

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

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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 probable 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 1, 2005.

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 and Andersen, 1988) to as much as 190 km (Curtis, 1989; McLaughlin and others, 1990; Jones and Curtis, 1991). For more about the bedrock geology, the following references contain geologic maps that include parts of the Hayward Fault: Crittenden (1951), Robinson (1956), Radbruch (1957), Hall (1958), Case (1963), Radbruch and Case (1967), Radbruch (1969), Dibblee (1972), Bishop and others (1973), Wagner (1978), Dibblee (1980a, 1980b, 1980c, 1981), Borchardt and others (1988c), Graymer (2000) Graymer and others (1994, 1995, 1996 2002, 2005).

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

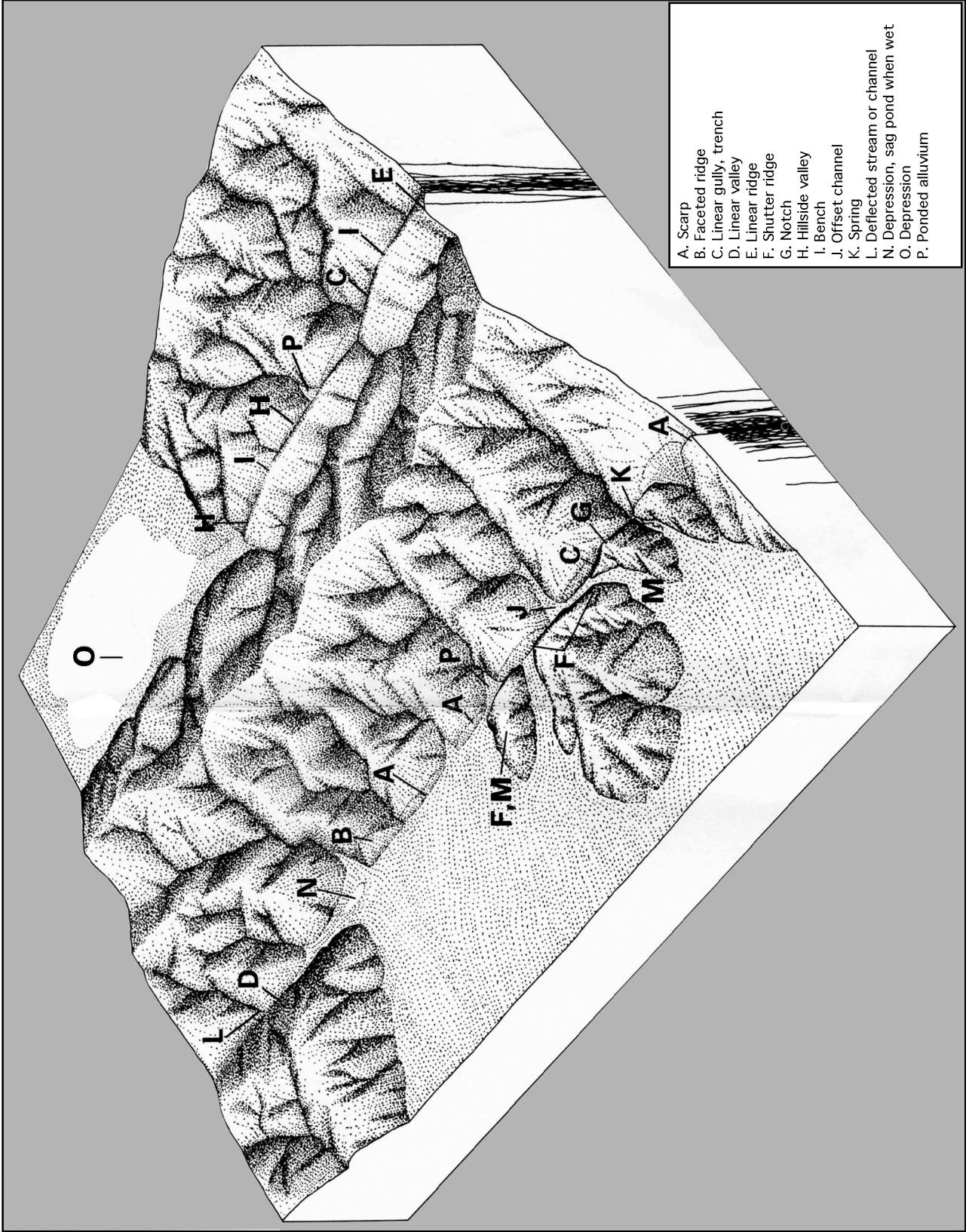


Figure 1. Block diagram showing landforms produced along recently active faults (Sharp, 1972).

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

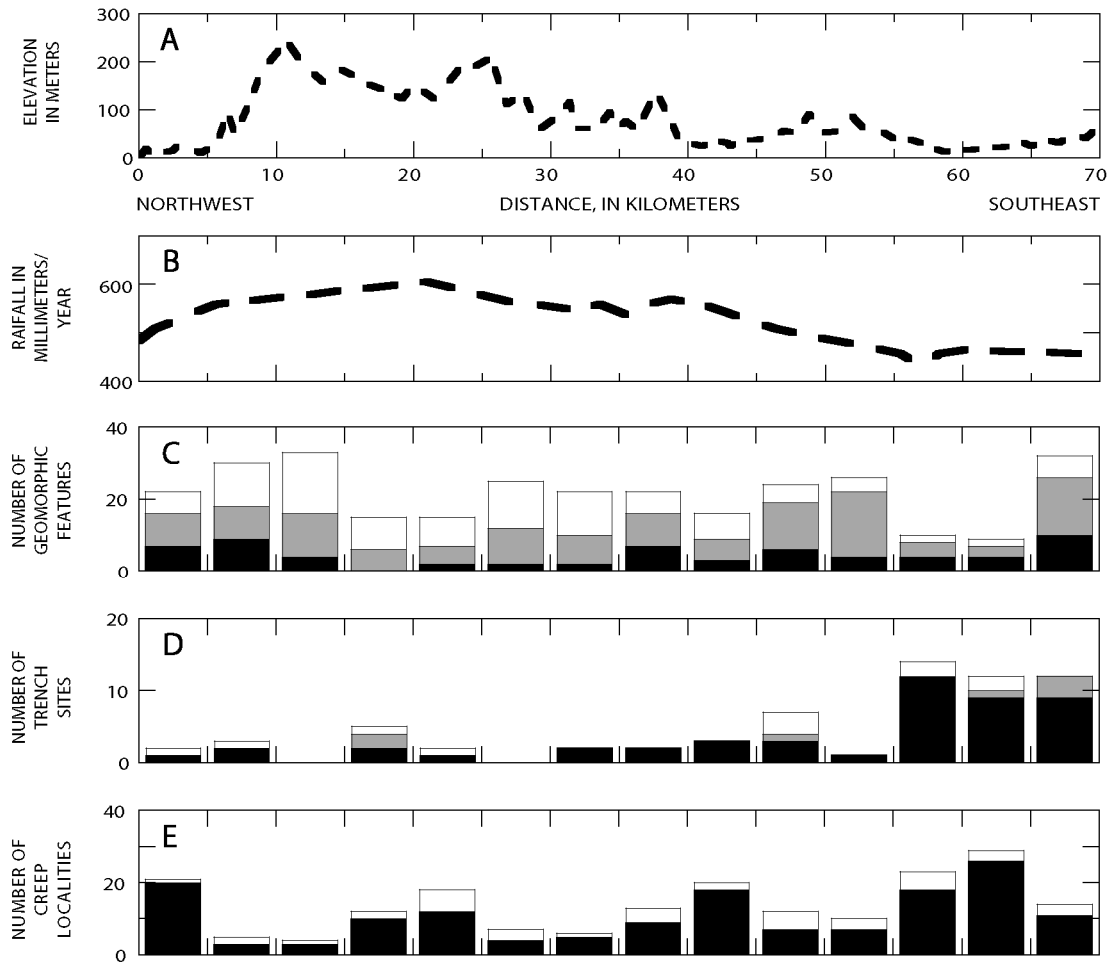


FIGURE 2. Summary histograms show amount and quality of faulting evidence from plate 1 as a function of distance along the fault. A) elevation of fault zone; B) average annual rainfall along fault zone (Rantz, 1971); C) fault-related geomorphic features (black, G1; gray, G2; white, G3); D) trench sites (black: H1, H2; gray: HP, P, U; white: H?, F?, NF); E) creep localities (black: C1, C2; white, C3). See figure 1 for location of kilometer grid. Note: this figure not updated from 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 orthophoto quadrangles (doqs) with little loss of precision locally. Relative accuracy over larger areas is estimated as similar to National Mapping Standards of $\leq \pm 12$ 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 $\leq \pm 20$ 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 $\leq \pm 12$ m, because basemaps 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 $\leq \pm 20$ 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 ($\leq \pm 40$ m and $\leq \pm 60$ 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 an 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 (Steinbrugge and others, 1960), and we now deduce

that creep has been occurring on that fault for at least several decades. A few years later, creep was discovered on the Hayward Fault in a few locations (Blanchard and Laverty, 1966; Bolt and Marion, 1966; Bonilla, 1966; Cluff and Steinbrugge, 1966; Radbruch and Lennert, 1966). In later years many other creep localities along the Hayward Fault were reported (Radbruch, 1968b; Nason, 1971; Bishop and others, 1973; Smith, 1980a, 1980b, 1981; Burford and Sharp, 1982; Hirschfeld and others, 1982; Lennert, 1982; Taylor, 1982, 1992; Lennert and Curtis, 1985; and many others too numerous to cite here.) Because there are so many places where creep evidence is publicly accessible in the field, and it continues to grow and change, I have annotated the map primarily with my own observations (1985-2005) and cited others only in places where I relied heavily on earlier work, such as survey measurements, creep offsets in tunnels and on private lands, and where the creep evidence has been altered or destroyed or where previous documentation was especially thorough and detailed. I only note on the map those surveyed features and creep monitoring arrays that I used to locate the fault trace or 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 creep 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 an 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).

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REFERENCES CITED (MAP AND TEXT)

- Berlogar Long and Associates, 1975, Soils engineering and engineering geologic investigation, mechanics work shed, La Vista Quarry, Hayward : California Geological Survey CGS CD 2003-01, AP report 70.
- Bishop, C.C., Knox, R.D., Chapman, R.H., Rodgers, D.A., and Chase, G.B., 1973, Geological and geophysical investigations for Tri-Cities [El Cerrito, Richmond, and San Pablo] seismic safety and environmental resources study: California Division of Mines and Geology Preliminary Report 19, 44 p.
- Blanchard, F.B., and Laverty, G.L., 1966, Displacements in the Claremont water tunnel at the intersection with the Hayward Fault: Seismological Society of America Bulletin, v. 56, no. 2, p. 291-294.
- Bolt, B.A., and Marion, W.C., 1966, Instrumental measurement of slippage on the Hayward Fault: Seismological Society of America Bulletin, v. 56, no. 2, p. 305-316.
- Bonilla, M.G., 1966, Deformation of railroad tracks by slippage on the Hayward Fault in the Niles district of Fremont, California: Seismological Society of America Bulletin, v. 56, no. 2, p. 281-290.
- Bonilla, M.G., and Lienkaemper, J.J., 1990, Visibility of fault strands in exploratory trenches and timing of rupture events: *Geology*, v. 18, no. 2, p. 153-156.
- _____, 1991, Factors affecting the recognition of faults in exploratory trenches: *U.S. Geological Survey Bulletin* 1947, 54 p.
- Borchardt, G., 1988, Soil development and displacement along the Hayward Fault, Point Pinole, California: California Division of Mines and Geology Open-File Report 88-13, 233 p.
- Borchardt, G., Hirschfeld, S.E., Lienkaemper, J.J., McClellan, P., and Wong, I.G., eds., 1993, Proceedings of the Second Conference on Earthquake Hazards in the Eastern San Francisco Bay Area, March 25-29, 1992, California State University, East Bay (formerly Hayward): California Geological Survey Special Publication 113, 569 p.
- Borchardt, G., Lienkaemper, J.J., Budding, K.E. and Schwartz, D.P., 1988a, Holocene slip rate of the Hayward Fault, Fremont, California: California Division of Mines and Geology Open-File Report 88-12, p. 17-52.
- Borchardt, G., Lienkaemper, J.J., and Schwartz, D.P., 1988b, Soil development and tectoturbation produced by Holocene downwarping along the Hayward Fault, Fremont, California: California Division of Mines and Geology Open-File Report 88-12, p. 53-114.
- Borchardt, G., and Mace, N., 1993, Clastic dike as evidence for a major earthquake along the northern Hayward fault in Berkeley: California Division of Mines and Geology Special Publication, v. 113, p. 143-151.
- Borchardt, G., Seelig, K.A., and Wagner, D.L., 1988c, Geology, paleosols, and crustal stability of Point Pinole Regional Shoreline, Contra Costa County, California: California Division of Mines and Geology Open-File Report 88-13, p. 3-94.
- 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.
- Brown, I.R., Brekke, T.L., and Korbin, G.E., 1981, Behavior of the Bay Area Rapid Transit tunnels through the Hayward Fault, Final Report: U.S. Department of Transportation, Urban Mass Transportation Administration Report UMTA-CA-06-0120-81-1, 208 p.
- Burford, R.O., and Sharp, R.V., 1982, Slip on the Hayward and Calaveras Faults determined from offset powerlines: California Division of Mines and Geology Special Publication 62, p. 261-269.
- Burkland and Associates, 1972, Engineering geologic investigation, Mission Meadows, Union City, California: California Geological Survey CGS CD 2003-01, AP report 671.
- _____, 1973, Preliminary geologic investigation, Glenmoor Hills unit 4, Fremont, California (Tract 3723): California Geological Survey CGS CD 2003-01, AP report 679.
- _____, 1975, Geologic and seismic hazards investigation, Tract 3450, Lot 50, Fremont, California: First Church of the Nazarene site: California Geological Survey CGS CD 2003-01, AP report 170.
- _____, 1976a, Geologic and seismic hazards investigation, Tract 3227, Unit 2, Fremont, California: California Geological Survey CGS CD 2003-01, AP report 511.
- _____, 1976b, Updated geologic and seismic hazards investigation report, Mission Peak Knolls (Tract 3756), Fremont, California: California Geological Survey CGS CD 2003-01, AP report 672.
- _____, 1976c, Geotechnical investigation, Lynde property, Union City, California: California Geological Survey CGS CD 2003-01, AP report 716.
- _____, 1977a, Supplementary geologic investigation, Motozaki property, Fremont, California: California Geological Survey CGS CD 2003-01, AP report 1475.
- _____, 1977b, Geologic and seismic hazards investigation, Tract 3857, Fremont, California: California Geological Survey CGS CD 2003-01, AP report 618.
- _____, 1977c, Geologic and seismic hazards investigation, Paseo Villages, Fremont,

- California: unpublished report filed with City of Fremont.
- ____ 1978, Geologic and seismic hazards investigation, Community Center building addition, Fremont, California: California Geological Survey CGS CD 2003-01, AP report 943.
- California Department of Transportation, 1991, Geotechnical report for fault evaluation: of [highway] Construct E[astbound]24/S[outhbound]13—[to]N[orthbound]13/W[estbound]24 Connector [Oakland, California]: California Geological Survey CGS CD 2003-01, AP report 2514.
- Case, J.E., 1963, Geology of a portion of the Berkeley and San Leandro Hills, California: University of California, Ph. D. dissertation, 216 p.
- Cleary Consultants Incorporated, 1989, Fault location investigation, Tiffany Parcel, Fremont, California: California Geological Survey CGS CD 2003-01, AP report 2460.
- Cluff, L.S. and Steinbrugge, K.V., 1966, Hayward Fault slippage in the Irvington-Niles districts of Fremont, California: Seismological Society of America Bulletin, v. 56, no. 2, p. 257-279.
- Consolidated Engineering Laboratories, 2000, Fault investigation report, Fremont Vista Assisted Living Facility, 35450/35540 Mission Boulevard, Fremont, California: California Geological Survey CGS CD 2003-01, AP report 3186.
- Cooper Engineers, 1986, Geologic hazards investigation, proposed residential development, 1694-164th Avenue, San Leandro, California: California Geological Survey CGS CD 2003-01, AP report 2582.
- 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: California Geological Survey CGS CD 2003-01, AP report 477.
- Cotton, W., and Associates, 1979, Seismic hazards investigation, Catholic Church property, East Warren Avenue, Fremont, California: California Geological Survey CGS CD 2003-01, AP report 1153.
- Cotton, W.R., Hall, N.T., and Hay, E.A., 1986, Holocene behavior of the Hayward-Calaveras Fault system, San Francisco Bay area, California, Final technical report: U.S. Geological Survey: contract report on 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, California: California Geological Survey CGS CD 2003-01, AP report 2457.
- 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, California: California Geological Survey CGS CD 2003-01, AP report 1080.
- ____ 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: California Geological Survey CGS CD 2003-01, AP report 1898.
- ____ 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 Center, Fremont, California: California Geological Survey CGS CD 2003-01, AP report 1898.
- ____ 1987a, Geotechnical evaluation, Fremont Apostolic Church property, 2390 and 2400 Durham Road, Fremont, California: California Geological Survey CGS CD 2003-01, AP report 2462.
- ____ 1987b, Geotechnical report, Mission property north, Fremont, California: California Geological Survey CGS CD 2003-01, AP report 1281b.
- ____ 1988a, Updated geologic study, Hillyer property, Fremont, California: California Geological Survey CGS CD 2003-01, AP report 2458.

- ____ 1988b, Geologic and seismic hazards evaluation, 1.12 acre parcel, East Warren Avenue, Fremont, California: California Geological Survey CGS CD 2003-01, AP report 2461.
- ____ 1990, Supplementary geologic and geotechnical engineering studies, Bettencourt Ranch project, Fremont, California: California Geological Survey CGS CD 2003-01, AP report 2456.
- ____ 1996, Soil engineering study Mission Estates, tract 6891, Fremont, California: California Geological Survey CGS CD 2003-01, AP report 2460.
- ____ 2000, Update geologic and soil engineering study, tract 7153, 2390 Durham Road, Fremont, California: California Geological Survey CGS CD 2003-01, AP report 2462.
- Ellsworth, W.L., 1990, Earthquake history, 1769-1989: U.S. Geological Survey Professional Paper 1515, p. 153-187.
- Engeo Incorporated, 1977, Alquist-Priolo investigation of the Hayward Fault Zone, property along 35th Avenue and Redwood Road, Oakland, California: California Geological Survey CGS CD 2003-01, AP report 538.
- Epigene Incorporated, 1986, Revised fault setback zones for property located adjacent to and north of 16,790 Los Banos Street, Castro Valley area, Alameda County: California Geological Survey CGS CD 2003-01, AP report 2586.
- ____ 1990, Geologic and fault investigation for site, located at the north end of Scenic Way, Alameda County, California: California Geological Survey CGS CD 2003-01, AP report 2566.
- Fox, K.F., Jr, Fleck, R.J., Curtis, G.H., and Meyer, C.E., 1985, Implications of the northwesterly younger age of the volcanic rocks of west-central California: Geological Society of America Bulletin, v. 96, no. 5, p. 647-654.
- Galehouse, J.S., 1991, Theodolite measurements of creep rates on San Francisco Bay region faults: U.S. Geological Survey Open-File Report 91-352, p. 375-384.
- Galehouse, J.S., 2002, Data from theodolite measurements of creep rates on San Francisco Bay region faults, California: 1979-2001: U.S. Geological Survey Open-File Report 02-225, 94 p.
- Galehouse, J.S., and Lienkaemper, J.J., 2003, Inferences drawn from two decades of alignment array measurements of creep on faults in the San Francisco Bay region: Bulletin Seismological Society America, v. 93, p. 2415-2433.
- Galehouse, J.S., Brown, B.D., Pierce, B., and Thordsen, J.J., 1982, Changes in movement rates on certain East Bay faults: California Division of Mines and Geology Special Publication 62, p. 236-250.
- Geotechnical Engineering Inc., 2002, Soil investigation including geologic faulting investigation, additions to Molliga family residence, 1226 Ash Street, Hayward, California: California Geological Survey CGS CD 2003-01, AP report 3224.
- Geotechnical Engineering Inc., 2004, Geologic faulting and soil investigation, new residential developments, two parcels at 21365 Ocean View Drive, Hayward, California: California Geological Survey CGS CD 2003-01, AP report 3317.
- Graham, S.A., McCloy, C., Hitzman, M., Ward, R., and Turner, R., 1984, Basin evolution during change from convergent to transform continental margin in central California: American Association of Petroleum Geologists Bulletin, v. 68, no. 3, p. 233-249.
- Graymer, R.W., 2000, Geologic map and map database of the Oakland metropolitan area, Alameda, Contra Costa, and San Francisco counties, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-2342.
- Graymer, R.W., Jones, D.L., and Brabb, E.E., 1994, Preliminary geologic map emphasizing bedrock formations in Contra Costa County, California; a digital database: U. S. Geological Survey Open-File Report 94-0622, 11 p.
- Graymer, D.L., Jones, D.L., and Brabb, E.E., 1995, Geologic map of the Hayward Fault Zone, Contra Costa, Alameda, and Santa Clara Counties, California: U. S. Geological Survey Open-File Report 95-597, 8 p.
- Graymer, R.W., Jones, D.L., and Brabb, E.E., 1996, Preliminary geologic map emphasizing bedrock formations in Alameda County, California; a digital database: U. S. Geological Survey Open-File Report 96-252.
- Graymer, R.W., Ponce, D.A., Jachens, R.C., Simpson, R.W., Phelps, G.A., and Wentworth, C.M., 2005, Three-dimensional geologic map of the Hayward Fault, Northern California; correlation of rock units with variations in seismicity, creep rate, and fault dip: Geology, v. 33, no. 6, p. 521-524.
- Graymer, R.W., Sarna-Wojcicki, A.M., Walker, J.P., McLaughlin, R.J., and Fleck, R.J., 2002, Controls on timing and amount of right-lateral offset on the East Bay fault system, San Francisco Bay region, California: Geological Society of America Bulletin, v. 114, no. 12, p. 1471-1479.
- Gribaldo Jones and Associates, 1970a, Soil and geologic investigation for California Nursery Company property, Fremont, California: California Geological Survey CGS CD 2003-01, AP report 64.
- ____ 1970b, Geologic investigation for Indian Hills, Planned Urban Development, Unit Number 2, Fremont, California: consultant report in U.S. Geological Survey library, Menlo Park, California.
- ____ 1978, Soil and geologic investigation for Branson Apartments, Fremont, California: California Geological Survey CGS CD 2003-01, AP report 735.
- Hall, C.A., 1958, Geology and paleontology of the Pleasanton area, Alameda and Contra Costa Counties, California: University of California Publications in the Geological Sciences Bulletin 34, 90 p.
- Hall, N.T., 1996, Fault rupture hazard investigation, Founders Common, Mills College, Oakland, CA: Geomatrix, Project No. 3226.03.
- Harding Lawson Associates, 1986, Geologic and fault investigation, proposed student housing, University of California: Berkeley, California:

- California Geological Survey CGS CD 2003-01, AP report 2529.
- ____ 1987, Fault investigation report, additions to Claremont Resort Hotel, Oakland, California: California Geological Survey CGS CD 2003-01, AP report 1992.
- ____ 1991, Fault hazard evaluation, Hillside School, Berkeley, California: Berkeley Unified School District, Berkeley, California, 21 p.: California Geological Survey CGS CD 2003-01, AP report 2601.
- Harsh, P.W., and Burford, R.O., 1982, Alinement-array measurements of fault slip in the eastern San Francisco Bay area, California: California Division of Mines and Geology Special Publication 62, p. 251-260.
- Hart, E.W., 1979, Fault evaluation report, Hayward, Mission, and Calaveras Faults, Niles quadrangle, on file at California Division of Mines and Geology, San Francisco, California; file no. FER-88, 13 p.
- Hart, E.W., and Bryant, W.A., 1997, Fault-rupture hazard zones in California: California Division of Mines and Geology Special Publication 42, 47 p.
- 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
- Hayward Fault Paleoearthquake Group, 1999, Timing of paleoearthquakes on the northern Hayward fault, CA —Preliminary evidence in El Cerrito, CA: U.S. Geological Survey Open-File Report 99-318, 33 p.
- Herd, D.G., 1977, Map of Quaternary faulting along the Hayward Fault Zone, Niles and Milpitas 7.5-minute quadrangles, California: U.S. Geological Survey Open-File Report 77-645, scale 1:24,000, 2 sheets.
- ____ 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.
- Herzog Associates, 1990, Geotechnical Investigation, El Portal School, Richmond, California: California Geological Survey CGS CD 2003-01, AP report 2616.
- Hillebrandt, D., Associates, 1978, Engineering geologic study and foundation investigation, four proposed residential sites, Monterey and Leimert Boulevards, Oakland, California: California Geological Survey CGS CD 2003-01, AP report 808.
- Hilley, G.E., Bürgmann, R., Ferretti, A., Novali, F., and Rocca, F., 2004, Dynamics of slow-moving landslides from permanent scatterer analysis: *Science*, v. 304, n. 5679, 1952-1955.
- Hirschfeld, S., Ridley, A., and Nason, R., 1982, Field trip stop 2, Hayward *in* Conference on Earthquake Hazards in the: Eastern San Francisco Bay Area, Field Trip Guidebook: Hayward, California, California State University, p. 45-59.
- 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.
- Hull, J., and Associates, 1976, Geotechnical investigation [of] Assessor's Map 414, Block 51, Lots 7, 8, 19, 20, and 21, between Locust and Birch Streets, near Hayward in Alameda County, California: California Geological Survey CGS CD 2003-01, AP report 784.
- ____ 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.
- ____ 1981, Seismic hazard investigation, proposed self-service station, Foothill Boulevard and Main Street, Hayward, California: California Geological Survey CGS CD 2003-01, AP report 2589.
- Johns, A., Finnigsmier, J. L., and Short, R. D., 2001, Surface fault rupture hazard study, Oakland Zoo, Oakland, CA: Kleinfelder, Inc. File No.44-000294/005.
- Jones, D.L., and Curtis, G., 1991, Guide to the geology of the Berkeley Hills, central Coast Ranges, California: California Division of Mines and Geology Special Publication 109, p. 63-73.
- Jones, W.F., Incorporated, 1980, Geotechnical hazards investigation for Windmill project, Fremont, California: California Geological Survey CGS CD 2003-01, AP report 1153.
- Kaldveer and Associates, 1981, Fault rupture hazard investigation for proposed shopping center, Oakland, California: California Geological Survey CGS CD 2003-01, AP report 2522.
- ____ 1982, Fault location study, Shell Oil Company, self-serve facility, Oakland, California: California Geological Survey CGS CD 2003-01, AP report 1519.
- Kelson, K.L., Koehler, R.D., Witter, R.C., Andrew D. Barron, Sojourner, A.C., Fite, M.R., Baldwin, J.N., and Lettis, W.R., 2000, Earthquake History of the Southern Hayward Fault, San Francisco Bay Area, California: Lettis and Associates Final Report for U. S. Geological Survey National Earthquake Hazard Reduction Program, Award Number 99-HQ-GR-0102.
- 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 Investigation Commission (Volume I): Carnegie Institution of Washington Publication 87, p. 434-448.
- 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.
- Lennert, B.J., and Curtis, G.H., 1985, Final fault hazard study, Dwight-Derby project, University of California, Berkeley, California: California Geological Survey CGS CD 2003-01, AP report 2530.

- Lettis and Associates, 1991, Fault hazard investigation, Hayward Fault, Lakepointe development site, Fremont, California: California Geological Survey CGS CD 2003-01, AP report 2459.
- Lettis and Associates, 1999, Surface fault hazard evaluation, proposed George Mark Children's House, Alameda County, California: California Geological Survey CGS CD 2003-01, AP report 2721.
- Lettis and Associates, 2000, Earthquake history of the southern Hayward fault, San Francisco Bay region, California: U.S. Geological Survey, National Earthquake Hazard Reduction Program, Final Report for Award No. 99-HQ-GR-0102, 23 p.
- Lettis and Associates, 2003, Geologic evaluation of the Hayward fault crossing, Pacific Gas & Electric Company Line B1, Fremont, CA. (unpublished report).
- Lienkaemper, J.J., 1989, Field trip guide to the Hayward Fault: U.S. Geological Survey Open-File Report 89-500, 23 p.
- Lienkaemper, J.J., 1992, Map of recently active traces of the Hayward fault, Alameda and Contra Costa Counties, California: U. S. Geological Survey, Miscellaneous Field Studies Map, MF-2196, 13 p., 1 plate.
- Lienkaemper, J. J., and Borchardt, G., 1996, Holocene slip rate of the Hayward fault at Union City, California: *Journal of Geophysical Research*, v. 101, no. B3, p. 6099-6108.
- Lienkaemper, J.J., Borchardt, G., and Lisowski, M., 1991, Historic creep rate and potential for seismic slip along the Hayward Fault, California: *Journal of Geophysical Research*, v. 96, no. B11, p. 18,261-18,283.
- Lienkaemper, J.J., and Galehouse, J.S., 1997a, Revised long-term creep rates on the Hayward Fault, Alameda and Contra Costa counties, California: U. S. Geological Survey Open-File Report 97-690.
- Lienkaemper, J.J., Galehouse, J.S., and Simpson, R.W., 1997, Creep response of the Hayward Fault to stress changes caused by the Loma Prieta earthquake: *Science*, v. 276, p. 2014-2016.
- Lienkaemper, J.J., Galehouse, J.S., and Simpson, R.W., 2001, Long-term monitoring of creep rate along the Hayward fault and evidence for a lasting creep response to 1989 Loma Prieta earthquake: *Geophysical Research Letters*, v. 28, no. 11, p. 2265-2268.
- Lienkaemper, J.J. and Hamilton, J.C., 1992, Stop A-3, Holy Sepulchre fault scarp: in *Field Trip Guidebook, Second Conference on Earthquake Hazards of the Eastern San Francisco Bay Area*, California State University, Hayward [East Bay], p. 151-156.
- Lienkaemper, J., Dawson, T., Personius, S., and Seitz, G., Reidy, L. and Schwartz, D., 2002a, Logs and data from trenches across the Hayward Fault at Tyson's Lagoon (Tule Pond), Fremont, Alameda County, California: U. S. Geological Survey, Miscellaneous Field Studies Map, MF-2386, 12 p., 2 plates.
- Lienkaemper, J.J., Dawson, T. E., Personius, S. F. and Seitz, G.G., Reidy, L. M. and Schwartz, D. P., 2002b, A record of large earthquakes on the southern Hayward fault for the past 500 years: *Bulletin Seismological Society America*, v. 92, no. 7, p. 2637-2658.
- Lienkaemper, J.J., and Williams, P.L. 1999, Evidence for surface rupture in 1868 on the Hayward Fault in North Oakland and major rupturing in prehistoric earthquakes: *Geophysical Research Letters*, v. 26, no. 13, p. 1549-1952.
- Lienkaemper, J.J., Williams, P. L., Dawson, T. E., Personius, S. F., Seitz, G. G., Heller, S. J., and Schwartz, D. P., 2003, Logs and data from trenches across the Hayward Fault at Tyson's Lagoon (Tule Pond), Fremont, Alameda County, California: U.S. Geological Survey Open-File Report 2003-488, 6 p., 8 plates.
- Lienkaemper, J.J., Williams, P.L., Sickler, R.R., and Fumal, T.E., 2005, Log of Trench 04A across the Hayward Fault at Tyson's Lagoon (Tule Pond), Fremont, Alameda County, California: U.S. Geological Survey Open-File Report 2005-1350, 2 plates.
- Liniecki-Laporte, M., and Andersen, D.W., 1988, Possible new constraints on late Miocene depositional patterns in west-central California: *Geology*, v. 16, no. 3, p. 216-220.
- Lisowski, M., Savage, J.C., and Prescott, W.H., 1991, The velocity field along the San Andreas Fault in central and southern California: *Journal of Geophysical Research*, v. 96, no. B5, p. 8369-8390.
- Louderback, G.D., 1947, Central California earthquakes of the 1830's: *Seismological Society of America Bulletin*, v. 34, no. 1, p. 33-74.
- Mace, N., and Petersen, M., 1993, Hayward fault investigation at the BART Irvington Station site for the Warm Springs Extension: Geotechnical Consultants, Inc.
- Maison, B., Fuelle, T., and Lee, D., 1998, Hayward fault creep mitigation for a major water aqueduct: *in 6th National Conference on Earthquake Engineering*, Seattle, WA., 12 p.
- McLaughlin, R.J., Sliter, W.V., Elder, W.P., McDougall, K., and Russell, P.C., 1990, 190-km post-middle Miocene offset on the Tolay-Hayward-Calaveras Fault system superposed on large-scale Late Cretaceous to early Eocene translation [abs.]: *Geological Society of America Abstracts with Programs*, v. 22, no. 3, p. 67.
- Merrill and Seeley Incorporated, 1979, Active fault investigation, 6.6 acre parcel, Briar Place, Fremont, California, Tract 4661 that California Geological Survey CGS CD 2003-01, AP report 1299.
- Myers, D., Associates, 1980, Geologic hazards investigation, Rancho Arroyo, Assessor's Parcel 507-124-22, 23 and portions of -16 and 17, City of Fremont, California: California Geological Survey CGS CD 2003-01, AP report 1281a.
- _____, 1981, Geologic hazards investigation, Delucchi property, City of Fremont, California: California Geological Survey CGS CD 2003-01, AP report 1339.
- _____, 1984, Fault hazard evaluation, Tana Development Company property, northeast side of Fletcher

- Lane, Hayward, California: California Geological Survey CGS CD 2003-01, AP report 1705.
- ____ 1987, Fault hazard investigation, San Pablo Ministorage Project, San Pablo, California: California Geological Survey CGS CD 2003-01, AP report 2046.
- ____ 1989, Fault hazard investigation, Subdivision 5496, 3156-73rd Avenue, Oakland, California: California Geological Survey CGS CD 2003-01, AP report 2341.
- ____ 1995, Fault hazard investigation, El Cerrito fire station property, 1520 Arlington Boulevard, El Cerrito, California, DMA Project 2003.95: California Geological Survey CGS CD 2003-01, AP report 2893.
- Nason, R.D., 1971, Investigation of fault creep slippage in northern and central California: San Diego, University of California, Ph. D. dissertation, 231 p.
- Nason, R.D., Phillipsborn, F.R., and Yamashita, P.A., 1974, Catalog of creepmeter measurements in central California from 1968 to 1972: U.S. Geological Survey Open-File Report 74-31, 287 p.
- Nason, R.D., and Rogers, T.H., 1970, Active slippage on the Calaveras, Hayward and San Andreas Faults: Geological Society of America, Cordilleran Section, guide book for field trip excursions, 1970 Field Trip 5, 26 p.
- Prescott, W.H., and M. Lisowski, 1983, Strain accumulation along the San Andreas Fault system east of San Francisco Bay, California: Tectonophysics, v. 97, p. 41-56.
- Purcell Rhoades and Associates, 1976, Soil and geologic investigation for two 30-unit apartment complexes, northeast of Gilbert street, Castro Valley, California: California Geological Survey CGS CD 2003-01, AP report 807.
- ____ 1989, Soil engineering and fault study: proposed residential apartment complex, 1472 Mowry Avenue, Fremont, California: California Geological Survey CGS CD 2003-01, AP report 2288.
- Radbruch, D.H., 1957, Areal and engineering geology of the Oakland West quadrangle, California: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-239, scale 1:24,000.
- ____ 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.
- ____ 1968b, New evidence of historic fault activity in Alameda, Contra Costa, and Santa Clara Counties, California: *in* Dickinson, W. R., and Grantz, A., eds., Geologic problems of San Andreas Fault System: Stanford University: California Publications in the Geological Science Series 11, p. 46-49.
- ____ 1969, Areal and engineering geology of the Oakland East [7.5 minute] quadrangle, California: U.S. Geological Survey Miscellaneous Geologic Quadrangle Map GQ-769, scale 1:24,000, 15 p.
- Radbruch, D.H., and Case, J.E., 1967, Preliminary geologic map of Oakland and vicinity, California: U.S. Geological Survey Open File Report 67-183, scale 1:24,000.
- Radbruch, D.H., and Lennert, B.J., 1966, Damage to culvert under Memorial Stadium, University of California, Berkeley, caused by slippage in the Hayward Fault Zone: Seismological Society of America Bulletin, v. 56, no. 2, p. 295-304.
- 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.
- Rantz, S.E., 1971, Mean annual precipitation and precipitation depth-duration-frequency data for the San Francisco Bay region, California: U.S. Geological Survey Open-File Report, scale 1:500,000, 23 p.
- Robinson, G.D., 1953, The Leona rhyolite, Alameda County, California: American Mineralogist, v. 38, no. 11-12, p. 1204-1217.
- ____ 1956, Geology of the Hayward quadrangle, California: U.S. Geological Survey Geologic Quadrangle Map GQ-88, scale 1:24,000.
- Rose, R.B., 1974, Geological report, Jefco Development, minor subdivision MS-74-12, Fremont, California: California Geological Survey CGS CD 2003-01, AP report 108.
- Rose, R.L., 1978, Age of the Alum Rock rhyolite [abs.]: Geological Society of America Abstracts with Programs, v. 10, p. 144.
- Rutherford and Chekene, 1991, Supplemental report, fault hazard evaluation, Kiwanis building, Temescal Regional Recreation Area, Oakland, California: East Bay Regional Parks District, Oakland, California.
- Schulz, S.S., 1989, Catalog of creepmeter measurements in California from 1966 through 1988: U.S. Geological Survey Open-File Report 89-650, p. 193.
- Schulz, S.S., Mavko, G.M., Burford, R.O., and Stuart, W.D., 1982, Long-term fault creep observations in central California: Journal of Geophysical Research, v. 87, no. B8, p. 6977-6982.
- Sharp, 1972, Map showing recently active breaks along the San Jacinto Fault zone between the San Bernardino area and Borrego Valley, California: U.S. Geological Survey Miscellaneous Investigations Map I-675, scale 1:24,000, 3 sheets.
- Smith, T.C., 1980a, Fault evaluation report, Hayward Fault, Richmond segment: on file at California Division of Mines and Geology, San Francisco, California; file no. FER-101.
- ____ 1980b, Fault evaluation report, Hayward Fault, Oakland segment: on file at California Division of Mines and Geology, San Francisco, California; file no. FER-102.
- ____ 1981, Fault evaluation report, Hayward Fault, Hayward segment: on file at California Division of Mines and Geology, San Francisco, California; file no. FER-103.
- ____ 1982, Self-guided field trip 4, fault creep along the Hayward Fault in the Richmond-San Pablo area in Conference on Earthquake Hazards in the [Eastern] San Francisco Bay Area, Field Trip Guidebook:

- Hayward, California, California State University (East Bay), p. 93-101.
- Soares, A., and Associates, 1986, Fault hazard investigation for Assessor's Parcel Number 37-2538-20, Cunningham Street, Oakland, California: California Geological Survey CGS CD 2003-01, AP report 2430.
- Soares, A., and Associates, 1981, Geotechnical investigation for Assessor's Parcel Number 48-200-11, Poplar Avenue in the Richmond area of Contra Costa County, California: California Geological Survey CGS CD 2003-01, AP report 2903.
- Soil Engineering Construction Company, 1973, Engineering geology investigation for Mission View Greens [Hayward, California]: California Geological Survey CGS CD 2003-01, AP report 29.
- Steinbrugge, K.V., Zacher, E.G., Tocher, D., Whitten, C.A., and Clair, C.N., 1960, Creep on the San Andreas Fault: *Seismological Society of America Bulletin*, v. 50, p. 389-415.
- 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.
- Taylor, C.L., Cluff, J., and Hirschfeld, S., eds., 1982, *Field Trip Guidebook, Conference on Earthquake Hazards in the [Eastern] San Francisco Bay Area*: Hayward, California, California State University (East Bay), 142 p.
- Taylor, C.L., compiler, and Hall, N.T., and Melody, M., eds., 1992, *Field Trip Guidebook of the Second Conference on Earthquake Hazards in the Eastern San Francisco Bay Area, March 25-29, 1992*, California State University, East Bay (formerly Hayward): Oakland, Geomatrix Consultants Inc., 225 p.
- Taylor, C.L., and Lienkaemper, J.L. 1992, Location of Hayward fault traces at Montclair Village area of Oakland, California: *Field Trip Guidebook, Second Conference on Earthquake Hazards of the Eastern San Francisco Bay Area*, California State University, Hayward [East Bay], p. 83-93.
- Taylor, C.L., and Page, B.M., 1982, Man made exposures of the Hayward Fault, Niles, [Fremont,] California *in* Conference on Earthquake Hazards in the [Eastern] San Francisco Bay Area, *Field Trip Guidebook*: Hayward, California, California State University, p. 37-43.
- Taylor, C.L., and Power, M. S., 1994, Geologic/geotechnical studies for fault crossings of major pipelines East Bay Municipal Utility District Seismic Hazard Evaluation Program: Geomatrix Consultants Project No. 2683.
- Terrasearch Incorporated, 1977a, Geologic investigation on lands of Harry Duncan (Tract 3822), Fremont, California: California Geological Survey CGS CD 2003-01, AP report 459.
- _____, 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.
- _____, 1978, Geologic investigation on Tract 3449, lands of Amaral, Mission Boulevard and Nursery Avenue, Fremont, California: California Geological Survey CGS CD 2003-01, AP report 871.
- _____, 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.
- _____, 1991, Geologic/seismic investigation on Parcel A and Lots 52 and 53, Tract 2123, San Pablo Dam Road, San Pablo, California: California Geological Survey CGS CD 2003-01, AP report 2516.
- Thompson, M.M., 1979, *Maps for America, Cartographic products of the U.S. Geological Survey and others*: U.S. Geological Survey, 265 p.
- Topozada, T.R., and Borchardt, G., 1998, Re-evaluation of the 1836 "Hayward Fault" earthquake and the 1838 San Andreas Fault earthquake: *Bulletin of the Seismological Society of America*, v. 88, p. 140-159.
- Wagner, J.R., 1978, Late Cenozoic history of the Coast Ranges east of San Francisco Bay: University of California, Berkeley, Ph.D. dissertation, 161 p.
- Wahrhaftig, C., 1984, Streetcar to subduction and other plate tectonic trips by public transport in San Francisco: Washington, D.C., American Geophysical Union, 76 p. [Trip 7, Hayward Fault, p. 55-63]
- Wallace, R.E., 1990, Geomorphic expression, *in* R. E. Wallace, ed., *The San Andreas Fault System, California*: U.S. Geological Survey Professional Paper 1515, p. 14-58.
- _____, ed., 1990, *The San Andreas Fault System, California*: U.S. Geological Survey Professional Paper 1515, 283 p.
- Water Infrastructure Partners, 2004, Geotechnical investigation seismic upgrade of [Bay Division Pipeline] BDPL Nos. 3 and 4 at the Hayward fault zone crossing, Fremont, California: San Francisco, San Francisco Public Utilities Commission.
- Wells, D.L., Hall, N. T., and Swan, F. H., 2001, Fault rupture hazard evaluation, California Memorial Stadium, University of California, Berkeley, CA: Geomatrix Consultants, Project No. 5442.
- Williams, P.L., 1991, Evidence of late Holocene ruptures, southern Hayward Fault, California: *Seismological Research Letters*, v. 62, no. 1, p. 14.
- 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.
- Williams, P.L., 1993, Geologic record of southern Hayward fault earthquakes: California Division of Mines and Geology Special Publication, v. 113, p. 171-179.
- Wills, C.J., 1991, Products of the Alquist-Priolo Fault Evaluation and Zoning Project: California Geology, v. 44, no. 3, p. 59-63.
- Wilmesher, J.F., and Baker, F.B., 1987, Catalog of alignment array measurements in central and southern California from 1983 through 1986: U.S. Geological Survey Open-File Report 87-280, 157 p.
- Wong, P., Bryant, W.A., and Treiman, J.A., 2003, Fault investigation reports for development sites within Alquist-Priolo Earthquake Fault Zones in northern California, 1974-2000: California Geological Survey CGS CD 2003-01.
- Woodward-Clyde and Associates, 1970a, Active fault risk investigation and evaluation, Hayward Commercial Development Center: consultant report in U.S. Geological Survey library, Menlo Park, California.
- ____ 1970b, Fremont Meadows active fault investigation and evaluation, Fremont, California: California Geological Survey CGS CD 2003-01, AP report 744.
- ____ 1976, Alquist-Priolo Special Study Zone report, Shinn property, Tract 3613, Fremont, California: California Geological Survey CGS CD 2003-01, AP report 380.
- ____ 1977, Active fault investigation, proposed mausoleum, Holy Sepulchre Cemetery, Hayward, California: California Geological Survey CGS CD 2003-01, AP report 436.
- ____ 1978a, Geologic/seismic hazards evaluation, Fairmont Hospital-Juvenile Hall, San Leandro, California: Alameda County Public Works Agency, Hayward, California: on file at California Division of Mines and Geology, San Francisco, California; file no. A2721.
- ____ 1978b, Phase II geologic assessment, San Pablo Redevelopment Agency Hillside Neighborhood, San Pablo, California: California Geological Survey CGS CD 2003-01, AP report 727.
- ____ 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.
- Woodward-Lundgren and Associates, 1972, Geologic and seismic site evaluation, Masonic Home of California, Union City, California: consultant report in U.S. Geological Survey library, Menlo Park, California.
- Working Group on California Earthquake Probabilities, 1990, Probabilities of large earthquakes in the San Francisco Bay Region, California: U.S. Geological Survey Circular 1053, 51 p.
- Working Group on California Earthquake Probabilities, 2003, Earthquake probabilities in the San Francisco Bay Region: 2000-2030: U.S. Geological Survey Open-File Report 03-214, 235 p.
- Yamashita, P.A. and Burford, R.O., 1973, Catalog of preliminary results from an 18-station creepmeter network along the San Andreas Fault system in central California for the time interval June 1969 to June 1973: U.S. Geological Survey Open-File Report, 215 p.
- Zickefoose and Associates, 1981, Geologic fault study, minor subdivision, Lots 3, 4, and 41, Block 24, Bernhard and Felix Avenues, Tewksbury Heights, Richmond, Contra Costa County, California: California Geological Survey CGS CD 2003-01, AP report 1356.

APPENDIX 1

MAP ABBREVIATIONS

C - CREEP EVIDENCE

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

G - GEOMORPHIC FEATURES

- 1 - strongly pronounced feature
- 2 - distinct feature
- 3 - weakly pronounced feature
- ? - additional uncertainty in tectonic origin
- af - alignment of multiple features as listed
- as - arcuate scarp
- bt - downthrown surface tilts back toward fault
- df - depression formed by some aspect of fault deformation, undifferentiated
- dr - sag, depression formed in right stepover of fault trace
- gi - linear break (or gradual inflection) in slope
- hb - linear hillside bench
- hv - linear hillside valley
- 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 (¹⁴C) 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 Abbreviated 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)

A29	Soil Engineering Construction Company (1973)	A2288	Purcell Rhoades and Associates (1989)
A64	Gribaldo Jones and Associates (1970a)	A2341	Myers Associates (1989)
A70	Berlogar Long and Associates (1975)	A2430	Soares and Associates (1986)
A108	Rose (1974)	A2454	Earth Systems Consultants (1985)
A170	Burkland and Associates (1975)	A2456	Earth Systems Consultants (1990)
A380	Woodward-Clyde Consultants (1976)	A2457	Crosby and Associates (1989)
A436	Woodward-Clyde Consultants (1977)	A2458	Earth Systems Consultants (1988a)
A459	Terrasearch Incorporated (1977a)	A2459	Lettis and Associates (1991)
A477	Cooper-Clark and Associates (1974)	A2460	Cleary Consultants Incorporated (1989)
A511	Burkland and Associates (1976a)	A2461	Earth Systems Consultants (1988b)
A538	Engeo Incorporated (1977)	A2462	Earth Systems Consultants (1987a)
A602	Terrasearch Incorporated (1977b)	A2514	California Department of Transportation (1991)
A618	Burkland and Associates (1977b)	A2516	Terrasearch Incorporated (1991)
A671	Burkland and Associates (1972)	A2522	Kaldveer and Associates (1981)
A672	Burkland and Associates (1976b)	A2529	Harding Lawson Associates (1986)
A679	Burkland and Associates (1973)	A2530	Lennert and Curtis (1985)
A704	Terrasearch Incorporated (1977c)	A2566	Epigene Incorporated (1990)
A716	Burkland and Associates (1976c)	A2582	Cooper Engineers (1986)
A727	Woodward-Clyde Consultants (1978b)	A2586	Epigene Incorporated (1986)
A735	Gribaldo Jones and Associates (1978)	A2589	Hull and Associates (1981)
A744	Woodward-Clyde and Associates (1970b)	A2590	Terrasearch Incorporated (1990)
A784	Hull and Associates (1976)	A2601	Harding Lawson Associates (1991)
A807	Purcell Rhoades and Associates (1976)	B66	Bonilla (1966)
A808	Hillebrandt Associates (1978)	B77	Burkland and Associates (1977c)
A871	Terrasearch Incorporated (1978)	B81	Brown, Brekke, and Korbin (1981)
A943	Burkland and Associates (1978)	B88A	Borchardt, Lienkaemper, Budding, and Schwartz (1988a)
A1075	Hull and Associates (1979)	B88B	Borchardt (1988)
A1080	Earth Systems Consultants (1979)	BL66	Blanchard and Lavery (1966)
A1153	Cotton and Associates (1979)	BM93	Borchardt and Mace (1993)
A1153	Jones, W.F., Incorporated (1980)	BS82	Burford and Sharp (1982)
A1240	Earth Systems Consultants (1980a)	C86	Cotton, Hall and Hay (1986)
A1281a	Myers Associates (1980)	C341	Woodward-Clyde Consultants (1978c)
A1281b	Earth Systems Consultants (1987b)	C375	Woodward-Clyde Consultants (1978a)
A1299	Merrill and Seeley Incorporated (1979)	C487	Earth Systems Consultants (1980b)
A1304	Earth Systems Consultants (1980c)	CC68	Cooper-Clark and Associates (1968)
A1339	Myers Associates (1981)	CS66	Cluff and Steinbrugge (1966)
A1356	Zickefoose and Associates (1981)	FER101	Smith (1980a)
A1473	Earth Systems Consultants (1981)	G01	Geomatrix (2001)
A1475	Burkland and Associates (1977a)	G70	Gribaldo Jones and Associates (1970b)
A1519	Kaldveer and Associates (1982)	G91	Galehouse (1991)
A1705	Myers Associates (1984)	G94	Geomatrix (1994)
A1898	Earth Systems Consultants (1983, 1986)	G96	Geomatrix (1996)
A1992	Harding Lawson Associates (1987)	GC93	Geotechnical Consultants Inc (1993)
A2046	Myers Associates (1987)	GE190	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)
NC70 Nason, R.D. and Carey, J.P., 1970, unpublished data; see
Woodward-Clyde (1970a).
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 Wilmeshier and Baker (1987)
WC70 Woodward-Clyde and Associates (1970a)
WL72 Woodward-Lundgren and Associates (1972)