The Recent Arvin-Tehachapi, Southern California, Earthquake[1]

John P. Buwalda and Pierre St. Amand

California Institute of Technology, Pasadena

THE STRONGEST EARTHQUAKE experienced in California since the San Francisco earthquake and fire of 1906 shook the southern end of the San Joaquin Valley on July 21, 1952. It was probably the largest seismic disturbance in the populated western portion of southern California since the Fort Tejon earthquake of 1857. Its magnitude was intermediate between the San Francisco earthquake and the more moderate shocks that occurred at Santa Barbara in 1925 and at Long Beach in 1933. On the Richter magnitude scale, which is designed to represent the energy of a shock, and on which the numbers are proportional to the logarithms of the square roots of the total energy dispersed by the earthquake waves during the shock, the magnitudes of the Arvin, San Francisco, and Long Beach disturbances were, roughly, 7.5, 8.2, and 6.3. The violence of shaking at a particular place is represented on the modified Mercalli scale, with the maximum figure XII indicating total destruction. Intensity naturally decreases with distance from the center of origin. This scale is based on human sensory impressions, disturbance of objects, or damage to buildings. It is believed that the Arvin shock reached an intensity of about X in the most heavily shaken zone.

The shock has been named the Arvin earthquake[2] because the center of the disturbance was much nearer to that town than to any other. Newspapers have called it the Tehachapi earthquake for the reason that damage in that community was more spectacular and was called to the attention of the newspapers first. Fourteen lives are known to have been lost in the July 21 Arvin shock, and two more persons were killed in a later disturbance at Bakersfield on August 22. The number of deaths was relatively small, considering the magnitude of the earthquake, because the fault along which the disturbance took place traverses territory in which no large towns are located. The section is mainly agricultural or pastoral and is relatively sparsely populated.

The shock was felt over a very large area. It shook the densely settled Los Angeles region about 80 miles to the southeast quite vigorously and alarmed the population. It was felt at San Diego and points farther south in Mexico, more than 200 miles away; at points north of San Francisco, roughly 300 miles to the northwest; and at Reno and in a large part of southwestern Nevada.

Property damage in the main Arvin and succeeding Bakersfield shocks has not yet been accurately estimated, but it will presumably total several tens of millions of dollars. As is usually the case in earthquakes in California, the damage to buildings was mainly in business and industrial structures rather than in residences. Brick and concrete-block parapet walls, cornices, store fronts, and side walls collapsed or fell outward when the buildings swayed. In some cases roofs dropped when the supporting walls fell away. These are the common types of earthquake failure. In the strongly shaken communities frame residences did not collapse or suffer material structural damage, but many lost brick chimneys, and had plaster badly cracked, and a few were shifted a few inches on their foundations, suffering rupture of water, gas, and sewage lines.

The town of Arvin is a young community of relatively new buildings, situated about four miles northwest of the earthquake-producing fault. Here, although more than half the business establishments on the main street suffered damage, none was damaged beyond repair. In Tehachapi, a larger and much older town in the Tehachapi Mountains, about 15 miles southeast of the fault, the damage was more severe; nearly all business structures were at least considerably damaged (Fig. 1), and a substantial fraction of them were completely wrecked. Nearly all the loss of life occurred here, most of it as a direct consequence of building collapse.

The greater destruction in Tehachapi, nearly four times as far from the fault trace as Arvin, can probably be ascribed mainly or entirely to the greater age and poorer construction of the buildings rather than to more violent shaking. In Bakersfield, about 19 miles northwest of the fault, and, like Arvin, situated on the flat floor of the deeply alluviated San Joaquin Valley, the damage from the July 21 earthquake was considerable but not severe. A much smaller second shock on July 29, originating on a fault only about 10 miles to the east, did some additional damage. The most extensive loss in Bakersfield resulted from a third earthquake on August 22. This shock badly damaged many business structures and caused some to collapse. Loss was severe along Chester Avenue, one of the older main north-south streets of the city. As usual, the failure was mainly in brick, stone, adobe, or concrete-block construction. There was slight damage on July

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[2] The name more recently settled upon for the shock is the Arvin-Tehachapi earthquake.

FIG. 1. Earthquake damage in Tehachapi, California, in shock of July 21, 1952. Illustrates a very common type of building failure in earthquakes: toppling outward or collapse of brick parapets, fronts, and side walls, which permits dropping of floors and roof trusses.

21 to buildings in Santa Barbara, about 65 miles southwest of the origin of the shock, as well as in Los Angeles, about 80 miles southeast of it.

The most severe loss in the Arvin earthquake was probably not in damage to buildings. In the southern end of the fertile San Joaquin Valley hundreds of miles of large concrete irrigation pipe buried in the fields were ruptured or telescoped by the earthquake waves. Concrete standpipes were sheared off at their bases, and the many large transformers serving the numerous deep-well irrigation pumps were toppled off their supports some 25 feet above the ground. There was considerable damage to the expensive wells and pumping equipment. Lower crop yields resulting from interruption of water supply during the height of the growing season will doubtless cause great losses.

In the extensive oil operations of the area affected by the shock, damage to oil wells and pumping equipment was not great, but oil, gasoline, and gas pipelines suffered severely from rupture or telescoping. High-pressure pumping plants and equipment of the various oil companies in the strongly shaken area were badly damaged. Large oil tanks resting on the ground settled, warped, and developed leaks. Smaller oil and water tanks mounted on elevated timber platforms crushed their supports, falling to the ground in the general direction of the fault, regardless of the side of the fault on which they were located.

Lurching in the deep alluvium of the San Joaquin Valley led to unequal settling, cracking, humping, and local horizontal shifting of the ground, with resulting damage to highway pavements, bridge approaches, irrigation reservoirs, and ditch systems.

The Valley Line of the Southern Pacific Railroad, used in this section jointly with the Atchison, Topeka & Santa Fe, crosses the fault zone three times in the course of a switchback, making a pattern with the fault zone resembling a dollar sign. Four tunnels in this loop were severely damaged and rendered unusable. In a frantic three-week effort to reopen the line to traffic, marked by epoch-making records in rates of excavation and fill, two of the tunnels and part of a third were converted to open cuts, and the fourth bore was by-passed with a shoofly track and is now being repaired.

The Arvin earthquake and succeeding shocks have been, and are still being, thoroughly investigated, both geologically and seismologically. In the field the very extensive and complex fracture pattern developed in the earthquake belt has been minutely studied and mapped, especially by the authors. The staff of the Seismological Laboratory, Drs. Gutenberg (director), Benioff, and Richter, with several assistants, have been analyzing a wealth of excellent seismographic records from approximately a dozen permanent stations of the California Institute of Technology, from stations of the U. S. Coast and Geodetic Survey scattered over southern California and Nevada, and from the several portable installations rushed immediately into the earthquake zone to record the hundreds of aftershocks, which are still continuing.

The Arvin earthquake originated through slip, not on the well-known San Andreas fault, which runs the length of the west side of California, or on any of the other northwest-southeast strike-slip faults long recognized as active, but on White Wolf fault (Fig. 2).

This important fracture trends northeast-southwest across the south end of the San Joaquin Valley, at right angles to the valley and to the San Andreas fault. It is roughly parallel to Garlock fault, a fracture on the opposite, or southeastern, side of the Tehachapi Mountains, which branches off the San Andreas near Tejon Pass and extends some 160 miles eastward to the south end of Death Valley. The known length of White Wolf fault is about 30 miles. It seems to have been first recognized by Lawson (*1*) half a century ago and was given its present name by Hoots (*2*). The habitual direction of slip on this fault in past geologic time is not definitely known, but its movement has had a vertical component that lifted the southeast side many thousands of feet relative to the block northwest of it. There is reason to believe that the fault is a thrust dipping steeply or moderately to the southeast.

To the southwest, approximately half the length of the fault lies beneath the alluvium of the San Joaquin Valley and has no surface expression, but it is conspicuously shown on geophysical (seismic reflection) maps. Data kindly made available by Rollin Eckis, chief geologist of the Richfield Oil Corporation of Los Angeles, indicate that the fault is known to continue its nearly straight S50°W course to within about 3 miles of the east-west north-facing scarp of Wheeler Ridge. The ridge is a sharp fold, overturned toward the north and cut by a south-dipping thrust, but the relation of White Wolf fault to this structure is not known. A narrow zone of long cracks crosses the higher part of Wheeler Ridge obliquely to its long axis, paralleling White Wolf fault almost exactly where the projection of the fault would cut the ridge. Similar cracks are not known on other parts of the ridge.

The Richfield maps show that on the southeast side of the fault, near its known southwestern end, the top of the Santa Margarita formation (upper Miocene) is at 4000 feet below sea level, whereas on the northwest side and two miles away the same horizon lies at −15,000 feet. One mile southwest of Comanche Point (Tejon Hills) the Santa Margarita is at −3000 feet on the southeast side of the fault, and at −12,000 feet less than a mile away on the northwest side. On Wheeler Ridge itself the same formation is 1000 feet above sea level, but two miles to the north it is at −14,000 feet; four miles to the north it is at −16,000 feet. Mr. Eckis states that in drilling along the northwest side of the fault steeply dipping and vertical beds are encountered to depths of thousands of feet, presumably dragged up by the fault movement.

About five miles south of Arvin the fault, still beneath alluvium, cuts off the northwest-trending structures in the Tertiary formations of the Tejon Hills. About four miles east of Arvin a system of surface ruptures begins and extends northeastward for some 18 miles along the hilly lower slopes of the great northwest-facing scarp of Bear Mountain and approximately along the presumed locus of White Wolf fault. In this stretch the surface rocks are mainly diorite, with a mantle of soil and disintegrated and decomposed rock. The lower half or more of the Bear Mountain scarp, which attains nearly 5000 feet in height, has suffered extensive landsliding, which has formed many ridges trending roughly parallel to the slope instead of extending up and down it, as well as closed or nearly closed basins behind (or uphill from) the ridges; has diverted streams for hundreds of feet to right or left of their original positions; and has shattered and crushed practically all the surface rock. These landslides had rather completely masked the location of White Wolf fault before the earthquake. Its location is not now evident, except that a zone of ruptures a fraction of a mile wide presumably marks the general position of the trace.

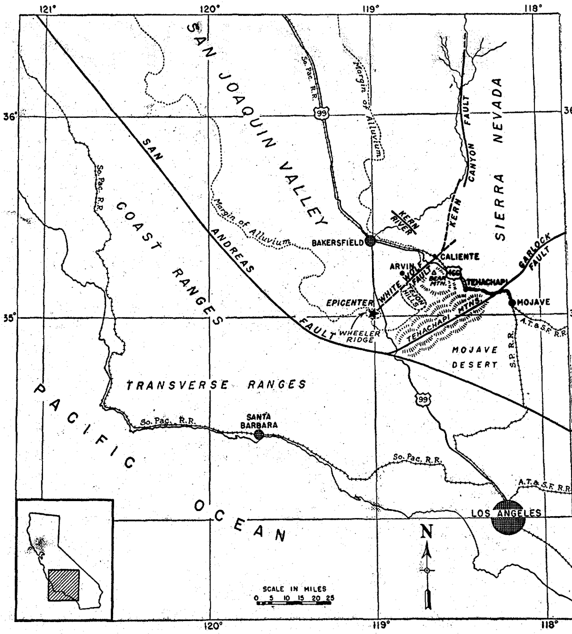

FIG. 2. Map of part of southern California showing some of the principal faults, White Wolf fault on which the earthquake originated, and location of epicenter.

It has been suspected for a long time that the Kern Canyon fault, which is followed for more than 70 miles by the south-flowing main fork of Kern River from north of Mount Whitney to Kernville, continued southward and southwestward to join or become White Wolf fault. It probably continues southward to an intersection or union with it, but it now appears from the northeastward persistence of the ground-rupture system and the distribution of aftershocks that White Wolf fault continues on its own course for at least some miles northeastward beyond the presumed point of intersection. It may go to upper Harper Canyon or beyond.

The epicenter of the main Arvin earthquake was approximately at Wheeler Ridge, at or near the known southwest end of White Wolf fault. From this initial point of rupture the fault slip apparently progressed rapidly northeastward and only in that direction, for all or practically all the hundreds of aftershocks originated northeast of the epicenter of the main

FIG. 3. One of the wider cracks in alluvium caused by the earthquake. On crest of ridge between Tehachapi and Caliente creeks, in fault zone. Photo by Southern Pacific Railroad.

shock. Perhaps of equal significance is the fact that the only foreshock, preceding the main shock by a few hours, occurred a short distance southwest of the main epicenter. Aftershocks can, of course, be expected to continue for several more months.

A strong earthquake is usually followed by a train of aftershocks that decrease in average frequency and in magnitude. In some cases a strong shock apparently unbalances crustal strains in the region in such a way that further relief by fault slip is soon necessary. The Arvin shock seems to have been in this category. Following the main July 21 earthquake, a second shock, on July 29—weaker but still moderately strong, and comparable to the Long Beach earthquake of 1933—originated 10 miles east of Bakersfield and did some additional damage in that city. Its focus may well have been on the northwest-southeast Kern River fault, which trends at right angles to White Wolf fault. On August 22 a third shock of comparable magnitude but originating only about five miles east of Bakersfield caused serious damage in that city—far more than either of the preceding earthquakes and estimated to be as high as $20,000,000. Each of these two later shocks had its own train of aftershocks. On August 20 a strong shock (magnitude greater than 7.0) originated on the San Andreas fault near the known northern end of its active belt off the southwestern Oregon coast. On August 23 another earthquake, of magnitude 4.5, occurred on or near the San Andreas between Palmdale and Elizabeth Lake, with its epicenter about 50 miles southeast of that of the Arvin shock. All four of these disturbances on faults other than White Wolf could, of course, be unrelated to the Arvin earthquake, but they are probably sympathetic and are the result of readjustments in the stress pattern in the fault net of the state. In the southern San Joaquin Valley region this net consists mainly of intersecting faults trending northeast-southwest, east-west, and northwest-southeast.

Several of the stronger earthquakes in the Southwest have been accompanied by the development of long and continuous surface traces of the originating faults, with vertical or horizontal offset of the land surface, roads, fences, streams, property lines, and other features. No such simple, continuous rupture resulted from the slip on White Wolf fault during the Arvin earthquake, and the writers have not seen much evidence of earlier scarplets or fault troughs. Although numerous fractures, long and short, of a variety of types occur, it is not certain that any one of them is actually the trace or outcrop at the surface of the main White Wolf fault. What, then, was the nature of the surface distortion where the fault plane, rising from a depth of at least 10 or 15 miles, intersects the landscape? So far as known, it caused no visible surface distortion on the flat alluvial floor of the San Joaquin Valley. In the hilly diorite or granite country between Arvin and some point north of Caliente, mostly along the base of the Bear Mountain scarp, a zone of ruptures a fraction of a mile in width marks the supposed course of the fault. Some ruptures are simply cracks (Fig. 3) roughly parallel to the fault zone (trending N50°E), fractions of an inch to inches in width, but locally one to three feet wide. They may or may not show horizontal or vertical displacement—usually in terms of inches, rarely a foot or two. The uplifted side

FIG. 4. Typical *en échelon* cracks, indicating left-hand horizontal shearing movement. Near Tunnel 5 of Southern Pacific Railroad.

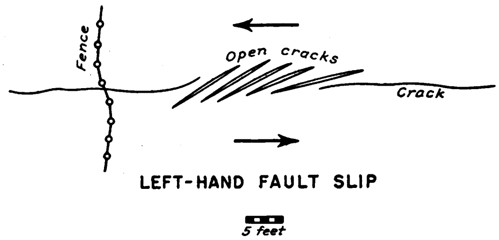

FIG. 5. Diagram of open *en échelon* cracks in alluvium caused by the Arvin earthquake and found at many places along the northeastern half of the fault. Inference of horizontal displacement on the cracks is corroborated by offsets of fences, roads, and trails.

is usually on the uphill side, but this is commonly reversed. The cracks apparently indicate tension. In places the cracks, which are crescentic in plan with the horns pointing downhill, appear to be the upper boundaries of large surface masses sliding downhill and pulling away from the surface material uphill from them. Many of the cracks are discontinuous and overlapping, oblique to the zone of cracks; they are *en échelon* (Fig. 4). These are believed to have re-

FIG. 6. Typical mole track, or compression ridge, in alluvium about four miles east of Arvin, California, viewed southwest toward point in east margin of alluvium of San Joaquin Valley, where long cracks and mole tracks end. Mole track at this point actually consists of *en échelon* mole tracks (seen in foreground to left of figures), indicating right-hand horizontal movement as well as compression. Block to left of mole track has risen about two feet with reference to block on its right.

sulted from horizontal shear, and the orientation of the open cracks with reference to the zone is thought to indicate the direction of shear and movement (described as left-hand when the mass on the other side of the zone or fault has shifted horizontally to the left with reference to the side on which the observer is standing [Fig. 5]). Left-hand movement seems to be much more common than right-hand, but right-hand and left-hand movements were noted at different places on the same long lines or zones of cracks. Another surface feature is the so-called mole track, a crooked, compressional ridge formed by humping up or buckling of the soil to a height measurable in inches or, at most, a foot or two (Fig. 6). Miniature overthrusts commonly accompany the mole tracks; they may dip either downhill away from Bear Mountain or toward it. They tend to be *en échelon,* indicating both compression and horizontal shear, either right- or left-hand. Rupture lines or zones two or three miles in length, which contains all these features, have been taken by many geologists to be actual traces of White Wolf fault. A rupture line may extend for hundreds or thousands of feet along the base of steep slopes, then it may go obliquely up over a high ridge, bearing no relation to topography. It may stand steeply where it crosses one canyon, but follow the contours horizontally back into the next canyon. At its end it may turn up the mountain face and rise one or two thousand feet before terminating. Some zones of cracks are found only along the crests of high wide ridges, as though the soil mantle had been shaken downhill on both slopes. The mole tracks—pressure ridges—are found most commonly along the bases of scarps and ridges. To complicate the pattern there are three or four rupture lines about two miles in length which extend from points on the Bear Mountain scarp across the presumed location of White Wolf fault out into the flat or gently rolling country to the northwest, with almost exactly north-south trends, making angles of about 50° with the main fault zone.

In the enormous cuts made by the Southern Pacific Railroad to replace the tunnels, it appears that the mole tracks on the landscape above the cuts are connected with old fractures or minor faults in the bedrock. In one of these fractures, dipping about 28° to the southeast and striking roughly parallel to White Wolf fault, old crystalline rock has overridden Quaternary gravel of the adjacent Clear Creek and old soil that accumulated on it. At or near this point the railroad track was shortened some eight feet by kinking (Figs. 7, 8). This looks like an overthrust fault, but it could equally well be a fracture at the base of a huge landslide. In spite of the low dip of the fracture, the movement on it as indicated by slickensides was horizontal; it is a strike slip. During the month of August the upper block moved northeastward two inches horizontally, as indicated by markers on the west side of the cut south of Tunnel 3. The post-earthquake movement and its direction can be reconciled better with landsliding on a huge scale than with faulting, but in this article it is not possible to discuss more of the characteristics of the fracture pattern than suffice to indicate its complexity. Full tectonic implications can come only by eventually combining all the geologic, structural, and seismological data. At this stage it is perhaps advisable to do no more than draw the following preliminary and probable inferences: (1) White Wolf fault, lacking such features as sag-ponds, offset streams, etc., is not a strike-slip fault of the San Andreas type. (2) It has experienced huge vertical dislocation in past geologic time, as evidenced by the high scarp of Bear Mountain and the buried structure along it beneath the alluvium of the San Joaquin Valley; hence the southeast side of the fault presumably rose during this earthquake. (3) Its straight course suggests that it is steep or vertical in

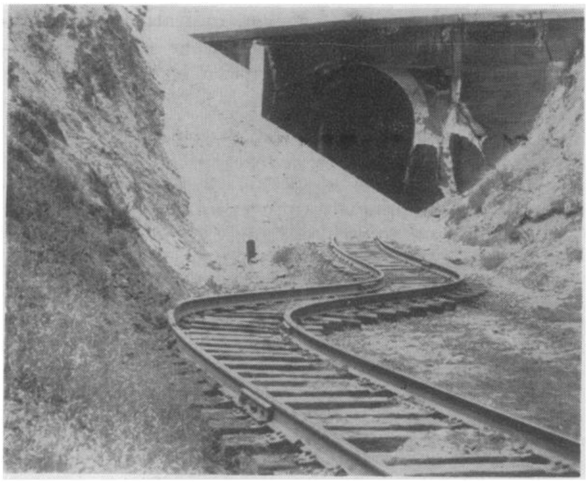

FIG. 7. View north toward the south end of Tunnel 3 of the Southern Pacific Railroad, showing part of damage to tunnel where one of the long cracks crossed the bore near its portal at a large angle. Also shows sharp kinking and presumed shortening of track by some eight feet, part of which occurs beyond white waste pile within tunnel.

FIG. 8. View into south end of Tunnel 3, showing kinking of track and damage to reinforced concrete tunnel walls, which here were pushed inward over kinked rails.

attitude but, if not, the buried fold in the sedimentary rocks under the valley suggests that it is a thrust fault dipping southeastward. (4) Comparing the magnitude of the earthquake with others in the Southwest for which the fault displacement was observed, the slip on White Wolf fault during this shock was probably 5–15 feet in the bedrock at depth. (5) The dislocation on the fault did not develop a single or simple continuous surface trace, as in many other earthquakes, but the complex rupture pattern, with its variety of fracture types, trends, and directions of displacement, is probably largely or wholly the result of shaking combined with gravity acting on small to huge earth masses, many of them blocked out by previous earth-mass movements, or it may represent relief of strain by distribution of the movement over a wide zone of incompetent material, utilizing smaller preexisting faults for this purpose.

In recent years Benioff has made intensive studies of elastic strain rebound characteristics. He thinks (*3*) that the aftershock sequence of the Arvin earthquake is such as to indicate that the strain relieved by the earthquake was mainly of the compressional type rather than the shearing type so common in Coast Range shocks.

In spite of textbook generalizations, earthquakes are found to differ greatly among themselves when studied carefully, and the Arvin shock exhibited several unique, or at least remarkable, characteristics. Although a large earthquake, it did not develop the common type of surface trace. The fault appears remarkably straight for a fault that is not of the strike-slip type. The earthquake occurred on a fault which, so far as known to the writers, has little or none of the evidence of recent activity along it usually associated with active faults in California. Considering the magnitude or energy output of the earthquake, its destructiveness appears to have been surprisingly low. The vigor of shaking seems to have been unsymmetrically disposed about the fault, in that the violence at Tehachapi and the Women's Prison, 12–16 miles away, was apparently not very different from that at Arvin, only about one fourth the distance from the fault and located on at least as great a thickness of alluvium. As mentioned earlier, all or virtually all the aftershocks occurred northeast of the epicenter of the main shock, whereas the one foreshock was apparently southwest of it. Most of the springs in the strongly shaken region increased their flow two- to fourfold, but some ceased to flow; streams normally dry in summer developed large flows of water within a few days, presumably after discharge from the bedrock had saturated the bed gravels; Caliente Creek above Caliente, normally dry in midsummer, was flowing an estimated 20 cubic feet per second on August 20, 1952.

The Arvin earthquake taught the same lesson that shocks in different parts of the world have taught humanity for decades: that earthquakes, per se, rarely harm anyone; that structures designed to be earthquake-resistant suffer little or not at all, whereas walls, parapets, and building fronts made of brick, adobe, or concrete blocks that are not reinforced with steel and tied securely to the remainder of the building collapse or fall outward, harming persons near them and permitting the interiors of the structures to fall. From comparisons of the behavior of different types of buildings in numerous shocks, it is perfectly evident that the solution of the earthquake problem is simply to build wisely by choosing proper design and appropriate materials. Fortunately this can be done with little added cost. Safety from earthquakes is more easily attainable than safety from floods, tornadoes, hurricanes, and some other natural hazards.

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