episode unusual was the number of aftershocks that were almost continuous throughout the day. By 6:00 AM, there had been 82 small shocks, averaging one every three minutes. There were 144 by midnight the same day. The area did not quiet down until near the end of the month, and by then more than 280 aftershocks had been recorded, all between 2.5 and 3.9 on the Richter Scale. During the entire Palm Springs sequence, there were eight shocks individually greater than 4.0.

There was minor damage to structures locally. There was considerable damage to the support abutments of Interstate 10 highway overpass bridges at the Whitewater and Route 62 exits. The Route 62 roadway was cracked and buckled, and the Highway 111 bridge at Windy Point required extensive repair. The old Route 66 bridge over Whitewater River is directly abovethe Garnet Hill fault, and the road approach to the bridge was pushed up and over the bridge floor 6 to 8 inches.

There was also heavy damage to the electric substation located between Palm Springs and Desert Hot Springs. This caused a total power loss to the Hinds Pumping Station of the Colorado Aqueduct at Chiriaco Summit, causing a shut-down of the aqueduct flow. As a result, more than one billion gallons of the flowing water had to be dumped onto the desert floor.

The greatest damage was to bridges and freeway overpasses. The State was well aware of this problem, and as a direct result of this quake, a program of bridge retrofit was undertaken in all earthquake-prone areas.

The Bishop Earthquake

The Bishop earthquake of July, 1986, while located near the Owens Valley of central California, was significant and unusual. It is described here as a model for evaluating a possible similar episode in southern California.

Recent earthquake experience was not unknown to the Bishop area. In May, 1980, the Mammoth Lakes earthquake had occurred as three jolts of 6.3, 6.4 and 6.3 on the Richter Scale over a two-day period.

Now, less than six weeks later, on 20 July, 1986, a 6.2 shock hit at 7:29 AM, 15 miles northwest of Bishop. A second major shock of 6.6 came at 7:42 AM the next day. In the next ten days, there were more than 140 aftershocks on the same epicenter. Of these, one was at 6.0, six were greater than 5.0, and 39 were greater that 4.0 -- all essentially on one epicenter.

This sequence of events occured in a remote area of California, involving small communities and open range land. But it could could happen within urban southern California. Multiple shocks over 6.0 would certainly cause considerable damage. But consider the psychological affect an episode such as this would have had on a large city. Noticeable shocks were coming at the rate of *one every 30 minutes for two days!*. A fearful population, already stressed out by three major initial shocks would be in a high state of anxiety, with many people verging on panic with this seemingly endless series of earthquakes.

A very scary scenario that is not beyond the realm of possibility.

Superstition Hills Earthquake

The Superstition Hills earthquake sequence consisted of two main shocks amid a series of aftershocks. On 23 November, 1987, there were two foreshocks of 4.2 and 4.0 at 5:32 AM and 5:53 AM respectively. One minute later, at 5:54 AM a main shock of 5.8 struck. Then again, at 5:15 AM on the 24th there was a shock of 6.0 magnitude on the Richter Scale. There would be total of 23 measurable shocks (2.5 or more) in this episode lasting through 1 December.

The epicenter of the first main shock was southwest of Westmoreland, on a previously unknown cross fault at the southern edge of the Salton Sea. The epicenter of the second was in open country, 14 miles southwest of Westmoreland, on the Superstition Hills fault, a member of the San Jacinto system. The two epicenters were six miles apart, suggesting the possibility of the first earthquake triggering the second.

Damage was heaviest in Calexico and Mexicali, including many power, telephone and gas line breaks. About 94 people were injured in the collapse of poorly built structures. Horizontal displacement along the fault was measured at four to seven inches on Imler Road.

CHAPTER 20
SUMMARY

A Regional Overview

The Geography

The low desert of Southern California is a large and distinctive landform. In outline as well as in structure, it is a long, inverted V-shaped valley trending southeast. The landform continues into Mexico, merging into and incorporating the Gulf of California. From 22,000 miles in space the entire geologic structure is highly visible. The apex of the enongated triangular structure is at San Gorgonio Pass, east of Los Angeles. Here, the valley is about two miles wide. Opening gradually to the southeast, it is about 40 miles wide at the Mexican border, and about 80 miles wide at the Gulf of Mexico. Its length from San Gorgonio Pass to the Gulf of Mexico about 185 miles, and the Gulf is about 1,000 miles in length.

This remarkable feature of the earth is the Salton Trough. A geographer would more likely call it the Salton Valley, while in current terms it is known as the Imperial Valley. The distinction is not precise in this book. Since this guidebook is a geographic description of the low desert, overlain with a historical perspective, combined with a geologic background, the terms will be used interchangeably.

Oriented northwest-southeast, the valley is defined on the north and east by the foothills of the San Bernardino Mountains, the Little San Bernardino Mountains, the Indio Hills and Mecca Hills, and the Orocopia and Chocolate Mountains. It is bounded on the west by the San Jacinto Mountains and the Santa Rosa Mountains. As the valley widens to the southeast, its margins becomes less distinct, being defined by lesser isolated ranges.

The Geology

The Salton Trough is a faulted basin with bordering mountain slopes defined by fault planes of members of the San Andreas fault system. The bordering mountain ranges generally consist of a thin cover of metamorphic rocks of varying ages dating back to Precambrian time, more than 600 million years ago, over a central core of granitic rocks of the late Mesozoic Era, about 135 millions ago.

Three major and many subordinate right lateral faults are in the immediate area. Principal among these, the San Andreas fault zone lies within the Salton Valley proper, in general defining its shape and structure.

While bounded by high mountain ranges of granitic rocks, the Salton Trough contains an immense sedimentary fill of sands and gravels that accumulated during Cenozoic time, or within the past 70 million years. Most of these sediments are only partially consolidated into sandstones and conglomerates.

This fill increases in thickness from north to south. At the foothills of the San Bernardino Mountains, the valley fill is a thin veneer. At Garnet Hill, it is 4,900 feet thick, and at Indio it is 6,800 feet thick. The greatest depth to bedrock is about 20,000 feet at the Mexican border.

The sedimentary beds are somewhat crumpled, eroded and exposed along the margin, making the general structural form of the valley slightly synclinal, or bowl-shaped, with upturned edges of many units exposed in the surrounding hills. As a result of this favorable structure, some of the sedimentary beds represent great potential as aquifers of groundwater. A number of permeable layers of sand and gravel serve as aquifers. Local water basins are compartmentalized by horizontal layers of impermeable sediments and vertical planes of fault gouge.

The steepness of the bounding scarps on both sides of the Salton Trough, plus the thickness of sediments that fill the trough are evidence of as much as two miles of vertical uplift in the recent geologic past. This uplift has resulted in the spectacular scarp of the San Jacinto Mountains near Palm Springs.

The Salton Trough owes its existence to the same tectonic forces that created the Gulf of California. The Salton Trough is being actively deformed even while you read this guidebook. Split down the middle, the western side is moving northwest more than one inch per year. Similarly, the valley floor, particularly the area at the south end of the Salton Sea, has subsided several inches in the past fifty years.

In terms of both socioeconomic and geologic factors, the Salton Valley consists of five distinct units or divisions. From north to south, these units are the Coachella Valley, the Salton Sea, the Imperial Valley and the Colorado River delta. The fifth unit, the Gulf of California, must also be considered since it is the controlling element of the regional structure.

The Coachella Valley

The Coachella Valley occupies the northern portion of the Salton Valley, from San Gorgonio Pass to the north shore of the Salton Sea. It is about 45 miles long, with an average width of 15 miles. Its area is about 220,000 acres, or 690 square miles.

San Gorgonio Pass, at the north end, is defined by high mountains and major vertical faults on each side. The two highest peaks in Southern California look down on the pass as opposing sentinels -- Mount San Gorgonio at 11,502 feet, and San Jacinto Peak at 10,831 feet. Elevations in the pass descend from the summit at 2,500 feet near Beaumont in a gradual slope to the valley floor.

Elevations of the Coachella Valley floor range from 1,000 feet at Desert Hot Springs, 500 feet at Palm Springs and 250 feet at Palm Desert to about 230 feet below sea level at the Salton Sea. About half the area of the Coachella Valley is below sea level.

Economically, the Coachella Valley consists of two units. The dividing line between the two is approximately at the City of Indio, which shares characteristics of both units. The Upper Coachella Valley has an economy based on services that support recreational and tourism industries. Resort communities are strung along State Highway 111 like beads, from Palm Springs to Indian Wells. The Lower Coachella Valley, from Indio to the Salton Sea, is agricultural land due to the availability of abundant irrigation water (Figure 1.4). It is among the most productive and valuable farmlands in the country. Small farm towns, such as Coachella, Thermal and Mecca are located along the railroad line.

The Coachella Valley is an alluvial plain, consisting mainly of partially consolidated, highly permeable sands and gravels which grade from bouldery gravels near the mountains to fine sand and silt in the central and lower reaches of the valley. These materials are erosional debris from the surrounding mountains brought to the floor during the tens of thousands of wet, cool years of the Pleistocene, or the glacial years. Flowing streams are rare, consisting mainly of creeks that drain the San Bernardino Mountains, and by minor streams draining the eastern slopes of the San Jacinto Mountains. All eventually reach the dry Whitewater River channel.

From Palm Springs past Thousand Palms to Indio, the central valley floor is largely covered with superficial drift sand and occasional patches of dune sand.

The Coachella Valley is laced with branches of the San Andreas fault system, many with distinctive surface expression of the fault traces.

The Imperial Valley

A flat, featureless playa floor, the Imperial Valley is almost entirely below sea level. To the west are the low-lying San Felipe Hills, the Superstition Mountains and other small groups of outlier mountains of the Peninsular Ranges. These are gently elevated and underlain predominantly by deformed recent sediments.

The east margin of the valley is bordered by the Chocolate Mountains and the Cargo Muchacho Mountains, both of which are of sharp relief and northwest alignment. They consist of Precambrian metamorphic and granitic rocks.

The Imperial Valley has many active faults and considerable earthquake activity. However, most of the fault zones in the Imperial Valley are hidden from direct view, being covered by the sedimentary fill. The San Andreas fault zone is exposed at the northeast, near the Salton Sea shore line. That faults are hidden does not deny they exist . . . witness the violent 1940 earthquake near the town of Imperial, and the many offsets of orchards, canals, roads and other linear features.

The Imperial Valley has a veneer of highly fertile lakebed sediments. Abundant water and sunshine combined with a 365-day growing season make the Imperial Valley a prime agricultural asset of California.

The Mexicali Valley, across the border, is a part of the Imperial Valley. It is a flat semi-desert area that is devoted to agriculture irrigated by Colorado River water. It is an active valley, with the Cerro Prieto fault and the southern extension of the Imperial fault, both the source of frequent earthquakes. The valley fill is a series of sandstones, siltstones and clays derived from Colorado River mud. Depth to basement at Cerro Prieto has been measured to be about 15,000 feet.

Recent volcanic eruptions, considerable geothermal resources and frequent earthquakes in the Imperial Valley are convincing evidence of current tectonic activity in the Salton Basin.

Topography and Climate

The Salton Valley is a broad, flat alluviated valley about 6,000 square miles in area. Except for its rise into San Gorgonio Pass, the entire valley lies below the 500-foot elevation contour. More than 3,000 square miles of the valley is below sea level, from the City of Indio to below the Mexican border. The lowest elevation is minus 273 feet at the deepest point in the Salton Sea.

It is a basin of interior drainage. All streams are normally dry channels. Infrequent storm runoff drains to the Salton Sea which occupies the central and lowest portion of the basin. The principal streambed is the Whitewater River channel extending from San Gorgonio Pass to the Salton Sea. To the southeast, Salt Creek drains the Orocopia

Mountains and Chocolate Mountains. On the west side of the valley, the headwaters of San Felipe Creek reach 50 miles into its watershed area. Drainage from the south is via the New River and the Alamo River from the Mexicali Valley into the Imperial Valley. The term "Salton Sink" is used to describe this central drainage system.

Typical of desert climates, annual precipitation within the valley is highly variable, but averages long term three to five inches per year. During summer months, temperatures routinely exceed 100°F. Sheltered in the lee of the coastal mountains, the valley's low rainfall, high temperatures, abundant sunshine and strong, drying winds make it one of the hottest and driest climates in the world.

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