9 February, 06:00:41.6. Mag. 6.4. Main shock of the San Fernando earthquake. Epicenter 34°24.7' N., 118°24.0' W., southern California, at a depth of about 8 km., P. This location is about 14 km. north of San Fernando in a sparsely populated area of the San Gabriel Mountains. No foreshocks were recorded. Numerous strong aftershocks were recorded. One hundred seventy-four aftershocks of magnitude 3.0 or greater were recorded up to 23:36:06.5 on February 9, with two of magnitude 5.8 occurring at 06:01:08.0 and 06:02:44.0. Thirty-one clear aftershocks were recorded on the Pacoima Dam strong-motion accelerograph, located about 8 km. south of the epicenter, from 06:01:08.0 to 06:05:58.0. The main shock record from the Pacoima Dam accelerograph showed the highest accelerations ever measured, 1.25 g. horizontally and 0.72 g. vertically. A very large number of aftershocks were felt, keeping people in a state of apprehension for weeks. An observer at Burbank reported over 120 aftershocks were felt up to June 21.

The earthquake was "generally" felt over approximately 208,000 sq. km. (80,000 sq. mi.) of California, Nevada, and Arizona (fig. 1). There were a few instances of the shock being felt beyond this area--at Bridgeport, Stockton, and Yosemite National Park, Calif., Tonopah, Nev., and Beryl, Utah.

Intensities ranging from VIII to XI (fig. 2) were indicated in an area of about 490 sq. km. (190 sq. mi.), with the one int. XI assigned to the Olive View Hospital complex. This facility, completed only a few months prior to the earthquake at a cost of approximately $23.5 million, was declared a total loss. Intensities ranging from IX to X were generally indicated in the San Fernando-Sylmar area and adjacent areas, and were based on ground ruptures, damage to buildings, dwellings, highway structures, dams, underground pipelines, and other utility facilities. Considerable damage, mainly to older buildings and dwellings, occurred in the int. VII zone. Some were posted as "unsafe" and others, notably in the Alhambra, Beverly Hills, Burbank, and Glendale areas, were to be demolished. A few large buildings sustained some structural damage, but damage to large or high-rise buildings was chiefly in the form of cracked partitions, fallen plaster, and broken windows. Thousands of chimneys were damaged. There were numerous reports of inoperative elevators, principally owing to counterweights being out of guiderails.

It was reported that 58 persons died as a direct consequence of the earthquake: Three at the Olive View Hospital, 49 at the Veterans Administration Hospital, 2 by collapse of freeway overpass, and 4 at other locations, including one person killed by the collapse of an old building in downtown Los Angeles. Over 2,000 injuries were reported, many requiring hospital treatment.

Damage to public and private property was estimated at over $500 million. It was reported that approximately 850 homes, 65 apartment buildings, and 574 commercial-industrial buildings were so damaged that they were vacated; some 4,800 homes, 265 apartment buildings, and 1,125 commercial buildings had appreciable

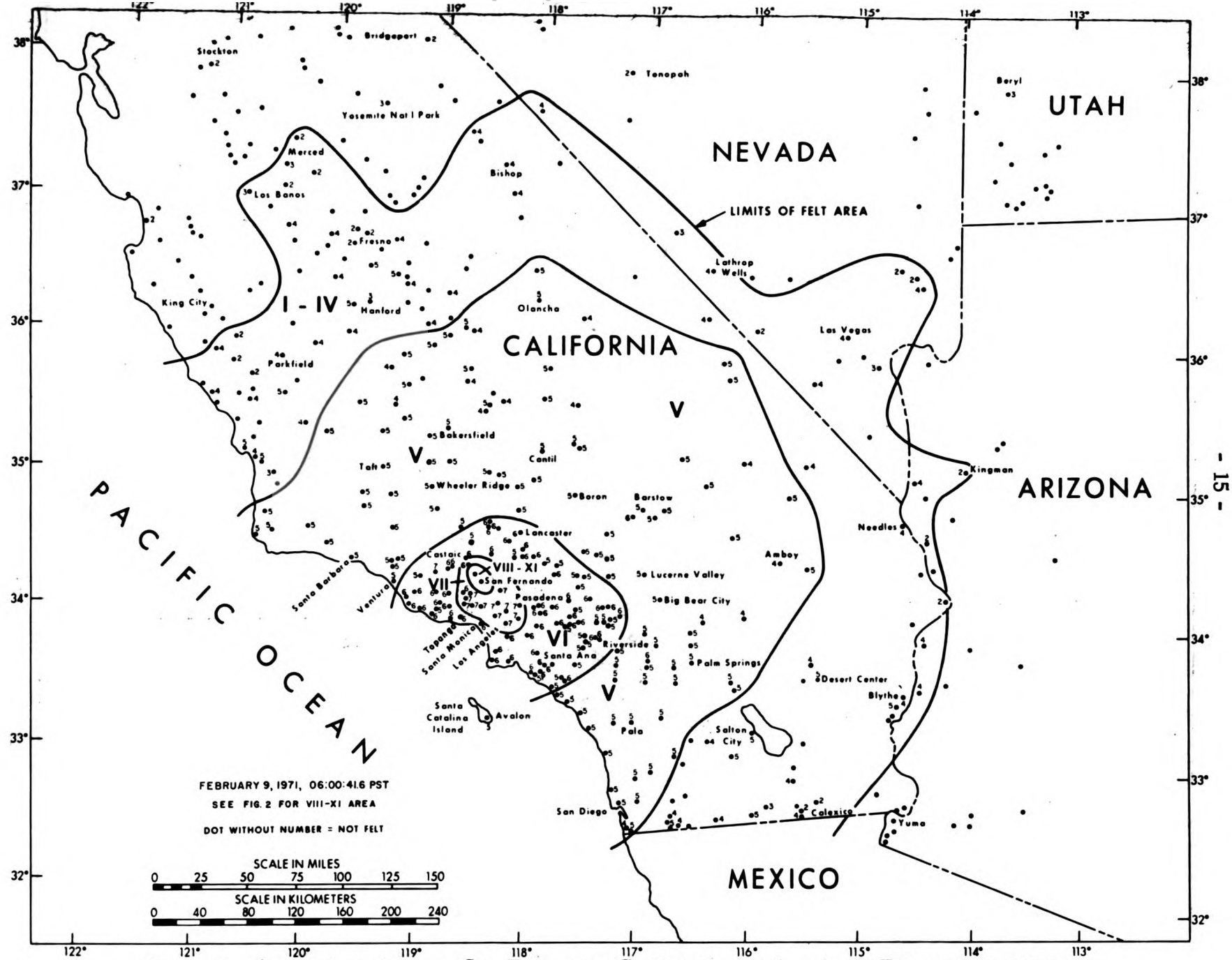

Figure 1. Area affected by the San Fernando, California, earthquake of February 9, 1971.

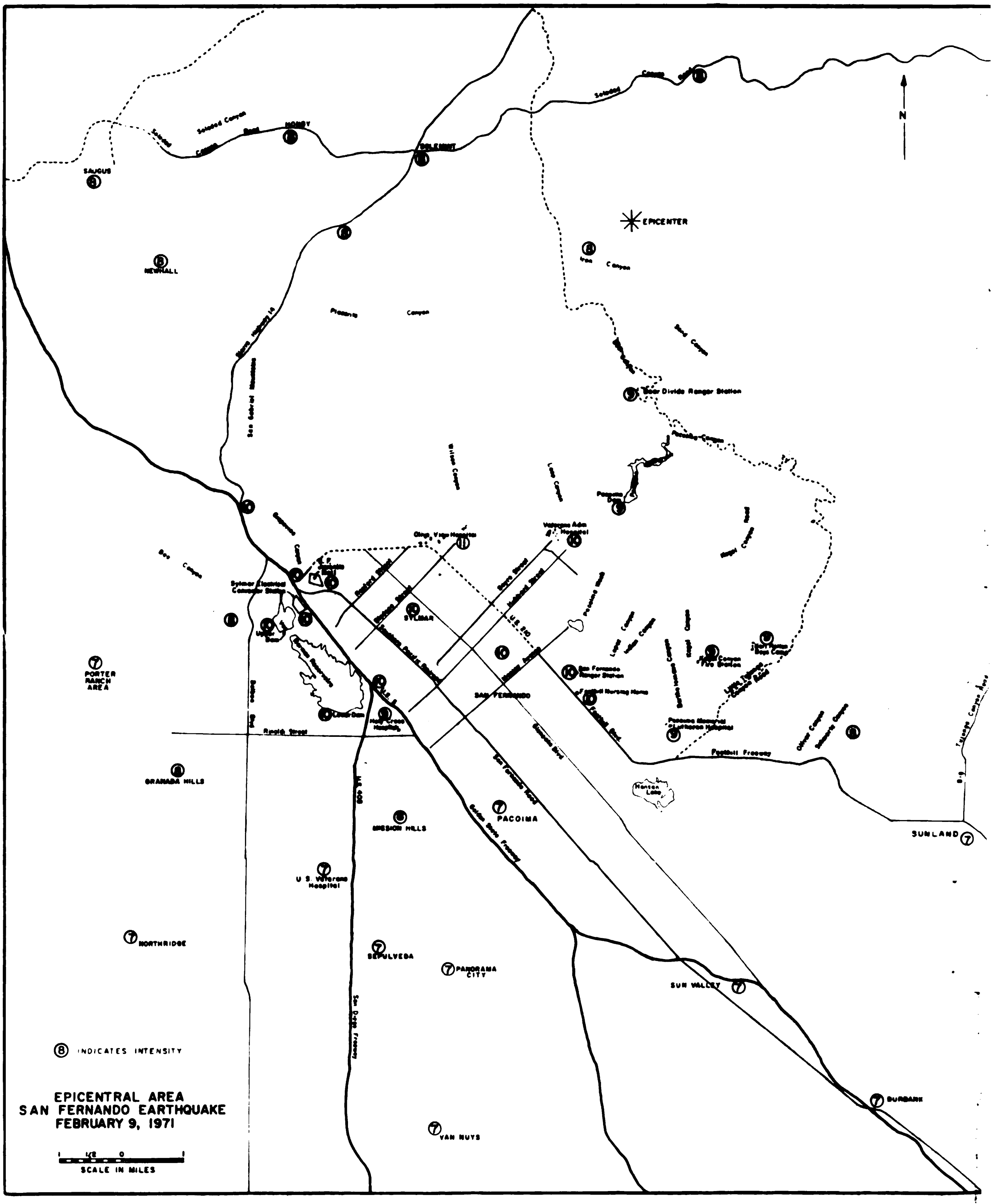

Figure 2. Epicentral area of the San Fernando, California, earthquake of February 9, 1971.

9 February, 06:00:41.6--Continued.

damage; and about 30,000 structures had lesser damage. About 1,700 mobile homes were substantially damaged. The most spectacular damage was the collapse of major structures at the Olive View Hospital and the Veterans Administration Hospital, and the collapse of freeway overpasses. Public utilities and facilities of all kinds were greatly damaged--water, gas, sewer, and electric--both above and below ground. The near failure of the Lower Van Norman Dam caused authorities to evacuate thousands of people from areas below the dam until the water in the reservoir could be lowered and the extent of damage and danger determined.

The following estimates of damage are from a report by the Los Angeles County Earthquake Commission[4]:

Jurisdiction or agency	Public property	Private property
City of Los Angeles	$ 92,000,000	$210,000,000
County of Los Angeles	100,000,000	6,800,000
Other local jurisdictions	5,200,000	30,000,000
State of California	15,000,000	
Federal Government	10,000,000	
Metropolitan Water District	6,000,000	
General Telephone		4,700,000
Los Angeles School District	22,500,000	
Southern California Gas Company		2,000,000
Southern California Edison Company		750,000
Total	$250,700,000	$254,250,000
Total (public and private)	$504,950,000	

4 See references, p. 141

9 February, 06:00:41.6--Continued.

The earthquake created a zone of discontinuous surface faulting, named the San Fernando Fault Zone, which extended from the Bee Canyon area (west of Upper Van Norman Lake) roughly eastward across the Sylmar-San Fernando area to the Big Tujunga Canyon area north of Sunland, a distance of about 20 km. The main rupture segment, designated the Sylmar segment, extended eastward from the intersection of Hubbard Street and Glenoaks Boulevard (in southern Sylmar-northern San Fernando area) across Foothill Boulevard to the Foothill Nursing Home. Although it was in this segment of the fault zone that the greatest concentration of ground distortion occurred, prominent ground displacements, fractures, and scarps were observed in other segments of the fault zone, notably in the Tujunga Segment, extending from the vicinity of the Foothill Nursing Home eastward into Big Tujunga Canyon, and in areas north and northwest of Upper Van Norman Lake. Surface faulting also occurred in areas away from the main segments of faulting, including an area just east of the Veterans Administration Hospital, Lopez and Kagel Canyon areas, on Kagel Mountain (just east of Pacoima Reservoir), and in areas east of Lower Van Norman Lake along the Golden State Freeway.

Severe ground fracturing and landsliding were responsible for extensive damage in areas not associated with faulting. There was severe ground cracking in the Olive View Hospital area, in the southwestern Sylmar and San Fernando areas, in the upper Granada Hills area west of Van Norman Lakes, and in many areas north and east of the Sylmar-San Fernando area. There was extensive landsliding and slumping, along with numerous fissures and sand boils, in the Van Norman Lakes area. It was reported that the appearance of the sand boils indicated liquefaction of soil in this area. The most damaging slide, called the "Juvenile Hall Slide," occurred in the Upper Lake area, where practically all structures and facilities located in or crossing this slide were severely damaged: highway overpasses and bridges, railroad, pipelines and canals, Sylmar Converter Station, San Fernando Valley Juvenile Hall, Joseph Jensen Filtration Plant, and other structures and facilities. Landslides and rockfalls were widespread and very numerous (over 1,000 were mapped from an aerial reconnaissance), with high concentrations in the foothills and mountainous areas of the San Gabriel Mountains. One of the larger slides occurred on the east side of Schwartz Canyon and was approximately 183 m. wide. Many roads were blocked by landslides and rockfalls in the area of severe shaking. Another type of ground rupture, which displayed the violence of this earthquake, was the numerous shattered ridge tops, with the soil of previously smooth surfaces upthrown, overturned, and pulverized. This type of ground disturbance was especially exemplified west of Grapevine Canyon, in the hills north of the Olive View Hospital, near Wallaby and Rajah Streets in the northeasternmost corner of Sylmar, west of Balboa Boulevard, east of Bartholomaus Canyon, and on the ridges above Oliver and Schwartz Canyons.

9 February, 06:00:41.6--Continued.

Intensity IX-XI:

San Fernando, Sylmar, and Adjacent Areas:

The one instance of int. XI was assigned to Olive View Hospital in the northern Sylmar area, north of Foothill Boulevard, where collapses of newly built, reinforced concrete, earthquake-resistive buildings reduced this $23.5 million complex facility to a total loss. Four five-story wings pulled away from the main building, three toppled. The second story of a two-story building dropped to the ground level. All other buildings were seriously damaged. This damage was reported to have been the result of severe ground shaking, not of ground faulting. The following is from a report by the Los Angeles County Earthquake Commission[4]: "Of particular interest is the new main Medical Center, which was dedicated just 30 days before the earthquake. Within this group are the six-story medical center building, a two-story psychiatric unit, a central heating plant, a one-story assembly building, and an ambulance-shelter canopy. All of these buildings suffered major structural damage. Three lives were lost in the medical center building: one from falling debris and two allegedly as a result of electric-power failure. The six-story building had four stair towers, which were isolated structurally from the upper five stories of the building. The supporting columns of three of these towers failed, permitting the towers to collapse onto the first-floor construction. The upper four stories of the main buildings, though damaged, retained their configurations. The lower two stories had column failures and some local floor areas collapsed. However, even though offset more than 2 feet, the structure as a whole remained standing, permitting the evacuation of the building through the two remaining interior stairs. Utilities in the building, including emergency facilities, were inoperative after the earthquake. The first story of the psychiatric building collapsed completely with the second floor settling down to ground level. No lives were lost in this building because no persons were present on the lower floor at the time of the earthquake. The 12 columns of the ambulance-shelter canopy all were shattered, permitting the roof to collapse on the ambulances beneath. The failure of cross-bracing members in one end wall was the main structural damage to the central heating building. Equipment within the building that was not anchored to the floor became displaced and one of the boilers shifted 52 inches relative to the building. The assembly building did not collapse, but the columns were severely distorted."

The following is from a report by U.S. Geological Survey Staff[10]: "Tectonic movements associated with the February 9, 1971, San Fernando earthquake produced a zone of surface breakage which partly follows the boundary between the San Gabriel Mountains and the San Fernando-Tujunga Valleys, and partly transects the northern salient of the San Fernando Valley. This latter zone of tectonic ruptures was specifically associated with some of the most extreme damage caused by the earthquake anywhere in the epicentral region. The zone of surface

9 February, 06:00:41.6. Intensity IX-XI--Continued.

breakage trends roughly east-west, is about 15 km long, and is slightly concave towards the south. A notable discontinuity occurs near the middle of the arc where the western half is offset about 1 km north of the eastern half. The sense of movement along the breaks is complex. Almost all scarps are south facing, with the mountain block up relative to the valley block. Most of the larger scarps consistently show a left-lateral sense of motion, but a broadly defined zone of smaller scarps and cracks, which parallels in part the main zone of breakage, shows right-lateral offsets. Within the entire 15 km length of the surface breakage, the maximum vertical offset measured on a single scarp is about 1 m, the maximum lateral offset about 1 m, and the maximum shortening (thrust component) about 0.9 m.

"Surface ruptures that are known or suspected to be tectonic breaks created during the earthquake extend discontinuously from the San Diego Freeway just south of Lower Van Norman Lake to Big Tujunga Canyon. No such ruptures were found between the San Diego Freeway and the Osceola Street School or in the area from just east of San Fernando Road to just west of the intersection of Glenoaks Boulevard and Hubbard Street. The zone of breakage bends to the south about 0.4 km south of Lopez Dam, but some breaks may be continuous through the low hills into Lopez Canyon to the east. From the Foothill Nursing Home, eastward along the front of the mountains, the surface faulting is generally well defined, but locally discontinuous, to a point just east of Little Tujunga Canyon. East of this point, for a distance of about 2 km, no surface faulting is found along the front of the range. About 0.3 km east of the Lakeview Terrace Sanitarium, surface breakage again is in evidence, with only a few interruptions, to a point about 0.3 km into Big Tujunga Canyon. About 0.4 km farther up the canyon, a 0.3 km scarp marks the eastern limit of surface ruptures. From approximately Lopez Canyon east to Little Tujunga Canyon, discontinuous, usually smaller, breaks occur north of the relatively throughgoing line of breaks along the front of the range. Two of these breaks are found in Lopez Canyon, two in Bartholomaus Canyon, four small breaks cross Kagel Canyon, and single breaks intersect Little Tujunga, Oliver, and Schwartz Canyons. A relatively short, presumably tectonic rupture characterized by a small south-facing scarp was recognized just east of the U.S. Veterans Hospital; it has no apparent continuity with the main zone of breakage to the south.

"The concentration of ruptures in some areas and their absence in others, and the apparent discontinuity near the middle of the breaks, allow a natural division into three segments. For convenience these segments are named as follows: (1) The surface faulting from the San Diego Freeway to just east of San Fernando Road is referred to as the Mission Wells segment of the San Fernando fault zone. (2) The ruptures from the intersection of Hubbard Street and Glenoaks Boulevard to the Foothill Nursing Home are referred to as the

9 February, 06:00:41.6. Intensity IX-XI--Continued.

Sylmar segment of the San Fernando fault zone. (3) Some of the breakage that roughly follows the mountain front east of the nursing home is referred to as the Tujunga segment of the San Fernando fault zone.

"Mission Wells Segment of the San Fernando Fault Zone: Near the Mission Wells historical monument, 1.5 km east of Lower Van Norman Lake, a small south-facing scarp 0.05-0.25 m in height trends about N. 60° E. Surface cracks showing left-lateral offsets extend from just southwest of the northwest corner of Osceola Street School to about one block east of San Fernando Road. Cracks were also found in the concrete pavement of the Golden State Freeway along the strike of this zone, but these may have been caused by landslides. This segment has no surficial expression between the San Diego Freeway and the Osceola Street School, nor from a point about one block east of San Fernando Road to the intersection of Hubbard Street and Glenoaks Boulevard.

"Sylmar Segment of the San Fernando Fault Zone: The Sylmar segment is a well-defined zone of tectonic fractures that extends eastward from the heavily damaged shopping center at the south corner of the intersection of Hubbard Street and Glenoaks Boulevard to the range front immediately south of Lopez Dam. Cumulative displacement across the central part of this zone consists of left-lateral, vertical, and horizontal-shortening components as great as 1.9 m, 1.39 m, and 0.6 m, respectively. The maximum components of displacement across any individual break in the zone, however, are about half of these values, and they are far less across most breaks. This zone generally ranges from about 75 to more than 200 m in width, but virtually all the lateral movement and shortening caused by thrusting, together with about one-half of the vertical displacement, are concentrated in a narrow band along the southern border of the zone. The remainder of the vertical displacement is distributed across many small normal (extension) faults and a few small thrust faults that occupy the remainder of the zone and show minor left- or right-lateral displacement. Thus, the zone of fractures is divided into a narrow southern zone of shearing and thrusting and a wider northern zone of extension; vertical displacement occurs in both. This distribution of displacement is well shown by ruptured utility pipes beneath streets and by sidewalks, curbs, and streets.

"The extension or compression of sidewalks and curbs with respect to the underlying ground provides a basis for estimating surface distortion. For example, all the northwest-southeast trending streets (Foothill, Eighth, Glenoaks) showed net extension across the fault zone, whereas the northeast-trending streets were shortened. Unfortunately, the large number of measurements required (commonly more than 100 in a block 400 m long) together with various uncertainties limits the accuracy of the determinations of net change across the fault zone to about $\pm$0.1 m. Our estimates were further hampered by street-

9 February, 06:00:41.6. Intensity IX-XI--Continued.

repair crews, who swiftly removed sections of splintered or buckled sidewalks and curbs.

"Few fractures of the ground surface can be traced across streets, houses, and yards. Owing to their rigidity, streets (including curbs and sidewalks) tend to bridge the shear zone; this rigidity commonly allows compression to be transmitted to buckles and overthrusts in streets, curbs, and sidewalks as much as 100 m from the zone of ground breakage. On the other hand, extension is usually expressed in the overlying sidewalks and curbs at the closest construction joint (generally within a few meters) and in asphalt pavement by tensile failures normal to the length of the street and apparently within a few tens of meters of the underlying ground extension. Houses commonly hide faults that pass beneath them unless displacement is large enough (about 50-100 mm) to visibly affect the house. Many fractures that are obvious on bare ground are completely hidden by cultivation or planting. However, the small number of fractures that have displacements greater than 0.1 or 0.2 m, such as those that cross Bromont Street and the street just west of it, generally maintain continuity across these features. The net result of these effects is that the shear zone is revealed, if not sharply bounded, by obvious left-lateral offset of each street that it crosses, whereas the zone of extension is marked by normal faults and extension fractures across each street within the zone.

"The southern boundary of the zone of fractures is sharp, whereas the northern boundary is not. Obvious ground fractures cease a few tens of meters beyond the southern boundary of shearing and thrusting, whereas the zone of extension fractures has a diffuse boundary, marked by a gradual reduction in the number of fractures and displacement across them. The northern boundary of the zone of extension roughly limits the area in which extension fractures are evident across bare ground.

"The sharply defined main strand of the Sylmar fault segment changes northward into a broad area broken by numerous, relatively closely spaced faults which almost uniformly display small right-lateral offsets. The dimensions of the area showing fractures of this kind are about 1.8 km in the east-west direction, somewhat less than the length of the main part of the Sylmar fault segment, and about 1.3 km from north to south. The faults share the east-west trend of the left-lateral zone and generally show slight extensional gaping as well as right-lateral displacement. Where present, the sense of vertical components of movement is usually down on the north, or opposite to the direction of vertical offset in the belt of apparent right slip within the zone of the Sylmar fault segment. The right-lateral faults are usually simple, nearly linear fractures in the ground but have somewhat more complex traces where they break pavements, sidewalks, and concrete slabs of houses. Spacing of

9 February, 06:00:41.6. Intensity IX-XI--Continued.

the faults ranges from a minimum of about 20 m to a maximum of about 100 m. Residents in the area state that many of the fractures showed only slight offsets immediately after the earthquake and that they continued to move for several days thereafter.

"One of the most complex sectors of surface rupturing occurs northeast of San Fernando Airport in the area of apparent discontinuity between the Sylmar and Tujunga segments of the San Fernando fault zone. The complexity involves not only geometric irregularity of the fault strands but also loss of demonstrable continuity of the fault traces and possible variation in the sense of the lateral component of displacement.

"Between Maclay Avenue and Pacoima Wash, the sense of horizontal separation on the Sylmar segment reverses from left- to right-lateral. The northern or northeastern side, however, is consistently the relatively upthrown block. On the first street southeast of Maclay Avenue, the break shows about 0.12 m of left-lateral separation of curbs; but one block farther southeast, no lateral separation is visible on curb lines, suggesting (from the angular relationship of the fault trace and street) a small left-lateral component of slip. One block farther east, curbs are separated right-laterally about 0.3 m, reflecting either a yet smaller left-lateral component combined with the vertical component of offset, or possibly a small right-lateral component of movement. Immediately east of Pacoima Wash, the Sylmar segment of the fault displaces an originally linear north-south fence about 1.0 m in a left-lateral direction. Because the trace of the ground rupture is almost exactly perpendicular to the fence line, there is no ambiguity as to the sense of the lateral component of offset at that point.

"Eastward from the northern point of the spreading basin next to Pacoima Wash, the trace of the Sylmar segment of the fault curves abruptly to a southward trend and becomes approximately coincident with the base of the steep mountain front. The trace is visible only for a short distance at that location; however, despite the near absence of surficial breakage along the base of the slope southward to the reentrant canyons at the Burns ranchhouse, damaged water pipes excavated after the earthquake indicate at least 0.43 m of east-west shortening of the ground surface about 0.4 km northwest of the ranchhouse. The mountain block, furthermore, rose at least a few centimeters relative to the alluvial flat at that point. No obvious disturbance or cracking of the ground surface was evident at the shortened pipelines, raising the possibility that a similarly imperceptible compression zone may continue southward to the vicinity of the San Fernando Ranger Station.

"Near the San Fernando Ranger Station, the sidewalks and pavements at the

9 February, 06:00:41.6. Intensity IX-XI--Continued.

southeast ends of two cul-de-sacs that run northwest-southeast were broken and shifted to the northwest; asphalt parking lots were disrupted; and two buildings were jammed together, causing severe structural damage to at least one of them. Their orientation indicates a strong component of northwest-southeast shortening. One of the cul-de-sacs, Montero Avenue, was shortened in a northwest-southeast direction by 1.07 m (the difference between the length measured by steel tape on February 14 and the length given in official records). A monument originally set on the projection of the centerline, and about 20 m southeast of the end of the street, was shifted about 0.2 m southwest of the centerline. The shortening buckled the sidewalk and flattened the circle at the end of the street and produced crescent-shaped openings between the curb and the sidewalk. The form of the ruptures both in the streets and in vacant lots indicates strong compression in the northwest-southeast direction and uplift of the southeast side, possibly combined with a minor right-slip component. Numerous landslide scarps up to 1 m high cut the flanks and ridges of the hill immediately to the east. Their presence suggests the possibility that settling and spreading of the bedded and jointed rock that constitutes the hill may have forced out a wedge of the alluvium at the base of the hill, produced most of the compressional effects, and masked whatever tectonic displacements may have occurred.

"The west end of the Tujunga fault segment may connect with the Sylmar segment along a hidden zone of compression near the base of the mountain slope in the vicinity of the San Fernando Ranger Station. It is furthermore possible that the Sylmar segment branches, and the eastern strand extends into the mountains along the line of the northernmost mapped faulting in Lopez Canyon. Demonstration of such a connection is not possible, however, because of the extensive landslides on the hill east of Burns Ranch.

"Tujunga Segment of the San Fernando Fault Zone: The Tujunga segment extends along the front of the hills on the north side of Tujunga Valley in a discontinuous fashion from the vicinity of the Foothill Nursing Home, which lies on the northeast side of Foothill Boulevard, eastward into Big Tujunga Canyon.

"In front of the nursing home the curb is raised about 1 m above the street level. A transverse component of movement, shown by about 0.9 m of shortening, was measured along a fence trending N. 50° E. on the east side of the nursing home. East of the nursing home, a low, but well-defined fault trace continues with only a few interruptions to the mouth of Lopez Canyon. Where the surface ruptures transect the lower slopes of the hills just east of the nursing home, the scarps are low, but well defined. A conspicuous zone of tension cracks about 2-3 m wide formed about 10 m upslope from the base of the scarps. On the west side of Lopez Canyon, the scarp, which is about 0.85 m in height, is a hummocky, multistranded bulge at the leading edge of the overriding northern block. In a trailer park immediately west of Lopez Canyon,

9 February, 06:00:41.6. Intensity IX-XI--Continued.

the fault appears to follow a shallow-dipping plane in Tertiary marine deposits. About 0.4 km west of Lopez Canyon and for approximately 200 m along strike, the fault plane has a rather uniform dip to about 55° N. Just east of the canyon, the fault zone is defined by many subparallel imbricate breaks.

"Eastward from Lopez Canyon the fault zone is made up of many en echelon segments. About 0.8 km east of the mouth of the canyon, the dip of the fault appears to lessen to about 15° N., but tectonic scarps are difficult to distinguish from the toes of landslides in this area. At the mouth of Bartholomaus Canyon, the scarp is about 0.25 m high, up on the north side, and shows about 0.1 m left-lateral offset of the streambank. The frontal scarp is about 0.60 m high and well exposed in Little Tujunga Canyon. East of this canyon for about 1.5 km, the zone is marked by compressional buckles and lacks developed scarps.

"A gap of 2.2 km, within which no tectonic breaks have been found along the range front, separates the breaks near Little Tujunga Canyon from a well-defined south-facing scarp on the north side if Big Tujunga Creek, about 0.4 km east of the Lakeview Terrace Sanitarium. The scarp is 150 m long and 0.35 m high, but it cannot be traced continuously across the creek. The southeast end of this ground breakage is connected by a few discontinuous scarps to a well-developed line of surface rupture that is continuously traceable for about 0.9 km to the east. This line of ruptures is developed mostly in unconsolidated stream sediments which have been extensively churned by earth moving equipment, and the appearance and height of the fault scarp here vary considerably along strike. About 1.5 km east of the Lakeview Terrace Sanitarium, this break cuts interlayered thin-bedded siltstone and conglomerate exposed on the north edge of Big Tujunga Wash. The fault plane here strikes about N. 70° W. and dips 55-60° N. Slickensides, which may or may not be related to the most recent movement, are developed in a thin zone of fault gouge and dip straight down the fault plane. The gouge indicates that the February 9 movement at this point occurred along a preexisting fault.

"A few meters east of the faulted bedrock, the scarp, which is again in the stream sediments, becomes indistinct and cannot be distinguished from ridges formed by earth-moving equipment. Two disconnected scarps, each about 150-200 m long, continue en echelon to the east. The more easterly of these offsets the extension of Oro Vista Avenue about 0.3 m in a left-lateral sense. The height of this scarp is about 0.5 m, in the stream bottom below this street. About 0.4 km east of this break lies the scarp which marks the eastern end of the tectonic breakage. This scarp is 0.3 km long and strikes N. 75° E. Part of it is developed in thin-bedded siltstone and with the siltstone dips 62° N. Movement was up on the north, about 0.4 m. Four cracks that cross Mount

9 February, 06:00:41.6. Intensity IX-XI--Continued.

Gleason Avenue about 0.7 km farther east show both left- and right-lateral displacements up to 0.02 m, and are probably not tectonic breaks.

"Surface Faulting in the Mountains North of the Tujunga Segment: In addition to the fault trace at the mouth of Lopez Canyon, other February 9 traces cross the canyon 0.6 km and 0.9 km north of its mouth. The northernmost of these occurred on an existing fault that was marked by gouge and shearing in the adjacent rock, but the earlier faulting apparently was not expressed in the modern topography. Where this trace extends westward from Lopez Canyon Road, it crosses a flat artificially graded surface underlain partly by bedrock and partly by alluvium. A distinct fault scarp about 1 m high formed in the bedrock, whereas a gentle monocline developed in the alluvium. The bedrock here consists of bedded friable sandstone, conglomerate, and thin shale, and it has about the same attitude (strike N. 80° W., dip 70° N.) on both sides of the fault. The fault strikes N. 80° W. and dips 65° N. at the surface, and this attitude continues to a depth of at least 10 m, where the fault was penetrated by a 36-inch borehole drilled to install a wire extensometer. The gentle monocline that marks the fault in the alluvium is some 30-35 m wide. Although the difference in height across the monocline is about the same as across the scarp, it would be difficult to identify this as a structural warp from the profile alone.

"Near the east end of the scarp, slickensides in the gouge are inclined 58° from the horizontal which indicates a somewhat lower ratio (0.635) of strike slip to dip slip than was obtained from the displaced bulldozer features (0.76). It is uncertain, however, whether these slickensides formed on February 9 or during an earlier movement on the same fault plane.

"About 0.6 km north of the mouth of Lopez Canyon, a small scarp bulges up the pavement of the Lopez Canyon Road, with the north side elevated about 0.2 m. A roadcut alongside the break exposes disturbed and somewhat slumped sandstone and siltstone, but no positive evidence or prior movement such as a gouge zone or structural truncation of bedding is visible. About 110 m due west of this scarp, however, a northward-dipping fault surface is visible on a steep face cut in similar sedimentary rocks. Although preearthquake reference lines are not present across this break, a thrust movement of a few centimeters, possibly with a minor left-lateral component of slip is evident. In contrast to the cut at the road, the offset here appears to have occurred along a preexisting fault, as shown by gouge and the slight structural discordance of the underlying beds at the fault. The offset apparently dies out westward within the upper part of the cut, and no tectonic rupturing was found on a projected line at any point higher on the hill. Whether this fault joins the scarp to the east of Lopez Canyon Road is uncertain. Pavement and soil in the intervening sector are located on fill and are strongly fractured. This breakage, however, is probably nontectonic, and the continuity of the two offsets is in doubt.

9 February, 06:00:41.6. Intensity IX-XI--Continued.

"Thirteen fractures exhibiting right-lateral offset break Lopez Canyon Road between 0.27 km and 0.53 km north of the Tujunga segment of the San Fernando fault zone. The net right-lateral offset across these breaks is about 0.5 m, of which about half is concentrated in a narrow zone at its southern edge. Although the breaks cannot be traced either west or east, it is likely that they are of tectonic origin. They appear to be similar to breaks within the broad zone of right-lateral rupturing immediately north of the Sylmar segment.

"Another well-developed south-facing scarp lies about 0.4 km up Little Tujunga Canyon from the frontal scarp. This upper scarp is a hummocky bulge similar to those at the range front. It dies out about 0.3 km east of Little Tujunga Road, but it continues westward almost to Kagel Canyon. Just west of Little Tujunga Canyon, the scarp is 0.45 m high. Several small scarps cross Kagel Canyon, but cannot be traced for any distance outside the canyon. A small south-facing scarp extends westward from the bottom of Bartholomaus Canyon but cannot be traced east of it. Although the scarp is little more than a buckle in the bottom of the canyon, on the ridge 0.3 km to the west, it is about 0.30 m high and displays about 0.58 m of left-lateral offset.

"Prominent scarps of probable tectonic origin cross the bottoms of Oliver and Schwartz Canyons about 0.4 km north of their mouths. The scarp in Oliver Canyon is about 0.9 m high and that in Schwartz Canyon about 0.3 m. Although both are probably parts of longer structural features, they cannot be traced with confidence outside of the canyons through the extensive landslides which mantle the surrounding hillsides.

"Scarp East of the Veterans Hospital: Although extensive damage to man-made structures occurred along a zone extending from Upper Van Norman Lake to the head of Pacoima Wash, there is only one scarp in this zone interpreted to be of possible tectonic origin. This scarp is about 300 m long and is expressed as a small nearly east-west surface rupture. It is between the U.S. Veterans Hospital and Pacoima Wash and is well exposed in cuts and fills of a partly developed housing tract near Rajah Street. In the banks of cuts, the slip surface dips generally northward between 36^{o} and 48^{o}, parallel to bedding of sandstone and conglomeratic sandstone of the Pacoima Formation. Displacement is apparently directly updip, and the maximum relative uplift of the northern slide is about 0.18 m. Westward the strike of the break gradually swings toward the southwest. A line joining the western end of the continuous fracture to a short scarp with vertical offset observed on Hubbard Street would have a southwesterly trend. Although the rupture has the appearance of a tectonic fracture, it conceivably could represent the bulged toe of an unexpectedly large landslide whose upslope limits have not been recognized.

"The projection of the fault, as it continues along its last observed trend,

9 February, 06:00:41.6. Intensity IX-XI--Continued.

passes well south of the Veterans Hospital. Although no further tectonic breaks were recognized west of the scarp, this does not preclude the possibility that the zone from west of Juvenile Hall to the Veterans Hospital was tectonically active during the earthquake. For example, left-lateral deformation may have occurred across the zone near the Juvenile Hall, as a postearthquake resurvey of San Fernando Road showed a small left-lateral and southward shift of a point due west of the Juvenile Hall with respect to a point at the corner of Roxford Street and San Fernando Road.

"Tectonic and Engineering Implications: To recapitulate, mapping of the tectonic fracture zones shows that faulting associated with the San Fernando earthquake was characterized by left-reverse oblique slip of up to 2.4 m along an approximately east-striking fault system that dips north about 55° at the surface. The sense of movement determined from surface measurements accords closely with that deduced from fault-plane solutions for the main shock. Detailed mapping has also shown that the zone of tectonic fractures is defined on the south by a conspicuous major break or narrow shear zone; we identify virtually no tectonic fractures south of this boundary. The northern boundary of the breakage zone, however, is diffuse.

"The gross relationship between earthquake damage and surface faulting is demonstrated by the remarkable concentration of major damage within the zone of surface breaks along the Sylmar segment. The gross relationship between damage and deformation in the thrust plate above the faults with surface breakage is shown, but more equivocally, by the great predominance of major damage in the upper plate. The occurrence of major damage along the mountain front between and beyond the Olive View and U.S. Veterans Hospitals suggests the possibility of faulting in that area. Tectonic fractures here could easily be masked by the abundant landslides; nevertheless, we have direct evidence of only one relatively short break along this zone that could be interpreted as tectonic."

The following is from a report by R. B. Saul[7]:

"Effects of the San Fernando Earthquake in the Oat Mountain Quadrangle: Within the quadrangle, disruption of the ground surface in response to the earthquake of February 9, 1971 was confined mainly to a zone roughly 2 miles wide along the eastern boundary of the quadrangle (a line roughly coincident with Balboa Boulevard) from Rinaldi Street on the south, north to about San Fernando Pass. Across most of the southeast quarter of the Oat Mountain quadrangle, the complexly imbricate surface zone of the Santa Susana thrust trends due east. In general, the sense of movement is from north to south. Furthermore, subsurface data indicate that this thrust is folded along

9 February, 06:00:41.6. Intensity IX-XI--Continued.

an east-west axis. West of Bee Canyon no element of this thrust appears to have moved during the recent earthquake. East of Bee Canyon tectonic and/or lurching motion appears locally to have been coincident with or closely parallel to the sole of the Santa Susana thrust zone as previously mapped and may represent a local deflection of energy along existing planes of weakness. Where the base of the Santa Susana thrust crosses the road to St. Vincent de Paul Camp left-lateral movement offset a line on the pavement about 1 foot, with no visible vertical component of movement. To the west of this road the trace of ground movement turns northwest into Bee Canyon, athwart the zone of the Santa Susana thrust, and appears to be absorbed along the strike of the bedding in the sedimentary rocks of the north wall of Bee Canyon. Northeast of St. Vincent de Paul Camp road, ground breakage follows the trace of the sole of the Santa Susana thrust along a discontinuous and locally ambiguous series of breaks as far as the large road cut on Balboa Boulevard north of Van Norman Lake. In the low-lying areas, surface cracks appear to be largely the result of lurching or settling of alluvium. In hilly areas, effects range from minor lurching of fills and soils to intensely shattered soil, landslides and rockfalls. The most severe effects are principally confined to the square mile surrounding the mouth of Bee Canyon. Here, soil and weathered rock debris on ridge crests lies in cracked and jumbled disorder as though it had been heaved, and the flanks of most ridges are scarred by shallow landslides. In the Bee Canyon and Cascade Oil Field area, rocky ridges, road cuts, and the steep cliff along the north side of the canyon yielded rockfalls."

The following is from a report by T. L. Youd[11]:

"A large number of landslides formed in the vicinity of the Van Norman Lakes in response to the February 9 earthquake. Only the slides in recent alluvium are discussed here. Extensive slumping occurred in the alluvium around the margins of both the Lower and the Upper Van Norman Lakes. In some places a nearly continuous line of scarps formed. The scarp on the west shore of the lower lake is more than 1 km long. Sand boils commonly formed below these scarps.

"A recently filled and graded area west of the upper lake was broken up by numerous fissures, which generally tended to parallel the shoreline and the contour of the previous surface . . . Extensional and vertical displacements in the fill indicate movement toward the reservoir either in the form of block glides or in slightly rotated slumps. Sand boils erupted in the southern part of this fracture zone some 180 m from the lake and several meters above the water level at the time of the shock.

"Many fissures formed in the area west of that described in the previous paragraph. Of those observed, the most notable were in a schoolyard in the mouth

9 February, 06:00:41.6. Intensity IX-XI--Continued.

of Bee Canyon, nearly 1 km from the upper lake. These fissures were characterized by vertical displacements of as much as 50 mm (millimeters) and continuous lengths of perhaps 100 m. They seemingly formed the head of a landslide which had moved down the very mild slope (about 1.5^{o} or 2.5 percent) eastward toward the upper lake.

"The most damaging slide in the vicinity of the lakes formed a tonguelike feature (in plan) extending northeastward from the upper lake for a distance of 1.2 km. Located on or crossing this slide, hereafter called the Juvenile Hall slide, are a major part of the San Fernando Valley Juvenile Hall, trunk lines of the Southern Pacific Railroad, San Fernando Boulevard, Interstate Highway 5, the Sylmar electrical converter station, and several pipelines and canals. Earthquake damage to these facilities will likely exceed $30 million.

"The available evidence indicates that the displacements associated with this feature are of landslide rather than tectonic origin.

"Resurvey of San Fernando Boulevard revealed that the distance across the slide from the survey point at the Interstate 5 overpass to a point near Olden Street had shortened 43 mm. Relative to the Roxford Street intersection with the San Fernando Boulevard (southeast of the slide), the survey points near the Interstate 5 overpass (northwest of the slide) had moved south 300 mm and west 210 mm. These relative movements are considerably less than the total downslope movements of the slide, which ranged from 0.5 to 1.0 m (based on visual observation and cumulative measurements of displacements across fissures). Thus, it appears unlikely that the feature mapped as the Juvenile Hall slide had a tectonic origin, even though the southwest movement of the Interstate 5 overpass with respect to the Roxford Street intersection could have been produced by left-lateral tectonic displacement on a northeast trending fault or fault zone through the area of the slide.

"The surface on which movement occurred has a very gentle slope; it averages about 1.5^{o} (2.5 percent) over its entire length assuming that the toe of the slide is at the shoreline of Upper Van Norman Lake. The maximum slope was about 3^{o} (5 percent) near the head. Surprisingly, the average slope between the Juvenile Hall and the converter station, which appeared to be the minimum, was only 0.9^{o} (1.5 percent).

"Numerous sand boils erupted on the lake floor, presumably near the toe of the slide. These were exposed after the water level was lowered. Sand boils were also found at the following locations: Behind the converter station near the base of the graded fill, in a field south of Juvenile Hall, and along the north edge of the railroad grade in front of the Juvenile Hall Administration Building.

9 February, 06:00:41.6. Intensity IX-XI--Continued.

"During the earthquake, the crest of the Upper Van Norman Dam subsided a maximum of 0.9 m and shifted downstream a maximum of 1.5 m with respect to its abutments. In the light of this it would appear that a low-gradient slide, similar to the one described above, may have cut through the valley floor behind the dam and caused these movements.

"The most reasonable explanation for slippage of the Juvenile Hall slide on a slope of such low gradient is that the underlying soils were partially or completely liquefied during the earthquake. The many sand boils observed on or near the slide are evidence that this occurred.

"It is also probable that movements on many, if not all, of the other slides in the alluvium surrounding the Van Norman Lakes were directly attributable to increased pore water pressures generated by the earthquake."

Highways, Railways, and Roads:

Most of the major and spectacular damage to highway structures and bridges occurred in an area along U.S. Highway 5 at the interchanges of 5/210 and 5/14, located about 1-1/2 km. apart. At the Route 5/210 interchange (Foothill Boulevard and Golden State Freeway), three highway overpasses totally collapsed and two required rebuilding. Two men were killed at this location when one of the overpasses collapsed onto their truck. Bridge columns failed. Pavement cracked and buckled. At the Route 5/14 interchange (Golden State and Antelope Valley Freeways), two spans of a nine-span bridge collapsed. A bridge also collapsed at the interchange between the Golden State Freeway and San Diego Freeway. It was reported that almost all remaining structures in the general vicinity of the interchanges (possibly as many as 70) were damaged to some extent, many requiring extensive repair. Bridges on the Antelope Valley, Foothill, and San Diego Freeways also were seriously damaged, especially along Foothill Freeway in the Sylmar-San Fernando area. Press reported the Newhall and Old Sierra Highways and Bouquet Canyon Road were closed by slides and bridge damage. There was some bridge damage along the Soledad Canyon Road areas east of Saugus. Many other roads were blocked by slides in the San Gabriel Mountains. Numerous roads and city streets in northern San Fernando Valley were made dangerous or impassable by landslides, cracks, and buckling. Railroad traffic also was disrupted owing to displacement and distortion of rails and to a collapsed overpass which fell onto the track. In front of the San Fernando Valley Juvenile Hall facilities, railroad tracks were twisted and broken and displaced as much as 1.2 m.

Dams:

The old Upper and Lower Van Norman earthfill dams were damaged to the extent

9 February, 06:00:41.6. Intensity IX-XI--Continued.

that rebuilding is required. The reservoir keeper of Lower Van Norman Dam reported: "We live on the reservoir grounds at the bottom of the dam on the west end (11729 Strandwood Ave.). No ground cracks around the house. Chimney damaged badly. One crack in foundation. Stove, refrigerator, and dresser shifted. No broken plaster; no broken windows. Damage was slight. My wife and child were up, getting ready for school. She heard the shock coming. I was asleep. I tried to get out of bed but couldn't, until the worst of it was over. I made a quick check of the family and a quick check of the house, then dressed and went to check the dam. When I got to the main road going to the top of the dam, I could see, through the dust, an irregularity of the crest of the structure below, looking to the top. I drove to the top of the dam and around the west abutment and saw the damage to the face. It was hard to believe what I saw."

Pacoima Dam, located about 2 km. northeast of the San Fernando Veterans Administration Hospital, reportedly sustained $1.5 million damage to its abutments. Massive rockslides blocked the access road to the dam, preventing immediate inspection of the accelerograph located there. Waterlines were damaged. In view of the apparent high intensity in this area, the following, as reported by the caretaker of the dam, is of interest: "Caretaker's house is a one-story wood frame building (built in 1953), situated on loose fill (fill done in 1938). It is approximately 12 by 12 m. and rests 0.6 m. off the ground on a concrete perimeter foundation with wood plate around the foundation. There was no damage to the concrete foundation and only minor damage to the wood support. The brick chimney was undamaged. There were hairline cracks in ceiling plaster and above doors; no doors were out of plumb. Doors on a 1.8-m.-high hutch opened and the first row of glasses was thrown out; then the doors closed and rest of glasses did not break. Some objects fell in the house. Huge rock rolled down and broke outside stucco but the rock did not come through into the house. An old nearby house (built in 1937) had outside brick chimney separate from frame but the chimney did not fall. At the dam, an empty tank (under construction) shifted about 15 cm. off foundation." It was reported that Lopez and Hansen Dams sustained only minor damage.

Other Water Supply and Distribution Systems, Flood Control, and Power Facilities:

There was extensive and severe damage to underground waterlines, gaslines, sewers, tunnels, flood control facilities, and electrical facilities and structures. It was reported that it will be necessary to completely rebuild the sewer system in the area bounded by Hubbard Street, Glenoaks Boulevard, Harding Street, and Eighth Street. In the Upper Van Norman Lake area, sections of several canals were damaged badly; several flood control dikes suffered slumping. Approximately $2-1/2 million damage was reported to the Los Angeles Flood Control facilities, and about half of this loss was caused by breakage of reinforced concrete open channel and underground box channels. In one case,

9 February, 06:00:41.6. Intensity IX-XI--Continued.

breakage extended for the length of a city block. Substantial damage occurred to Wilson Canyon Channel, Mansfield Avenue Storm Drain, Pacoima Wash, Lopez Canyon Channel, and Glenoaks Boulevard Drain, all in the San Fernando-Sylmar area. Lopez Debris Basin, north of Hansen Dam, was seriously damaged. Damage was estimated at $6 million to Metropolitan Water District of Southern California. At Joseph Jensen Filtration Plant (about 0.4 km. northwest of Upper Van Norman Lake), there was extensive ground cracking in the plant area, with lateral movement of 0.3 m. or more, and extensive damage to above and below ground structures. A huge steel water storage tank buckled and anchor bolts pulled out. The Balboa Inlet Tunnel (4.3 m. in diameter) had about 90 m. of lining damaged badly at a point about 457 m. from its downstream portal. It was reported the San Fernando Tunnel (5.4 m. in diameter and about 9 km. long, which extends from Magazine Canyon to Pacoima Wash, experienced about a 1.9-m. vertical displacement between its portal and a point 7.2 km. into the tunnel. The First and Second Owens River Aqueducts were damaged. The Second Aqueduct was damaged in its Saugus pipeline portion (pipes buckled and supports moved) between Terminal Hill and Magazine Canyon. Water service to the Granada Hills, Porter Ranch, Sylmar, and other high-elevation areas in the San Fernando Valley was disrupted by the many trunkline breaks on the Susana, Granada, and Maclay trunklines. On the Granada line, most of the 10 or 12 breaks were in the Joseph Jensen Filtration Plant area. The wood roof collapsed at the small Maclay Reservoir on the Maclay High Line, and cracking occurred at the sides and corners of the basin. Damage at the Sylmar Converter Station (Pacific Intertie), west of Upper Van Norman Lake, was estimated at approximately $22 million. It was reported the most severe damage to this plant involved electrical equipment and underground conduit. There was extensive damage to converters, transformers, and circuit breakers. Heavy outdoor electrical equipment, some weighing many tons, was overturned. Building damage included many cracks and separations of concrete walls. It was estimated that this facility would be out of operation for about a year. A power-generating plant north of the station also was damaged seriously. There was severe damage to electrical equipment at the Olive Switching Station, about 0.8 km. west of the Sylmar Converter Station, where insulator-supported equipment collapsed and several large transformers overturned. Severe damage was sustained at the Olive View Powerplant, where large boilers were shifted as much as 1.2 m. and where tanks and motors were torn loose from anchorages. Many elevated water tanks were damaged; some were shifted, overturned, and destroyed. A large steel tank just north of Olive View Hospital was ruptured. An elevated water tank east of San Fernando Ranger Station (in Lopez Canyon) was shifted from its pad and destroyed. A Fiberglas tank near the northwest shore of Lower Van Norman Lake was overturned. A large tank at Granada Hills was damaged. Many water wells were damaged. In general, all utility facilities--gas, electric, and water--in the severe damage areas of San Fernando and Sylmar were out of service. The water distribution system for the city of San Fernando was almost completely destroyed by ground cracking and by violent shaking.