5. GEOLOGICAL EFFECTS OF THE ARVIN-TEHACHAPI EARTHQUAKE

BY JOHN P. BUWALDA * AND PIERRE ST. AMAND *

ABSTRACT

The Arvin-Tehachapi earthquake of July 21, 1952, originated on the White Wolf fault. This fault runs from west of Wheeler Ridge to the vicinity of Harper Peak. The strike is roughly N 50° E; the length is at least 32 miles and it appears to be a steep reverse fault or a thrust. The overall movement seems to be oblique slip, up dip, with a left lateral component of motion. The vertical offset is greater than 10,000 feet.

The geologic effects included landslides, rock falls, changes in ground water and stream flow, lurches and fault trace development. A series of ground ruptures extended intermittently along the length of the fault, except across the alluvium of the San Joaquin Valley, where lurching was developed. At the foot of Bear Mountain the traces were compressional, indicating thrusting of the southeastern block over the valley, coupled with a small component of right lateral movement. Near the White Wolf Ranch a left lateral tear fault crossed the upper and lower blocks of the White Wolf fault. To the northeast of this the fresh displacements on the White Wolf fault were primarily left lateral and tensional. There are, in places, minor exceptions to the general displacements and nearly all the traces are complicated by landsliding.

INTRODUCTION

The Arvin-Tehachapi disturbance was the strongest in California since the San Francisco earthquake of 1906 and in southern California since the Fort Tejon shock of 1857. Because some of the stronger earthquakes in California and Nevada during the past century were accompanied by surface displacements and other geologic and physiographic changes along the faults on which the shocks originated, it was hoped that similar features would be found along the White Wolf fault. This expectation was realized only in part, and the features developed were quite different from those produced in the San Francisco earthquake of 1906, Imperial Valley in 1940, Owens Valley in 1872, and Pleasant Valley, Nevada, in 1915.

Immediately after the earthquake, instrumental parties, under instructions from Dr. Beno Gutenberg, Director, and Dr. C. F. Richter, Seismologist, of the Seismological Laboratory of the California Institute of Technology, located mobile seismographic units at different and changing points in the earthquake area to record aftershocks with a view to securing evidence on exact location, extent, and mechanism of the faulting, depth of foci, and other problems. The authors, at the same time, started an intensive, systematic field investigation of all the geologic and physiographic changes that occurred at the time of the earthquake along the causative fault. This work continued intermittently for 2 months, and was concentrated along the fault zone. Rupture and other phenomena were abundant for several miles on either side of the fault and some attention was given to them, but field work was terminated when it was realized that all of the myriad of surface evidences of ground disturbance could not be studied—the effort had reached the stage of decreasing returns for time invested.

A brief field examination was also made along the trace of the northwest-trending Kern River fault after a rather strong shock, magnitude about 6.5, apparently occurred on it on July 29, 1952. No evidence of surface fault displacement was found. All the phenomena recorded in this paper are believed to relate to the Arvin-Tehachapi earthquake of July 21, 1952 and possibly to aftershocks centered near the White Wolf fault zone.

Hundreds of ruptures cut the alluvium on the floor of the entire southern end of the San Joaquin Valley at least as far north as points west of Pixley, which is some 45 miles north-northwest of Bakersfield. The authors did not attempt to map these, but other geologists have made careful studies of them in some areas (Warne, Part I, Contribution 6, this bulletin).

In the field study the ground ruptures along the White Wolf fault were traced and mapped carefully from Tejon Hills to Centennial Ridge, 4 miles northeast of Caliente. Similar features were examined on Wheeler Ridge, toward the south end of the fault, and on Harper Peak, which is 9.5 miles northeast of Caliente and possibly near a northeastern extension of the fault. Attention was also given to a number of localities showing other unusually interesting ground fractures, among them the south end of Walker Basin, the west side of Breckenridge Mountain, the higher parts of Bear Mountain, and a short section on the Garlock fault where the Oak Creek Pass road crosses it.

Two preliminary papers relating to the 1952 Kern County earthquakes were published (Benioff, et al., 1952; Buwalda and St. Amand, 1952).

LOCATION AND EXTENT OF WHITE WOLF FAULT

The Arvin-Tehachapi earthquake originated on the White Wolf fault, at the south end of the San Joaquin Valley. This crustal fracture is known to extend from Wheeler Ridge, in the middle of the south end of the Valley, on a course N. 50° E., to cross the eastern margin of the valley to or beyond a point on Caliente Creek 1.0 mile northeast of Caliente. Its known length is therefore about 32 miles. The White Wolf fault was first shown on a map by A. C. Lawson (1906a, facing p. 432) but not mentioned or named by him. It was named and described briefly by H. W. Hoots (1930) and its position was indicated on his geologic map for about 5 miles northeastward from Comanche Point. Previous to the earthquake the surface geologic evidence for the existence, location, and attitude of this fault was rather general. From Comanche Point northeastward, in the Tejon Hills, the inferred fault is roughly a boundary between valley alluvium and the Tertiary formations. Farther northeast it is either a boundary between valley alluvium and the old crystalline rocks of Bear Mountain or lies with old crystalline rocks on both sides. The one possible exception is a fault contact between Tertiary strata to the northwest and the old crystalline rocks on Caliente Creek 1.0 mile northeast of Caliente, but this point may be northwest of the fault. From the Tejon Hills northeastward the zone of the fault trace has nearly everywhere suffered enormous and widespread landsliding from Bear Mountain scarp. The usual types of geologic evidence for tracing a fault between Tejon

* Division of Geological Sciences, California Institute of Technology.

Ed. note: This paper was set in type after Dr. Buwalda's death in August, 1954.
Hills and Caliente Creek, some 16 miles, are therefore missing or have been obscured. The existence and general location of the White Wolf fault was inferred originally from the bold scarp forming the northwest face of Bear Mountain, rising 4,000-5,000 feet above the floor of the San Joaquin Valley, and the depression along its base in which the White Wolf Ranch is located. Since the base of the bold northwest face of Bear Mountain is not a straight regular line, such as marks many steep fault scarps, mainly because of landsliding, and there is little contrast in rock types in the scarp and in the foothills, the exact location and course of the fault trace has not been, and is not now, determinable so far as the writers are aware. It has been located only roughly, and northeast of Comanche Point entirely or almost entirely on physiographic evidence.

Geologists have long suspected that the White Wolf fault is a southwest-trending terminal segment of the important Kern Canyon fault or fault zone which is followed for over 70 miles by the south-flowing main fork of Kern River from north of Mount Whitney to Kernville and which, with a more westerly branch (Breckenridge fault) as shown on Dibblee's map, forms the high scarp bounding Walker Basin on the west. It is not yet certain that this is not the true relation but it appears from the distribution of aftershocks and of ground ruptures that the White Wolf fault probably continues northeastward beyond the point where the Kern River or Breckenridge fault projected southward would meet it. Although it has not been possible to trace the Breckenridge fault to the White Wolf it is improbable that such a long and important fault zone would terminate only a few miles from an intersection with another important fault.

While it has not been possible to trace the White Wolf fault northeastward by ordinary geologic or physiographic evidence beyond Tehachapi Creek, it may be more than a coincidence that a quite strong earthquake, magnitude 6.3, occurred on 15 March, 1946 north of Walker Pass, about 44 miles to the northeast and on or close to its projection. No fault is known at the epicenter of the Walker Pass earthquake.

Reverting now to the southwest 12 miles of the White Wolf fault, from Comanche Point to Wheeler Ridge, it is not indicated by surface evidence. This deeply alluviated plain at the south end of the San Joaquin Valley showed no scarp or warped surface, so far as known, to mark the course of this important fracture, either previous or subsequent to the earthquake. But geophysical studies demonstrate the existence and general location of the fault very clearly. Its position as plotted on the map (plate 2) is based on seismic reflection data and was kindly furnished by M. Rollin Eckis, Chief Geologist, and Dr. Mason Hill, Senior Geologist, of the Richfield Oil Corporation of Los Angeles. The line shown is not the surface outcrop of the fault but its approximate trace, within the limits of geophysical accuracy of location, on the surface of the granite basement. The fault in all probability dips southeastward and the line shown is therefore presumably the northwestern overhanging edge of the granite block southeast of the fault. From the surface near the mouth of Sycamore Canyon, northwest of Comanche Point, the trace descends to an elevation of nearly 8,000 feet below sea level at a point about 3.5 miles southwest of the point. The bedrock trace has apparently veered to a position roughly three-quarters of a mile southeast of the southwestward projection of the nearly straight section of the fault as inferentially traced from Sycamore Canyon northeastward past White Wolf Ranch to the neighborhood of the railroad; since it dips south this is expectable. In the next 6 or 7 miles southwestward the bedrock trace, in approaching the northeast face of Wheeler Ridge, rises from about —8,000 feet to about —9,000 feet. While the geophysical data here are less exact the trace does not appear to return toward the southwestward projection of the surface trace of the fault, but continues sub-parallel to it. If a fact, this is explicable either by a change to a slightly more southerly strike, as it proceeds southwestward, or to a slight flattening of the dip of the fault. The course of the surface trace of the fault as inferred northeast of Sycamore Canyon, projected southwestward, would pass slightly north of the highest point on Wheeler Ridge, and the projected bedrock or seismic trace would pass a bit south of it. It is interesting that a zone of surface ruptures occurs on Wheeler Ridge on the southwestward projection of the bedrock trace; the zone also has about the same trend as the strike of the fault. Presumably the steeper White Wolf fault passes southwestward under the lower, south-dipping Wheeler Ridge overthrust and the Pleito thrust south of it, both of which trend more nearly east-west than the White Wolf. At any rate, in spite of the fact that the epicenters of the main shock and of the one foreshock were somewhat south of the highest part of Wheeler Ridge, no evidence of the White Wolf fault southwest of the ridge was found. From the point where the bedrock trace of the White Wolf fault passes under the northeast face of Wheeler Ridge it is about 17 miles measured along its southwestern projection to the San Andreas fault. One might well suspect that a fault with as large displacement as the White Wolf would continue at depth to an intersection with the San Andreas, which it would meet at an angle of about 60°, but this can apparently only be speculation at present.

It is interesting that the White Wolf fault trends roughly at right angles to the Kern River, Bena, Tejon, and other northwest-striking faults of the eastern part of the southern end of the San Joaquin Valley.

Although the magnificent northwest face of Bear Mountain obviously resulted from relatively recent vertical fault movement at its base, the White Wolf fault had not generally been considered one of the State's active fractures, and an expected source of earthquakes, by geologists in the past. No scarplets due to late displacement along the base of the scarp, such as occur at numerous points along the south base of the San Gabriel Mountains, had been noted so far as is known, and the course of the fault under or through the alluvium between Comanche Point and Wheeler Ridge is not known to be marked by such evidences of recent disturbance as scarplets, sagponds, trenches, and drainage derangement so common along the San Andreas and other major active faults.

**GEOPHYSICAL EFFECTS OF THE EARTHQUAKE**

When movement on the White Wolf fault occurred on the morning of July 21, 1952, an interesting expression
of that movement developed along the fault trace. For nearly 40 miles, a succession of features ranging from lurch cracks to actual fault displacement marked the position of the fault zone. In many places the features were obscured and complicated by landsliding and slumping and in others cross faulting developed on an impressive scale. The following account is a detailed description of the phenomena developed along the surface expression of the White Wolf fault.

Chronologically, attention was first attracted to the fault zone in the region of Bealville where damage was done to the railway tunnels and along the Arvin cutoff road where conspicuous scarplets were developed. This account presents the observations in a geographic sequence, beginning in the epicentral region and continuing in a northeasterly direction to where the fault zone dies out in the region of Caliente. The reader may find the map of the fault trace (plate 2 in pocket) helpful as references, by number, are made to specific localities thereon.

San Emigdio Ranch. The shaking at the San Emigdio Ranch, near the western end of Wheeler Ridge was severe, causing damage to structures and developing a number of gaping furrows 6 inches wide and 200 feet long near the ranch house. The cracks were long and parallel to the contour lines. In places the cracks were best developed in irrigated, filled land. A number of 1- and 2-inch water pipes lying on flat alluvium were ruptured; similar pipes on nearby hillsides were not. The fissures were deemed to be lurch cracks caused by severe shaking rather than actual fault displacement.

Wheeler Ridge. The most southerly ground ruptures that are probably more or less directly related to the movement on the White Wolf fault during the Arvin-Tehachapi earthquake, rather than merely to the lurching which presumably produced most or all of the cracks on the floor of the San Joaquin Valley, lie in a narrow northeast-southwest zone obliquely across the upper half of the highest part of the east-west Wheeler Ridge. This ridge is a more or less isolated feature rising 1000-1500 feet above the flat floor of the south end of the San Joaquin Valley; it lies immediately west of the main Los Angeles-Bakersfield highway—the Ridge Route. The ruptures are of particular interest for several reasons. Ground distortions and fractures, more or less directly related to the fault movement, which are so conspicuous from Caliente to Tejon Hills, are not developed from the 12 miles of flat San Joaquin Valley floor southwest of the Tejon Hills, but apparently reappear in Wheeler Ridge. They occur on the part of the Ridge which is reapparent on the southeastward projection of the first one and begins where the cracks are least and, in a small area, where they are almost too small to be discerned. They are not en echelon, but are not en echelon. They do not occur on other parts of the Ridge. Their trend is that of the fault. Their trend projected southwestward passes close to the instrumental epicenter of the main shock.

As in the Tejon Hills-Caliente section of the fault zone there are at least three types of ruptures on Wheeler Ridge. The most numerous are soil cracks; these are often tens of feet long, occasionally one or two hundred feet long, and tend to be parallel to the contour lines. They are often rather widely open and are clearly due to a thin layer of soil, not over a few feet in thickness in most cases, slipping directly down the slope on the firmer rock surface on which it rested. Some of these cracks developed in other parts of Wheeler Ridge also. A second type occurs around the upper end of old or new landslides; it is more curved, the horns of the arc pointing down hill. These ruptures are clearly the result of movement or resumption of movement of landslide masses, the upper parts pulling away from the stationary ground above. The landslide ruptures were most numerous near the main northeast-southwest zone of ruptures; the local direction of slope of ground determining the direction of landslide movement and hence the trend of the ruptures.

The third and most important of the breaks were the long straight ones which crossed the crest of the hills obliquely on the projection and trend of the fault. Unlike the two previous types they were independent of topography, traversing hills and depressions differently. There were three of these cracks. One began in the deep canyon draining northward west of the主要 group of Standard Oil Co. wells, at a point perhaps one third of the way from the crest of the ridge down to the north base. This crack climbs the hillside with a strike of S. 55° W., and crosses a road at a point 250 feet S. 58° E. of RCI well No. 29. At this point the crack is clearly an old fracture, N. 45° W. faulting from 9 to 60° north-northwest. A layer of gouge about a sixteenth of an inch thick occurs on it. The grooves and striations indicate both equal dip-slip and strike-slip movement, right lateral in direction. The crack continues to the crest of Wheeler Ridge and ends in the second gulch east of the main oilled road leading to the Standard Oil camp from the south. It is roughly ½ mile in length. Near its southwestern end it crossed a tight east-west wire fence at an angle of 30-40 degrees; movement on the crack did not break or slacken this alignment. This could have resulted from the foot of a dip slip on the fracture. The crack is nearly straight in general plan but quite crooked in detail and apparently did not experience much horizontal movement. Usually the northwest side of the crack had dropped down 1 to 4 feet and the opening between walls was 6 to 12 inches wide. The rupture clearly cut the Pliocene Etchegoin formation and was not due to soil slippage or to ordinary landsliding. The southwestern end of the crack is roughly an eighth of a mile southeast of the superintendent's house.

A second long crack ends northeastward at the same second gulch, about 1500 feet east of the oiled road, at which the first crack ends southwestward, and about 300 feet north of its end. Crossing the main oiled road 100 feet south of the east-west fence line and cattle guard about ½ mile south of the camp, it continues with the same S. 50° W. strike across the canyon and beyond the crest of the next northward gulch in the trees of the north enclosed superintendent's house on the hilltop. It passes about 50 feet north of a huge boulder which lies about 650 feet south of the superintendent's house. This crack shows no horizontal offset; the oiled road surface on the north side of the hill dropped a few inches relatively. It is also about three-eighths of a mile south of the 12 mile north of the fault. It is the paved road next west of the one lending northward to the Tejon Hills, is more curved, and is a pole along the road. Search failed to reveal any ground ruptures hereabouts or in the territory to the southwest.

The zone of cracks and the pipeline rupture presumably are the surface expression of fractures and sharp distortion which have extended steeply upward through the Wheeler Ridge overthrust plate from the trace of the White Wolf fault below it.

San Joaquin Valley. There were many cracks in the San Joaquin Valley floor that were distributed over a distance on either side of the fault. Most of them were lurch cracks and were not actual fault displacements. Offsets were two to five feet or more common but as often in one direction as in another, and after a few hundreds of feet, the displacement on a particular crack sometimes reversed. At a point on the Arvin-Wheeler Ridge road about 3 miles north of the fault the slicing was especially severe. Large lurch cracks abounded and a reservoir on the west side of the road was ruined by them.

Comanche Point. There are at least six prominent cracks between Comanche Point and Little Sycamore Canyon, numbered from 6. The crack at point 6 is the most remarkable of all. It is a 4-inch thick overthrust plate from the trace of the White Wolf fault below it.
stone. The crack lies 100 feet above the margin of the valley alluvium.

A 300-foot fracture at point 2, trending N. 40° E., consisting of an echelon cracks indicative of a small left lateral motion, shows a consistent upthrow of 15 inches. This crack is located 100 feet northwest of the base of the hills.

At 3, the crack lies to the southeast of, and overlaps, the one described at point 2. This is not a continuous break but consists of small echelon cracks indicative of a small left lateral strike slip displacement and was accompanied by an upthrow of 17 inches on the southeast side. This crack lies at the base of the hill and is partly in alluvium and partly in bedrock. The down dragging appeared as if the alluvium had settled. The indicated left lateral motion, there is but little other evidence of horizontal movement as the irregularities in the individual cracks fit together. The trace is curved, and along the base of the hills the rupture developed into a compressive moletrack 30 to 40 feet wide and appeared to dip towards the hills at angles of 30 to 60 degrees. This crack does not follow the base of the hill faithfully, but cuts across the base of promontories and then over alluvium-filled valleys and again over the bases of the hills. The trace dies out in the alluvium of the Comanche Creek fan.

The crack at point 4 is a few hundred feet long, down on the southern side a fraction of a foot and trends N. 30° E. It is in the alluvium, about three-quarters of a mile from the fault line. At 10, the base of the hills, at point 5, is a rupture 200 feet long, downthrown on the southerly side. Its trend is parallel to the base of the hill, N. 50° E. and there is some indication of compressive movement.

At 12, to the east of the fault trace, is a rupture that appeared to be the result of landsliding. It is 1,000 feet long, trends N. 30° E., was downthrown on the southwest 17 inches, and is usually continuous. In places however, it developed an en echelon habit with a right lateral pattern. It lies at the base of a face which is apparently the back of a landslide mass. This crack is of interest because it was probably of landslide origin, but resembled those near the fault trace.

**Little Sycamore Canyon.** The northwest end of the smooth, broad alluvial fan is traversed by Little Sycamore Canyon (point 7) which is well developed with a zone of cracks about 30 feet wide with several up to 900 feet in length. The trace is subdued and there was very little vertical displacement. Two or three pressure ridges run parallel to the course of the trace and several 1- to 2-inch cracks indicate a feeble right lateral offset.

**Trace Along the Foot of Bear Mountain, East of Arvin.** Although this portion of the fault trace is the most continuous and impressive of all, it is of different character in different places along its length and at times demonstrates a differing offset. It will be described in detail beginning from the southwest end. The trace was first noticeable at point 8, approximately half a mile south of Bear Mountain Boulevard. Here the trace lies in the alluvium of the San Joaquin Valley. It is distinguished by a series of pressure ridges from 2 to 10 feet in length with little or no evidence for other movement. There was no perceptible change in elevation across the trace. It was difficult to follow in this section because of grass, cultivation and trampling by cattle. Where the moletrack crosses north-south fences it demonstrates right lateral offsets of a fraction of a foot. The trend of the trace in this section varies from N. 22° E. to N. 35° E. Between 8 and 12, the traces form a gradually curving track which turns more and more eastward until it becomes almost east-west at the foot of Bear Mountain. As it nears the mountain it crosses a road not shown on the map and in so doing develops a compression crack 6 inches high and 60 feet long which indicates a right lateral offset.

At point 9 and southwest the trace is a series of pressure ridges with a small amount of right lateral movement. At point 10, the trace developed a clear vertical uplift of 3 to 4 feet on the southeast side, probably indicating uplift of the mountain. Here the trace is a single pressure ridge with a few cracks on the southeast side. The ridge is essentially a buckle, or a broken warp, without great evidence of shortening. There was some evidence of right lateral strike slip movement at this point.

In the vicinity of 11, the trace developed into a series of pressure ridges at the base of a low hill. The total shortening over four of these ridges was estimated as 2 feet. The vertical uplift was of the order of 2 or 3 feet. The evidence of horizontal movement was not clear, of the order of an inch or so, and indeterminate.
respect to the other portion, indicating that the mountain had moved northwesterly with respect to the valley block.

At point 18, the trace is still mainly a compressive moletrack and is accompanied by a vertical offset of 4 feet in the profile of the hill. A combination of open cracks and pressure ridges is present which indicated some right lateral shearing movement.

At point 17, the trace consists of pressure ridges 4 to 5 feet in height over a zone 100 feet wide. The largest ridge is just above the base of the hill and appears to have a dip of 15° or less to the southeast and to offset the profile 2 to 3 feet vertically. It is impossible to determine the nature of the lateral movement at this point, or even if it exists, because of the complicated moletracks and the surficial slumping and sliding which appears to have taken place. At each canyon hereabouts the soil slid down the sides of the canyons into the trough and the whole mass had migrated down hill as well. Between point 18 and point 17, a branch trace ran up a canyon as shown on the map. There are several of these features and they show the same characteristics as the parent moletrack to a large extent but are not as well developed.

Between 16 and 17, the trail has been crumpled by the moletrack and little platelets of dried soil were pushed up to form overtrusted ridges. A broken 1-inch water pipe crossed the trace near here and the ends were offset a fraction of a foot in a right lateral sense.

At point 18 the overtrusted character of the moletrack was best developed. Here a pressure ridge composed of a series of soil plates was found humped up between 6 and 10 feet. The whole movement must have taken place during or since the earthquake because the blades of dried grass when observed, were standing at an angle of 25 to 30 degrees to the vertical, away from the hill side. It was not possible to judge the amount or sense of lateral movement at this point. Just to the northeast, there were tensional cracks developed which indicated a feeble right lateral movement.

The trace continues, mainly as a pressure ridge, or moletrack, with no well defined evidence of shear movement, until a left lateral displacement may be noted at point 19. Here it loses its primarily compression characteristics and demonstrates a 24-foot left lateral offset of a fence. This is contrary to the displacement of all the traces to the southwest where the lateral movement was primarily right lateral in sense and very feeble.

Eastward of 19, the trace continues over the nose of the spur on which 19 is located and then turns up the next canyon to the east. The shaking must have been severe, because boulders near here, both on spurs and in valleys, have been rocked out of their nests and vigorously jostled. This was especially noticeable between points 19 and 23.

The trace makes a sharp turn and proceeds up the canyon, following it faithfully, although changing at times from one side to the other. The trace here is double part of the way, and as it climbs the canyon shows increasing signs of becoming tensional in nature. At point 20, the trace bounds the east side of a swale perhaps 100 feet across. Here the trace is an open fissure, down on the west side on both parts, 3 feet on the easterly part and one foot or less on the westerly part. Broken roots in the trace have displaced ends which showed that the westerly side moved south 6 inches to a foot. A fence stretched across the swale at this point, and formerly occupying the bottom of it, has been stretched so that the lower ends of the posts in the middle of the swale were 7 feet in the air. The posts were formerly buried for about 2 feet of this length and this makes the uplift of the bottom of the fence posts at least 9 feet.

Beyond this point, the trace turns south and begins to double back as if it were ringing a huge landslide mass. The trace dies out at the point shown on the map, showing tensional qualities and having stretched another fence at 21, going over a nose so tightly that it lies upon the ground. Other ruptures at about the 3500 foot level were mostly tensional in nature.

In a number of localities, noted on the map, tensional features may be seen on the tops of ridges above the moletrack which winds along the base of hills.

A search near 19 failed to produce any evidence that there was a moletrack, or fault trace of any sort, going northeasterly to connect with those farther along the scarp in the vicinity of the White Wolf Ranch. There was landsliding in this area, one or two small springs were developed in canyons, and some boulders rocked out of their nests; near the highway, the fills and cuts of which showed considerable mass movement, a large boulder had been rolled down hill and lay partially blocking a small canyon.

Another trace begins at Point 22 and winds along the base of a low scarp, up the White Wolf grade, rounding the edge of the little valley in which the White Wolf Ranch is located and climbs gently toward the hills. This trace is primarily a compressive moletrack with some indication of right lateral strike slip movement. The trace goes over several noses and the compression is enhanced where it climbs their western sides. Near its northwesterly end, the trace begins to climb and soon dies out on the steep slopes of Bear Mountain. It could not be followed northeast of point 23.

North-South Fault Near White Wolf Ranch. The next trace is of considerable interest and trends at a large angle to the others. It is a cross fault with a generalized trend of N. 10°E. The break is continuous and was easily followed for 3½ miles. The predominant displacement was left lateral and varies from imperceptible amounts to several feet. The trace could first be discerned at point 24 near the 3500 foot contour on Bear Mountain. The whole mountain face in the vicinity of the fault is shattered; locally, sliding and mass movement obscure the trace. The whole mass of the mountain appears to be crushed and nowhere are any extensive bodies of solid rock visible. Above the end of the trace, the ground at about the 4000 foot contour, at an excellent spring, suffered severe lurching and sliding. There are perhaps 25 tension cracks between the end of the trace and the spring. Pipes running down hill from the spring were stretched, but not broken, and many of them have been pulled so that they are no longer in contact with the ground. Near 25 the trace offset fences and wheel ruts in a left lateral manner.

At point 25, the trace bifurcates and the two branches continue down the mountain to rejoin at point 26. At the 2800 foot level, the westernmost branch is a crack which is up on the west from 1 to 4 feet. The crack is often a foot to a foot and a half wide and en echelon cracks indicate left lateral movement. Many of the trees here have had branches broken off and one live oak

---

**FIGURE 2.** Tensional fracturing. View east near point 20.

**FIGURE 3.** Stretched fence at point 20; tensional trace in middle ground.
tree with a defective 15-inch trunk was snapped off at the base. Boulders were rotated by slippage on the moletrack. The material between the two branches appeared to have slid down hill. The trace itself seems to be related to minor topographic features, such as small swales, cols and large terraces. The feature persists as a strong left lateral moletrack to the north of 28 and at a point near 27 it leaves the hill and enters the alluvium of the little valley containing the White Wolf Ranch. At point 27 it offset a north-south fence in a left lateral direction some 10 inches, indicating a considerable displacement, even through some depth of alluvium. The trace was easily followed northward as a zone of en echelon fractures, and where it crossed the Arvin road it developed an excellent set of en echelon fractures in the asphalt. The total opening in the cracks, measured along the center line of the road the day following the earthquake was 1.1 feet; the white line was offset 3 inches. Later the road was patched and on 11 August it was noted that the same set of cracks had again opened, indicating that movement on this fault continued for some time after the main shock. The fence wires on both sides of the road were stretched inordinately tight and the barbs were dragged across the fence posts, scratching them deeply and even pulling out some of the staples.

North of 28 the trace closely follows a small stream course as it crosses the next field. It appears that the stream course had been determined by previous movement on this fault, as its course was very straight and ran across the regular drainage pattern. A former crack had been utilized by the vall in the past and was reopened by the earthquake. Where the trace crosses highway 466 at 29, the pavement had been patched and no measure of offset could be taken. The trace crossed 466 at a culvert, still following the water course. North of this point the trace was still distinct and could be followed as a set of en echelon left lateral cracks which continued to point 30, located in a col between two hills.

This cross fault is an important structure and appears to exist in both the upper and lower blocks of the White Wolf system. Perhaps it is primarily a lower block feature and was extended into the upper block by frictional forces but it may actually cut the White Wolf fault in a primary sense, dividing both blocks into two parts.

Between the White Wolf Ranch and Rogers Ranch. The trace at 31 appeared to be greatly complicated by landsliding, the sliding utilizing the trace as an upper boundary and modifying it. Here two rupture zones run around the nose of the spur above the edge of the valley alluvium. The ruptures are sub-parallel to the contours. The upper one is an open vertical fissure, the lower one an over-thrust, flat fracture in the soil. The two ruptures gradually die out toward the center of the area. There is some indication of left lateral shear along the upper, or transiental feature, the north edge of which dropped down a fraction of a foot.

Farther up the same slope near 32, the whole slope is shattered and there are a number of features, primarily tensional, upon which no left or right lateral movement was noted. There may have been some lateral movement, but the features appear to be the result of landsliding.

A trace heading northeastward was noted near the end of this fracture; it continues to the next mole track to the north, at 33, and beyond. There is some evidence that this crack, which also looks like a landslide feature, but which shows left lateral and extensional movement near 33, extends farther to the north, as the road continues in the area near the Arvin Road. The White Wolf Ranch was fractured, as was the Arvin road, 35, one quarter mile west of the junction with highway 466, and 466 itself was fractured at a point N. 5° W. of this point. The indication is that a zone of fracturing of considerably less, and indeterminate, offset crosses the roads and perhaps joins with the north-trending cross fault that passes near the White Wolf Ranch. This trace is dotted on the map to indicate that it is not definitely connectable throughout the whole distance.

The fracture at 36 is primarily a compressional feature with some evidence of left lateral displacement. Pipes crossing the trace are bent and show a general shortening of the area. The edges of the cracks, and occasional en echelon cracks and pressure ridges indicate left lateral movement. The trace is confused near point 33 and terminated in the vicinity of the northeast-trending fracture at that point. To the east, the trace reached a maximum displacement and development in the center of the ridge it transected.

Further up the mountain face at 37, is another trace, removed a considerable distance from the general zone of fracturing. The north side of this rupture was uplifted 6 inches to a foot. There is a spring at both ends and in the middle of it. This extensional trace was first noted by C. R. Allen on 13 September and may not have been made by the main shock, as it was not noticed earlier, when the area was examined, although it is quite possible that it was overlooked. This feature disappears in the detritus in the canyon at both ends.

From 38 eastward the rupture shows left lateral movement all along its length, and the trace it makes on the hill sides suggests that it dips to the southeast under Bear Mountain at angles varying from vertical to 45°. Where the trace of this rupture makes a sharp turn as it does at 39, and the tendency would be for a left lateral fault to pull apart, it developed grabens and extensional fracturing on an impressive scale, some of the cracks being wide enough to admit a man and up to 10 feet deep. West of 39 the trace runs up and down over ridges and was at times hard to follow, but east of 39, the left lateral offset attains several feet and was clearly indicated by offset foot paths, wheel ruts, fences and the sides of a turkey pen. The vertical offset was variable, the south side being uplifted in some cases, the north in others. Where the trace passes near the easternmost house of the Rogers Ranch, a frame building occupied by Mr. and Mrs. C. V. Thompson, it transects a fence, the posts of which were offset in an interesting manner. The posts were vertical, with the top driven into the ground, and seated in the moletrack. When the moletrack was vertical, the posts on either side sloped away from the moletrack. The trace of the fence was also surprising in that it simply bulged or bowed a foot downhill in plan over a distance of 60 feet, to the north threatened, along the center of the road the day following the earthquake there was no simple way to explain this odd distortion, as the road is offset just northeast of here and there is abundant evidence of a left lateral offset to the southwest of this point. Oldham described a similar feature which
be called the Bordwar fracture on page 149 et seq. of his report on the 1897 Indian earthquake.

The trace forks at 40, within 100 feet of this point and one branch, the Bealville fault, departs from the general zone of fracturing and strikes N. 10° E. as does the cross fault in the region of the White Wolf Ranch. The other branch roughly parallels the fence just described, and eventually reaches the railway tunnels which were damaged by the earthquake. The fact that this trace runs parallel to the fence for a distance may have altered the offset of the fence somewhat and perhaps is responsible for the peculiar fence displacement.

**Bealville Fault.** After branching off at point 40, the Bealville fault passes through a field and over the road at the intersection of the Bealville road and highway 466; here it offsets the fence in a left lateral manner and proceeds as a moletrack around the northwest side of the hill, locally known as “Shaking Mountain.” It then crosses the Bealville road, displacing fences on both sides of it by about 1 foot and snapping fence wires. Where the trace crossed the railway tracks 800 feet west of Bealville 8 inches of rail were removed by workers to correct the shortening. The trace crosses a field and ends at 41, a quarter of a mile north of the railway tracks. In places the trace is marked by open cracks with 6 inch gaps; in others the ground surface was humped up. The vertical movement varied, being alternately down on one side and then on the other. Left lateral en echelon cracks mark the course of this fracture.

**South of Sawmill.** Returning for a moment to the region south of the sawmill, there are several rupture traces parallel to the main moletrack. Near 43 is a spring, serving the sawmill, opened by a tunnel driven into the mountain. The roof of the tunnel had caved in about 20 feet from the entrance. A typical compressional moletrack passes parallel to the front of the hill just below the spring; to the west it bifurcates, one branch going up the hill, the other following the base. The upper trace soon ends, but the lower goes around the hill and up into a canyon where the upper trace reappears and joins the lower trace. It then crosses the canyon and enters it again as the canyon swings right. Beyond this point the trace fades out but it reappears in a short distance and continues up the hill parallel to the longer track above it. The indication of movement on this feature is predominantly left lateral with alternating compression and extension along it, but in general there was more extension; it, however, did not amount to more than a few inches.

To the east, the trace has developed characteristics of a landslide or slump feature and continues with interruptions until a trace with a N. 25° E. trend was found at 43 leading eventually to the Bealville fault which it joins. The predominant movement on both was left lateral.

**Railway Tunnel Faults.** Returning to point 40, the southerly branch of the fault may be traced easterly. This branch swings off within 100 feet of the bulged fence near the easternmost Rogers Ranch building, runs subparallel to it for a matter of a few hundred feet, and then strikes across a field displaying a fine set of left lateral en echelon fractures. Where it crossed fences, posts were tilted and wires broken. It then goes over a low ridge just west of highway 466 without changing trend and crosses the highway under a marker post designated KER58E. The pavement was cracked and broken and the moletrack emerges on the northeast side of the highway as a fissure open 6 inches to a foot and displaying signs of small left lateral movement. The northwest side of this fissure went up. This means that the upthrow was, locally at least, on the uphill side and on the block north of the fault. These traces on “Shaking Mountain” at 44 were visited by many people in the weeks following the earthquake. The cracks continued to open after the earthquake. They were first observed the morning following the earthquake and then again 2 days later; in the intervening time they had opened an additional 3 or 4 inches.

As this trace continues eastward it frays into several branches which die out and into two important branches at 45, which pass over the brink of the hill above tunnels 3 and 4 of the Southern Pacific and Santa Fe railroads. One branch passes into a gulley just south of tunnel 3 and the other through tunnel 4.

**Tunnel Area.** The fault zone crossed the Southern Pacific Railroad tracks like the bar in a dollar sign and the three tunnels at two of these crossings suffered severely. Huge excavations and fills were made immediately to reopen the railroad. The tunnel offsets and the high and costly cut faces afforded the best information to be found anywhere along the fault zone bearing on the nature of the fault movement. Only here were cross sections of the ruptures brought to view. These exposures shed considerable light on the true nature of the ruptures or moletracks followed on the surface for miles to the southwest and northeast. Much more detailed information was gathered in the field than can be set forth here.

The southern part of the 700-foot north-south Tunnel 3 was so badly damaged that the southern 206 feet of it was converted to open cut. At the south end the arch or upper part of the tunnel moved relatively 10 inches south with reference to the lower part along a nearly horizontal fracture at the spring line. This was shown by the offset of the portal face and by the bent reinforcing steel. The lower part of the tunnel walls or lining was shoved inward toward the center about 3 feet. The steel rails of the single track were thrown into letter-S figures both inside the south end and south of the tunnel and pushed sidewise through the concrete lining to the rock walls. The deformation of the rails has been described in another section of this bulletin (Kupfer, Muessig, Smith, and White). The movement of the crown portion of the tunnel with reference to the lower part and the kinking of the steel rails indicate or strongly suggest horizontal shortening in a north-south direction such as might result from reverse movement on a southeast-dipping fault.

The clean-walled open cut made south of the south portal at 47 displays beautifully a reverse or thrust fault dipping 20-30 degrees southeast and striking about N. 45° E. It rises northward from below track level on both the east and west sides of the cut from a point about 100 feet south of the new portal to an elevation slightly above the cap of the concrete portal face and hence was exposed on three sides of the cut. On the east side of the cut the rock above the thrust surface is shattered diorite; below it are beds of somewhat compacted sand and boulders.
Figure 8. View west toward fault trace just east of south portal of tunnel 4. T. R. Fahy photo.

dipping about 3° northerly. They are probably old Quaternary sediments and not less than 30 feet thick. These brown and yellow beds enclose the south end of the present concrete tunnel barrel. Ten feet west of the portal face, before being covered by concrete, they could be seen terminating and abutting against a diorite surface sloping 40° E.; this was quite certainly not a fault but a depositional contact. The trace of the thrust fault above the sediments can be followed just over the top of the tunnel; where the sediments end west of the portal it enters diorite and descends southward to track level on the west face of the cut. The diorite above the thrust is badly shattered and is cut by numerous northwest-trending steep minor faults, marked by gouge layers 1-4 inch in width. The trace of the thrust dips about 30° at track level but is convex upward and practically horizontal above the tunnel portal. It is clearly an old fault, for there is commonly half an inch of gouge along it, and in some places as much as 10 inches in pocket-like accumulations. In a cut 50 feet east of and at the same elevation as the portal cap, the striations on the fault surface strike about N. 35° E., suggesting mainly left lateral displacement.

One of the interesting features of this thrust fault is that while movement presumably occurred on it during the main or July 21, 1952, shock which severely damaged the tunnel, which it cut, displacement continued on it after the earthquake. The cut was made about August 1 and a photograph of the west face of the cut made on September 1, 1952. The hanging wall had moved eastward over 2½ inches during August. On an unsecured date, nails had been driven into the gouge above and below the slip surface, their heads originally in contact. Their separation indicated that the direction of movement of the upper block was about N. 45° E., or almost entirely strike slip with left lateral displacement. From dated pencil marks on the underside of the hanging wall it is clear that the movement did not occur at any one time but was distributed, irregularly or regularly, between August 1 and September 15. Oddly, the trace of the thrust fault on the clean east face of the cut showed no offset whatsoever. This raises the question whether the post-earthquake offset on the west face of the cut was the result of aftershocks or fault creep on the one hand or of merely settlement and plastic spreading of the shattered rock in the hill mass above the fault, on the other.

Tunnel 4, now abandoned, was a few hundred feet south of Tunnel 3, trended northwest, and was 334 feet in length. The tunnel was so badly damaged by fault offset, collapse of roof at several places, and shattering of lining that the Southern Pacific Company, instead of repairing it, cut a shelf at tunnel floor level across the hill spur through which the tunnel passed, immediately east of the tunnel, and re-located its track on it. The uncovered barrel of the abandoned tunnel remains. Rising above it to the southwest is a huge cut face, some 400 feet long, roughly 200 feet high, with perhaps 1:1 slope and several berms; an unfortunate necessity, it is a magnificent geological exposure in the fault zone.

The most severe damage in the tunnel was about 80 feet from the south portal, where a fault crossed it and caused uplift of about 3 feet, and a shift of about 2 feet eastward, of the block north of it. This movement continues downhill to Clear Creek and is probably the same break that is so well exposed at 48, at the south portal of Tunnel 5. Westward from the tunnel it rises obliquely up the 200 foot face of the cut with a dip of about 30° southward, and a strike roughly east. The gouge along it is as much as 3 inches wide. The diorite above the fault is gray in color, less shattered and weathered than the diorite below it, which is brown and badly broken and decomposed. The crushed zone along the fault is about 3 feet wide and contains good spherical fault-rolled pebbles, “rollers,” 1 inch-3 inches in diameter. Striations on the footwall on the bench at the top of the tunnel indicate dip slip movement; on the next higher bench, 50 feet above the tunnel, the striations slope 30° eastward on the footwall, suggesting mainly right lateral movement. Below the fault there is a brown weathered zone some 50 feet wide, parallel to it, and northwest of it is more gray, less shattered and weathered diorite. Viewed from a distance the brown weathered zone seems to be steeper than the fault.

Figure 9. Thrust fault that cut tunnel 3; view east. Sketched from photo.

The rupture or zone of ruptures which crosses Highway 496 at 44 forks on top of the hill at 45, above and west of the tunnels and one branch goes down a gulch to the south end of the original Tunnel 3 at 47, where so much damage was done. The more southerly branch goes to the top of the 200-foot high face above Tunnel 4 at 46, and after itself forking, connects with the fault above described which goes through the south end of Tunnel 4. We have the dilemma that the faults indicated at the tunnels show displacements of at least several feet while the molotrackers which are presumably their continuation on the hill above show relatively small offsets both horizontally and vertically.

A slice of bedrock remaining along the northeast side of the tunnel barrel consists of brown somewhat weathered diorite cut by a number of roughly east-west faults dipping southward 45-75°. One minor fault dips about 45° N. The main fault which offset the tunnel is steep in this cross section, still strikes approximately east, and shows about 3 feet of breccia and several inches of brown gouge.

Below the track and roughly opposite the northwest end of Tunnel 4 conspicuous rock outcrops existed, now largely buried by fill. A striking fault cut this outcrop; it dipped about 90° S., with strike of about N. 60° E. It has somewhat the same trend as the main fault which cut the south end of Tunnel 4 but must have been some 300-500 feet north of it.

Another fault cuts the upper part of the south end of the 200-foot cut face above Tunnel 4; it dips roughly 90° S. and strikes approximately east-west.
Longest of the tunnels (1169.6 feet), under the most cover (over 200 feet), and through badly shattered rock, Tunnel 5 was very severely damaged and required months for repair. It is on the east side of Clear Creek from Tunnels 3 and 4, is northeast of them, and hence also in the fault zone. Collapse of the tunnel roof and failure of the disintegrated dioritic rock resulted in three or four glory holes on the hill surface above the tunnel. Long sections of the bore were filled with material which flowed in from the roof. Mr. Mehrwein reported that in one section of 100 feet in the tunnel the track was shortened 2.33 feet.

For train operation a shofty was built around the end of the spur pierced by the tunnel and along it a face over 1,000 feet long was cut nearly normal to the fault zone, all in shattered diorite. Only one fault was found cutting this face; it is near its south end. It dips about 45° S., and strikes about N. 75° E. It is accompanied by a crushed zone about 1 foot wide, with breccia and gray gouge. Traced eastward up the crest of the spur this fracture probably connected with the southern of four long cracks above the tunnel.

The cracks above the tunnel form a zone some hundreds of feet wide trending N. 65° E. and therefore roughly at right angles to the tunnel. They extend from somewhat west of the tunnel line for many hundreds of feet northeastward across the spurs extending southward from the crest of the ridge pierced by the tunnel. These cracks are most conspicuous in large landslide basins just south of the crest and east of the tunnel line. They are up to 12 inches wide and roughly vertical, widest in thick soil, narrowest in thin soil. They are crooked and showed very little horizontal displacement. The total widening across the cracks must have been over 6 feet. The most northwesterly crack of the four showed left lateral displacement in its southwestern portion, right lateral in its northeastern part; the southeast side was down about 12 inches. The other three cracks showed downthrow of 6-10 inches on the northwest side. There are numerous shorter cracks south of this more conspicuous zone, both east and west of the tunnel; one of these, in rising up the ridges east of the landslide basin, showed strong left lateral displacement.

A rather conspicuous fault crosses the south portal cut; it dips about 80° N. and strikes roughly east. Its trend is quite irregular. It may well be the fault which crosses the south portion of Tunnel 4. At Tunnel 5 it connects with a moletrack on the natural land surface both east and west of the cut. Eastward the moletrack goes half a mile to a saddle in the crest of the ridge and ends near a striking old landslide basin. This is Tunnel 5; the gouge zone along it is quite wide. It continued to creep on both sides of the portal cut after the earthquake.

Ground ruptures are virtually absent north of Tunnel 5. Tunnel 6 was not badly damaged but the railroad company deemed it advisable to convert it to open cut.

A rather conspicuous fault crosses the south portal cut; it dips about 80° N. and strikes roughly east. Its trend is quite irregular. It may well be the fault which crosses the south portion of Tunnel 4. At Tunnel 5 it connects with a moletrack on the natural land surface both east and west of the cut. Eastward the moletrack goes half a mile to a saddle in the crest of the ridge and ends near a striking old landslide basin. This is Tunnel 5; the gouge zone along it is quite wide. It continued to creep on both sides of the portal cut after the earthquake.

Ground ruptures are virtually absent north of Tunnel 5. Tunnel 6 was not badly damaged but the railroad company deemed it advisable to convert it to open cut.

A rather conspicuous fault crosses the south portal cut; it dips about 80° N. and strikes roughly east. Its trend is quite irregular. It may well be the fault which crosses the south portion of Tunnel 4. At Tunnel 5 it connects with a moletrack on the natural land surface both east and west of the cut. Eastward the moletrack goes half a mile to a saddle in the crest of the ridge and ends near a striking old landslide basin. This is Tunnel 5; the gouge zone along it is quite wide. It continued to creep on both sides of the portal cut after the earthquake.

Ground ruptures are virtually absent north of Tunnel 5. Tunnel 6 was not badly damaged but the railroad company deemed it advisable to convert it to open cut.

A rather conspicuous fault crosses the south portal cut; it dips about 80° N. and strikes roughly east. Its trend is quite irregular. It may well be the fault which crosses the south portion of Tunnel 4. At Tunnel 5 it connects with a moletrack on the natural land surface both east and west of the cut. Eastward the moletrack goes half a mile to a saddle in the crest of the ridge and ends near a striking old landslide basin. This is Tunnel 5; the gouge zone along it is quite wide. It continued to creep on both sides of the portal cut after the earthquake.

Ground ruptures are virtually absent north of Tunnel 5. Tunnel 6 was not badly damaged but the railroad company deemed it advisable to convert it to open cut.
# Earthquakes in Kern County, 1952

**Summary of data regarding ground rupture.**

<table>
<thead>
<tr>
<th>Trace or location (map numbers, pl. 1)</th>
<th>Trend</th>
<th>Dip</th>
<th>Length (ft.)</th>
<th>Vertical</th>
<th>Extension or compression</th>
<th>Lateral movement</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Side up</td>
<td>Amount (ft.)</td>
<td>Sense</td>
<td>Amount (ft.)</td>
</tr>
<tr>
<td>San Emigdio R.</td>
<td></td>
<td></td>
<td></td>
<td>SE</td>
<td>0-1½</td>
<td>R</td>
<td>Small</td>
</tr>
<tr>
<td>Wheeler Ridge</td>
<td>N45 to 55° E</td>
<td>Steep</td>
<td>3,000±</td>
<td>SE</td>
<td>0-1½</td>
<td>R</td>
<td>Small</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>SE</td>
<td>0-1½</td>
<td>R</td>
<td>Small</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>SE</td>
<td>0-1½</td>
<td>R</td>
<td>Small</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>SE</td>
<td>0-1½</td>
<td>R</td>
<td>Small</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>SE</td>
<td>0-1½</td>
<td>R</td>
<td>Small</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>SE</td>
<td>0-1½</td>
<td>R</td>
<td>Small</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>SE</td>
<td>0-1½</td>
<td>R</td>
<td>Small</td>
</tr>
<tr>
<td>Comanche Point</td>
<td></td>
<td></td>
<td></td>
<td>SE</td>
<td>0-1½</td>
<td>R</td>
<td>Small</td>
</tr>
<tr>
<td>Main Molotrack, East of Arvin</td>
<td></td>
<td></td>
<td></td>
<td>SE</td>
<td>0-1½</td>
<td>R</td>
<td>Small</td>
</tr>
<tr>
<td>Trace at Top White Wolf Grade</td>
<td></td>
<td></td>
<td></td>
<td>SE</td>
<td>0-1½</td>
<td>R</td>
<td>Small</td>
</tr>
<tr>
<td>Cross Fault Near White Wolf Ranch House</td>
<td></td>
<td></td>
<td></td>
<td>SE</td>
<td>0-1½</td>
<td>R</td>
<td>Small</td>
</tr>
</tbody>
</table>

**Evidence**

- Lurches, parallel to contours.
- En echelon cracks
- Alluvium
- Landslide crack?
- Zone ½ mile wide.
- Zone up to 50 feet.
- From here on to 14." north of 14.
- Overthrust zone.
- 100' wide zone, soil slip.
- Soil slip accompanies molotrack.
- 4-5' high ridge, 100' zone.
- Fence pulled up tight.
- Fence pulled down.
- Nothing between 19 and 22.
- Fence trace splits.
- Fences
- Road, fences.
- En echelon cracks
- En echelon cracks; path & fences.
- Fence trace splits.
### Summary of data regarding ground rupture—Continued.

<table>
<thead>
<tr>
<th>Trace or location (map numbers, pl. 1)</th>
<th>Trend</th>
<th>Dip</th>
<th>Length (ft.)</th>
<th>Vertical</th>
<th>Extension or compression</th>
<th>Lateral movement</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Sense (ft.)</td>
<td>Amount (ft.)</td>
<td>Sense (ft.)</td>
</tr>
<tr>
<td>Between White Wolf Ranch and Clear Creek</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>31-32</td>
<td>Curved</td>
<td>--</td>
<td>--</td>
<td>-- 0</td>
<td>E 1</td>
<td>?</td>
<td>L Small</td>
</tr>
<tr>
<td></td>
<td>N-S</td>
<td>--</td>
<td>--</td>
<td>-- 0</td>
<td>E ?</td>
<td></td>
<td>L Small</td>
</tr>
<tr>
<td>34-35</td>
<td>N-S</td>
<td>SE?</td>
<td>--</td>
<td>-- --</td>
<td>C 1 ±</td>
<td>L 1 ±</td>
<td>En echelon cracks</td>
</tr>
<tr>
<td></td>
<td>N70W</td>
<td>V</td>
<td>N 34-1</td>
<td>E 0-34</td>
<td>I</td>
<td></td>
<td>L 1 ±</td>
</tr>
<tr>
<td>36-37</td>
<td>N45-50E</td>
<td>SE?</td>
<td>--</td>
<td>-- --</td>
<td>C --</td>
<td></td>
<td>L &gt;1</td>
</tr>
<tr>
<td>38-39</td>
<td>--</td>
<td>NW</td>
<td>N 34</td>
<td>E 2-3</td>
<td>L &gt;1</td>
<td></td>
<td>En echelon cracks</td>
</tr>
<tr>
<td>39-40</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>-- --</td>
<td>C 1 ±</td>
<td>L &gt;1</td>
<td>En echelon cracks</td>
</tr>
<tr>
<td>40-41</td>
<td>N16E</td>
<td>--</td>
<td>--</td>
<td>-- --</td>
<td>C Small?</td>
<td>L 1 ±</td>
<td>En echelon cracks</td>
</tr>
<tr>
<td>42-43</td>
<td>N45-50E</td>
<td>--</td>
<td>--</td>
<td>-- --</td>
<td>C Small?</td>
<td>L &gt;1</td>
<td>En echelon cracks</td>
</tr>
<tr>
<td>43-44</td>
<td>N20E</td>
<td>V</td>
<td>--</td>
<td>-- --</td>
<td>C Small?</td>
<td>L &gt;1</td>
<td>En echelon cracks</td>
</tr>
<tr>
<td>46-47</td>
<td>E-W</td>
<td>?</td>
<td>2,000</td>
<td>S 34</td>
<td>E 0-34</td>
<td>L Small</td>
<td>En echelon cracks</td>
</tr>
</tbody>
</table>

| Between Tehachapi and Caliente Creeks |
| 49-50                                | N40E  | --  | 1,500        | E 34     | C Small      | I 1 ±        | Fence |
| 50-51                                | N50E  | S75° | 3,000       | S 1      | C ?          | L ?          | En echelon cracks |
| 52-53                                | N50E  | --  | 2,500        | E 3-4    | C ?          | L ?          | En echelon cracks |
| 54-55                                | N15E  | --  | 500          | S 36     | E 1 ±        | L ?          | En echelon cracks |
| 56-57                                | N30W  | --  | 500 ± S      | 36     | I 1-½-3     | L ½-1        | En echelon cracks |
| 58-59                                | N10-20E | --  | 3,400        | E 4-1-½  | 2 to 4      | L ½-1        | En echelon cracks |
| 59-60                                | N70E  | --  | 1,000 ± E    | 34-1½   | --          | L 2-3        | En echelon cracks |
| 61-62                                | N40W  | --  | 500 ± <1     | S 0-½    | E <1        | I 0-½        | Three cracks. |
|                                      | --    | --  | 400 ± <1     | S 0-½    | E <1        | I 0-½        | Three cracks. |

**Legend:**

- **Column Symbol:**
  - DIP (V, E, C, I)
  - Extension or compression (E, C, I, L, R, I)
  - Lateral movement (L, R, I)

- **Meaning:**
  - V: Vertical
  - E: Extension
  - C: Compression
  - I: Indeterminate
  - L: Left lateral
  - R: Right lateral
  - I: Indeterminate.
Tunnel 5 has been the scene of considerable trouble in the past. The roof had collapsed before, following a derailment and fire in the tunnel. The rock flowed down producing a glory hole high on the hill. Four of these glory holes revealed a foot of brown soil and several feet of badly weathered diorite, grading into fresher, but unbroken rock.

Between Tehachapi and Caliente Creeks. Some of the largest cracks and fissures produced by the earthquake were found on the ridge separating Tehachapi and Caliente creeks. At 48 a trace with a trend N. 40° E. went up the stream bluff. The east side of this fracture was elevated 20 inches. The crack crosses the stream.

A compressional moletrack at 50 ran N. 80° E. for about 700 feet; the south side was elevated 2 feet. In crossing an east-west fence, the moletrack slackened the wires about a foot, indicating a combination right lateral and compressional movement.

Beginning at 51 and trending N. 80° E. is a strong compressional crack. The south side was elevated one foot and the trace when crossing a canyon indicates that the feature dips to the south 75°. There seemed to be little if any horizontal motion and the feature cuts across spurs and swales independently of topography. The rupture at 52 was compressional and trends N. 80° E.

Farther up Caliente Creek at 53 an exposed fault dips 50° SE. strikes N. 40° E. It appears from the exposure on the stream bluff that the igneous bedrock crops out on the upstream side and the sedimentary material on the lower side. The rock is so badly macerated, however, that a decision was not possible.

There is a gigantic crack at 54 trending N. 15° E. The east side of which was uplifted 3-4 feet. The crack was extensional and at places developed a graben 50 feet wide and 4 feet deep. This crack itself seemed to show no horizontal displacement, but associated en echelon cracks indicated a left lateral habit.

FIGURE 13. View east toward ground rupture between Caliente and Tehachapi Creeks. Surfaces are jagged, demonstrating lack of appreciable strike-slip movement.

At 55 is a crack a few hundred feet long, downthrown 6 inches on the south side and exhibiting no lateral movement. Parallel to the crack at 55 is a similar one at 56. This is situated on the crest of the ridge and like 55 passes through a col between two knobs. Its trend is N. 40° W., the south side was elevated 4 inches, 6 feet deep; the north side was up-lifted 12 to 18 inches and there was about 6 inches of left lateral movement. Northward this feature runs parallel to the contours, passing through a saddle at a point where the slope of ridge suddenly steepens. The material downhill from it appears to be sedimentary, that uphill appears to be igneous, but it is difficult to decide.

A moletrack at 58 was uplifted 6 to 10 inches on the uphill or southeast side, showed some left hand en echelon cracking and trends N. 70° E. for a considerable distance, about 100 feet east of the ridge.

There are two parallel cracks at 59, each 200 feet long, consisting of beautifully developed shear patterns showing left lateral displacement. The en echelon fractures are 3 inches wide, 20 feet long, and trend north and trend south. The cracks at 59 proceed intermitently to the region of 60 where there is a zone 200 feet wide consisting of about 8 cracks, all of left lateral en echelon habit and each having a different horizontal displacement. The total displacement was perhaps 2 to 3 feet. There are in this zone some parallel cracks each open about 2 inches. Some show uplift of 1 to 4 inches on the east or downhill side.

At 61 is a 4-inch vertical crack trending N. 40° W. with no vertical or horizontal movement.

At 62 there is a group of cracks, all extensional, with a fraction of a foot vertical displacement and with no strike slip movement.

Between 62 and 63 the ground is broken by innumerable small cracks. Southward from 63 the cracks decrease rapidly and no significant break was visible between 63 and 64.

The fissures on this ridge were primarily extensional in nature, but showed compression as they approached stream bottoms; they are disposed to pass through cols or saddles and yet run along the sides of ridges and across canyons disregarding topographic features; they are long and comparatively straight. The trends seemed to fall into two groups; one about N. 50-55° E., the other more nearly north-south. Almost all the lateral movement was left.

No large or continuous fractures were found to the northeast of Caliente Creek, but there were some smaller ones.

Centennial Ridge. North of Caliente Creek and east of Harper Canyon, the northeastern part of this ridge lies approximately on the northeasterm projection of the White Wolf fault zone. It trends more nearly east-west than the fault. Harper Canyon, straight in plan but crooked in detail, has the trend of the fault and may well be an expression of part of it, although it appears to be somewhat northwest of its projection. Centennial Ridge was examined for about 2 miles from its northeast end. Huge landslides which occurred during the main earthquake and its aftershocks produced great scars on its lower south side and its west end.

There are numerous ground ruptures along the crest of Centennial Ridge from its northwest end to about the 3,000-foot elevation, near 65, a distance of about a mile and a half. They are steep cracks striking from N. 50-55° E., and always roughly parallel to the crest of the ridge. They are rather straight, not en echelon, and showed no lateral movement. They were usually open 4-14 inches, sometimes 2-4 inches. Where the ridge is rather sharp, the cracks are in one zone along the top; where the crest is nearly flat there are usually two sets of cracks, one set near each rim of the flat area where it drops off to the steep cliffs. Virtually no ruptures cross the ridge obliquely with the strike of the fault zone.

The fissures on this ridge were primarily extensional in nature, and their location along the sharp crest or along the rims of the flat upper surface of the ridge, lead to the inference that they are primarily due to movement of soil down the slope during the shaking rather than to faulting. However, their abundance and their limitation to the portion of the ridge lying approximately across the projection of the fault zone, suggest strongly that the fault passes beneath the northwest end of the ridge.

From Centennial Ridge one could see scattered landslide cracks along the north side of Harper Canyon and on hill slopes along Caliente Creek to the east.

Harper Peak. Ground ruptures on Harper Peak (elevation 5,700 feet), about 10 miles northeast of the railroad tunnels, are of interest because they are the most northeasterly cracks found and they are roughly on the northeasterly projection of the fault zone. Mr. Weatherwax, a Walker Basin rancher who discovered them, kindly drove the authors to them by jeep. They are on the east and south sides of the top of the peak. Although curved they strike about N. 50° E. Of the several cracks the largest was 1 inch wide and the northwest side was raised 1 inch to 2 inches, and it continued for several hundred feet. There was no en echelon pattern, and no suggestion of horizontal offset. The nests in which individual boulders lie hereabouts show no enlargement and it is clear the shaking was less severe than at the railroad tunnels and at White Wolf Ranch.
Walker Basin. Because the Breckenridge fault, named by Dibblee, which created the imposing scarp west of Walker Basin, has sometimes been thought to be the continuation of the White Wolf fault, this region was examined carefully for ground ruptures. Practically no ground disturbance was noted along the Oil Well Canyon road into Walker Basin. The ridge leading eastward from the summit on this road toward Harper Peak displayed no cracks.

In a borrow pit at 67, on the west side of the highway 1 mile south of the Rankin Ranch, which is at the south end of Walker Basin, several ruptures were found. This is at the south end of the Walker Basin scarp. One about 125 feet long crossed the east side of the borrow pit; the south part of it is on a rock-cut and the north part on an east-sloping grassy hillside. It is crooked and a quarter to half an inch wide. About 400 feet east of the highway there is a crack about 40 feet long on the top of the next little north-south ridge east of the quarry. It is about 1 inch wide and trends N. 5° E. There are a number of other small north-south cracks hereabouts. All seemed to be tension cracks; there was no suggestion of vertical or horizontal offset.

No ground ruptures attributable to the recent earthquake or scarplets in the alluvium produced by geologically late movements on the Breckenridge fault were found at the base of the Walker Basin scarp.

At the Joe Walker mine, on the northeast side of Walker Basin, a long irregular crack in soft wet earth marks the end of what appears to be a landside mass. A spring near the crack was flowing vigorously on August 31, 1952, 6 weeks after the earthquake, and we were informed by Mr. Cannon that at the time of the 1946 Walker Pass earthquake the discharge of this spring was roughly quadrupled.

Breckenridge Mountain. This 7,000-foot north-south ridge lies along the west side of Walker Basin and is apparently a block tilted toward the west along the Breckenridge fault. On its southwest slope a crack was formed at the time of the earthquake, about 1 mile long and striking N. 40° 60°W. It passes through a col at the 4,400-foot level about 1 mile southeast of the junction of Central Fork of Cottonwood Creek and Weys Canyon, at 35° 24' 30" north latitude and 118° 36' 30" west longitude, on the divide between Cottonwood and Walker Basin creeks. The crack is about 4 inches wide, with downslope of 4-5 inches on the south-west side. The manner in which it crosses ridges and valleys suggests that it dips 60°-70° to the southwest. It seems to have been displaced in a right lateral manner in some places, left lateral in others. There is a landslide basin downhill from the crack in some places, but not in others. There was a spring near the southeast end of the crack. The rupture was discovered during range riding by Mr. Charlton, who kindly led the authors to it at the request of Mr. Leroy Rankin of Rankin's Ranch in Walker Basin. Mr. Charlton reported that he did not notice any other cracks on the west slopes of Breckenridge Mountain. This long crack is of interest because it is about 9 miles due north of the White Wolf fault zone at the railroad tunnels; it presumably cuts bedrock and is not merely a soil phenomenon; it has approximately the same trend and seems to lie on the southeastern projection of a line of scarp extending northward from Allen Ranch through Hoosier Flat to Kern River with a strike of N. 45° W.

Garlock Fault

On the day following the earthquake the senior author, through the courtesy of Mr. Hearst of White Oak Lodge, examined the Garlock fault for about 18 miles, from Cottonwood Creek west of the Lodge to Cameron. Numerous short lurch cracks were found crossing the road at different places and with various trends; they were attributed to shaking. At one locality the ground ruptures seemed to have more significance. The paved Oak Creek Pass road to Tehachapi, 0.8 mile northwest of its junction with the Oak Creek road, is crossed nearly at right angles by a zone of cracks; it is 4 feet wide and the roadbed was dropped 6 inches between the two outside cracks, necessitating a detour, regrading, and repaving before the road could be put into use again. This is exactly where the Garlock fault crosses the road. The cracks extend 100 feet west and 300 feet east of the road. Neither side was appreciably uplifted with reference to the other, nor could any lateral displacement be discerned. The trend of the zone of cracks is that of the fault. While the low and damp meadow west of the road approaches a sagpond in form the area east of the road does not appear to be deeply alluviated, so the area should not be particularly susceptible to lurching. It may be that the ruptures merely resulted from shaking, but their length, their position exactly on the fault (and yet no other long cracks found anywhere else in that territory), and the coincidence in strike of the zone of cracks and the fault, cannot but cause one to suspect that some slight local movement or other change in the Garlock fault, presumably triggered by the main Arvin-Tehachapi earthquake of July 21, 1952, may have produced the cracks.

Landslides

Landslides, a common phenomenon on steep slopes in all strong earthquakes, developed on a huge scale in the Arvin-Tehachapi disturbance and its aftershocks. There are two aspects of this subject. One comprises the slides that occurred during this earthquake; the other relates to downhill mass movements of earlier decades and centuries along the White Wolf fault zone.

There were many hundreds of large and small slides on the morning of the main earthquake. They were of course most numerous near the causative fault but many occurred 50-60 miles from it. The main Los Angeles-San Francisco highway, the Ridge Route (U.S. Route 99), was blocked at a number of places between Grapevine and Castaic. Large quantities of rock came down onto the Pasadena-Vincent highway over the San Gabriel Mountains. The road along Caliente Creek between Harper Canyon and Loraine was closed by rock slides for weeks, as was the road up the Kern River gorge east of Bakersfield. In nearly all the deeper canyons on the northwest face of Bear Mountain slides occurred. The steep slopes around Syeamore Canyon, and even some of the gentler areas high on the mountain around the head of this deep cleft, suffered severely and spectacularly from landsliding. Canyons were dammed with rock debris and some small lakes were formed.
Dependent upon topography and rock type the slides took quite diverse forms. Some were types of slides found both under ordinary conditions and after earthquakes: rock falls, avalanches or rock slides; long but narrow shallow soil flows; and old deep and massive landslides which resumed movement for a few feet, opening up cracks at their heads and buckling the ground at their toes. A type unique to strong shocks consists of the movement of the soil as a sheet over the bedrock over quite a large area, sometimes several acres, with roughly subparallel ruptures distributed over the entire area. This was well developed around Sycamore Canyon. In other cases the soil sheet slid down one or both steep sides of a ridge with tension cracks along the crest, or along the two edges or rims of the crest where rounded or nearly flat.

Landsliding on the northwest face of Bear Mountain continued for at least two months after the main shock, probably mainly under the stimulus of aftershocks. Whenever one of the numerous aftershocks was felt, clouds of dust from landslides would be seen rising out of the canyons shortly afterward.

The second aspect of the landsliding related to the White Wolf fault is that along the whole lower northwest face of Bear Mountain and in the flat upland valley lying northwest of and parallel to it landsliding on an enormous scale has apparently been going on for centuries in the past. A large part of a strip from half a mile to a mile wide from Little Sycamore Canyon to the railroad tunnels presents striking landslide topography. It is quite certain that many or most of the small hills in this zone, probably many of the large ones, are the tops of landslide masses. A considerable area northwest of the White Wolf grade, 5 to 9 miles east of Arvin, and a much larger tract south of it, reaching up on the mountain slopes and extending eastward to White Wolf Ranch and beyond, shows convincing landslide topography and macerated rock material. Equally striking subsidence topography lies between the railroad tunnels and the Tehachapi-Bakersfield highway. These landslide masses are mostly large ones, up to hundreds of feet long and wide. Many of them showed little or no effects of movement during this earthquake period. Their unique and characteristic features are that they form ridges or long rounded hills that parallel the mountain front instead of running down the slope as normal ridges between canyons; they often have steep faces toward the mountain front as well as away from it; they often have abnormally flat depressions behind them on the side toward the mountain, some depressions resemble or actually are closed basins; the ridges sometimes divert drainage so that it runs nearly parallel to the mountain face for hundreds of feet; the topography as a whole is the hummocky type so typical of landslide areas; and the material of which the ridges and hummocks are made is completely shattered and much of it is a jumbled mass of rock fragments and fine material.

Landslide topography is so widespread and so marked along the northwest base of Bear Mountain that the authors were very dubious during much of the field investigation whether all of the ground ruptures traced and mapped were not merely landslide features. Unquestionably a large fraction of the total number are of that origin, especially the curved and short ones and the ruptures that trend in directions quite different from the strike of the fault zone. But the long straight ones trending northeast are in all probability the surface expressions of branches of the White Wolf fault that experienced displacement at the time of the earthquake. It would appear from the authors’ observations that an active reverse fault with numerous branches, creating a high scarp, is a very favorable zone for landsliding on a large scale. It creates a wide zone of crushed, pulverized and jumbled rock readily amenable to weathering and open to surface waters; the block above the fault is shattered and weakened; the fault movements produce over-steepened slopes and a tendency to overhang by repeated uplift of the scarp side of the fault; and violent shaking from time to time resulting from the movements aids the constant downward pull of gravity. This seems to the authors to be the explanation of the extreme amount of landslide activity that has occurred along the northwest lower portion of Bear Mountain.

Dislodged Boulders

At many places within a few miles from the fault large boulders resting on hillsides were dislodged by the earthquake and rolled down hill varying distances. In one of the canyons on the face of Bear Mountain south of White Wolf Ranch a sub-spherical boulder about 10 feet in diameter rolled down a long steep hillside, bounding 200-300 feet at a time and cutting trenches 2-3 feet deep at each contact; it finally stopped after mowing down some quite large trees. On the north slope south of the sharp switchback curve half a mile west of the junction of the east-west Caliente road with the main highway, at 71, several large boulders rolled down the hill and one of them jumped the highway. All left spectacular curved dribble paths. At an elevation of about 1400 feet on the White Wolf grade, at 72, a rock about the size of an automobile rolled down against a highway fill near a culvert. About 10 miles from the fault, on the southeastern extremity of Bear Mountain, on the northeast sides of Cummings and Brites valleys and about a mile and a half northeast of the former California Institution for Women, many rocks rolled down the hillside into the canyons and left interesting dribble trails. This is the greatest distance from the fault that extensive rolling of boulders was noted. Landsliding seems to have occurred at much greater distances from the fault than the rolling of boulders.

It is interesting that, as might be expected, it was the large boulders that rolled down the hillsides; the small ones either were not dislodged or were soon trapped. The smaller ones apparently could roll down only the steepest slopes.

Some large rock masses in outcrops or still resting in their nests seemed to have been elevated a fraction of an inch by the shaking and presumed rocking, which permitted smaller rock fragments to roll or slide under them.

In places within the White Wolf fault zone the shaking apparently actually jostled some of the larger boulders at least partly out of their nests, so that they were rotated a bit when they came to rest.

Within one or two hundred feet, and only at that short distance, from any one of the long straight ruptures considered to be actual fault traces, boulders rest-
ing in soil often enlarged their nests in horizontal diameter by 5-10 percent. This appeared to be an inertia effect rather than due to rocking, but it could be both.

**INTERESTING OR UNIQUE FEATURES OF THE FAULT AND EARTHQUAKE**

While no two strong earthquakes are alike with reference to the nature of the shocks and the character of the faulting which causes them, the Arvin-Tehachapi earthquake and the White Wolf fault presented some interesting and unusual features when compared with other California earthquakes and earthquake-producing faults.

1. The shock was the strongest in southern California in nearly a century—since the 1857 Fort Tejon earthquake, which occurred on the nearest portion of the San Andreas fault.

2. The White Wolf fault on which the Arvin-Tehachapi earthquake occurred is surprisingly short for a shock of this magnitude; its known length is only about 32 miles. However, the area of the fault surface is in all probability large enough to make up for the shortness.

3. The majority of strong earthquakes which have occurred west of the Sierra Nevada have originated in the Coast Ranges west of the Great Valley, but this series of shocks centered at the south end and along the east side of the southern San Joaquin Valley.

4. The fault on which the main shock originated does not trend west of north, like the San Andres and the other faults on which so many earlier strong earthquakes have had their sources, but rather strikes at right angles to the San Andres—roughly northeast—and subparallel to the Garlock fault.

5. The White Wolf fault is apparently not a typical strike-slip fault like the vertical San Andreas fault or the vertical Garlock fault, but is mainly a reverse fault, or perhaps even a thrust fault, which has experienced a very large vertical component of displacement in the past.

6. While generally oblique-slip, the movement on the fault in the Arvin-Tehachapi earthquake was apparently more dip-slip than strike-slip; it apparently differed somewhat along the fault, and involved other complexities—all in contrast to the relatively simpler strike-slip movement on the San Andreas fault during the 1906 San Francisco earthquake and the 1940 Imperial Valley shock.

7. The maximum intensity of this earthquake, which is related to the vigor of the shaking and therefore to its destructiveness, seems to have been lower than usual for a shock of this magnitude.

8. There is some reason to think that the intensity was higher on the southeast side of the White Wolf fault than on the northwest. To judge from the damage at Tehachapi, the California Institution for Women, and Monolith, the vigor of shaking was nearly or quite as great in that territory as it was at Arvin on the opposite, or northwestern, side of the fault but only about a quarter the distance from it (44 miles). To be sure the damage at Tehachapi was mainly to old buildings, but those at the women's prison and at Monolith were not weak structures; also, Arvin is located on the deep alluvium of the San Joaquin Valley, in which the vigor of shaking would expectably be accentuated. A plausible explanation for the unsymmetrical distribution of intensity on the two sides of the fault might be that it is due to the fault's southeast dip, toward and under the Tehachapi region. Perhaps the actual permanent displacement of the initial fling enhanced the intensity on the upper block.

9. The White Wolf fault, on which the main earthquake originated, was not regarded by geologists as one of those more active faults of the state along which most of our stronger shocks develop. It was recognized as a young fault because of the age of the youngest (Upper Tertiary) strata which it cuts and the high, bold, and relatively little-dissected scarp on the end of Bear Mountain which it created; but the fault lacked such evidences of recent activity as fresh scarps in alluvium, old moletracks, sagponds and fault trenches—so common along the principal active Coast Ranges faults.

10. Though east- and northeast-trending faults in southern California have for a long time been recognized as active, and though the Santa Barbara earthquake of 1925 presumably originated on an east-trending fracture, most or nearly all of the historic strong shocks in the western part of the state have come from the northwest-trending faults; these have strikingly restless fault physiography, like the San Andreas. Geologists and seismologists have come to expect that future strong shocks will emanate from these long northwest faults. The Arvin-Tehachapi earthquake should modify judgment somewhat on this score. Apparently shocks must be expected in the future from faults not in the old orthodox category. Strong shocks are likely to originate on relatively short faults as well as on long ones; on east- and northeast-trending fractures and perhaps still other trends, as well as on the traditional northwest-southeast Coast Ranges directions; and on faults which do not exhibit striking indications of recent activity and which on the basis of other geologic considerations would not be regarded as being active faults. Since moderately strong earthquakes (Bakersfield August 22, 1952 and others) have now occurred along the eastern margin of the San Joaquin Valley and the floor of the valley is known to be folded and faulted more or less like the Coast Ranges to the west, it is clear that strong shocks will not always be limited in future entirely to the Coast Ranges. They may be expected from foci beneath the San Joaquin Valley and probably from beneath the Sacramento Valley. This probability takes on added importance because of the thickness of alluvium beneath these valleys.

11. The earthquake did not develop a simple clean-cut trace along the fault, like the strike-slip ruptures on the San Andreas fault near San Francisco in 1906 and in Imperial Valley in 1940, or like the dip-slip scarps on the Sierra Nevada fault along the Alabama Hills in Owens Valley in 1872 or the fault along the east side of Pleasant Valley south of Winnemucca, Nevada, in 1915. Instead, a complex pattern of ruptures in a zone along the fault, a half mile or more in width, were formed.

12. The ruptures have quite different trends and the displacements on them are in diverse directions. There are quite long minor faults meeting and crossing the
zone of ruptures at angles approximating 45 degrees. From these facts and from the results of U.S. Coast and Survey re-triangulation and re-leveling, it appears that the movement on the fault may have been quite complicated.

13. While the zone of ruptures marking the northeastern 20-24 miles of the White Wolf fault ends southwestward at the Tejon Hills and the alluvial surface of the San Joaquin Valley between the Hills and Wheeler Ridge, for some 12 miles, does not indicate the existence or the location of the fault, it is a very interesting fact that another series of ruptures appears on the higher part of Wheeler Ridge. The epicenter of the main shock has been located by Dr. Gutenberg and Dr. Richter somewhat south of the highest part of the ridge. The east-trending ridge is an anticlinal structure pushed northward toward the San Joaquin Valley on a rather flat south-dipping thrust fault whose trace would lie near the north base of the ridge. Presumably the White Wolf fault passes beneath the thrust. The ruptures in the upper half of Wheeler Ridge occur where the White Wolf fault would pass under it, and their trend is the same as that of the White Wolf fault. Careful search and inquiry revealed no ruptures in any other parts of the ridge. It would be an odd coincidence if the only ruptures on the ridge, occurring on the projection of the White Wolf fault and parallel to it in trend, were not related to it.

14. It is interesting and rather odd that, huge as the vertical offsets have been on the White Wolf fault, it does not appear to continue southwestward from Wheeler Ridge, and the epicenter of the main shock, to the southeast end of the Kern Canyon fault zone. It is also odd that the surface geology does not more clearly indicate whether the White Wolf fault turns gradually northward at its northeast end near Caliente and merges into the southern part of the Kern Canyon fault zone—or whether the White Wolf continues northeastward from Caliente and whether the Breckenridge does not connect southward to intersect or join it. Possibly the White Wolf connects with both the San Andreas and the Breckenridge faults at depth.

15. The epicenter of the main shock is even southwest of the known southwest end of the White Wolf fault and from the fact that all the aftershocks occurred northeast of the epicenter it is believed that the slip on the fault that caused the earthquake progressed in only one direction from the point of initial rupture. Only the single foreshock, which occurred about 2 hours before the main shock, originated southwest of the main shock epicenter.

16. The many aftershocks, a number of them actually moderately strong earthquakes, did not all originate in the fault which caused the main shock; a large fraction of them apparently had their source in the block above and the block below the sloping fault surface and at a distance of some miles from it.

17. From the initial shock at 4:52 on the morning of July 21 until the afternoon of July 22, the aftershocks all originated in the block above and southeast of the fault; later the aftershocks occurred in both blocks.

18. The sequence of events in connection with many strong earthquakes has been thought to be the occurrence of the main shock, preceded by some or no foreshocks, and followed by a long train of aftershocks in or close to the fault surface, decreasing in general both in frequency and in magnitude during the ensuing months or a few years. In the case of the Arvin-Tehachapi earthquake, in addition to the long train of aftershocks, a series of quite independent earthquakes developed in the months following the main shock, some of them presumably on faults roughly at right angles to the White Wolf and with epicenters up to 20 miles distant from it. Each of these shocks had its own train of aftershocks. Some of the shocks were moderately strong earthquakes which did damage at nearby points, as for instance the one which struck Bakersfield August 22, 1952, a month after the Arvin-Tehachapi earthquake, and caused major damage at Bakersfield.
EXPLANATION

Quaternary landslides

Mio-Pliocene Chonoc and Beno fms. continental sediments

Miocene marine sediments (Santa Margarita sand, Maricopa shale, Round Mountain sh., Temblor fm., Freemon sh., Pyramid Hills and Vedder sands)

Oligocene (?) Walker fm., continental sands

and gravels, including Bealville fanglomerates and Tecuay fm.

Eocene Tehachapi fm., marine

Jurassic(?), hornblende-biotite quartz diorite, inclussions of Paleozoic-Triassic(?), Kernville & Pompa quartz schists, limestone

Pre-Cambrian(?) Pelona schist

--- Fault-vertical or near-vertical

- Fault-normal or near-normal to normal (hachures indicate dawn thrust block)

--- Fault-reverse or thrust (toward upthrust block)

Faults solid where accurately located, dashed where inferred, dotted where concealed. Arrows indicate strike-slip or lateral movement.

Geology generalized by T.W. Ottsbee Jr.
STATE OF CALIFORNIA
DEPARTMENT OF NATURAL RESOURCES

MAP OF THE WHITE WOLF FAULT ZONE
SHOWING EARTH RUPTURES PRODUCED BY
THE EARTHQUAKE OF 21 JULY, 1952
Compiled by J.P. Buwalda and Pierre St.Armand

EXPLANATION
Boundary of landslides
Fault, dashed at approximate location, dotted where concealed
Earth ruptures, relative movement indicated by arrows, up U, down D
Anticline showing plunge

BULLETIN 171 PLATE 2

SCALE

Contour interval 100 and 500 feet, dashed contours at 1000 feet below sea level on basement-sediment contact
EARTHQUAKES IN KERN COUNTY CALIFORNIA DURING 1952

(A symposium on the stratigraphy, structural geology, and origin of the earthquakes; their geologic effects; seismologic measurements, application of seismology to petroleum exploration; structural damage and design of earthquake-resistant structures.)

Prepared Under the Direction of
OLAF P. JENKINS
GORDON B. OAKESHOTT, Editor

Price $4.00