DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

A CONTRIBUTION OF THE NATIONAL CENTER FOR
EARTHQUAKE RESEARCH OF THE GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH THE
CALIFORNIA DIVISION OF MINES AND GEOLOGY

MISCELLANEOUS GEOLOGIC INVESTIGATIONS
MAP I-741 (SHEET 1 OF 3)

A

B

Base from U.S. Geological Survey 7.5' quadrangles as indicated

INTERIOR—GEOLOGICAL SURVEY, WASHINGTON, D.C.—1974—G72063

APPROXIMATE MEAN DECLINATION, 1973

SCALE 1:24 000

1 ½ 0 1 MILE

1 .5 0 1 KILOMETER

CONTOUR INTERVALS 20, 40, AND 50 FEET
DATUM IS MEAN SEA LEVEL

EXPLANATION

Fault traces

Heavy line, youngest trace at any location along the fault, as determined by degree of preservation of continuity and fault topography; light line, distinctly older traces at any location along the fault. Absolute age of the youngest trace may differ greatly from place to place. Solid line, obvious topographic or photogeologic evidence of recent movement shown by such features as alined scarps, benches, ridges, and offset channels;[1] *long dashed where position of trace uncertain because of erosion of fault features; short dashed line, less obvious evidence of recent movement, but very likely a fault trace; queried where tectonic origin uncertain; dotted line, possible location of fault traces across Koehn Lake, but surface expression is lacking. Ball on relatively downthrown side of scarps along breaks on which movement has been predominantly horizontal; hachures on relatively downthrown side of scarps along breaks on which movement has been predominantly vertical*

Shoreline or nearshore bar of former lake

[1]Notes along the fault traces indicate clear examples of various fault features. The features noted are not limited to these locations, but are present all along the mapped fault lines, generally as scarps. The number of notes at different places on the map is roughly proportional to the abundance and degree of preservation of the features noted.
The notes also give estimates of the heights of scarps and amount of offset of channels that appear to preserve tectonic displacement; that is, neither the height of the scarps nor the position of the channels has been greatly changed by erosion since they were displaced. All offset features noted on this map are left lateral except for those on the Brown Mountain fault, which are right lateral.

Field investigation in May and June 1969 by M.M. Clark, assisted by J.B. Pinkerton

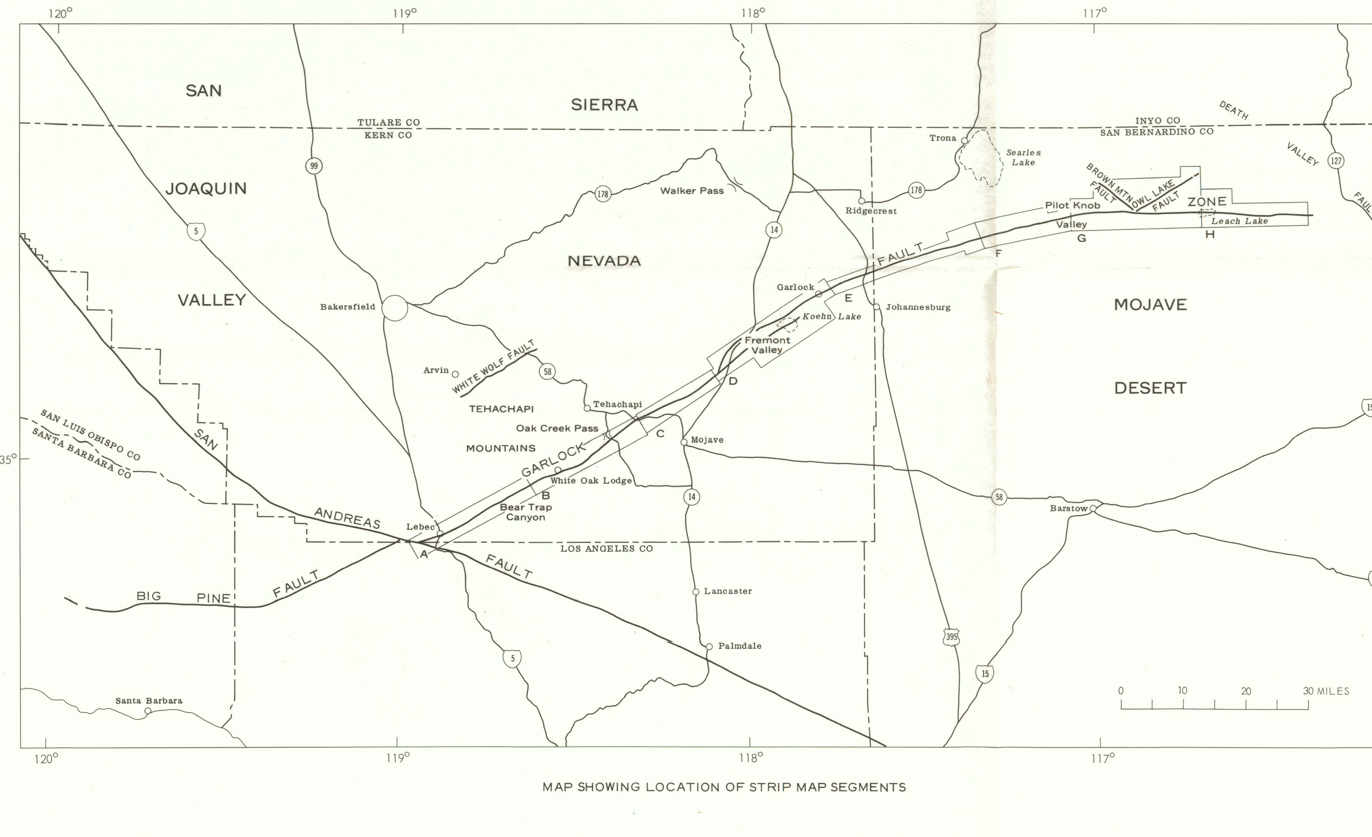
ACCESS TO THE GARLOCK FAULT EAST OF SEARLES LAKE QUADRANGLE IS RESTRICTED AND CONTROLLED BY THE U.S. NAVAL WEAPONS CENTER, CHINA LAKE, AND BY FORT IRWIN MILITARY RESERVATION

MAP SHOWING RECENTLY ACTIVE BREAKS ALONG THE GARLOCK AND ASSOCIATED FAULTS, CALIFORNIA

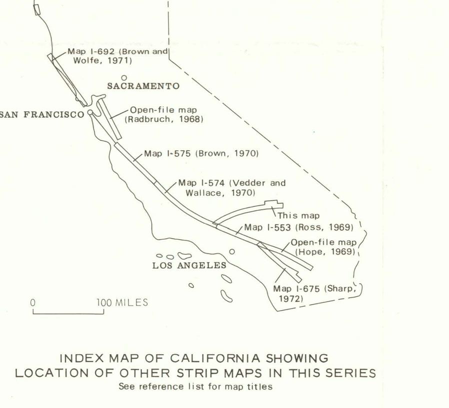
By
Malcolm M. Clark

1973

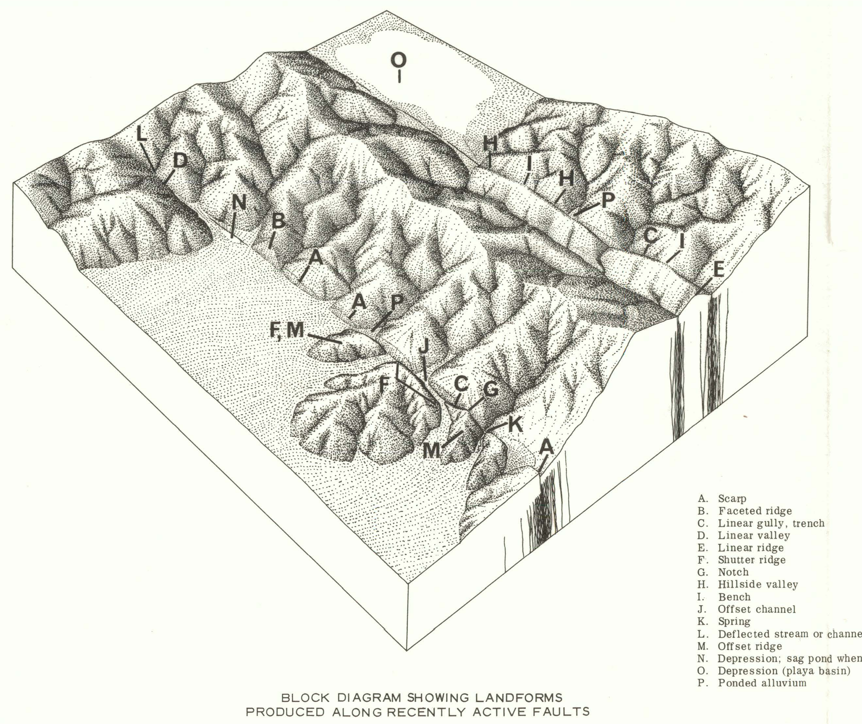
Other recently active breaks that have not produced distinctive surficial features may be present



MAP SHOWING LOCATION OF STRIP MAP SEGMENTS



INDEX MAP OF CALIFORNIA SHOWING LOCATION OF OTHER STRIP MAPS IN THIS SERIES
See reference list for map titles



A. Scarp
B. Faceted ridge
C. Linear gully, trench
D. Linear valley
E. Linear ridge
F. Shutter ridge
G. Notch
H. Hillside valley
I. Bench
J. Offset channel
K. Spring
L. Deflected stream or channel
M. Offset ridge
N. Depression; sag pond when wet
O. Depression (playa basin)
P. Ponded alluvium

BLOCK DIAGRAM SHOWING LANDFORMS PRODUCED ALONG RECENTLY ACTIVE FAULTS

PURPOSE OF THIS STRIP MAP

This strip map is designed to show the lines of inferred most recent movement in the Garlock fault zone. The character and location of these lines are important to scientists and engineers who study faulting and earthquakes and should be helpful to those concerned with land use and development on or near the faults. The mapped lines mark known or suspected faults along which displacements of the ground surface by rupture or creep have occurred within the Garlock fault zone. Map users should understand that these lines are primarily guides for locating fault traces on the ground; they are not located with the precision needed for some types of engineering or land-use projects.

THE GARLOCK FAULT AND FAULT ZONE

The Garlock fault zone is a break in the earth's crust that extends 150 miles northeastward from the San Andreas fault zone near Lebec to the Death Valley fault zone, near the eastern border of California (see index map). In contrast to the San Andreas fault, however, displacement along the Garlock fault is left lateral rather than right lateral. That is, to an observer looking across the fault, streams and ridges on the opposite block are displaced to the left. Although the Garlock fault has not moved in historic time, it shares many characteristics with the San Andreas fault. Both have a history of millions of years of horizontal displacement and both display well-preserved topographic evidence of recent activity such as offset stream channels, scarps across alluvium, and unfilled linear depressions. There is no reason to believe that displacement along the Garlock has permanently ceased; indeed fault features of recent origin along some parts of the Garlock fault are as little eroded as are historically active parts of the San Andreas system that occur in a similar climate and geologic setting. Conversely, such features along other parts of the Garlock are conspicuously more eroded than examples along nearby, historically active stretches of the San Andreas fault.

Movement within the Garlock fault zone has been distributed along many parallel or subparallel faults that differ in age and amount of relative displacement. This complex zone of movement ranges in width from a few hundred feet to several miles and presumably has accumulated miles or tens of miles of horizontal offset in late Cenozoic time (25± million years).

In keeping with terminology used for the San Andreas fault (Noble, 1926; Ross, 1969), this zone or band of parallel and apparently interrelated faults is called here the *Garlock fault zone;* and the surface traces of most recent movement are called here the *Garlock fault.*

LOCATION OF FAULT BREAKS

The faults shown on this map were located both by study of aerial photographs and by field investigation of the entire fault zone in 1969. A small number of breaks shown on the map are visible only on aerial photographs or were not checked in the field, but many breaks or parts of breaks shown on this map, especially along the eastern third of the fault, were identified only in the field and are too small to be evident on the photographs used.[1]

All breaks were recorded on these airphotos and transferred to base maps with a projector. Fault features shown by the contour lines of this map are generally plotted within 50 to 100 feet of their correct position; however, in areas where fault zone topography does not show on the contour lines of the map, fault breaks may be plotted as much as 200 feet from their correct position. Furthermore, several errors in the positions of topography, streams and culture exist on the Mojave 15-minute and Lebec 7.5-minute base maps. Some of the errors have been corrected on this strip map; however elsewhere on these maps, and in a few places on the Pastoria Creek 7.5-minute map, position and length of fault breaks have been altered to conform with incorrectly shown topography, but nowhere have fault traces been changed to conform with incorrectly placed roads. The remaining base maps used for this strip map have no significant errors in the fault zone. Geologists and engineers who make specific use of this strip map should independently verify position of the mapped faults and confirm their fault origin.

FIELD RECOGNITION OF MOST RECENT FAULTING

Recently active fault breaks can generally be recognized by topographic features or by contrasts in vegetation that reflect varying ground-water depths or soil differences across the fault. The most common features are scarps, trenches or troughs, notches, parallel ridges, offset drainage channels, sag ponds, ponded alluvium, undrained depressions, and shutter ridges (see block diagram). Most of these features have been developed by repeated displacement accompanied by erosion and deposition along the fault.

Horizontal and vertical displacements along a fault result from successive shifts amounting to a few inches or a few feet during earthquakes, from intervals of slow fault creep between earthquakes, or from a combination of both. Regardless of their specific origin, the displacements produce scarps and other topographic features that delineate the fault lines shown on the map. The annotations along the fault traces indicate numerous examples of these features. Many of the examples are cited because they are exceptionally clear or well preserved, but such features are generally present to some degree all along the mapped faults. As opposing fault blocks slide laterally, some blocks are juxtaposed or relatively depressed to form depressions or sag ponds, or elongate graben (down-dropped blocks) form between parallel breaks. Other slivers are raised, tilted, or slid diagonally to produce linear ridges and shutter ridges. Notches and trenches or troughs along the faults may reflect increased erosion of the crushed and broken rocks in the fault zone, or they may be primary fault features.

Surface features created by faulting are generally ephemeral; they may be obliterated by erosion, buried by alluvium or other sediment, obscured by soil creep and vegetation, or modified or destroyed by the activities of man. Fault features persist only in places where their rate of tectonic growth exceeds or equals the rate of the process which removes them, or in places where faulting is so recent that the process of destruction has not yet erased them. Thus, eroded 20- to 100-foot-high scarps, which are common in the Garlock fault zone and apparently were produced by multiple displacements, may be tens to hundreds of thousands of years old, and the 1,000-to 2,000-foot-high escarpment along the fault zone between Mojave and Fremont Valley may have grown over a far longer period. On the other hand, along parts of the fault, abundant 1- to 2-foot-high scarps that cross all but the presently active channels of washes or alluvial fans indicate faulting since the last episode of major flooding or deposition in those places. Unfortunately our very meager knowledge of erosion and deposition rates along the Garlock fault prevents us from making accurate estimates of the age of the youngest fault features. Indeed the probable variation in these rates means that some well-preserved features along the arid eastern part of the fault may be much older than features of similar appearance along the western parts of the fault that receive 3 to 5 times as much rain. Nevertheless, the fact that surface fault features are preserved at all and the similarity of many of these features to those on historically active parts of the San Andreas fault that have similar climate means that the Garlock fault must be considered capable of movement at any time.

SIGNIFICANCE OF LOCATING RECENT FAULT BREAKS

Evidence contained in scarps and offset channels plainly shows that much of the Garlock fault has repeatedly broken along the same strands. For example, in many places scarps abruptly decrease in height by several feet as they pass from older to younger alluvium. This greater displacement of the older alluvium indicates one or more episodes of offset before deposition of the younger alluvium. Subsequent formation of a scarp across the younger alluvium alined with the larger scarp on the older deposit shows that the displacement recurred along the same fault trace. Furthermore, eroded scarps as much as 50 to 100 feet high usually have less eroded 1- to 3-foot-high scarps or benches near their bases, indicating that the large scarps are probably created by many separate episodes of smaller uplift. In similar fashion, the amount of horizontal offset of stream channels along a single linear break a few miles long commonly varies randomly from roughly 10 feet on small, young channels to thousands of feet on large, old ones, revealing repeated episodes of displacement along the same line.

The San Andreas fault system displays similar evidence of repeated movement along the same strands; some of this movement is associated with historic earthquakes. Geomorphic studies of that fault in the Carrizo Plain by Wallace (1968) show that displacements have recurred many times along the same trace during the last 10,000 to 20,000 years, including possibly as much as 30 feet of horizontal displacement at the time of the great earthquake of 1857; which also broke the part of the fault that intersects the Garlock fault. Horizontal dislocations of as much as 20 feet along traces that had experienced prehistoric movement accompanied the disastrous earthquake of 1906 in central California. In 1940, severe structural damage resulted from horizontal movements of more than 14 feet along previously active strands of the Imperial fault, part of the San Andreas fault system; and ground breakage during the 1966 Parkfield-Cholame earthquakes closely followed previously mapped fault traces (Brown and others, 1967, p. 4). Tectonic creep along previously active traces in the Hayward and Calaveras fault zones is dislocating railroad tracks, a culvert, a water tunnel, a bridge, streets, and buildings (Radbruch and others, 1966; Radbruch, 1968). South of Hollister, tectonic creep along recently active fault breaks in the San Andreas fault zone is indicated by the deformation of fences and by fractures in paved roads (Brown and Wallace, 1968).

In summary, all these observations suggest that the line of most recent ground breakage is likely to break again during future major earthquakes. Thus, the most recently active breaks should be recognized as geologically hazardous by builders, planners, engineers, landowners, school boards, civil defense officials, and others; or by anyone concerned with existing man-made structures, land utilization, or planned construction on or near these most recent fault breaks. At present, no one can predict when movement on recently active faults will occur or which ones will move next, but it is virtually certain that some will move again. It should not be inferred, however, that future movements will be confined entirely to these mapped features or that movements will occur on all of them. Surface fracturing may develop anywhere within the fault zone or on branching or other faults beyond the fault zone. Most gaps or discontinuities along the main fault trace of this map do not represent stable or unfaulted segments; they are merely places where no obvious surficial evidence for faulting survives.

IMPORTANT FEATURES OF THE GARLOCK FAULT

Throughout much of its length, the Garlock fault is a simple, clearly defined break or, locally, closely spaced parallel or en echelon breaks, commonly in a zone less than 100 yards wide. The most prominent interruption of the gross continuity of the fault occurs near its center in Fremont Valley (see index map). Here, an en echelon overlap, with the overlapping ends about 2 miles apart, breaks the otherwise continuous Garlock fault into an eastern and a western segment. The eastern segment forms a broad east-west arc, for the most part across broad alluvial plains, and displays the best-preserved evidence of former displacement. The western segment follows a nearly straight, roughly NE-SW course along the base of the southern Sierra Nevada and through the Tehachapi Mountains, in many places traversing narrow valleys or bedrock. In general, it is less well preserved than the eastern segment. Normal faults (that is, faults with combined vertical and pull-apart displacement) along the western and southern borders of Fremont Valley, shown on this map, nearly connect the two major strands of the Garlock fault and are probably directly related to movement along the Garlock fault.

At its west end, the Garlock fault is far less conspicuous than the intersected 1857 break of the San Andreas fault zone, which displays sharply delineated and nearly continuous fault topography. In contrast, the Garlock fault for 12 miles east of the intersection of the two faults near Lebec consists of a series of widely separated and greatly eroded notches, offset ridges and streams, and short linear valleys. These differences in preservation of fault topography probably indicate that displacements along this westernmost segment of the Garlock fault are older or were smaller than were those along the intersected segment of the San Andreas. Eastward, however, the Garlock fault becomes, in an irregular fashion, progressively better preserved. The easternmost 50 miles are generally the best preserved.

Three areas along the fault display particularly well-preserved evidence of movement:

(1) For one mile on either side of Oak Creek Pass Road in the Tehachapi Mountains (Monolith quadrangle), low scarps, linear valleys and swales, and small offset gullies display striking continuity in a region of subdued, rounded, grass-covered hills (this part includes an area in which Buwalda and St. Amand (1955, p. 53) reported fresh breaks after the Arvin-Tehachapi earthquake of 1952; see below).

(2) A 12-mile length of the fault that extends eastward from a point 4 miles west of the Searles Lake-Wingate Pass quadrangle boundary includes hillside benches and valleys alined with low scarps across the older gravels of most washes and with narrow pathways of clay-silt across bouldery alluvium. These features impart a degree of continuity and precision of location to the active trace that is not present anywhere to the west.

(3) Along a 4-mile stretch of the fault that extends westward from the Leach Lake-Avawatz Pass quadrangle boundary, the most recently active break displays an estimated 70- to 90- percent continuity and offsets nearly all surfaces (including low ridges of soft, easily eroded silts and muds) except presently active channels of washes.

HISTORY OF HORIZONTAL DISPLACEMENT

Smith (1962) postulated 40 miles of left-lateral displacement of distinctive dikes that intrude Mesozoic granitic rock (>60 million years old) that crops out on both sides of the eastern segment of the fault, and Michael (1966) argued for 46 miles of left-lateral displacement of a nearly early Tertiary(?) fault zone (30-60 million years old). Others have reported smaller displacements of progressively younger rocks (summarized by Smith, 1962, and Dibblee, 1967). The horizontal displacements of Quaternary deposits and landforms (up to about 2 million years old) evident on this strip map range from half a mile for an alluvial fan 3 miles east of the town of Garlock, to 250 feet for a late Pleistocene lake bar 1 mile northeast of Koehn Lake, to abundant channel offsets of 15 to 150 feet along parts of the western and most of the eastern segments of the fault.

TIME OF MOST RECENT DISPLACEMENT

Noble (1926, p. 425) expressed the opinion, shared by some other geologists, that displacements along the Garlock fault generally are not as young as those on the San Andreas, as must certainly be true at the western end. Moreover, Smith (1960) determined that a 40-foot-high scarp along the fault in Searles Valley was in existence during a late Pleistocene filling of Lake Searles, estimated to be 50,000 or more years ago, and concluded that the fault has not experienced major movement since. However, as noted above, the trace that traverses a large scarp usually experiences many episodes of displacement during the life of the scarp. Indeed, more recent work by Smith (written commun., 1970) has shown that most scarps along the Garlock fault in Searles Valley result from several individual displacements. Furthermore, he reports streams offset laterally as much as 40 feet by the Garlock fault and 2- to 5-foot-high scarps in deposits that are possibly as young as 10,000 years. Smith has also found inconclusive evidence of 1/2- to 2-foot displacements that may be from a few hundred to 2,000 years old. This youngest age range reported by Smith is compatible with the recency of movement implied by the degree of preservation of the Garlock fault in the eastern 4 miles of the Leach Lake quadrangle. The degree of preservation of many features of the most recently active trace in that location are similar to comparable parts of the active strike-slip Coyote Creek fault northwest of Imperial Valley, which broke in 1968 and has a demonstrated history of previous activity that includes multiple faulting during the last 3,000 years (Clark and Grantz, 1971). The two locations have similar climate, vegetation, topography, and rock type, and the similarity of preservation of fault topography suggests at least grossly comparable rates of displacement.

Field study in May 1969 revealed en echelon cracks with 1/8 to 1/4 in. of left-lateral displacement across six dry stream channels directly on the fault trace in Pilot Knob Valley. Whether these displacements represent tectonic movement along the fault or rather resulted from nontectonic causes such as desiccation or settling is not known.

In summary, although some sections of the Garlock fault have much lower rates of displacement than nearby parts of the San Andreas fault, other segments appear to differ little in age from historically active segments of the San Andreas fault.

POSITION OF THE ACTIVE TRACE

Surface expression of the Garlock fault varies according to the type of rock that it crosses. Throughout most of its length, except in the Tehachapi Mountains and locally elsewhere along range fronts, the fault is in poorly consolidated Quaternary sediments or alluvium rather than in bedrock. In these young sediments the most recently active trace is fairly simple, consisting of a single strand or en echelon strands that are distinctly better preserved than diverging or parallel secondary traces. (Although dissected segments of alluvial fans that have been uplifted along these secondary faults stand out prominently north of the town of Mojave and in Pilot Knob Valley, most of the secondary faults are distinctly older than the recently active trace of the Garlock fault, and few exhibit evidence of lateral displacement.)

In contrast to the simple traces of the fault in alluvium, multiple closely spaced zones of sheared rock tens to hundreds of yards wide mark the fault zone where it crosses exposed bedrock. In many of these places the most recently active trace is impossible to identify. In particular, in the Tehachapi Mountains between the head of Bear Trap Canyon and Cottonwood Creek (Winters Ridge and Liebre Twins quadrangles), displacement appears to be distributed across most of the 1/2- to 2-mile width of a 20-mile-long body of highly sheared schist. Geologic maps (Wiese, 1950; Dibblee, 1967) show the schist to be completely bounded by a bifurcation of the Garlock fault. However, in addition to being thoroughly sheared parallel to the Garlock fault, the schist includes throughout its width abundant landslides and many scarps, notches, and hillside benches and valleys more or less parallel to the fault but without a throughgoing alinement or continuity as in most of the other parts of the fault zone. In contrast, portions of the faults mapped by Wiese and by Dibblee that separate the schist from adjacent granitic rocks show no obvious signs of recent movement. This evidence, plus the fact that prominent surface traces of the Garlock fault occupy a narrow zone immediately beyond each end of the schist body strongly implies that the active trace traverses the schist as a series of many small, discontinuous breaks distributed across the entire body of sheared schist.

Thus it is reasonable to assume that in areas of simple breaks future breakage will occur on or near the most recent trace, whereas in areas characterized by wide shear zones that lack a distinct recent trace, future breakage is liable to take place anywhere within the zone.

RELATION OF THE GARLOCK FAULT TO THE WHITE WOLF FAULT

The Arvin-Tehachapi earthquake of 1952 was one of California's major historic earthquakes and was accompanied by surface rupture along at least 19 miles of the White Wolf fault (Oakeshott, 1955). The White Wolf fault runs approximately parallel to the Garlock fault about 18 miles to the northwest, at the base of the Tehachapi Mountains. The complex surface rupture of 1952 consisted of many discontinuous breaks of irregular trend and length occupying a zone as much as 2 miles wide. Dominant displacement was thrusting of the Tehachapi Mountains over the terrain northwest of the fault, with minor left-lateral movement along many of the breaks (Dibblee, 1955). The Garlock fault was apparently not affected by this earthquake except for a 400-foot-long zone of cracking where the Oak Creek Pass Road from Tehachapi crosses the fault zone. No net displacement across the fault was found here; it is not known whether the cracks resulted from very small displacement across the fault or from compaction of poorly consolidated sediments (Buwalda and St. Amand, 1955). Inasmuch as the White Wolf fault is roughly parallel to the Garlock and experienced some left-lateral displacement in 1952, it appears to be related to the Garlock fault and perhaps reacts to the same or similar crustal stresses as affect nearby parts of the Garlock fault. If so, then the recent movement on the White Wolf fault, which indicates that these stresses are presently active, suggests that the Garlock fault is potentially active also.

[1]East of Fremont Valley, the aerial photographs used were from the U.S. Dept. of Agriculture 1952-1953 1:20,000-scale AXL and ABL series; to the west, they were from the USGS 1966 1:12,000-scale WRD series.

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Strip map of a part of the San Andreas fault south of the Garlock intersection.

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