3. PHYSIOGRAPHIC FEATURES OF FAULTING IN SOUTHERN CALIFORNIA *

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The abundance and variety of faults in southern California provide good opportunity for study of landforms created directly by faulting or indirectly by other processes acting upon faulted materials. High-angle gravity faults, high- and low-angle thrusts, and faults with large strike-slip displacement are present (see Chapter IV). Furthermore, all degrees and dates of activity are represented.

Landforms created by faulting can be classed as primary and seconary, or as original and subsequent (Lahee, 1952, p. 248). Primary features are those formed by actual fault displacement. They are nearly always modified by erosion, but should be classed as primary until completely effaced. Secondary or fault-line features are those formed solely by other processes acting upon faulted materials. Further subdivision into initial and modified primary forms and into erosional and depositional secondary forms would be possible, but it is not urged.

PRIMARY FAULT FEATURES

Fault Scarps. Southern California contains literally hundreds of fault scarps, a few feet to many thousands of feet high. Some of these scarps and the blocks, horsts, and grabens bounded by them, are the largest topographic features of faulting in the region. The Sierra Nevada scarp towers more than 10,500 feet above the floor of Owens Valley, the face of San Jacinto Peak behind Palm Springs is nearly as high, and the little-mentioned San Gabriel scarp near Cucamonga rises abruptly 6,500 feet above the alluvial fans at its base. The steepness of the scarps depends primarily upon their age and upon the nature and structure of the rocks composing them. The west face of the Black Mountains, sloping a good 35° toward the floor of Death Valley, is exceptionally steep for a major fault scarp in this region. A number of scarps steepen near the base because of rejuvenation by later uplifts, but some scarps along thrusts are steeper near the top owing to superposition of hard rocks on softer materials, for example the scarp of the San Cayetano thrust in Ventura County. Late Tertiary and Pleistocene thrusts are abundant in southern California, and many of those of high angle are marked by primary thrust scarps (Kerr and Schenck, 1925, p. 480; Cotton, 1950, p. 728).

In general, the height of a scarp indicates the minimum vertical displacement, but along a fault of large strike-slip displacement crossing rugged topography, this may not be true. It is possible that the south face of the San Bernardino Mountains was created by an oblique slicing apart of the San Gabriel-San Bernardino uplift along the San Andreas fault (Noble, 1932, p. 356). Smaller scarps formed by lateral displacement of hillocks and ridges can be seen along the Garlock and San Andreas faults.

Triangular Facets. Triangular facets, truncated spurs, and related forms are remnants of a fault scarp dissected by transverse streams and as such hardly warrant the extended attention accorded them in the literature. Fine examples of large triangular facets are seen along the west base of the Panamint Range (Hopper, 1947, p. 399) and on the west face of the Black Mountains east of Death Valley. The Black Mountain facets should not be confused with stripped remnants of a folded thrust, locally known as "turtle-backs," also seen here (Curry, 1938b; see also Curry, Contribution 7, Chapter IV).

Fault Scarplets. Owing to the recency of faulting, low scarps in alluvium are common and widespread. Piedmont scarplets break alluvial slopes at the foot of many mountain ranges, especially in the Basin Range region north of the Garlock fault, but they are not limited to this setting and in the Mojave Desert are found well out on the valley or basin floors. Most scarplets are a few feet to a few tens of feet high, but the Raymond scarp displaces the Pasadena alluvial apron by fully 100 feet near the Huntington Hotel. The height of a piedmont scarplet reflects in part its susceptibility to erosion by streams flowing from the mountains. Near Cucamonga, piedmont scarps 250 feet high in interstream areas record the sum of repeated fault movements, while lower scarps nearer the streams measure only the latest displacement (Eckis, 1928, pp. 229-230). An irregular trench along the base of many recent piedmont scarplets is probably produced by settling of loose debris along the fault trace.

Most piedmont scarplets face outward from the mountains, but some are back-facing, a good example being along the Garlock fault near Garlock station (Dibblee, 1952, p. 39). This particular back-facing scarp appears to have been formed by lateral offset of a higher part of the fan, but other back-facing scarps are produced by relative upward movement of the valley block. Shallow grabens are created in alluvial aprons by opposed piedmont scarplets, as beautifully demonstrated along the west base of the Panamint Range at the mouth of Wildrose Canyon (Noble, 1927, p. 39; Maxson, 1950, p. 104). A small lake south of Lone Pine in Owens Valley occupies a similar graben formed in part at the time of the 1872 earthquake (Hobbs, 1910, pp. 369-370, 374). Small grabens have also been created in fans by the extension associated with shearing along a strike-slip fault (Dibblee, 1952, p. 39).

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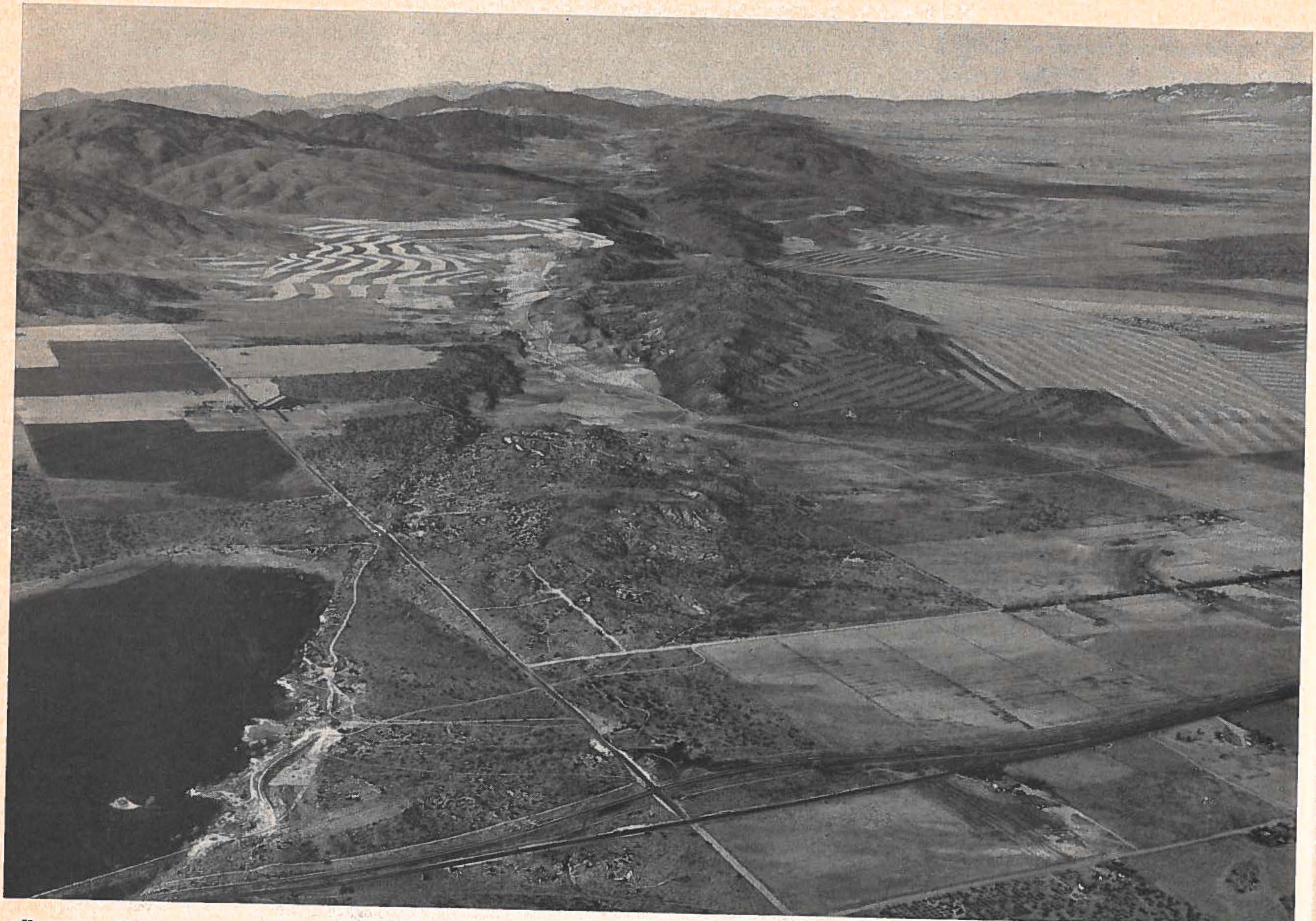

FIGURE 1. View west-northwest along San Andreas fault zone near Palmdale, California. Trace of most active fault lies along right side of Palmdale reservoir. Older fault trace, 0.5 mile to the right, bounds block of Pliocene Anaverde formation which underlies low hills of central foreground. Bend in drainage lines in middle and far distance suggests about 2.5 miles of right lateral displacement on San Andreas fault. Tehachapi Mountains on right skyline contain Garlock fault, which is converging upon the San Andreas fault from the northeast. *Photo by Fairchild Aerial Surveys, Los Angeles.*

A much eroded but still primary product of piedmont faulting is the midfan mesa, an island-like remnant of an old upfaulted fan (Eckis, 1928, pp. 243-246). Although commonly a product of faulting, it need not be exclusively of this origin. A closely allied form is the piedmont bench, consisting of an upfaulted fan or pediment surface at the base of the mountains bounded on its outer side by a piedmont scarplet. Piedmont benches are displayed along the west base of the Panamint Range and along the south sides of the San Gabriel and San Bernardino Ranges.

Fault Rifts. A major and distinctive feature of faulting in southern California is the great rift of the San Andreas (Lawson, et al., 1908, pp. 25-52; Noble, 1927, pp. 26-27; Davis, 1927). It comprises a linear belt of peculiar topographic features which cuts obliquely across the normal topographic grain of the country and is best appreciated as seen from the air. Much of the rift is a shallow trough as much as 6 miles wide, containing various combinations of smaller fault forms, such as slice ridges, sag ponds, shutterridges, offset streams, and other features described in succeeding paragraphs. In some places it is much narrower, consisting simply of one or two deep fault valleys or fault-line valleys with narrow intervening fault-slice ridges, and elsewhere it is simply a broad pass or saddle across a ridge or major divide. If the San Andreas is as old as some of the geologic evidence suggests (Noble, 1932, p. 362; Hill and Dibblee, 1953, pp. 445-449), many of the features in the rift are the product of erosion (Crowell, 1952, p. 22). However, the distinctive topographic details within the rift are largely fault features (Wallace, 1949, pp. 792-795).

Fault-Slice Ridges. These are narrow linear ridges a few feet to a few hundred feet high representing slices of rock squeezed up within a fault zone (Davis, 1927, p. 70). They are also known as pressure ridges (Wallace, 1949, p. 793), and some of the larger ones are bounded by distinct fault branches. Slice ridges are abundant along the San Andreas and other strike-slip faults, and a few have been formed in association with high-angle thrusts, such as the Raymond fault near Santa Anita Park.

Shutterridges. Shutterridges are formed by vertical, lateral, or oblique displacements on faults traversing a ridge-and-canyon topography. The displaced part of a ridge shuts off the adjacent canyon, hence the term (Buwalda, 1937).

Offset Streams. Offset stream channels are a common companion of shutterridges along strike-slip faults and in places lateral displacements of as much as 1.5 miles are thus recorded (Wallace, 1949, pp. 799-800; Hill and Dibblee, 1953, p. 451). Offsets of this magnitude must have been produced by repeated small shifts, with the stream reestablishing the continuity of its course during the intervening periods. The best examples of offset streams are associated with relatively recent displacements and involve shallow gullies, ravines, or small canyons. In the instance of deeper canyons, a distinction between displacement by faulting and diversion by subsequent erosion and capture is not always easily made. Excellent examples of offset streams are found along the San Andreas fault in Carrizo Plains (Wood and Buwalda, 1931) and along the Garlock fault north of Randsburg (Hill and Dibblee, 1953, p. 451). Offset streams also indicate recent strike-slip movement on some of the faults in the Basin Range country (Curry, 1938b; Noble, 1941, p. 960; Hopper, 1947, p. 399; Maxson, 1950, p. 107).

Closed Depressions. Depressions with closure are a common, and in many instances distinctive, product of recent faulting. If small and containing water, they are known as sag ponds, otherwise they may be termed fault-sags (Lawson, et al., 1908, p. 33). These depressions are created chiefly by differential movement between slices and blocks within a fault zone or by warping and tilting associated with differential displacement along a fault. Closure created through damming of fault trenches, troughs, or valleys by deposition is a secondary feature. Closures can also be created by fault displacements which dam normal drainages, or by relative depression of large blocks between separate faults. The basin of Searles Lake may be an example of the former (D. F. Hewett, personal communication).

Fault Valleys. Faulting creates linear depressions of various sizes and characteristics. The largest fault valleys in southern California are grabens, of which Owens Valley is certainly an outstanding example. Another type is the fault-angle valley occupying the depression between a fault scarp and the backslope of a forelying tilted block (Cotton, 1950, p. 748). Panamint Valley appears to be such a feature. Still other valleys are created by relative uplift on opposite sides of two parallel thrust faults, as demonstrated by the central section of Santa Clara Valley, Ventura County, which is bounded on the north and south respectively by the San Cayetano and Oakridge thrusts. The relatively youthful age of sedimentary rocks composing the Santa Clara Valley block and a considerable alluvial fill indicate that this is primarily a fault valley and not a secondary product of erosion. Smaller, narrower valleys are created within major fault zones by relative depression of narrow slices. These features are particularly difficult to distinguish from subsequent fault-line valleys formed by erosion.

Fault Troughs. In size and character fault troughs resemble narrow fault valleys but differ therefrom in not being limited to a

FIGURE 2. View east-southeast along San Andreas fault zone near Palmdale, California. Trace of most active fault extends along left side of Palmdale reservoir, past small sag pond just beyond highway, along the trough beyond, and eventually into the San Gabriel Mountains where it forms broad notch on skyline ridge. *Photo by Fairchild Aerial Surveys, Los Angeles.*

single drainage system. Troughs can cross divides or ridges and may include several fault valleys. Fault troughs constitute major features within rift zones.

Fault Trenches. Trenches or clefts (Davis, 1927, p. 63) are similar to fault troughs but smaller. They form principally within major fault zones and are usually underlain by a fault slice that has been depressed. The moat along the base of a piedmont scarplet in alluvium is a type of trench, and open cracks in the ground formed by lurching associated with recent earthquakes have also been called fault trenches.

Kernbuts and Kerncols. These forms were originally defined by Lawson (1904, pp. 331-343) as primary features created by displacement on a fault traversing a hill slope in such a manner that a projecting ridge or buttress, the kernbut, and an intervening depression or fosse, the kerncol, are formed. The type locality has since been shown to be one of fault-line forms (Webb, 1936, p. 636), but this does not destroy the validity of Lawson's original concepts, and his terms should be retained for the corresponding primary features (Lahee, 1952, p. 317). The forms related to Cotton's cicatrice (1950, p. 753) are closely similar if not identical in some instances. Fault benches (Lahee, 1952, p. 316) are also created by hillside faulting. The outer edge of a bench may be a kernbut but the kerncol is lacking.

Fault Gaps. A fault gap is formed by a displacement that laterally offsets a ridge so that the two parts are no longer continuous (Lahee, 1952, p. 336). Small gaps of this nature are fairly common along the larger strike-slip faults with recent displacement. Some of the major passes leading into the southern California coastal region may be at least partly of this nature.

Fault Saddles. These are notches, cols, or saddles in ridges created by actual displacement of the ridge crest by faulting. They are much less common than fault-line saddles and might well be treated as a particular type of kerncol.

Ground Features. Various types of open cracks, furrows, and small ridges are created in the ground by lurching and other movements associated with earthquakes. These features are all geologically short-lived, and many of them do not appear to represent the actual displacement on the fault plane (Buwalda and St. Amand, 1952, pp. 4-5). One of the more striking of these forms is a small ridge 1 to 2 feet high, known as a mole track, formed by humping up and cracking of the ground.

Knick Points. Some streams crossing active faults display a sudden steepening of gradient. Such knick points may have migrated upstream from the fault, but if their relief is the product of actual fault displacement they should be treated as primary features. It would of course also be possible to have a fault-line knick point produced by differential erosion of hard and soft rock brought into juxtaposition by faulting. Streams within the Panamint Range display steepened profiles attributed to movement on the boundary fault (Maxson, 1950, pp. 108-112).

Folds. The principal surface expression of buried faults may be folds of one type or another. The belt of en echelon folds constituting the Newport-Inglewood uplift has been attributed to forces associated with strike-slip displacement on the Inglewood fault (Reed and Hollister, 1936, pp. 125-133). L. F. Noble (personal communication) is also inclined to relate small en echelon folds on the floor of Death Valley to lateral fault displacements.

SECONDARY FAULT FEATURES

Fault-Line Scarps. The principal secondary fault feature is the fault-line scarp, a form created wholly by erosion acting upon rock units of different resistance juxtaposed by faulting. The relief between top and bottom of a fault-line scarp is due solely to erosion. It may be the product of first-cycle erosion, without an intervening episode of planation, or of second-cycle erosion following planation. The fault-line nature of scarps facing in opposite direction to the original fault scarp is more easily established than of scarps facing in the same direction (Blackwelder, 1928). Broad geomorphological and geological relations are of help in this connection (Cotton, 1950, pp. 719-721), and on such a basis a number of fault-line scarps can probably be shown to exist within the Transverse Ranges (Putnam, 1942, p. 751).

Composite scarps on which the relief is due partly to fault displacement and partly to erosion may be even more common. In places, the south face of the San Bernardino Mountains near Beaumont and Banning is a composite scarp.

Fault-Line Valleys. Fault-line valleys are developed by erosion in the soft crushed material along fault zones and are abundant in this region. Many fault-line valleys are undoubtedly formed by headward erosion and are subsequent in the purest sense, but there is no reason why they must all be of this origin as inferred by Cotton (1952, p. 182). Probably, a number of fault-line valleys in southern California originated as consequent stream courses along fault depressions which have since been transformed to fault-line valleys by erosion. Many, of course, are composite, the present valleys being created partly by faulting and partly by erosion. The east and west forks of San Gabriel River look like good examples of subsequent fault-line valleys

FIGURE 3. View south across active trace of San Andreas fault in Cajon Pass. Note sag pond at right, offset stream in center showing right-lateral displacement, and change of vegetation at fault trace crossing Cajon Wash, indicating a difference in ground-water conditions on opposite sides of the fault. *Air photo by J. S. Shelton and R. C. Frampton.*

developed by headward erosion. Many valleys along the San Andreas rift, such as Lone Pine Canyon and Swartout Valley, are possibly of fault-line origin, although more study is needed to establish this point and to determine whether they are consequent or subsequent. Mill and Mission Creeks in the San Bernardino Range come in the same category, and at least part of the Kern River Canyon in the southern Sierra Nevada has been shown to be a fault-line feature (Webb, 1936, p. 636).

Evidences of stream capture can be useful in establishing the subsequent nature of some fault-line valleys, and care must be exercised in deeply dissected areas to avoid mistaking diversion of streams by capture for displacement by faulting.

Fault-Line Gaps. Fault-line gaps resemble fault gaps but are formed solely by erosion of resistant ridge-making units laterally offset by earlier faulting. Small fault-line gaps are relatively numerous in parts of the Transverse Ranges displaying fault-line features. Many of the larger gaps in southern California created by faulting are possibly composite forms in which the initial relief of the original fault gap has been increased by deepening through erosion, as demonstrated by the course of Cajon Creek along the San Andreas fault between the San Gabriel and San Bernardino Mountains (Noble, 1927, p. 33).

Fault-Line Saddles. Fault-line saddles are created by more rapid erosion of ridge crests where crossed by faults. They are one of the most sensitive indicators of ancient fault lines that lack almost all other forms of topographic expression. Good examples of fault-line saddles can be seen along the San Gabriel fault within the San Gabriel Range.

Drainage Rejuvenation. Dissection resulting from fault displacement is a secondary product which cannot always be satisfactorily interpreted because of its possible polygenetic origin. However, careful work can show in some instances that interruptions of stream cycles expressed in the form of dissected terraces and entrenched open-valley forms are due to faulting. Terraces in the San Gabriel Mountains are graded to piedmont benches along the south face of the range which have been uplifted by faulting (Muehlberger, 1950, p. 14).

Depositional Forms. Deposition creates a host of secondary topographic features along fault scarps and to a lesser extent along fault-line scarps. Alluvial cones, fans, and aprons along the bases of fault scarps are common in southern California and attain spectacular development in the desert country, particularly in Owens, Panamint, and Death Valleys.

Various products of mass movements are locally associated with fault scarps, the most distinctive being landslides and rock falls. An exceptionally fine example of a rock fall derived from a fault scarp can be seen at Blackhawk Canyon on the north side of the San Bernardino Mountains (Woodford and Harriss, 1928, pp. 287-289).

Topographic Fault-Line Outliers. Low-angle thrust faults have been described from a considerable area in the eastern Mojave Desert and the southeastern Basin Range country (Hewett, 1928; Noble, 1941; Kupfer, 1953). Erosion of these low-angle thrust masses has left a number of isolated hillocks and ridges capped by remnants of the thrust plates. Good examples are found in the Shadow Mountains, Silurian Hills, Ibex Hills, and the Jubilee Pass area. These are strictly secondary fault-line forms created by erosion which owe their special character to the more resistant capping of the thrust plate.

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