



Missouri University of Science and Technology
Scholars' Mine

International Conferences on Recent Advances
in Geotechnical Earthquake Engineering and
Soil Dynamics

2001 - Fourth International Conference on
Recent Advances in Geotechnical Earthquake
Engineering and Soil Dynamics

31 Mar 2001, 8:00 am - 9:30 am

Use of Microzonation to Site Facility on Low Angle Thrust and Associated Fault Bend Folding

Frank R. Bickner

Laco Associates, Consulting Engineers, Eureka, CA

Giovanni A. Vadurro

Laco Associates, Consulting Engineers, Eureka, CA

Gary L. Manhart

Laco Associates, Consulting Engineers, Eureka, CA

David N. Lindberg

Laco Associates, Consulting Engineers, Eureka, CA

Christopher J. Watt

Laco Associates, Consulting Engineers, Eureka, CA

See next page for additional authors

Follow this and additional works at: <https://scholarsmine.mst.edu/icrageesd>



Part of the [Geotechnical Engineering Commons](#)

Recommended Citation

Bickner, Frank R.; Vadurro, Giovanni A.; Manhart, Gary L.; Lindberg, David N.; Watt, Christopher J.; and Chaney, Ronald C., "Use of Microzonation to Site Facility on Low Angle Thrust and Associated Fault Bend Folding" (2001). *International Conferences on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics*. 11.

<https://scholarsmine.mst.edu/icrageesd/04icrageesd/session11/11>

This Article - Conference proceedings is brought to you for free and open access by Scholars' Mine. It has been accepted for inclusion in International Conferences on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics by an authorized administrator of Scholars' Mine. This work is protected by U. S. Copyright Law. Unauthorized use including reproduction for redistribution requires the permission of the copyright holder. For more information, please contact scholarsmine@mst.edu.

Author

Frank R. Bickner, Giovanni A. Vadorro, Gary L. Manhart, David N. Lindberg, Christopher J. Watt, and Ronald C. Chaney

USE OF MICROZONATION TO SITE FACILITY ON LOW-ANGLE THRUST AND ASSOCIATED FAULT-BEND FOLDING

Frank R. Bickner, Giovanni A. Vadurro, Gary L. Manhart, David N. Lindberg, Christopher J. Watt, and Ronald C. Chaney
LACO ASSOCIATES Consulting Engineers, 21 W. Fourth St., Eureka, Ca 95501

ABSTRACT

The campus of the College of the Redwoods is located completely within the Little Salmon Fault Zone, designated by the State of California as an active fault. The College has been extensively investigated for fault rupture and other seismic hazards in 1989, 1993, 1997, 1998, and 1999. The Little Salmon Fault Zone bounds the College and consists of two main northwest-striking, northeast-dipping, low-angle thrusts. The west splay daylight along the southwest edge of the campus and projects beneath it. A recurrence interval of 268 years and slip rate of 5 ± 3 mm/yr is estimated by CDMG. Individual dip-slip displacements along the west trace are reported to be 12 to 15 feet (3.6 to 4.5 m). Movement on the Little Salmon fault (LSF) is accompanied by growth of broad asymmetric folds in the upper thrust sheet resulting in surface rupture, localized uplift and discrete fault-bend fold axial surfaces.

College of the Redwoods is located approximately 8 miles (13 km) south of Eureka and 25 miles (40 km) north-northeast of Cape Mendocino and the Mendocino Triple Junction (MTJ) in northern California. The MTJ is the point of transition from strike-slip faulting of the San Andreas transform system to low-angle thrust faulting and folding associated with the convergent margin of the Cascadia Subduction Zone. Campus infrastructure is located along the base of the Humboldt Hill Anticline (HHA), a major fault-bend fold of the Cascadia fold and thrust belt.

A new learning resource center (LRC) is proposed for a location 400 feet (120 m) northeast of where the west trace of the LSF daylight and 200 feet (60 m) above the low-angle fault plane. Building setback and design recommendations to mitigate for both fault rupture hazards and fault-generated folding hazards are presented.

INTRODUCTION

A seismic hazard analysis was conducted at the College of the Redwoods Campus south of Eureka, California. This site is located within a zone of faulting and folding associated with the Little Salmon Fault Zone. The subject area lies entirely within Alquist-Priolo Special Studies Zone (Hart, 1994). This and previous studies (LACO 1989, 1993, 1998 and 1999 a, b) focuses on determination of geologic hazards related to faulting and folding at existing and proposed building sites on the campus (Figure 2).

Interpretation of the subsurface geologic conditions existing at the campus are based on geotechnical borings conducted during earlier phases of development of the campus (Harding and Associates, 1965), from other earlier studies of the surrounding area (Ogle, 1953; Woodward Clyde, 1980; Carver and Burke 1989), and from investigations conducted on the campus at previously-proposed library sites (LACO, 1989 & 1993), a Learning Resource Center (LRC) site

(LACO, 1998) and a Child Development Center (CDC) site (LACO, 1999).

REGIONAL TECTONIC SETTING

The College is located approximately 25 miles (40 km) north-northeast of Cape Mendocino and the Mendocino Triple Junction (MTJ). The MTJ is the point of transition from strike-slip faulting of the San Andreas transform system to low-angle reverse (thrust) faulting and folding associated with the convergent margin of the Cascadia Subduction Zone (Figure 1).

The regional tectonic framework north of the MTJ is controlled by the Cascadia Subduction Zone wherein oceanic crust of the Juan de Fuca/Gorda plate is subducted beneath the continental crust of the North American plate. Plate convergence along the Gorda segment of the Cascadia Subduction Zone is occurring at a rate of about 30-40 mm/yr (Heaton & Kanamori, 1984). Crustal deformation associated

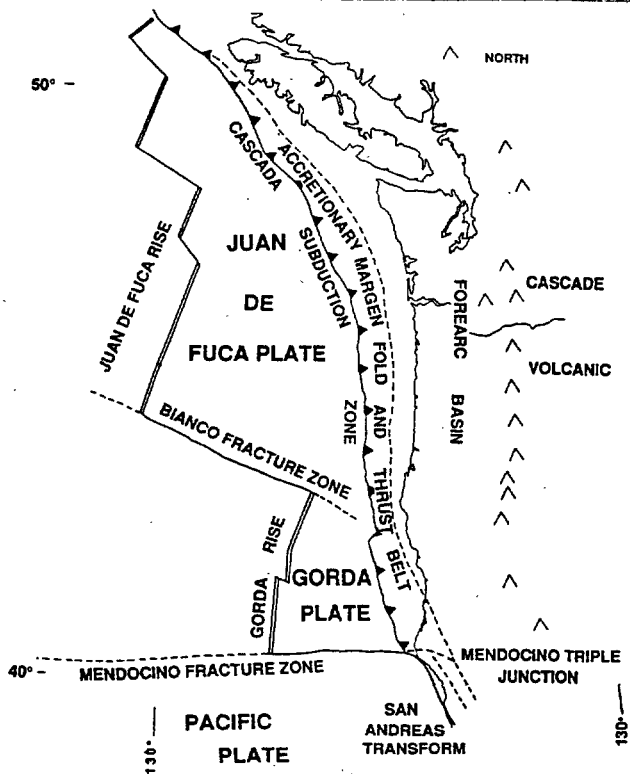


Fig. 1. The Cascadia Subduction Zone (McPherson, 1989)

with subduction of the Gorda plate is expressed as a 54-61 mile (87-97 km) wide fold and thrust belt comprising the accretionary complex along the North American plate margin.

Little Salmon Fault

The LSF is a major northwest-striking, northeast-dipping thrust fault located mostly in the onshore portion of the Cascadia Subduction Zone fold and thrust belt (Figure 2). The LSF is designated by the State of California as an active fault. No earthquakes have occurred on the LSF since at least 1850, the period for which records have been kept. The California Division of Mines and Geology has assigned a maximum moment magnitude (M_w) of 7.3 and a recurrence interval of 268 years to earthquake events on the onshore segment of the LSF (Petersen *et al*, 1996). At Little Salmon Creek, southeast of the College, a minimum of three dated events have been recorded in the last 1,700 years, yielding a recurrence interval of 300 to 560 years (Clarke and Carver, 1992). Total length of the LSF including its offshore segment is 50 miles (80 km) (Petersen *et al*, 1996). The fault can be traced from east of Carlotta, northwest to the coast at Humboldt Bay (Ogle, 1953). Offshore, the LSF terminates along a major structural discordance (Clarke, 1992).

The strike of the onshore portion of the Little Salmon fault varies from N60W near its southeast terminus to N35W at the

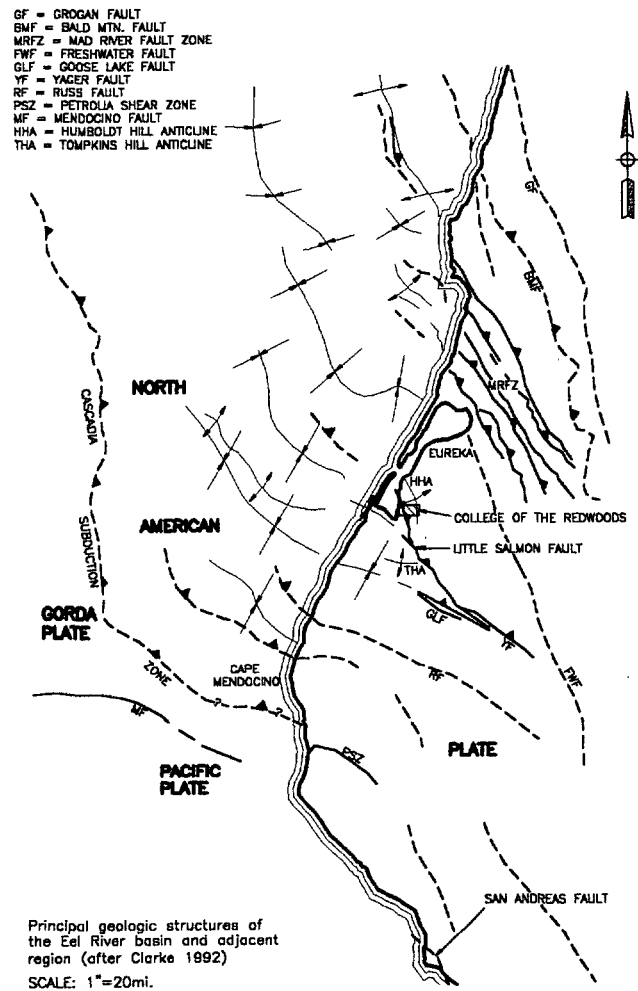


Fig. 2. Principal Regional Geologic Structures

College. In map view the surface trace is sinuous and broadly convex to the southwest. Northwest of the Tompkins Hill anticline, the main surface trace splays into two well-recognized segments. The east trace is located along the base of the HHA. The west trace has been mapped along the base of the bluff on which the College is located. Where the west trace underlies the College the fault plane dips 10-15 degrees to the northeast. Petroleum industry exploratory electric well-log data and structure contouring indicate the fault plane steepens down-dip to 29 degrees where it underlies the HHA and likely merges with the east trace.

STUDY AREA GEOLOGIC CONDITIONS

The College is located on a low-relief bluff at the base of the HHA, a major fault-bend fold produced by repeated movement along the east trace of the LSF. Field investigation has shown the bluff on which the College is built to also be a fault-bend fold generated by repeated movement along the west trace of the LSF underlying the campus. The fold is expressed as a broad northwest-trending anticline with a

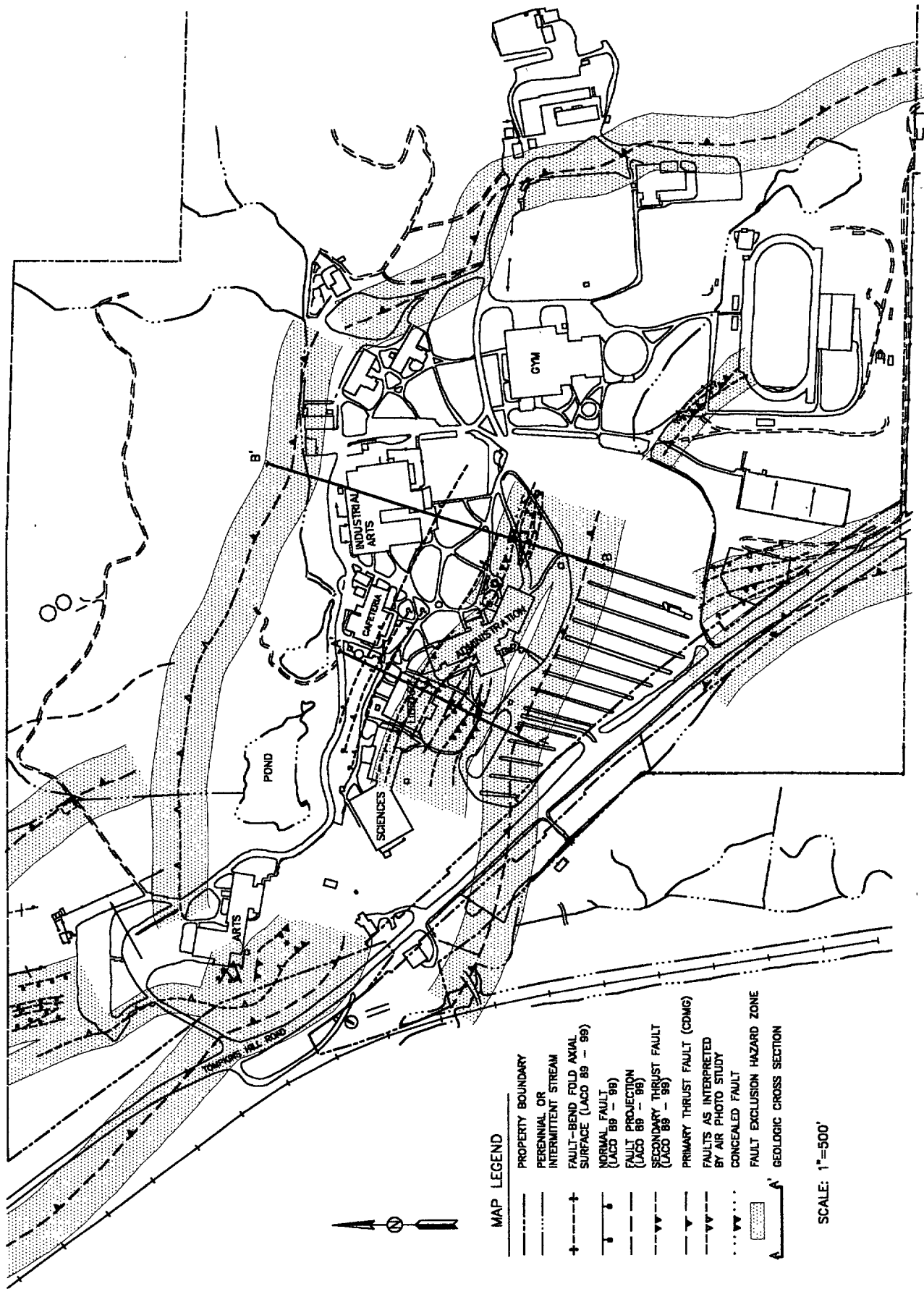


Fig. 3. Microzonation map delineating faults, fold axial surfaces, and exclusionary hazard zones.

steeply dipping forelimb, flat lying crest, and shallow dipping backlimb. The campus is underlain by the Pleistocene Hookton Formation (Ogle, 1953), late Pleistocene marine terrace deposits, and late Pleistocene to Holocene fluvial, alluvial and colluvial sediments.

Styles of Deformation

Major faulting and associated folding were observed in trenches across the entire study area (Figure 3). Several trench exposures revealed 80-160 foot (25-50 m) wide zones of deformation displaying multiple faults and fractures as well as discrete axial surfaces distributed throughout the hangingwall.

Structural variability along strike of the LSF is pronounced. High and low-angle faults exhibiting both reverse and normal offsets were mapped. Typical fault patterns consist of subparallel reverse faults that dip to the southwest and record as much as 5.9 ft (1.8 m) of offset. Southwest dipping reverse faults were interpreted to be secondary back-thrusts. Back-thrusts increase in dip towards the main thrust tip and are truncated by the modern day graded surface. Presence of back-thrusts suggest proximity of the northeast dipping master thrust. Graben structures composed of opposing high-angle normal faults that record about 3.3 ft (1 m) of cumulative vertical separation were also observed. Normal faults both decrease in slip and terminate downwards. Grabens record extension in the hangingwall as it rides over bends in the underlying thrust ramp.

Primary off-fault deformation also includes folding of strata across discrete axial surfaces. Axial surfaces coincide with changes in dip of the underlying thrust ramp. Fault-generated folding in the overriding thrust sheet results in differential displacement of the ground surface across active axial surfaces.

Tectonic Zones Of Deformation

The geologic cross-sections presented in Figures 4 & 5 represent a synthesis of data based on trenches logged in 1989, 1993, 1997, 1998 and 1999, plus available boring logs, and existing geologic mapping. Cross-sections were constructed based on methods outlined in Suppe (1983), Mitra and Namson (1989), Mount *et al* (1990), and Medwedeff and Suppe (1997). Several areas of diffuse surface fracturing (distributive faulting) and localized folding were identified. Diffuse surface fracturing is relatively minor along individual faults but cumulatively may result in significant structural damage to existing and proposed buildings. Likewise, areas of localized folding where differential displacement is expected to occur may also distress building foundations producing unacceptable losses.

Dip-slip displacement per event measured along the west trace of the LSF equals 12-15 ft (3.6-4.5 m) (Clarke and Carver, 1992). Based on kinematic modeling, average slip per event coupled with 10 degree changes in fault dip yield differential displacement amounts of 0.8-1.0 ft (0.25-0.31 m) across active axial surfaces along the ground surface (LACO 1998).

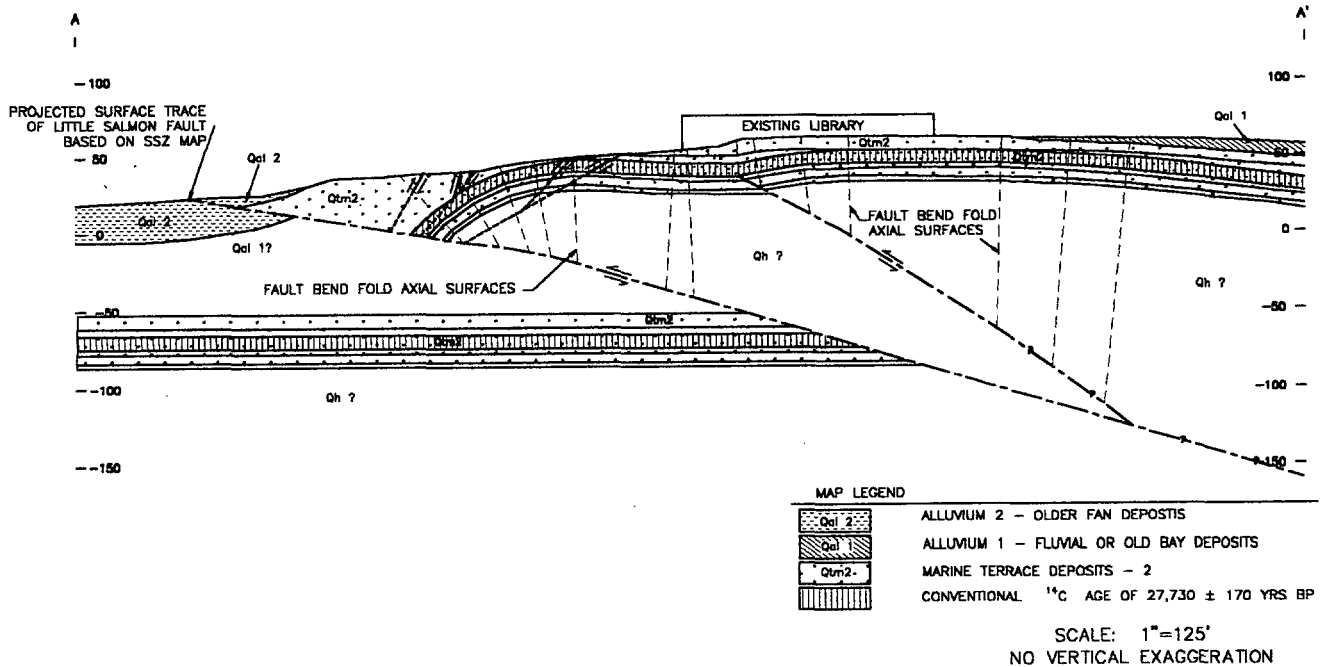


Fig. 4. Geologic cross section A-A'.

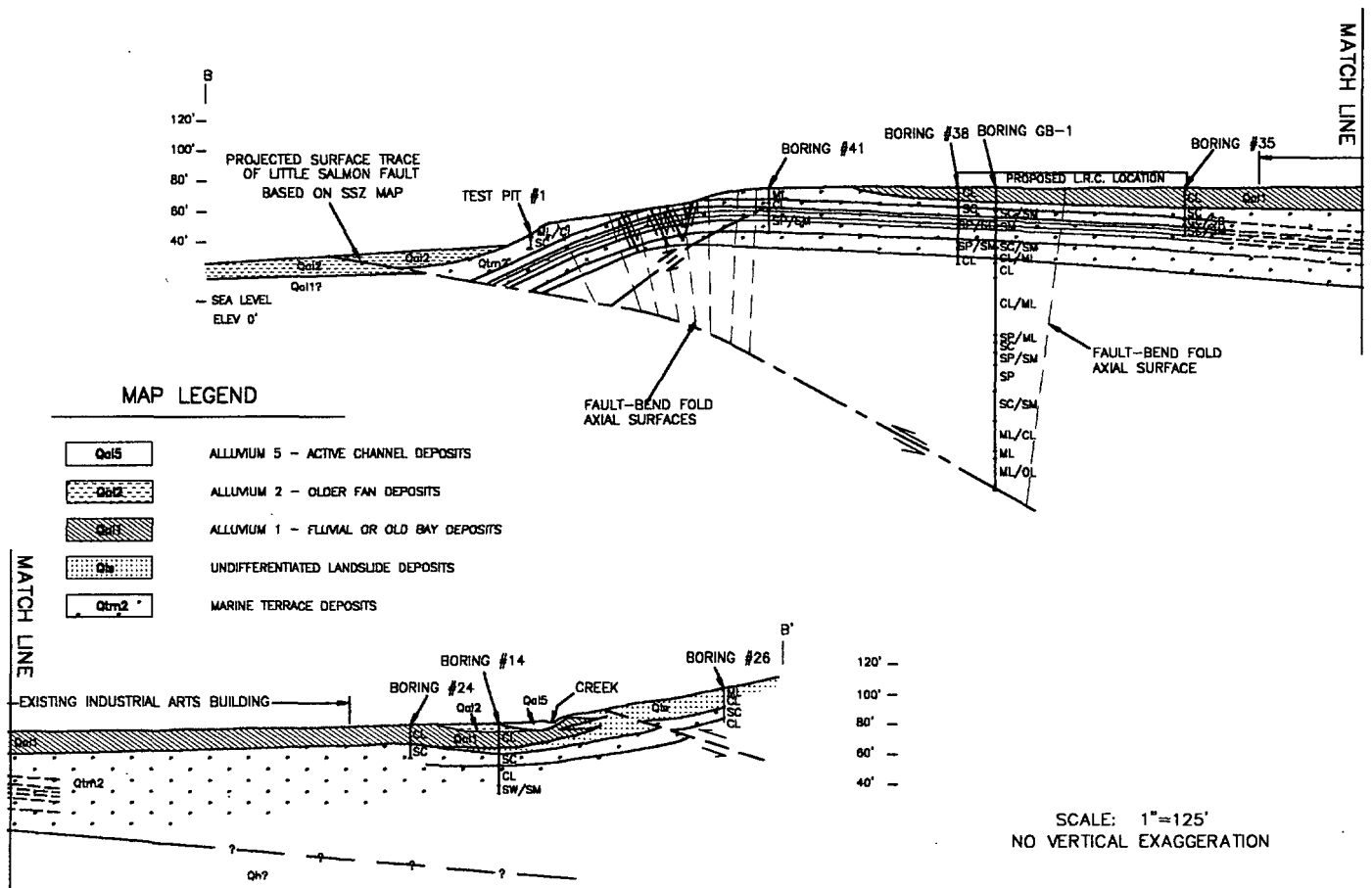


Fig. 5. Geologic cross section B-B'

MICROZONATION AND FACILITY SITING

Fault rupture in deposits of probable Holocene age has occurred throughout the campus. Surface fault traces and fold axial surfaces project under several existing buildings. Recommended setbacks for proposed building sites are currently 50 feet from surface fault traces considered potentially active. Future setbacks, however, will require the 50-foot setback zone to be measured perpendicular to the fault plane thereby increasing the horizontal distance from the surface fault trace (Sydnor, 1999). Areas underlain by active axial surfaces may be considered buildable with appropriate mitigation by the structural engineer during the design phase.

Many existing campus buildings are located on or near observed fault ruptures and/or axial surfaces. Structural damage will occur to a building located atop a fault rupture. Likewise, deformation associated with surface folding across active axial surfaces is considered potentially damaging to any structure located on such a feature. As presently proposed, the LRC does not appear to be sited directly on observed or projected fault surface ruptures. However, the proposed LRC site does appear to be sited on an active axial surface. Potential differential displacement of the ground surface is to be mitigated through foundation design which includes a structural mat underlain by engineered fill (LACO, 1999b).

REFERENCES

Carver, G. A.; R. M. Burke (1989), Trenching Investigations of Northwestern California Faults, Humboldt Bay Region, unpublished final report, NEHRP; U.S.G.S. Grant 14-08-0001-G1082, 53p.

Clarke, S. H. (1992), Geology of the Eel River Basin and Adjacent Region: Implications for Late Cenozoic Tectonics of the Southern Cascadia Subduction Zone and Mendocino Triple Junction; AAPG Bulletin, V. 76, pp. 199-221.

Clarke, S. H.; G. A. Carver (1992), Late Holocene Tectonics and Paleoseismicity, Southern Cascadia Subduction Zone: Science; v. 255, p.188-192

Harding and Associates (1965), Soil and Foundation Investigation for College of the Redwoods, Eureka, California.

Hart, E. W. (1994), Fault-Rupture Hazard Zones in California; California Division of Mines and Geology, Special Publication 42, 1994 revised edition, 34p.

Heaton, T. H.; H. Kanamori (1984), Seismic Potential Associated with Subduction in the Northwestern United States; B.S.S.A, v. 95, pp. 933-942.

LACO ASSOCIATES (1989), Geologic Investigation, Fault Rupture Hazard Evaluation, Little Salmon Fault Zone, College of the Redwoods Library Addition; Unpublished consulting report for the College of the Redwoods.

LACO ASSOCIATES (1993), Geologic/Seismic Hazards-Risk Zoning Phase B Report, Little Salmon Fault Zone, College of the Redwoods Library Addition; Unpublished consulting report for the College of the Redwoods.

LACO ASSOCIATES (1998), Geotechnical Report; Liquefaction Evaluation and Seismic Response Spectrum, College of the Redwoods Library Addition; Unpublished consulting report for the College of the Redwoods.

LACO ASSOCIATES (1999a), Site Evaluation for the CDC, Fault Rupture Hazard, Phase C Investigation; Unpublished consulting report for the College of the Redwoods.

LACO ASSOCIATES (1999b), Final Report of Seismic Study Phase 3 at College of the Redwoods Eureka Campus; Unpublished consulting report for the College of the Redwoods.

McPherson, R. C. (1989), Seismicity and Focal Mechanisms Near the Mendocino Triple Junction, Northern California; Unpublished M.S. thesis, Humboldt State Univ., 81 p.

Medwedeff, D. A.; J. Suppe (1997), Multibend Fault-Bend Folding; *Journal of Structural Geology*, V. 19, Nos. 3-4, p. 279-292.

Mitra, S.; J. Namson (1989), Equal-Area Balancing; *American Journal of Science*, Vol. 289, p. 563-599.

Mount, V. S. *et al* (1990), A Forward Modeling Strategy for Balancing Cross Sections; *AAPG Bulletin*, V. 74, No. 5, p. 521-531.

Ogle, B. A. (1953), Geology of the Eel River Valley Area, Humboldt County, California; *DMG Bulletin* 164, 128p.

Petersen, M. D., *et al* (1996) Probabilistic Seismic Hazard Assessment for the State of California; *DMG OFR 96-08*, 59 p.

Sydnor, R. H., (1999), Engineering Geology and Seismology Review, CDC, College of the Redwoods; *DMG, DSA File #12-C1*.

Suppe, J., (1983), Geometry and Kinematics of Fault-Bend Folding; *American Journal of Science*, Vol. 283, p. 684-721.

Woodward-Clyde Consultants; (1980) Evaluation of the Potential for Resolving the Geologic and Seismic Issues at the Humboldt Bay Power Plant Unit Number 3; Unpublished consulting report for Pacific Gas and Electric Company, Summary Report.