October 30, 1985

Edward A. Danehy  
Certified Engineering Geologist No. 8  
County of Alameda  
Public Works Agency  
399 Elmhurst Street  
Hayward, CA 94544-1395

Dear Ed:

We are placing on open file the following report, reviewed and approved by the County of Alameda in compliance with the Alquist-Priolo Special Studies Zones Act:

Evaluation of active faulting and other potential hazards, 145-acre parcel at Northfront and McLaughlin Roads near Livermore, CA; by Merrill, Seeley, Mullen, Sandefur, Inc., October 14, 1985.

Sincerely yours,

Earl W. Hart, CEG 935  
Senior Geologist & Program Manager

EWH:tfq  
cc: A-P file
Mr. Earl Hart  
California Division of Mines and Geology  
380 Civic Drive  
Pleasanton Hill, CA 94523-1997

Dear Mr. Hart:

Subject: Review of Evaluation of Active Faulting and other Potential Geologic Hazards, 145 acre Parcel at Northpoint and Laughlin Roads, near Livermore, California

Merrill, Seeley, Mullen, Sandefur, Inc., prepared a geologic fault investigation, dated August 12, 1985, and an Addendum, October 14, 1985, for the subject site. A copy is provided to you with this letter.

The geologic investigation of the subject site, which is within the Special Studies Zone for the Greenville fault, was done under the direction of Mark W. Seeley, C.E.G. No.1047. Evidence for several potentially active traces of the fault was found by this extensive investigation. The width of the proposed setback zones varies depending upon the strength of the information obtained. This does not preclude more detailed investigations which may define lesser areas of setback.

The referenced items satisfy the requirements of the Alquist-Priolo Special Studies Zone Act and are accepted by Alameda County with the Geologic Zoning Map, revised October, 1985, being the basis for land development.

Very truly yours,

Edward A. Danehy  
CERTIFIED ENGINEERING GEOLOGIST NO. 8

EAD:pat  
EAD2A10  
Enc.
EVALUATION OF ACTIVE FAULTING
AND OTHER POTENTIAL GEOLOGIC HAZARDS
145 ACRE PARCEL
AT NORTHFRONT AND LAUGHLIN ROADS
NEAR LIVERMORE, CALIFORNIA
Mr. Jerry Bibler  
520 Westchester Drive  
Campbell, California 95008

October 14, 1985  
Project 85087-A

Dear Mr. Bibler:

ADDENDUM  
EVALUATION OF ACTIVE FAULTING  
AND OTHER POTENTIAL GEOLGIC HAZARDS  
145 ACRE PARCEL  
AT NORTHFRONT AND LAUGHLIN ROADS  
NEAR LIVERMORE, CALIFORNIA

On September 25, 1985, Mr. Ed Danehy, the Alameda County Geologist, discussed with me his review comments on the above-referenced report. After reviewing the report, and his comments, we met at the county offices in Hayward on September 30, 1985, to discuss further his review and the results of our exploration.

Based on the County Geologist's review comments and our discussions, we have revised Plates 1 and 17. Also, we have added the following statement to the last paragraph of page C-7: "Although the fault (associated with lineament 2) was not observed in Trench 8 it is likely that the southern extension of the fault observed in Trench 2 crosses Trench 8 in the area between Stations 197' and 280'."

The revisions to Plate 17 result in a wider Zone F in the central part of the property and in the extension of Zone A1 north-westward along the large meander in Altamont Creek. Mr. Danehy expressed the opinion that the County would permit buildings for human occupancy within Zone F if additional, site specific subsurface exploration within the zone could prove the absence of active or potentially active faults through the proposed building sites. If this approach to development is attempted it is our opinion that great care should be taken during subsurface exploration and building designs should take into account the need to mitigate the potential ground deformation that could accompany the design earthquake. If buildings are approved within Zone F the restrictions described for Zone A1 would be applicable to Zone F also.
We have attached copies of Plates 1 and 17 that are annotated "Revised: October 1985". Please replace the original copies of the Plates with the revised copies and fix this addendum letter to the cover letter of your report copies dated August 12, 1985. It is our understanding that with the above described changes the County Geologist will approve the report.

If you have any questions please call my office.

Sincerely yours,
Merrill, Seeley, Mullen, Sandefur, Inc.

Marc W. Seeley
Principal

MWSswh

Attachment: Revised Plates 1 and 17

CC: Tony Varni
    Ed Danely
Mr. Jerry Bibler  
520 Westchester Drive  
Campbell, California 95008

Dear Mr. Bibler,

The attached report presents the results of our active fault exploration and geologic hazards evaluation. In summary, the exploration found evidence of activity or potential activity along three traces of the Greenville fault through the property. Zones of restricted development have been placed along those three fault traces. We also delineated an area in the south-central portion of the property where ground surface deformations would likely accompany the maximum credible earthquake (MCE). Within this area special design for buildings is recommended. Throughout the property subsurface soils and groundwater conditions were found to vary a great deal. Future design level geotechnical exploration and engineering studies should address impacts that include expansive soils, liquefiable soils, high groundwater table, and seismically induced ground failures. Although there are a number of geotechnical conditions that impact the property, much of the land should be developable if the recommendations presented in this report are followed.

Our reviewing geologist for this project was Gary Anttonen, Ph.D., and our staff geologist was William R. Short. The geologists who assisted in field were Jaques Hebert and Bob Fehr. Our field assistant was Don Mastes. Consultant's retained by Merrill, Seeley, Mullen, Sandefur, Inc., for this project were Glen Borchardt, Ph.D. and J. Ross Wagner, Ph.D.
We have enjoyed the opportunity of working on this interesting and challenging project. Should you have any questions after reading the attached report, or if we can be of further service, please call our office.

Sincerely,

Marc W. Seeley  
Principal Engineering Geologist  
EG 1047  
MWS:lm
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INTRODUCTION

The owner of the subject property at North Front and Laughlin Roads has proposed developing the site as a light industrial or office park. Because the site is traversed by the Greenville fault, which has been classified as active by the California Division of Mines and Geology (CDMG, 1982), a large portion of the subject property falls within the boundaries of an Alquist-Priolo Special Studies Zone. State law requires that buildings for human occupancy constructed within an Alquist-Priolo Special Studies Zone cannot be sited across active or potentially active fault traces. In addition, before buildings can be sited within a Special Studies Zone, the locations of active and potentially active faults must be evaluated on the basis of geologic studies. The County of Alameda, which locally enforces the provisions of the Alquist-Priolo Act, has also recommended studies of some areas outside of the Special Studies Zone.

The intent of the Alquist-Priolo Act and the County's enforcement is to reduce the risk of property damage, injury, and loss of life due to surface fault displacement. Surface faulting is a distinct geologic hazard associated with larger earthquakes. Appendix A, which describes surface faulting in detail, is useful in placing this hazard in perspective with other earthquake related hazards at the proposed business park site.

In addition to addressing potential surface faulting hazards, the property owner has requested a preliminary evaluation of other geotechnical aspects of the property that might impact future potential development. These other geologic conditions include secondary earthquake effects (eg. liquefaction, lateral spreading, etc.) expansive soils, slope stability, and groundwater table.

PROJECT DESCRIPTION

The subject property is located north of Highway 580 between North Front and Laughlin Roads on the east side of the Livermore Valley (Figures 1 and 2). It is our understanding that the proposed development will consist of a light industrial park and/or an office park. The density and configuration of the project, not yet established, would be dependent on the results of this study.
PURPOSE
The purposes of this study are to evaluate the presence and location of active faults that traverse the site; to describe important characteristics of the Greenville fault; to make recommendations to mitigate the potential for surface fault rupture hazards and other seismic and geologic hazards; and to present our opinions regarding the potential for future surface faulting at the site. The evaluation of surface faulting is required by law because of the inclusion of most of the site within an Alquist-Priolo Special Studies Zone by the State Geologist. Approximately 80% of the subject property is within the Alquist-Priolo Special Studies Zone that has been delineated along the Greenville fault (CDMG, 1982). Appendix B describes the criteria used by the California Division of Mines and Geology (CDMG) to designate active and potentially active faults.

SCOPE OF WORK
This investigation is based on an evaluation of existing published and unpublished literature, an analysis of stereo-pair aerial photographs, a site geologic reconnaissance, exploratory trenching, and evaluations of the age of site soils.

The scope of work consisted of the following tasks:

- Collection and review of existing fault maps and published and unpublished geological literature;
- Interpretation of stereo-pair aerial photographs;
- A geologic reconnaissance of the site;
- Compilation of a geologic map of the site with probable fault locations;
- Research of information regarding fault displacements likely to accompany the maximum credible earthquake on the Greenville fault;
- Evaluations of the age of site soils;
- Logging of exploratory trenches and test pits;
- Formulation of recommendations to mitigate the surface fault displacement hazard;
• Preparation of a geologic zoning map showing setbacks from identified faults;
• A review of other potential geologic impacts and mitigations;
• Preparation of this report, client reviews, and consultation.

PREVIOUS STUDIES
Prior to the Livermore earthquakes of 1980, the Greenville fault was not recognized as being active, and geologic study of the site area was relatively limited. In 1975, Herd (1977) a geologist with the U.S.G.S., excavated a trench across one of the local traces of the fault in the northwest corner of the subject property (Plate I). He considered the fault to be potentially active, based on data collected during his investigation. More recent studies in the vicinity of the site and at other locations along the Greenville structural trend conducted after the 1980 earthquakes, which established the fault as active, include Hart and Bedrossion (1980), Bonilla and others (1980), Carpenter and others (1980), Cockerham and others (1980), Dibblee (1980), Earth Science Associates (1982), Wright and others (1982), Merrill & Seeley, Inc. (1984a&b), and Springer (1984). These investigations, which specifically discuss the geology and seismicity of the Greenville fault and the eastern Livermore Valley, and other pertinent geologic references are cited in the following sections as appropriate.

GEOLOGIC SETTING
The Livermore Valley is an east-west trending structural basin within the Diablo Range of the California Coast Range Province. The Coast Range province is a series of predominantly northwest trending valleys and ridges bounded by three major fault systems; the San Andreas, the Sur-Nociemento, and the Coast Range Thrust. These fault systems separate three distinct blocks that are composed of rocks of different origins. The Diablo Range comprises the block that lies between the San Andreas fault system and the Coast Range Thrust (Carpenter and others, 1980). North of Hollister, the San Andreas fault system branches into three subparallel fault zones that form the San Andreas, the Hayward and the Calaveras faults through the San Francisco Bay area (Figure 1). These fault zones have generated extensive seismic activity during the past 10,000 years and are characterized by predominantly right lateral strike-slip displacement. In the San Francisco Bay area, several large earthquakes associated with ground surface displacement have occurred in historic times on the San Andreas, Hayward, and Calaveras faults.
The Livermore Valley is bounded on the west by the Calaveras fault, on the east by the Greenville fault, and along part of the southern boundary by the Los Positas fault. The valley is a structural low filled with young (late Tertiary and Quaternary, less than 25 million years old) sedimentary deposits derived from the surrounding hills (Springer, 1984).

The Greenville fault separates the eastern Livermore Valley from the uplifted Altamont Hills. The Greenville fault consists of a series of northwest-trending en-echelon fault breaks that form a wide zone extending from Marsh Creek in Contra Costa County, to the southeast corner of the Livermore Valley. The Greenville fault was referred to as the Riggs Canyon fault by early geologists (Vickery, 1925; Clark, 1935). The most recent geologic mapping along the Greenville fault has been done by Herd (1977), Merrill & Seeley, Inc. (1980), Hart and Bedrossian (1980), and Earth Science Associates (1982).

The Greenville and other nearby faults are believed to be part of a zone of older faults that have been reactivated by major crustal movements along the San Andreas fault farther to the west (Carpenter and others, 1980; Merrill & Seeley, Inc., 1984c). Some of the strain accumulated by the present regional right-lateral sense of displacement on the San Andreas fault is apparently being released along this older zone of crustal weakness on structures like the Greenville fault.

The zone of faulting, which includes the Greenville fault, is a large structural feature along the eastern side of the Diablo Range known as the Greenville Structural Trend (Wright and others, 1982). The Greenville Structural Trend consists of three en-echelon fault segments of approximately equal length extending from Suisun Bay south to Bear Valley. Recent movement on the fault segments has been predominantly right-lateral strike-slip, and, therefore, the Greenville Structural Trend has been identified by Wright and others (1982) as the easternmost branch of the San Andreas system. The three segments (the Clayton, the Marsh Creek-Greenville, and the Arroyo Mocho) are distinguished by differences in topographic expression of the fault and by different levels of seismic activity.

The northernmost segment (the Clayton), is a single, continuous fault trace marked by poorly defined saddles, benches, and linear drainages. Tertiary rocks have been offset 1.7 km (1.05 mi) during the past 10-15 million years, indicating a long-term average slip rate of .01-.02 cm/yr (0.0039-0.0079 in/yr) (Earth Science Associates, 1982). It is not clear whether there is a direct near surface connection between the Clayton segment and the Marsh Creek-Greenville segment to the south.
The northern end of the Marsh Creek-Greenville segment is at the head of the Marsh Creek drainage which is approximately 6 km (3.7 mi) south and 2 km (1.2 mi) east of the southern end of the Clayton segment. On the east side of the Livermore Valley, the Marsh Creek-Greenville segment is characterized by a wide zone of discontinuous faulting and fault related geomorphic features, including seep ponds, scarps, linear drainages and ridges, benches and saddles, troughs, and tonal lineaments observable on aerial photographs. This segment is approximately 34 km (21 mi) long; it extends to the southeast through the site area toward the southern edge of the Livermore Valley. A possible correlation of displaced Pliocene and older rocks indicates a right lateral offset of 7 to 7.5 km (4.3 to 4.6 mi) during the last 10-15 million years with an average long-term slip rate of .05-.08 cm/yr (.02-.03 in/yr) (Earth Science Associates, 1982). The series of earthquakes that occurred along the Marsh Creek-Greenville segment in 1980 and the ground surface displacement associated with these earthquakes provided data to more accurately locate this segment of the fault. The Marsh Creek-Greenville fault (which is the subject of this evaluation) and the seismic activity associated with it are discussed in more detail in a following section of this report.

The southernmost segment of the Greenville Structural Trend is the Arroyo Mocho fault which extends 36 km (22 mi) from the southeast corner of the Livermore Valley, stepping 1 km (0.62 mi) west of the Marsh Creek-Greenville segment, toward Bear Valley. The Arroyo Mocho segment is characterized by a single continuous fault which probably forms the linear drainages of Arroyo Mocho, Colorado and Sweetwater Creeks to the south and east of the Livermore Valley. Evidence from an offset stream terrace indicates .09 km (.056 mi) of right lateral offset during the past 125,000-180,000 years, giving an estimated long-term average slip rate of .05-.07 cm/yr (.018-.027 in/yr) (Earth Science Associates, 1982).

Herd (1977) recognized the potentially active nature of the Greenville fault on the basis of observations he made in a trench excavated across a linear feature within the fault zone where it traverses the northwest corner of the subject property (Plate 1). The activity of the fault zone was confirmed by a magnitude 5.9 earthquake (the Livermore Valley earthquake on January 24, 1980) and a magnitude 5.3 aftershock (on January 26, 1980) with epicenters on the mapped trace of the Greenville fault. The main shock and the series of aftershocks occurred in an area with little previously recorded seismicity (Ellsworth and others, 1982). The earthquakes caused small discontinuous surface ruptures with a right-lateral sense of offset for a distance of approximately 4 miles along the northern segment of the fault trace that was mapped by Herd three years earlier (Carpenter and others, 1980). As a consequence of this earthquake, the Greenville fault is now recognized as an active right-lateral strike slip fault which bounds the Amador-Livermore Valley on the east (Springer, 1984).
SEISMIC SETTING
The historic record of seismic activity in the San Francisco Bay region goes back only 200 years and is very short when compared with geologic time. Early earthquake reports tend to be sketchy and usually document only large events that occurred near populated areas. Since the largest earthquakes in the Bay area have occurred on the San Andreas and Hayward faults (38 miles and 19 miles respectively from the site), these faults have received the most attention and have been studied more extensively by geologists and seismologists. The Livermore Valley was sparsely populated prior to 1900, and the area is, in general, seismically less active than other parts of the Bay area. Therefore, the local historic record of seismicity is very limited.

Large earthquakes that produced surface fault displacement occurred on the San Andreas fault in 1838 and 1906, on the Hayward fault in 1836 and 1868, and possibly on the Calaveras fault (12 miles from the site) in 1861. The great San Francisco earthquake of 1906 was felt in the Livermore Valley and caused structural damage and ground failure in several locations (Lawson and others, 1908; Youd and Hoose, 1978). During the 1861 earthquake, ground failure was reported to have occurred near San Ramon along the Calaveras fault (Carpenter and others, 1980).

Prior to the January 1980 earthquakes on the Greenville fault, the Livermore Valley was characterized by a low level of seismic activity. When plotted on a map, earthquake epicenters formed random clusters that did not display systematic relationships to the known faults in the area (Ellsworth and Marks, 1980). This may reflect the fact that, until recently, Livermore was located on the periphery of the seismographic network in the Bay area; epicenters cannot be accurately located when they occur near the edges of such networks.

The recent earthquake on the Greenville fault occurred on January 24, 1980 at 11 a.m. The main shock was a magnitude 5.9 event with an epicenter 17 km (10.5 miles) north of the City of Livermore. The main shock was preceded on the same day by a single foreshock of magnitude 2.5 at 10:58 a.m. Approximately 600 aftershocks occurred during the following 33 days. The largest aftershock, of magnitude 5.3, occurred on January 26 at 6:30 p.m. It was located 24 km (8.7 miles) southeast of the main shock (Cockerham, 1980). Ground surface displacement occurred along at least 4.2 km (2.6 miles) and possibly as much as 6.2 km (3.8 miles) of the discontinuous fault traces that form the Marsh Creek - Greenville segment of the Greenville fault to the north of Highway 580 (Donilla and others, 1980).
SITE GEOLOGY
Most of the subject property is underlain by flat-lying Quaternary alluvial deposits. The low hills along the eastern part of the site and the small topographic highs along the northern portion of the site are underlain by a Tertiary unit, the Cierbo formation (Herd, 1977; Dibblee, 1980). Herd (1977) subdivided the Quaternary alluvial deposits into stratigraphic units on the basis of morphology, topographic position (such as stream terraces), and soil profile development. Herd (1977) mapped two Quaternary alluvial units at the site, Qfa (recent flood plain alluvium) and Qoa2 (older alluvium estimated to be Late Pleistocene, older than 40,000 years) (Plate I). Exploratory trenches excavated for this study indicate that subsurface sedimentary units consist predominantly of unconsolidated silty clay interbedded with lenses of clayey silt and sand, and less commonly, clean well-sorted lenses of sand and gravel. Surface soils are clay-rich and have a moderate to moderately high potential for expansive activity. The groundwater table is generally within 5 to 10 feet of the ground surface at the subject property.

These fine-grained sediments were deposited in a structural low parallel to the Greenville fault. This low is a continuation of the basin containing Frick Lake to the northwest. Local sediments appear to reflect a changing depositional environment that fluctuated between shallow, intermittent marshes and small lakes and fluvial deposition by small meandering streams similar to the creek that currently traverses the site.

Four traces of the Greenville fault have been mapped across the subject property by previous workers (Figure 2). A detailed description of faulting at the site, the underlying sedimentary sequence, and the ages of site soils are presented in the following report sections.

LOCAL CHARACTERISTICS OF THE GREENVILLE FAULT
This section presents a summary description of the Greenville fault as it exists through the subject property. The descriptions are based on our interpretations of aerial photographs, literature review and, most importantly, on the results of our exploratory trenching. Table II presents a brief summary of the results of the trenching and more detailed information is presented in Appendix C and on the trench logs (Plates 4 through 16).

In the area of the subject property, the Greenville fault appears to consist of three or four individual traces located in a zone approximately 1,500 feet wide extending to the west from the base of the Altamont Hills (Plates 1 and 2). A compilation of possible fault traces and air photo lineaments from Herd (1977), Dibblee (1980), CD MG, (1982), and Hart and Bedrossian...
(1980) is presented in Figure 2. Plates 1 and 2 show the locations of lineaments recognized on aerial photographs during this study as well as fault locations from CDMG (1982), site geology and trench locations.

The most easterly of the probable traces of the Greenville fault crosses the east corner of the property near the break in slope along the Altamont Hills. Our analysis of stereo-pair aerial photographs revealed that a tonal lineament is coincident with the break-in-slope. This tonal lineament is most apparent to the north of the subject property; it becomes less distinct where it traverses the property and is even less easily recognized south of Highway 580 (Plate 2). Three trenches excavated across this probable fault trace during this study discovered no evidence of active faulting (Appendix C and Table II).

A second fault trace traverses the subject property (northwest to southeast) approximately 1,000 feet to the west of the eastern trace located at the break-in-slope. This second trace appears as a distinct tonal alignment on aerial photographs; it is also associated with a subtle break-in-slope in the northern part of the property (Plate 2). During the 1980 earthquakes, 0.2 cm (3/4 inches) of right lateral strike-slip movement occurred on this trace about 800 feet northwest of the site boundary (Hart and Bedrossian, 1980). Near the southern boundary of the site this trace merges with a third trace located farther to the west. Distinct evidence of faulting was found in two of the three trenches excavated across this structure for this study. In the third trench the evidence of faulting was less distinct (Table II and Appendix C).

The third fault trace also forms a distinct tonal lineament on aerial photographs and is associated with a very subtle break-in-slope in the northern part of the property (Plate 2). An exploratory trench was excavated across this trace in 1975 by the U.S. Geological Survey (Plates I and 2). Older Quaternary alluvium was found to be displaced in this trench, indicating that movement on this trace had occurred during or after the Late Pleistocene (Appendix B; Herd, 1977; Hart & Bedrossian, 1980). However, no rupture of the ground surface was observed along this trace during the 1980 earthquakes. Cracks were observed in the asphalt surface of Laughlin Road at a point to the south of where this western trace projects across Laughlin Road (Figure 2) after the 1980 earthquakes. However, these cracks did not exhibit lateral displacement; they appear to have been caused by settlement of road fill or were due to extensional stresses related to ground shaking. An exploratory trench excavated for this study adjacent to the trench of Herd, discovered distinct evidence of faulting (potentially active). A second trench excavated across this same trace but 1,150 feet to the south, discovered only questionable evidence of faulting.
As part of a previous study, an exploratory trench was excavated about 1,000 feet north of the subject property (Merrill & Seeley, Inc., 1984a) between this western trace and the previously described central trace (Figure 2). This trench was purposely located away from the mapped fault traces and lineaments identified on aerial photographs in order to document the absence of faulting between the mapped traces. No evidence of faulting was discovered in that trench.

A fourth subtle lineament identified on aerial photographs also crosses the southwestern part of the subject property. This lineament becomes more distinct to the northwest (Plate 2) where it coincides with a fault trace mapped by Dibblee (1980). However, only very equivocal indications of faulting were found in a trench which was excavated across this linear feature for this study (Appendix C). This lineament is extremely subtle through most of the property.

A fifth and very questionable trace of the Greenville fault was mapped by Herd (1977) across the southwest corner of the site (Figure 2 and Plate 1). This trace, which is queried by Herd (1977) does not appear on aerial photographs reviewed for this study (see Plate 2) and has not been included within the Alquist-Priolo Special Studies Zone by the California Division of Mines and Geology (CDMG, 1982). No other investigators have recognized this mapped trace, and the basis for it being mapped is not known. An exploratory trench excavated across this mapped questionable trace discovered excellent soil stratigraphy and no evidence of faulting (Table 2 and Appendix C).

**AGE OF SOILS**

An evaluation of the continuity and age of the various soil horizons exposed by our trenching investigation at the subject property is critical to an evaluation of the local pattern of structural deformation associated with the Greenville fault and to an evaluation of the potential for surface fault displacement on the fault traces that traverse the property. The ages of the surface and near-surface soil horizons were evaluated by: (1) a detailed study of the surface soil stratigraphy, (2) carbon-14 dating of organic material retrieved from trenching investigations, and (3) dating of a fossil bone fragment found in Trench No. 6 (Plate 12).

Welch and others (1966), mapped three soil types in the site area: the Altamont Clay, covering the eastern hillslopes; the Linne Clay loam, on the slight topographic high located between lineaments 3 and 4 (Plates 1 and 2); and the San Ysidro loam covering the majority of the site. Borchardt (1985) in a more detailed study of the site area has recategorized the flatland soils into two main soil types: (1) a well-drained alluvial soil the San Ysidro loam, covering areas of raised ground, and (2) a poorly-drained flood plain soil, the Pescadero clay, in low areas and shallow basins.
A detailed description of the soil-stratigraphic techniques used to estimate the age of the surface soils at the subject property are presented in Appendix D. Based on an evaluation of internal structure, thickness, color, age of parent material, and a correlation with Quaternary stratigraphy and probable cycles of soil formation in the Bay area, the well-drained alluvial soil at the site is considered to be 40,000 to 80,000 years old (Appendix D).

The poorly-drained flood plain soil is a "two-story" soil. The upper part of this unit is a thin flood plain deposit that "appears to be the only Holocene deposit (less than 10,000 years old) in evidence at this site" (Appendix D). The lower "story" of this poorly-drained soil unit is considered to be equivalent in age to the well-drained alluvial soil found elsewhere at the site (based on an application of the same soil-stratigraphic techniques and analysis noted above) and is, thus, considered to be about 80,000 years old. Because the lower part of the poorly-drained soil unit exhibits several characteristics indicating that it formed in a well-drained topographic environment at some point in the past (Appendix D), its current position in topographic lows with a thin cover of much younger flood plain deposits suggests that fault movement and tectonic warping along the Greenville structural trend has resulted in the slow development of local topographic depressions at the site within the last 40,000 to 80,000 years.

Organic rich material was sampled from Trench No. 4 (Plate 1 and Plates 5-8) from a depth of about 7½ feet between Stations 303' and 550'. The material was found along the base of a sandy channel deposit and hence appeared to have been deposited on an eroded (and therefore older) soil unit. The material was sent to Geochron Laboratories of Cambridge, Massachusetts (Appendix E). Results of the C-14 age dating of this material indicate it is approximately 17,140 +/- 800 years old. This date is consistent with a reasonable age for the fossil vertebrate bone discussed in the following paragraph, but is younger than the age of the soils examined by Borchardt and described in Appendix D. It is likely that these older soils were removed by erosion in this area and that younger materials were deposited later by streams flowing through the area.

A fossil vertebrate bone retrieved from Trench No. 6 (Plate 12) has been identified as part of a femur from a Harlan's ground sloth (Hutchinson, 1985). These animals disappeared from the Bay area after the last glacial epoch approximately 10,000 years ago. Their fossil record extends to at least 1.5 million years ago. The stratigraphic unit, from which the bone fragment was recovered, lies seven feet below surficial soil deposits that are 40,000 to 80,000 years old (Appendix D) and, thus, the unit is at least 10,000 years old or older. However, because of a possible age for the bone fragment that ranges up to 1.5 million years (based only on the fossil record), this fossil does not provide a definitive age for the deposit in which it was found.
The three methods of estimating the ages of the soils on the subject property indicate that even the youngest soils being greater than 10,000 years old. Thus soils encountered in all of the trenches are old enough to document the absence of faulting for at least the past 10,000 years (and more likely the past 40,000 to 80,000 years) where soil stratigraphy and/or structure does not exhibit evidence of faulting. In the parts of Trenches 4 and 5 where channel deposits are common, the channel-type soils encountered at a depth of 7 to 8 feet are probably at least 10,000 to 16,000 years old.

**LOCAL EFFECTS OF THE 1980 EARTHQUAKES**

During the January, 1980 earthquakes, surface fault displacement occurred at several locations near the property. These locations included open fields to the northwest of the subject property. However, no surface fault displacement was reported to have occurred within the property boundaries. Occurrences of surface fault displacements nearest the site are described below. These examples are characteristic of the kinds and amounts of displacements observed along the entire length of the fault rupture.

- Approximately 3 miles northwest of the site and northwest of Vasco Road in sloping terrain, a N30°W trending series of fractures occurred in the soil. These discontinuous fractures extended for about 3,500 feet to the northwest. Right-lateral displacements as great as 25 mm (1 inch) and, extension as great as 27 mm (1+ inch) were measured (Bonilla and others, 1980) and observed by Mr. Marc Seeley (Photograph 1). The extensional displacements were the result of gravity effects (i.e., landsliding).

- On Vasco Road, approximately 2-3/4 miles northwest of the subject property, the asphalt pavement was offset right laterally along a fault trace. A displacement of 20 mm (3/4 inch) was measured (photograph 2).

- Near the northwest corner of the property 20 hairline fractures occurred in the pavement of Laughlin Road. These fractures trended from N40°W to N60°W and increased in number with time (Bonilla and others, 1980). No lateral offset was observed on these fractures; they appeared to be the result of extensional stress.
Other earthquake effects that occurred as a result of ground shaking are as follows:

- The chimney of a single-story, wood-frame house on Laughlin Road, approximately 150 feet north of the property, was damaged by earthquake shaking during the January 24, 1980 earthquake. The house is located approximately 180 feet from the mapped fault trace that was trenched by Herd (Photograph 3). No damage due to surface displacement was observed.

- Damage from ground shaking during the January 24, 1980 earthquake occurred at the Interstate 580 overpass structure at Greenville Road, approximately 300 feet southeast of the property boundary (Figure 2 and photograph 4). Even though many fractures were observed in the asphalt pavement along Northfront and Altamont Pass Roads, no offset was observed on these cracks. Bonilla and others (1980) reported as much as 6 mm (¼ inch) of extension across these cracks. They also reported that the cracks appeared to be pre-existing fractures that might have enlarged due to ground shaking. A survey of these cracks was conducted as part of this study. The cracks occur along Altamont Pass Road from a point several hundred feet east of the property, along Northfront Road to Vasco Road, and along Greenville Road. The cracks are oriented across the roads and are spaced at approximately regular intervals. The cracks on Northfront and Altamont Pass Roads are oriented NW-SE whereas the cracks along Greenville Road are oriented NE-SW.

The surface fault displacement that occurred during the January, 1980 earthquakes was distributed between three distinct and discontinuous traces of the Greenville fault across a zone approximately 1,000 feet wide (Hart and Bedrossian, 1980). The total width of the fault zone in the vicinity of the subject property is at least 2,000 feet (CDMG, 1982). This wide distribution of fault displacement associated with the 1980 earthquakes appears to be characteristic of the long-term behavior of the Greenville fault along the eastern margin of the Livermore Valley. Frick Lake, north of the site, is believed to have formed as a result of extensional stresses distributed over a wide zone (1,000 feet) between right stepping (en-echelon) traces of the Greenville fault. Similar topographic depressions of a more subtle nature appear to exist between fault traces crossing the subject property, indicating a broad distribution of tectonic stress release in this area as well.
MAXIMUM CREDIBLE EARTHQUAKE (MCE) FOR THE GREENVILLE FAULT

The term maximum credible earthquake (MCE) is defined as the largest earthquake that is likely to be generated along an active fault zone (Slemmons and Chung, 1982). The magnitude of the MCE is estimated from the geologic character and the earthquake history of the fault.

The MCE of the Greenville fault has been estimated to be between 5 and 6.7 by Shedlock and others (1980), 6.5 by Wright and others (1982), 6.5 by Earth Science Associates (1982), and 6.5 by Merrill & Seeley, Inc. (1980). Using curves of fault length versus magnitude developed by Slemmons (1977), a magnitude 6.5 earthquake appears to be a reasonable MCE for the Greenville fault. Thus, the main shock of the 1980 earthquake sequence (magnitude 5.9) approached the MCE for the Greenville fault.

Using Slemmons (1977) length of surface faulting versus magnitude curve, it is estimated that the length of surface faulting would be 15-20 km (9.3-12.4 mi) for a magnitude 6.5 earthquake, as compared to the 4.2 km (2.6 mi) of discontinuous surface rupture observed after the January, 1980 earthquakes. The width of the zone in which displacement might occur during a MCE is probably very similar to the width of the 1980 fault rupture zone (approximately 1,000 feet) based on the geomorphic expression of the fault traces.

COMPARISON OF THE GREENVILLE FAULT WITH OTHER BAY AREA FAULTS

Before presenting an evaluation of seismic hazards associated with building in the Greenville fault zone, a comparison of the Greenville fault with other active faults in the Bay area is in order. Table 1 presents a summary of the characteristics of the San Andreas, Hayward, Calaveras, and Greenville faults. As can be seen from Table 1 and the preceding discussions, the Greenville fault has somewhat different characteristics from these major strike-slip faults located farther to the west. The length of the Greenville fault is an order of magnitude less than the lengths of the Hayward and Calaveras faults and two orders of magnitude less than that of the San Andreas fault (tens of miles compared to hundreds or thousands of miles).

The largest historic earthquake on the Hayward fault released approximately 30 times more energy than the largest historic earthquake on the Greenville fault (January 24, 1980) and about 10 times more energy than the MCE estimated for the Greenville fault. The largest historic earthquake on the San Andreas fault released approximately 75 times more energy than the January 24, 1980 Livermore earthquake and about 55 times more energy than the MCE estimated for the Greenville fault. A similar contrast exists between the amounts of historic displacements observed: 19.7 ft. and 2.9 ft. on the San Andreas and Hayward faults, respect-
ively and only 0.10 inches on the Greenville fault. Except for the largest magnitude earthquakes on the San Andreas, the frequency of occurrence for earthquakes is much less for the Greenville fault.

Another very important difference between the style of faulting expressed by the Greenville fault (in the site area) and the other major Bay area faults is the amount and distribution of surface rupture. As described previously, the Greenville fault occupies a zone about 2,000 feet wide in the area of the subject property. The very small displacements associated with surface faulting during the January, 1980 earthquakes were distributed across a zone approximately 1,000 feet wide. This contrasts sharply with the very narrow (generally less than 3 feet wide) rupture zone associated with the April 18, 1906 "San Francisco" earthquake on the San Andreas fault. Almost 20 feet of lateral displacement occurred along this zone in 1906 (Table 1).

**POTENTIAL SEISMIC AND GEOLOGIC HAZARDS AND IMPACTS**

Because the subject property lies within a zone of active faulting, and is within a region of high seismicity, there is a potential for a variety of seismic hazards to impact the property. These include the potential for surface fault rupture, intense ground shaking, differential settlement and warping of the ground surface, landslides (in the easternmost part of the property), liquefaction, lateral spreading, lurch cracking, and stream bank failure. The potential for some of these hazards is exacerbated by the local near-surface groundwater conditions. In addition to earthquake-related hazards, other potential geologic hazards at the site include the presence of moderately expansive soils underlying some areas of the subject property, landslides (not related to earthquakes) on the hillslopes at the eastern end of the property, and groundwater (and possible flooding) at or near the surface during or after periods of heavy rainfall. These potential hazards are discussed below.

**Surface Faulting Displacement**

Using earthquake Magnitude vs. Length relationships of Bonilla and Buchanan (1970) and assuming that a Richter magnitude of 6.5 is the maximum credible earthquake for the Greenville fault, it is estimated that a maximum of 0.7 m (27 inches) of surface displacement might occur across the fault zone. This estimated 27 inches of displacement would likely be distributed across a zone at least 1,000 feet wide, and possibly as wide as 2,000 feet in the vicinity of the property. Based on the characteristics of the 1980 earthquakes, the geomorphic expression of past surface faulting, and the results of our subsurface exploration, there is a potential for surface rupture and displacement along 2, or possibly 3, fault traces in the northern parts of the subject property. The absence of surface rupture on the subject property
during the 1980 earthquakes, the continuity of soil horizons in trenches, and the apparent long-term release of strain as a broad zone of tectonic warping in the southern part of the property, all indicate that distinct surface ruptures would likely diminish toward the south within the boundaries of the subject property and be distributed as broad zones of ground deformation with either minor or indistinct surface fault rupture. Assuming that the three most pronounced fault traces mapped in the northern part of the site experience displacement during a MCE event, considering the model proposed by Hart and Bedrossion (1980) for the Frick Lake area, and considering the preceding discussion, maximum credible displacements across each of these three fault traces are estimated to be on the order of 9 inches or less.

A surface fault displacement of even a few inches can cause damage to most types of structures located across the surface rupture. In addition, subsurface utility lines can be damaged by even relatively small fault displacements. Even though the potential for surface displacement appears to diminish to the south across the site, areas traversed by fault traces or possible fault traces (expressed on aerial photographs as lineaments), which are associated with disruption of near-surface soil horizons in trenches on the north side of the site and along which surface rupture occurred in 1980 to the north of the site, should be avoided during development of the subject property. Future earthquakes on the Greenville fault might result in propagation of surface fault rupture to the south across the entire property.

**Ground Shaking**

Ground shaking is a complex surface wave motion produced by the passage of seismic waves through the Earth's outer crust. Factors which determine shaking intensity at a given location are distance from the epicenter, magnitude and duration of the earthquake, and local soil, geologic, and groundwater conditions. In general, the shaking intensity decreases with increasing distance from the epicenter. However, for very large magnitude earthquakes (M 7.0+), the shaking intensity is more directly related to subsurface geologic conditions than to distance from the epicenter for distances less than 20 to 30 miles.

Ground shaking generated by earthquakes causes far more damage over a wider area than does surface fault rupture. The intensity of shaking also plays a major role in the production and severity of seismically induced ground failures (liquefaction, lateral spreading, etc.) that occur during large earthquakes. Near the epicenter of a large earthquake, the ground shakes in all directions, producing ground accelerations as high as 0.5, or more, times the acceleration of gravity (g) in both the horizontal and vertical directions. Within the same region, ground shaking tends to be more severe in areas underlain by unconsolidated deposits (especially if they
are saturated) than in areas underlain by bedrock. In addition, shaking lasts longer and surface waves have a greater amplitude in areas underlain by unconsolidated deposits when compared to nearby bedrock areas. Amplification of seismic waves also increases as the thickness of the unconsolidated deposits increases (Borcherdt and others, 1975; Hays, 1980).

As was discussed in previous sections, the site area is underlain by unconsolidated deposits of silty clay with less common lenses of silt, sand and gravel. A very large earthquake on the San Andreas (magnitude 8+) or Hayward and Calaveras (magnitude 7+) faults will produce moderately strong to very strong shaking in the site area, depending on the location of the epicenter and magnitude of the event. However, a more moderate earthquake (magnitude 6.5 or less) on the Greenville fault could produce severe local ground motion with near-field ground accelerations exceeding 0.5g if the epicenter occurs near the subject property. Based on the history of local and regional seismicity, the potential for moderate to severe ground shaking at the subject property due to a large earthquake on a major Bay area fault (the San Andreas, Hayward, or Calaveras) or a more moderate event on the Greenville fault is judged to be moderately high within the expected lifetime of the proposed development.

**Landslides**

Earthquake shaking exacerbates the instability of landslide-prone areas in several ways. Ground shaking reduces the cohesive strength of rock and soil masses and can promote their mobilization on even relatively gentle slopes, particularly where pre-existing zones of weakness such as old slide planes exist. In those instances where very strong ground shaking occurs, horizontal ground accelerations caused by the earthquake may approach the downward forces exerted by the weight of the slide mass itself (Bolt and others, 1975). Although these dynamic accelerations last for a very short time, they can, in theory, locally exceed the downward force of gravity (1.0g) and, thus, have an enormous effect in promoting slides on marginally stable slopes. Keefer (1984) analyzed 40 historic earthquakes and found that landslides are normally associated with events exceeding M 5.5. As might be expected, landslide abundance increased with increasing earthquake magnitudes and proximity to the epicenters.

In the event of strong ground shaking, the only area where a potential for landsliding exists within the boundaries of the subject property is along the hill slopes at the eastern end of the site. Most existing slope failures in the Altamont Hills are of the earthflow type. Earthflows involve mobilization and failure of just the soil and colluvium on the slopes and not the underlying bedrock units. Seismically induced landslides are much more apt to occur during periods of wet weather when slopes are saturated and typically less stable. Our review of land-
slide mapping of the area (Nilsen and others, 1976), and our interpretation of aerial photographs indicate there are no existing areas of landsliding on or adjacent to the property, and that the potential for seismically induced landsliding is low.

Lateral Spreading
Lateral Spreading of the ground surface toward a free face on very gentle slopes is intermediate in nature and effects to landslides, which occur on steeper slopes, and liquefaction, which requires no slope at all. Lateral spreading most commonly occurs when the upper layers of an unconsolidated sedimentary sequence move in a translational manner on zones of liquefied gravel, sand, or silt down a very gentle slope or toward a free face such as a stream or canal bank, man-made cut slope, or artificial fill slope. Saturation of the basal zone is necessary before spreading can occur. Keefer (1984) noted that lateral spreading is most common in man-made fill and flood plain alluvium composed of Holocene silt, silty sand, and fine-grained sand. It can occur on slopes inclined as low as 0.3 degree.

Lateral spreading can cause severe cracking and differential displacement of the ground surface for distances of up to several hundred feet from the free face toward which the sedimentary mass moves. Lateral spreading appears to be initiated when the intensity of ground shaking is strong and of a relatively long duration. Lateral spreads tend to move very rapidly when they occur.

Because a potential for moderate to severe seismic shaking exists at the site in conjunction with scattered lenses of well-sorted relatively clean sand in the subsurface, a high groundwater table, and stream banks that average about 4 to 5 feet in height, a moderate potential for lateral spreading is considered to exist at the site. However, the relatively modest height of the stream banks and the probable discontinuous nature of liquefiable subsurface materials which would promote lateral spreading indicate that this potential hazard would be triggered only by violent ground shaking caused by a local earthquake on the Greenville fault. Large earthquakes on more distant major faults (the San Andreas, Hayward, and Calaveras) would probably not generate local shaking of sufficient intensity to cause lateral spreading.

Liquefaction
Strong seismic shaking is the major cause of liquefaction. Earthquake waves can momentarily compact loose granular materials and, if these materials are saturated, cause a transient increase in pore pressure and reduce the shear strength of the materials to nearly zero. The most easily liquefied sediments under such conditions are clean, well-sorted layers of silt or sand.
Liquefaction of a subsurface sedimentary layer is the mechanism which causes lateral spreading to occur on very gentle slopes. However, materials liquefied beneath a flat surface can also cause differential ground settlement due to: (1) a sudden loss of bearing strength and consequent differential loading beneath building foundations or (2) the mass transport of the liquefied material to the surface along seismically induced ground cracks where the mixture of water and sediments appears as sand boils, mud volcanoes, and geysers. The latter results in differential settlement and cracking of the surrounding ground surface caused by the withdrawal of subsurface materials.

As with lateral spreading, the site is judged to have a moderate potential for liquefaction caused by very strong ground shaking during an earthquake on the Greenville fault with a local epicenter. The highest potential within the site area is at those locations underlain by lenses of relatively clean, well-sorted sand and having a high groundwater table. The potential for both lateral spreading and liquefaction increases during the winter and spring months when the water table is nearer the ground surface.

**Lurch Cracks**
Numerous random ground cracks and fissures are often produced in deep alluvium when the intensity of seismic shaking is very strong. Many lurch cracks are directly related to areas of lateral spreading and liquefaction. Others are produced when the amplitudes of the seismic waves that deform the alluvium are so great that permanent deformation and cracking of the ground surface occurs. Lurch cracks can also form at the contact between unconsolidated and consolidated deposits along the margins of a valley. Numerous variables that contribute to the occurrence of lurch cracks make it difficult to predict accurately the distribution of lurch crack potential at the site. However, the cracks reported by Bonilla and others (1980) along Laughlin, Northfront, and Altamont Pass Roads that were associated with the 1980 earthquake sequence, and the infilled cracks observed in several of the exploratory trenches suggest there is a high potential for at least minor lurch cracking to occur during moderate to large nearby earthquakes.

**Stream Bank Failures**
Small localized rotational slumps can be caused by strong seismic shaking of very steep stream banks in unconsolidated sediments. This type of failure generally affects a 10 to 30-foot-wide area on either side of the stream, depending on bank height, and is caused by a simple rotational slump of bank materials towards an unsupported face. Bank failures are much more localized than lateral spreading in their effects and do not require the presence of a liquefied subsurface layer for their occurrence. During a large earthquake, such failures could occur along any of
the steep to nearly vertical stream banks along Altamont Creek which traverses the subject property. Because these stream banks are very low (generally 4 to 5 feet high), any seismically induced failures should be small and very localized in extent and in their impact on structures at the site. The potential for this kind of failure to occur along the existing stream banks during a large earthquake is high to moderate.

**Differential Settlement**

Differential settlement of the ground surface often occurs in areas affected by liquefaction and lateral spreading. During strong seismic shaking, differential settlement can also occur in an area underlain by thick, unconsolidated alluvium due to a reduction in volume of low density layers induced by the ground movements. Because the distribution of the amounts of compaction induced by shaking are not uniform, differential settlement of the ground surface (including cracking) can occur. The potential for differential settlement due to simple seismic shaking is present in areas underlain by relatively thick, young unconsolidated sedimentary deposits and thick, poorly compacted artificial fill. In general, the potential for seismically-induced differential settlement cannot be accurately estimated at a specific site (even by relatively detailed geologic studies), since ground surface settlement might occur over a very large area that exceeds the boundaries of a specific site. In the area of the subject property, an estimate of the potential effects of differential settlement is further complicated by the potential for vertical elevation changes produced by tectonic warping whereby strain release along various traces of the Greenville fault appears to be accomplished by this mechanism in addition to surface fault rupture.

**Expansive Soils**

Expansive soils are rich in clay minerals that expand when wetted and shrink when dried. While this geologic hazard does not produce the catastrophic impacts of a large earthquake, its cumulative economic cost to a development can be considerable. Shrink-swell activity in near-surface soils can seriously damage building foundations, streets and other paved areas, and underground utilities. When expansive soils are present on a slope, they can promote downslope creep of the entire thickness of surficial deposits present on the slope (in some cases to depths of more than 10 feet).

Various parts of the subject property are underlain by moderately to highly expansive soils. Appropriate engineering practices should be followed to minimize the potential for expansive soils present at the site to damage the proposed structures and improvements.
High Groundwater Table
The subject property is underlain by a relatively high groundwater table that was present within 5 to 10 feet of the surface even during the summer months of our field exploration. Presumably, the water table is a perched water table that overlies a deeper aquiclude. This water table probably approaches the ground surface in the property area during periods of unusually wet winter weather. A high groundwater table can be exacerbated by poor surface drainage. The pescadero clay soil which covers much of the site is characteristic of areas of poor drainage and standing surface water. In addition, a high groundwater table can exacerbate the impacts of certain seismically induced hazards (e.g. liquefaction, lateral spreading) caused by strong ground shaking during a large earthquake. Development of the subject property should incorporate engineering design that will help alleviate the impact of the near-surface groundwater table.

MITIGATION OF SEISMIC AND GEOLOGIC HAZARDS
The seismic and geologic hazards described in the preceding section can be mitigated to some degree by adopting policies to evaluate the potential for their occurrence at a given site and implementing site planning and engineering practices that will minimize the impacts if a specific hazard is found to exist at the particular site. In general, measures to mitigate the impacts of earthquake-related hazards will be most effective for earthquakes that generate only moderate to moderately strong shaking intensities within the area of the property. These measures will be significantly less effective in mitigating the impacts of a magnitude 6.5 earthquake (the MCE) on the Greenville fault with a local epicenter. The very strong shaking intensities and potentially high ground accelerations (possibly exceeding 1.0g at some localities), which could occur in the local area during such an event, could cause widespread secondary ground failures (lateral spreading, and liquefaction) and differential settlement in parts of the subject property. Fortunately, the potential for such an occurrence appears to be relatively low, based on an evaluation of the geomorphic expression of the Greenville fault trace where it trends through the site area or our evaluation of faulting exposed in trenches, and on the long term displacement rate of the fault (Table 1). One of the most important steps in mitigating both seismic and other geologic hazards will be site specific geotechnical studies to evaluate subsurface geologic conditions and to provide the necessary information for seismic design of specific structures.
Surface Fault Displacement

As described in a previous report section, the maximum historic displacement associated with an individual trace of the Greenville fault was 0.10 inches of right lateral displacement. During a MCE there might be as much as 9 inches of displacement across a single fault trace. In addition to surface fault displacement, an area of surface deformation on either side of the fault trace generally occurs (Appendix A). The Alquist-Priolo Special Studies Zones Act was established to mitigate this particular hazard.

Based on the results of our evaluation of the locations and activity of faulting through the subject property and in the vicinity, we have established fault set-back zones in which certain kinds of development should not be permitted (Plate 17). Within those zones the risk of surface faulting and resultant damage to buildings for human occupancy as defined by Hart (1980) is estimated to be moderately high to high. The development of parking lots, landscaped areas, roadways and sidewalks are not restricted within the fault set-back zones. Also, certain kinds of structures that are not considered structures for human occupancy might be permissible within the zones. These kinds of structures might include open storage yards and carports. The public agency having jurisdiction over development of the property should review proposed development of structures within the set-back zones on a case-by-case basis. In any event, developers should recognize that there is a moderately high to high potential for damage from surface fault displacement and accompanying ground deformation to structures or improvements permitted within the set-back zone.

Proposed roads, bridges, and utility lines that cross a fault set-back zone should be designed and constructed in a manner that recognizes potential surface displacement and deformation. For water, gas and electric lines, consideration should be given to equipping the lines with automatic shut-off devices which operate if the lines are ruptured, or should in some other acceptable and cost-effective way be designed to accommodate the potential surface fault rupture, or alternatively they should be designed for ease of repair in the event of fault rupture.

Ground Shaking

Mitigation of this hazard for non-critical structures for human occupancy could be accomplished by designing the structures to meet the requirements of the Uniform Building Code. Critical or sensitive structures should be designed to a standard higher than minimum code requirements. Subsequent engineering studies and evaluations might indicate that even non-critical structures for human occupancy should be designed to resist potentially strong to violent ground shaking.
Secondary Ground Failures (Lateral Spreading, Liquefaction, Landslides, etc.)

In parts of the property underlain by unconsolidated deposits, geotechnical exploration and engineering studies should evaluate the potential for lateral spreading, liquefaction and other types of ground failure in areas of proposed structures. These investigations should include subsurface exploration (drilling and/or trenching) to identify potentially liquefiable soil horizons, depth and seasonal fluctuations of the water table, the presence of soil horizons of low density, proximity of the site to stream banks (or other natural or man-made cuts that would constitute an unsupported "free face" in the unconsolidated sedimentary sequence), and other factors deemed significant to an evaluation of the potential for secondary ground failures induced by earthquake shaking.

In cases where the potential for earthquake-induced ground failure is found, such measures as are formulated by the geotechnical and/or structural engineer to mitigate the probable effects of the specific hazard(s) should be employed in the design of the proposed structure(s).

Structures for human occupancy should not be located in landslide-prone areas unless geotechnical investigations demonstrate the proposed site has an acceptably low risk with regard to slope failures, even after development activities such as grading, road construction, planting, irrigation, etc.

Expansive Soils and Shallow Groundwater Table

Where the presence of expansive soils is confirmed on the subject property by geotechnical explorations and laboratory testing of soils, engineering and building design measures formulated by the geotechnical engineer to mitigate the effects of this geologic hazard should be employed to protect building foundations, streets, paved surfaces, etc.

Drainage and foundation systems for the proposed development should take into account the shallow groundwater table present throughout parts of the property. During, and after, periods of heavy rainfall, the water table can be expected to approach the ground surface in places, unless mitigated by surface and/or subsurface drainage improvements.

CONCLUSIONS

Based on the preceding discussions and on our experience in active fault and geologic hazards evaluations, we have formulated the following conclusions:

- It is our opinion that the Maximum Credible Earthquake (MCE) for the Greenville fault is a Richter Magnitude 6.5 event.
- It is our opinion that the recurrence interval for the MCE on the Greenville fault is probably on the order of 200 years. However, it is our opinion that the probability of the site experiencing the MCE during the design life of the proposed project cannot be predicted based on available information.

- It is our opinion that there are four traces of the Greenville fault through the subject property, three of which exhibit indications of activity or potential activity through or just to the north of the subject property. These active or potentially active fault traces coincide closely with lineaments 2, 3, and 4 (Plates 1 and 2).

- It is our opinion that the eastern most fault trace associated with lineament 1 (Plates 1 and 2) is a very old bedrock fault that is not active and has a very low potential for being re-activated as a result of future larger earthquakes on the Greenville fault. It is our opinion that the three trenches excavated across this feature discovered no evidence of active or potentially active faulting and that the age of soils encountered in those trenches is sufficient to document lack of activity during at least the past 10,000 years.

- It is our opinion that the next fault to the west (that associated with lineament 2; Plates 1 and 2) is an active, or potentially active, fault through the subject property. It is our opinion that at its northern end definite evidence of activity was exposed in Trench No. 10. In Trench No. 2 the fault was observed but the evidence of its activity was less convincing than that exposed in Trench No. 10. In Trenches No. 8, 6, 5 and 4, evidence of faulting was not observed along this trace. It is our opinion that the activity of this fault diminishes to the south through the property and from Altamont Creek southward this fault is potentially active.

- It is our opinion that the next fault to the west (that associated with lineament 3, Plates 1 and 2) is potentially active through the subject property. Although to the north of the property this fault is probably active and its activity diminishes southward. It is our opinion that distinct evidence of faulting was observed in Trench No. 1 and that we observed the same fault that was reported by Herd (in Hart, 1980). It is also our opinion that evidence of the fault was observed in Trench No. 6 to the south, but that because of the age of the overlying undisturbed soils, the fault is, at most, potentially active where exposed in that trench and to the south. It is our opinion that no evidence of faulting was discovered in Trench No. 5 coincident with this fault.
• It is our opinion that the next fault to the west (that associated with lineament 4, Plates 1 and 2) is active or potentially active to the north of the subject property. However where Trench No. 11 crosses this fault there is, at most, questionable evidence of the fault and that it is probably not active at that location. It is our opinion that this fault, like the two faults to the east, has diminished activity to the south through the subject property. It is our opinion that this fault is potentially active from Laughlin Road to several hundred feet southeast of Trench No. 11, and from there south, it is inactive and has been inactive for the past 40,000 to 80,000 years.

• It is our opinion that the questionable fault mapped by Herd (1977) through the western corner of the property is neither an active nor potentially active fault. No evidence of faulting was found in Trench No. 9.

• It is our opinion that the soil stratigraphy and the age of soils encountered in the trenches are sufficient to document the presence or absence of active and potentially active faulting through the property.

• It is our opinion that faulting through the subject property generally decreases southward along the three central fault traces (associated with lineaments 2, 3 and 4) and that as distinct fault displacements diminish, strain is relieved by more widespread ground deformation which is probably most pronounced between traces 2 and 3, especially in the low-lying area south of Altamont Creek.

• It is our opinion that there is a moderate potential for earthquakes less than the MCE (i.e. similar to the January 25, 1980 event) to occur during the design life of the proposed project. In our opinion, such earthquakes might cause surface fault displacements of only a tenth of an inch or so and might not result in surface fault displacement through the property.

• It is our opinion that in the event of an earthquake with an epicenter near the property, and a magnitude between 5.5 and the MCE (6.5), surface fault displacements would be generally coincident with lineaments 2, 3, and 4 shown on Plate 1 and 2 that are along the trend of the previously mapped faults on Plate I. It is also our opinion that distinct surface faulting would diminish to the south through the property where ground deformation and extensional stresses would be the dominant mode of strain release.
- It is our opinion that the lateral displacements resulting from a large earthquake on the Greenville fault, would be accompanied by small, vertical and extensional displacements. The amount of these displacements would be less than the lateral displacements.

- It is our opinion that the surface faulting hazard associated with the Greenville fault is low in comparison to the hazard associated with the San Andreas, Hayward, and Calaveras faults.

- It is our opinion that the hazard associated with surface fault displacement at the subject property is lower than other seismic hazards that effect the property such as strong seismic shaking and secondary ground failures.

- It is our opinion that the MCE might result in individual right-lateral offsets of up to 9 inches along one or more of the three central fault traces mapped through the property. Larger displacements are not likely, in our opinion. In our opinion, a substantial amount of the accumulated strain would be released over a fairly broad area (one thousand feet wide) in the southern part of the property where evidence of active faulting is not present.

- In our opinion, the risk of damage resulting from surface fault displacements to property, risk of injury, and risk of loss of life due to surface fault displacement would be low if the proposed development were constructed with no structures for human occupancy in Zone F.

- It is our opinion that Zone F could be developed with roads, parking lots, structures not for human occupancy (as defined by CDMG and Alameda County) and landscape areas, providing the risk of damage to those improvements is acceptable to the owner.

- It is our opinion that the area between lineaments 3 and 4 and the area adjacent to these lineaments, especially in the southern part of the property are developable with structures for human occupancy providing the structures are designed to tolerate the expected ground deformation that might accompany the MCE.
• It is our opinion, based on our field observations and on our review of the subsurface conditions encountered during our exploration of the site, that the foundation soils encountered in the exploratory trenches are highly variable in their strengths, composition, potential for expansive activity, and for liquefaction. It is our opinion that the soils conditions and their susceptibility to the effects of seismic shaking need to be addressed in detail in subsequent geotechnical engineering studies of the property. The geologic and soils conditions will in our opinion, cause the property to be relatively costly to develop.

RECOMMENDATIONS

• It is recommended that the site plan for the proposed development be configured so that structures for human occupancy are not built in Zone F.

• It is recommended that critical or sensitive structures not be built in Zone AI. Such structures would include hospitals, schools, fire stations or similar facilities.

• It is recommended that a structural engineer evaluate the design of proposed structures relative to the potential earthquake effects (including ground deformation and seismic shaking), as appropriate (Plate 17).

• It is recommended that design of individual structures for the proposed development be based on a detailed subsurface exploration and geotechnical engineering study of the specific site of the proposed building.

LIMITATIONS

The conclusions and recommendations presented in this report are based on our interpretation of existing information and are made for a development consisting of non-critical facilities. If the proposed construction or land use will differ from that anticipated at the present time, our firm should be notified so that supplementary recommendations can be made. Future exploration work should be done under the direct, full-time observation by representatives of our firm to verify in the field the subsurface conditions anticipated. The recommendations presented herein should not be considered applicable if unanticipated subsurface conditions are encountered in the field and our firm has not been retained to observe these conditions and make supplemental recommendations.
REFERENCES

Archer, R., 1985, Survey plate showing the location of exploration pits and trenches on the Bibler property, Laughlin Road, Alameda County, California: Ron Archer Civil Engineer, Inc., Pleasanton, California, June 26, 1985, scale 1" = 200'.


California Division of Mines and Geology, 1982, Alquist-Priolo Special Studies Zone Map, Altamont 7½ minute Quadrangle: California Division of Mines and Geology, map scale 1:24,000.


REFERENCES (Cont'd)


REFERENCES (Cont'd)


Pacific Aerial Surveys, 1980, Black and white stereo-pair air photos of the Livermore area: Pacific Aerial Surveys, Oakland, California, Flight AV-1860-05, frames 03 and 04, and Flight AV-1860-06, frames 05 and 05, taken 4-30-80.


REFERENCES (Cont'd)


Photograph 1 - View of typical ground cracks that occurred during January, 1980 earthquake. These cracks were located approximately 3 miles north of proposed site (photo taken on 1-26-80). These cracks exhibit a small amount of lateral displacement (less than 0.1 inch), extension, and downslope gravity effects.

Photograph 2 - View of cracks and patched cracks across Vasco Road approximately 2-3/4 miles north of site. 2 cm (0.79 in) of right-lateral strike-slip displacement occurred on the fault trace that crosses the road at this location. Photo taken on 1-26-80.
Photograph 3 - Damage to the chimney of a one-story, wood-frame house caused by ground shaking during the January 24, 1980 earthquake. This house is located on Laughlin Road approximately 180 feet from a mapped fault trace and 150 feet northwest of the project site. No ground surface displacement occurred in this area. Photograph taken 1-26-80.

Photograph 4 - Damage to Interstate 580 overpass structure at Greenville Road caused by ground shaking during January 24, 1980 earthquake. Location is approximately 300 feet southeast of project site. Photograph taken 1-26-80.
From Carpenter et al., 1980

FIGURE 1

REGIONAL FAULTS AND SITE LOCATION
EXPLANATION

"1980" dates on map are locations of January 1980 surface rupture.
Mapped faults and possible faults from various sources:

- Herd, 1977
- Hart, 1980
- Dibblee, 1980
- CDMG, 1982

Earth Sciences Associates, 1982

FIGURE 2
PREVIOUSLY MAPPED FAULTS AND LINEAMENTS

Modified from CDMG, 1982
### TABLE 1

**COMPARISON OF BAY AREA FAULTS**

<table>
<thead>
<tr>
<th>FAULT</th>
<th>LENGTH KM (mi)</th>
<th>LARGEST HISTORICAL EARTHQUAKE MAGNITUDE</th>
<th>MAXIMUM CREDIBLE EARTHQUAKE MAGNITUDE</th>
<th>MAXIMUM HISTORICAL DISPLACEMENT</th>
<th>ESTIMATED* RECURRENCE INTERVAL</th>
<th>REFERENCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAN ANDREAS</td>
<td>1,200 (745)</td>
<td>8.3</td>
<td>8½</td>
<td>6m (19.7ft) of right-lateral strike-slip in 1906</td>
<td>100-1000yr</td>
<td>Bocherdt, 1975; Slemmons, 1977</td>
</tr>
<tr>
<td>HAYWARD</td>
<td>280 (174)</td>
<td>6.8</td>
<td>6-3/4-7½</td>
<td>.9m (2.9ft) of right-lateral strike-slip in 1868</td>
<td>10-100yr</td>
<td>Bocherdt, 1975; Slemmons and Chung, 1982</td>
</tr>
<tr>
<td>CALAVERAS</td>
<td>280 (174)</td>
<td>6+</td>
<td>6-3/4-7½</td>
<td>UNKNOWN</td>
<td>10-100yr</td>
<td>Borcherdt, 1975; Slemmons and Chung, 1982</td>
</tr>
<tr>
<td>GREENVILLE</td>
<td>50 (31)</td>
<td>5.9</td>
<td>6½</td>
<td>.25 cm (0.10in) right lateral strike-slip in 1980</td>
<td>230yr</td>
<td>Bonilla &amp; others, 1980; Shedlock &amp; others, 1980; Slemmons and Chung, 1982</td>
</tr>
</tbody>
</table>

* for the maximum earthquake.
## TABLE 2
SUMMARY OF TRENCH RESULTS

<table>
<thead>
<tr>
<th>LINEAMENT NUMBER</th>
<th>TRENCH NUMBER</th>
<th>PLATE NUMBER</th>
<th>EVIDENCE OF FAULTING</th>
<th>EVIDENCE OF SECONDARY EFFECTS</th>
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<tr>
<td>1</td>
<td>4</td>
<td>5-8</td>
<td>NO</td>
<td>NO</td>
</tr>
<tr>
<td>1</td>
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<td>4</td>
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<td>NO</td>
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<td>8 - 11</td>
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<td>8</td>
<td>13 - 14</td>
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<tr>
<td>2</td>
<td>10</td>
<td>15</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>3</td>
<td>USGS (Hart, 1980)</td>
<td>N/A</td>
<td>YES</td>
<td>NO</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>4</td>
<td>YES</td>
<td>NO</td>
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<td>8 - 11</td>
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<td>YES</td>
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<td>12</td>
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<td>?</td>
</tr>
<tr>
<td>4</td>
<td>11</td>
<td>15</td>
<td>?</td>
<td>?</td>
</tr>
</tbody>
</table>

Herd's (1977) Questionable Fault
APPENDIX A

SURFACE FAULT DISPLACEMENT*

A fault is a fracture in the crust of the earth along which the sides have moved or been displaced, relative to each other, in a direction parallel to the fracture. Active faults are the main sources of earthquakes. Land use planners should consider the possible future effects of fault movement in conjunction with the placement and design of new structures. Two aspects of fault displacement should be considered:

- The effects that sudden displacement along faults may have on structures built across their traces.
- The relatively slow effects of fault creep - the gradual ground distortion and movement along a fault trace not accompanied by significant earthquakes.

Fault displacements involve forces so great that the only means of limiting damage to man-made structures is to avoid areas along traces of active faulting or to design structures to accommodate the expected displacement. To avoid faults, their locations must be identified and to design for displacements, the maximum credible earthquake and earthquake mechanisms must be known.

All active and potentially active faults have not been located and mapped. Locating faults is done through geologic mapping and subsurface investigation. Although there are thousands of faults - both large and small - in California, most of these are no longer active and are not likely to be subject to further displacement. Regional studies of fault activity are conducted principally by geologists of the California Division of Mines and Geology, the U.S. Geological Survey and universities; detailed site investigations are conducted by consulting geologists.

Once a trace of an active fault has been recognized, the consulting geologist must advise the developer of the relative risks to developments constructed at different distances from the fault trace. It may be that certain high-risk areas should not be developed. Unfortunately, there are few development guidelines because little is known concerning the detailed effects of fault displacement. Swaths of no development along active fault traces, as narrow as 20 feet

* This discussion is taken largely from Alfors and others (1973) with some modification.
and as wide at 350 feet, have been recommended. In Alameda County a 50 foot set-back from major active faults such as the Hayward and Calaveras faults is generally required. For smaller, less active faults where the potential displacements may be smaller, a lesser amount of set-back might be appropriate.

Existing State legislation treats fault displacement under the general category of geologic hazards. Section 65302 of the Government Code requires each General Plan to contain a seismic safety element including, among other items, the "identification and appraisal of seismic hazards such as susceptibility to surface ruptures from faulting." Section 15002.1 of the State Education Code requires the governing board of any school district to have proposed school sites studied in order to detect the presence of unfavorable geological characteristics. Both laws require appraisals of surface ruptures from faulting, the protection of the community from geologic hazards and geologic mapping in areas of known geologic hazards.

The Alquist-Priolo Act (Hart, 1980), is designed to reduce losses due to fault displacement. This law requires the State Geologist to delineate special studies zones encompassing active and potentially active faults. Local government agencies must require special studies within these zones before permitting structures for human occupancy within the special study zones shall be approved by the city or county having jurisdiction over such lands pursuant to policies and criteria to be established by the State Mining and Geology Board.

The Uniform Building Code does not recognize fault displacement as a factor to be considered during development, but local ordinances are beginning to be enacted to mitigate this problem.

In keeping the hazard of surface fault displacement in perspective with other seismic hazards, it should be noted that losses from fault displacement tend to be low when compared to losses from seismic shaking. Essentially all the damage resulting from the recent (January, 1980) Greenville earthquakes near Livermore resulted from earthquake shaking and not from surface faulting.

Major losses due to fault displacement resulting from the magnitude 6.5, 1972 San Fernando earthquake were limited to an estimated 200 houses (average value $25,000, 1972 dollars) and three commercial buildings (estimated value $200,000) destroyed in 1971 for a total loss of $5,200,000. Structural losses due to fault displacement in 26 other major earthquakes in California are unknown, but were probably small, averaging perhaps $5,000 per event for an additional total of $130,000. Damage to roads, pipelines, canals and other linear man-made facilities can be more significant.
A further aspect of fault displacement is fault creep, which involves the slow movement along a fault without accompanying significant earthquakes. Damage due to fault creep has been recorded along four faults in the San Francisco Bay area; the Hayward fault in Hayward, Berkeley and Richmond; the Calaveras fault in Hollister and east of Morgan Hill; the San Andreas fault south of Hollister, and the Concord fault in Concord.

The creep is expressed by the rupture or bending of buildings, irrigation ditches, tunnels, streets and curbs. Although the structures have been damaged, in all cases they are still in use and, therefore, the losses are small. Fault creep has not been recorded in the Livermore area, although post-earthquake slip has been observed on the Greenville fault (Harsh, 1980), and on the Las Positas fault (Schwartz, 1980).

The present state of the art is such that active faults can be identified and located through detailed geologic mapping, seismicity studies, air photo analysis, and exploratory trenching. Although this is expensive, it is possible to locate most active faults accurately and thereafter guide development so that losses due to fault displacement on known active faults can be reduced.
APPENDIX B
DEFINITION OF ACTIVE AND POTENTIALLY ACTIVE FAULTS

The California Division of Mines and Geology (Hart, 1980) defines an active fault for purposes of complying with the Alquist-Priolo Special Studies Zones Act as follows:

"For purposes of this act, an active fault is defined by the State Mining and Geology Board as one which has 'had surface displacement within Holocene time (about the last 11,000 years).' The inverse of this, that other faults are inactive, is not necessarily true. A fault may be presumed to be inactive based on satisfactory geologic evidence, but the evidence necessary to prove inactivity is difficult to obtain and locally may not exist. The Board's definition of an active fault is intended to represent minimum criteria only, and local jurisdictions 'may wish to impose more restrictive definitions requiring a longer time period of demonstrated absence of displacement for critical structures.'"

For purpose of this Act, faults were considered to be potentially active, and were zoned, if they showed evidence of surface displacement during Quaternary time (last 2 to 3 million years). Exceptions were made for certain Quaternary faults that were presumed to be inactive, on the basis of direct geologic evidence, and these faults were not zoned.

<table>
<thead>
<tr>
<th>GEOLOGIC AGE</th>
<th>YEARS BEFORE PRESENT (estimated)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Era</td>
<td>Period</td>
</tr>
<tr>
<td>CENOZOIC</td>
<td>QUATERNARY</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| Faults along which movement has occurred during this interval are defined as active by Policies and Criteria of the State Mining and Geology Board.

Faults defined as potentially active for the purpose of evaluation for possible zonation.
Twelve (12) exploratory trenches and five (5) test pits, totalling 4,319 feet in length and averaging over ten (10) feet in depth, were excavated and logged between May 7 and June 20, 1985. The purposes of excavating the trenches and test pits were to examine the subsurface materials beneath the site, to make a detailed log of the materials encountered, to formulate an opinion regarding the age of materials encountered, and to evaluate the presence or absence of evidence of faulting.

Trenches were located across suspected traces of the Greenville fault that were compiled from our literature review and aerial photograph interpretation. Test pits were located at five (5) sites having representative topographic and physiographic expression. The locations of the trenches and test pits are shown on Plate 1 and 2.

The exploratory trenches and test pits were excavated by various backhoes, such as a John Deere 810 and a Case 780 backhoe with buckets ranging from 30 to 36 inches wide. The maximum depth of excavation for the trenches was thirteen (13) feet, with most of the trenches averaging about nine (9) to ten (10) feet in depth. The depths of excavation for the test pits ranged from ten (10) to twelve (12) feet. The required depths of excavation for the trenches and test pits were determined in the field by the project geologist. After each trench or test pit was excavated it was shored with hydraulic jacks. Where water was encountered, a portable sump pump was used to drain the excavations. In accordance with the methods described by Taylor and Cluff (1973) and Merrill and Seeley (1980), the south wall of each trench was carefully and completely cleaned of backhoe bucket smear with hand picks. A level string line was established along the cleaned walls of the trenches to provide a horizontal reference for mapping. A 100-foot long surveyor's measuring tape was placed along the level line to establish horizontal station numbers and a six-foot long engineer's measuring staff was used for measurement of vertical elevations. A team of three (3) geologists then made a detailed inspection of the materials encountered to observe potential evidence for faulting. The field geologists were Bill Short, Jaques Hebert, and Bob Fehr. They were supervised, and their work was reviewed, on a daily basis by Marc Seeley, Principal Engineering Geologist of the firm. Stratigraphic contacts and other significant features were measured and logged relative to the level line at a horizontal and vertical scale of one inch equals five feet. The units logged in the trench were visually examined in the field and classified as to mode of origin and composition. Descriptions of the units were made using the Unified Soil Classification, and the Munsell soil color classification chart. The descriptions included notation of the soil structure, texture,
strength, moisture content, minor constituents, and any other distinguishing characteristics present. Representative samples of the soil units from some of the excavations were taken and analyzed in the laboratory for grain size distribution. Organic rich deposits were carefully collected from Trench 4 so as not to be contaminated, and sent to a laboratory for Carbon 14 dating analysis. A fossilized bone found in Trench No. 6 was taken to the paleontology museum at U.C. Berkeley for species and age determination. Descriptions and other notations are presented on the logs (Plates 3 through 16).

During the trenching operations, the trenches were examined a number of times by geologists from various agencies. These geologists included Marc Seeley, Dr. Gary Anttonen, Dr. Ross Wagner and Karen Hee of Merrill, Seeley, Mullen, Sandefur, Inc.; Ed Danohey, Alameda County Geologist; Dr. Dave Carpenter and others from Lawrence Livermore Laboratory; Earl Hart of the California Division of Mines and Geology; as well as geologists from the U.S. Geological Survey.

Dr. Glen Borchardt, Soil Scientist working for Merrill, Seeley, Mullen, Sandefur, Inc., examined the soils in all the test pits and in Trenches 1 and 2 with geologists Marc Seeley, Bill Short, Jaques Hebert, and Bob Fehr. The purpose of these group examinations was to establish a calibration and consistency in describing and logging the soils encountered in the test pits and trenches. Development of a consistent method of interpretation made correlation of specific units possible between the various trenches and test pits.

After the trenches and test pits were logged, survey stakes were placed at the ends of the excavations and at locations of significant features. The hydraulic jacks were then removed and the excavations were backfilled with the native material. The fill was not compacted. Locations of the stakes along the trenches and test pits were surveyed and plotted on the base map (see Plate 1) by Ron Archer, Civil Engineer (Archer, 1985).

Trench No. 1 was located parallel to the trench excavated by the U.S. Geological Survey in 1975 (Hart, 1980). The 120-foot long trench was excavated to a maximum depth of 12 feet, with most of the trench averaging about nine (9) feet in depth. The purposes of this trench were to observe the evidence of faulting reported by Herd (in Hart and Bedrosian, 1980), to learn something about the correlation between the fault and the air photo lineament, and to evaluate the age of soils encountered in the trench.
In this trench we found evidence of a fault (see Plate 4) at approximately Station 26'. The suspected fault was characterized by a zone of clayey sand ranging from 1 to 1½ feet in width within the lowermost unit encountered in the trench (Unit IV). The zone was characterized by a well-defined contact on the west and a slightly less well-defined contact on the east. Within the sandy clay zone there were a few vertically to subvertically oriented pebbles. There appeared to be an additional few similarly oriented pebbles above this zone in the overlying soil Unit (II). Along the western side of the zone were a number of vertically oriented, wet, soft, grayish clay stringers less than 1 inch wide. Also along the western margin of this contact there was a zone of vertical veins of crystallized calcite. After the trench was open for several days these clay stringers were re-examined. At this time the clay was dryer and suggestions of subhorizontal slickensides were observed. With the exception of the few pebbles in Unit II that appeared to be vertically oriented, no suggestion of faulting was observed above a depth of approximately 6 feet. This suspected fault zone is also characterized by a step (down to about 3 feet to the east) in Unit IV. The surface profile above this step and the suspected fault displayed no step but rather a gentle slope to the east with a subtle break in slope about 40 feet to the east of Station 26'. That break-in slope is the location of the air photo lineament shown on Plate 1, and that subtle topographic break is believed to be a very old and eroded (resequent) fault line scarp.

Based on our observations in Trench I and the conclusions of Borchardt (Appendix D) regarding the age of soils in this trench, we concluded that the feature at Station 26' is a very old fault that has not displaced the surface in perhaps forty thousand years. The structure encountered in this trench and represented by the air photo lineament crossed by the trench (Plate 1) is considered to be potentially active.

Trench No. 2 was excavated across a second suspected fault trace farther to the east (Plate 1). The trench was excavated to a maximum depth of eleven (11) feet with an average depth of ten (10) feet. The 200-foot long trench was logged along the westernmost 100 feet. The eastern portion of the trench collapsed due to the high groundwater table and weak materials before the hydraulic jacks could be placed in the trench.

In this trench we found distinct evidence of a fault. This fault is evidenced by a zone of shearing between Station +12½' and Station +25' and an apparent truncated gravel bed at Station +19½' (see Plate 4). This zone is quite complex as shown on the trench log (Plate 4) and included features such as near vertically oriented pebbles, gray silty clay gouge, and near vertically oriented mottling (similar to that observed in Trench I). When the clay gouge was allowed to

...
dry for several days, suggestions of subhorizontal slickensides were observed. These were more distinct than those observed in Trench I. Distinct shears extended through Units IV and II to within about three feet of the surface. There is evidence of a history of multiple displacements suggesting this fault trace has been relatively active as compared to other faults observed in the other trenches (Plate 4). Although surface faulting was observed approximately 1,100 feet to the northwest of this trench along the trend of the trenched lineament, no distinct shears were observed in the uppermost soil unit (I) above the fault. However, some subtle evidence of faulting in the upper soil unit was detected by Hart (personal communication). Above the clearly defined fault in Units IV and II, we observed a zone of step-like ped structures that might have resulted from faulting.

The fault observed between stations +12½' and +25' was approximately 40 feet west of a topographic lineament observed on air photos (Plate I). This feature is similar to that encountered in Trench I in that it appears to be associated with an air photo lineament that represents an eroded (resequent) fault line scarp.

Based on our observations in this trench and on the conclusions of Borchardt (Appendix D) regarding the age of soils, we believe the structure encountered between Stations +12½' and +25' is an old fault with evidence of multiple displacements that has however, been more active during the past forty thousand years than the fault encountered in Trench I. There is a suggestion that the surface soils overlying the fault are disturbed and it is known that there was surface fault displacement to the northwest along this structure therefore, it is our opinion that this fault is active.

Trench No. 3 was excavated twenty (20) feet north of the coved portion of Trench No. 2. The 60-foot long trench was excavated to a maximum depth of 11½ feet with an average depth of 11 feet. Groundwater was encountered at a depth of 10 feet. No evidence of faulting was discovered (see Plate 4).

Trench Nos. 4 and 5 were excavated to check both previously mapped and unmapped (lineaments) suspected traces of the fault within the Alquist-Priolo Special Studies Zone along the southern boundary of the property. The trenches were also used to investigate the soil stratigraphy across the site. Trench No. 4 was excavated for a length of 1,243 feet with an average depth of about 9½ feet and a maximum depth of 12½ feet. Trench No. 5 was excavated to a maximum depth of 13½ feet with an average depth of approximately 8½ feet, for a length of 1,235 feet.
In Trench No. 4 a thin discontinuous organic rich layer of silty clay was discovered between Stations 303' and 550'. In addition, a few discontinuous organic rich appearing zones were encountered farther west in the trench (see Plates 5-8). Samples of the organic material were submitted to a laboratory for radiometric age determinations (see text of Report). Through much of its length, the trench exposed buried channel deposits and silty clay lacustrine deposits. Soil stratigraphy was generally well-defined and groundwater was encountered throughout much of the length of the trench at about 10 feet below the surface. There are a few locations near the western end of the trench where features suggestive of seismic effects were observed (see Plate 8). These features are between Stations 1,118' and 1,205' and are described briefly in the following paragraphs.

At Station 1,118' there is a nearly vertical approximately 1 foot drop (down to the west) in soil Unit III. Below this drop off the contacts between the underlying units are indistinct. No vertical shearing, clay gouge or other indications of faulting were observed here. This location is approximately 35 feet west of the southern end of the air photo lineament that is coincident with the fault encountered in Trench 2.

At Station 1,156' there is a wedge-shaped vertically oriented fissure infilled with more organic rich soil from the overlying unit. There are vertical shears in the infilled soil and olive silty clay along the vertical contact of the fissure. The feature does not extend to the bottom of the trench and was not observed on the north wall. No shearing, or other features suggestive of faulting, were observed above this infilled fissure.

At Station 1,170' there is another one foot downdrop (down to west) in one of the soil units (IVa). This downdrop is associated with a number of vertical shears with soil infilling. Those shears do not extend into the upper three soil units. The lower contact (between Units VIa and III) is indistinct in this area.

At Station 1,205' there is another fissure infilled with soil almost identical to that observed at Station 1,156'.

Based on our observations in this trench and the conclusions of Borchardt (Appendix D) regarding the ages of the soils, we believe the features observed between Stations 1,118' and 1,205' are very old (probably forty thousand years) and are the result of secondary earthquake effects such as lurch cracking, differential settlement and/or lateral spreading, or alternatively these features are the result of very old surface faulting that was dissipated over a wide zone.
In Trench No. 5 the water table was encountered between 7 and 10 feet below the surface and the soils appeared to have a similar genesis as those observed in Trench No. 4 except that these soils are more sandy. There were a few locations where the soils appeared disturbed, possibly by faulting. These locations are described as follows:

Between Stations 64' and 70' there is a distinct color change in Soil Unit 3 along a sloping (down to the west) contact (see Plate 8). The elevation change across this 6 foot distance is about 3 feet. Below this contact is a sand lens that has the appearance of being truncated along its eastern end. There is no evidence of shearing or other features that might suggest fault displacement at this location.

Between Stations 1,180' and 1,200' (Plate II) at the western end of the trench, there is a silty clay (Unit IV) that is rich in sand and pebbles that appears to be strongly downwarped (down to the east). There is however, no suggestion of fault displacement in this area.

Based on our observations in this trench and the conclusions of Borchardt (Appendix D) regarding the ages of the soils, we believe the features observed between Stations 64' and 70' and Stations 1,180' and 1,200' are the result of secondary seismic effects and not surface faulting. The other features observed in this trench are the result of channel erosion and deposition.

Trench No. 6 was excavated across the southern projection of the fault trace exposed by Trench No. 1. The 350-foot long trench was excavated to a maximum depth of 13 feet with an average depth of 12 feet.

In Trench No. 6 we discovered a fault feature between Station 21' and 22' which is about 25 feet east of our air photo lineament that is the southern projection of the lineament that coincides with the fault discovered in Trench No. 2 to the north. The fault feature consists of a truncated sequence of sands and gravels overlying and roughly coincident with four distinct clay stringers (see Plate 12). A sloth bone was discovered in this sand layer sequence at about Station -54' about 40 feet east of the fault. The clay stringers are blue green-gray with some caliche and well-developed clay films on each side. The clay stringers which appear to be fault gouge are truncated by the overlying sand lens.
This feature appears to be a fault gouge zone that has been modified by erosion and has not been active since deposition of the sand lenses and overlying silty clay units. Based on our observations in this trench and Borchardt's conclusions as to the ages of the soils, we believe the fault at this location has not been active for at least forty thousand years. This part of the fault is estimated to be potentially active.

Trench No. 7 was excavated at the base of the hills across two (2) suspected traces of the fault. The 220-foot long trench was excavated to an average depth of 10 feet and a maximum depth of 11½ feet. Bedrock was encountered in the upslope (eastern) part of the trench and good soil stratigraphy was present throughout the length of the trench. No evidence of faulting or secondary earthquake effects were observed.

Trench No. 8 was excavated across the same lineament as that crossed by Trench No. 2. The 280-foot long trench was excavated to a maximum depth of 9½ feet with an average depth of 8½ feet. Due to the high groundwater table, the westernmost 80 feet of the trench collapsed before hydraulic shores could be installed, thus, only the easternmost 197 feet of this trench was logged.

In this trench a number of throughgoing (i.e., observable on both sides of the trench wall) features were observed between Stations 8' and 40' and at Station 119' that were suggestive of seismic ground deformation. These features are thin blue-green clay stringers with caliche, and are generally vertically oriented (see Plate 13). Some, but not all, of these clay seams extended from the bottom of the trench to the top of the lowermost Unit (III). None of the clay seams extended upward into the overlying soil units. There was no evidence of shearing along the clay seams nor was displacement of contacts crossing these features observed. Between Stations 158' and 181' a zone of subhorizontal slickensides was observed in the upper one foot or so of soil Unit III. These features are just to the west of the mapped location of the lineament that is coincident with, but just east of, the fault encountered in Trench No. 2. From Station 190' through the end of the trench at Station 280' a zone of very weak soils and high groundwater was encountered. From Station 197' a massive cave-in occurred which prevented the trench from being logged in detail. This zone includes the area through which the fault trace of Hart and Bedrossion (1980) is mapped and through which the contact between the Cierbo formation and older alluvium is mapped (see Plate 1).
Trench No. 9 was excavated across a questionable trace of the fault which lies outside the Alquist-Priolo Special Studies Zone. The trench was excavated to an average and maximum depth of 9 feet. The stratigraphy in this trench was very pronounced and the soils appeared to be very old with well-developed clay films and strong columnar structure. No evidence or suggestion of faulting was observed (Plate 14).

Trench No. 10 was excavated across the same lineament as Trench Nos. 2 and 8. The 130-foot long trench was excavated to a maximum depth of 12½ feet with an average depth of 11 feet.

In this trench clearer evidence of faulting was observed in addition to evidence of ground shaking effects. At Station 67' (see Plate 15) there is a narrow zone of vertically oriented shearing with subhorizontal slickensides and at least one vertically oriented pebble. Groundwater seepage was occurring on the east side of the shear zone. There is a blue-gray clay stringer parallel to the shear zone in the lower part of the trench. Shears were observed to extend upward into the uppermost soil unit (I). This fault is approximately 35 feet west of the lineament mapped through this area that is coincident with the fault in Trench No. 2 and approximately 10 feet east of the fault as mapped by Hart and Bedrossian (1980) (see Plate I).

At Stations 5', 36', 82' and 89' there are fissures filled in with soil from the overlying soil unit. Those appear to be secondary fault features caused by seismic ground shaking.

Trench No. 11 was excavated across the westernmost suspected trace of the fault within the Alquist-Priolo Special Studies Zone. The 184-foot long trench was excavated to a maximum depth of 11½ feet with an average depth of 10½ feet.

Well developed stratigraphy was observed in this trench. Between Stations 134' and 150' there was a series of near vertically oriented cracks in the lower four soil units (see Plate 15). These cracks are 1/8" to 1/4" wide and some are infilled with carbonate coated fine sand. One of the more pronounced cracks (at Station 134') contained a vertically aligned pebble. That crack was found to be coincident with a mapped lineament (Plate I). No shearing or slickensides were observed along those cracks and their relationship to faulting is questionable, and they appear to be very old features.
Trench No. 12 was excavated at the base of the eastern hills across two (2) lineaments. The 151-foot trench was excavated to a maximum depth of 11½ feet and an average depth of 10 feet. Features suggestive of faulting were not observed in this trench despite well developed soil stratigraphy (see Plate 16).

Test Pit No. 1 was located near the base of the hills on the flood plain of Altamont Creek. The pit was excavated to a depth of 10½ feet (see Plates 1 and 3).

Test Pit No. 2 was located on the slope of a slight topographic high near Altamont Creek. The excavation was dug to a depth of 12 feet (see Plates 1 and 3, and Appendix D).

Test Pit No. 3 was located in the flood plain of Altamont Creek in a topographic low. The pit was excavated to a depth of 12 feet (see Plates 1 and 3, and Appendix D).

Test Pit No. 4 was located outside the Alquist-Priolo Special Studies Zone away from the creek. The pit was dug to a depth of 10½ feet (see Plates 1 and 3, and Appendix D).

Test Pit No. 5 was located near the southern boundary of the property away from Altamont Creek. The pit was dug to a depth of 10 feet (see Plates 1 and 3).
APPENDIX D
INTRODUCTION
An assessment of seismic risk due to fault rupture often can be aided greatly by the techniques of soil science. This is because the youngest geological unit overlying a fault trace is generally a soil horizon. The age of faulting often can be estimated by evaluating the age of overlying soil units displaced or otherwise disturbed by a fault.

Soil horizons exhibit a wide range of physical, chemical, and mineralogical properties that evolve at varying rates. Soil scientists use various terms to describe these properties (see glossary at the end of this Appendix). A black, highly organic "A" horizon, for example, may form within a few centuries, while a dark brown, clayey "Bt" horizon may take as much as 40,000 years to develop. Certain soil properties are invariably absent in the youngest of soils. For instance, soils developed in granitic alluvium of the San Joaquin Valley do not have
Munsell hues redder than 10YR until they are at least 100,000 years old (Harden, 1982; Birkeland, 1984, p. 210). Still other properties, such as the movement and deposition of clay-size particles and the precipitation of calcium carbonate at great depth, indicate soil formation during a climate much wetter than at present. In the absence of a radiometric age date for the parent material of a particular soil, an estimate of its age must take into account all the known properties of the soil and the landscape and climate in which it evolved.

METHOD
The first step in studying a soil is the compilation of the data necessary for describing it (Birkeland, 1984, pp. 353-361). At minimum, this requires a Munsell color chart, hand lens, acid bottle, and pH kit or meter. The second step involves the collection of samples of each horizon for laboratory analysis of particle size. This is done to check the textural classifications made in the field and to evaluate the genetic relationships between horizons and between different soils in the landscape. When warranted, the clay mineralogy and chemistry of the soil is also analyzed in order to provide additional information on the changes undergone by the initial material from which the soil weathered. The last step is the comparison of this accumulated soil data with that for soils having developed
under similar CTPOT* conditions. Such information is scattered in soil survey reports, soil science journals, and consulting reports. In a particular locality, there is seldom enough comparative data available for this purpose. That is why, at the very least, the study of one soil profile always makes the evaluation of the next that much easier.

RESULTS OF THIS EVALUATION

There are two main soil types on the site. The first is a well-drained alluvial soil, San Ysidro loam (Welch and others, 1966, p. 83), best typified by the exposure in Test Pit 4 (Description No. 1, Table D-1, and Description No. 5); the second is a poorly drained flood plain soil, Pescadero clay, best typified by the buried profile in Test Pit 3 (Description No. 2).

Well-drained Soil

Briefly, the most important characteristics of this soil are its:

1. Pale brown (10YR6/3d, 3/3m) loam A horizon with abrupt smooth boundary at 35 cm
2. Dark brown (10YR3/3m, 6/3d) clay to clay loam columnar Bt horizon to 94 cm
3. Manganese-oxide stained light clay loam BCt horizon to 247 cm
4. BCkt horizon to over 300 cm

*Acronym for climate, topography, parent material, organisms, and time; the five factors of soil formation.
This soil is 40,000-80,000 years old. My reasoning is as follows:

1. Structure

Its strong blocky to columnar Bt horizon indicates that this soil is much more than 10,000 years old. Holocene soils (i.e., those less than 10,000 years old) generally do not have blocky or columnar structure and usually do not have clay films in the B horizon.

2. Depth

This soil profile's deep BCt and BCkt horizons indicate that most of its development occurred under a climatic regime much wetter than at present. The high pH of the Bt2 horizon at the 70-cm depth reveals this to be the current maximum depth of soil leaching. During the wet period the corresponding zone developed at 247 cm, indicating that rainfall was about three and a half times what it is now. A similar observation was made for Pleistocene soils in Southern California (Mcfadden, 1982).

3. Particle Size Distribution

The laboratory results indicate a particle size distribution typical of a moderately to strongly developed soil (Table D-2 and Figure D-1). As expected, clay contents in the A horizon are uniformly low—primarily as a result of translocation to the B horizon and mixing by ground squirrels. The clay content of the upper portion of the B horizon is higher than in the lower
portion—a phenomenon generally indicative of soils that are greater than 10,000 years old. The soil seems to have developed from a single parent material, as indicated by the relative uniformity of various sand and silt ratios (Table D-3).

4. Color
The dark brown (10YR3/3m) color of the B horizon, however, is not red enough and the clay content in the B horizon is not great enough for this soil to be older than 100,000 years. Soils on Herd's (1977) much older Qoa3 and Qoa4 surfaces in the Livermore area generally have 5YR colors.

5. Age of the Parent Material
Herd (1977) mapped the alluvium in the area as Qoa2, the second oldest of four Pleistocene units, but gave no age estimates except to say that all Qoa units have soils with argillic (Bt) horizons. He cited the oft-repeated generalization (see Birkeland, 1984, p. 208) that Bt horizons require up to 40,000 years to form in the sandy glacial outwash in the San Joaquin Valley. Unfortunately, this observation does not apply directly to our site because the parent materials here have significant quantities of clay prior to soil development. Bt horizons form within 9,000 years in colluvium reworked from clayey paleosols in the Sierran foothills (Borchardt, Rice, and Taylor, 1980). They also develop within 10,000 years in semiarid Southern California (McFadden, 1982). Even in subhumid
Wisconsin, Bt horizons do not form in sandy soils during the Holocene unless a clay-rich loess cap is present (Borchardt, Hole, and Jackson, 1968).

Helley and others (1979) classified the alluvium in the area as late Pleistocene—between 10,000 and 70,000(? years old (p. 35). Their younger age is applicable for materials near San Francisco Bay that are graded to the current high stand of sea level, while the older age seems applicable to our site.

6. Quaternary Stratigraphy
Soil stratigraphers often attempt to correlate the dates of alluvial deposition with glacial events and corresponding changes in sea level. There are two main approaches to this effort. In the first and most common, sedimentary deposition is considered to be rapid during glacial advances and soil formation is considered to occur only during interglacial periods (Morrison, 1978). In the second, sedimentary deposition is considered to occur during interglacial periods and soil formation to occur during glacial periods. The first approach is suited, of course, to areas actually covered by continental and alpine glaciation or subject to alluvial or eolian deposition as a direct result of glaciation. However, as pointed out by Borchardt, Rice, and Taylor (1980), the second approach is necessary for understanding soil formation in areas now subject to a Mediterranean climate. Our site is such an area.
In the San Francisco Bay area the cool, wet climate produced during glacial periods generally produced stable land surfaces on which soils could form rapidly. The change in climate allowed coniferous woodlands consisting mostly of Douglas-fir and incense-cedar to grow on the alluvial deposits in the flat inland valleys (Helley and others, 1979, p. 18). During these periods sea level dropped by more than 100 meters, causing Bay area streams to cut new base levels to the sea. This resulted in the abandonment of alluvial fans and flood plains in the valleys and of river terraces high on the sides of valleys. Sediments were carried far out to sea instead of being deposited in the inland valleys and at the base of the hills surrounding the Bay. In accord with the second approach to soil stratigraphy, the glacial period was occasion for soils to develop at the bottom of what is now San Francisco Bay (Helley and others, 1979, p. 35).

We are currently in an interglacial period in which alluvial deposition once again is quite rapid. Aggradation is occurring at average rates up to a meter per thousand years on inland flood plains such as those in the San Ramon Valley (Wigginton and Carey, 1982) and on alluvial fans such as the one at the mouth of Alameda Creek at Niles. Being active depositional surfaces, soils in these areas seldom get more than a few centuries of aerial exposure before they are buried by the next flood deposit. As we will see in the next description, the return to an
aggrading environment has affected some of the soils on the site.

In sum, the parent material for this soil most likely was deposited during the last major interglacial period (isotope stage 5; Shackleton and Opdyke, 1973) prior to 80,000 years B.P. when the climate and sea level was much like it is now. Alternatively, it may have been deposited during the minor interglacial event (isotope stage 3) that occurred between 40,000 and 60,000 years ago. In either case, the soil would have experienced the high rainfall, cool climate, and invasion of conifers that occurred with the advance of the continental and alpine glaciers. This climate caused carbonates to be deposited at depths below 2.5 meters. As indicated by the high pH in the Bt2 horizon, the present climate barely allows carbonates to be leached to a depth of 70 cm. Because clay illuviation generally does not occur below the active zone of carbonate accumulation, the present climate is incapable of producing the majority of clay films found in this soil.
Poorly Drained Soil

This soil is the poorly drained phase of the one above and is overlain by a thin alluvial deposit which is not more than 10,000 years old. Briefly, the most important characteristics (Description No. 2) of this soil are its:

1. Grayish brown (10YR5/2d, 4/2m) loam A horizon with abrupt smooth boundary at 10 cm
2. Grayish brown (10YR5/2d, 4/2m) light clay loam Bt horizon to 24 cm
3. Very dark gray (10YR3/1d) light silty clay 2Ab horizon to 37 cm
4. Very dark gray (10YR3/1md) clay 2Abk horizon to 60 cm
5. Grayish brown (10YR5/2d, 6/2m) clay 2Bgb horizon to 138 cm
6. Greenish gray (5GY5/1m) mottled silty clay 2Btgb horizon with low chroma clay films to 270 cm

This is a two-story soil. From a distance, the upper soil looks like a thin (24 cm) flood plain deposit not more than a few centuries old. Closer inspection, however, reveals that the lower portion of the unit is a Bt horizon having angular blocky structure and incipient clay films on pedds and in pores. Laboratory analysis verified that this horizon does indeed have more clay (27%) than the one above it (22%) (Table D-2 and Figure D-2). The depositional discontinuity at 24 cm is confirmed by sand-to-silt ratios in the upper depositional unit that are three
to four times greater than those in the material below (Table D-3). Also unlike the material below, it contains almost no coarse sand (Table D-2). It appears to be the only Holocene deposit in evidence at this site, the buried A horizon beneath it being extremely high in clay and showing few signs of having received additions of coarse fluvial or lacustrine materials in the past. The lower portion of the buried A horizon contains veinlets of calcium carbonate that effervesce violently with HCl. This is an additional indicator of the considerable age of the material that buried it—such features can take thousands of years to develop. It is possible that the upper unit may be coeval with the widespread colluvial event that affected the Sierran Foothills about 9,000 years ago (Borchardt, Rice, and Taylor, 1980).

The lower story of this soil profile appears to be the poorly drained phase of the well-drained soil already described and considered to be between 40,000 and 80,000 years old. Although the two soils are the same age, the soil at this poorly drained site contains much greater quantities of clay. This is to be expected. Borchardt and Hill (1985), for instance, have shown that clay in sandy Holocene alluvium forms ten times faster in poorly drained sites than in upland sites.

One observation may have a bearing on tectonic activity in the area. At depths below 138 cm, this soil has common low chroma clay films in pores (Description No. 2). Because clay films are
rare in poorly drained soils, this may indicate that the soil was well drained during its early evolution and that the oxides in then existing clay films were subsequently reduced. This is consistent with the fact that the site is currently a depression in what once must have been a higher position in the landscape at the time of its original deposition.

Trench No. 1

The soils in this trench are exceedingly complex. The eastern end of the trench has soil similar to the well-drained soil whose age was estimated at 40,000 to 80,000 years B.P. Proceeding upslope and to the west, we reach the soil at Station 30.5 (Description No. 3), which is 1.5 m east of the contact with the Cierbo Formation. This soil has a clay loam A horizon and a clay loam Bw horizon (i.e., a "structural B horizon" devoid of clay films.) The particle size distribution within both horizons is nearly identical (Table D-2). This is typical of "vertisols", that is, soils in which the surface material tends to mix with the B horizon by falling into shrinkage cracks during the summer. This process tends to destroy existing clay films, which nevertheless may be found at depth in the BCt horizon. As mentioned, these are indicative of Pleistocene soil development. About 3 m to the west and on the other side of the suspect contact (see trench logs), the soil at Station 21.5 (Description
No. 4), has a strong brown (7.5YR) Bt horizon. This horizon, like the B horizon at Station 30.5, is gradually being destroyed by the infilling of material from the A horizon. Clay films still exist in this horizon and also in the deep BCt horizon beneath it. The strong brown colors seem indicative of development in an alluvial unit still older than the Qoa2--perhaps the Qoa3 of Herd (1977).

The dense, well crystallized calcium carbonate concretions and veins encountered at 252 cm may be part of the Cierbo Formation or a still older alluvial unit. Clasts reworked from this zone were found surrounded by a matrix of alluvium in the parent material of the soils on both sides of the contact.

No tectonic shears were observed at the geologic contact in this trench and no shears or offsets were observed in the B horizons at Station 30.5, Station 21.5, or the soil between them.

CONCLUSION

A similar approach may now be taken to assess the age of faulting wherever the soils are similar to the San Ysidro loam or the buried Pescadero clay described here. In particular, Holocene tectonic movement might be indicated by a disruption of the pedogenic carbonate distributed between 50 and 300 cm or by offsets of B horizons exhibiting clay films or strong blocky structure. Post 40,000-year movement surely would be indicated by offset of clay films found in deep BCt horizons.
REFERENCES


DESCRIPTION NO. 1

SOIL PROFILE DESCRIPTION FOR TEST PIT 4 ON THE BIBLER PROPERTY, LIVERMORE, CA

San Ysidro loam described on May 8, 1985 at approximately 37 deg. 43 min. latitude, 121 deg. 42 min. longitude and 169 m elevation. North face of a 3.2-m excavation on an alluvial plain about 200 m northeast of Green School on Laughlin Road northeast of Livermore, CA. Parent material is Quaternary alluvium (unit Qoa2 of Herd (1977)). Mediterranean climate with mean annual precipitation of 380 mm. Grassland vegetation. Slope 2% east. Drainage good. Soil dry in surface, moist below the Bt horizon. The soil is slightly acid in the A horizon, becoming strongly alkaline in the Bt2 horizon and mildly alkaline in the C horizon. Numerous ground squirrels inhabit the area. Tentative scientific classification: Abruptic Palexeralf.

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Depth, cm</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0-35</td>
<td>Pale brown (10YR6/3d, 3/3m) loam; coarse strong granular to coarse moderate subangular blocky structure; slightly sticky and slightly plastic when wet, slightly hard when dry; many very fine roots; many very fine to medium discontinuous random vesicular pores; pH 6.35 at 0-10 cm, 6.25 at 10-25 cm, and 6.58 at 25-35 cm; abrupt smooth boundary (Sample Nos. 85B075, 76, and 77, respectively). ESTIMATED AGE = 40,000 to 80,000 years.</td>
</tr>
<tr>
<td>Bt1</td>
<td>35-70</td>
<td>Dark brown (10YR3/3m, 6/3d) clay; coarse strong blocky to medium moderate columnar structure; sticky and plastic when wet, hard when dry; few very fine roots; few very fine continuous random dendritic tubular pores; few thick clay films in pores; few vertical 2 mm-wide tongues of soil from the A horizon; upper peds have rounded silt caps; pH 7.32; gradual smooth boundary (Sample No. 85B078). ESTIMATED AGE = 40,000 to 80,000 years.</td>
</tr>
<tr>
<td>Bt2</td>
<td>0-94</td>
<td>Dark brown (10YR3/3m, 5/6d) clay loam; coarse strong blocky structure; sticky and plastic when wet, hard when dry; few very fine roots; few very fine continuous random dendritic tubular pores; common thin to moderately thick clay films in pores; few thin clay films on peds; pH 8.69; gradual smooth boundary (Sample No. 85B079). ESTIMATED AGE = 40,000 to 80,000 years.</td>
</tr>
<tr>
<td>Bct</td>
<td>94-247</td>
<td>Yellowish brown (10YR5/4m, 6/4d) light clay loam with many medium prominent black (10YR2/1md) mottles; medium strong angular blocky structure; slightly sticky and slightly plastic when wet, slightly hard when dry; few very fine continuous random dendritic tubular pores; few thin clay films in pores; many moderately thick clay films on vertical ped faces; many</td>
</tr>
</tbody>
</table>
thick clay films in vertical fissures; many clay films on ped surfaces coated with manganese oxides; pH 8.02; diffuse smooth boundary (Sample No. 85B080). ESTIMATED AGE = 40,000 to 80,000 years.

**BCkt 247-300**

Yellowish brown (10YR5/6m, 6/4d) light clay loam with common medium prominent black (10YR2/1md) mottles overlying clay films and common white (10YR8/1md) moderately thick veinlets of calcium carbonate that effervesce strongly with HCl; medium strong angular blocky structure; slightly sticky and slightly plastic when wet, firm when moist, slightly hard when dry; few very fine continuous random dendritic tubular pores; continuous thin to moderately thick clay films in pores and on peds; pH 7.91; diffuse smooth boundary (Sample No. 85B081). ESTIMATED AGE = 40,000 to 80,000 years.

**C 300-320**

Yellowish brown (10YR5/6m, 6/6d) heavy loam with few medium prominent black (10YR2/1md) manganese oxide coatings adjacent to pores on ped faces and common white (10YR8/1md) thin veinlets of calcium carbonate that effervesce strongly with HCl; massive structure; slightly sticky and slightly plastic when wet, slightly hard when dry; few very fine and medium continuous random dendritic tubular pores; continuous moderately thick clay films in pores commonly overlying calcium carbonate; pH 7.79 (Sample No. 85B082). ESTIMATED AGE = 40,000 to 80,000 years.
DESCRIPTION NO. 2

SOIL PROFILE DESCRIPTION FOR TEST PIT 3 ON THE BIBLER PROPERTY, LIVERMORE, CA

Buried Pescadero clay described on May 8, 1985 at approximately 37 deg. 43 min. latitude, 121 deg. 42 min. longitude and 171 m elevation. South face of a 3-m excavation in an alluvial depression about 570 m east of Laughlin Road, Livermore, CA. Parent material is Recent flood plain alluvium (unit Qfa of Herd (1977)). Mediterranean climate with mean annual precipitation of 380 mm. Grassland vegetation. Slope less than 1% to the south. Drainage poor. Soil dry to 60 cm and moist to water table at 270 cm. The soil is neutral in the A horizon, strongly alkaline in the 2Abk horizon, and very strongly alkaline at lower depths. Tentative scientific classification: Fluvaquentic Haplaquoll.

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Depth, cm</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0-10</td>
<td>Grayish brown (10YR5/2d, 4/2m) loam; coarse strong granular structure; slightly sticky and slightly plastic when wet, very hard when dry; many very fine roots; common medium roots; many very fine and medium continuous random dendritic tubular pores; few medium continuous vertical simple tubular pores; pH 6.64; abrupt smooth boundary (Sample No. 85B069). ESTIMATED AGE = 9,000 to 10,000 years.</td>
</tr>
<tr>
<td>Bt</td>
<td>10-24</td>
<td>Grayish brown (10YR5/2d, 4/2m) light clay loam; coarse strong angular blocky structure; slightly sticky and slightly plastic when wet, very hard when dry; many very fine roots; common medium roots; many very fine and medium continuous random dendritic tubular pores; few medium continuous vertical simple tubular pores; few thin clay films on peds and in pores; lower 5 cm has thin horizontal laminae of alternating light and dark gray silty clay loam; pH 7.00; abrupt smooth boundary (Sample No. 85B070). ESTIMATED AGE = 9,000 to 10,000 years.</td>
</tr>
<tr>
<td>2Ab</td>
<td>24-37</td>
<td>Very dark gray (10YR3/1md) light silty clay; coarse moderate subangular blocky to angular blocky structure; sticky and plastic when wet, firm when moist, very hard when dry; many very fine roots; few medium roots; many very fine and fine continuous random dendritic tubular pores; few medium continuous vertical simple tubular pores; common pressure faces and random slickensides on peds; pH 8.55; clear smooth boundary (Sample No. 85B071). ESTIMATED AGE = 40,000 to 80,000 years.</td>
</tr>
<tr>
<td>2Abk</td>
<td>37-60</td>
<td>Very dark gray (10YR3/1dm) clay with common white (10YR8/1md) thin veinlets of calcium carbonate that effervesce violently</td>
</tr>
</tbody>
</table>
with HCl; coarse moderate subangular blocky structure; sticky and plastic when wet, firm when moist, very hard when dry; common very fine roots; few medium roots; many very fine and fine continuous random dendritic tubular pores; few medium continuous vertical simple tubular pores; common pressure faces and random slickensides on peds; pH 8.83; gradual smooth boundary (Sample No. 85B072). ESTIMATED AGE = 40,000 to 80,000 years.

2Bgb  60-138
Grayish brown (10YR5/2m, 6/2d) clay with common vertical tongues of dark grayish brown (10YR4/2m) clay; massive to medium moderate subangular blocky structure; sticky and plastic when wet, slightly hard when dry; few very fine roots; few medium roots; common pressure faces and random slickensides on peds; effervesces slightly with HCl; pH 9.32; diffuse smooth boundary (Sample No. 85B073). ESTIMATED AGE = 40,000 to 80,000 years.

2Btgb  138-270
Greenish gray (5GY5/1m) silty clay with mottles of yellowish brown (10YR5/6m), white (10YR8/2md), and black (N2/0md); massive structure; sticky and plastic when wet, very hard when dry; few medium roots; many very fine continuous random dendritic tubular pores; rare 1-mm flakes of vermiculite; common isolated and weathered manganese oxide coatings; common thick low chroma clay films on pores; effervesces very slightly with HCl; pH 9.19 (Sample No. 85B074). ESTIMATED AGE = 40,000 to 80,000 years.
Soils in Trench No. 1

DESCRIPTION NO. 3

SOIL PROFILE DESCRIPTION FOR STATION 30,5 IN TRENCH NO. 1
BIBLER PROPERTY, LIVERMORE, CA

Chromic Pelloxerert described on May 8, 1985 at approximately 37 deg. 43 min. latitude, 121 deg. 42 min. longitude and 174 m elevation. South face about 1.5 m east of the contact between late Pleistocene alluvium and the Cierbo Formation. Site is about 3 m south of a trench excavated in 1975 by the USGS. Parent material is Quaternary alluvium (unit Qoa2 of Herd (1977)). Mediterranean climate with mean annual precipitation of 380 mm. Grassland vegetation. Slope about 7% east. Drainage good. The soil is neutral in the A horizon, strongly alkaline in the BCt2 horizon, and moderately alkaline at depth.

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Depth, cm</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0-22</td>
<td>Dark grayish brown (10YR4/2d, 3/2m) clay loam; coarse strong subangular blocky to medium weak angular blocky structure; slightly sticky and slightly plastic when wet, extremely hard when dry; many very fine roots; few very fine continuous random tubular pores; rounded and angular gravel to 2 cm; pH 7.23; diffuse smooth boundary (Sample No. 85B052). ESTIMATED AGE = 40,000 to 80,000 years.</td>
</tr>
<tr>
<td>Bw</td>
<td>22-70</td>
<td>Yellowish brown (10YR3/2m) clay loam; coarse strong blocky structure; slightly sticky and slightly plastic when wet, very firm when moist; many very fine roots; common very fine continuous vertical simple tubular pores; more gravel than above horizon; pH 8.06; clear smooth boundary (Sample No. 85B053). ESTIMATED AGE = 40,000 to 80,000 years.</td>
</tr>
<tr>
<td>BCt1</td>
<td>70-100</td>
<td>Yellowish brown (10YR5/4m) loam; massive to medium weak angular blocky structure; slightly sticky and slightly plastic when wet, friable when moist; few very fine roots; many very fine continuous random dendritic tubular pores; few thin strong brown (7.5YR4/6m) clay films on peds; few calcareous fragments; pH 8.48; diffuse smooth boundary (Sample No. 85B054). ESTIMATED AGE = 40,000 to 80,000 years.</td>
</tr>
<tr>
<td>BCt2</td>
<td>100-130</td>
<td>Yellowish brown (10YR5/6m) loam; massive structure; sticky and slightly plastic when wet, very firm when moist; many very fine continuous vertical simple tubular pores; many thick strong brown (7.5YR4/6m) clay films in pores and in fractures; pH 8.91; diffuse smooth boundary (Sample No. 85B055). ESTIMATED AGE = 40,000 to 80,000 years.</td>
</tr>
<tr>
<td>2Bct</td>
<td>130-225</td>
<td>Yellowish brown (10YR5/4m) silty clay loam; massive structure; slightly sticky and slightly plastic when wet, very friable when moist; continuous thick clay films on clasts and in vertical fissures; pH 8.12; clear smooth boundary (Sample No. 85B056). ESTIMATED AGE = 40,000 to 80,000 years.</td>
</tr>
<tr>
<td>3Bct1</td>
<td>225-265</td>
<td>Yellowish brown (10YR5/4m) sandy clay loam; massive structure; slightly sticky and slightly plastic when wet, very friable when moist; continuous thick clay films on clasts and in vertical fissures; many detrital calcium carbonate clasts; pH 8.14; diffuse smooth boundary (Sample No. 85B057). ESTIMATED AGE = 40,000 to 80,000 years.</td>
</tr>
<tr>
<td>3Bct2</td>
<td>265+</td>
<td>Light yellowish brown (10YR6/4m) sandy clay loam; massive structure; slightly sticky and slightly plastic when wet, very friable when moist; many very fine continuous random dendritic tubular pores; continuous thick dark yellowish brown (10YR4/6m) clay films on calcium carbonate clasts; pH 8.21 (Sample No. 85B058). ESTIMATED AGE = 40,000 to 80,000 years.</td>
</tr>
</tbody>
</table>

Most important characteristics for field identification: 1. Dark grayish brown (10YR4/2d) clay loam A horizon  2. Very dark grayish brown (10YR3/2m) clay loam Bw horizon to 70 cm  3. Yellowish brown (10YR5/4m) BCt horizon to 265+ cm
DESCRIPTION NO. 4

SOIL PROFILE DESCRIPTION FOR STATION 21.5 IN TRENCH NO. 1
BIBLER PROPERTY, LIVERMORE, CA

Typic Argixeroll described on May 8, 1985 at approximately 37 deg. 43 min. latitude, 121 deg. 42 min. longitude and 174 m elevation. South face about 1.5 m west of the contact between late Pleistocene alluvium and the Cierbo Formation. Site is about 3 m south of a trench excavated in 1975 by the USGS. Parent material is Quaternary alluvium (unit Qoa3(?) of Herd (1977)). Mediterranean climate with mean annual precipitation of 380 mm. Grassland vegetation. Slope about 7% east. Drainage good. The soil is mildly alkaline in the A horizon and strongly alkaline at depth.

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Depth, cm</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0-20</td>
<td>Very dark grayish brown (10YR3/2dm) silty clay loam; coarse moderate subangular blocky structure; slightly sticky and slightly plastic when wet; many very fine roots; many very fine and few medium continuous random tubular pores; pH 7.54; diffuse smooth boundary (Sample No. 85B059). ESTIMATED AGE = 40,000 to 80,000 years.</td>
</tr>
<tr>
<td>AB</td>
<td>20-41</td>
<td>Very dark grayish brown (10YR3/2dm) silty clay loam; coarse moderate subangular blocky structure; slightly sticky and slightly plastic when wet; many very fine roots; many very fine continuous random tubular pores; few thin clay films on sand grains; pH 7.35; gradual smooth boundary (Sample No. 85B060). ESTIMATED AGE = 40,000 to 80,000 years.</td>
</tr>
<tr>
<td>A/Bt</td>
<td>41-75</td>
<td>Strong brown (7.5YR5/6dm) silty clay; coarse strong blocky structure; sticky and plastic when wet; many very fine roots; many very fine continuous random dendritic tubular pores; few thin clay films on sand grains; many thin vertical tongues of dark grayish brown (10YR3/2dm) soil from the A horizon; pH 8.10; clear smooth boundary (Sample No. 85B061). ESTIMATED AGE = 40,000 to 80,000 years.</td>
</tr>
<tr>
<td>Bct</td>
<td>75-170</td>
<td>Strong brown (7.5YR5/6dm) clay loam; medium moderate angular blocky structure; slightly sticky and slightly plastic when wet; continuous moderately thick clay films on peds; pH 8.54; abrupt wavy boundary (Sample No. 85B062). ESTIMATED AGE = 40,000 to 80,000 years.</td>
</tr>
<tr>
<td>2Bct</td>
<td>170-252</td>
<td>Brownish yellow (10YR6/6m) silty clay; massive to coarse weak subangular structure; sticky and plastic when wet; continuous moderately thick strong brown (7.5YR5/6m) clay films in pores</td>
</tr>
</tbody>
</table>
D-22

and in fractures; pH 8.72; abrupt wavy boundary (Sample No. 85B063). ESTIMATED AGE = 40,000 to 80,000 years.

3K 252-277 Very pale brown (10YR8/3m) up to 100 mm crystallized concretions and 10-mm thick vertical veins of calcite in a matrix of brownish yellow (10YR6/6m) silty clay; massive to coarse moderate subangular blocky structure; sticky and plastic when wet; common thick dark yellowish brown (10YR4/6m) clay films on calcite concretions overlain by manganese oxide coatings; pH 9.04; diffuse wavy boundary (Sample No. 85B064). ESTIMATED AGE = >80,000 years.

Most important characteristics for field identification: 1. Very dark grayish brown (10YR3/2dm) silty clay loam A horizon extending via vertical tongues into: 2. Strong brown (7.5YR5/6dm) silty clay Bt horizon with coarse strong blocky structure 3. Strong brown (7.5YR5/6dm) clay loam Bt horizon to 70 cm 4. Concretions and vertical veins of crystallized calcite at 252 cm
DESCRIPTION NO. 5

SOIL PROFILE DESCRIPTION FOR TEST PIT 2 ON THE BIBLER PROPERTY, LIVERMORE, CA

San Ysidro loam described on May 7, 1985 at approximately 37 deg. 43 min. latitude, 121 deg. 42 min. longitude and 170 m elevation. South face of a 3-m excavation on an alluvial plain about 20 m east the small, meandering stream that drains the area east of Laughlin Road northeast of Livermore, CA. Parent material is Quaternary alluvium (unit Qoa2 of Herd (1977)). Mediterranean climate with mean annual precipitation of 380 mm. Grassland vegetation. Slope 2% southwest. Drainage good with water table at 3 m. Erosion slight. Soil dry in surface, moist below the Bt horizon. The soil is strongly acid in the A horizon and strongly alkaline in the BCt horizon. This is a shallow variant of the dominant soil in the area which is represented by the soil in TP4. Tentative classification: Abruptic Palexeralf.

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Depth, cm</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0-20</td>
<td>Light yellowish brown (10YR6/4d, 3/3m) loam; massive to fine weak granular structure; slightly sticky and slightly plastic when wet, slightly hard when dry; many very fine roots; few very fine to medium discontinuous random vesicular pores; pH 5.40; abrupt smooth boundary (Sample No. 85B065). ESTIMATED AGE = 40,000 to 80,000 years.</td>
</tr>
<tr>
<td>Bt</td>
<td>20-48</td>
<td>Brown (10YR4/3d, 3/3m) loam; coarse strong blocky structure; sticky and plastic when wet, extremely hard when dry; many very fine roots; continuous thin clay films on peds overlain by few manganese oxide coatings; few thin clay films in pores; pH 7.77; clear smooth boundary (Sample No. 85B066). ESTIMATED AGE = 40,000 to 80,000 years.</td>
</tr>
<tr>
<td>BCt1</td>
<td>48-150</td>
<td>Dark yellowish brown (10YR4/4m) light clay loam; medium angular blocky structure; slightly sticky and slightly plastic when wet, very friable when moist; continuous thick clay films in pores and on peds; many clay films on ped surfaces coated with manganese oxides; pH 8.56; diffuse smooth boundary (85B0067). ESTIMATED AGE = 40,000 to 80,000 years.</td>
</tr>
<tr>
<td>BCt2</td>
<td>150-300</td>
<td>Dark yellowish brown (10YR4/4m) loam; massive structure; few thick clay films in pores; pH 8.66; abrupt smooth boundary (Sample No. 85B068). ESTIMATED AGE = 40,000 to 80,000 years.</td>
</tr>
<tr>
<td>2C</td>
<td>300+</td>
<td>Sand. ESTIMATED AGE = 40,000 to 80,000 years.</td>
</tr>
</tbody>
</table>

Most important characteristics for field identification: 1. Pale brown (10YR6/3d) loam A horizon 2. Manganese-oxide stained BCt horizon to 300 cm
Table D-1. Soils in Test Pits 1 and 5 were similar to the one in Test Pit 4. The following measurements illustrate the range in properties:

<table>
<thead>
<tr>
<th>Property</th>
<th>Test Pit No. 1</th>
<th>Test Pit No. 4</th>
<th>Test Pit No. 5</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A horizon, cm</strong></td>
<td>0-38</td>
<td>0-35</td>
<td>0-45</td>
</tr>
<tr>
<td>color</td>
<td>10YR6/4d</td>
<td>10YR6/3d</td>
<td>10YR6/3d</td>
</tr>
<tr>
<td></td>
<td>10YR4/4m</td>
<td>10YR3/3m</td>
<td>10YR3/3m</td>
</tr>
<tr>
<td><strong>pH average</strong></td>
<td>6.10</td>
<td>6.40</td>
<td>6.31</td>
</tr>
<tr>
<td><strong>Bt horizon, cm</strong></td>
<td>38-100</td>
<td>35-94</td>
<td>45-90</td>
</tr>
<tr>
<td>color</td>
<td>10YR4/4m</td>
<td>10YR3/3m</td>
<td>10YR4/3m</td>
</tr>
<tr>
<td><strong>pH average</strong></td>
<td>8.32</td>
<td>8.01</td>
<td>8.25</td>
</tr>
<tr>
<td><strong>Water table, cm</strong></td>
<td>201</td>
<td>&gt;320</td>
<td>&gt;274</td>
</tr>
<tr>
<td><strong>Depth to BCkt, cm</strong></td>
<td>nd*</td>
<td>247</td>
<td>214</td>
</tr>
</tbody>
</table>

Comments:

TP1 had a dark yellowish brown (10YR3/4m) krotovina at 115 cm that had a pH of 8.89. This was in equilibrium with its surrounding matrix which had a pH of 8.99. This indicates that the krotovina was derived from the present surface, but that sufficient time has passed for it to attain the high pH of its surroundings.

TP5 had the following additional horizons produced by variations in the alluvial parent material:
- BCt1 horizon 90-186 cm fine loamy sand grading to medium loamy sand
- BCt2 horizon 186-189 cm gravel
- BCt3 horizon 189-214 cm sandy clay loam
- BCkt4 horizon 214-274 cm silty clay loam

*nd = not determined
Table D-2. Particle size distribution of soil profiles sampled along the Greenville fault, Livermore, California.

<table>
<thead>
<tr>
<th>Field sampled, Horizon</th>
<th>Total</th>
<th>Sand</th>
<th>Silt</th>
<th>Clay</th>
<th>Very Coarse Coarse Medium Fine Very Coarse Coarse Medium Fine &gt;2 mm of whole</th>
<th>Texture</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interval</td>
<td>No. cm</td>
<td>0.05-</td>
<td>0.002</td>
<td>2-0.05</td>
<td>0.05</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>85B075</td>
<td>0-10</td>
<td>A1</td>
<td>39.0</td>
<td>46.0</td>
<td>15.0</td>
<td>0.0</td>
</tr>
<tr>
<td>85B076</td>
<td>10-25</td>
<td>A2</td>
<td>37.5</td>
<td>46.1</td>
<td>16.4</td>
<td>0.0</td>
</tr>
<tr>
<td>85B077</td>
<td>25-35</td>
<td>A3</td>
<td>36.0</td>
<td>48.0</td>
<td>16.0</td>
<td>0.0</td>
</tr>
<tr>
<td>85B078</td>
<td>35-70</td>
<td>Bt1</td>
<td>21.0</td>
<td>37.0</td>
<td>42.0</td>
<td>0.0</td>
</tr>
<tr>
<td>85B079</td>
<td>70-94</td>
<td>Bt2</td>
<td>28.0</td>
<td>39.2</td>
<td>32.8</td>
<td>0.0</td>
</tr>
<tr>
<td>85B080</td>
<td>94-247</td>
<td>Bct</td>
<td>23.0</td>
<td>49.0</td>
<td>28.0</td>
<td>0.5</td>
</tr>
<tr>
<td>85B081</td>
<td>247-300</td>
<td>Bckt</td>
<td>29.9</td>
<td>41.6</td>
<td>28.5</td>
<td>0.3</td>
</tr>
<tr>
<td>85B082</td>
<td>300-320</td>
<td>C</td>
<td>33.3</td>
<td>42.8</td>
<td>23.9</td>
<td>0.2</td>
</tr>
<tr>
<td>85B095</td>
<td>0-10</td>
<td>A</td>
<td>36.0</td>
<td>42.0</td>
<td>22.0</td>
<td>0.7</td>
</tr>
<tr>
<td>85B090</td>
<td>10-24</td>
<td>Bt</td>
<td>29.0</td>
<td>44.0</td>
<td>27.0</td>
<td>0.0</td>
</tr>
<tr>
<td>85B091</td>
<td>24-37</td>
<td>2Ab</td>
<td>12.0</td>
<td>48.0</td>
<td>40.0</td>
<td>0.0</td>
</tr>
<tr>
<td>85B092</td>
<td>37-60</td>
<td>2Abk</td>
<td>8.0</td>
<td>33.5</td>
<td>58.5</td>
<td>0.0</td>
</tr>
<tr>
<td>85B093</td>
<td>60-138</td>
<td>2Bgb</td>
<td>7.0</td>
<td>31.5</td>
<td>61.5</td>
<td>0.0</td>
</tr>
<tr>
<td>85B094</td>
<td>138-270</td>
<td>2Btgb</td>
<td>11.0</td>
<td>51.5</td>
<td>37.5</td>
<td>0.0</td>
</tr>
<tr>
<td>85B095</td>
<td>0-20</td>
<td>A</td>
<td>39.0</td>
<td>52.0</td>
<td>9.0</td>
<td>0.0</td>
</tr>
<tr>
<td>85B096</td>
<td>20-48</td>
<td>Bt</td>
<td>26.0</td>
<td>51.0</td>
<td>23.0</td>
<td>0.0</td>
</tr>
<tr>
<td>85B097</td>
<td>48-150</td>
<td>Bct1</td>
<td>27.5</td>
<td>45.5</td>
<td>27.0</td>
<td>0.0</td>
</tr>
<tr>
<td>85B098</td>
<td>150-300</td>
<td>Bct2</td>
<td>27.1</td>
<td>47.0</td>
<td>25.9</td>
<td>0.5</td>
</tr>
</tbody>
</table>

*Analyses performed by Merrill, Seeley, Mullen, Sandefur, Inc.*
Table D-3. Derivative ratios from the particle size distributions of soil profiles sampled along the Greenville fault, Livermore, California.

<table>
<thead>
<tr>
<th>Interval</th>
<th>Field sampled, Horizon</th>
<th>cos/fs*</th>
<th>fs/vfs</th>
<th>s/si</th>
<th>cosi/msi</th>
<th>msi/fsi</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. cm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>85B075 0-10 Al</td>
<td>0.16</td>
<td>0.50</td>
<td>0.85</td>
<td>1.03</td>
<td>3.64</td>
<td></td>
</tr>
<tr>
<td>85B076 10-25 A2</td>
<td>0.14</td>
<td>0.51</td>
<td>0.81</td>
<td>0.84</td>
<td>3.63</td>
<td></td>
</tr>
<tr>
<td>85B077 25-35 A3</td>
<td>0.12</td>
<td>0.68</td>
<td>0.75</td>
<td>0.87</td>
<td>2.55</td>
<td></td>
</tr>
<tr>
<td>85B078 35-70 Btl</td>
<td>0.07</td>
<td>0.64</td>
<td>0.57</td>
<td>0.68</td>
<td>3.80</td>
<td></td>
</tr>
<tr>
<td>85B079 70-94 Bt2</td>
<td>0.14</td>
<td>0.40</td>
<td>0.71</td>
<td>0.70</td>
<td>3.85</td>
<td></td>
</tr>
<tr>
<td>85B080 94-247 BCt</td>
<td>0.15</td>
<td>0.52</td>
<td>0.47</td>
<td>0.89</td>
<td>3.46</td>
<td></td>
</tr>
<tr>
<td>85B081 247-300 BCkt</td>
<td>0.05</td>
<td>0.48</td>
<td>0.72</td>
<td>1.22</td>
<td>2.39</td>
<td></td>
</tr>
<tr>
<td>85B082 300-320 C</td>
<td>0.09</td>
<td>0.56</td>
<td>0.78</td>
<td>1.41</td>
<td>2.36</td>
<td></td>
</tr>
</tbody>
</table>

**DESCRIPTION NO. 1**

<table>
<thead>
<tr>
<th>Interval</th>
<th>Field sampled, Horizon</th>
<th>cos/fs*</th>
<th>fs/vfs</th>
<th>s/si</th>
<th>cosi/msi</th>
<th>msi/fsi</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. cm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>85B069 0-10 A</td>
<td>0.03</td>
<td>0.44</td>
<td>0.86</td>
<td>1.12</td>
<td>2.36</td>
<td></td>
</tr>
<tr>
<td>85B070 10-24 Bt</td>
<td>0.00</td>
<td>0.30</td>
<td>0.66</td>
<td>0.92</td>
<td>3.00</td>
<td></td>
</tr>
<tr>
<td>85B071 24-37 2Ab</td>
<td>0.59</td>
<td>0.20</td>
<td>0.25</td>
<td>0.57</td>
<td>1.92</td>
<td></td>
</tr>
<tr>
<td>85B072 37-60 2Abk</td>
<td>0.79</td>
<td>0.49</td>
<td>0.24</td>
<td>0.36</td>
<td>1.73</td>
<td></td>
</tr>
<tr>
<td>85B073 60-138 2Bgb</td>
<td>0.50</td>
<td>0.57</td>
<td>0.22</td>
<td>1.09</td>
<td>1.29</td>
<td></td>
</tr>
<tr>
<td>85B074 138-270 2Btgb</td>
<td>0.17</td>
<td>0.50</td>
<td>0.21</td>
<td>0.64</td>
<td>2.38</td>
<td></td>
</tr>
</tbody>
</table>

**DESCRIPTION NO. 2**

<table>
<thead>
<tr>
<th>Interval</th>
<th>Field sampled, Horizon</th>
<th>cos/fs*</th>
<th>fs/vfs</th>
<th>s/si</th>
<th>cosi/msi</th>
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<td>85B052 0-22 A</td>
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**DESCRIPTION NO. 4**

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<th>cosi/msi</th>
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<tr>
<td>85B065 0-20 A</td>
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*s = sand, si = silt, co = coarse, m = medium, f = fine, vf = very fine.
Figure D-1. Depth versus clay content in the San Ysidro loam sampled in Test Pit 4.

Figure D-2. Depth versus clay content in the buried Pescadero clay sampled in Test Pit 3.
SOILS GLOSSARY

AGRADATION. A modification of the earth's surface in the direction of uniformity of grade by deposition.

ALKALI (SODIC) SOIL. A soil having so high a degree of alkalinity (pH 8.5 or higher), or so high a percentage of exchangeable sodium (15 percent or more of the total exchangeable bases), or both, that plant growth is restricted.

ALKALINE SOIL. Any soil that has a pH greater than 7.3. (See reaction, soil.)

ALLUVIATION. The process of building up of sediments by a stream at places where stream velocity is decreased. The coarsest particles are the first to settle and the finest muds the last.

BEDROCK. The solid rock that underlies the soil and other unconsolidated material or that is exposed at the surface.

BURIED SOIL. A developed soil that was once exposed but is now overlain by a more recently formed soil.

CALCAREOUS SOIL. A soil containing enough calcium carbonate (commonly with magnesium carbonate) to effervesce (fizz) visibly when treated with cold, dilute hydrochloric acid. A soil having measurable amounts of calcium carbonate or magnesium carbonate.

CLAY. As a soil separate, the mineral soil particles are less than 0.002 millimeter in diameter. As a soil textural class, soil material that is 40 percent or more clay, less than 45 percent sand, and less than 40 percent silt.

CLAY FILM. A thin coating of oriented clay on the surface of a sand grain, pebble, soil aggregate, or ped. Clay films also line pores or root channels and bridge sand grains. Synonyms: clay coat, clay skin, argillan.
COLLUVIIUM. Any loose mass of soil or rock fragments that moves downslope largely by the force of gravity. Usually it is thicker at the base of the slope.

CONCRETIONS. Grains, pellets, or nodules of various sizes, shapes, and colors consisting of concentrated compounds or cemented soil grains. The composition of most concretions is unlike that of the surrounding soil. Calcium carbonate and iron oxide are common compounds in concretions.

CONSISTENCE, SOIL. The feel of the soil and the ease with which a lump can be crushed by the fingers. Terms commonly used to describe consistence are --

Loose.--Noncoherent when dry or moist; does not hold together in a mass.

Friable.--When moist, crushes easily under gentle pressure between thumb and forefinger and can be pressed together into a lump.

Firm.--When moist, crushes under moderate pressure between thumb and forefinger, but resistance is distinctly noticeable.

Plastic.--When wet, readily deformed by moderate pressure but can be pressed into a lump; will form a "wire" when rolled between thumb and forefinger.

Sticky.--When wet, adheres to other material, and tends to stretch somewhat and pull apart, rather than to pull free from other material.

Hard.--When dry, moderately resistant to pressure; can be broken with difficulty between thumb and forefinger.

Soft.--When dry, breaks into powder or individual grains under very slight pressure.

Cemented.--Hard and brittle; little affected by moistening.

CTPOT. Easily remebered acronym for climate, topography, parent material, organisms, and time; the five factors of soil formation.

DEGRADATION. A modification of the earth's surface by erosion.
ELUVIATION. The removal of solid particles, mostly clay and humus, from a soil horizon by percolating water.

EOLIAN. Deposits laid down by the wind, landforms eroded by the wind, or structures such as ripple marks made by the wind.

FLOOD PLAIN. A nearly level alluvial plain that borders a stream and is subject to flooding unless protected artificially.

GENESIS, SOIL. The mode of origin of the soil. Refers especially to the processes or soil-forming factors responsible for the formation of the solum (A and B horizons), or true soil, from the unconsolidated parent material.

GEOMORPHIC. Pertaining to the form of the surface features of the earth. Specifically, geomorphology is the analysis of landforms and their mode of origin.

GLEYED SOIL. A soil having one or more neutral gray horizons as a result of waterlogging and lack of oxygen. The term "gleyed" also designates gray horizons and horizons having yellow and gray mottles as a result of intermittent waterlogging.

GRAVEL. Rounded or angular fragments of rock between 2 millimeters to 7.5 centimeters in diameter. An individual piece is a pebble.

HOLOCENE. The most recent epoch of geologic time, extending from 10,000 years ago to the present time.

HORIZON, SOIL. A layer of soil, approximately parallel to the surface, that has distinct characteristics produced by soil-forming processes. These are the major soil horizons:

O horizon.--The layer of organic matter on the surface of a mineral soil. This layer consists of decaying plant residues.
A horizon.--The mineral horizon at the surface or just below an O horizon. This horizon is the one in which living
organisms are most active and therefore is marked by the accumulation of humus. The horizon may have lost one or more of soluble salts, clay, and sesquioxides (iron and aluminum oxides).

B horizon.--The mineral horizon below an A horizon. The B horizon is in part a layer of change from the overlying A to the underlying C horizon. The B horizon also has distinctive characteristics caused (1) by accumulation of clay, sesquioxides, humus, or some combination of these; (2) by prismatic or blocky structure; (3) by redder or stronger colors than the A horizon; or (4) by some combination of these. Combined A and B horizons are usually called the solum or true soil. If a soil lacks a B horizon, the A horizon alone is the solum.

C horizon.--The weathered rock material immediately beneath the solum. In most soils this material is presumed to be like that from which the overlying horizons were formed. If the material is known to be different from that in the solum, a number precedes the letter C.

R layer.--Consolidated rock beneath the soil. The rock usually underlies a C horizon but may be immediately beneath an A or B horizon.

These lowercase letters may be appended:

a  Highly decomposed organic matter
b  Buried
c  Concretions
e  Intermediately decomposed organic matter
f  Frozen
g  Gleyed
h  Humus
i  Slightly decomposed organic matter
k  Carbonates
m  Cemented
n  Sodium
o  Oxides (residual)
p  Plowed
q  Silica
s  Oxides (illuvial)
t  Translocated clay
u  Unweathered
v  Plinthite
w  Color or structural B
x  Fragipan
y  Gypsum
z  Salts
HUMUS. The well decomposed, more or less stable part of the organic matter in mineral soils.

ILLUVIATION. The deposition by percolating water of solid particles, mostly clay or humus, within a soil horizon.

INTERFLUVIAL. The land lying between streams.

KROTOVINA. An animal burrow filled with soil.

LEACHING. The removal of soluble material from soil or other material by percolating water.

MORPHOLOGY, SOIL. The physical makeup of the soil, including the texture, structure, porosity, consistence, color, and other physical, mineral, and biological properties of the various horizons, and the thickness and arrangement of those horizons in the soil profile.

MOTTLING, SOIL. Irregularly marked with spots of different colors that vary in number and size. Mottling in soils usually indicates poor aeration and lack of drainage. Descriptive terms are as follows: abundance—few, common, and many; size—fine, medium, and coarse; and contrast—faint, distinct and prominent. The size measurements are these: fine, less than 5 mm in diameter along the greatest dimension; medium, from 5 to 15 mm, and coarse, more than 15 mm.

MRT (MEAN RESIDENCE TIME). The average age of the average carbon atom within a soil. Under ideal conditions for its preservation, the humus in a soil will have a C-14 date that is half the true age of the soil.

PALEOSOL. A fossil soil, usually buried by younger soils or sediments and indicative of a former stable surface.

PARENT MATERIAL. The great variety of unconsolidated organic and mineral material in which soil forms. Consolidated bedrock is not yet parent material by this concept.
PED. An individual natural soil aggregate, such as a granule, a prism, or a block.

PERCOLATION. The downward movement of water through the soil.

pH VALUE. (See Reaction, soil). A numerical designation of acidity and alkalinity in soil.

PLEISTOCENE. An epoch of geologic time extending from 10,000 years ago to 1.8 million years ago; it includes the last Ice Age.

PROFILE, SOIL. A vertical section of the soil through all its horizons and extending into the parent material.

QUATERNARY. A period of geologic time that includes the past 1.8 million years. It consists of two epochs--the Pleistocene and Holocene.

REACTION, SOIL. The degree of acidity or alkalinity of a soil, expressed in pH values. A soil that tests to pH 7.0 is precisely neutral in reaction because it is neither acid nor alkaline. An acid, or "sour," soil is one that gives an acid reaction; an alkaline soil is one that is alkaline in reaction. In words, the degrees of acidity or alkalinity are expressed thus:

- Extremely acid------ Below 4.5
- Very strongly acid--- 4.5 to 5.0
- Strongly acid-------- 5.1 to 5.5
- Medium acid--------- 5.6 to 6.0
- Slightly acid-------- 6.1 to 6.5
- Neutral------------ 6.6 to 7.3
- Mildly alkaline----- 7.4 to 7.8
- Moderately alkaline-- 7.9 to 8.4
- Strongly alkaline---- 8.5 to 9.0
- Very strongly alkaline 9.1 and higher

SAND. Individual rock or mineral fragments in a soil that range in diameter from 0.05 to 2.0 mm. Most sand grains consist of quartz, but they may be of any mineral composition. The textural class name of any soil that contains 85 percent or more sand and not more than 10 percent clay.

SILT. Individual mineral particles in a soil that range in diameter from the upper limit of clay (0.002 mm) to the lower limit of very fine sand (0.05 mm). Soil of the silt textural class is 80 percent or more silt and less than 12 percent clay.
SLICKENSIDES. Polished and grooved surfaces produced by one mass sliding past another. In soils, slickensides may occur at the bases of slip surfaces on the steeper slopes; on faces of blocks, prisms, and columns; and in swelling clayey soils, where there is marked change in moisture content.

SMECTITE. A fine, platy, alumino-silicate clay mineral that expands and contracts with the absorption and loss of water. It has a high cation-exchange capacity and is plastic and sticky when moist.

SOIL. A natural, three-dimensional body at the earth's surface that is capable of supporting plants and has properties resulting from the integrated effect of climate and living matter acting on earthy parent material, as conditioned by relief over periods of time.

SOIL TONGUE. That portion of a soil horizon extending into a lower horizon.

STRUCTURE, SOIL. The arrangement of primary soil particles into compound particles or aggregates that are separated from adjoining aggregates. The principal forms of soil structure are--platy (laminated), prismatic (vertical axis of aggregates longer than horizontal), columnar (prisms with rounded tops), blocky (angular or subangular), and granular. Structureless soils are either single grained (each grain by itself, as in dune sand) or massive (the particles adhering without any regular cleavage, as in many hardpans).

TECTOTURBATION. Soil disturbance resulting from tectonic movement.

WATER TABLE. The upper limit of the soil or underlying rock material that is wholly saturated with water.

WEATHERING. All physical and chemical changes produced in rocks or other deposits at or near the earth's surface by atmospheric agents. These changes result in disintegration and decomposition of the material.
APPENDIX E
RADIOCARBON AGE DETERMINATION

Our Sample No.  GX-11278

Your Reference:  Letter of 06-04-85.

Submitted by:  Marc W. Seeley
Merrill & Seeley, Inc.
60 Mission Drive
Pleasanton, CA  94566

Sample Name:  Project 85087-A.  Fault exploration trench, Greenville fault, Livermore, CA.

AGE =  17,140 +/- 800 C-14 Years B.P. (C-13 corrected).

Description:  Sediment organic matter.

Pretreatment:  The entire sample was dispersed in a large volume of water and the clays and organic matter were eluted away from any sand and silt by sedimentation and decantation. The clay/organic fraction was then treated with hot dilute HCl to remove any carbonates. It was then filtered, washed, dried, and roasted in oxygen to recover carbon dioxide from the organic matter for the analysis.

Comment:

$\Delta^{13}C_{PDB} = -24.0$

Notes: This data is based upon the Libby half life (5570 years) for $^{14}C$. The error stated is $\pm 1\sigma$ as judged by the analytical data alone. Our modern standard is 95% of the activity of N.B.S. Oxalic Acid. The age is referenced to the year A.D. 1950.
OVERSIZED DOCUMENT HAS BEEN PULLED AND SCANNED WITH THE MAP FILE.
**EXPLANATION**

- **SAND**
- **CLAY FILMS**
- **CLAY FILMS**
- **VARVE TYPE DEPOSIT**
- **SHELL FRAGMENT**
- **SECONDARY CALICHÉ CEMENT**
- **CALICHÉ CLAST**
- **KROTOVINA**
- **GROUNDWATER**
- **BLOCKY STRUCTURE**

**LOG OF TRENCHES 3 & 4**

**SOUTHWEST WALL**

**PROJECT:** 85087-A

**CONSULTING GEOLOGISTS AND GROUNDWATER ENGINEERS:**

**MERRILL. SEELEY, MULLEN. SANDEFUR, INC.**
TRENCH #4

LOG OF TRENCH 4
SOUTHWEST WALL

EXPLANATION

- SAND
- CLAST
- CALICHE CLAST
- SECONDARY CALICHE CONCRETION
- VARVE TYPE DEPOSIT
- BLOCKY STRUCTURE
- CLAY FILMS
- KROTOSVNA

SCALE

0 2 4 6 8 10
FEET

MERRILL, SEELEY, MULLEN, SANDEFUR, INC.
CONSULTING GEOTECHNICAL ENGINEERS AND GEOLOGISTS

120 SPRING STREET, PLEASANTON, CA 94566

PLATE 6
**TRENCH #5**

**EXPLANATION**

- **SAND**
- **CLAST**
- **CALICHE CLAST**
- **BLOCKY STRUCTURE**
- **SECONDARY CALICHE CEMENT**
- **CLAY FILMS**
- **KROTOVINA**
- **MANGANESE DEPOSITS**

**LOG OF TRENCH 5**

SOUTH-WEST WALL

**PROJECT: 85087-A**

MERRILL, SHELEY, MULLEN, SANDEFUR, INC.

CONSULTING GEOLOGICAL ENGINEERS AND GEOLOGISTS

120 SPRING STREET, PASADENA, CA 91106

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**DIAGRAM**

- **TRENCH #5 DESCRIPTIONS AT STATION 900**
  - 900: **Silty Clay, Medium Gray, Loamy, Medium Stiff to Steep, Sharply Contact**
  - 915: **Silty Clay, Medium Gray, Loamy, Medium Stiff to Steep, Sharply Contact**
  - 930: **Medium to Coarse Sand**

- **TRENCH #5 DESCRIPTIONS AT STATION 1000**
  - 1000: **Silty Clay, Medium Gray, Loamy, Medium Stiff to Steep, Sharply Contact**
  - 1015: **Silty Clay, Medium Gray, Loamy, Medium Stiff to Steep, Sharply Contact**

- **TRENCH #5 DESCRIPTIONS AT STATION 1100**
  - 1100: **Silty Clay, Medium Gray, Loamy, Medium Stiff to Steep, Sharply Contact**
  - 1115: **Silty Clay, Medium Gray, Loamy, Medium Stiff to Steep, Sharply Contact**

- **TRENCH #5 DESCRIPTIONS AT STATION 1200**
  - 1200: **Silty Clay, Medium Gray, Loamy, Medium Stiff to Steep, Sharply Contact**
  - 1215: **Silty Clay, Medium Gray, Loamy, Medium Stiff to Steep, Sharply Contact**
  - 1230: **Silty Clay, Medium Gray, Loamy, Medium Stiff to Steep, Sharply Contact**

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**NOTES**

- **Very Fine Sand and Silty Clay**
- **Sand Increases and Coarse to the West**
- **Blocky Structure**
- **Secondary Caliche Cement**
- **Kurotovina**
- **Manganese Deposits**
TRENCH #8

TRENCH #9

EXPLANATION

- GROUNDWATER
- SAND
- CLAST
- CALICHÉ CLAST
- SECONDARY CALICHÉ CEMENT
- CLAY FILMS
- VARVE TYPE DEPOSIT
- BLOCKY STRUCTURE
- COLUMNAR JOINTING
- KROTONJA
**EXPLANATION**

- **GROUNDWATER SAND**
- **CLAY**
- **CALICHE CLAY**
- **SECONDARY CALICHE CEMENT**
- **CLAY FILMS**
- **BLOCKY STRUCTURE**
- **KROTOVINA**