DEPARTMENT OF THE INTERIOR
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TO ACCOMPANY MAP I-1483

MAP SHOWING RECENTLY ACTIVE BREAKS ALONG THE SAN ANDREAS FAULT AND ASSOCIATED FAULTS BETWEEN SALTON SEA AND WHITEWATER RIVER-MISSION CREEK, CALIFORNIA

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PURPOSE OF THE MAP

The character and location of surface traces of recently active faults are important to scientists and engineers who study faulting and earthquakes and to people concerned with land use and development on or near the faults. This strip map is one of a series of maps along the San Andreas and related fault zones in California (fig. 1) and shows surface traces of faults that appear to have been recently active between the Salton Sea and Whitewater River-Mission Creek (fig. 2). The mapped traces mark known or suspected recent faulting due to sudden rupture or creep within and near the San Andreas fault zone. The lines on the map that represent fault traces are primarily guides for locating these traces on the ground; they are not located with the precision needed for certain engineering projects or land uses. As used with this map, "recently" means during late Quaternary time, roughly the past 100,000 years.

DISPLACEMENT ALONG THE SAN ANDREAS FAULT SYSTEM

The San Andreas fault system of major subparallel fractures or breaks in the Earth's crust extends at least from the Gulf of California in Mexico northwestward through southern and western California for more than 1,000 km. Throughout its history, the sense of movement on the major faults of the San Andreas system has been dominantly horizontal and right lateral; total offset is measured in tens to hundreds of kilometers (see Crowell, 1962). The portion of the system shown by this map carries the name *San Andreas fault zone* and is the easternmost of the prominent members of the San Andreas fault system on land in southern California. Westward, this group includes the San Jacinto, Agua Caliente, and Elsinore fault zones in the Peninsular Ranges (fig. 2).

Although the portion of the San Andreas fault zone shown on this map has locally experienced historic displacement, and also shows clear evidence of Holocene (past 10,000 years) displacement, the San Jacinto fault zone may now be the main location of displacement and source of earthquakes for the southern San Andreas fault system. The Elsinore and other subparallel faults west of the San Jacinto fault zone have had few large historic earthquakes, have no record of historic displacement, and in only a few places display clear geologic evidence of recent displacement (Clark, 1982). Of the members of the fault system south of the Transverse Ranges, the San Jacinto has the greatest number of historic earthquakes and displays the most prominent, best preserved, and, so far, best studied geologic record of Holocene displacement. The adjacent portion of the San Andreas fault zone has experienced no large historic earthquakes except for the 1948 Desert Hot Springs earthquake of magnitude 6.5, which may not have been caused by slip on the San Andreas. The 1948 earthquake was associated with no known ground rupture, and the best estimate of its epicenter is 5 km northeast of the San Andreas fault zone (Richter and others, 1958).

The portion of the San Andreas fault on this map did experience creep during distant earthquakes in 1968 and 1979 (see section "Significance of Locating Recent Fault Traces"), and it shows abundant and clear evidence of Holocene slip. Recent studies in Indio Hills by Keller and others (1982) suggest about 700 m of right slip in the past 20,000 to 30,000 years, and a trench study by Sieh (1981) at the southern tip of Indio Hills indicates about 1 m of displacement during the past 480-680 years (perhaps by aseismic creep) that was preceded by major offset, possibly during a large earthquake.

Although possibly subordinate to the San Jacinto fault zone in recurrence of Holocene earthquakes, the San Andreas fault zone between Salton Sea and the San Bernardino Mountains is a major active fault and is capable of producing a large earthquake at any time.

Displacement within the San Andreas fault zone has been distributed along many subparallel and branching faults that differ in age, amount, and direction of slip. This complex zone of movement ranges in width from a few tens of meters to several kilometers or more. In accordance with terminology used elsewhere for the San Andreas (for example, Vedder and Wallace, 1970; Ross, 1969; Brown and Wolfe, 1972), and San Jacinto (Sharp, 1972), this zone or band of parallel and apparently interrelated faults is here called the San Andreas fault zone, and the surface traces of most recent movement are called the San Andreas fault.

For simplicity the two main strands of the San Andreas fault in the northwestern part of this map are called the north and south branches. This follows the terminology of Dibblee (1968), but the names Mission Creek fault (north branch) and Banning fault (south branch) (Allen, 1957) are also widely used.

LOCATION OF FAULT TRACES

The faults shown on this map were located primarily from topographic evidence revealed by both reconnaissance field inspection of all the main traces in 1972, 1973, and 1979 and by study of aerial photographs.[1] Many traces of the normal faults shown northeast of the main fault on strip B near Indio and Mecca Hills are obvious only on aerial photographs or were not checked in the field. Elsewhere many traces were identified only in the field and are too small to be evident on the aerial photographs used.[2]

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[1] This map differs from an earlier U.S. Geological Survey map (Hope, 1969) that was based mainly on photointerpretation.

[2] This investigation used the following photographs: 1:12,000-scale USGS 1966 WRD series along all of the San Andreas fault; 1:30,000-scale USGS 1972 VCWE series for faults east of Mecca Hills; 1:8,000-scale USGS 1975-76 low-sun series for the normal faults in and near Indio and Mecca Hills; 1:18,000-scale Fairchild 1939 flight 6060 of Desert Hot Springs (loaned by Whittier College Department of Geology); and 1:18,000-scale Spence Airplane Photos 1930 flight of the San Andreas fault from Whitewater River to Salton Sea (prints owned by USGS, copies available from University of California, Los Angeles, Department of Geography).

All traces were recorded on aerial photographs and transferred to base maps with a projector. Most fault traces are plotted within 20 to 30 m of their correct position where contour lines of the base map show fault-zone topography. At some places, however, fault traces may be as much as 50 m from their correct position. Geologists, engineers, and others who make specific use of this strip map should independently verify position of the mapped faults and confirm their fault origin.

FIELD RECOGNITION OF RECENT FAULTING

Recently active faults can be recognized in the field by distinctive topography, displaced young deposits and soils, or young deposits in fault-bounded basins. The most common topographic expressions of active faults are scarps, benches, trenches, notches, linear ridges and valleys, hillside valleys, depressions, shutter ridges, and offset channels and ridges (see fig. 3). Displaced young deposits and soils may show either structural and stratigraphic discontinuities or contrasting colors, textures, and vegetation. Deposits that accumulate in basins bounded by active faults include ponded alluvium and those of sag ponds or depressions. All these characteristics of recently active faults develop from repeated displacement accompanied by erosion and deposition along the fault.

Horizontal and vertical displacements along a fault result from successive episodes of slip that range from a few millimeters to several meters during earthquakes, from intervals of slow fault creep between earthquakes, or from a combination of both. Regardless of their specific origin, displacements of the ground surface along the fault traces produce the features marked on the map. Annotations along the fault traces point out examples that are exceptionally clear or well preserved, but such features are generally present to some degree all along the mapped faults. These features may show that fault activity has occurred recently in several ways. Because they are easily destroyed, their very existence indicates recent creation. If they affect young deposits, the features demonstrate displacement younger than the deposits themselves. Deposits that accumulate in fault-bounded basins, of course, must be younger than the displacement that created the basins.

In many places topographic expression offers the most obvious evidence of recent faulting. Vertical components of displacement may produce scarps, benches, changes in slope, and grabens (downdropped blocks). Horizontal components of displacement along faults offset channels and ridges and create shutter ridges, scarps, benches, troughs, hillside valleys, and changes in slope. Displacement may also relatively depress fault blocks to form scarps, depressions, and sag ponds. Slivers between parallel traces may rise, tilt, or slide diagonally to produce grabens, linear ridges, and shutter ridges. Concentration of erosion by fault topography may produce or enlarge trenches, troughs, and notches. The younger the deposits in which fault topography appears, the more recent is the displacement.

Active faults that offset young deposits or soils may also produce visible effects without topographic form. Horizontal displacement can juxtapose contrasting deposits and soils to produce either contrasts in color or texture or distinctive vegetational effects. Active faults may also be visible only in natural or man-made exposures of offset or truncated strata or structures in gullies, roadcuts, or excavations. Faults can dam moving ground water in young deposits to form vegetational boundaries and springs. Faults can collect, hold, or concentrate either ground water or surface runoff to produce alined vegetation.

Deposits that mark active faults occur wherever fault topography traps sediment, as in depressions and sag ponds. Fault deposits are particularly evident where faults cross slopes in bedrock or coarse material. Benches, hillside valleys, and uphill-facing scarps intercept fine material such as sand and silt eroded from upslope and create ponded alluvium and sandy or silty benches that may contrast with surrounding coarser materials.

A thorough evaluation of recent faulting requires investigation of all these features of active faults; the reconnaissance investigation carried out for this map, however, concentrated on fault topography. Investigations that use detailed geologic mapping make extensive use of stratigraphic and structural relations to discover faults in young deposits. For example, detailed geologic maps in the Mecca Hills (Hays, 1957; Sylvester and Smith, 1976) reveal many Quaternary faults (roughly, the past 2 million years) not shown on this map. Other investigators examine trenches, borings, and natural exposures to recognize faulted young deposits and fault-related deposits (see for example, Clark and others, 1972; Sieh, 1978a, 1981; Sharp, 1981; Keller and others, 1982). Such investigations may yield ^{14}C ages and displacement rates. As detailed geologic mapping and special fault studies continue in this part of the San Andreas fault zone, some faults may be added to this map and others may be eliminated.

Not all features noted on this map require recent displacement. Scarps and ridges created by faulting in very resistant rock may persist for a long time. Notches, trenches, or valleys may result solely from relatively rapid erosion of the crushed and broken rocks of an inactive fault zone. Such features may show the location of a fault but do not necessarily indicate recent activity. To unequivocally demonstrate recent faulting, topographic forms must either be present in young deposits, and hence be younger than those deposits, or occur in relatively weak material in which erosion will quickly erase all but very young fault topography. Similarly, vegetation contrasts and springs commonly develop along faults in old deposits, whether or not the faults have been recently active. Recent displacement is indicated only where such features clearly are related to displacement of young deposits.

Most features created by recent faulting are ephemeral; they may be obliterated by erosion, buried by alluvium or other sediment, obscured by vegetation or soil creep, or modified or destroyed by human activity. Fault features persist only where their rate of creation by fault displacement exceeds or equals the rate of processes that either destroy or conceal them, or where faulting is so recent that these processes have not had time to change the features. Hence the degree of preservation of these features of active faults may be a rough measure of the rate of displacement of a particular fault or fault segment.

The hazard posed by active faults is clearly related to displacement rate. The higher that rate, the higher the probability of significant displacement, or earthquakes, at any given time. A proper evaluation of future fault hazard requires detailed examination of past fault behavior at a given site. For a preliminary evaluation, however, it is prudent to assume that areas containing well-preserved or abundant features of recent activity may have a high potential for future displacement and the accompanying earthquakes.

Topographic features along the San Andreas fault zone may have a large range of ages. Some eroded 5- to 20-m-high fault scarps in unconsolidated sediment record multiple displacements and may be tens of thousands of years old. Other 1- to 2-m-high fault scarps cut all but the youngest alluvium in channels; these scarps postdate all but the most recent major floods and are possibly only a few hundred years old. Unfortunately, the meager knowledge of erosion and deposition rates and of the exact ages of young alluvium precludes an accurate estimate of the age of the youngest faulting. Nevertheless, abundant survival of surface fault features and the similarity of many of these features to those on the historically active Coyote Creek fault, 30 km to the southwest in the San Jacinto fault zone (fig. 2) in a similar climate, indicate Holocene movement along much of the San Andreas fault in this area. Most of the fault must be considered capable of movement at any time.

SIGNIFICANCE OF LOCATING RECENT FAULT TRACES

Some scarps and offset channels plainly show that parts of the San Andreas fault system have broken repeatedly along the same strands. Along some traces scarps are higher in older deposits than in younger deposits; this demonstrates earlier episodes of displacement of the older deposits along the same fault trace. Benches or small, younger scarps near the base of eroded scarps 10 to 20 m high suggest that the large scarps were created by many separate small offsets. In similar fashion, along any single linear break a few kilometers long, the amount of horizontal offset of stream channels may vary from a few meters on small young channels to hundreds of meters on large older ones; this varation also indicates repeated episodes of horizontal displacement along the same fault.

This geologic evidence of repeated displacement along the same traces has been clearly confirmed in 1968 and 1979 by creep along faults in the southern part of this map. Creep during both years amounted to a few centimeters of right-lateral offset and occurred along essentially the same scarps, benches, and soil and vegetation contrasts created by earlier fault displacements. The creep in 1968 was triggered by the Borrego Mountain earthquake, 70 km southwest in the San Jacinto fault zone (Allen and others, 1972), and that in 1979 was caused by the Imperial Valley earthquake, 90 km south along the Imperial fault (Sieh, 1982). We do not yet know what portion of the fault topography shown on this map was formed by creep like that of 1968 and 1979 and what portion was formed at the time of local earthquakes.

Other faults of the San Andreas system and nearby fault zones also display evidence of repeated movement along the same narrow strands, some of it associated with historic earthquakes. In 1940, severe structural damage resulted from earthquake shaking that accompanied horizontal movements of as much as 6 m along the previously active Imperial fault, a southern strand of the San Andreas fault system. The earthquake of October 15, 1979, was associated with renewed displacement of as much as 0.8 m along part of the fault trace that ruptured in 1940 (Sharp and others, 1982). Ground breakage during the 1968 Borrego Mountain earthquake along the Coyote Creek fault closely followed preexisting fault traces (Clark, 1972). Geomorphic studies of the San Andreas fault in the Carrizo Plain by Wallace (1968) and Sieh (1978b) show that displacements have recurred many times along the same trace during the past 10,000 years, and possibly as much as 10 m of horizontal displacement accompanied the great earthquake of 1857.

In summary, all these observations indicate that the line of most recent ground breakage is likely to break again during major earthquakes. Recently active traces should be recognized as potentially hazardous by builders, planners, engineers, landowners, school boards, civil defense officials, or by anyone concerned with existing man-made structures, land use, or planned construction on or near these fault breaks. No one can yet accurately predict when movement on recently active faults will recur or which faults will move next, but many will move again. Movement, however, need not be confined to mapped features nor need it occur on all of them. New surface fractures may develop anywhere within the fault zone or on branching or other faults beyond the fault zone. Gaps or discontinuities along the main fault traces shown on this map do not necessarily represent stable or unfaulted segments; they may be places where no obvious surficial evidence for faulting survives.

SIGNIFICANT CHARACTERISTICS OF RECENTLY ACTIVE FAULT TRACES OF THE SAN ANDREAS FAULT FROM SALTON SEA TO WHITEWATER RIVER-MISSION CREEK

Relation to active faults to the northwest and southeast. Recently active traces shown on this map may or may not be continuous with other active segments of the San Andreas fault along strike to the northwest and the active faults of Imperial Valley to the southeast and south. To the northwest, the course of the San Andreas fault through the San Bernardino Mountains is complicated by branching, significant vertical displacement, and locally dominant thrusting; the trace of most recent displacement is also not certain (Allen, 1957; Dibblee, 1968, 1975; Ehlig, 1977). Studies by Morton and Matti (1981) in the San Bernardino Mountains suggested that the north branch is not now active. These geologists identified possible Holocene displacement on the south branch, but much of that is vertical, rather than horizontal, in contrast to clearly dominant horizontal displacement on the south branch in Coachella Valley. Moreover, in Coachella Valley, the north branch appears to be more recently active than the south branch. To the south, Sharp and others (1981) found no evidence for continuity at the surface between the San Andreas fault at Salton Sea and the Brawley and Imperial fault zones. They also found no convincing evidence for any extension of the San Andreas fault southeastward from its apparent surface termination near Bombay Beach.

Salton Sea to Mortmar (strips D and E). This segment of the San Andreas fault lies entirely below the last high stand of Holocene Lake Cahuilla (roughly the 40-foot contour), and hence its prominent vegetation contrasts and most of its extensive and well-defined scarps have developed since the latest disappearance of that large intermittent Holocene lake 200-300 years ago (Sharp, 1981; K. E. Sieh, written commun., 1981). Because almost all of the scarps in this segment coincide with the widely spaced ruptures formed by creep in 1968 and 1979, these young, low scarps (nearly all less than 1 m high, with exceptions that may have been exaggerated by erosion) might have been built entirely from such creep. Conversely most parts of this segment that have no topographic expression may not have experienced any displacement in the past 200-300 years. If correct, these inferences indicate that no large earthquakes have occurred along this segment in that period, because large earthquakes would likely have produced a far more continuous surface rupture than is now evident.

Mortmar to Thousand Palms Canyon (strips B, C, and D). Northwest of Mortmar the fault extends without topographic or other surficial expression past the shoreline of the last high stand of Lake Cahuilla into uplifted, folded, and faulted Quaternary sediments of the Mecca Hills. For a few kilometers on both sides of California State Highway 195, offset channels and hillside benches and valleys define the trace in uplifted sediments, but clear topographic evidence of recent displacement again disappears for a distance of nearly 3 km in the structurally complex badlands southeast of Painted Canyon. The approximate position of the fault shown here is based partly on detailed geologic mapping by Hays (1957). However, between Painted Canyon and Thermal Canyon to the northwest the trace shows clear, abundant, and locally continuous topographic evidence of recent displacement, both in the complex badlands and across alluvial fans near Thermal Canyon. Here also ground ruptures from creep in 1968 and 1979 closely followed preexisting fault topography.

It is significant that creep was not found in 1968 or 1979 in the badlands southeast of Painted Canyon, the same area that shows no topographic evidence for recent displacement. It is possible that displacement in this interval is either spread over a wide zone or is partly or entirely absorbed by folding or other distortion of the young sediments of the badlands.

From Thermal Canyon northwest to the Coachella Canal the trace is plainly marked by alined scarps across alluvial fans. Farther to the northwest, the trace is now obscured by the canal and its levees and, south of the canal, by farming. Aerial photographs taken in 1930, before construction of the canal or farming, show vegetational and other lineaments along the projection of the trace in this area. Surface evidence for the fault reappears on the northeast side of the canal west of Dillon Road. From here to Biskra Palms the trace is marked by vegetational boundaries and by discontinuous eroded fault topography that is less sharply defined than the fault topography to the southeast near Thermal Canyon. In this interval and to the northwest, scattered groves of palms mark the trace of the fault.

Although clear evidence of the fault is obscure or missing from the ridges that flank Biskra Palms and Pushawalla Palms, the position of the fault is clearly expressed between Macomber Palms and Pushawalla Palms by both large offset channels and by sharply defined small scarps, benches, and hillside valleys that resemble those near Thermal Canyon and southeast of Mortmar.

Seven large entrenched and offset channels southwest of the fault bear clear evidence of both uplift and major strike-slip displacement. The seven channels are between Biskra Palms and Thousand Palms Oasis, and each presently intercepts the discharge of one or more nearby channels upstream and across the fault to the northeast. Slow southeastward movement of the block northeast of the fault eventually separates the upstream channels from their downstream counterparts. The upstream channels are then captured by the next large downstream channels to the southeast, across the fault. Thus the discharge of each channel northeast of the fault has progressively switched from one to the next among the seven large channels across the fault. The seven channels may have originated when initial uplift of Indio Hills caused entrenchment of seven local alluvial channels across the alluvial fans that later, from slow uplift, became the Indio Hills. The upstream portions of those seven original channels have not been identified, but are now offset to the southeast, either in or beyond Indio Hills.

The two branches of the San Andreas fault shown on strips A and B join near Biskra Palms. The north branch has far more surficial evidence for recent displacement, both near the junction and to the northwest. The south branch, which follows the southwest boundary of Indio Hills between Biskra Palms and Thousand Palms Canyon, exhibits only a few eroded scarps in alluvium near Thousand Palms Canyon.

North Branch, Thousand Palms Canyon to Mission Creek (segments A and B). From about 2 to about 5 km northwest of Thousand Palms Canyon the northern branch shows no clear surface evidence for recent movement. But northwest of this section, within the badlands of the Indio Hills, a 3-km length of the fault displays continuous and well-preserved fault topography comparable to the most clearly expressed segments to the southeast. Farther to the northwest, however, topographic evidence for the recent trace abruptly loses continuity and fresh appearance. Although drifted sand along the north slopes of the Indio Hills and alluvium beyond toward Desert Hot Springs conceal some of the fault trace, the position of the trace is clear, and the interrupted course and eroded nature of the exposed scarps in this area may indicate a lower rate of offset than to the southeast. Convincing evidence for very recent faulting along this strand ends at Desert Hot Springs, beyond which the only evidence for recent faulting appears as intermittent and eroded fault topography along the range front between White House Canyon and a point about 1 km east of Mission Creek.

South Branch, Thousand Palms Canyon to Whitewater River (segments A and B). The south branch of the San Andreas fault between Thousand Palms Canyon and Whitewater River shows distinctly less evidence of recent faulting than does the north branch or the combined trace of the San Andreas fault southeast of the junction of the branches. However, there are eroded scarps in alluvium near Thousand Palms Canyon, and some channels are possibly offset by faulting in Indio Hills. The south branch shows clear fault topography only northwest of Seven Palms Valley. Scarps along this northwest part of the fault are fragmentary and rounded by erosion. Horizontally offset topography occurs only in the hills between California State Highway 62 and Whitewater River.

Variation of preservation of recently active trace. Three of the previously described sections of the fault northwest of Thermal Canyon display preservation of recent displacement comparable to that of the zone to the southeast that ruptured in both 1968 and 1979. These are between Thermal Canyon and the Coachella Canal, between Macomber Palms and Pushawalla Palms, and northwest of Thousand Palms Oasis. The clear coincidence between earthquake-induced creep and preserved evidence of earlier movement southeast of Thermal Canyon suggests that these three segments may also creep in response to nearby earthquakes. The Desert Hot Springs earthquake of 1948, for example, possibly triggered creep in some of these sections; however, they were evidently not investigated in 1948.

Evidence for recent displacement along the fault traces on this map varies widely. For example, the youngest deposits of Holocene Lake Cahuilla have distinct, locally continuous low scarps and vegetation contrasts, whereas long sections of the south branch have no comparably detailed surface indications of the exact position of the most recently active traces. In general, the best preserved evidence of recent displacement occurs southeast of the junction of the two branches, although as noted above, parts of the north branch in Indio Hills also look very youthful. Between Indio Hills and the San Bernardino Mountains, neither branch displays obvious surficial evidence of major recent displacement.

Variations in late Quaternary displacement rates may explain most differences in preservation of the recently active trace, but windblown sand may be locally important. Blown sand may quickly bury or erode fault topography, making traces difficult to recognize or concealing evidence of recent activity. Blown sand may account for the dearth of fault topography along the south branch in and immediately west of Indio Hills.

The north branch shows a pronounced change in preservation of topographic evidence of recent faulting along the north flank of Indio Hills, where the excellent preservation and continuity of fault topography in the sand-free badlands within the Indio Hills diminish markedly to the northwest on the sand-swept northern slopes of the Indio Hills. It seems likely that at least part of this change is caused by blown sand, although a comparable change in character of the recent trace occurs to the southeast of the same segment, where blown sand is evidently not a factor.

Normal faults of Indio Hills and Mecca Hills (strips B and C). Hundreds of normal faults offset Quaternary alluvium northeast of the north branch in and next to Indio Hills roughly from Thousand Palms Oasis to Macomber Palms, and also northeast of the combined branches in two adjacent locations between the Indio and Mecca Hills. These faults appear to be directly related to movement on the San Andreas fault, and most offset young alluvium that is otherwise undeformed except for broad uplift. At each location this uplift both increases southeastward and creates low hills that are elongated parallel to the fault. In the Indio Hills, offset on these normal faults also clearly increases southeastward, along with uplift.

Most of these normal faults are less than a few hundred meters long and lie within 5 km of the San Andreas fault, but they trend more northerly than does the San Andreas. Vertical displacement ranges from less than 0.1 m to more than 10 m and is about equally divided between scarps that face east and those that face west. Many scarps are very rounded and deeply incised by weathering. Some of the higher scarps are steeper and less weathered within about 1 m of their base, indicating that the high scarps were probably formed by repeated, smaller movements. A few of these faults offset older deposits more than younger deposits, demonstrating recurrent displacement along the same trace. A few of the faults displace very young channel deposits.

These normal faults were located and plotted principally from their expression on 1:8,000-scale low-sun-angle (5°-20° above the horizon) aerial photographs flown in 1975 and 1976 for this project. The low-angle illumination of these photographs emphasizes even very subdued relief, and rounded scarps as low as 100 mm (4 in.) are visible on them. Although many scarps were checked in the field, others were not, and no attempt was made to verify fault origin of all or to search for others in the abundant natural exposures in channel walls in this region.

These faults are clearly related to local areas of uplift on the northeast side of the San Andreas fault. It is also very likely that this uplift is in turn related to displacement across the San Andreas fault, because of the position of the uplifted areas next to the fault.

ANNOTATED REFERENCES

Allen, C. R., 1957, San Andreas fault zone in San Gorgonio Pass, southern California: Geological Society of America Bulletin, v. 68, p. 316–350.

A thorough study of the complex nature of the San Andreas fault zone to the northeast of the area of this map documents the important role of thrust faulting along the San Andreas system in the San Bernardino Mountains.

Allen, C. R., Wyss, Max, Brune, J. N., Grantz, Arthur, and Wallace, R. E., 1972, Displacements on the Imperial, Superstition Hills, and San Andreas faults triggered by Borrego Mountain earthquake, *in* The Borrego Mountain earthquake of April 9, 1968: U.S. Geological Survey Professional Paper 787, p. 87–104.

Fault creep triggered by the Borrego Mountain earthquake occurred exactly along the traces of earlier displacement on these faults. Most right-lateral offset along the San Andreas fault was between 5 and 10 mm in a zone about 39 km long.

Brown, R. D., Jr., 1970, Map showing recently active breaks along the San Andreas fault between the northern Gabilan Range and Cholame Valley, California: U.S. Geological Survey Miscellaneous Geologic Investigations Map I–575, scale 1:62,500.

Strip map of part of the San Andreas fault in central California.

Brown, R. D., Jr., and Wolfe, E. W., Jr. 1972, Map showing recently active breaks along the San Andreas fault between Point Delgada and Bolinas Bay, California: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-692, scale 1:24,000.

Strip map of the northernmost segment of the San Andreas fault exposed on land.

Clark, M. M., 1972, The surface rutpure along the Coyote Creek fault, *in* The Borrego Mountain earthquake of April 9, 1968: U.S. Geological Survey Professional Paper 787, p. 55–86.

The 30-km-long rupture of the M=6.5 Borrego Mountain earthquake followed exactly along traces of earlier faulting.

———— 1973, Map showing recently active breaks along the Garlock and associated faults, California: U.S. Geological Survey Miscellaneous Geologic Investigations Map I–741, scale 1:24,000.

Strip map of the left-lateral Garlock fault.

———— 1982, Map showing recently active breaks along the Elsinore and associated faults, California, between Lake Henshaw and Mexico: U.S. Geological Survey Miscellaneous Investigations Series Map I–1329, scale 1:24,000.

Strip map of the southern part of the Elsinore fault.

Clark, M. M., Grantz, Arthur, and Rubin, Meyer, 1972, Holocene activity of the Coyote Creek fault recorded in the sediments of Lake Cahuilla, *in* The Borrego Mountain earthquake of April 9, 1968: U.S. Geological Survey Professional Paper 787, p. 112–130.

A trench across the 1968 rutpure showed repeated displacement along one fault trace and yielded estimates of Holocene displacement rates along the Coyote Creek fault.

Crowell, J. C., 1962, Displacement along the San Andreas fault, California: Geological Society of America Special Paper 71, 61 p.

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———— ed., 1975, San Andreas fault in southern California: California Division of Mines and Geology Special Report 118, 272 p.

An excellent general introduction and guide to the San Andreas fault from Mexico to Carrizo Plain. Includes several papers that deal directly with aspects of the fault covered by this map.

Dibblee, T. W., 1968, Displacements on the San Andreas fault system in the San Gabriel, San Bernardino, and San Jacinto Mountains, southern California, *in* Dickinson, W. R., and Grantz, Arthur, eds., Proceedings of conference on geologic problems of the San Andreas fault system: Stanford University Publications in Geological Sciences, v. 11, p. 268–278.

Major right slip along the San Andreas fault system in the San Bernardino Mountains has occurred along a complex series of anastomosing faults, but mainly on the north branch. There have been associated large vertical displacements.

———— 1975, Late Quaternary uplift of the San Bernardino Mountains on the San Andreas and related faults, *in* Crowell, J. C., ed., San Andreas fault in southern California: California Division of Mines and Geology Special Report 118, p. 127–135.

Discussion of late Quaternary interaction between the complex faults of the San Andreas and nearby fault systems in the San Bernardino Mountains.

Ehlig, P. H., 1977, Structure of San Andreas fault zone in San Gorgonio Pass, southern California [abs.]: Geological Society of America Abstracts with Programs, v. 9, no. 4, p. 416.

Lithologic contrasts indicate that the main course of the San Andreas fault through the San Bernardino Mountains is by a newly recognized fault connecting the south and north branches in the upper parts of Banning and Whitewater Canyons.

Hays, W. H., 1957, Geology of the central Mecca Hills, Riverside County, California: Yale Univ., New Haven, Conn., Ph.D. thesis, 324 p.

Detailed map and study of the complexly folded and faulted sediments near Thermal and Box Canyons in the Mecca Hills.

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A predecessor to this report, based chiefly on photointerpretation.

Keller, E. A., Bonkowski, M. S., Korsch, R. J., and Shlemon, R. J., 1982, Tectonic geomorphology of the San Andreas fault zone in the southern Indio Hills, Coachella Valley, California: Geological Society of America Bulletin, v. 93, p. 46–56.

An offset alluvial fan near Biskra Palms yields a late Quaternary horizontal displacement rate along the fault of 10 to 35 mm/yr. The report also describes geologic structure and fault geomorphology at Pushawalla Palms.

Morton, D. M., and Matti, J. C., 1981, Earthquake hazards studies, upper Santa Ana Valley and adjacent areas, southern California, *in* Summaries of technical reports, v. VI, National earthquake hazards reduction program: U.S. Geological Survey Open-File Report 81–167, p. 70–72.

Morton and Matti find major Quaternary vertical displacement on the Banning fault, including 3 mi of right slip in the past half million years in the northwest part of Coachella Valley (south branch of San Andreas fault). They also conclude that the Mission Creek fault in the San Bernardino Mountains (north branch of San Andreas fault) is either temporarily locked or abandoned.

Radbruch-Hall, D. H., 1974, Map showing recently active breaks along the Hayward fault zone and the southern part of the Calaveras fault zone, California: U.S. Geological Survey Miscellaneous Geologic Investigations Map I–813, scale 1:24,000.

Strip map of two parts of the San Andreas fault system in central California.

Richter, C. F., Allen, C. R., and Nordquist, J. M., 1958, The Desert Hot Springs earthquakes and their tectonic environment: Seismological Society of America Bulletin, v. 48, no. 4, p. 315–337.

These authors conclude that the M = 6.5 earthquake of December 1948 was on the north branch (Mission Creek fault) and assume that the fault dips northeasterly. The main shock and most of its aftershocks cluster more than 5 km northeast of the surface trace of the fault near Desert Hot Springs.

Ross, D. C., 1969, Map showing recently active breaks along the San Andreas fault between Tejon Pass and Cajon Pass, southern California: U.S. Geological Survey Miscellaneous Geologic Investigations Map I–553, scale 1:24,000.

Strip map of a part of the San Andreas fault south of the Garlock fault intersection, including the surface rupture of 1857.

Sharp, R. V., 1972, Map showing recently active breaks along the San Jacinto fault zone between the San Bernardino area and Borrego Valley, California: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-675, scale 1:24,000.

Strip map of the San Jacinto fault zone.

________ 1981, Variable rates of late Quaternary strike slip on the San Jacinto fault zone, southern California: Journal of Geophysical Research, v. 86, p. 1754–1762.

Geologic investigations, including the use of trenches, show that the rate of horizontal offset along the San Jacinto fault zone has varied during Holocene time, possibly inversely with variation in rate of offset of nearby faults of the San Andreas fault system.

Sharp, R. V., Lienkaemper, J. J., Bonilla, M. G., Burke, D. B., Cox, B. F., Herd, D. G., Miller, F. K., Morton, D. M., Ponti, D. J., Rymer, M. J., Tinsley, J. C., Yount, J. C., Kahle, J. E., Hart, E. W., and Sieh, K. E., 1982, Surface faulting in central Imperial Valley, *in* Johnson, C. E., and others, eds., The Imperial Valley, California, earthquake of October 15, 1979: U.S. Geological Survey Professional Paper 1254, p. 119–143.

Surface rupture of the 1979 earthquake closely followed the rupture of 1940 and the trace of earlier displacements.

Sharp, R. V., Lienkaemper, J. J., and Rymer, R. J., 1982, Surface displacement on Imperial and Superstition Hills faults triggered by the Westmorland, California, earthquake of 26 April 1981: U.S. Geological Survey Open-File Report 82–282, 33 p.

These earthquakes occurred in northern Imperial Valley between the surface ruptures of 1979 in the Brawley and the Imperial fault zones and the triggered ruptures on the San Andreas fault.

Sieh, K. E., 1978a, Prehistoric large earthquakes produced by slip on the San Andreas fault at Pallet Creek, California: Journal of Geophysical Research, v. 83, No. B8, p. 3907–3939.

Trenches across a trace of the San Andreas fault southeast of Palmdale expose faulted Holocene sediments that record the 1857 earthquake and eight major prehistoric earthquakes since the sixth century A. D.

________ 1978b, Slip along the San Andreas fault associated with the great 1857 earthquake: Seismological Society of America Bulletin v. 68, no. 5, p. 1421–1448.

Detailed description and analysis of displacements along the surface rupture of the 1857 and earlier earthquakes.

________ 1981, Aspects of the late Holocene behavior of the San Andreas fault system, *in* Summaries of technical reports, v. XII, National earthquake hazards reduction program: U.S. Geological Survey Open-File Report 81–833, p. 170-171.

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Triggered slip appeared discontinuously along 39 km of the San Andreas fault near Salton Sea. Right-lateral displacement was commonly 4 mm, with a maximum of 10 mm, and occurred almost exactly where similar slip was triggered by the Borrego Mountain earthquake of April 1968.

Sylvester, A. G., and Smith, R. R., 1976, Tectonic transpression and basement-controlled deformation in San Andreas fault zone, Salton trough, California: American Association of Petroleum Geologists Bulletin, v. 60, no. 12, p. 2081–2102.

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Vedder, J. G., and Wallace, R. E., 1970, Map showing recently active breaks along the San Andreas and related faults between Cholame Valley and Tejon Pass, California: U.S. Geological Survey Miscellaneous Geologic Investigations Map I–574, scale 1:24,000.

Strip map of the area immediately north of the intersection of the San Andreas and Garlock faults, including the surface rupture of 1857.

Wallace R. E., 1968, Notes on stream channels offset by the San Andreas fault, southern Coast Ranges, California, *in* Dickinson, W. R., and Grantz, Arthur, eds., Proceedings of conference on geologic problems of San Andreas fault system: Stanford University Publications in Geological Sciences, v. 11, p. 6–21.

Presents evidence for recurring right-lateral displacement along the same fault breaks in the Carrizo Plain area.

The following 1:250,000-scale geologic maps in southern California show the location of the San Andreas and associated faults and list the detailed geologic maps from which they were compiled.

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Rogers, T. H., 1965, Santa Ana sheet, Geologic map of California (Olaf P. Jenkins edition): California Division of Mines and Geology.

________ 1967, San Bernardino sheet, Geologic map of California (Olaf P. Jenkins edition): California Division of Mines and Geology.