CALIFORNIA DIVISION OF MINES AND GEOLOGY
FAULT EVALUATION REPORT FER-228

The Antioch fault, Contra Costa County, California

by

Christopher J. Wills
Associate Geologist
November 6, 1991

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INTRODUCTION

The Antioch fault was first mapped by Burke and Helley (1973) as an active, creeping fault. Based solely on the data shown on this map, it was included within an Alquist-Priolo Special Studies Zone in 1976. Since that time, numerous consulting geologists have investigated the fault but none have found convincing evidence for Holocene offset.

The continuing inability of consulting geologists to find evidence for Holocene offset on the Antioch fault suggests that the fault may not be "sufficiently active and well defined" (Hart, 1990) for zoning under the Alquist-Priolo Act. Available published and unpublished reports have been reviewed for this study.

GEOLOGIC SETTING

The Antioch area is located on the eastern margin of the Coast Ranges adjacent to the Sacramento-San Joaquin delta. Bedrock of the area consists of north-dipping Eocene through Pliocene sedimentary rocks. Resistant beds, mostly sandstones, of these rocks form east-west strike ridges in the hills south of Antioch. Surface mapping (Colburn, 1961; Brabb and others, 1971; Dibblee, 1981) and correlation of subsurface units in the Brentwood oil field (Ditzler and Vaughan, 1964) show that the bedrock forms a north-dipping homoclinal sequence. This sequence is cut by faults that trend north and northwest.

The youngest of the bedrock units, a poorly bedded nonmarine conglomerate, siltstone and sandstone, has been assigned to the Wolfskill Formation (Brabb and others, 1971) or the Tehama Formation (Burke and Helley, 1973). This unit overlies the 4.5-million-year-old Lawlor Tuff, and contains the 3.3-million-year-old Putah Tuff (Sarna-Wojcicki, 1976).

The older parts of Antioch are built on an alluvial plain composed of horizontally bedded sand and silty sand mapped as "older sediments" (Burke and Helley, 1973) or "older alluvium," (Atwater, 1982). The alluvium is overlain by eolian sand of the upper Modesto Formation east of Antioch. Radiocarbon dating shows that the Modesto Formation is younger than about 40,000 years and older than about 10,000 years (Atwater, 1981; Marchand and Aldwardt, 1981); therefore the older alluvium of the Antioch area must be of latest Pleistocene age or older.

The soils formed on the Antioch alluvial plain also suggest a late Pleistocene surface. These soils, mapped as the Ambrose clay loam (Carpenter and Crosby, 1939) or the Rincon clay loam (Welch, 1977), are described as having a well developed Bt horizon with extremely hard angular blocky structure and many clay films. This soil was described for this report near the Antioch fault in Antioch (see soil descriptions, Appendix A). The thickness and development of its B horizon suggest that the soil took more than 10,000 years to form.

Minor streams draining north to the San Joaquin River have dissected the Antioch alluvial plain. One of these streams, which reached the San Joaquin River between J and L Streets in Antioch, formed a channel now filled with up to 50 feet of bay mud, peat and marsh deposits (Diablo Soils Engineers, 1980; Harding Lawson Associates,1977,1986a). The depth of soft sediments in this channel and adjacent to the San Joaquin River suggest that the channel was graded to a level about 50 feet lower than the present elevation of the San Joaquin River.

The current river elevation at Antioch is only about 5 feet above sea level, therefore the low river base level must have coincided with a low sea level stand. Since the most recent low stand was about 22,000 years ago, the stream channel must be approximately 22,000 years old. By the law of superposition, the Antioch alluvial plain must be older than the channel incised into it. Additionally, the marsh deposits now filling the stream channel probably were deposited in Holocene time as sea level approached its present elevation.

THE ANTIOCH FAULT

Regional Studies

South of Antioch, north- to northwest-trending faults have been mapped at the surface (Colburn, 1961; Brabb and others, 1971; Dibblee, 1981) and by correlation of subsurface units in the Brentwood oil field (Ditzler and Vaughan, 1964). These maps show right-lateral separation of north-dipping sedimentary units across these faults (Figure 2). This sense of separation is consistent with normal, down-to-the-east, or right-lateral offset. Ditzler and Vaughan (1964) present a structure contour map based on oil well data that shows three faults in about the same position and orientation as the Davis fault of Colburn (1961) and Brabb and others (1971). One of these faults offsets both limbs of a minor fold right-laterally by about the same amount, suggesting that the displacement is predominantly right-lateral. Another, parallel fault has predominantly normal offset.

Burke and Helley (1973) proposed that a previously unmapped fault explained the alignment of parts of the Davis fault, another bedrock fault in Antioch, the linear ridge of Fraser Shoal in the San Joaquin River, and the linear west edge of the Montezuma

Hills. They show a single, straight, N30°W-trending fault cutting Tertiary sedimentary rocks in the hills south of Antioch and a zone of "anomalous features" in the City of Antioch that they thought could be due to fault creep. They proposed that creep displacement had occurred on this fault in the very recent past, possibly triggered by a series of small earthquakes in 1965. Although Burke and Helley did not formally name this fault, it quickly became known as the Antioch fault by consultants and others working in the area (Burkland and Associates, 1975; DWR, 1978).

The "Antioch fault" commonly referred to in recent studies and in this report includes this new fault mapped by Burke and Helley (1973) and those parts of the Davis fault south of the junction of the two faults (Figure 2). This usage probably came about because Burke and Helley noted evidence for recent movement on the Antioch fault and parts of the Davis fault and because the Alquist-Priolo Special Studies Zones Maps (CDMG, 1976a,b) show only those traces, which appear to form a single fault (Figure 3). The trace of the Antioch fault referred to in this report also includes a line drawn down the center of Burke and Helley's "zone of anomalous features" by CDMG on the Antioch North quadrangle. This part of the trace was drawn for zoning purposes and does not nessecarily reflect field observations.

Assuming that the offset on the Antioch and Davis faults is purely right-lateral, as suggested by Burke and Helley (1973), total offset can be measured at several locations. The apparent right-lateral offset of Eocene beds across the Davis fault is approximately 1200 m. (Brabb and others, 1971; Burke and Helley, 1973)(Figure 2). According to Burke and Helley (1973), the Antioch fault offsets the contact between the Miocene Neroly and Cierbo Formations by 1000 feet (about 300 m) right-laterally (Figure 2). DWR (1978) remapped this locality and excavated several trenches across the fault. DWR could verify no more than 46 m of right-lateral offset.

A long-term slip-rate can be calculated from the offset of these late Miocene units. 300 meters of right-lateral offset (Burke and Helley, 1973) in approximately 10 million years since the deposition of the Neroly Formation (Creely and others, 1982; Graham and others, 1983) yields an average slip-rate since Miocene time of 0.03 mm/yr. The alternative, lesser offset of 46 m (DWR, 1978) yields an average slip-rate of 0.005 mm/yr.

The average slip-rates calculated above are unusually low for an active fault in the San Andreas fault system. They suggest that the Antioch fault was active for only a short period. The proposed post-Miocene offset of 300 m could accumulate in only 300,000 years at the low (for the San Andreas fault system) slip rate of 1 mm/yr. It is then important to determine if the fault was active primarily in the Miocene (as tentatively proposed by

DWR, 1978), or has formed recently and is still active (as Burke and Helley's creep data suggest).

Total displacement of bedrock units of different ages should reflect the age of displacement on the fault. As noted above, Eocene rocks are offset across the Davis fault about 1200 m. Miocene rocks are offset a total of about half that amount; 300 meters across the Antioch fault and 360 m across the Davis fault according to Burke and Helley (1973). Much of the movement therefore appears to have occurred between Eocene and late Miocene times.

Evidence for creep

Burke and Helley's (1973) conclusion that the Antioch fault is creep-active led the Division of Mines and Geology to issue Alquist-Priolo Special Studies Zones maps of the Antioch North and Antioch South quadrangles in 1976 (CDMG, 1976a;1976b). Zones established in 1976 were based on more permissive criteria than the current standard of "sufficiently active and well defined" (Hart, 1990). Nevertheless, the Antioch fault probably would not have been zoned if it were not for the probable creep reported by Burke and Helley.

Because Burke and Helley's (1973) evidence for fault creep is the critical data for active faulting in Antioch, each of their localities was revisited in 1991. Burke and Helley's observations at each of their 29 sites are listed verbatim below. Field observations by this writer in May and June 1991 follow each of Burke and Helley's descriptions in small type (see Figure 2 for locations):

1. Distorted railroad sidings; main-line tracks seemingly undisturbed.

   This site has been modified substantially since Burke and Helley's observation: all the sidings have been removed, leaving only the main line. The main line does appear to be slightly deflected right laterally at the projection of K Street. This site corresponds to the eastern edge of an old slough, filled with very soft bay mud, peat and artificial fill. Settlement of the soft sediments toward the San Joaquin River could produce a right lateral deflection.

2. Right-lateral offsets on curbs on both sides of street. Horizontal displacements of 2 mm on north side, 7 mm on south. No walks on street.

   Some settlement and cracking of curbs was noted on the north side of 2nd Street between J and K Streets. There is no systematic offset of curbs or walks.

3. No offset fractures on 1970 walks and curbs.

   No evidence for faulting noted.

4. Zone of thoroughly fractured asphalt in street trending N20W. Undisturbed 1973 walk and curb on extension of zone on east side of street.

   This is along the old slough. Drilling on the west side of the street (Diablo Soils Engineers, 1980) penetrated about 12 feet of fill over about 12 feet of bay mud and peat. The drill stem sank through the bay mud and peat under its own weight. This area is obviously highly prone to settlement and associated cracking.

5. Fractures but no offsets between joints on old curbs on both sides of street. Newer walks undisturbed.

This is at edge of old slough, cracking is probably due to settlement. No evidence for faulting observed.

6. Dirt road with no walks or curbs.

No evidence for faulting.

7. Right-lateral offsets on old curbs on both sides of street. Horizontal displacement of 4 mm on north side, 2 mm on south. Walks recently replaced and undisturbed.

This is at edge of old slough, at the base of a sinuous scarp. Curbs with minor (<5 mm) deflections noted on 4/15/91. They are probably due to settlement.

8. Right-lateral offset of 2 mm on old curb on north side of street; no disturbance in younger (1966?) walk. Right-lateral offset of 12 mm along joint on old curb on south side aligned with 2 mm offset between joints on old walk.

There are no curbs or walkways in this block. Examination of aerial photographs shows that there were no curbs or walkways in this block in 1950 or 1973 (USDA, 1950; Pacific Resources Inc, 1973; Cartwright Aerial Surveys, 1973). This locality may have been mislocated by Burke and Helley (1973).

9. Two fractures with 1 mm of right-lateral offset each on old curb on north side of street; new walk undisturbed. One fracture but no lateral offsets between joints on old curb on south side; new walk undisturbed.

Random minor right-lateral and left-lateral deflections observed.

10. East-west buckle with about 15 cm of relief on west side of road with joint on crest. Old curb and asphalt-covered concrete street are buckled, but new walk undisturbed. Buckle dies out eastward, and east side of street is unaffected.

No buckle of this size or unusual cracks in old curbs and gutters or street. Perhaps this refers to a minor buckle with less than 2 cm relief (possible typo on MF 533, maybe it should read 15 mm relief).

11. East-west buckle with about 2 cm relief on east side of street in walk and curb with numerous patchwork repairs; joint on crest. Buckle dies out westward, and west side of street is unaffected.

Walkways have been replaced adjacent to 809 H Street, no cracks suggestive of faulting were observed.

12. Broad east-west buckle with about 3 cm of relief on walk and curb on east side of street.

Settlement of curbs and minor cracks in this area, buckle not verified.

13. Patchwork repair of curbs with many fractures of inconsistent offset in older portions. No offsets on more uniform younger walks.

Random minor cracks in old curbs and sidewalks.

14. Patchwork repair of walks and curbs. No obvious buckles unrelated to tree root growth.

Random minor cracks, buckles clearly related to tree roots.

15. No offset fractures between joints; inconsistent small offsets along joints.

Random minor cracks.

16. Right-lateral offset of 5 mm and other slight left- and right-lateral offsets on old curb on north side of street. Right-lateral offset of 3 mm on old curb on south side. Numerous left- and right-lateral offsets on walks on both sides of streets.

Curb on N side of 12th Street has been replaced adjacent to two trees.

17. Three offset fractures on 1948 curb on north side of street: 5 mm right-lateral with adjacent undisturbed young walk; 1 mm right-lateral with adjacent 1948 walk similarly offset 2 mm; 2 mm left-lateral with adjacent 1948 walk undisturbed. Three right-lateral offsets of 1,2, and 3 mm and two left-lateral offsets of 1 and 3 mm on 1948 walk and curb on south side.

15 mm right-lateral offset of curb on north side of street adjacent to 418 W 13th Street does not extend into walk or street. 2 mm right-lateral on crack about 50 feet to east near transverse cracks in walk and street, no cracking in curbs directly across street.

18. Open cracks as much as 1 cm wide in north and east walls of cafeteria and generally northwest-southeast fractures in floor with extension and relative down-drop to the northeast of about 5 mm.

No fault found in trenching by Woodward-Clyde Consultants (1975). Examination of surrounding streets at that time by WCC (1975; A. Ridley p.c. 1991) and Earl W. Hart of CDMG (p.c. 1991) could not confirm any systematic offsets or deformation of streets. Distress to building is thought to be due to expansive soil.

19. Right-lateral offset of 7 mm on pre-1965 curb on south side of street adjacent to undisturbed 1966 walk; undisturbed 1966 repair patch in walk and curb on north side.

Curb on south side of street noted is still apparently offset about 7 mm. It does not align with any cracks in walkway or street. No faults found in trenching on N side of 18th Street by Kaldveer Associates (1989).

20. Numerous fractures with no offsets or with right-lateral offsets of less than 2 mm in 1957 walks and younger (but pre-1965) curbs. Fractures on north side of street occur largely in western part of area; fractures on south side occur largely in eastern part.

No evidence for faulting observed.

21. Thoroughly disturbed old walks, curbs, and asphalt-covered concrete street with many large trees. No obvious anomalous offsets or buckles.

No evidence for faulting observed.

22. Fractures with no offsets or with right-lateral offsets of less than 2 mm on old curb on north side of street; undisturbed new curb. Undisturbed new walk and curb on south side.

No evidence for faulting observed.

23. No obvious distortion of railroad tracks, although much of the original siding has been removed.

No evidence for faulting observed. Burkland and Associates (1975) and Kneupfer (1977) note several cracks in concrete walls to E which have minor right-lateral offsets. None extend into adjacent pavement.

24. Right-lateral offset of 2 mm and left-lateral offset of 1 mm on pre-1960 curb on north side of street; undisturbed 1972 walk. Two right-lateral offsets on south side: 5 mm offset on pre-1960 curb with undisturbed new walk; 2 mm on pre-1960 curb, walk, and low retaining wall.

No unusual cracks or offsets in curbs constructed in the early 1950's, walks dating from the late 1950's or in street. The "low retaining wall" is apparently an old brick planter with many random cracks.

25. Largely new undisturbed construction. Many large trees near remaining older construction; no obvious anomalous offsets or buckles.

Burkland and Associates (1975) and Kneupfer (1977) noted cracks in curbs and a scarplet in a street in this area. Their conclusions will be discussed in more detail below.

26. East-west buckles in early-1960's walks and curbs with about 2 cm of relief.

No unusual cracks in old sidewalks curbs or street.

27. Two left-lateral offsets of less than 1 mm on early-1960's walk and curb on north side of street. Right-lateral offset of 8 mm on similar walk and curb on south side.

Darwin Myers and Associates (1981) also noted these cracks in the curbs as well as distress to the adjacent house on the north side of the street and distress to two houses and a retaining wall to the southeast. Field checking for this report revealed no consistent sense of cracking or zone of cracks. Cracks do not suggest right-lateral displacement, they may be due to expansive soils.

28. On north side, canal lining bulged inward about 4 cm and left-laterally offset about 5 mm. On south side where drain pipe enters canal, lining bulged inward about 5 cm.

Bulges and left-lateral offset verified, all appear to be larger than described by Burke and Helley. No right-lateral offset observed.

29. Indistinct, east-facing step in alluvium no more than 15 cm high. Stream channel on higher, western side entrenched to level of eastern side.

Site was investigated and trenched by DWR (1978) who verified fault in bedrock and probable fault in 100,000 to 200,000 year old alluvial material, Fault did not cut alluvial material estimated to be 50,000 to 70,000 years old. Scarp could not be verified by DWR (1978).

Of the 29 sites where Burke and Helley (1973) describe evidence for creep (Figure 2), seven sites (3,5,6,14,15,23 & 25) provide no evidence of ground deformation of any kind. Eleven sites (10,11,12,13,18,19,21,22,26,28 & 29) provide evidence of some

type of ground deformation but not right-lateral offset. Most are easily explained by expansive soils or settlement. Eleven sites (1,2,4,7,8,9,16,17,19,24 & 27) suggest possible right-lateral offsets. Of these, sites 1,2,4,7,8 & 9 are within or along the margin of an old slough which contains very soft sediment that is prone to settlement. The remaining five sites (16,17,19,24 and 27), record only minor, isolated, right-lateral offsets of curbs, sidewalks or planters. No consistent offsets in nearby curbs, linear zones of cracks, or en echelon cracks in pavement were found. None of the minor offsets that could be relocated have grown significantly in the 18 years since they were noted by Burke and Helley.

As part of his measurements of creep on Bay Area faults, J.S. Galehouse of San Francisco State University, has repeatedly surveyed two arrays across the Antioch Fault. One of these, adjacent to site 26 of Burke and Helley, has shown no systematic movement in more than 10 years of monitoring. The other, in the bedrock hills near Lone Tree Way, may have had very slight right-lateral slip across it, but the amount of movement is within the possible measurement error. Galehouse (1990) concludes that "not much, if any, net slip" has occurred on the Antioch fault at the two monitoring sites.

Geomorphic expression

Geomorphic evidence for faulting along the trace of the Antioch fault was interpreted on aerial photographs and checked in the field. Aerial photographs of 1:27,000 scale, and 1:20,000 scale, taken by the USDA in 1939 and 1950 respectively, were used for the entire area. Aerial photographs of 1:12,000 scale taken by Cartwright Aerial Surveys (1973) were also consulted at the Contra Costa County Community Development Department. Field checking of geomorphic features was done in conjunction with field checking of creep localities and geologic exposures in April and May 1991. Geomorphic features will be described from northwest to southeast.

The "zone of anomalous features" mapped by Burke and Helley (1973), reaches the San Joaquin River in a low-lying area on the west side of downtown Antioch. This low area is an old slough, now largely filled in, that follows a meandering northerly course between H and K Streets (locality 1, Figure 3). The slough is apparent on the USGS 7½ minute Antioch North quadrangle (1953) as a series of artificial closed depressions (bounded by slightly raised streets) from the San Joaquin River to south of 10th Street. It is also apparent as a swampy, sparsely developed area on 1939 and 1950 aerial photographs. The meandering, northerly course of the slough indicates that its location is not controlled by the northwest-trending Antioch fault.

The mapped trace of the Antioch fault crosses the east bank of the slough at a low angle. It then crosses the alluvial plain upon which much of Antioch is built. No geomorphic features suggestive of active faulting were observed along the mapped trace of the Antioch fault on this alluvial plain. Since the geologic relationships, geomorphic setting and soils development on this alluvial plain indicate that it is of late Pleistocene age (Atwater, 1982 and discussion above), the lack of any geomorphic expression of faulting suggests that no Holocene faulting has occurred.

Tonal lineaments on the Antioch alluvial plain were observed on the 1939 USDA photos. These vague lineaments are northeast of the trace of the Antioch fault and trend more westerly than the fault (locality 2, Figure 3). They are defined on the aerial photographs by a change in color of the vegetation and possibly in the soil. This contrast could be due to differences in soil composition or soil moisture. The tonal lineaments do not form a narrow zone or pattern that suggests faulting nor are they associated with any topographic features that suggest faulting. They are roughly parallel to the belt of late Pleistocene dunes of the Modesto Formation east of Antioch (Atwater, 1982) and may be due to variations in eolian sand content in the soil.

South of the Antioch alluvial plain, the trace of the Antioch fault passes into an area underlain by a north-dipping homoclinal sequence of Pliocene Tehama Formation and older bedrock units. This area is characterized by low, rolling hills underlain by relatively resistant bedrock and broad valleys underlain by less resistant bedrock. Hills underlain by the Tehama Formation and the Miocene Neroly and Cierbo Formations are typically rounded, with broad flat tops and steep sides. They reach an elevation of up to 220 feet (up to about 100 feet above the surrounding valleys).

The Antioch fault passes through the northernmost hills without any distinctive geomorphic features along its projected trace. At one locality within the hills, however, (locality 3, Figure 3) a relatively linear southwest-facing hill front and swale follow the mapped trace of the fault. These features are not linear in detail; the hill front is marked by several projections and reentrants and the swale is somewhat sinuous.

South of the Contra Costa Canal, a resistant "spine" of calcite cemented fault breccia marks the trace of the fault along the crests of three linear ridges (Burke and Helley, 1973) (locality 4, figure 3). This "spine" apparently projected several feet above the surrounding hill crests before the area was graded (photograph in Kneupfer, 1977, p. 33).

In order for the fault breccia to be expressed as a spine along linear ridges, it must be more resistant to erosion than the

surrounding bedrock. This seems inconsistent with recent faulting that would fragment the calcite, making it more susceptible to dissolution and erosion. If the calcite cementing was fragmented by recent fault movement, the fault breccia would form a series of topographically low areas, features such as linear valleys, saddles and side-hill benches typical of active faults.

The linear spine of calcite-cemented fault breccia is not unique to the mapped trace of the Antioch fault. Other similar features were noted on aerial photographs in the same area (Cartwright Aerial Surveys, 1973). One tonal lineament along the crest of a line of hills trends approximately N30°E and appears to be a conjugate shear to the N30°W Antioch fault (Figure 3).

Tonal lineaments are evident south of the linear fault breccia outcrops. One tonal lineament follows the mapped trace of the fault north of Lone Tree Way (locality 5, Figure 3). Other short northwest-trending tonal lineaments are evident in the surrounding area. No geomorphic features that suggest recent faulting were found south of Lone Tree Way except a set of sharp tonal lineaments that nearly coincide with the mapped trace of the fault east of Deer Valley Road (locality 6, Figure 3). This line is a crude oil pipeline (Soil Foundation Systems, 1989). Other straight, parallel, tonal lineaments are probably access roads.

Geomorphic features formed by erosion along a bedrock fault are found along the portion of the Antioch fault that had been mapped as the Davis fault (Brabb and others, 1971). These features include truncated ridges, scarps in bedrock, and saddles (Figure, 3). No geomorphic features that suggest Holocene displacement could be found.

In summary, geomorphic evidence for the Antioch fault is either completely lacking (on the alluvial plain and south of Lone Tree Way), weakly suggestive of faulting (a somewhat linear hill front and swales) or contrary to what is expected along an active fault (fault breccia that is more resistant to erosion than the surrounding bedrock). The Davis fault is clearly defined by fault line scarps, saddles and truncated ridges typical of a fault in bedrock. The strongest geomorphic evidence for recent faulting consists of a roughly linear swale and hill slope on the Antioch fault, neither of which is as sharp or as linear in detail as similar features along active faults.

Site-specific fault studies

Numerous consulting geologists have studied parcels along the Antioch fault in compliance with the Alquist-Priolo Act. Other geologists have investigated portions of the Antioch fault for evaluations of existing or proposed dams. Many of these sites have been re-examined in the field for this study and one trench

has been excavated and logged to re-evaluate an earlier study. These studies are described below from northwest to southeast. They are also summarized in the same order in Table 1. Outlines of the areas studied and trench locations are plotted on Plate 1. For ease of reference, the number of each of these reports in the DMG files is listed in the text and on Table 1 and shown on Plate 1.

Slough Area

Consultants reports near the northeast end of the Antioch fault (North of 4th Street and West of J Street) document the presence of soft sediment and artificial fill in the old slough. None have found any fault related features (Harding Lawson Associates, 1977 (AP-405), 1983 (AP-1567), 1986a (AP-1945), 1989 (AP-1107); Woodward-Clyde Consultants, 1979 (AP-1107); Western Geological Consultants, 1979 (C-559); Diablo Soils Engineers, 1980 (AP-1415); Darwin Myers Associates, 1980 (AP-1415)). Boring logs in these reports show that the soft fill and marsh deposits adjacent to the deformed railroad tracks is up to 40 feet deep (Harding Lawson Associates, 1986a (AP-1945)) (locality 7, Plate 1). They also show that the deposits are soft and prone to settlement. Diablo Soils Engineers (1980) (AP-1415) logged two borings where, after drilling through the upper 12 feet of fill, the drill stem sank under its own weight for another 12 feet through soft bay mud and peat (locality 8, Plate 1).

Alluvial Plain

Consultants reports for properties east of the slough and south to 20th Street describe trenches in older alluvium of the Antioch alluvial plain. No consultants found faults in this area (Harding Lawson Associates, 1976 (AP-337), 1986b (AP-1387), 1986c (AP-1946), 1988 (AP-2222); Darwin Myers Associates, 1981 (AP-1387); Hallenbeck-McKay and Associates, 1978 (AP-765); Western Geological Consultants, 1989 (AP-2363); Engeo, 1982 (AP-1474); Woodward-Clyde Consultants, 1975 (C-89); Kaldveer Associates, 1989 (C-772)).

Of particular importance among these reports are the reports by Woodward-Clyde Consultants (1975)(C-89) and Kaldveer Associates (1989)(C-772). WCC investigated damage to the multi-purpose building at John C. Fremont School (locality 9, Plate 1) (Site 18 of Burke and Helley). Their trenching found no evidence for faulting and they concluded that the damage to the building was probably due to expansive soils. Kaldveer Associates investigated the adjacent Antioch Junior High School property. Their trenches were more than 600 feet long and crossed the center of the Alquist-Priolo zone (locality 10, Plate 1). They found no evidence for faulting in old alluvium. Their trenching demonstrates that no Holocene faulting has occurred on the trace of the Antioch fault shown on the Special Studies Zones Map at this location. The lack of evidence for faulting in this trench or any trenching study to the north, and the lack of geomorphic

expression, suggest that the Antioch fault does not offset the alluvium north of 20th Street (where Burke and Helley described 22 of their 29 "creep" localities).

South of 20th Street, Engeo (1978)(AP-758), Western Geological Consultants (1979)(C-558) and Abel Soares and Associates (1979)(AP-1416) did not find evidence for faults in trenches. Engeo noted cracks in curbs and sidewalks in two locations (locality 11, Plate 1). These cracks roughly coincide with the trace of the Antioch fault shown on the Special Studies Zones map (CDMG 1976a), prompting Engeo to speculate that they could be due to fault creep. When this site was field checked, minor right-lateral offset of curbs along east-west expansion joints was noted at one location, left-lateral offset of a curb on a north-south expansion joint was noted at the other. Right-lateral displacement on a N30°W fault would cause right-lateral displacements on north-trending joints and compression or left-lateral displacements on east-west joints. The offset curbs in this area are not consistent with right-lateral creep on the Antioch fault. The displacements are probably due to expansive soil or other non-tectonic causes.

Burkland and Associates (1975)(AP-811) investigated a group of sites along A Street south of the Southern Pacific Railroad (Plate 1). They reported evidence for creep and exposures of faults in two trenches (Figure 4). These features define a zone that is east of, and parallel to, the fault zone plotted on the Special Studies Zones Map (locality 12, Plate 1). Their evidence for creep consists of cracks with right-lateral offsets in two low retaining walls and in three curbs, and deflection of the Southern Pacific Railroad tracks. A scarplet in a street was also noted along the same alignment. These sites were checked by this writer and Glenn Borchardt of CDMG on April 15 and May 1, 1991 and the cracks were verified. However, cracks in the retaining walls typically had more displacement near the top of the wall than near the base and did not have systematic right-lateral or left-lateral displacements. The cracks also did not appear to be confined to a narrow zone. Cracks in curbs at three street corners could not be traced into adjacent walkways or pavement. Curbs across the streets from the damaged curbs, on the projection of the fault trace, were not offset. The "scarplet in street" appears to be the east side of a small drainage swale that drains to the north. It is a very broad low feature that rises less than five feet over a width of more than 200 feet. On 1950 aerial photographs (USDA, 1950), a north-draining swale at about this location appears to be a tributary to a larger drainage that drains to the northeast. There does not appear to be any relation between the swale and the projected fault zone.

The trenches by Burkland and Associates (1975) (locations shown on Figure 4) exposed southeast- dipping siltstones and sandstones

identified as the "Tehema" (sic) Formation. In trench 3, bedding within the Tehama Formation is shown as offset. In Trench 2 the contact between the Tehama Formation and the overlying soil is shown as offset. In both trenches, faults were traced to the surface through the "dark brown to brown residual soil" and the "highly expansive" upper topsoil layer. The faults are shown on the trench log as a zone of "highly sheared clay and/or bedrock material." Murray Levish, the geologist who supervised the project for Burkland and Associates, recalls that the fault zone extended to the ground surface and thinks there may have been vertical offset of the topsoil, although his memory is not as clear on this point (M. Levish, p.c. 1991).

These soils trenched by Burkland and Associates (1975)(AP-811) appear to be the youngest materials displaced by the Antioch fault. Trench logs show a fault, drafted as a solid line, extending from the bedrock to the ground surface (Figure 5). However, the existence of shears extending through the topsoil to the ground surface is not consistent with expansive soils on a site that had been developed as an orchard (USDA aerial photographs 1939, 1950) or had once had a farmhouse and several outbuildings on it (Mr. Ralph Garrow Sr., p.c. 1991). All this activity would tend to obscure or destroy evidence for faulting in the topsoil. No evidence of surface disturbance was noted by Burkland and Associates (1975) on most of the site.

There is an apparent conflict between the geologic relationships shown on the trench logs by Burkland and Associates (1975) and what is expected at a site with expansive soils that had been previously developed. In an attempt to resolve this apparent conflict, this writer contacted the landowner and the City of Antioch and arranged for a trench to be excavated adjacent to Trench 2 of Burkland and Associates.

On June 10, 1991, a City of Antioch, Department of Public Works backhoe excavated a 65 foot long trench 9 feet deep parallel to, and about 5 feet north of, Trench 2 (locality 13, Plate 1). This trench was located to cross the faults logged by Burkland and Associates (1975) and was carefully logged by this writer, with the assistance of Glenn Borchardt, Earl W. Hart and William A. Bryant of the Division of Mines and Geology. Glenn Borchardt also described the soil profile in detail. After the trench was logged, it was examined by several other geologists including Murray Levish, who supervised the original trenching for Burkland and Associates, David Schwartz of the USGS, Todd Nelson, former Contra Costa County Geologist, and Bob Wright, who investigated the Antioch fault for a study of Contra Loma Dam (ESA, 1982).

Despite careful logging and examination of the trenches by numerous geologists, no faults or fault-related features were identified. The units exposed in the trench consisted of, from top to bottom, a well developed soil profile with Ap (disturbed),

A and Bt horizons (see soil description 2, Appendix A), a layer of alluvial sand, locally containing small channels of coarse sand and pebbles, and a massive, pervasively fractured mudstone. These units are continuous across the trench except minor variations in thickness and the pinching out of the sand, which seems to occupy a broad channel (see trench log, Figure 5).

A soil profile about 1.5 m thick is developed on the silty clay alluvium and the stratified "bedrock" at the site. It includes a B1t horizon with blocky structure, a B2t horizon with prismatic structure, and a Btkc with minute calcite concretions disseminated through it (see soil description 2, Appendix A). The thickness of the soil profile, the development of prismatic structure with clay films on the ped faces and the presence of a k (caliche) horizon together indicate that this is not a recently developed soil.

According to Glenn Borchardt, DMG soil scientist, this well-developed soil horizon could form in as little as 10,000 years under ideal conditions, but is much more likely to be between 20,000 and 50,000 years old.

The alluvial sand and the mudstone interfinger between stations 8 and 9 in the trench, indicating that they are of roughly the same age. The mudstone is probably not a late Quaternary alluvial unit because it is lithified, pervasively fractured, and only a small remnant of the original bedding is still apparent. Since the mudstone is probably part of the Tehama Formation, both it and the overlying sand are probably of Pliocene to early Pleistocene age.

None of the units exposed in the trench, which range in age from Pliocene or early Pleistocene to late Pleistocene are offset. Thus, no active fault exists where Burkland and Associates (1975) mapped it. Figure 5 compares the trench log by Burkland and Associates with the trench log described for this study. It is possible that Burkland and Associates observed vertical caliche stringers in the sand or vertical ped surfaces in the prismatic soil horizon (B2t) and mistakenly attributed these features to faulting.

Bedrock Hills

South of State Highway 4, Western Geological Consultants (1979 (AP-1417), 1988 (AP-2337), 1989 (AP-2271)); Converse Consultants (1984)(AP-1638); Darwin Myers Associates (1981)(AP-1419); and Burkland and Associates (1977)(AP-443) have investigated a scattered group of sites within the Special Studies Zone. None of the sites are across the mapped trace of the Antioch fault and none of these consultants found faults. Following construction of a shopping center on the site studied by Converse Consultants (1984)(AP-1638), other geologists have noted faults in the Tehama Formation in a cut slope (T. Nelson, p.c. 1991)(locality 14,

Plate 1). These faults were briefly examined on May 8, 1991. They offset the Tehama Formation but do not appear to extend into the overlying alluvium.

Along the trace of the Antioch fault to the southeast, large residential tracts have been developed. Before development, an engineering geologist investigated the Antioch fault on each of these tracts (Burkland and Associates, 1974 (AP-802, also filed as C-64); Burkland and Associates and Harlan Engineers, 1973 (AP-336); Purcell, Rhoades Associates, 1978 (AP-849); Earth Systems Consultants, 1979 (AP-1106); Kaldveer and Associates, 1988a,b (AP-2247); Darwin Myers Associates, 1983 (AP-1626); Berlogar, Long and Associates, 1979 (AP-1105); Berlogar Geotechnical Consultants, 1986 (AP-1953); Terrasearch, 1988 (AP-2517); Soil Foundation Systems, 1988 (AP-2169), 1989 (AP-1976); Engeo, 1987 (AP-1976), 1984 (AP-1771)). These reports cover a continuous three-mile-long section of the Antioch fault except a gap at the Contra Costa Canal.

Most consultants report a narrow zone of faults in bedrock between Roosevelt Lane and Lone Tree Way (plate 1). This narrow zone of northwest-trending bedrock faults disappears south of Lone Tree Way. Consultants were unable to find evidence for any faulting along Burke and Helley's mapped trace of the Antioch fault between Lone Tree Way and the Davis fault.

Trenching at one locality (Earth Systems Consultants, 1979, AP-1106) (locality 15, Plate 1) uncovered what was thought was conclusive evidence for faulting of the soil. Two trenches revealed a fault in bedrock that could be traced into the overlying soils. In one trench the fault offsets the contact between two horizontal silty clay units and reportedly continued to the ground surface. In the other trench, the fault did not extend through the upper soil horizon. These soils are probably relict soils, formed by in-place weathering of the bedrock, because they are on the crest and upper slopes of a hill. Faults in these soils could have formed after the soil or could be "inherited" from the bedrock. It is not conclusive evidence of recent faulting.

A cut slope near this site was also discussed and photographed by Kneupfer (1977) and logged by Earth Science Associates (1982)(locality 16, Plate 1). Two north-trending normal faults bound a broad, shallow graben in the Tehama Formation with younger deposits downfaulted in the center. The age of these younger deposits, described as "dark grey, sandy organic soil and colluvium" (ESA, 1982), is not known. Displacement of the base of this colluvium suggests late Quaternary faulting but the location of the graben on the crest of a hill and lack of surface expression of the faults suggest that the offset has not occurred in Holocene time. The relationship of these faults to the Antioch fault is also unclear. They trend northerly to slightly

east of north, rather than N30°W as the Antioch fault has been mapped. Thus, although late Quaternary displacement may have occurred on these faults, it is not clear if this suggests Quaternary offset on the Antioch fault.

To the south, Burkland and Associates and Harlan Engineers (1973) (AP-336) and Kaldveer Associates (1988a,b)(AP-2247) investigated the area where the mapped trace of the fault follows a somewhat linear hill-front and swale. These geologists found faults in the bedrock. They inferred recent movement on these faults based on steps in the bedrock-soil contact and soil filled fissures along bedrock fault zones. Kaldveer and Associates (1988a) noted that the faults extend through the bedrock and the overlying sandy clay. The sandy clay unit is laterally gradational with a silty sand that contains relict "bedrock-like" fabric (Kaldveer and Associates, 1988a, p.5) and therefore may be a relict soil formed by in-place weathering of the bedrock. Faults in this relict soil may be inherited from the bedrock and may represent faulting before the formation of the soil.

Glenn Borchardt of the CDMG examined the soil in the trenches by Kaldveer Associates and noted a well developed B horizon with clay-films and weathering rinds on clasts. He estimated the soil to be of pre-Holocene age (G. Borchardt personal communication to Kaldveer Associates, 1988). Earl W. Hart also examined these trenches on the same day. He noted that the soil horizon was not clearly faulted (E.W. Hart, p.c. 1991).

South of the Contra Costa Canal, DWR (1978) and Berlogar, Long and Associates (1979)(AP-1105) investigated the fault (locality 17, Plate 1). This site was chosen by DWR (1978) for trenching because of the prominent ridges of calcite-cemented fault breccia mapped in the area by Burke and Helley (1973).

DWR (1978) noted steps in the bedrock-soil contact and soil filled fissures along faults in a zone 8 m wide. A fault plane in bedrock trended N30°W and had horizontal striations on its surface. DWR recognized that all but the upper, 6-inch-thick A horizon has formed by in-place weathering of the bedrock to form AC and Cca horizons. Their soils consultant, Dr. E.L. Begg of U.C. Davis, estimated the age of the soils to be 50,000 to 70,000 years based on the development of a "distinct zone of lime accumulation" and a "weak argillic horizon." Although DWR was able to find no evidence for faulting of this soil, they noted that such evidence could have been destroyed by burrowing animals.

Berlogar, Long and Associates (1979)(AP-1105) trenched the same feature in the same area as DWR (1978) and also noted numerous soil-filled fissures and steps in the bedrock-soil contact. In contrast to DWR, who recognized that these features can form by differential soil development or the action of burrowing animals;

Berlogar, Long and Associates reported that these represent (tectonic) "disturbance of the surface soil."

Other studies to the south also report steps in the bedrock-soil contact and soil-filled fissures along the fault (Berlogar Geotechnical Consultants, 1986 (AP-1953); Terrasearch, 1988 (AP-2517)). Neither of these studies found shears in the soil or offset soil horizons. Most steps in the bedrock-soil contact are probably caused by differential soil development. Thin soil over sandstone across a fault from thicker soil over siltstone (Terrasearch, 1988, Trench 1 for example) probably forms because siltstone has higher clay content. Siltstone will form thicker soils where sandstone may form only a weak, thin soil. Also, burrowing animals make more and deeper burrows in soil that is easier to excavate, leading to deeper soils over softer bedrock and in fault zones. In a few cases, however, trenches showing thick soils on one side of a fault do not have a contrasting bedrock across the fault (Terrasearch 1988, Trench 2 for example) and are not easily explained by differential soil development. It is possible, therefore, that some faulting has occurred within the time of soil formation.

South of Lone Tree Way, Soil Foundation Systems (1988) (AP-2169) found a fault in bedrock east of Burke and Helley's trace that trends northerly away from the mapped Antioch fault. They did not find evidence of any faults in bedrock along the Antioch fault of Burke and Helley (1973). DWR (1978) also could not verify the Antioch fault in this area, based on their surface mapping. Farther south, Purcell Rhoades Associates (1982, trench logs included in Soils Foundation Systems, 1988) and Soils Foundation Systems (1988,1989)(AP-2169, AP-1976) excavated trenches across much of the Special Studies Zone and found no faults.

Near the south end of the Special Studies Zone, DWR (1978) investigated the Davis fault of Brabb and others (1971) near site 29 of Burke and Helley (1973)(locality 18, Plate 1). DWR could not verify the small scarp in alluvium noted by Burke and Helley. They did, however, verify a bedrock fault in the adjacent hills. DWR found "some features which could be interpreted as being caused by fault movement" in soil that they correlated with the 200,000-year-old middle Riverbank Formation of the San Joaquin Valley. DWR could find no evidence of faulting in younger soils. They concluded that no surface displacement on the Davis fault had occurred in at least the last 50,000 years.

SEISMICITY

The Antioch fault is located at the eastern edge of the seismically active area associated with the San Andreas fault system (Hill and others, 1990, figure 5.6). It is within a less active belt of seismicity extending from the west side of the San Joaquin Valley, through the Antioch area and northward through

the Sacramento Valley (Eaton, 1986). This zone has been called the Coast Ranges-Sierran Block boundary zone (Wong and others, 1988). Studies of microseismicity in the Montezuma Hills and Antioch segments of this zone show that right-lateral, oblique and reverse or thrust earthquakes have occurred. These earthquakes are unusually deep, with the majority occurring below 20 km (Wong and others, 1988; Wong and Biggar, 1989).

The largest instrumentally recorded earthquake seems to fit the pattern defined by the microseismicity. In 1965 a magnitude 4.9 event with a right-lateral focal mechanism occurred on a northwest-trending fault plane at a depth of about 15 km (McEvilly and Casaday, 1967). Aftershocks of this earthquake define a north-northeast-trending fault zone, not consistent with the northwest-trending focal plane defined by first-motion studies (McEvilly and Casaday, 1967).

The largest historic earthquake in the Antioch area occurred on May 19, 1889, and had an estimated magnitude of 6.0 (Toppozada, 1981). "Two small fissures were opened in the earth on Main Street" (San Francisco Chronicle, May 20, 1889, p.8) leading to speculation that this earthquake may have caused surface rupture on the Antioch fault (Toppozada, 1981; Wong and others, 1988). Main Street of 1889 has since been renamed I Street and is a north-south street that crosses the filled slough just west of downtown Antioch. The fissures caused by the 1889 earthquake may represent settlement of the soft fill and marsh deposits in the slough, rather than fault rupture.

CONCLUSIONS

The Antioch fault was thought to be active based on the evidence for creep assembled by Burke and Helley (1973). This evidence can be explained by settlement of marsh deposits and fill in a slough, expansive soils, and random cracking of concrete pavement over time.

There is no geomorphic evidence for Holocene movement on the fault. Instead, the only distinctive geomorphic feature along the fault, a ridge of calcite-cemented fault breccia, seems to contradict active faulting.

The Antioch fault can be traced as a fault in bedrock for approximately two miles, from Roosevelt Lane to north of Lone Tree Way in Antioch. The fault does not offset the late Pleistocene alluvium of the Antioch alluvial plain. Trenching by Kaldveer Associates (1989) and numerous other consultants found no evidence for faulting. A trench where evidence for active faulting was reported (Burkland and Asssociates, 1975) has been re-opened. They apparently mistakenly identified vertical caliche stringers and vertical soil structure as fault features.

Many consultants have found permissive evidence for active faulting such as steps in the bedrock-soil contact and soil-filled fissures. A small graben bounded by faults that offset Quaternary alluvium and colluvium (Earth Science Associates, 1982)(Locality 16, Plate 1) may represent late Quaternary faulting. The faults at this locality are not the Antioch fault, however, although they could be splays off the main fault. The lack of any geomorphic expression of the faults in this area suggests the faulting has not occurred in Holocene time.

Consultants have not found the fault south of Lone Tree Way. The connection mapped between the Antioch fault and the Davis fault apparently does not exist. The Davis fault is defined by a series of tonal lineaments and fault-line scarps along a bedrock fault. DWR (1978) found evidence that displacement on the fault has occurred in the last 200,000 years. The fault is overlain by soils that are at least 50,000 years old.

RECOMMENDATIONS

The Antioch fault should not be zoned for special studies. The existing Special Studies Zones maps of the Antioch North and Antioch South Quadrangles should be withdrawn.

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I have reviewed the report and agree with the recommendations.
Earl W. Hart
11/21/91

REFERENCES CITED

Atwater, B.F., 1982, Geological maps of the Sacramento-San Joaquin Delta, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-1401.

Berlogar, Long & Associates, 1979, Geotechnical investigation, Wilson property, Antioch, California: unpublished consultants report, 22 p. (AP-1105)

Berlogar Geotechnical Consultants, 1986, Geotechnical investigation, Prewett Property, Lone Tree Way, Antioch, California: unpublished consultants report, 20 p. with supplement dated 11/5/86, (AP-1953)

Borchardt, G., 1989, Smectites, in Dixon, J.B. and Weed, S.B., editors, Minerals in soil environments, 2nd edition: Soil Science Society of America Book Series, n. 1, p. 675-727.

Brabb, E.E., Soneman, H.S., and Switzer, J.R. Jr., 1971, Preliminary Geologic map of the Mount Diablo-Byron area, Contra Costa, Alameda, and San joaquin Counties, California: U.S. Geological Survey, San Francisco Bay region environment and resources planning study, Basic Data Contribution 28.

Burke, D.B., and Helley, E.J., 1973, Map showing evidence for recent fault activity in the vicinity of Antioch, Contra Costa County, California: U.S. Geological Survey Miscellaneous Field Studies Map MF 533.

Burkland and Associates, 1974, Geologic and seismic hazards investigation of four sites in Assessment district No. 9, Antioch, California: unpublished consultants report, 19 p. (AP-802, also filed as C-64).

Burkland and Associates, 1975, Geologic and seismic hazards investigation, fourteen parcels, Antioch, California: unpublished consultants report, 22 p. (AP-811)

Burkland and Associates, 1977, Geotechnical evaluation, Reeves property, Antioch, California: unpublished consultants report, 11 p. (AP-443)

Burkland and Associates and Harlan Engineers, a joint venture, 1973, Geologic and seismic hazards investigation, Montaire meadows and Harbour Park Projects, Antioch, California: unpublished consultants report, 22 p. (AP-336.)

California Department of Water Resources, 1978, Preliminary report, faults and seismicity at Los Vaqueros Dam site: DWR Division of Design and Construction, Project Geology Section, 49 p.

California Division of Mines and Geology, 1976, Official Special Studies Zones Map of the Antioch North Quadrangle, scale 1:24,000

California Division of Mines and Geology, 1976, Official Special Studies Zones Map of the Antioch South Quadrangle, scale 1:24,000

Carpenter, E.J. and Cosby, S.W., 1939, Soil Survey of Contra Costa County, California: U.S. Department of Agriculture, Soil Conservation Service, series 1933, no. 26, 88 p.

Cartwright Aerial Surveys, 1973, Aerial photographs, black and white, vertical, flight CC, numbers 3526-4-164 to 174 and 221 to 236, scale approximately 1:12,000.

Converse Consultants, 1984, Geotechnical investigation for Lone Tree Way and Tregallas Road, Antioch, California: unpublished consultants report, 20 p. (AP-1638)

Creely, S., Savage, D.E., and Ogle, B.A., 1982, Stratigraphy of upper Tertiary nonmarine rocks of central Contra Costa Basin, California in Ingersoll R.V., and Woodburne, M.O. editors, Cenozoic nonmarine deposits of California and Arizona: Pacific Section SEPM, 122p.

Diablo Soil Engineers, 1980, Preliminary geotechnical report for Lots 1-3, 10-12, Block 11, J Street, Antioch, California: unpublished consultants report, 18 p. (AP-1415)

Dibblee, T.W. Jr., Preliminary geologic map of the Antioch South Quadrangle, Contra Costa County, California: U.S. Geological Survey Open File Report 80-536.

Ditzler, C.C., and Vaughan, R.H., 1964, Brentwood oil and gas field, Contra Costa County, California, in Geological Society of Sacramento, Guidebook and field trip to the Mount Diablo area, p. 81-87.

Earth Science Associates, 1982, Seismotectonic study of Contra Loma Dam and vicinity: unpublished consultants report, 112 p.

Earth Systems Consultants, 1979, Geologic and seismic hazards investigation, Sidrian Property, Antioch, California: unpublished consultants report, 20 p. (AP-1106).

Eaton, Jerry, 1986, Tectonic environment of the 1892 Vacaville/Winters earthquake, and the potential for large earthquakes along the western edge of the Sacramento Valley, California: U.S. Geological Survey Open File Report 86-370, 14 p.

Engeo, Inc., 1978, Property at C Street and Railroad Avenue, Antioch, California: unpublished consultants report, 13 p. (AP-758)

Engeo, Inc., 1982, G Street and Tenth Street, Antioch, California: unpublished consultants report, 13 p. (AP-1474)

Engeo, Inc., 1987, Alquist-Priolo special Study Report, Minor Subdivision 70-86, Deer Valley Road, Antioch, California: unpublished consultants report, 15 p. (AP-1976).

Engeo, Inc., Alquist-Priolo Exploration, Parcel A, MS 55-83, Deer Valley Road, Antioch, California: unpublished consultants report, 14 p. ((AP-1771).

Galehouse, J.S., 1990, Theodolite measurements of creep rates on San Francisco Bay region faults, in Jacobsen, M.L., compiler, National earthquake hazards reduction program, summaries of annual reports volume XXXI, U.S. Geological Survey Open File Report 90-680, p. 260-268.

Graham, S.A., Gavigan, C., McCloy, C., Hitzman M., Ward, R., and Turner, R., 1983, Basin evolution during the change from convergent to transform continental margin: An example from the Neogene of central California in Cherven, V.B and Graham, S.A., editors, Geology and sedimentology of the southwestern Sacramento Basin and East Bay hills: Pacific Section SEPM field trip guidebook, p. 101-117.

Hallenbeck-McKay and Associates, 1978, Geologic and seismic safety investigation, three lots, Tenth and F Streets, Antioch, California: unpublished consultants report, 5 p. (AP-765)

Harding Lawson Associates, 1976, Geologic hazards investigation Antioch City Hall addition, Antioch, California: unpublished consultants report, 9 p. with additional correspondence dated 1980 (AP-337)

Harding Lawson Associates, 1977, Geologic investigation, Antioch property, for Mr. Al Shuck: unpublished consultants report, 9 p. (AP-405)

Harding Lawson Associates, 1978, Geologic investigation, service station site, A Street and Rossi Avenue, Antioch, California: unpublished consultants report, 7 p. (AP-724)

Harding Lawson Associates, 1983, Geologic hazards investigation, planned Marina Park, Antioch, California: unpublished consultants report, 16 p. (AP-1567)

Harding Lawson Associates, 1986, Geologic hazards and soils engineering assessment, Antioch redevelopment, Antioch 24 property, Site 3, Antioch, California: unpublished consultants report, 17 p. (AP-1945)

Harding Lawson Associates, 1986, Geotechnical and geologic hazards investigation, Antioch redevelopment, Church property, Site 1, Antioch, California: unpublished consultants report, 24 p. (AP-1946)

Harding Lawson Associates, 1986, Geotechnical and geologic hazards investigation, Antioch redevelopment, Showboat property, Site 2, Antioch, California: unpublished consultants report, 21 p. (AP-1387)

Harding Lawson Associates, 1988, Seismic hazards study, Smiths Landing project, 801 West 2nd Street, Antioch, California: unpublished consultants report, 13 p. (AP-2222)

Harding Lawson Associates, 1989, Geotechnical investigation, Antioch Police Facility, 4th and L Streets, Antioch, California: unpublished consultants report, 21 p. (AP-1107)

Hart, E.W., 1990, Fault Rupture Hazard Zones in California: Division of Mines and Geology Special Publication 42, 24 p.

Kaldveer Associates, 1989, Fault rupture hazard investigation for Antioch Junior High School, Antioch, California: unpublished consultants report, 15 p. (C-772).

Kaldveer Associates, 1988, Fault rupture hazard investigation for proposed high school, Antioch, California: unpublished consultants report, 8 p. (AP-2247).

Kaldveer Associates, 1988, Fault rupture hazard investigation, Brookside Estates, Subdivision 7155, Antioch, California: unpublished consultants report, 13 p. with supplement dated 3/10/89. (AP-2247).

Kneupfer, P.L., 1977, Geomorphic investigations of the Vaca and Antioch fault systems, Solano and Contra Costa counties, California: Stanford University M.S. thesis (unpublished), 53 p.

Marchand, D.E. and Aldwardt, Alan, 1981, Late Cenozoic stratigraphic units, northeastern San Joaquin Valley, California: U.S. Geological Survey Bulletin 1470, 70 p.

McEvilly, T.V., and Casaday, K.B., 1967, The earthquake sequence of September, 1965 near Antioch, California: Bulletin of the Seismological Society of America, v. 57, p. 113-124.

Darwin Myers Associates, 1980, Geologic hazards investigation, J Street property, Assessor's Parcels 66-106-06, 07, 08 and 09, Antioch, California: unpublished consultants report, 11 p. (AP-1415).

Darwin Myers Associates, 1981, Geologic hazards reconnaissance, Assessors Parcel #068-221-67, Antioch, California: unpublished consultants report, 15 p. (AP-1419).

Darwin Myers Associates, 1981, Geologic hazards investigation, Antioch Gardens, Assessor's Parcel #66-061-02 thru -07 City of Antioch, California: Appendix C in Alan Kropp and Associates, Geotechnical investigation, Antioch Gardens, Antioch, California: unpublished consultants report, 14 p. (AP-1387)

Darwin Myers Associates, 1983, Fault hazard investigation, 7-acre Sbranti property, eastern terminus of Boulder Drive, Antioch, California: unpublished consultants report, 12 p. (AP-1626)

Purcell, Rhoades and Associates, 1978, Geologic and seismic evaluation, proposed Subdivision 5375, Antioch, California: unpublished consultants report, 12 p. (AP-849).

San Francisco Chronicle, 1889, Sharp earthquake, a lively early morning visitor: San Francisco Chronicle daily newspaper, 5/20/1889, p.8.

Abel R. Soares and Associates, 1979, Geotechnical investigation for Assessor's Parcel No. 067-266-09, Railroad Avenue in the City of Antioch: unpublished consultants report, 9 p. (AP-1416)

Sarna-Wojcicki, A.M., 1976, Correlation of late Cenozoic tuffs in the central coast ranges of California by means of trace- and minor-element chemistry: U.S. Geological Survey Professional Paper 972, 30 p.

Soils Foundation Systems, 1989, Enea Ranch, Antioch California, geologic study for evaluation of on-site faulting: unpublished consultants report, 11 p. (AP-1976)

Soils Foundation Systems, 1988, Geologic study report on evaluation of on-site faulting for the Anden Property, Lone Tree Way and Deer Valley Road, Antioch California: unpublished consultants report, 22 p. (AP-2169).

Swarbrick, J.C., 1976, Brentwood Field in Drummond, Keith, editor, Tour of the Reservoir Rocks of the Western Sacramento Delta: Pacific Sections AAPG, SEG, SEPM, field trip guidebook, p. 34-48.

Terrasearch, Inc., 1988, Soil and geologic investigation, proposed residential development, Lone Tree Way, Antioch, California: unpublished consultants report, 70 p. (AP-2517)

Toppozada, T.R., Real, C.R., and Parke, D.L., 1981, Preparation of isoseismal maps and summaries of reported effects for pre-1900 California earthquakes: California Division of Mines and Geology Open-File Report 81-11 SAC, 182 p.

U.S. Department of Agriculture, 1939, Aerial photographs, black and white, vertical, flight BUU, numbers 288-19 to 288-23, Mines and Geology Open-File Report 81-11 SAC, 182 P.

U.S. Department of Agriculture, 1950, Aerial photographs, black and white, vertical, flight BUU, numbers 3G-51 to 3G-56 and 3G 136 to 3G-141, scale approximately 1:20,000.

Welch, L.E., 1977, Soil Survey of Contra Costa County, California: U.S. Department of Agriculture, Soil Conservation Service, 122 p.

Western Geological Consultants, 1979, Geologic hazards investigation, Lone Tree Way and East Tregallis Road, Antioch, California: unpublished consultants report, 5 p. (AP-1417)

Western Geological Consultants, 1979, Fault hazard evaluation, lot at 3rd and L Streets, Antioch, California: unpublished consultants report, 6 p. (C-559)

Western Geological Consultants, 1979, Fault hazard evaluation, proposed addition to Silvera Lumber Company, Antioch, California: unpublished consultants report, 10 p. (C-558)

Western Geological Consultants, 1989, Fault hazard study, 112 East Tregallis Road, Antioch, California: unpublished consultants report, 7 p. (AP-2271)

Western Geological Consultants, 1988, Geologic hazards report, Worrell road project, Antioch, California: unpublished consultants report, 7 p. (AP-2337)

Western Geological Consultants, 1989, Geohazards study, 1031 E Street, Antioch, California: unpublished consultants report, 9 p. (AP-2363)

Wong, I.G., and Biggar, N., 1989, Seismicity of eastern Contra Costa County, San Francisco Bay region, California: Bulletin of the Seismological Society of America, v. 79, p. 1270-1278.

Wong, I.G., Ely, R.W., and Kollman, A.C., 1988, Contemporary seismicity and tectonics of the northern and central Coast Ranges-Sierran Block boundary zone, California: Journal of Geophysical Research, v. 93, no. B7, p. 7813-7833.

Woodward Clyde Consultants, 1975, Geologic investigation, John Fremont School, Antioch, California: unpublished consultants report, 12 p. (C-89)

Woodward Clyde Consultants, 1979, Phase I Alquist-Priolo study, planned industrial development, parcels 2, 3, and 4, 4th and L Streets, Antioch, California: unpublished consultants report, 7 p. (AP-1107)

APPENDIX 1, SOIL DESCRIPTIONS

Soil Description 1. Abbreviations and definitions are given in Soil Survey Staff (1951;1975)

North facing road cut exposure along 7th Street 50 feet east of H Street and west facing road cut exposure along H Street 50 feet south of 7th, Antioch, California at 38° 00' 47" north latitude, 121° 48' 50" west longitude and ≈31 feet elevation. The landform is a gently north-sloping slightly dissected alluvial plain. Soil is formed on silty alluvium. Description by Glenn Borchardt and C.J. Wills, May 1, 1991.

A1: 0-9 cm. dark brown (10YR3/3m) silt loam; massive structure; many very fine dendritic roots; few very fine pores; clear smooth boundary.

A2: 9-45 cm. dark brown (10YR3/3m) silt loam; medium, moderate, granular structure; many very fine dendritic roots; many medium and fine pores. pH 6.1; gradual smooth boundary.

A3: 45-70 cm. dark brown (10YR3/3m) silt loam; moderate, medium granular structure; common fine roots, few medium roots, common fine pores, few medium pores, gradual smooth boundary.

A4: 70-115 cm. dark brown (10YR3/3m) silt loam; weak moderate subangular blocky structure; common fine and medium roots; gradual smooth boundary.

B1: 115-130 cm. dark yellowish brown (10YR4/4m,6/4d) clay loam; strong moderate angular blocky structure; sticky and slightly plastic when wet, friable when moist, slightly hard when dry; common very fine pores; pH 6.8; clear smooth boundary.

B2: 130-151 cm. dark yellowish brown (10YR4/4m,6/4d) clay loam; strong coarse angular blocky structure; sticky and slightly plastic when wet, firm when moist, slightly hard when dry; many very fine pores; pH 6.8; clear smooth boundary.

Bt3: 151-166 cm. yellowish brown (10YR5/4m,6/4d) sandy clay loam; strong moderate angular blocky structure; sticky and slightly plastic when wet, firm when moist, hard when dry; some fine roots; pH 6.6; clear smooth boundary.

Bk: 166-191 cm. dark yellowish brown (10YR4/4m,6/4d) sandy clay loam; strong moderate angular blocky structure; slightly sticky and slightly plastic when wet, very firm when moist, very hard when dry; 1.0-cm diameter sandy clay loam filled trace fossils (usually vertical but occasionally horizontal) coated with thin (<0.5 mm) films of caliche; violent effervescence in HCl; pH 6.7; clear smooth boundary.

2Bk1: 191-235 cm. yellowish brown (10YR5/8m,5/4d) loamy sand; strong moderate angular blocky structure; non-sticky and non-plastic when wet, very firm when moist, very hard when dry; continuous white (10YR8/2d7/2m) carbonate filaments on fractures and edges of trace fossils; pH 6.6; gradual wavy boundary.

Bk2: 235-275 cm. yellowish brown (10YR5/4m,6/4d) loamy sand; strong moderate angular blocky structure; non-sticky and non-plastic when wet, very firm when moist, very hard when dry; continuous carbonate filaments on fractures and edges of burrows to 1 mm thick; gradual boundary.

2Bqj: 235-300 cm. dark yellowish brown (10YR4/4m,6/4d) sand; single grain structure; wet non-sticky and non-plastic, moist friable, dry loose; nodules cemented with silica (?) no effervescence in HCl, pH 8.5.

Soil Description 2. Abbreviations and definitions are given in Soil Survey Staff (1951;1975)

Trench on Garrow property approximately 5 feet north of trench by Burkland and Associates (1975) east of A Street between East Madill and Bryan Streets, Antioch, California at 38° 00' 01" north latitude, 121° 48' 20" west longitude and ≈45 feet elevation. The landform is a gently north-sloping slightly dissected alluvial plain. Soil is formed on silty alluvium. Description by Glenn Borchardt, June 11 and 12, 1991.

Ap: 0-22 cm. grayish brown to very dark grayish brown (10YR5/2d,3/2m) clay loam; massive structure; slightly sticky and plastic when wet, friable when moist, very hard when dry; few medium dendritic roots, few medium tubular pores; compacted; contains fill in upper part; pH 7.0, 390 µS; abrupt smooth boundary.

A: 22-60 cm. grayish brown to very dark grayish brown (10YR5/2d,3/2m) silty clay loam; medium moderate granular, medium strong subangular blocky and medium weak angular blocky structure; slightly sticky and plastic when wet, friable when moist, hard when dry; common fine dendritic roots, few medium tubular pores, common fine tubular pores; pH 6.1, 330 µS; clear smooth boundary.

B1t: 60-96 cm. brown to dark brown (10YR5/3d,3/3m) silty clay; medium strong angular blocky to coarse strong angular blocky structure; sticky and plastic when wet, very firm when moist, very hard when dry; common fine dendritic roots, few medium tubular pores, common fine tubular pores; pH 6.4, 410 µS; gradual wavy boundary.

B2t: 96-117 cm. yellowish brown to dark brown (10YR5/4d,4/3m) clay; medium strong prismatic to coarse strong prismatic structure; sticky and very plastic when wet, very firm when moist, very hard when dry; few very fine tubular pores; continuous thin clay films on peds; pH 7.0, 925µS; clear wavy boundary.

Btkc: 117-140 cm. dark brown to dark yellowish brown (10YR4/3d,4/4m) clay loam; medium strong prismatic to coarse strong prismatic structure; sticky and very plastic when wet, very firm when moist, very hard when dry; few very fine tubular pores; continuous thin clay films on peds, dark brown clay films on sides of peds; pH 7.5, 1280 µS; broken wavy boundary.

2BCtk: 140-196 cm. very pale brown to yellowish brown (10YR7/4d,5/4m) loamy sand; massive to medium weak subangular blocky structure; nonsticky and nonplastic when wet, loose when moist, hard when dry; brown (7.5YR4/4m,5/4d) clay films on discontinuous vertical surfaces; few vertical 15-mm diameter trace fossils; pH 7.7, 1410 µS; broken wavy boundary.

3BCtk: 196-255 cm. very pale brown (10YR7/4d,7/4m) clay loam; medium strong angular blocky structure; sticky and very plastic when wet, friable when moist, very hard when dry; calcite in pores and on ped faces; many thin clay films (7.5YR4/4m) coating pores; manganese oxide coating clay films in pores, some clay films over manganese oxide; pH 7.6, >1990 µS.

TABLE 1: Site specific geological reports within the Special Studies Zone on the Antioch fault divided into geologic areas and listed from northwest to southeast. See Plate 1 for locations of sites and trenches.

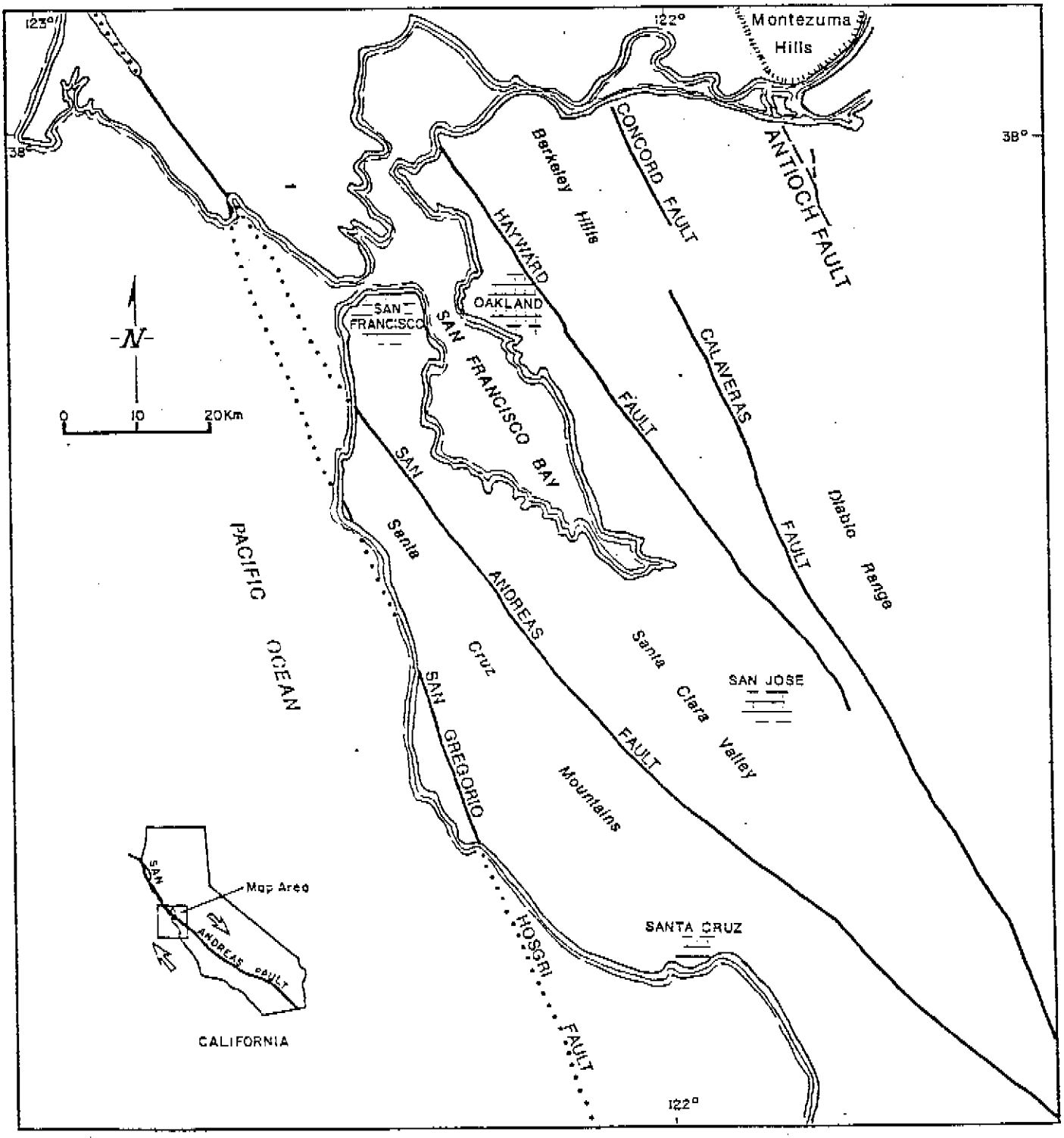
FILE #	CONSULTANT, DATE	TRENCH ?	FAULT FOUND ?	COMMENTS
Slough Area				
AP-1567	Harding Lawson, 1983	no	no	Borings only
AP-1107	Woodward Clyde, 1979, Harding Lawson, 1989	no	no	WCC Report is review and reconnaisance only, Harding Lawson report is soils report only.
AP-1945	Harding Lawson, 1986	no	no	Borings only
AP-405	Harding Lawson, 1977	yes	no	Trench 10 feet deep in horizontally bedded alluvium. Up to 5 feet of dark brown plastic clay at east end of trench. Edge of old slough?
C-559	Western Geo Consultants, 1979	no	no	Literature review only
AP-1415	Diablo Soils Engineers, 1980; D. Myers, 1980	yes	no	Inconclusive trenching in deep fill and marsh deposits borings show fill and marsh deposits to 25 feet.
Alluvial Plain				
AP-337	Harding Lawson, 1976	yes	no	12' deep building excavation in horizontally bedded alluvium
AP-2222	Harding Lawson, 1988	no	no	Site "shadowed" by report AP-1387 see below
AP-1387	D. Myers, 1981; Harding Lawson, 1981	yes	no	Trenches up to 7 feet deep to unfaulted carbonate cemented alluvium
AP-1946	Harding Lawson, 1986	yes	no	Trenches 7 feet deep in horizontally bedded alluvium
AP-765	Hallenbeck-McKay, 1978	yes	no	Trenches 12 feet deep in horizontally bedded alluvium
AP-1474	Engeo, 1982	yes	no	Trench 7 feet deep in horizontally bedded alluvium
AP-2363	Western Geo Consultants, 1989	no	no	Literature review only
C-89	Woodward Clyde Consultants, 1975	yes	no	Damage to building cited by Burke and Helley as evidence for creep is concluded to be due to expansive soils.
C-772	Kaldveer & Associates, 1989	yes	no	Trenches up to 620 feet long, 10 feet deep across center of SSZ found continuous, horizontally bedded Pleistocene alluvium, no faults
AP-758	Engeo, 1978	yes	no	Trenches 9 feet deep in horizontally bedded alluvium. "tenuous" evidence for creep noted adjacent to site.
AP-1416	A. Soares, 1979	yes	no	Trenches 9 feet deep in horizontally bedded alluvium
C-558	Western Geo Consultants, 1979	yes	no	Trench 8 feet deep in horizontally bedded alluvium

TABLE 1: Site specific geological reports within the Special Studies Zone on the Antioch fault divided into geologic areas and listed from northwest to southeast. See Plate 1 for locations of sites and trenches. (continued)

FILE #	CONSULTANT, DATE	TRENCH ?	FAULT FOUND ?	COMMENTS
AP-811	Burkland & Associates, 1975	yes	yes	Faults shown to ground surface through "expansive sandy clay" soil. Evidence for creep noted at several localities
AP-724	Harding Lawson, 1978	yes	no	Small site adjacent to site of AP-811

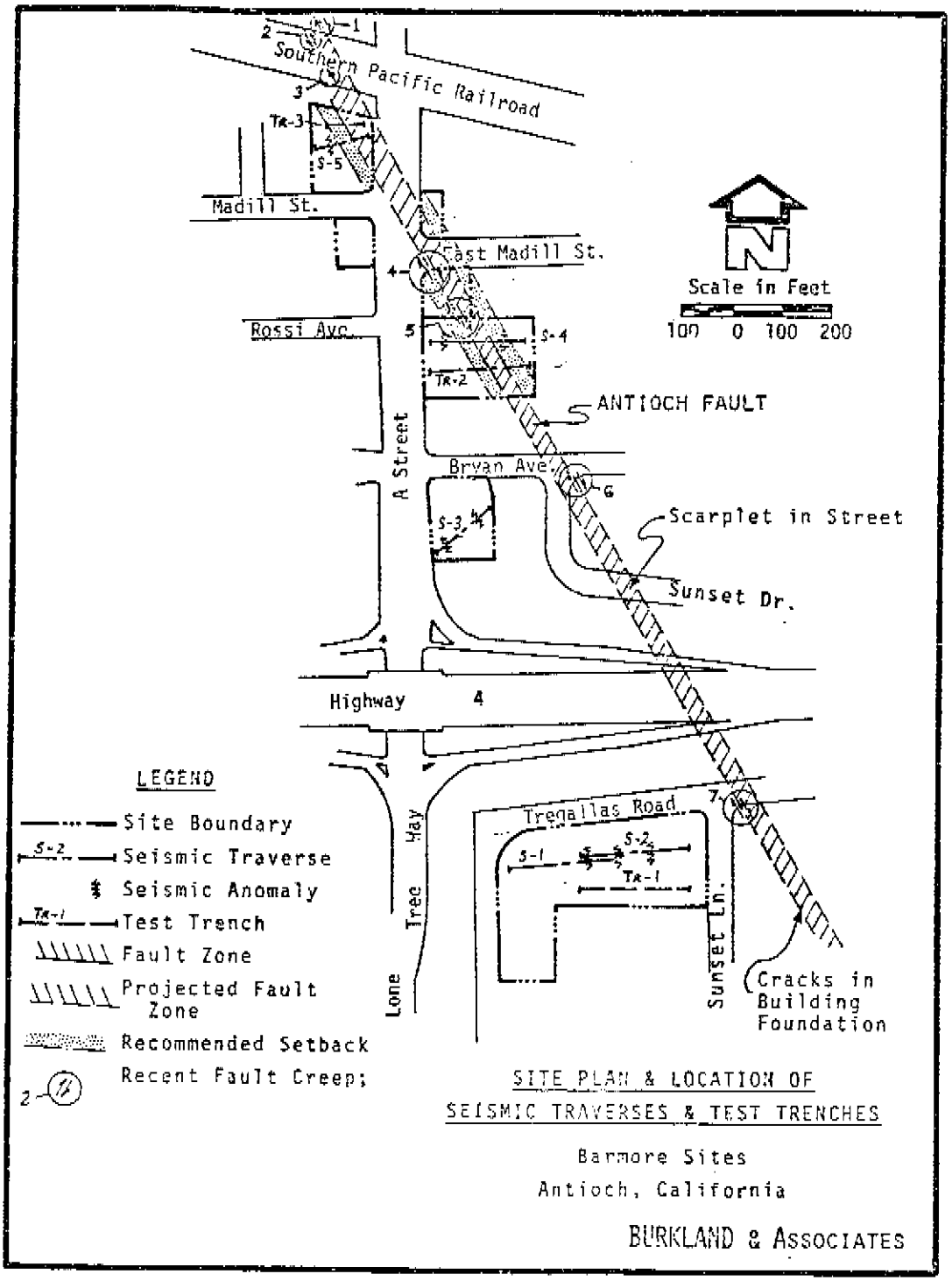
Bedrock Hills

AP-1417	Western Geo Consultants, 1979	no	no	Literature review and reconnaisance only
AP-2271	Western Geo Consultants, 1989	yes	no	Trench 8 feet deep in horizontally bedded alluvium
AP-1638	Converse Consultants, 1984	no	no	Monitoring of excavation during excavation recommended, no record of this in file.
AP-2337	Western Geo Consultants, 1988	yes	no	5-7 foot deep trench in alluvium and bedrock
AP-1419	D. Myers, 1981	no	yes?	"Distress" evidence for creep? mapped along a fault to west of site
AP-443	Burkland & Associates, 1977	yes	no	Cut slope logged, log of cut slope missing from report in file
AP-849	Purcell, Rhoades, 1978	yes	no	Trench 5-12 feet deep or to bedrock
AP-802, C-64	Burkland & Associates, 1974	yes	yes	Offset of bedrock-alluvium contact
AP-1106	Earth Systems Consultants, 1979	yes	yes	Fault to ground surface, report area overlaps AP-802
AP-336	Burkland & Associates, 1974	yes	yes	Faults in bedrock possibly extending into soils. Consultant reports that EBMUD has had no damage to their aqueduct since it was installed in 1925
AP-2247	Kaldveer & Associates, 1988	yes	yes	Faults in bedrock reportedly create steps in bedrock-alluvium contact and have soil filled fissures along bedrock faults. soil not clearly offset. overlaps AP-336
AP-1626	D.Myers, 1983	yes	no	Trenches to bedrock, no faults found
AP-1105	Berlogar-Long, 1979	yes	yes	Faults in bedrock offset bedrock-alluvium contact.
AP-2517	Terrasearch, 1988	yes	yes	Step in bedrock-soil contact at fault, soil filled fissures along faults.
AP-1953	Berlogar,1986	yes	yes	Faults in bedrock and steps in bedrock-alluvium contact
AP-2169	Soil Foundation Systems, 1988	yes	yes	Faults in bedrock only, no faults found along trend of faults to the north. Many "trenches by others" shown on map, trench logs not provided.
AP-1976	Soil Foundation Systems, 1989; Engeo, 1987	yes	yes	Faults in bedrock only found in trenching by SFS
AP-1771	Engeo, 1984	yes	no	Property west of mapped trace of fault



FER 228, Figure 1,

Sketch map of the San Francisco Bay area showing major active faults and the Antioch fault. Modified from Wagner (1990).



FER 228, Figure 4,

Sketch map of sites investigated by Burkland and Associates (1975) showing sites where evidense for creep was found and locations of trenches.