DEFORMATION OF THE VAN NORMAN RESERVOIRS AREA, NORTHERN SAN FERNANDO VALLEY, CALIFORNIA[I]

by

R. F. Yerkes[II], T. L. Youd[III], and J. N. Alt[II]

SYNOPSIS

The Upper and Lower Van Norman dams are within the east-trending system of active reverse faults that forms the south boundary of the San Gabriel Mountains. The reservoirs are also near the west margin of surface deformation associated with the 1971 San Fernando earthquake. Mapped effects of this deformation include tectonic ruptures along one of the mountain-front faults, differential arching, and horizontal displacements. Although the 1971 tectonic ruptures did not cross the reservoirs, the site for a replacement dam halfway between the existing dams is traversed by active faults subsidiary to the mountain-front fault zone. Also, displacement probably larger than that of 1971 occurred on a fault of the zone 7 km east of the reservoirs about 200 years before present. Thus, the Van Norman area will, in the future, be subjected to ground deformation and shaking effects greater than in 1971.

INTRODUCTION

The Van Norman reservoirs occupied a small drainage at the west margin of the northern San Fernando Valley immediately upstream from the densely populated central part of the valley and about 35 km northwest of Los Angeles. The reservoir complex consisted of an upper reservoir of about 2.3 million m^3 capacity and a lower reservoir of about 25 million m^3 capacity. Both dams date from before 1921 and were emplaced by hydraulic fill over alluvium as thick as 15 m. Both were severely damaged by slide failures within the hydraulic fill during the 1971 San Fernando earthquake. The lower dam was taken out of service after the earthquake and the reservoir drained, whereas the upper dam still impounds a small reservoir for emergency storage.

SETTING

The lower reservoir is traversed by a zone of east-trending north-dipping faults that are part of the active system that forms the south boundary of the San Gabriel Mountains (fig. 1). Most of these frontal faults show hundreds of meters of reverse slip in

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[II]Geologist, U.S. Geological Survey, Menlo Park, California.

[III]Civil Engineer, U.S. Geological Survey, Menlo Park, California.

Cenozoic time. The San Andreas fault, which bounds the San Gabriel Mountains on the north, trends much more easterly in this part of southern California than it does to the northwest or southeast. This segment of the fault--the "great bend"--last ruptured in 1857 (Fort Tejon earthquake) and now appears to be quiescent. The resistance to transmission of horizontal stresses around the buttress of this great bend, as coastal California moves northward relative to the continent, results in strong north-south compressive effects. The 1952 Kern County earthquake, associated with left-oblique-reverse movement on the south-dipping White Wolf fault (north of the San Andreas fault), as well as the 1971 San Fernando earthquake and its associated left-oblique-reverse faulting, are attributable to such effects.

Bedrock in the reservoir area is poorly to moderately indurated pebbly sandstone, conglomerate, and mudstone of Pliocene and Pleistocene age. The reservoir area is on the steep south limb of a northeast-trending syncline (fig. 2); the south limb is truncated by the zone of faults along which the 1971 ruptures occurred. An inferred zone of ancient faults at least 1 km wide extends from the mountain-front fault zone east of the lower reservoir northwestward through the site of the proposed replacement dam, into the abutments of the upper dam (fig. 3). The pronounced angular unconformity at the bedrock-surficial deposits contact, of late Pleistocene age, locally has been displaced by prehistoric movement on faults in the proposed dam site; these faults also are considered active.

SAN FERNANDO EARTHQUAKE

The 1971 San Fernando earthquake (M 6½) occurred on one of the east-trending, north-dipping reverse faults of the mountain-front zone. Surface ruptures of the fault traversed the northern San Fernando Valley for 6 km just east of the lower reservoir and thence east for another 9 km along the base of the San Gabriel Mountains; this zone of surface ruptures is named the San Fernando fault zone. Maximum measured components of displacement on the 1971 ruptures were: vertical, 1.4 m; horizontal (left-lateral), 1.9 m; horizontal shortening across the fault, 0.6 m; net (left-oblique-reverse) slip, 2.4 m. Geologic, topographic, and hydrologic evidence shows that the 1971 ruptures followed a long-established zone of similar fault movements. Radiometrically dated ancient wood was found beneath a buried fault scarp more than 1 m high, which is alined with 1971 ruptures having vertical separation of less than a meter. If the buried scarp is due to a single event, a larger earthquake probably occurred along the San Fernando fault zone 200± 100 years before present.[2/]

Deformation of the ground surface associated with the 1971 earthquake has been mapped in detail. Figure 4 shows vertical displacements in the northern San Fernando Valley between preearthquake (1968-1970) and, post-earthquake (1971-1972) surveys. Notable features are listed.

1) A west-plunging arch generally coincident with the south limb of the syncline extends westward into the valley and the reservoir area from its maximum development in the foothills east of the valley; vertical displacement ranges from more than 2 m in the foothills to

0.5 m in the center of the reservoirs and 0.2 m along their west margin.

2) An area of low hills just east of the reservoirs and north of the rupture zone was elevated 0.83 m; this uplift extends northwestward into the site of the proposed dam.

3) A linear zone of slight depression about 0.1 to 0.3 km wide trends across the valley immediately south of the 1971 rupture zone.

4) The east abutment of the upper dam was elevated 0.317 m and the west abutment 0.213 m; the east abutment of the proposed dam was elevated about 0.555 m and the west abutment about 0.323 m.

5) Areas that were elevated in 1971 coincide with pre-existing topographic highs underlain at or near the surface by steeply dipping bedrock.

6) Abrupt discontinuities in the gradient of arching coincide with the 1971 rupture zone and its westward extension (fig. 5, profiles B, C, D).

The map of horizontal displacements (fig. 6) defines the 1971 rupture zone and its westward extension as an abrupt discontinuity; north of the zone the displacement averaged about 0.5 m westward, whereas south of the zone it averaged about 0.3 m northward. Although the amounts of displacement decrease progressively westward, the discontinuity persists across the reservoir area, whereas the rupture zone did not. Differential displacements of the east abutment area relative to the west abutment for each dam site were determined:

Upper dam (between stations 472 m apart): 0.091 m S. 18° W. and 0.136 m up;

Proposed dam (between stations 689 m apart): no significant relative horizontal displacement, 0.232 m up;

Lower dam (between stations 808 m apart): 0.145 m N. 44° E., no significant vertical displacement.

The planar deformation of each of 250 triangular elements based on 90 horizontal control points in the northern San Fernando Valley was determined and maps of assumed homogeneous dilation, maximum shear strain, and magnitude and orientation of principal strains were made but not included here (see ref. 5). The map of dilational strains shows a conspicuous, elongated band of compression (values greater than -0.30 percent) coincident with the 1971 rupture zone just east of the lower reservoir. The band follows the westward trend of the 1971 rupture zone across the reservoir, but the intensity of compression decreases progressively westward. Areas of most intense expansion (values as great as +0.15%) coincide with areas of greatest differential elevation; each of these areas is also a topographic high. A conspicuous, elongated band of shear strain (values

greater than 10^{-3} radians) also coincides with the 1971 rupture zone and decreases in intensity westward across the lower reservoir. In the vicinities of the upper and proposed dams, the major principal strains generally parallel the dam axes and attain values of 0.02% extension. The minor principal strains are oriented generally normal to the trend of the dam axes and attain values of 0.03% compression.

INTERPRETATION

Although the entire valley north of the 1971 rupture zone was translated westward and the nearby area south of the zone was translated northward, differential deformation was concentrated along the 1971 rupture zone and its westward extension. The reservoir area itself was subjected to relatively moderate differential deformation, although the combination of high dilational and shear strains along the rupture zone and in the area of maximum differential elevation just east of the lower reservoir indicates relatively intense distortion at those localities. The reservoir area is traversed by faults of the system on which the 1971 earthquake occurred, and is at the west margin of, but well within, the area of 1971 deformation. This fact, combined with evidence that the local tectonic stress system produced a larger-than-1971 earthquake on the same fault in the recent past and that this system is long established and expected to continue, assures that the Van Norman area will, in the future, be subjected to shaking effects and permanent deformations greater than those of 1971.

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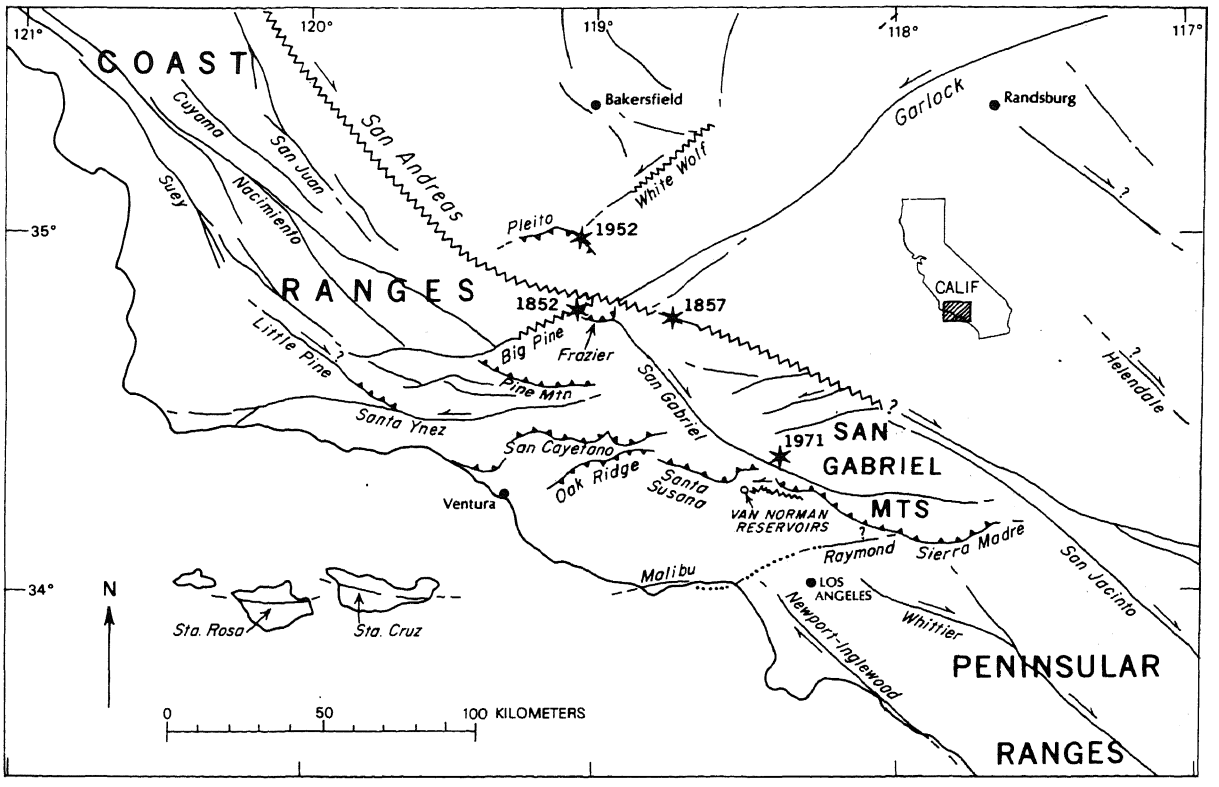

FIGURE 1.--Outline map of part of southern California showing relation of the Van Norman reservoirs area in northern San Fernando Valley to major faults of coastal southern California, and epicenters of larger historic earthquakes (stars and dates) associated with tectonic surface ruptures (sawtooth lines) attributable to the same stress system as the 1971 San Fernando earthquake. Arrows indicate relative horizontal movement on strike-slip faults; reverse or thrust faults shown by barbed lines, barbs on upper plate. Adapted from Hill[17]

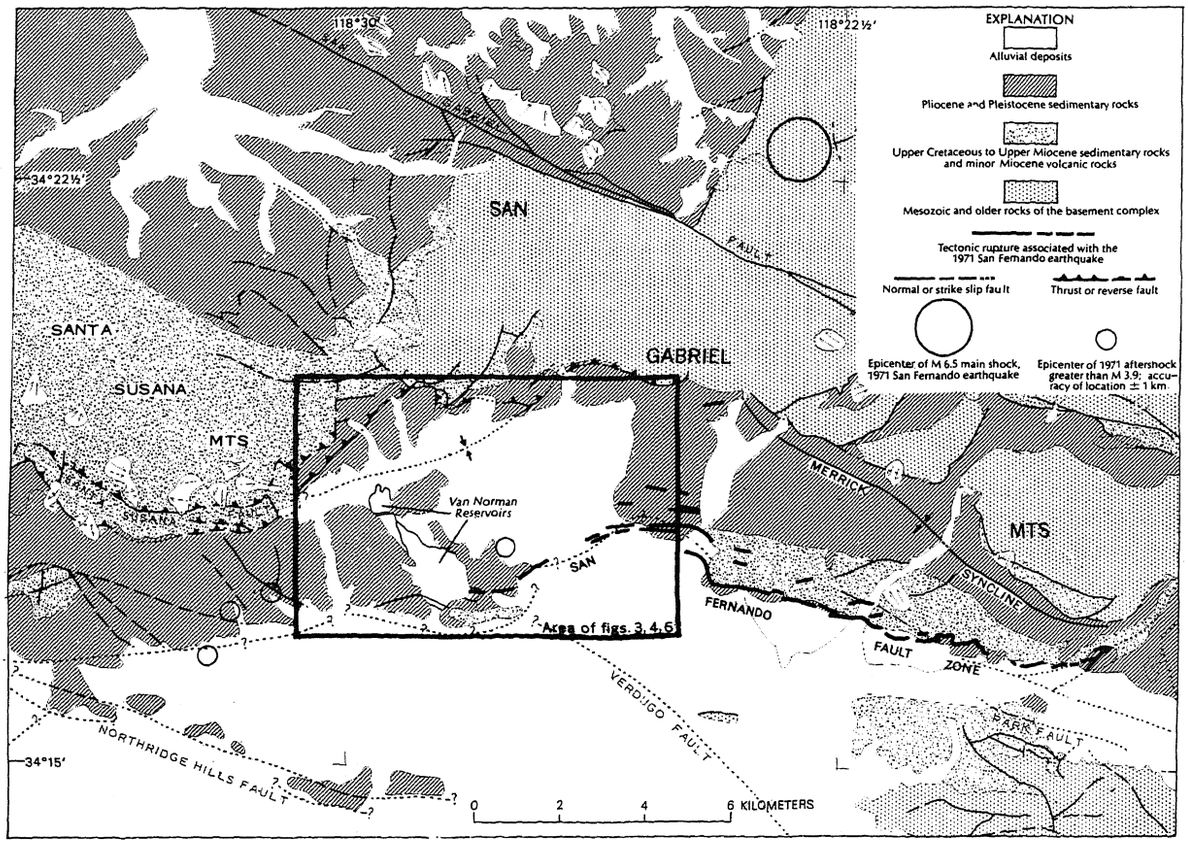

FIGURE 2.--Generalized geologic map of northern San Fernando Valley and western San Gabriel Mountains showing the Van Norman reservoirs, epicenters of the 1971 San Fernando earthquake and selected aftershocks, and the associated zone of tectonic ruptures. Unpatterned areas with half-arrows represent landslides. Adapted from Yerkes and Wentworth[4].

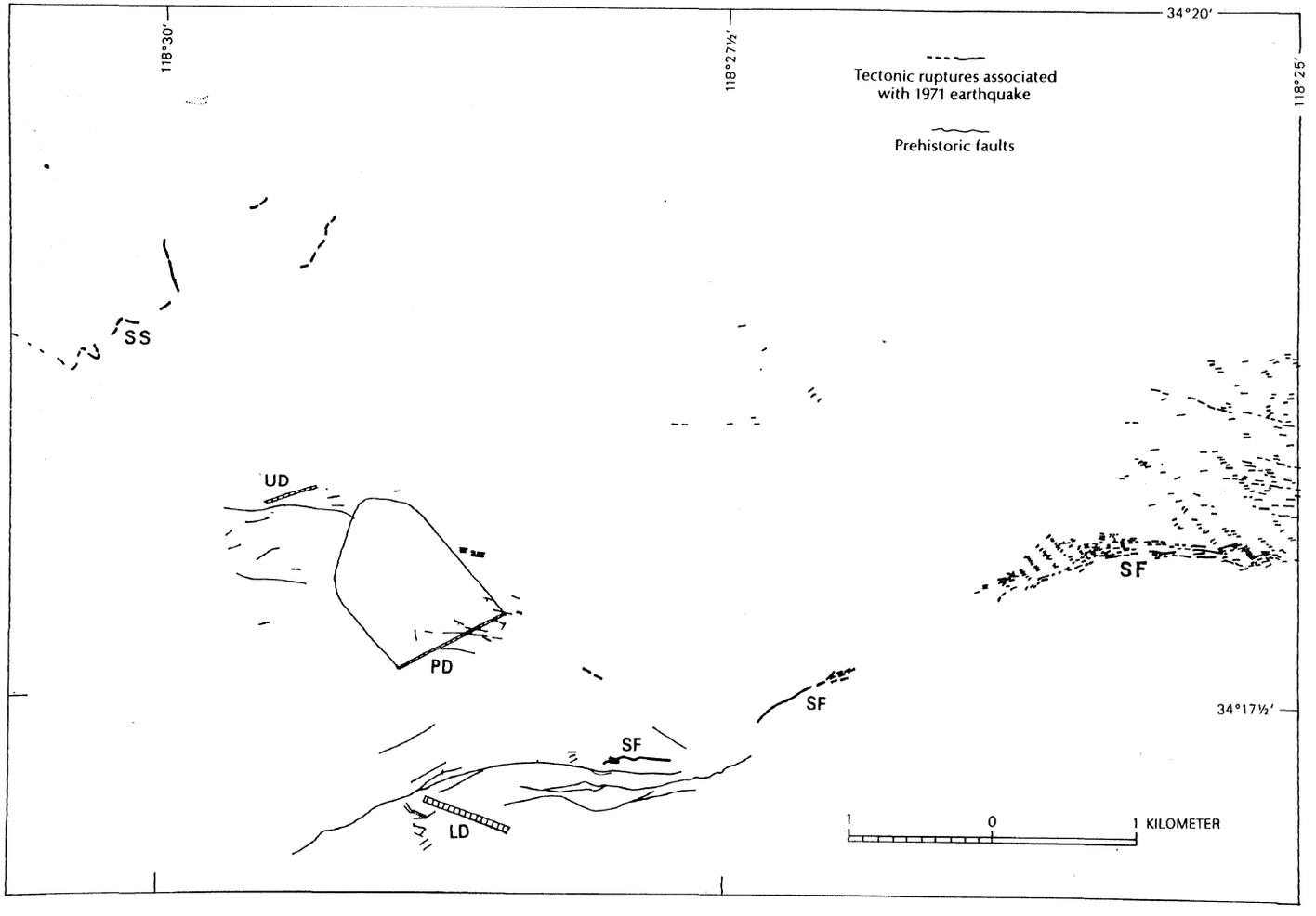

FIGURE 3.--Map of northern San Fernando Valley showing tectonic ruptures associated with the 1971 San Fernando earthquake, and known prehistoric faults in the Van Norman reservoirs area. UD-upper dam, PD-proposed dam and reservoir, LD-lower dam, SF-1971 tectonic ruptures along the San Fernando fault zone, SS-tectonic(?) ruptures along the lower trace of the Santa Susana thrust. Based in part on U.S. Geological Survey Staff[3].

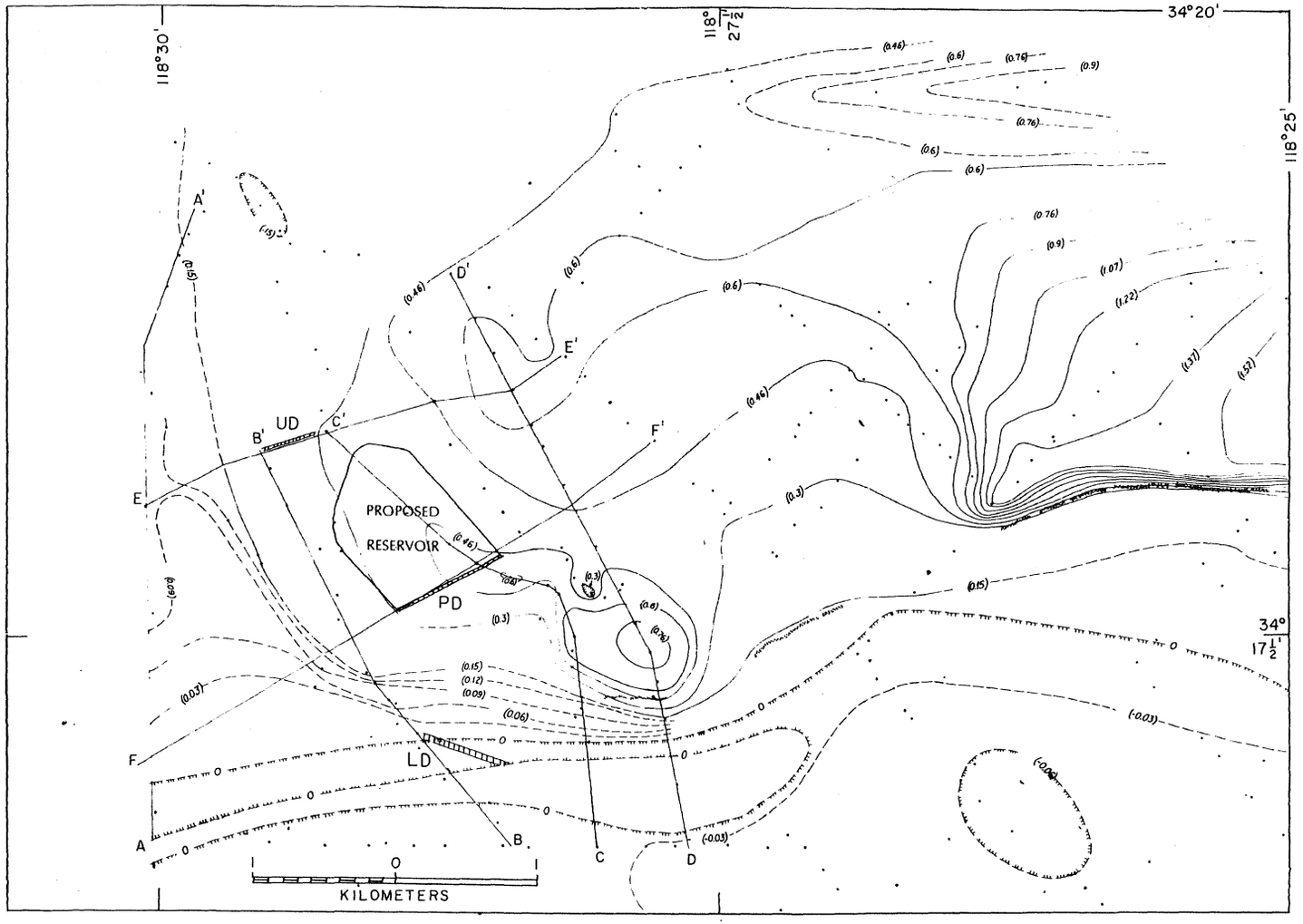

FIGURE 4.--Map of northern San Fernando Valley showing contours of elevation change in meters, tween 1968-1970 and postearthquake surveys (pre-earthquake survey of line D-D' made in 1955). Locations of survey stations shown by dots; accuracy of elevations ±0.015 m. Locations of 1971 tectonic ruptures along San Fernando fault zone shown by fine sawtooth lines. Lines A-A' to F-F' are profiles of elevation change (see figure 5). UD-upper dam, PD-proposed dam, LD-lower dam.

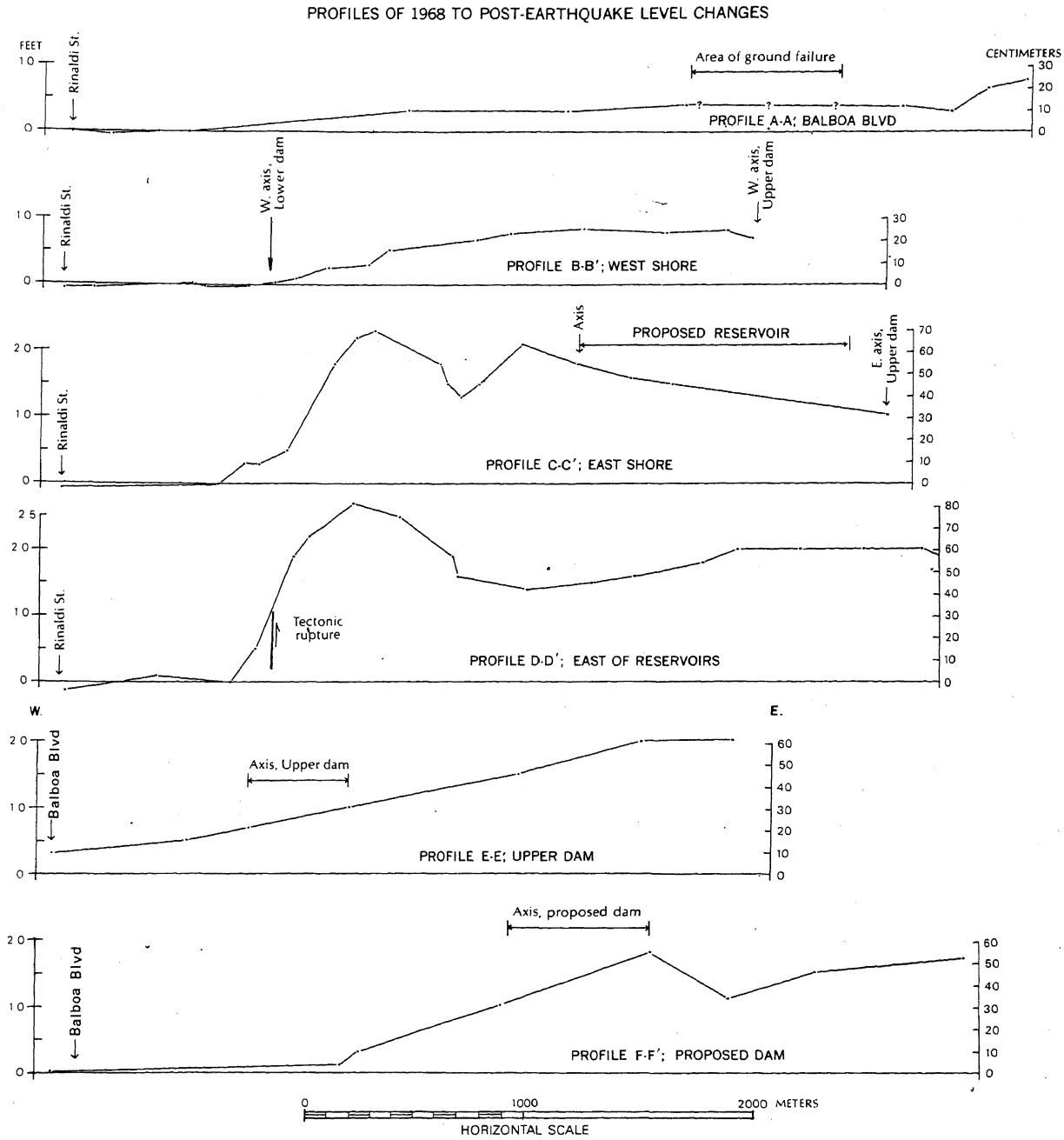

FIGURE 5.--Profiles of elevation change between 1968-1970 and postearthquake surveys in Van Norman reservoirs area; pre-earthquake survey of line D-D' made in 1955.

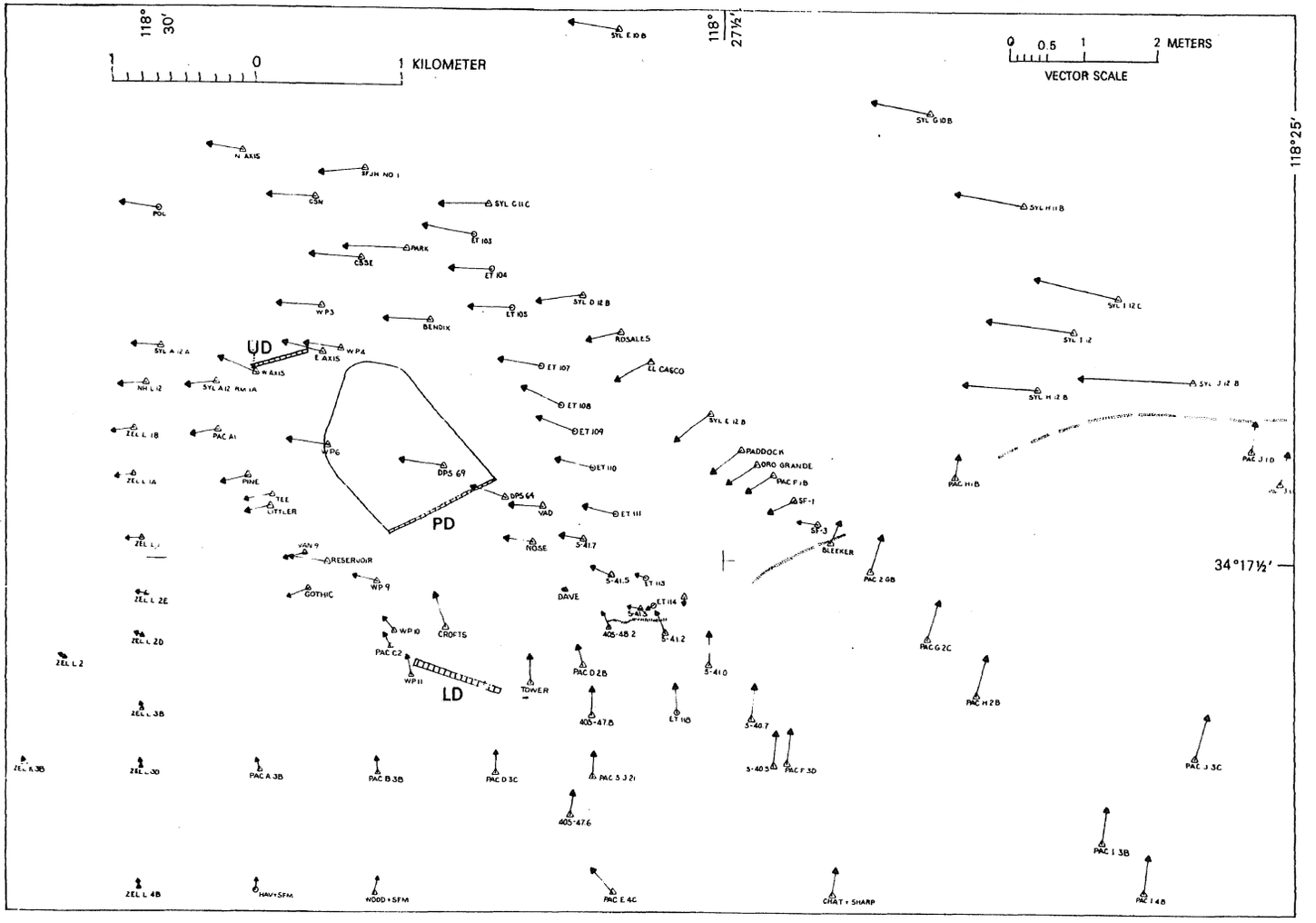

FIGURE 6.--Map of northern San Fernando Valley showing horizontal displacements between 1940-1970 and postearthquake surveys; accuracy of changes shown by vectors about ±0.03 m. Points held fixed for free adjustment by U.S. National Geodetic Survey are located 22 and 30 km southeast of the reservoir area. Locations of 1971 tectonic ruptures along San Fernando zone shown by fine sawtooth lines. UD-upper dam, PD-proposed dam and reservoir, LD-lower dam.