Geologic Faulting in Southern California

The Process, Its Effects, and Its Consequences

By JOHN P. BUWALDA

IN regions like southern California where the population occasionally experiences vigorous earthquakes, geological faults are mentioned from time to time in conversation, lectures, and newspaper articles. Since the faults themselves are usually covered with soil or sliderock waste from the slopes above them, they are seldom seen by the general public or even by non-geological but more discriminating observers or engineers. Nevertheless, they are structural features of profound interest and importance not merely to geologists but to all the inhabitants of the regions traversed by them, for they affect the lives of the people in a multitude of ways not immediately suspected.

What are these faults? They are great fractures or breaks extending from the surface down into or through the crust of the earth. The crustal block on one side of the fault has moved horizontally or vertically with reference to the block on the other side. See Fig. 1. Some of these fractures are vertical, others are inclined, and a few are horizontal. In the last type the block or slab of rock above the fault has sometimes moved forward horizontally for distances of miles or even tens of miles over the country ahead of it. Faults range in length from a few yards to hundreds of miles, but the ones in which we are mainly interested in this discussion—the so-called major faults which have blocked out our mountains and valleys— are usually at least some tens of miles in length. The crustal slices between faults are commonly some miles or tens of miles in width. Minor faults usually cut the crustal blocks in various directions, so that there are many more small fractures than major faults. With the use of earthquake data (seismograms) it is found in southern California that the faults on which earthquakes originate extend to depths of at least 12 or 15 miles.

The shift of one side of the fault with reference to the other, vertically or horizontally or obliquely in direction, varies from a few inches or feet on myriads of minor faults to thousands of feet and even a few tens of miles on the more important major ones.

Faulting is of course only one of several processes which bring about the deformation involved in mountain making. In more recent geologic time the western margins of North and South America have been subjected to this process, apparently mainly by the application of east-west compressional forces in the crust, producing the Rocky Mountain and Andean systems. In earlier times the eastern margin of North America was somewhat similarly crumpled to form the Appalachians. At such times, the flexible rocks (sandstones, shales, conglomerates, and limestones) that happen to comprise the crust of the earth in the area of deformation yield to the horizontal forces by bending and form great mountain arches and valley troughs. This process is termed folding. The rocks in the lower part of the crust, at depths of many miles, yield to the horizontal forces by plastic flow, and the crust thickens by bulging both downward into the subcrust and upward, thereby giving the overlying folded part of the crust still greater elevation. Faulting, the third mode of yielding of the crust to the forces applied to it, is common in those areas in which flexible rocks are thin or wanting at the surface and where brittle formations like granite form the upper part of the crust. Naturally the faults developed in the brittle underlying granite frequently cut through overlying flexible sedimentary rocks.

Southern California, from the San Bernardino region to Santa Monica, and from the mountains to the sea, is traversed by a considerable number of major faults. Except that these fractures are somewhat more numerous and are rather active, this territory is not greatly different from others parts of California or from most of the area of the Rocky Mountain states. As a matter of fact, important and active faults occur across the entire width of the continent, as destructive earthquakes in the Mississippi Valley and on the eastern seaboard have indicated several times. Nor should the reader conclude that faulting is the only form of mountain making which is occurring in southern California. Indeed, folding is creating such ranges as the Santa Monica and Santa Susanna Mountains, while downwarping is largely responsible for the Santa Clara and San Fernando Valleys and the Los Angeles Basin.

THE FAULT MOSAIC

The major faults of southern California fall into two sets, not merely on the basis of their trends, but also because of the directions of their movements. See Fig. 1. One set trends roughly northwest-southeast and along these faults the southwest side invariably moves horizontally and northwestward with reference to the northeast side. This direction of movement is demonstrated by fault slips of 15 to 35 feet within historic times, by offset stream channels crossing the faults, by the pattern of subsidiary faults and folds along the margins of the fault blocks, and by the directions of first motion in hundreds of minor earthquakes, as determined by Gutenberg, which indicate the directions of the strains that were relieved by these small shocks.

Well known faults in this set, from northeast to southwest, are the Mission Creek, the San Andreas lying along the southwest base of the San Bernardino Mountains, the Elsinore, the Inglewood, and probably one or two faults off the coast. Our strongest earthquakes have originated on these faults.

The second set comprises roughly east-west faults. They dip or slope toward the north, usually at angles of 45 to 80 degrees measured from the horizontal, and the movement on them is not horizontal but one in which the upper block moves up the fault surface. Thus, they tend to shorten a line drawn on the country at right angles to the length of the faults, and hence are regarded as compression fractures. Like the northwest-

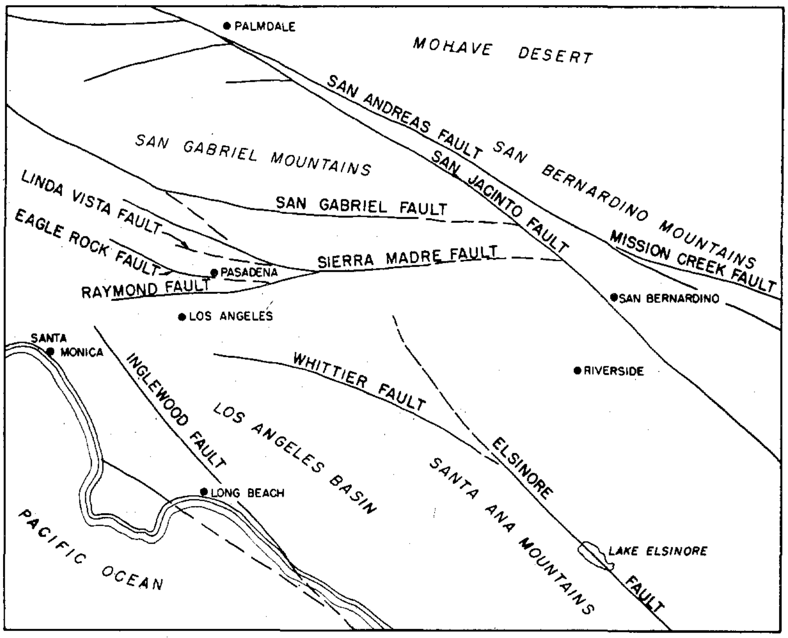


Fig. 1 Sketch fault map of a part of southern California; the northwest-southeast horizontally-slipping faults, and the east-west vertically-slipping faults.

southeast faults they also are active. This is indicated by earthquakes originating on them and by the fact that landscape surfaces situated above them have actually been offset vertically along their trace in recent geologic time. Faults of this category include the San Gabriel within the San Gabriel Mountains, the Sierra Madre along the south base of the same range, the Eagle Rock fault along the south side of the Verdugo Mountains and San Rafael Hills, the Raymond fault forming the escarpment between Pasadena and South Pasadena and south of the Huntington Library, and the Whittier fault following the south base of the Puente Hills. In each case, the north side of the fault has risen with reference to the south side which has been depressed, tilting the block to the north. As the blocks have been lifted progressively higher going north the series forms a gigantic stairway as one proceeds from the northern part of the Los Angeles basin through Pasadena to the crest of the San Gabriel Range. See Fig. 2.

NATURE OF THE FAULTING PROCESS

The displacements on the individual faults range from hundreds to many thousands of feet. But these displacements do not occur in single slips; on each fault the total offset was accomplished by thousands of very small slips, many of them only fractions of an inch. Occurring also is a much smaller number of large slips. Apparently the less frequent larger slips account for the major part of the offset, although even the more important slips seldom involve more than a fraction of the length of the fault.

We infer from the facts given above and from the evidence of the proven drift of triangulation monuments in the Coast Ranges of California, as determined by repeated precise surveys by the U. S. Coast and Geodetic Survey, that at the time of a major slip the entire block on one side of the fault does not suddenly move ahead several or some tens of feet with reference to the block on the other side of the fracture. Apparently, the main portion of a block, usually miles wide and tens of miles long, slowly drifts or is carried along at a more or less constant rate on the more mobile basaltic second shell of the earth for the entire interval between fault slips. But because of frictional resistance to fault slip the adjoining margins of the blocks are strained out of shape, and when slip occurs these margins merely resume their original form by sudden elastic rebound. Therefore only a small marginal fraction of each block on the two sides of the fault moves at the time of the slip. See Fig. 3.

EFFECTS OF THE FAULT SLIPS

The immediate effect of the slip is an earthquake. The energy stored up as elastic strain in the margins of the blocks on the two sides of the fault since the last slip is suddenly released and radiates outward in the form of elastic waves; these constitute the earthquake. About 75 shocks strong enough to be recorded at three or more of the eight stations in the California Institute seismological net (many of them are not intense enough to be felt) originate every month from epicenters within about 200 miles of Pasadena. Some of these arise from minor slips on parts of major faults; the remainder are caused by small dislocations on minor fractures within the blocks. Earthquakes strong enough to be damaging or destructive over a small fraction of the area of southern California occur on the average about once a decade or perhaps somewhat oftener. Major earthquakes that shook violently a large part of southern California occurred in 1769, 1812, and 1857. The history of seismic countries indicates that the areas in which light shocks occur most frequently are in general also those in which damaging quakes can be expected from time to time. Seismic studies indicate that the minor slips on faults only relieve a small fraction of the accumulating strain.

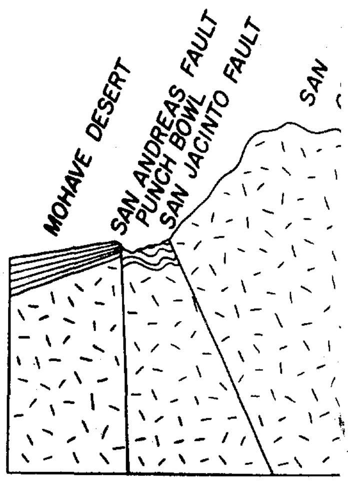


Fig. 2 North - south sketch cross-section through Pasadena showing stair-like fault block structure from the Los Angeles Basin through the San Gabriel Range. Also the water basins formed by tilting of the granitic fault blocks and accumulation of stratified sand and gravels in the resulting depressions.

Fortunately, we are not as helpless against earthquakes as are populations elsewhere in relation to other violent types of natural phenomena. We can now construct buildings at very little added cost that will withstand without damage the kinds of earthquakes reasonably to be expected in California.

A second effect of the faulting is that this region has been broken up into blocks, as above indicated, which have undergone quite different geological histories in recent time. They have acted more or less independently of each other as regards uplift or depression, and the degree of internal deformation in each has differed from that of the others, as has also the nature of that deformation, whether by faulting, or folding, or a combination of the two. The process is still continuing, but is apparently somewhat more active in some areas than in others.

CONSEQUENCES OF THE FAULTING

The consequences of the dislocations on the faults, particularly the vertical slips, have been profound for southern California and have affected nearly every human activity in this region in greater or less degree. It is no exaggeration to say that the region between San Bernardino and Santa Monica and between the mountains and the sea owes most of the unique advantages—topographic, climatic, economic, and indirectly cultural—which have brought a dense population and a vigorous civilization to it, directly or indirectly to vertical movement on the faults. The displacement on the east-west faults has been almost entirely vertical, but the dislocation along some sections of the northwest-southeast faults has also had a large vertical component.

TOPOGRAPHIC CONSEQUENCES

The first topographic result of the faulting is that, in contrast with the boundless flat prairies and plains of the Middle West and the tracts of high rugged mountains forming much of the Rockies, most of southern California consists of low-lying fertile valleys and intervening hill or mountain ranges. Among these valleys are the San Bernardino, San Jacinto, Elsinore, San Gabriel, and other small depressions. Examples of up-faulted mountain blocks are the San Bernardino, San Gabriel, and Santa Ana Mountains, the Puente Hills and the Verdugo Mountains (of which the San Rafael Hills west of Pasadena are a part). The Los Angeles Basin, the Santa Monica and Santa Susanna Mountains, and the San Fernando and Santa Clara valleys are due in part to faulting and in part to warping.

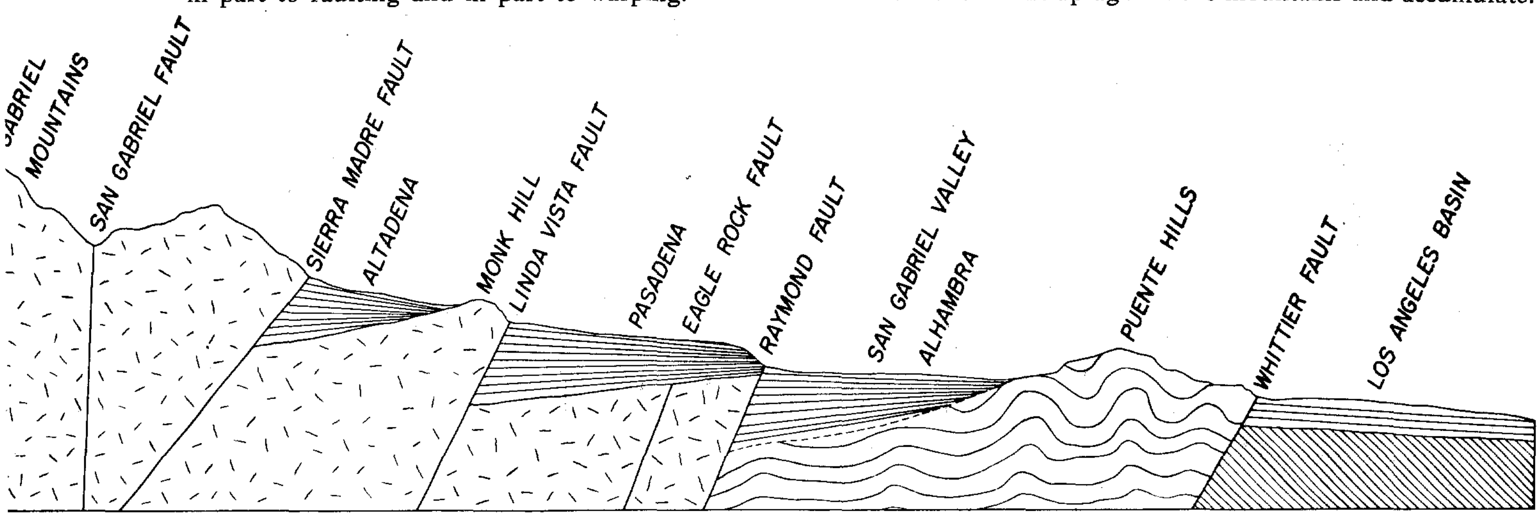
A second topographic result of faulting is that the Los Angeles-San Bernardino region is hemmed in by high mountains on its landward side and forms a protected coastal strip between these mountains and the sea. It is in fact directly connected with the interior country through only four gateways or passes: Tejon Pass (to the San Joaquin Valley), Soledad Pass (to Palmdale and the northern Mojave Desert), Cajon Pass (to the southern Mojave Desert), and San Gorgonio Pass (to Palm Springs and the Imperial Valley). Through these passes flows virtually all the rail, highway, and air transportation. These passes themselves are largely fault features—great fracture zones in the encircling ring of mountains.

CLIMATIC CONSEQUENCES

The fault block mountains with the aid of the folded ranges to the west shelter the Los Angeles region from the extremes of temperature which are more characteristic of the interior and help to give it its vaunted southern California climate. Santa Barbara and San Diego are likewise protected and also enjoy a largely marine climate.

Much of southern California is semi-arid, but the Los Angeles region would receive considerably less rainfall if faulting had not elevated parts of the area. If the lower portion of the territory were all part of a low flat coastal plain, it would probably be nearly as arid as parts of Baja California. The encircling ranges force the northeastward-flowing rain-laden storm air to rise, chill, and drop a large part of its moisture as rain or snow, making available much water to the southland which would otherwise be carried inland to the desert region. This may appear at first sight an injustice levied by Nature in favor of the coastal territory, but climatically it was probably a fortunate happenstance, for the increase or concentration of water in the coastal belt increased its habitability enormously, while the extra water abstracted from the clouds by the mountains would, if allowed to pass, have been spread over such a wide desert area that it would have ameliorated its aridity only slightly.

One unfortunate effect of the encircling mountains relates to the smog. In a plains country slight movement of the atmosphere in any direction will move contaminated air away from a densely settled area. In our region air flowing southward or westward will readily carry smog out to sea, but the movement of seaward-flowing air is somewhat impeded by the mountains. On the other hand, the contaminated air from the cities, when relatively quiet or moving only gently inland, tends to bank up against the mountains and accumulate.



ALLUVIATION OF THE DEPRESSED FAULT BLOCKS

The high-grade high-velocity streams on the uplifted fault blocks cut vigorously and easily carry down their canyons vast quantities of both coarse and fine materials —gravel, sand, and clay. When they cross subsiding fault blocks or the sinking side of tilting fault blocks their grades and velocities are slackened, their capacities to transport erosional waste rapidly decrease, and they deposit a large part or nearly all their load before they reach the ocean. The flat or gently sloping floors of our southern California valleys were built up in this way. Beneath most of these smooth valley surfaces the gravel, sand, and clay are hundreds of feet thick, accumulated in recent geologic time while the blocks were subsiding.

Much of this alluvial fill was deposited, and is now being laid down, in the form of great alluvial fans or cones, the apices of which are at the mouths of the canyons in the mountains from which the material issues. In travelling, for instance, from Pasadena to San Bernardino, the highway rises and falls gently but continuously in passing over fan after fan, lying side by side, each one built outward from the mouth of one of the canyons in the south face of the San Gabriel Mountains.

On these cones or fans, the detrital material is effectively classified, because streams with decreasing velocity and hence diminishing capacity to carry rock waste drop the coarse particles first. Therefore, boulders and gravel are deposited on the upper slopes of the fans, sand on the middle, and clay on the lower slopes. As a consequence the soils near the mountains are commonly rocky; farther down the slopes they are sandy; approaching the coast they are clayey or adobe. The fertile loam areas—mixtures of sand and clay where most of the truck gardening is done, are naturally not near the mountains but well down on the slopes of the fans. The higher parts of the cones can be and are utilized for citrus groves and other crops tolerating loose open soils.

WATER BASINS

A surprising fact, not realized until quite recently, is that on the average very little or none of the rain that falls on an area passes downward through the soil to replenish the groundwater unless the precipitation exceeds about 15 to 20 inches a year, varying somewhat in different localities. This amount of water, or less, arriving in successive storms during perhaps five winter months, is lost, partly by immediate runoff, partly by immediate evaporation, and the remainder by later evaporation from the damp soil and by transpiration by grass, shrubs, and trees. With such scanty winter rainfall the upper few feet of soil become moist, but that moisture generally moves upward, by capillarity to supply evaporation at the surface during the next dry season, rather than downward to join the water table—the zone of water-saturated alluvium usually located some tens of feet below the surface.

The significance of this fact is that, with southern California so largely dependent on pumped water for its huge and rich agricultural industry, it is most fortunate that high mountains, causing moderately heavy precipitation on the basinward slopes, shed annually large quantities of water to the lowlands. The cubic miles of gravel and sand, porous and pervious, which have accumulated on the subsiding fault blocks serve as excellent underground reservoirs, but in the long run only as much water can be pumped from each basin each year on the average as is contributed to it. The bulk of the water added annually to replace that withdrawn during the previous irrigation season comes from the mountains. It finds its way underground most readily on the upper parts of the fans, where the stream issuing from the bedrock canyon flows usually for some miles over the coarse gravel forming the apical part of the cone. Were it not for the high upfaulted mountain blocks around us and in our midst, the underground water available for agricultural, domestic, and industrial use would be very limited. With a much smaller safe yield of underground water this region would not have been able to develop nearly so rapidly, its wealth would have increased much more slowly, and the cultural development permitted by wealth and leisure would consequently have been greatly retarded.

COASTLINE AND SEA BOTTOM

The present position of the shoreline of the Pacific in southern California, as elsewhere, is determined largely by the present general elevation of the land; for instance, a general uplift of a few hundred feet would drive the strand many miles westward. But the pattern of the coastline—its promontories, points, bays, and other indentations — is largely the result of recent faulting and folding, modified in an important way by wave erosion. In general, the promontories result from anticlinal uplift or rise of fault blocks; the embayments result from depression along the coast or erosion of the less resistant formations which commonly lie in the depressed parts of the shore.

Even though new sediments are supplied plentifully to the waves and currents along the California shore and are used to smooth out the irregularities of the seabottom by filling in the depressions, the sea floor off our coast has a configuration resulting largely from recent deformation by faulting and folding. Great closed depressions occur in it, as yet unfilled by recent waste washed from the land. Long ridges rise above the general level. Islands like San Clemente and probably also Santa Catalina are merely the emerged edges of uplifted fault blocks.

In summary, then, it can be stated that while faulting causes our earthquakes, it has likewise given to southern California the fortunate and attractive characteristics which the land now possesses.

Fig. 3 Slickened and grooved fault surface, exposed by removal of the rock on the near side of the fault. Movement was somewhat oblique on a dominantly horizontally slipping fault.