DIGITAL DATABASE OF RECENTLY ACTIVE TRACES OF THE HAYWARD FAULT, CALIFORNIA

By James J. Lienkaemper

INTRODUCTION

[Version 1.1, minor revision, 2008; see last paragraph of introduction.]

The purpose of this map is to show the location of and evidence for recent movement on active fault traces within the Hayward Fault Zone, California. The mapped traces represent the integration of the following three different types of data: (1) geomorphic expression, (2) creep (aseismic fault slip), and (3) trench exposures. This publication is a major revision of an earlier map (Lienkaemper, 1992), which both brings up to date the evidence for faulting and makes it available formatted both as a digital database for use within a geographic information system (GIS) and for broader public access interactively using widely available viewing software. This pamphlet describes in detail the types of scientific observations used to make the map, gives references pertaining to the fault and the evidence of faulting, and provides guidance for use of and limitations of the map.

The term "recently active fault trace" is defined here as a fault trace that has evidence of movement in the Holocene or approximately the last 10,000 years. This definition also satisfies the legal definition of active fault used in the implementation of the Alquist-Priolo Act of 1972 (Hart, 1990). This map provides a starting point for planners by showing locations of fault creep and trench exposures of active traces.

A major scientific goal of this mapping project was to learn how the distribution of fault creep and creep rate varies spatially, both along and transverse to the fault. The results related to creep rate are available in Lienkaemper and others (1991, 1997, 2001) and are not repeated here. Detailed mapping of the active fault zone contributes to a better understanding of the earthquake source process by constraining estimates of (1) the probability recurrence times of major earthquakes, (2) the size of expected surface displacements, and (3) the expected length of ruptures accompanying these earthquakes. Following the 1989 Loma Prieta earthquake the Working Groups on California Earthquake Probabilities (1990, 2003) considered the Hayward Fault the most probable source of a major earthquake (magnitude 6.7 or larger) in the San Francisco Bay region in the next few decades.

This map also is of general use to engineers and land-use planners. The traces shown on the map are those that can be expected to have the most fault slip in future major earthquakes on the Hayward Fault. However, the small scale of the map (nominally 1:24,000) does not provide sufficient details of the local complexities of the fault zone for site development purposes.

Minor fault traces may not be recognized because many sections of the fault were already urbanized by 1939, the date of the earliest aerial photography for the entire fault. Thus, geomorphic features indicative of active faulting have been degraded or destroyed by human activity, especially secondary traces that have minor cumulative slip. For this reason, subsurface investigations are usually the main method of recognizing and precisely locating active fault strands in sites that lack reliable creep evidence. Mapping of creep evidence and monitoring of fault creep can be the most definitive method to precisely locate active traces.

Because subsurface investigations and other evidence of fault activity continue to become available, this map is considered current to June 30, 2008. Version 1.1 updates creep and trench evidence at only three sites: Berryman Reservoir and Memorial Stadium in Berkeley and Holy Redeemer College in Oakland. Some minor revisions have been made to 21 fault trace locations using 2007 LiDAR data available at: http://earthquake.usgs.gov/research/data/NoCal_GeoES_LiDAR_hs.kmz

GEOLOGIC SETTING

The Hayward Fault is a major branch of the San Andreas Fault system. Like the San Andreas, it is a right-lateral strike-slip fault, meaning that slip is mainly horizontal, so that objects on the opposite side of the fault from the viewer will move to the viewer's right as slip occurs. For a better understanding of the basic principles of strike-slip faulting and the relation of the Hayward Fault to this larger fault system see Wallace (1990).

Because this map documents only recently active traces of the fault, this text will touch only briefly on the early geologic history of the fault. The surface trace of the Hayward Fault follows a zone of crustal weakness that is mid-Cretaceous in age (99 ± 3 Ma) (Rose, 1978) or older (≥125 Ma) (Jones and Curtis, 1991), as suggested by a linear zone of keratophyric intrusive and volcanic rocks. The earliest known offset occurred about 10 Ma, probably on a dominantly dip-slip fault (Graham and others, 1984). The presently dominant right-slip style may not have developed until after 8 Ma, and perhaps only as recently as 4 to 5 Ma (Jones and Curtis, 1991). Most late Tertiary geologic units are incompletely preserved on the southwest side of the fault due to erosion. Thus, the apparent matching of various tentatively correlated late Tertiary units across the fault has led to contradictory estimates of total right slip along the Hayward Fault Zone that range from a few kilometers or a few tens of kilometers (Graham and others, 1984; Fox and others, 1985; Liniecki-Laporte...
EARLIER MAPPING OF THE ACTIVE TRACES

Although a 40-km-long surface rupture on the southern Hayward Fault accompanied a major earthquake in 1868 (M7), this rupture was not mapped until after the great 1906 earthquake (Lawson, 1908). Another large earthquake, in 1836, had often been presumed to have occurred along the Hayward Fault (Louderback, 1947; Ellsworth, 1990; Lienkaemper and others, 1991), but further historical research supports a location south of the San Francisco Bay Area (Topozada and Borchardt, 1998).

Radbruch-Hall (Radbruch, 1968a; Radbruch-Hall, 1974) compiled the 1868 rupture evidence of Lawson (1908) together with (1) bedrock fault traces, (2) newly recognized creep evidence, and (3) geomorphically recent traces. Herd (1977; 1978) interpreted Quaternary traces of the fault using 1939 aerial photographs. Hart (1979) and Smith (1980a; 1980b; 1981) compiled (1) the first 7 to 8 years of trenching results from Alquist-Priolo reports; (2) their geomorphic interpretations of Holocene traces from the 1939 aerial photographs; and (3) creep data from the literature and field work. Smith argued that many traces portrayed on earlier maps actually show no evidence of recent movement based either on his geomorphic analysis or from logs of trenches that crossed previously mapped bedrock or inferred fault traces.

In this report and map, earlier mapping is brought up-to-date using new findings from trenching and creep investigations. New methods are introduced for integrating on a single map geomorphic interpretations with a far greater amount of trenching and creep data than was available to previous map compilers. This map also focuses in much greater detail than its predecessors on the demonstrability of recent movement for each trace shown.

ORGANIZATION OF DIGITAL FILES

Lienkaemper (1992) presented the entire length of the Hayward fault on a single oversized printed sheet at a scale of 1:24,000. As such, the map was rather unwieldy. To take advantage of advances in digital technology, the current map is made accessible online in various convenient formats through viewing programs at http://pubs.usgs.gov/ds/2006/177/ and at http://quake.wr.usgs.gov/research/geology/hf_map/index.html. Informal users may zoom in on large or small areas of interest. Those with a deeper interest in a specific section of the fault may view and print page-sized maps of the fault composed at 1:12,000-scale and labeled with evidence supporting the location and activity level of each fault trace.

More technical users may wish to query the GIS database and develop their own map views of the fault using either ArcGIS software (proprietary) or ArcReader (free on internet). As with all GIS data, the reader must be aware of scale limitations of each set of data. Accuracy limits of these data sets will be discussed further below and in the metadata of each GIS file. Full documentation of the database fields is included in the metadata of each GIS file and will not be repeated here.

The projection of all GIS files in the download package is UTM10-NAD27 to conform to a requirement of the USGS Quaternary fault map that is currently in preparation.

METHODOLOGY

MAP ABBREVIATIONS

This fault strip map takes a much different approach than its predecessor strip maps of other California fault zones (summarized in Wallace, 1990) by presenting evidence of fault activity in highly abbreviated labels (see abbreviation lists, Appendixes 1 and 2). This was done for two reasons: (1) geomorphic features, visible on 1939 aerial photographs, are now largely destroyed by urbanization, and the map serves as a comprehensive archive of this evidence; and (2) creep and trench data are now greater in density per kilometer along the Hayward Fault than any other active fault in the world.

Considerable abbreviation was required to comprehensively combine the geomorphic, creep, and trench data on a single map sheet. Much simplification was required in some areas because of map-scale limitations. More trenches may exist at some sites, but they were too close together to plot or were distant from the fault trace. To minimize cluttering the map where data are dense, labels may appear next to multiple trenches and relate to the same cited reference. Map users needing further site detail should refer to the reference cited. Immediately adjacent creep localities that share a common description are sometimes described by a single label midway between the two creep symbols.

KILOMETER GRID

For indexing features discussed in this report, the map includes a kilometer grid oriented along the average strike of the Hayward Fault, N. 35° W. The km 0 mark is located where the fault intercepts the shoreline at San Pablo Bay near Point Pinole. This grid coincides with the grid on the 1:100,000-scale Hayward Fault map in Lienkaemper and others (1991, 1997, 2001), but it differs from Nason’s (1971) distances from Point Pinole, which are 0.4-0.7 km less for a given locality. This grid is available in the GIS data package as a shape file.

The idealized grid, a great circle path near the fault, is rectified against latitude and longitude on the base map at each 5-km interval. Maximum discrepancies of 10-20 m result from distributing closure errors on the base map, but most positions can be referred to uniquely on the grid to within ± 10 m (0.01 km), in accord with the National Map Accuracy Standard of 12 m for well-located objects on 1:24,000-scale maps (Thompson, 1979). As with the original (1992) hand-drafted grid the digital version is only rectified against map coordinates at the fault trace.

FAULT LOCATION FROM GEOMORPHIC EXPRESSION

Geomorphic interpretation, both on aerial photographs and in the field, is a critical element in identifying recently active fault traces (Wallace, 1990). The block diagram (fig. 1) illustrates some of the typical landforms produced by strike-slip faulting. Most of these geomorphic features result when horizontal sliding along the fault brings...
different materials into contact at the fault, for example, bedrock against unconsolidated
alluvium or colluvium. The most visible effect is that fault slip causes abrupt disruptions in the natural drainage system, including interrupted subsurface water flow, and results in offset streams and the formation of ponds and springs.

Most disrupted streams along the Hayward Fault are offset right-laterally and vary widely in the total amount of offset. The two largest stream offsets occur on large streams and show accumulated slip of 2-3 km. Many smaller streams have offsets ranging from tens of meters to a few hundred meters. These smaller streams, particularly those entrenched in weak alluvium, tend to escape their right-laterally offset lower channels and flow straight across the fault again. Some streams have captured the headwaters of adjacent streams and form apparent left-lateral offsets. The repetition of these processes over millennia creates linear valleys along the fault trace, which are commonly called "rift" valleys. These narrow strike-slip rifts in the San Andreas Fault system are in most locations primarily erosional features and are not genetically related to true rift valleys that are caused by extension, such as those in eastern Africa and along oceanic spreading centers.

These geomorphic expressions of faulting occur at many scales. The size of a geomorphic feature tends to relate inversely to its age. Typically, smaller features result from the most recent fault movements. For example, assuming that late Pleistocene slip rate has been similar to the Holocene rate of about 9 mm/yr (Lienkaemper and Borchardt, 1996), we deduce that the largest offsets of streams on the Hayward Fault reflect tens of thousands of years to a few hundreds of thousands of years of fault slip. Conversely, the smallest recognized right-lateral offset of a gully is 2-3 m and is the result of a combination of fault creep and coseismic slip associated with the earthquake in 1868 (and possibly earlier earthquakes too).

Because the most recent fault features are the smallest and most fragile, few have survived the intense urbanization of the East Bay that has occurred since World War II. Fortunately, aerial photographs of the entire fault were taken in 1939 (U.S. Department of Agriculture, BUU-BUT series, scale 1:20,000, available from National Archives, Washington, D.C.). These 1939 photographs are the primary source of geomorphic evidence of recent fault traces. For greater detail, I used 1:6,000-scale (1966, U.S. Geological Survey, WRD series) and 1:4,000-scale aerial photographs (1991, U.S. Geological Survey, HFZ series, color). Other miscellaneous USGS 1:24,000-scale aerial photographic series from the 1940's and 1950's were marginally useful in some areas to resolve uncertainties in interpretation.

I did not consider all fault features to be equally useful in accurately delineating complex patterns of recent faulting. Each feature is unique and reflects varying amounts of fault-trace complexity. However, erosion and degradation of features by human activities often obscures this geomorphic evidence and can lead the analyst to incorrect or crudely approximated fault-line interpretations. For example, a well-preserved, narrow, straight fault scarp (sn) can be confidently attributed to a simple narrow style of fault rupture. Other scarps have formed by broadly distributed surface rupturing (sb). Evidence from well-preserved geomorphic expression, detailed creep investigation, or trenching may confirm that the fault zone is truly broad and complex and not simply a degraded narrow scarp (sn). Generally one cannot differentiate the broad fault scarp that represents widely distributed slip from a narrow one that has been broadened by erosion and degraded by human activities.

The codes G1 (strongly pronounced), G2 (distinct), and G3 (weakly pronounced) are a system to classify my overall judgment about the reliability of geomorphic features for accurately locating recent fault traces. For example, considerable fault complexity might appear as a feature of only G3 quality, or alternatively the fault trace might originally have been narrow and simple but was later altered by agricultural or other human activity. We cannot certainly distinguish the original character of such a feature without either earlier photographic or subsurface evidence.

Recency of faulting from geomorphic expression is a separate idea, but difficult to completely separate in fact. I did not specifically intend the G1, G2, and G3 classification to be an evaluation of certainty that traces are of Holocene age. I intend it to be mainly a scale of clarity. Not surprisingly, fault traces that are geomorphically more distinct (G1, G2) can be precisely delineated and, thus, tend to confirm Holocene activity. Unfortunately, the weakly pronounced traces (G3) in most cases reflect degradation by human activities, so we cannot geomorphically delineate the fault precisely. However, I believe that most of the G3 traces shown on the map are Holocene active.

Even distinct geomorphic features (G1, G2) need to be corroborated. For example, near Lake Temescal (km 20-21) at least two earlier maps confidently plotted the active Hayward Fault using aerial photo-interpretation of geomorphic expression. I would have described the geomorphic feature that they mapped as a G2-quality linear fault scarp if I had not learned that the feature actually is a long-abandoned railroad cut that is obscured by a canopy of trees. Recent trenching and creep data suggest that the active fault trace may be 60-100 m to the southwest of the old railroad cut (California Department of Transportation, 1991; Rutherford and Chekene, 1991).

I also use geomorphic expression as one means of estimating the uncertainty of fault location more quantitatively, as shown on the map by the variable lengths of gaps between dashes in the fault linework as described in the map explanation. Fault-related geomorphic features separate smoother and generally more stable areas on opposite sides of the fault. The width of these features is measurable on aerial photographs. For geomorphic features such as a G3-quality linear scarp that is neither narrow nor distinct, I plot the center of the feature and estimate the uncertainty in locating the active trace as half the width of the feature. Where precise trench or creep data are available, these establish the lateral position of the fault, and I use the lower quality geomorphic features only for the orientation and continuity of the fault trace. For example, creep data may show that the active trace is high or low, rather than mid-slope, on a fault scarp that is geomorphically indistinct. Higher quality (G1 and G2) geomorphic features tend to agree well with locations of active traces as identified in trenches and from creep evidence.
The fault traces plotted on the map ideally show the center of each intense zone of shearing that can be reasonably discretized and plotted distinctly at a scale of

![Graph A: Evolution of rainfall as a function of distance along the fault.](image)

![Graph B: Rainfall in millimeters/year.](image)

![Graph C: Number of geologic features.](image)

![Graph D: Number of trench sites.](image)

![Graph E: Number of creep localities.](image)

**Figure 1:** Summary histograms showing the number of occurrences of creep localities, rain fall, and number of trenches. Note that this figure is updated from the 1992 edition.
1:24,000. Although 90 percent of well-defined cultural features on the base map are required to be located within ±12 m of their correct position at a scale of 1:24,000, many positions of cultural and natural features that I relied on to transfer the fault traces do not meet the rigorous definition of well defined. In my judgment, ±≤20 m is a reasonable estimate of the general reliability of the fault-trace plotting error. Especially in this revised digital edition much of the data are plotted much more accurately than this standard. This is particularly true in the case of creep data and trenching data. Most of the creep data were documented in the field on aerial photos of 1:6000- and 1:4000-scale with accuracy of about 1-2 meters. These points were generally easy to transfer to the USGS digital orthoimage quadrangles (digs) with little loss of precision locally. Relative accuracy over larger areas is estimated as similar to National Mapping Standards of ≈12 m for 90 percent of well-located base map features. Trench locations are generally taken from copies of paper maps from reports in publicly accessible files. For the digital recompilation these maps were scanned and georeferenced by fitting them to common points on grayscale USGS doqs using ArcGIS software. In most cases average registration errors (estimated by the software) for these trench maps ranged between 2-3 meters. The newer color doqs used to present the digital data agree well with the older grayscale doqs. The color doqs are more detailed and accurate than the older ones but were not available in time for most of the recompilation of creep and trench evidence.

A separate issue from the accuracy of cartographic plotting is the accuracy of the position of fault trace between points on the fault that are well located by creep, trench logging, or narrow geomorphic features. Detailed mapping and surveying of creep evidence show that the deformation zone of the main creeping trace is as much as 20-m wide (Nason, 1971; Lienkaemper and others, 1991). Although individual creeping traces can be less than a few meters wide, the fault zone tends to be complex and not linear at large scales; so I chose ±≈20 m as a reasonable upper bound for the delineation error (meandering of the principal strands of well-located fault traces between exactly located points). Exactly located points can in all cases be plotted to within ±≈12 m, because base maps have improved since the last edition of this map.

The above discussion is rather involved, but the practical outcome is that faults shown as being located within ±±20 m (see explanation for fault symbols) are reliably located within ±±12 m, compared to other features, of where the map shows them to be on the doq base maps. The larger estimates of uncertainty (≈±40 m and ±≈60 m) derive mostly from aerial photo-interpretation on segments of the fault where creep and trenching data are sparse. Even highly degraded geomorphic features constrain the position of the principal fault trace within interpretable boundaries. The dash length of fault linework is fixed to cover 30 m on the map for two reasons: (1) the portrayal of uncertainty can be varied over short distances, and (2) using the dash length as a frame of reference, with a little practice, the map user can distinguish the two lengths between dashes (40 m and 60 m on the map). These approximate dash gap lengths and line weights were set in the digital map for a data frame reference scale of 1:12,000 and work fairly well for a range of 1:6,000 to 24,000.

Differing from the 1992 edition, solid lines are now used to portray fault traces for well-located traces, because available basemaps are much improved. However, where active traces are known in great detail, they tend to be complex structures that form en echelon patterns and are multi-stranded in a way that usually does not generalize easily into a single smooth fault trace. Therefore, the line on the map should be thought of as being near the center of an active zone of complex faulting.

The uncertainty estimates are not intended to represent the total width of the zone of active faulting. Many cultural features that were surveyed for creep offset (Lienkaemper and others, 1991, 1997) show significant secondary active faulting and rotations several tens of meters from the main active trace. Commonly these secondary traces have no extant geomorphic expression. Larger errors in location than have been estimated may exist, and many unrecognized secondary active traces may exist. Therefore, map users who need site-specific information must verify the local evidence for faulting to satisfy their particular requirements.

Geomorphic fault-zone features tend to be more distinct in the southern (km 35-70) and northernmost (km 0-10) parts of the mapped region as shown in figure 2C. This tendency may partly depend on rainfall (fig. 2B) and elevation (fig. 2A). However, it may be more important that the El Cerrito to Oakland areas (km 10-35) were substantially more developed than the adjacent regions in 1939, the date of the earliest complete aerial photography that was used to analyze the fault. Two other factors that are both secondary effects of rainfall (and indirectly of elevation) reduce the distinctness of geomorphic features in the hilly areas from Oakland to El Cerrito (km 10-35): (1) heavier vegetation, especially oak and eucalyptus woodlands; and (2) more slope instability (soil creep and landsliding).

An apparent scarcity of geomorphic data in two areas of the map (km 40-45 and km 55-65) is largely an artifact of map-editing decisions. Actually, many geomorphic features of high quality show in these areas in the 1939 aerial photographs, but at a scale of 1:24,000 they could not be labeled as comprehensively as elsewhere. The trench and creep data are extremely abundant in these areas, and because it is essential to fully annotate the more exact creep and trench data, little space remained to annotate the geomorphic data. Consequently, the geomorphic annotation is less detailed in these areas than elsewhere, although more important features are still noted, particularly those that are most relevant to the accurate delineation of the fault traces.

**FAULT LOCATION FROM CREEP EVIDENCE**

Fault creep, the common name for aseismic slip observed along the surface trace of a fault, has now been recognized along many branches and segments of the San Andreas Fault system (Calaveras, Concord, Green Valley, Hayward, Imperial, Maacama, central San Andreas, Sargent, and Superstition Hills Faults). Creep was first discovered on the central San Andreas Fault in 1956
nontectonic causes (C3), such as soil creep, landsliding or evidence that might be attributable to yet unidentified which I am reasonably confident (C1 and C2) from (inconclusive) are intended to discriminate traces that are creeping from those that are not.

Averaged over several decades, rates of creep ranged from 3-6 mm/yr along most of the Hayward Fault (km 0-62), but they were distinctly higher, 8-10 mm/yr, near the south end (km 63-67). No evidence for creep has been recognized south of km 69. For more detail on long-term creep rates see Lienkaemper and others (1991, 1997, 2001) and Galehouse and Lienkaemper (2003). For earlier creep rates from alinement arrays, see Harsh and Burford (1982); Wilmesher and Baker (1987); and Galehouse (1991); from creepmeters, see Yamashita and Burford (1973); Nason and others (1974); Schulz and others (1982); Schulz (1989); and from regional and local trilateration surveys, see Prescott and Lisowski (1983); Lisowski and others (1991).

Field recognition of creep evidence has been discussed in several field guides on the Hayward Fault, including: Nason and Rogers (1970); Taylor and others (1982); Wahrhaftig (1984); Bortugno (1988); Lienkaemper (1989). Hirschfeld (1982) is a good introduction to recognizing and understanding the significance of en echelon pavement cracks in the field. Smith (1982) discusses the common pitfalls in mistaking nontectonic phenomena for evidence of fault creep. Lienkaemper and others (1991) discuss many of the most distinctly offset curbs, fences, and other cultural features along the entire length of the fault and show detailed plots of each one. A wealth of additional field observations along the fault is available from many sources within the Field Guide (Taylor and others, 1992) and the Proceedings (Borchardt and others, 1993) of the Second Conference of Earthquake Hazards in the Eastern San Francisco Bay Area.

Like geomorphic expression, not all creep evidence is equally reliable for proving the existence of and establishing the precise positions of the active traces of the fault. The creep reliability ratings C1 (strongly pronounced), C2 (distinct and certain), and C3 (inconclusive) are intended to distinguish evidence about which I am reasonably confident (C1 and C2) from evidence that might be attributable to yet unidentified nontectonic causes (C3), such as soil creep, landsliding or fill failure, expanding tree roots, broken water pipes, vehicular collision, uneven loading or thermal and shrink-swell phenomena in pavements and slabs and their underlying soil, differential settlement, and other soil-structure interactions.

Where nontectonic forces are known to be acting, and they provide a more credible explanation of a deformed or distressed feature, nothing is recorded on the map. That is, creep best explains all C3 localities, but the creep is not yet strongly developed nor adequately corroborated by additional nearby evidence. C1 quality ratings are assigned sparingly, only for creep evidence that is especially obvious in the field. Many features given C2 ratings are straight features that have distinct offsets as seen in the results of alinement surveys, such as those in Lienkaemper and others (1991), but the offsets may be distributed over several meters and, thus, may be less obvious in the field. Conversely, many C3 features, such as offset fences that have not been surveyed yet, might be reclassified as C2 when surveyed.

Creep evidence of all three reliability ratings serves to locate the fault precisely for purposes of this map and agrees well with good quality geomorphic evidence. Rare exceptions to this are the two water tunnels, San Pablo (km 12.93) and Claremont (km 19.99). The active trace locations in the tunnels are only approximately known from original sources (Blanchard and Laverty, 1966; Lennert and Curtis, 1985). Connecting the geomorphic trace to the approximate location of creep in these tunnels would suggest steep (but not vertical) northeastward dips. However, the more precisely located creep evidence in the Bay Area Rapid Transit tunnels (km 20.28) (Brown and others, 1981) appears to lie vertically below the geomorphic trace. The exact creep locations in the water tunnels must be verified before drawing any conclusions regarding dip.

Much speculation has been offered regarding the scarcity of creep observations in the hilly areas from El Cerrito to Oakland (km 5-35). Figure 2E summarizes the number of creep localities shown on the map. Roughly similar to the situation for geomorphic features, higher rainfall and steep slopes add to the difficulty in reliably locating the active fault traces using creep evidence. More tree roots and various slope stability problems in these hilly areas make creep recognition more difficult. Because these areas were generally built up much earlier, the fault must intercept many older cultural features. In most places this would make creep evidence easier to identify, but because most slopes are steep, the roads, curbs, and fence lines tend to be curved. Therefore, broadly distributed creep offsets are extremely difficult to judge reliably, and other creep effects are rarely distinguishable from abundant nontectonic disruptions.

**FAULT LOCATION FROM TRENCHING EVIDENCE**

Prior to 1992 most trenches across the Hayward Fault were done as part of site-oriented fault investigations to satisfy legal requirements of the Alquist-Priolo (AP) Special Studies Zones Act of 1972 (Hart and Bryant, 1997) which is administered by the California Geological Survey (CGS, formerly California Division of Mines and Geology,
CDMG), Sacramento, California. For a summary of some products related to the AP Act see Wills (1991). Hundreds of AP reports have been filed for the Hayward Fault Zone. These reports are now available on CD (Wong and others, 2003) from CGS (Menlo Park). Most AP investigations were conducted on parcels that showed no probable evidence of active traces, but trenching was usually required to demonstrate that no concealed secondary fault traces exist where development was planned. The majority, 38 of 69, trench sites that contained trenches across major active fault traces (38/69; 55 percent) are along the southernmost part of the fault (km 55-70, fig. 2D; only pre-1992 shown), because most development along the rest of the fault occurred before the 1972 Alquist-Priolo Act. From 1992-2005 only about 10 additional AP sites have become available that include trenches crossing the fault. However, the current map includes evidence from several other trenching studies that have been done for other purposes: site studies for public utilities and other public entities, scientific investigations, and various other site-specific reports that have not been filed with the AP program.

About seventy AP reports contain logs of trenches that cross Holocene-active traces. Many of these trenching investigations involved large tracts and multiple trenches. The map shows only those trenches that crossed or came near to Holocene-active fault traces and traces that show latest Pleistocene to Holocene (?) activity.

For engineering purposes, it would be interesting to know the approximate likelihood of being able to demonstrate the existence and location of a Holocene-active fault trace at a given site using the methods of trench logging that have actually been used to date. To get a rough idea of what proportion of trenching sites show distinct evidence of Holocene faulting, I summed the different categories of trenching evidence (see Trench Exposures’ explanation) for those 69 trenching sites that had trenches across independently identified “major active fault traces” (MAFT sites.) The logs show distinctly Holocene fault traces (H1, H2 evidence) at most MAFT sites (50/69; 72 percent), but evidence is at best weakly conclusive or permissible of faulting (H?, F?, NF) at some MAFT sites (11/69; 16 percent). At a few other MAFT sites (8/69; 12 percent) significant faulting was evident, but evidence of Holocene age was not clearly demonstrable (HP, P, U). The above percentages reflect the most conclusive evidence at a given site, but other exposures at the same site in some cases showed inconclusive results. I suspect that in most cases of weak or permissible evidence (H?, F?, NF), the fault was identified only because the investigator was cued by nearby geomorphic or creeping evidence. The category NF as included in the above statistics covers a few difficult cases where no discrete fault offset appears in the trench log, but investigators acknowledge a highly approximate location of the trace from miscellaneous indirect evidence.

The above results for trenching across recognizable main traces of the fault suggest we may not always identify secondary traces when they do exist, particularly where no Holocene cover exists. Most consultants and reviewers are conservative and presume pre-Holocene (HP, P, U) shears are active or treat weak or permissible evidence of faulting (H?, F?, NF) as genuinely active traces for purposes of development. Therefore, some building exclusion zones might avoid nonexistent or inactive fault traces, and other exclusion zones might reflect incorrectly located active traces. These problems can be avoided in some cases by adopting the following practices: (1) placing corroborative trenches through nearby areas that are more likely to have stratified Holocene units; (2) logging both trench walls in detail where faulting is suspected including noting orientations of soil shears and slickensides; and (3) in monotonous fine soil horizons, performing array sampling of soil transverse to the fault and plotting clay-sand ratios or other factors indicating subtle material contrasts (Borchardt and others, 1988b). For further discussion of factors affecting the visibility and recognition of faulting in exploratory trenches, and for a more detailed treatment see Bonilla and Lienkaemper (1990, 1991).

**DISCUSSION**

Ideally, this strip map of the Hayward Fault is one in a series of progress reports that summarizes our present knowledge of active fault traces. It is important for both scientific and engineering reasons that we continue to discover and map all the active traces and monitor creep distribution in greater detail so that we can better understand and cope with this highly urbanized fault zone.

In some areas the main fault trace continues to be located with large uncertainty, for example (1) near Point Pinole (km 0.0-1.1); (2) near Wildcat Creek (km 6.3-7.9); (3) in Kensington (km 11.9-13.6); (4) near Lake Temescal (km 20.3-21.3); and (5) in central Oakland between High Street and 82nd Avenue (km 28.1-32.0). Except near Lake Temescal, the dominant problem is the ambiguity produced by the interaction of the fault zone and landsliding. Particularly in the case of central Oakland, the fault may also be genuinely complex with multiple strands and en echelon stepovers.

Where multiple strands exist, the most active strand does not in all cases correspond to the most geomorphically distinct trace. For example, north of the Masonic Home in Union City (km 54) two active traces are spanned by the trilateration array, UNION (Prescott and Lisowski, 1983). Surprisingly, the geomorphically more distinct eastern trace exhibits no creep above the detectable limit (<1 mm/yr), while the geomorphically weaker western trace creeps at about 5 mm/yr. Geomorphic distinctness is a better indicator of relative activity at the MAR trilateration array in El Cerrito (km 9) (Prescott and Lisowski, 1983). The MAR array spans only the western and geomorphically less pronounced of two active traces and shows no creep (<1 mm/yr), while the slightly more pronounced eastern trace creeps at about 5 mm/yr at nearby Olive Avenue (km 8.35).

**ACKNOWLEDGMENTS**

Special thanks go to the Alquist-Priolo project staff and others in the California Geological Survey, E.W. Hart, P. Wong, C.J. Wills, and G. Borchardt for their many kind efforts in helping me cope with seemingly endless AP and other reports essential to the original map. Likewise many thanks to W.A. Bryant, California Geological Survey, Sacramento for giving me access to the most recent AP

REFERENCES CITED (MAP AND TEXT)


Bortugno, E., 1988, Living on the fault, a field guide to the visible evidence of the Hayward Fault (Catalog no. 94604-2050): Oakland, California, Association of Bay Area Governments.


Curtis, G.H., 1989, Berkeley Hills in C.
Crosby, J., and Associates, 1989, Geotechnical
Crittenden, M.D., 1951, Geology of the San Jose
Cotton, W., and Associates, 1979, Seismic
____ 1974, Phase II fault investigation, 35-acre parcel,
vicinity of Overhill Drive, Hayward, California:
Cleary Consultants Incorporated, 1989, Fault location
investigation, Tiffany Parcel, Fremont, California:
Cluff, L.S. and Steinbrugge, K.V., 1966, Hayward Fault
slippage in the Irvington-Niles districts of Fremont,
Consolidated Engineering Laboratories, 2000, Fault
investigation report, Fremont Vista Assisted Living
Facility, 35450/35540 Mission Boulevard, Fremont,
Cooper Engineers, 1986, Geologic hazards investigation,
proposed residential development, 1694-164th
Avenue, San Leandro, California: California
Cooper-Clark and Associates, 1968, Soil investigation
A709, southern Alameda-Fremont: unpublished report:
San Francisco Bay Area Rapid Transit District, Oakland, California.
____ 1974, Phase II fault investigation, 35-acre parcel,
vicinity of Overhill Drive, Hayward, California:
Cotton, W., and Associates, 1979, Seismic hazards
investigation, Catholic Church property, East
Warren Avenue, Fremont, California: California
behavior of the Hayward-Calaveras Fault system,
San Francisco Bay area, California: Final technical
file at U.S. Geological Survey, Menlo Park,
California, 15 p.
Crittenden, M.D., 1951, Geology of the San Jose-Mt.
Hamilton area, California: California Division of Mines and Geology Bulletin 157, 74 p.
Crosby, J., and Associates, 1989, Geotechnical
investigation at 44,885 Gardenia Way, Fremont,
Curtis, G.H., 1989, Berkeley Hills in C. Wahrhaftig, ed.,
Geology of San Francisco and vicinity, 28th
International Geological Congress, Field Trip
Guidebook T105: American Geophysical Union,
Washington, D.C.
Dibblee, T.W., Jr., 1972, Preliminary geologic map of the
Milpitas, Lick, and San Jose quadrangles, Alameda
and Santa Clara Counties, California: U.S.
Geological Survey Open-File Report, scale
1:24,000, 3 sheets.
____ 1980a, Preliminary geologic map of the Hayward
quadrangle: U.S. Geological Survey Open-File
Report 80-540, scale 1:24,000.
____ 1980b, Preliminary geologic map of the Richmond
quadrangle, Alameda and Contra Costa Counties,
California: U.S. Geological Survey Open-File
Report 80-1100, scale 1:24,000.
____ 1980c, Preliminary geologic maps of the La Costa
Valley, Livermore, and Niles quadrangles, Alameda
and Contra Costa Counties, California: U.S.
Geological Survey Open-File Report 80-533, scale
1:24,000, 3 sheets.
____ 1981, Preliminary geologic map of the Mare Island
quadrangle, Solano and Contra Costa Counties,
California: U.S. Geological Survey Open-File
Report 81-234, scale 1:24,000.
Earth Systems Consultants, 1979, Geologic and seismic
hazards investigations, Eaton Square, Fremont,
____ 1980a, Geologic and seismic hazards investigation,
Sands property, Fremont, California: California
Geological Survey CGS CD 2003-01, AP report
1240.
____ 1980b, Supplemental subsurface investigation,
Inverness Glen, Hayward, California: on file at
California Division of Mines and Geology, San
Francisco, California; file no. C-487.
____ 1980c, Geologic and seismic hazards investigation,
McIntyre property, Fremont, California: California
Geological Survey CGS CD 2003-01, AP report
1304.
____ 1981, Geotechnical report, Fremont Station project,
Tyson Lane, Fremont, California: California
Geological Survey CGS CD 2003-01, AP report
1473.
____ 1983, Geologic and seismic hazards evaluation,
proposed city library, Fremont, California:
____ 1985, Geotechnical report, Niles school site
development, Fremont, California: California
Geological Survey CGS CD 2003-01, AP report
2454.
____ 1986, Special Studies Zone trenching: Fremont Civic
____ 1987a, Geotechnical evaluation, Fremont Apostolic
Church property, 2390 and 2400 Durham Road,
____ 1987b, Geotechnical report, Mission property north,
Fremont, California: California Geological Survey
CGS CD 2003-01, AP report 1281b.

Geomatrix, 2007, Addendum to Final Report, Fault-Rupture Hazard Investigation, Student Athlete High Performance Center, University of California, Berkeley, prepared for Facilities Services, University of California, Berkeley, California

Geotechnical Engineering Inc., 2002, Soil investigation including geologic faulting investigation, additions to Moliga family residence, 1226 Ash Street, Hayward, California; California Geological Survey CGS CD 2003-01, AP report 3224.


Hall, N.T., 1996, Fault rupture hazard investigation, Founders Common, Mills College, Oakland, CA: Geomatrix, Project No. 3226.03.


Harza Consulting Engineers and Scientists, 1994, Geologic hazards evaluation, Redwood Heights Elementary School modernization, 4401 Thirty-Ninth Avenue, Oakland, California: California Geological Survey CGS CD 2003-01, AP report 2961


____ 1978, Map of Quaternary faulting along the northern Hayward Fault Zone; Mare Island, Richmond, Briones Valley, Oakland West, Oakland East, San Leandro, Hayward, and Newark 7.5-minute quadrangles, California: U.S. Geological Survey Open-File Report 78-308, scale 1:24,000, 8 sheets.


Hirschfeld, S.E., 1982, Creep patterns and surface deformation within the Hayward Fault Zone, Hayward, California: California Division of Mines and Geology Special Publication 62, p. 65-74.


____ 1979, Soil and geology investigation, proposed apartment complex, 5.4 acres, Calhoun Street, Hayward, California: California Geological Survey CGS CD 2003-01, AP report 1075.


Lawson, A.C., 1908, The earthquake of 1868, in A. C. Lawson, A.C., ed., The California earthquake of April 18, 1906; Report of the State Earthquake

Lennert, B.J., 1982, Accurate location of the active trace of the Hayward fault between Ashby and Marin Avenues in Berkeley, with proposed models of stress-strain conditions for creep and rapid offset: California Division of Mines and Geology Special Publication 62, p. 45-54.


Mace, N., and Petersen, M., 1993, Hayward fault investigation at the BART Irvington Station site for the Warm Springs Extension: Geotechnical Consultants, Inc.


Merrill and Seeley Incorporated, 1979, Active fault investigation, 6.6 acre parcel, Briar Place, Fremont,


____ 1968a, Map showing recently active breaks along the Hayward Fault Zone and the southern part of the Calaveras Fault Zone, California: U.S. Geological Survey Open-File Report, scale 1:24,000.


Radbruch-Hall, D.H., 1974, Map showing recently active breaks along the Hayward Fault Zone and the southern part of the Calaveras Fault Zone, California: U.S. Geological Survey Miscellaneous Investigations Map I-813, scale 1:24,000, 2 sheets.


Rutherford and Chekene, 1991, Supplemental report, fault hazard evaluation, Kiwanis building, Temescal Regional Recreation Area, Oakland, California: East Bay Regional Parks District, Oakland, California.


____ 1991, Supplemental report, fault hazard evaluation, Kiwanis building, Temescal Regional Recreation Area, Oakland, California: East Bay Regional Parks District, Oakland, California.

Taylor, C.L., and Page, B.M., 1982, Man made exposures

Taylor, C.L., and Lienkaemper, J.L. 1992, Location of

Taylor, C.L., compiler, and Hall, N.T., and Melody, M.,

____ 1992, Active fault creep better defines location of

Steinbrugge, K.V., Zacher, E.G., Tocher, D., Whitten,

Soil Engineering Construction Company, 1973,


____ 1992, Field Trip Guidebook of the Second


Taylor, C.L., 1982, Geologic studies conducted for the Alameda County Fairmont Hospital-Juvenile Hall complex: California Division of Mines and Geology Special Publication 62, p. 299-308.

____ 1992, Active fault creep better defines location of fault traces in the Montclair area of Oakland, California [abs.]: Earthquake Hazards in the Eastern San Francisco Bay Area, 2nd Conference, Abstracts with Program.


____ 1977b, Soil and geologic investigation on proposed residential development, Driscoll Road, Fremont, California [Tentative Tract 3885]: California Geological Survey CGS CD 2003-01, AP report 602.

____ 1977c, Soil and geologic investigation on proposed residential development, Mowry Avenue and Bonner Avenue, Fremont, California: California Geological Survey CGS CD 2003-01, AP report 704.


____ 1990, Supplemental geologic/seismic investigation on Lake Chabot Terrace, 13575 Lake Chabot Road, Alameda County, California: California Geological Survey CGS CD 2003-01, AP report 2590, 4 p.


Williams, P.L., and Hosokawa, A.M., 1992, Geomorphic features related to the Hayward Fault at the University of California, Berkeley, in Field Trip Guidebook, Second Conference on Earthquake Hazards of the Eastern San Francisco Bay Area: California State University, Hayward [East Bay], p. 65-69.


____ 1978c, Active fault investigation, Hillcrest School, Hayward Unified School District, Hayward, California: on file at California Division of Mines and Geology, San Francisco, California; file no. C-341.


APPENDIX 1

MAP ABBREVIATIONS

<table>
<thead>
<tr>
<th>C - CREEP EVIDENCE</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - strongly pronounced fault creep</td>
<td></td>
</tr>
<tr>
<td>2 - distinct and certain creep evidence</td>
<td></td>
</tr>
<tr>
<td>3 - inconclusive evidence for creep</td>
<td></td>
</tr>
<tr>
<td>? - additional uncertainty in tectonic origin</td>
<td></td>
</tr>
<tr>
<td>aa - alignment array</td>
<td></td>
</tr>
<tr>
<td>cb - concentration of cracks in above-grade structure</td>
<td></td>
</tr>
<tr>
<td>cc - concentration of cracks in concrete slab</td>
<td></td>
</tr>
<tr>
<td>cp - concentration of pavement cracks</td>
<td></td>
</tr>
<tr>
<td>cr - clockwise rotation of sidewalk</td>
<td></td>
</tr>
<tr>
<td>cs - curb separating from sidewalk or pavement</td>
<td></td>
</tr>
<tr>
<td>cw - clockwise rotation of wall</td>
<td></td>
</tr>
<tr>
<td>ec - en echelon left-stepping cracks in pavement</td>
<td></td>
</tr>
<tr>
<td>jo - opening of joints or cracks in concrete</td>
<td></td>
</tr>
<tr>
<td>pp - multiple patches in pavement</td>
<td></td>
</tr>
<tr>
<td>pu - compressional pop-up or buckle in concrete</td>
<td></td>
</tr>
<tr>
<td>ra - right-laterally offset aqueduct, water pipe, or tunnel</td>
<td></td>
</tr>
<tr>
<td>rb - distortion of above-grade structure (including separating additions and stairways)</td>
<td></td>
</tr>
<tr>
<td>rc - right-laterally offset curb or form line or railing</td>
<td></td>
</tr>
<tr>
<td>rf - right-laterally offset fence line</td>
<td></td>
</tr>
<tr>
<td>rp - right-laterally offset painted line</td>
<td></td>
</tr>
<tr>
<td>rr - right-laterally offset railroad tracks or guardrail</td>
<td></td>
</tr>
<tr>
<td>rs - right-laterally offset sidewalk</td>
<td></td>
</tr>
<tr>
<td>rt - right-laterally offset line of trees</td>
<td></td>
</tr>
<tr>
<td>rw - right-laterally offset wall</td>
<td></td>
</tr>
<tr>
<td>so - surveyed offset feature</td>
<td></td>
</tr>
<tr>
<td>u - unspecified evidence</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>G - GEOMORPHIC FEATURES</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - strongly pronounced feature</td>
<td></td>
</tr>
<tr>
<td>2 - distinct feature</td>
<td></td>
</tr>
<tr>
<td>3 - weakly pronounced feature</td>
<td></td>
</tr>
<tr>
<td>? - additional uncertainty in tectonic origin</td>
<td></td>
</tr>
<tr>
<td>af - alignment of multiple features as listed</td>
<td></td>
</tr>
<tr>
<td>as - arcuate scarp</td>
<td></td>
</tr>
<tr>
<td>bt - downthrown surface tilts back toward fault</td>
<td></td>
</tr>
<tr>
<td>df - depression formed by some aspect of fault deformation, undifferentiated</td>
<td></td>
</tr>
<tr>
<td>dr - sag, depression formed in right stepover of fault trace</td>
<td></td>
</tr>
<tr>
<td>gi - linear break (or gradual inflection) in slope</td>
<td></td>
</tr>
<tr>
<td>hb - linear hillside bench</td>
<td></td>
</tr>
<tr>
<td>hv - linear hillside valley</td>
<td></td>
</tr>
</tbody>
</table>
ls - fault scarp height enlarged by landsliding
lv - linear valley or trough
mp - Youngest traces disturbed by human activities. Mapped trace bisects disturbed zone. Location uncertainty (dash gap in linework) equals half width of disturbed zone.
n - notch
pr - pressure ridge in left stepover
rr - right-laterally offset ridge line
rs - right-laterally offset stream or gully
sb - broad linear scarp (implies multiple traces)
sc - scissor point, sense of vertical separation reverses
se - subsoil exposed
sl - linear scarp, undifferentiated
sn - narrow linear scarp (implies dominant trace)
sp - spring
ss - swale in saddle
vl - line of vegetation

T - TRENCH EXPOSURES (and other geologic evidence)
H1 - Holocene age of offset determined by radiocarbon ($^{14}$C) dating
H2 - Modern soil or alluvial unit distinctly offset, or contains features conclusive of shearing, such as
gouge, rotated pebbles, transported materials in shear zone, and filled fissures over distinct
Pleistocene faults
H? - Inconclusive signs of Holocene offset, such as steps in base of soil or apparent shears in clay-rich
materials. Without corroboration such evidence neither proves nor disproves either existence
or age of faulting
H - Active trace reported in trench, trench logs not in public file
HP - Distinct faulting in unconsolidated alluvium of possibly Holocene or more likely latest
Pleistocene age
F? - Feature shown as fault in log resembles nontectonic feature such as bedrock-alluvial contact,
buried terrace riser, or landslide plane
NF - No fault observed
P - Distinct evidence of significant faulting in Pliocene or Pleistocene sediments
RC - Roadcut log
WB - Ground water barrier
U - Age of faulting unobtainable because surficial deposits removed

REFERENCE CODES (see also Abbiated Map References and text for full references.)
A2456 - Trench log or creep evidence in Alquist-Priolo report AP-2456, available on CD from
California Geological Survey [Wong and others, 2003]
C200 - Trench log or creep evidence in non-Alquist-Priolo consultant’s report filed at CDMG.
G70 - Non-Alquist-Priolo unpublished report referenced in abbreviated references as G70.
# APPENDIX 2

## ABBREVIATED MAP REFERENCES

(See text for full references)

<table>
<thead>
<tr>
<th>Reference</th>
<th>Title</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>A29</td>
<td>Soil Engineering Construction Company</td>
<td>1973</td>
</tr>
<tr>
<td>A64</td>
<td>Gribaldo Jones and Associates</td>
<td>1970a</td>
</tr>
<tr>
<td>A70</td>
<td>Berlogar Long and Associates</td>
<td>1975</td>
</tr>
<tr>
<td>A108</td>
<td>Rose</td>
<td>1974</td>
</tr>
<tr>
<td>A170</td>
<td>Burkland and Associates</td>
<td>1975</td>
</tr>
<tr>
<td>A380</td>
<td>Woodward-Clyde Consultants</td>
<td>1976</td>
</tr>
<tr>
<td>A436</td>
<td>Woodward-Clyde Consultants</td>
<td>1977</td>
</tr>
<tr>
<td>A459</td>
<td>Terrasearch Incorporated</td>
<td>1977a</td>
</tr>
<tr>
<td>A477</td>
<td>Cooper-Clark and Associates</td>
<td>1974</td>
</tr>
<tr>
<td>A511</td>
<td>Burkland and Associates</td>
<td>1976a</td>
</tr>
<tr>
<td>A538</td>
<td>Engeo Incorporated</td>
<td>1977</td>
</tr>
<tr>
<td>A602</td>
<td>Terrasearch Incorporated</td>
<td>1977b</td>
</tr>
<tr>
<td>A618</td>
<td>Burkland and Associates</td>
<td>1977b</td>
</tr>
<tr>
<td>A671</td>
<td>Burkland and Associates</td>
<td>1972</td>
</tr>
<tr>
<td>A672</td>
<td>Burkland and Associates</td>
<td>1976b</td>
</tr>
<tr>
<td>A679</td>
<td>Burkland and Associates</td>
<td>1973</td>
</tr>
<tr>
<td>A704</td>
<td>Terrasearch Incorporated</td>
<td>1977c</td>
</tr>
<tr>
<td>A716</td>
<td>Burkland and Associates</td>
<td>1976c</td>
</tr>
<tr>
<td>A727</td>
<td>Woodward-Clyde Consultants</td>
<td>1978b</td>
</tr>
<tr>
<td>A735</td>
<td>Gribaldo Jones and Associates</td>
<td>1978</td>
</tr>
<tr>
<td>A744</td>
<td>Woodward-Clyde and Associates</td>
<td>1970b</td>
</tr>
<tr>
<td>A784</td>
<td>Hull and Associates</td>
<td>1976</td>
</tr>
<tr>
<td>A807</td>
<td>Purcell Rhoades and Associates</td>
<td>1976</td>
</tr>
<tr>
<td>A808</td>
<td>Hillebrandt Associates</td>
<td>1978</td>
</tr>
<tr>
<td>A871</td>
<td>Terrasearch Incorporated</td>
<td>1978</td>
</tr>
<tr>
<td>A943</td>
<td>Burkland and Associates</td>
<td>1978</td>
</tr>
<tr>
<td>A1075</td>
<td>Hull and Associates</td>
<td>1979</td>
</tr>
<tr>
<td>A1080</td>
<td>Earth Systems Consultants</td>
<td>1979</td>
</tr>
<tr>
<td>A1153</td>
<td>Cotton and Associates</td>
<td>1979</td>
</tr>
<tr>
<td>A1153</td>
<td>Jones, W.F., Incorporated</td>
<td>1980</td>
</tr>
<tr>
<td>A1240</td>
<td>Earth Systems Consultants</td>
<td>1980a</td>
</tr>
<tr>
<td>A1281a</td>
<td>Myers Associates</td>
<td>1980</td>
</tr>
<tr>
<td>A1281b</td>
<td>Earth Systems Consultants</td>
<td>1987b</td>
</tr>
<tr>
<td>A1299</td>
<td>Merrill and Seeley Incorporated</td>
<td>1979</td>
</tr>
<tr>
<td>A1304</td>
<td>Earth Systems Consultants</td>
<td>1980c</td>
</tr>
<tr>
<td>A1339</td>
<td>Myers Associates</td>
<td>1981</td>
</tr>
<tr>
<td>A1356</td>
<td>Zickefoose and Associates</td>
<td>1981</td>
</tr>
<tr>
<td>A1473</td>
<td>Earth Systems Consultants</td>
<td>1981</td>
</tr>
<tr>
<td>A1475</td>
<td>Burkland and Associates</td>
<td>1977a</td>
</tr>
<tr>
<td>A1519</td>
<td>Kaldveer and Associates</td>
<td>1982</td>
</tr>
<tr>
<td>A1705</td>
<td>Myers Associates</td>
<td>1984</td>
</tr>
<tr>
<td>A1992</td>
<td>Harding Lawson Associates</td>
<td>1987</td>
</tr>
<tr>
<td>A2046</td>
<td>Myers Associates</td>
<td>1987</td>
</tr>
<tr>
<td>A2288</td>
<td>Purcell Rhoades and Associates</td>
<td>1989</td>
</tr>
<tr>
<td>A2341</td>
<td>Myers Associates</td>
<td>1989</td>
</tr>
<tr>
<td>A2430</td>
<td>Soares and Associates</td>
<td>1986</td>
</tr>
<tr>
<td>A2454</td>
<td>Earth Systems Consultants</td>
<td>1985</td>
</tr>
<tr>
<td>A2456</td>
<td>Earth Systems Consultants</td>
<td>1990</td>
</tr>
<tr>
<td>A2457</td>
<td>Crosby and Associates</td>
<td>1989</td>
</tr>
<tr>
<td>A2458</td>
<td>Earth Systems Consultants</td>
<td>1988a</td>
</tr>
<tr>
<td>A2459</td>
<td>Lettis and Associates</td>
<td>1991</td>
</tr>
<tr>
<td>A2460</td>
<td>Cleary Consultants Incorporated</td>
<td>1989</td>
</tr>
<tr>
<td>A2461</td>
<td>Earth Systems Consultants</td>
<td>1988b</td>
</tr>
<tr>
<td>A2462</td>
<td>Earth Systems Consultants</td>
<td>1987a</td>
</tr>
<tr>
<td>A2514</td>
<td>California Department of Transportation</td>
<td>1991</td>
</tr>
<tr>
<td>A2516</td>
<td>Terrasearch Incorporated</td>
<td>1991</td>
</tr>
<tr>
<td>A2522</td>
<td>Kaldveer and Associates</td>
<td>1981</td>
</tr>
<tr>
<td>A2529</td>
<td>Harding Lawson Associates</td>
<td>1986</td>
</tr>
<tr>
<td>A2530</td>
<td>Lennert and Curtis</td>
<td>1985</td>
</tr>
<tr>
<td>A2566</td>
<td>Epigene Incorporated</td>
<td>1990</td>
</tr>
<tr>
<td>A2582</td>
<td>Cooper Engineers</td>
<td>1986</td>
</tr>
<tr>
<td>A2586</td>
<td>Epigene Incorporated</td>
<td>1986</td>
</tr>
<tr>
<td>A2589</td>
<td>Hull and Associates</td>
<td>1981</td>
</tr>
<tr>
<td>A2590</td>
<td>Terrasearch Incorporated</td>
<td>1990</td>
</tr>
<tr>
<td>A2601</td>
<td>Harding Lawson Associates</td>
<td>1991</td>
</tr>
<tr>
<td>A2607</td>
<td>B66 Bonilla</td>
<td>1966</td>
</tr>
<tr>
<td>A277</td>
<td>Burkland and Associates</td>
<td>1977c</td>
</tr>
<tr>
<td>A281</td>
<td>Brown, Brekke, and Korbin</td>
<td>1981</td>
</tr>
<tr>
<td>A288A</td>
<td>Borchardt, Lienkaemper, Budding, and Schwartz</td>
<td>1988a</td>
</tr>
<tr>
<td>A288B</td>
<td>Borchardt</td>
<td>1988</td>
</tr>
<tr>
<td>A2886</td>
<td>Borchardt</td>
<td>1988</td>
</tr>
<tr>
<td>A2886</td>
<td>BL66 Blanchard and Laverty</td>
<td>1966</td>
</tr>
<tr>
<td>A2886</td>
<td>BM93 Borchardt and Mace</td>
<td>1993</td>
</tr>
<tr>
<td>A2886</td>
<td>BS82 Burford and Sharp</td>
<td>1982</td>
</tr>
<tr>
<td>A2886</td>
<td>C86 Cotton, Hall and Hay</td>
<td>1986</td>
</tr>
<tr>
<td>A2886</td>
<td>C341 Woodward-Clyde Consultants</td>
<td>1978c</td>
</tr>
<tr>
<td>A2886</td>
<td>C375 Woodward-Clyde Consultants</td>
<td>1978a</td>
</tr>
<tr>
<td>A2886</td>
<td>C487 Earth Systems Consultants</td>
<td>1980b</td>
</tr>
<tr>
<td>A2886</td>
<td>CC68 Cooper-Clark and Associates</td>
<td>1968</td>
</tr>
<tr>
<td>A2886</td>
<td>CS66 Cluff and Steinbrugge</td>
<td>1966</td>
</tr>
<tr>
<td>A2886</td>
<td>E06, E08 Engeo Incorporated</td>
<td>2006, 2008</td>
</tr>
<tr>
<td>A2886</td>
<td>FER101 Smith</td>
<td>1980a</td>
</tr>
<tr>
<td>A2886</td>
<td>G01 Geomatrix</td>
<td>2001</td>
</tr>
<tr>
<td>A2886</td>
<td>G70 Gribaldo Jones and Associates</td>
<td>1970b</td>
</tr>
<tr>
<td>A2886</td>
<td>G91 Galehouse</td>
<td>1991</td>
</tr>
<tr>
<td>A2886</td>
<td>G94 Geomatrix</td>
<td>1994</td>
</tr>
</tbody>
</table>
G96    Geomatrix (1996)
GC93   Geotechnical Consultants Inc (1993)
GEI90  Geotechnical Engineering Inc. (1990)
H82A   Hirschfeld (1982)
H82B   Hirschfeld, Ridley, and Nason (1982)
HB82   Harsh and Burford (1982)
L82    Lennert (1982)
L01    Lienkaemper and others (2001)
L03    Lienkaemper and others (2003)
L05    Lienkaemper and others (2005)
L91    Lienkaemper, Borchardt, and Lisowski (1991)
L97    Lienkaemper Galehouse (1997)
N71    Nason (1971)
PL83   Prescott and Lisowski (1983)
RC91   Rutherford and Chekene (1991)
RH74   Radbruch-Hall (1974)
RL66   Radbruch and Lennert (1966)
TP82   Taylor and Page (1982)
W91    Williams (1991)
WB87   Wilmesher and Baker (1987)
WC70   Woodward-Clyde and Associates (1970a)
WL72   Woodward-Lundgren and Associates (1972)