Paleoseismology, Active Tectonics, and Seismic Hazards of the Verdugo Fault Zone, Los Angeles County, California

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Abstract

After an air photo and field analysis of a 20-km-long reach of the Verdugo fault in Glendale and Burbank, California, we identified two undeveloped, potential paleoseismologic trench sites; the remainder of the fault is covered by either buildings or streets. In order to locate a trench site at our primary site (Brand Park in Glendale), we completed a 10-hole transect of continuously cored boreholes, as well as several ground-penetrating radar (GPR) profiles across the presumed trace of the fault. We identified an apparent stratigraphic and GPR anomaly that may correspond to the fault trace, but our attempted trench across this feature failed due to the extremely friable nature of the sediments and space constraints related to landscaping in the park. We then turned our efforts to our secondary site (Palm Park in Burbank), where we have recently obtained permission to conduct a program of large-diameter bucket-auger holes designed to locate a future paleoseismologic trench site.

Investigations

After an air photo and field analysis revealed only two prospective undeveloped trench sites along the trace of the Verdugo fault, we focused our efforts on a site at Brand Park in Glendale, where the trace of the fault is locally buried by a young alluvial fan. At Brand Park we conducted a comprehensive borehole and ground-penetrating radar search for the most recently active trace of the fault. Although we did identify one apparent stratigraphic anomaly in our borehole and GPR transects, our attempt to excavate a trench across this feature failed due to the unstable nature of the sandy alluvium, and we remain uncertain as to whether or not this feature represents a recently active strand of the Verdugo fault, although we suspect that it does. Because of the failure of this trench and the laterally discontinuous nature of the alluvial strata in this upper- alluvial fan setting, we are not fully convinced that we can reliably locate the surface trace of the Verdugo fault where it crosses Brand Park. Thus, we think that the Brand Park site will not provide useful paleoseismologic data in the short term. We have shifted our efforts to our secondary site, at Palm Park in Burbank, where we have obtained permission from the City of Burbank to conduct a northeast-southwest transect of large-diameter bucket-auger boreholes designed to locate the surface trace of the fault. Once we have located the surface trace of the fault, we will open a paleoseismologic trench, which we hope will expose colluvial stratigraphy associated with ancient surface ruptures on the Verdugo fault.

Results

The Verdugo fault is a 30-km-long, northeast-dipping reverse fault that extends along the northeastern edge of the San Fernando Valley north of Los Angeles (Figure 1). The Verdugo fault lies ~7 km southwest of, and parallel to the Sierra Madre fault, the major north- to northeast-dipping reverse fault that bounds the southern edge of the San Gabriel Mountains. The Verdugo fault extends southeastward as the Eagle Rock fault into a poorly understood junction with the left-lateral Raymond fault system in southwestern Pasadena (Figure 1) (Weber, 1980; Dibblee, 1989, 1991a, 1991b, 1991c).

Our research focused on the 20-km-long stretch of the Verdugo fault in the Glendale and Burbank area, where the fault is well-expressed geomorphically. In this area the fault separates uplifted Cretaceous plutonic and Cretaceous or older metamorphic rocks of the Verdugo Mountains from a broad alluvial plain to the southwest (Figures 1 and 2) (Dibblee, 1991a, 1991b, 1991c). The numerous alluvial fans that emanate from canyons draining the Verdugo Mountains coalesce downslope into a broad, southwest-facing alluvial apron. The southwestern edge of the Verdugo Mountains exhibits a sharp topographic break in slope and many triangular facets, and the Verdugo fault has been mapped at or just southwest of the topographic mountain front by several researchers (e. g., Weber, 1980; Dibblee, 1991a, 1991b).

We began our study with an analysis of aerial photographs of the fault taken between 1928 and the 1980’s. The early photographs, taken before complete development, reveal what appear to be small-scale (single event?) scarps in young alluvium at several locations. Unfortunately, however, all of these sites have now been obliterated by development.

The entire length of the Verdugo fault that we examined is almost completely covered with buildings (mostly single-family houses) and streets. Our air photo and field analyses revealed only two open, undeveloped sites along the fault--Brand Park in Glendale and Palm Park in Burbank (Figure 2). We concentrated our search for a suitable paleoseismologic trench site at these two parks.

Of the two open park sites, Brand Park appeared to be the better option. Brand Park occupies the upper reaches of a large alluvial fan that emanates from Brand Canyon, which is one of the larger canyons draining the Verdugo Mountains (Figures 2 and 3). Air photo and field analysis revealed probable fault scarps on either side of the alluvial fan, but no scarp extending across the fan, suggesting that evidence of the most recent Verdugo fault surface rupture was buried beneath recent alluvium within the park. Specifically, a several-meter-high, gently south-facing scarp, which we interpret as the most recently active trace of the Verdugo fault, extends west-northwestward from the northwestern edge of Brand Park (Figure 3). To the southeast, 1928 Fairchild air photos reveal what may be two fault scarps in the alluvium about 50 m south of the sharply defined topographic mountain front. These two scarps appear to be only a meter or a few meters high and may represent single-event scarps formed during the most recent Verdugo fault surface rupture. They have both been covered by subsequent development. Thus, at Brand Park we had what appeared to be a promising situation for a paleoseismologic trench site, where evidence of the most recent surface rupture had likely been buried by recent sedimentation. Burial of the most recently active trench suggested that we would be able to bracket the age of at least the most recent surface rupture on the Verdugo fault.

Our first step was then to exactly locate the fault within the park boundaries. Extensive modification of the topography in the eastern half of the park to create parking lots and playing fields limited our search to the northwestern part of the park, where ground surface modification appears to have been minimal. Unfortunately for the results described below, this part of the park also coincides with the most recently active part of the Brand Park fan, with consequent very rapid sedimentation rates and little soil development.

Small-Diameter Borehole Transect

In the northwestern part of the park the nearest reliable fault location is provided by an exposure of bedrock about 100 m northwest of the park boundary; the fault must thus lie southwest of that outcrop. Unfortunately, the dip of the fault is unknown at this locality and thus we could not accurately project the location southeastward into the park at the mouth of Brand Canyon.

Initially, we had hoped to locate a north-side-up step in the depth to bedrock associated with past reverse displacement along the Verdugo fault. But the boreholes revealed that the alluvium/bedrock contact was deeply buried, beyond the 29 m depth of our deepest borehole (VF-1; Figures 4 and 5). The sediments we encountered were predominantly sand with various percentages of pebble- to cobble-sized gravel. In general, the upper 3.5 to 4.5 m of the cores consisted predominantly of sand beds, whereas below ~3.5 m we encountered increasing percentages of gravel. The gravels all had a sandy matrix, and clast size ranged from small pebbles to cobbles. The abundance of sand in such a proximal, fan-head setting is due to the disaggregation of the predominantly plutonic rocks in the adjacent Verdugo Mountains into their constituent mineral grains.

The sediments exposed in the cores were in general very friable and exhibited minimal evidence of soil development, in the form of a few 5- to 60 cm-thick buried A horizons and some possible buried cambic (or color B) horizons marked by medium brown colors that stood out against the otherwise pale yellow-brown colors of the granitic sands. The lack of significant soil development attests to a very rapid sedimentation rates at this fan-head site, and may have resulted in deep burial of evidence of the most recent Verdugo fault surface rupture. Our deepest borehole (VF-1/1B) exposed 29 m of predominantly granitic sand and pebble gravel, with a section of relatively lithified angular pebble-cobble gravel exposed between 22 and 26 m depth. The VF-1 data indicate that bedrock beneath the main channel of Brand Creek beneath the head of the Brand canyon fan is deeply buried.

Once we realized that any northeast-side-up bedrock step associated with the Verdugo fault was too deeply buried to reach, we focused our efforts on finding a north-side-up displacement of one of the weak soil horizons that we encountered. We identified one possible anomaly between boreholes VF-7 and VF-10 (Figure 5). Borehole VF-7, the more northeasterly of the two, exhibited several coalesced A horizons extending down to ~1.2 m depth. Below 1.7 m depth the borehole entered a gravel-rich section. Similalry, in boreholes VF-8 and VF-9, northeast of VF-7, the base of the coalesced A horizons was encountered at ~1.3 m depth, and 1.5 m depth, respectively, and the top of the gravel-rich section was encountered at 2.6 m in both holes.

An overall similar sequence was observed in borehole VF-10, located 7 m to the south of VF-7 (Figure 5). In VF-10, however, both the base of the coalesced A horizons and the top of the gravel-rich section were encountered at a deeper depth (base of A horizon and top of gravels in VF-10 both at 3.4 m depth). We suspected that these relationships were due to a north-side-up step across the most recently active strand of the north-dipping Verdugo fault.

There may also be a similar north-side-up step in the top of the gravel-rich section between boreholes VF-5 and VF-6 to the south, although an apparent southwestward thickening of the A horizon was not observed there, as it was between VF-7 and VF-10 (Figure 5).

Ground-Penetrating Radar (GPR) Profiles

In addition to the borehole transect, we also acquired several shallow-penetration ground-penetrating radar (GPR) profiles across the presumed fault trace in the northwestern part of Brand Park (Figures 4, 6, and 7). Just east of our trench site (Figure 6), the GPR data showed a zone of anomalous reflectivity that approximately corresponds to the possible north-side-up separation between boreholes VF-7 and VF-10. Although the anomalous zone of reflectivity revealed by the GPR profile could be due to channelization, it could also reflect the presence of the most recently active trace of the Verdugo fault in the shallow subsurface.

Farther north, we noted narrow (~10-15 m) zones of enhanced reflectivity and deeper penetration on three parallel profiles near the northern end of our GPR transects (e. g., figure 7; see location of profile near the "Dr.'s House" in Figure 4). We initially suspected that this enhanced reflectivity might be the result of ponded groundwater along the north side of a shallow trace of the Verdugo fault. However, in map view these areas of reflectivity did not form a simple pattern suggest of a continuous fault trace. We examined this feature near the westernmost of our GPR profiles (GPR-1) with five closely spaced, parallel (average spacing ~3 m) profiles. All five profiles imaged the reflective feature, and at that location it trends approximately north-south. This trend is at a high angle to the presumed ~N60-65W fault trace in this area, but is much closer in trend to the ~N25E main channel emanating from Brand Canyon. We thus interpret these features as channel deposits not related to surface faulting.

Attempted Paleoseismologic Trench

The geomorphology of the area just northwest of the park leads us to suggest that approximate trace of the Verdugo fault lies somewhere between the "Doctor's house" and the "Tea House", northeast of the trace suggested by Dibblee (1991a) (Figures 3 and 4). Specifically, the nearest reliable fault location is provided by the southwesternmost part of an exposure of crystalline bedrock about 100 m northwest of the park boundary (Figure 3). Unfortunately, the dip of the fault is unknown at this locality. Thus, because the northwestern corner of the park lies at the mouth of Brand Canyon, which is deeply incised into the surrounding mountain front, we cannot accurately project the fault location southeastward into the park.

Were it not for the park landscaping (which we were required to restore to pre-excavation condition), the easiest means of locating the fault trace in the park would have been to excavate an ~100-m-long trench across the entire possible location of the surface trace. Since we could not do that, we attempted to excavate a conventional one-meter-wide trench across the apparent north-side-up observed between boreholes VF-7 and VF-10, coincident with the reflective zone observed in the GPR data (Figures 4 and 5). However, because of the very friable nature of the sediments, we immediately encountered unstable trench conditions, with raveling sands and unstable walls. In the interests of safety we immediately closed the trench. The presence of trees and other landscaping throughout this part of the park prevented us from excavating a wide, benched trench across this feature. We thus remain uncertain as to whether or not the apparent north-side-up displacement we observed in the boreholes is the most recently active strand of the Verdugo fault, although we suspect that it is.

In summary, despite an intensive borehole and GPR program, and an attempted trench, we were unable to confidently locate the surface trace of the Verdugo fault where it crosses Brand Park, and were thus not able to generate any paleoseismologic data from the fault at this location.

Palm Park Site, Burbank

We have now turned our efforts to the second possible trench site across the Verdugo fault in Palm Park in Burbank, ~2.3 km northwest of Brand Park (Figure 2). We have already received permission from the City of Burbank to excavate at the site.

Palm Park straddles the break in slope at the steep southwest-facing mountain front of the Verdugo Mountains just west of the mouth of Sunset Canyon (Figure 2). The park lies atop a large underground reservoir built in 1955. Although construction of the reservoir has obliterated the original ground surface in the center of the park, what appears to be the original ground surface still exists along the southeastern edge of the park, the northwestern half of the park, and the topographically lowest southwestern part of the park.

Excavations for the reservoir tank (which is now overlain by a baseball diamond) created 3- to 10-m-high exposures of bedrock (a pale grayish-brown foliated quartz diorite; Dibblee, 1991b) along the northwestern and northeastern edges of the park. Exposures near the northeastern half of the southeastern park boundary reveal several meters of pebble to cobble colluvium overlying crystalline basement. A ~1.5-m-thick dark red (2.5 YR 3.5/7 to 3.5 YR 4.5/8) argillic horizon (Bt) is developed within the colluvium. The thickness and color of this argillic horizon suggest that the present surface soil is very old, probably reflecting something on the order of ~100,000+/-50,000 years of development. The presence of the old red soil atop colluvium and crystalline basement in the hanging wall of the fault suggests that the reverse-slip rate on the fault may be relatively slow.

In the northwestern part of the park, to the northwest of the reservoir, high-standing crystalline basement outcrops drop off abruptly southwestward at an apparently original very sharp, steeply south-facing break in slope that we interpret as the main trace of the

Verdugo fault. Below this sharp break in slope, the southwestern half of the park lies on gently southwest-sloping alluvium of the northwestern shoulder of the Sunset Canyon fan (Figure 2).

Based on the geomorphology of the site, with the northeast edge of the park sitting astride crystalline basement rocks of the Verdugo Mountains, and the southwest edge of the park on gently southwest-sloping young alluvium, we believe that the most recently active trace of the Verdugo fault lies within the park boundaries. Unfortunately, in the northwestern part of the park, where the fault is best-defined geomorphically, a pumping station is built adjacent to the presumed fault trace, precluding excavation of a trench in this part of the park.

We therefore plan a two-stage study of the southeastern half of the site. First we will locate the exact position of the fault by drilling a series of large-diameter bucket-auger holes along the southeastern edge of the park that will trace the position of the granodiorite and the orange soil that caps it. We will begin within the known granodiorite outcrop and work southwestward (Figure 8). The reverse component of slip on the fault evinced by crystalline basement rocks at the surface in the hanging wall suggests that there will be an abrupt southwest-side-down displacement across the fault that should be discernible in the boreholes.

Once we have located the surface trace(s) of the fault with the borehole study, we will excavate a trench(es) designed to map out colluvial stratigraphy associated with ancient surface ruptures (Figure 8). If such colluvial stratigraphy is present, and given the reverse or oblique-reverse nature of the fault we expect that it will be, we will also be able to estimate reverse slip per event in ancient earthquakes. The park contains sufficient open space along its southeastern and southern margins to excavate a trench at any point. Thus, we feel confident of our ability to successfully complete the project from a logistical standpoint.

Acknowledgments

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Figure Captions (captions for figures 1-5 and 8 printed on figures)

Figure 6. Twenty-six-meter-long portion of N30E-trending ground-penetrating radar (GPR) profile, acquired from between the Tea House and the "Doctor's House" in the northwestern part of Brand Park, Glendale (see figure 4 for location). Northeast is to the left in figure; southwest is to the right. Note the prominent near-vertical zone of enhanced reflectivity in center to center-right of image (15 to 25 m from left [northeast] edge of profile), with relatively unreflective sections to the northeast and southwest. This zone of anomalous reflectivity corresponds approximately to the possible south-side-down step observed between boreholes VF-7 and VF-10 (see figure 4 for borehole locations; see text for discussion). The shallow, highly reflective feature in the center of the image (13 m from left [northeast] edge of profile) is a buried utility line. 400 mHz antennae. Base of profile is about 75 nsec two-way travel time. Total depth of profile shown is therefore ~3 m assuming a sediment velocity of ~13 nsec/m (4 nsec/foot).

Figure 7. Thirty-meter-long portion of N30E-trending ground-penetrating radar (GPR) profile, acquired from near the northwest corner of the "Doctor's House" in the northwestern part of Brand Park, Glendale (see figure 4 for location). Northeast is to the left in figure; southwest is to the right. Note the prominent, southward-increasing sediment reflectivity that is abruptly truncated at ~26 m from northeast side of profile. Also note gentle northward dip of reflectors in the center of the image, north of the reflective package. 200 mHz antennae. Base of profile is about 150 nsec two-way travel time. Total depth of profile shown is therefore ~6 m assuming a sediment velocity of ~13 nsec/m (4 nsec/foot). The near-horizontal reflectors in the center-left part of the image were not discernible on a second period of acquisition from this same profile location three months after this profile was acquired. We suspect that the sub-horizontal reflector

package, which clearly cross-cuts bedding, may represent the base of a wetting front related to irrigation of the park. We eventually plan to run a seismic refraction profile along the length of the aprk in order to identify any bedrock step associated with the deeply buried alluvium/bedrock contact. if we can resolve the location fo this step, it may provide us with a fault location. we will report on this later????.

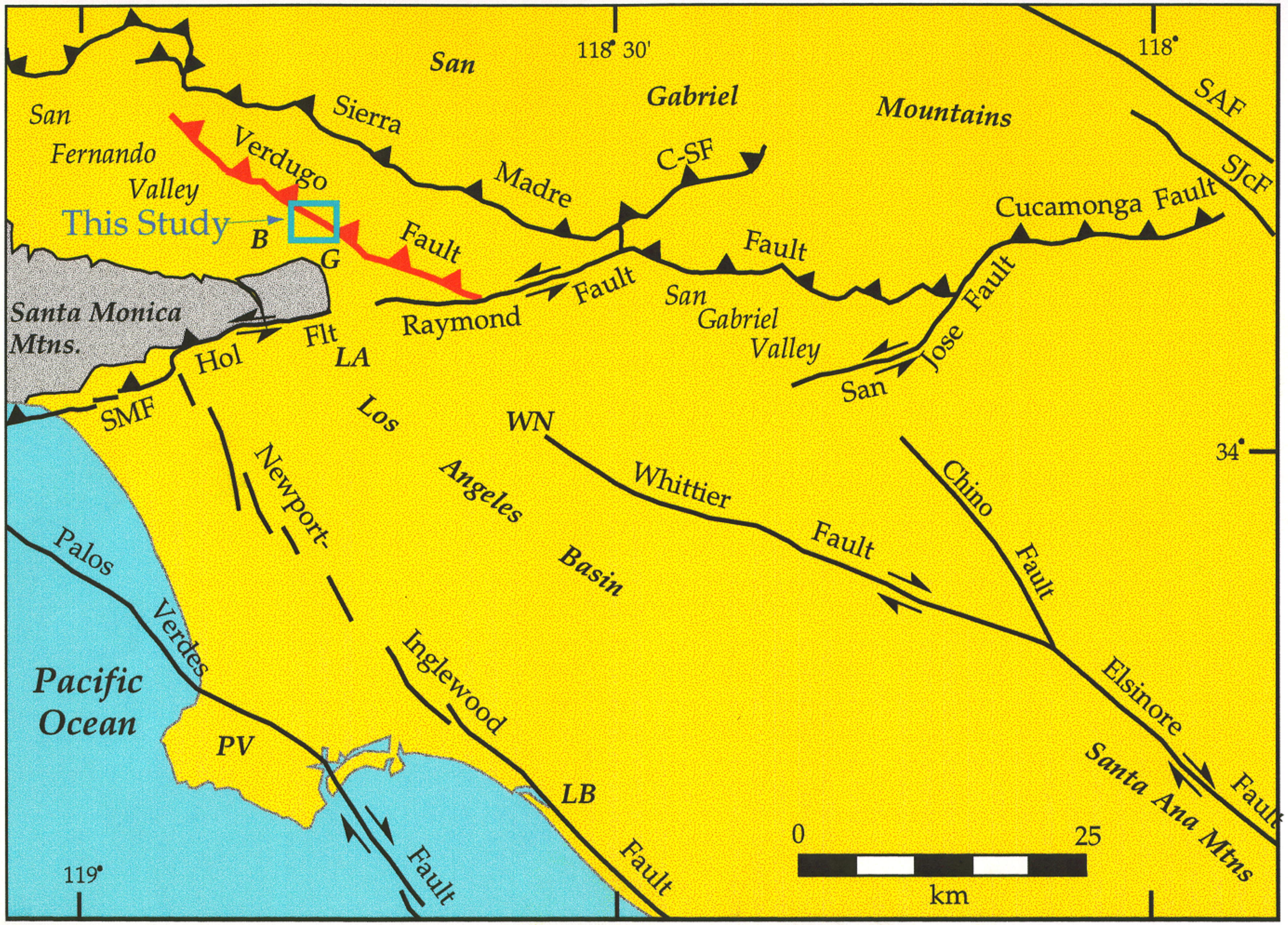

Figure 1. Regional neotectonic map of southern California showing major active fault systems. The Verdugo fault trace extends through the cities of Glendale and Burbank just north of downtown Los Angeles. Area of figure 2 shown by box. ELATB=East Los Angeles fold-thrust belt; Hol flt=Hollywood fault; RMF=Red Mountain fault; SCIF=Santa Cruz Island fault; SJF=San Jose fault; SJcF=San Jacinto fault; SSF=Santa Susana fault; B=Burbank; G=Glendale; LA=Los Angeles; LB=Long Beach; M=Malibu; NB=Newport Beach; Ox=Oxnard; P=Pasadena; PH=Port Hueneme; PM=Point Mugu; PP=Pacific Palisades; V=Ventura; WN=Whittier Narrows. Modified from Dolan and others (1997).

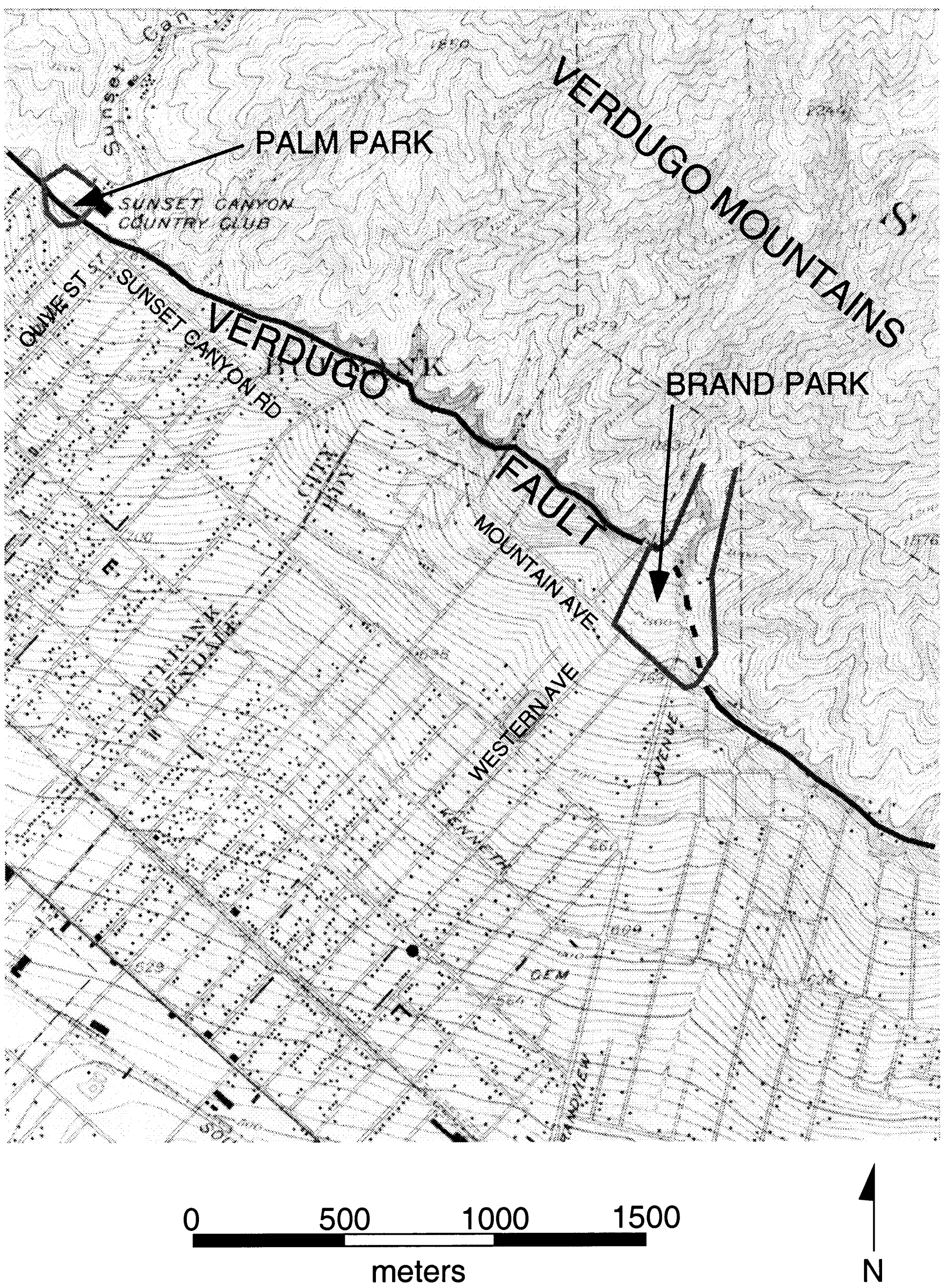

Figure 2. Location map of northwestern Glendale and eastern Burbank showing Brand and Palm Parks and approximate trace of Verdugo fault. Topographic base of from 1926 USGS 6' quadrangle. Contour interval is 5' below 800' elevation (about at mountain front) and 25' above 800' elevation.

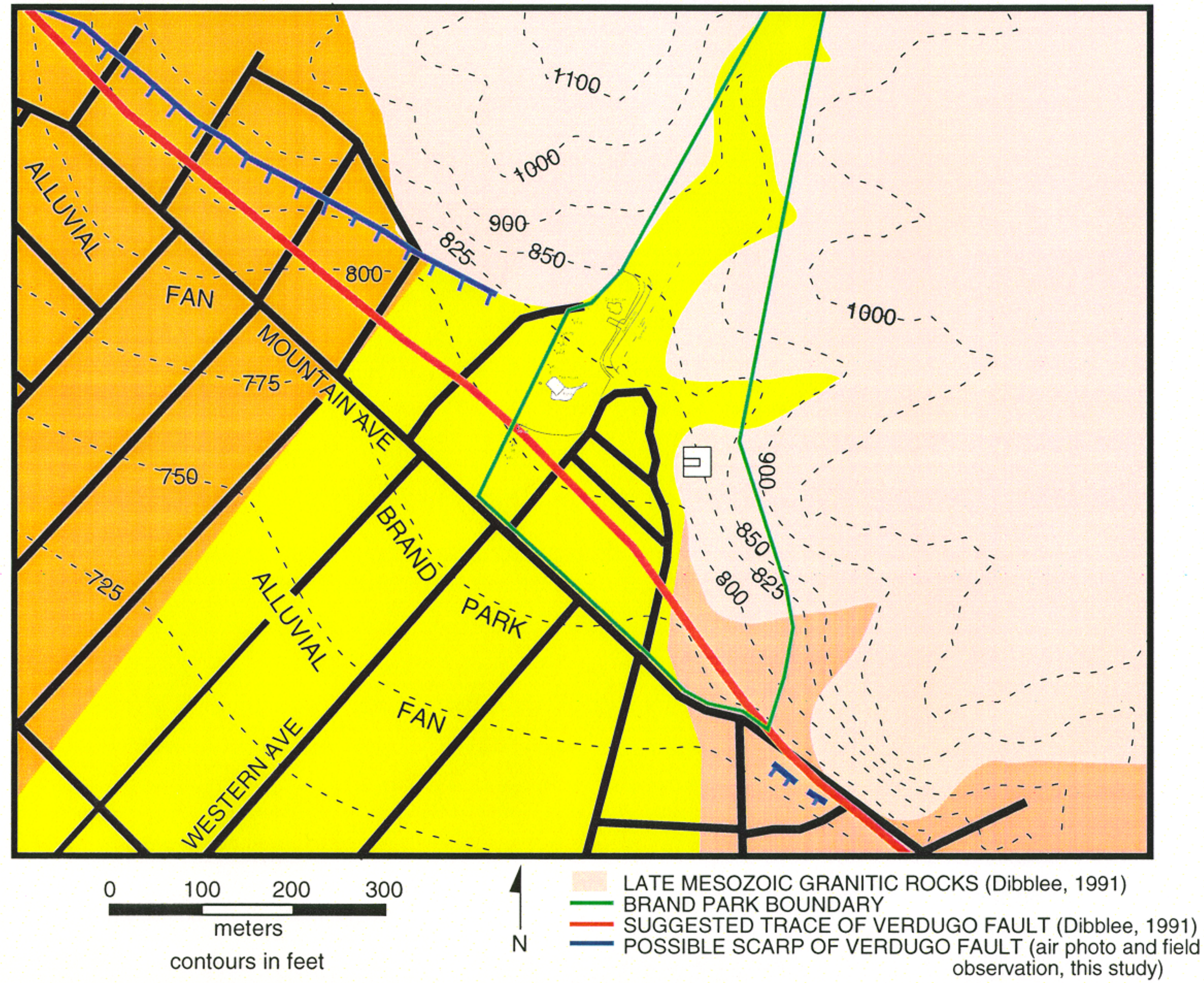

Figure 3. Map of Brand Park area in northwestern Glendale showing location of Verdugo fault trace suggested by Dibblee (1991) as well as location of gentle south facing scarp northwest of park (based on our air photo and field studies). Near the northwestern park boundary this apparent scarp merges with the bedrock/alluvium contact.

Brand Park Site Map

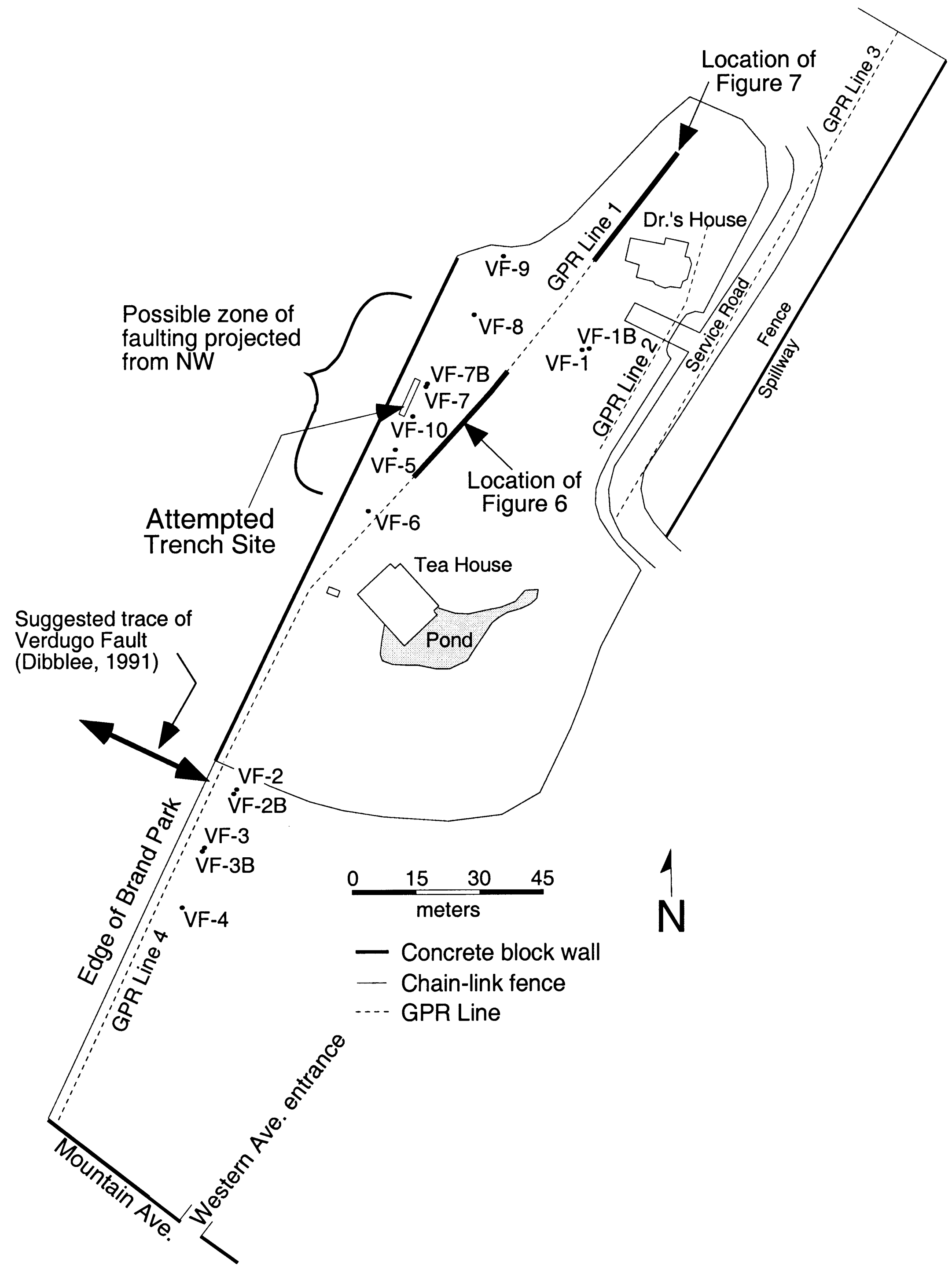

Figure 4. Map of northwestern part of Brand Park showing location of continuously cored (10 cm diameter) boreholes and ground-penetrating radar profiles.

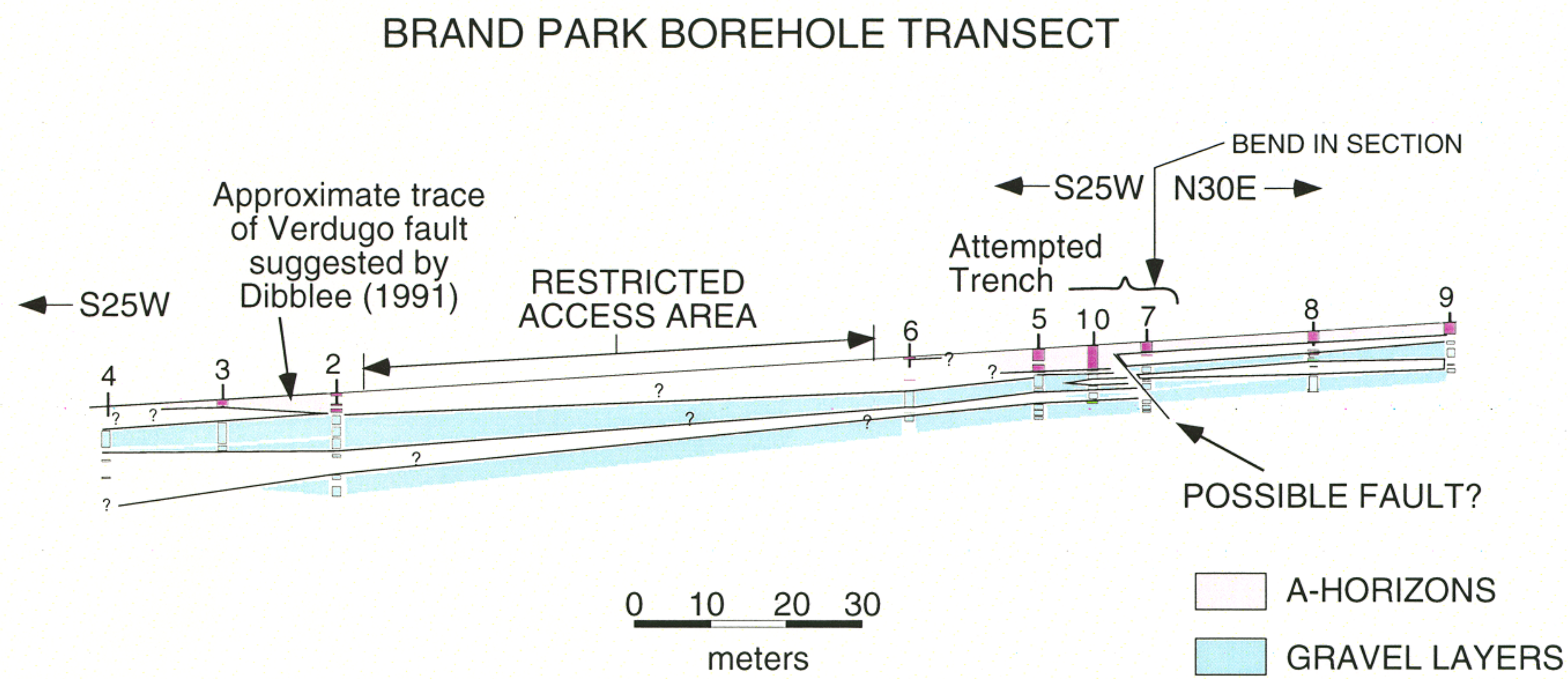

Figure 5. Northeast-southwest cross section through Brand Park across presumed location of Verdugo Fault. Numbers denote different continuously cored boreholes. Note apparent southwest thickening of coalesced A horizons and south-side-down step in top of gravels between boreholes 7 and 10. We interpreted this as a reverse separation on a recently active strand of the Verdugo fault and attempted to excavate a trench across it. However, we encoutered unstable soil conditions and we were unable to examine the trench.

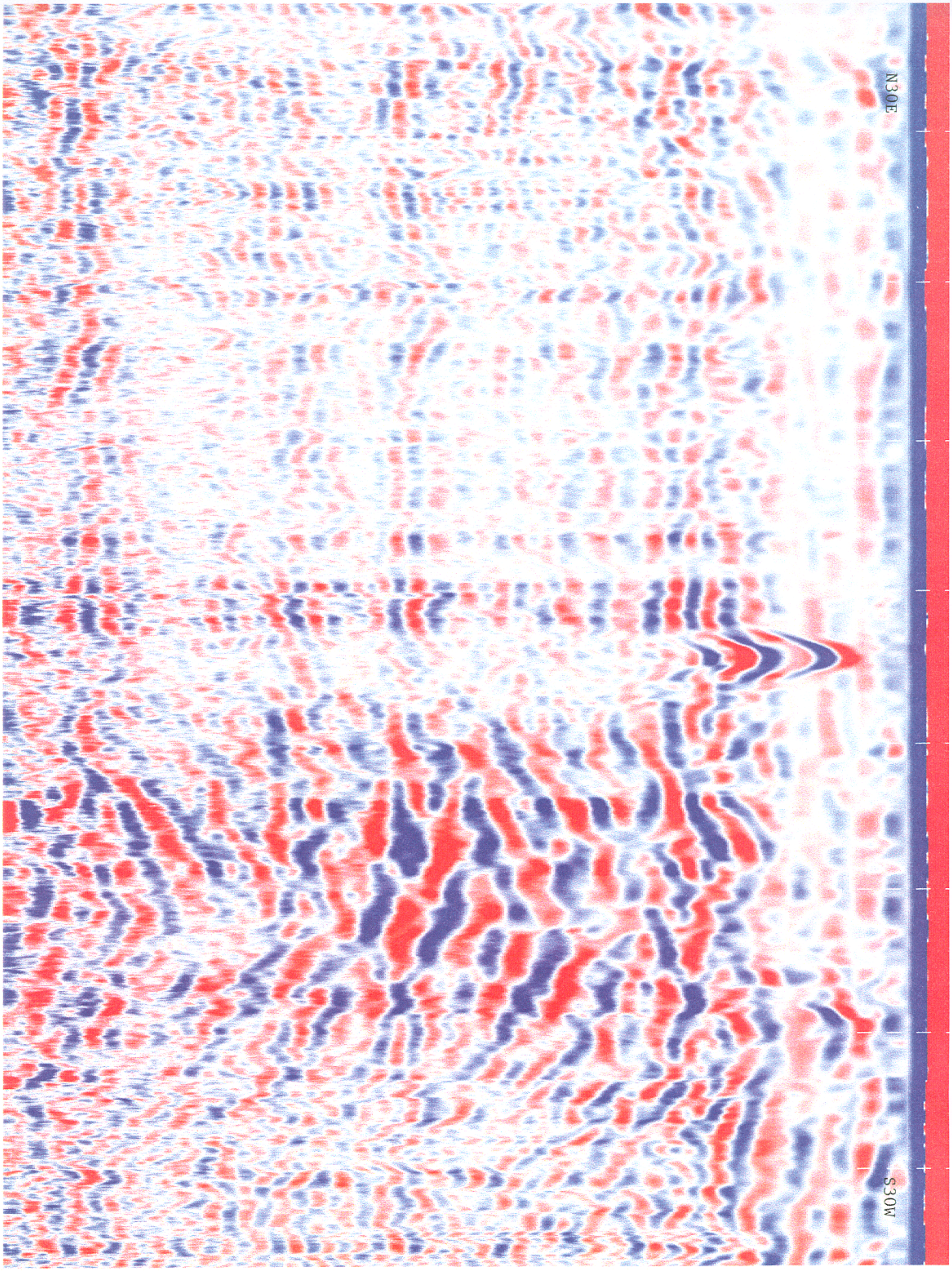

Figure 6

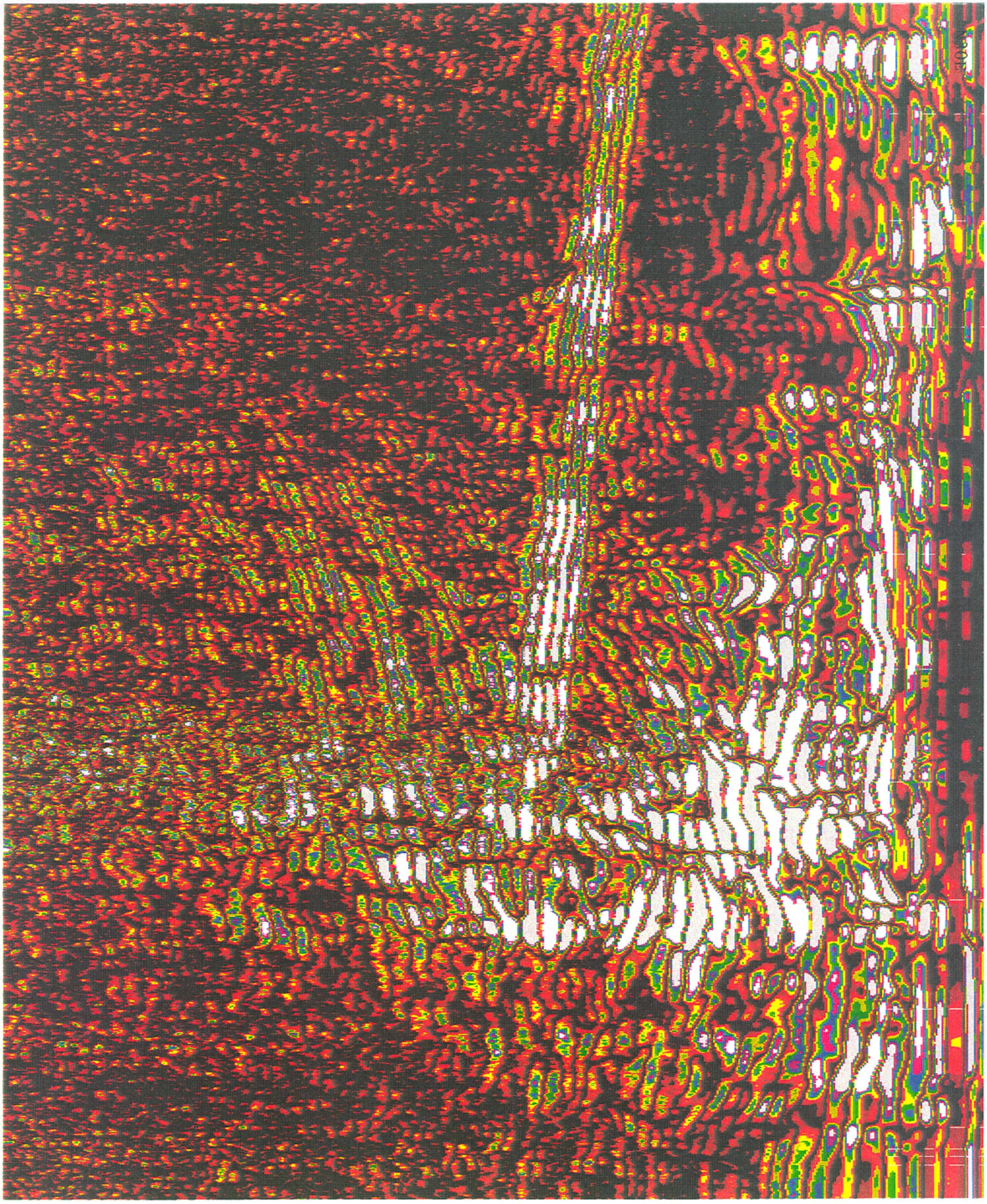

Figure 7

S30W

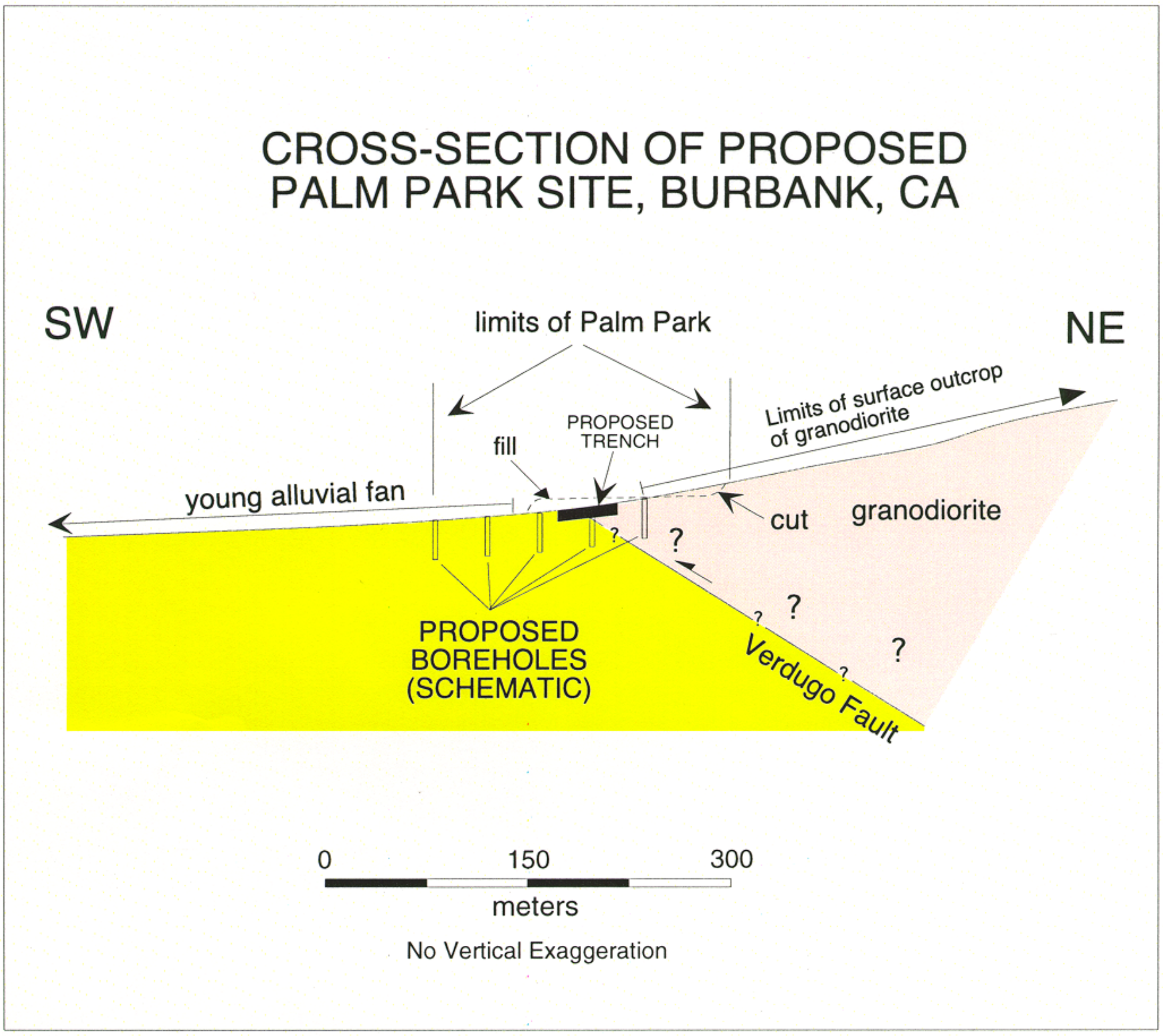

Figure 8. Cross section of proposed borehole transect through Palm Park in Burbank showing limits of outcrop of granitic rocks and postulated subsurface fault geometry.