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April 2, 2010
2335-7B, L-28884

Mr. Richard Stanton
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RE: Geologic and Geotechnical Investigation Report
Building 85 Stabilization
Lawrence Berkeley National Laboratory
Berkeley, California
(Subcontract No. 6859200)

Dear Mr. Stanton:

The attached report presents the results of our geologic and geotechnical investigation for the proposed Building 85 Stabilization project at the Lawrence Berkeley National Laboratory. The accompanying report presents information regarding geologic and geotechnical conditions at the site and presents conclusions and recommendations pertaining to the design of the project. The interpretations, conclusions and recommendations presented in this report were developed in accordance with generally accepted professional principles and practices at the time that the report was prepared.

Should you have questions or comments concerning the geologic characterization, the geotechnical design concepts discussed, or our recommendations, please do not hesitate to call.

Very truly yours,

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2335-7B LBNL B85 - FINAL ltr of trans

EXECUTIVE SUMMARY

The following report presents the results of a design-level geotechnical study by Alan Kropp and Associates, Inc. (AKA) and William Lettis & Associates, Inc. (WLA) for the Building 85 Slide Mitigation Project at the Lawrence Berkeley National Laboratory (LBNL). The purpose of our study was to provide design-level geotechnical recommendations for the Project and site-specific subsurface data for the contractor to use in preparing their bids to perform the work. The scope of our work included reviewing existing data, performing field explorations and laboratory testing, characterizing geotechnical and geologic conditions, performing engineering analyses, developing geotechnical engineering recommendations, and preparing this report. Our study builds upon previous work performed by AKA/WLA for this project and at other sites in this general area of the LBNL facility.

LBNL Buildings 85 and 85A are located along the western side of a narrow north/south-trending valley known as the East Canyon. This study identifies four Quaternary-age landslides (Qls) in the direct vicinity of the project. Landslide Qls-1 underlies the central portion of the canyon east of Buildings 85 and 85A. Landslide Qls-2 is located a short distance upcanyon and does not directly impact Buildings 85 or 85A. Landslide Qls-3 underlies a portion of Building 85A. Landslide Qls-4 underlies a portion of Building 85. Although geologically young in age, the four landslides identified appear not to have moved significantly since the East Canyon area was developed (starting in the early 1960s).

LBNL is located in a region that is seismically active. The closest active fault to the project is the Hayward fault, which is located about 3,500 feet to the southwest. The Hayward fault is part of a major regional fault system and is capable of producing very strong ground shaking at the project site. Previous work by AKA/WLA indicated that the western margin of Landslide Qls-1 passed through Buildings 85 and 85A, and that the landslide could be reactivated by earthquake shaking. In this study, additional subsurface explorations were performed to refine our understanding of the East Canyon geology. This additional work produced the finding that Landslide Qls-1 does not intersect Building 85 or 85A, but that these buildings are partially underlain by smaller previously-unrecognized landslides (Qls-3 and Qls-4) that are also considered unstable under strong seismic shaking.

As currently planned, the Building 85 Slide Mitigation Project will include the installation of below-grade structural retention systems designed to limit seismic ground deformations in the area of Buildings 85 and 85A. The retention systems will be comprised of linear groupings of closely-spaced drilled piers that will be restrained near their tops by tiebacks; the bottoms of the drilled piers and the anchorage zone of the tiebacks will be designed to be embedded within "in-place" bedrock below the depth of landsliding. The drilled piers will be installed east of Buildings 85 and 85A with the tiebacks extending back beneath both buildings. The drilled piers and tiebacks are designed to restrain Landslides Qls-3 and Qls-4; in general, Landslide Qls-1 will not be restrained and will therefore be free to slide past and/or pull away from the face of the drilled piers during an earthquake.

The primary objective of our geotechnical engineering analyses was to evaluate the lateral forces that the new below-grade structural elements would need to resist. Our analytical approach was based upon the official State of California guidelines presented in SP 117A. Our evaluations of earthquake-induced slope displacements were performed using the methods outlined in the professional paper "*Simplified Procedure for Estimating Earthquake-Induced Deviatoric Slope Displacements*" by Bray and Travasarou (2007). We performed our slope stability modeling using conventional 2-dimensional (2D) analysis methods and engineering cross sections based on the interpreted geologic cross sections. In general, these methods relate lateral resisting forces to displacements caused by a specified level of earthquake shaking (with higher resisting forces needed to produce lesser displacements).

We and the project team solicited input from LBNL Facilities Division technical personnel on: (1) the level of earthquake shaking to be used for the design; and (2) "allowable" seismic displacements. "Design-level" earthquake shaking was defined at the 10 percent probability of exceedance in 50 years level (which is equivalent to the ground motion intensity with a 475-year return period). Calculated median seismic displacements of 2 inches or less were considered "acceptable" for the design-level earthquake shaking. These criteria can be generally characterized as stringent, which was considered appropriate for this particular LBNL facility.

We evaluated probable seismic displacements for Landslide Qls-1 in order to demonstrate that the landslide could slide past and/or move away from the drilled pier restraint system during an earthquake. As an initial step, we evaluated the yield acceleration of Landslide Qls-1 using a computer slope stability model (the yield acceleration can be viewed as the horizontal ground acceleration at which the landslide just starts to move). A very low yield acceleration value (~0.02g) was obtained, which correlates to a calculated median slope displacement of about 8 feet. As noted by Bray and Travasarou, probable seismic slope displacements can be estimated to be between half and twice the median calculated value (i.e., 4 feet to 16 feet).

We evaluated the lateral forces that the new below-grade structural elements would need to resist (i.e., from Landslides Qls-3 and Qls-4). For each landslide we used the Bray and Travasarou method to evaluate the yield acceleration that would be needed to produce a calculated median displacement of 2 inches. We then used the slope stability model to determine the additional lateral resisting force that would need to be applied at the location of the retaining structure to obtain the requisite yield acceleration value. These analyses resulted in landslide forces of 70 kips and 158 kips for Landslides Qls-3 and Qls-4, respectively. Since our analyses were performed using 2D methods, the calculated values correspond to the total lateral force per foot of landslide width.

These calculated values were used to develop design lateral pressures for the below-grade structural restraint system. We recommend redistributing these forces into either a uniform (rectangular) or apparent (trapezoidal) earth pressure distribution for design purposes. We also provide recommendations to account for counteracting resistive effects from: (1) the existing piers that support Building 85 (which penetrate Landslide Qls-4 and extend into bedrock); and (2) active and hydrostatic pressures acting on the face of the restraint system due to sloughing and infilling of the crack at the Landslide Qls-1 interface.

In addition to the lateral pressures from Landslides Qls-3 and Qls-4, we recognize that there is an alternate failure mode by which Landslide Qls-1 would exert a lateral shear force if it slides past the face of the below-grade structural system. This mode is only applicable for the area between Building 85A and the emergency generator pad (southeast of Building 85A) due to geometric constraints. In this study, we recommend that shear loads be evaluated using uniform values of 2000 psf and 3000 psf for soil and rock, respectively.

This design-level study provides geotechnical engineering recommendations for the design of the drilled pier and tieback structural restraint system as well as for other geotechnical aspects of the project. It is critical that we observe the geotechnical aspects of construction to check field conditions and verify that our recommendations are appropriately implemented.

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1.00 INTRODUCTION

This report presents the results of a design-level geotechnical investigation by Alan Kropp and Associates, Inc. (AKA) and William Lettis & Associates, Inc. (WLA) for the Building 85 Slide Mitigation Project at the Lawrence Berkeley National Laboratory (LBNL). Our study was conducted in general accordance with Architect-Engineer Subcontract No. 6859200, between LBNL and AKA. The approximate location of the project is shown on the attached Vicinity Map, Figure 1. As currently envisioned, the project will involve LBNL Buildings 85 and 85A, which are shown on the attached Site Plan, Figure 2.

1.01 Background

LBNL occupies an approximately 200-acre site in the hills above the University of California, Berkeley (UCB) campus. Buildings 85 and 85A are located within the eastern portion of LBNL along the west side of a north/south-trending valley known locally as the East Canyon. As is common within the Berkeley Hills, the natural processes that formed the East Canyon have included landsliding at a variety of scales. Prior to this investigation, AKA and WLA conducted several geotechnical and geologic studies in the general area of Buildings 85 and 85A; the most relevant of these reports are described below. A more complete listing of pre-existing information relevant to our study is presented in the reference list, Section 10.00.

> ***AKA 2006a*** - In September 2004, AKA and WLA began a geotechnical investigation for a new Animal Care Facility (ACF or Building 86) to be located east of Building 85 near the central axis of the East Canyon. During the scoping phase of the ACF study, we noted the possibility that the building site might be underlain by landslide-related deposits based on our review of historic photographs and pre-existing subsurface data from previous LBNL reports. In an initial continuously sampled boring (AKA-1), bedrock-derived landslide debris and clayey shear zones were identified that were consistent with the landslide hypothesis. Inferences drawn regarding the possible western lateral extent of landsliding included the possibility that the landslide deposits extended beneath Building 85. Slope stability and deformation analyses performed as part of the ACF study predicted that the interpreted landslide underlying the ACF could move several feet during a large earthquake. Our geotechnical investigation report for Building 86 (AKA 2006a) was finalized in January 2006.
>
> ***AKA 2006b*** - In September 2005, AKA and WLA began an initial phase of broader geotechnical and geologic study pertaining to the interpreted landslide within the central portion of the East Canyon. This initial study was intended as a first step toward evaluating concerns that landslide deposits could potentially pose a hazard to Buildings 85 and 85A and focused upon evaluating whether the interpreted landslide extended beneath one or both of these buildings. In a key boring drilled at the northeast corner of Building 85 (AKA-3), a 6-inch-thick layer of clay was identified at a depth of 65 feet that was tentatively identified as a landslide slip surface. This is deeper than was anticipated based on the inferences drawn in our previous study for the ACF (AKA 2006a). Additional borings drilled to evaluate the lateral continuity and orientation of this feature (AKA-5 and AKA-7) found conditions interpreted as being consistent with a deeper landslide slip surface. Based on these data, we interpreted that landslide deposits extend beneath the eastern portions of Buildings 85 and 85A. This interpretation, coupled with our previous conclusions pertaining to seismic slope movements, caused us to conclude that earthquake-induced landsliding posed a potential hazard to both buildings. Our initial East Canyon landslide characterization study report (AKA 2006b) was finalized in July 2006.

AKA 2007 **-** In October 2006, LBNL requested that AKA develop a conceptual-level design to mitigate the potential for excessive earthquake-induced landslide movements beneath Buildings 85 and 85A. Our study was necessarily preliminary in that no reliable data existed at that time regarding: (1) overall landslide head and toe geometries; (2) dynamic properties (i.e., shear wave velocity) of the materials beneath the site; (3) landslide geometry and bedrock conditions at Building 85; and (4) landslide geometry and conditions upslope of Building 85A. We presented our preliminary analyses and conceptual designs and cost estimates in a report dated April 27, 2007 (AKA 2007). This work was performed with the assistance of Dr. Jonathan Bray of the University of California, Berkeley; Timothy Mathison of Tuan and Robinson Structural Engineers (TRSE); and Brad Saylor of Leland Saylor and Associates, cost estimators.

WLA 2008 **-** In September 2008, AKA and WLA began a study of a mapped fault intersecting the proposed Building 85 site (the East Canyon fault). Previous investigators working in the East Canyon postulated the existence of this feature based on the alignment of springs, apparent displacement of bedrock units, bedrock weathering and a trench exposure. As part of the previous study (AKA 2006b), WLA excavated exploratory trenches south of Building 85 that encountered bedrock undisrupted by faulting. In the September 2009 study, additional trenching was performed that: (1) extended the zone of investigation towards the west to intersect other potentially plausible orientations for the East Canyon fault; and (2) closed a data gap between two discontinuous trenches excavated during the previous phase. The results of the trenching demonstrated that the East Canyon fault does not exist in the area where it had previously been mapped. Our surface fault rupture hazard investigation for the East Canyon fault (WLA 2008) was finalized in October 2008.

1.02 Project Description

The Building 85 Slide Mitigation Project is part of a larger project known as: "*LBNL Seismic Life-Safety, Modernization, and Replacement of General Purpose Buildings, Phase II,*" (commonly shortened to "Seismic Phase II"). The Seismic Phase II project team includes the following design firms:

- RMW Architecture (architects and lead consultant);
- Forell/Elsesser (structural engineers); and
- Creegan + D'Angelo (civil engineers).

As currently envisioned, the Building 85 Slide Mitigation Project will include the installation of structural systems (principally drilled piers and tiebacks) intended to retain landslide deposits beneath Buildings 85 and 85A and isolate both buildings from adjacent unretained landslide deposits. At the conceptual design phase, very large forces were calculated for structural systems retaining landslide deposits moving down-canyon (i.e., from north to south). This specific difficulty was not able to be resolved as part of the conceptual-level study. However, a possible design concept intended to influence the landslide failure mechanics upslope of Building 85A was included in the conceptual-level designs and cost estimates (AKA 2007).

1.03 Study Objectives

1.03.1 Purpose and Approach

As outlined in our August 13, 2008 proposal, the primary purpose of our study was to provide design-level geotechnical recommendations for the Building 85 Slide Mitigation Project and site-specific subsurface data for the contractor to use in preparing their bids to perform the work. To accomplish this purpose, additional investigations were needed to fill data gaps and to check assumptions made during our previous geologic and geotechnical studies (AKA 2006b) and in our conceptual-level designs and cost estimates (AKA 2007). The study described in this report therefore includes new subsurface investigations (borings and trenches) in areas not previously explored by AKA or WLA. These investigations consisted of:

- Two exploratory borings (AKA-8 and AKA-9) along the central axis of the East Canyon; south (down-canyon) and north (up-canyon) of previous AKA borings;
- Four exploratory borings (AKA-10 to 13) within the secured area of the Building 85/85A facility;
- Three exploratory boreholes (AKA-14 to 16) near the old quarry southeast of Building 85;
- Three test pits (TP-1 to TP-3) near the old quarry southeast of Building 85; and
- One test pit (TP-4) and a 55-foot-long rock cut (RC-1) upslope (northwest) of Building 85A.

Also considered in this study were new data and interpretations developed by AKA and WLA as part of other recent LBNL studies, including:

- Exploratory trenching performed southwest of Building 85 for the East Canyon fault study (WLA 2008);
- Exploratory borings drilled south of Building 85 as part of a LBNL study involving the Centennial Drive overcrossing of Lawrence Road (AKA 2009);
- Ongoing data reviews, interpretations and analyses relating to the geology of the LBNL and UCB campuses (multiple projects).

Our general approach to this study, therefore, included a thorough re-evaluation of the initial interpretations, conclusions and evaluations presented in our previous reports pertaining to Buildings 85 and 85A (AKA 2006b and AKA 2007) considering the totality of the current data.

1.03.2 Compliance with Official State Regulations and Guidelines

Buildings 85 and 85A are located within an official State of California Earthquake-Induced Landslide Hazard Zone, as mapped by the California Geological Survey (CGS). This mapping was conducted under the Seismic Hazard Mapping Act of 1991 and is intended to provide guidance to cities, counties and other lead agencies in their efforts to protect public health and safety, and is directed at structures intended for human occupancy. In 1997, the California Division of Mines and Geology (CDMG, which is now known as the CGS), published Special Publication 117 (SP117) presenting guidelines for evaluating and mitigating seismically-induced landslide and liquefaction hazards in California. SP117 (CDMG 1997) is widely used by cities, counties and peer reviewers throughout California to determine the adequacy of geotechnical investigations conducted within the mapped seismic hazard zones. In 2008, the CGS issued SP117A (CGS 2008), an updated version of SP117. It was our objective that the evaluations and recommendations presented in this report pertaining to landslide hazards be developed in general conformance with the current applicable SP117A guidelines.

The faults that exist in the direct vicinity of the site are not considered by the CGS to be active and the site is not within a previous or current State of California Earthquake Fault Zone, as delineated under the Alquist-Priolo Earthquake Fault Zoning Act. CGS Special Publication 42 (SP42, CGS 1999) provides guidelines for evaluating and mitigating fault rupture hazards within designated Earthquake Fault Zones (A-P Zones). Although our overall geologic characterization of the site includes information on various faults in the project vicinity, it was not our objective to investigate or document these features in accordance with the rigorous SP42 guidelines, as the faults in the direct vicinity of the site are not zoned as active. As previously indicated, the East Canyon fault was not found in trenches excavated south and west of Building 85 (WLA 2007), and its existence is considered speculative.

1.04 Scope of Services

1.04.1 Base Scope

As outlined in our August 13, 2008 proposal and cost estimates, our scope of services included the following tasks:

Scope of Services – By Task

Task No.	Task Description
1	Conceptual Design Meetings and Consultation
2	GIS Data Compilation
3	Geologic Reconnaissance and Drilling Preparation
4	Borings AKA-8 and AKA-9
5	Borings AKA-10 through AKA-13
6	Boring AKA-14 (not performed; deleted from scope)
7	Trench WLA-4 (performed under supplemental authorization)
8	Downhole Shear Wave Velocity Measurements
9	Detailed Review of Core Samples
10	Review Meeting to Discuss Project Objectives
11	Geologic Map and Cross Sections
12	Laboratory Testing and Evaluations
13	Site-Specific Ground Motions
14	Evaluation of Slide Body Response
15	Seismic Stability, Deformations and Forces
16	Geotechnical Design Recommendations
17	Draft Geologic and Geotechnical Report
18	Review Meeting to Discuss Project Findings
19	Final Geologic and Geotechnical Report

Tasks 1 through 4 and Task 8 were completed in September 2008 under our initial subcontract authorization. Tasks 5 and 9 through 17 were completed by the date of this draft report. Task 6 was deleted from the project scope due to operational and access constraints. As discussed in Section 1.04.2, the scope of Task 7 was broadened and completed under a supplemental authorization and included multiple exploratory test pits (AKA TP-1 to TP-4) and additional boreholes (AKA-14 to AKA-16).

1.04.2 Scope Revision

In August 2009, we met with LBNL representatives to discuss the status of our investigations (Task 10 of our authorized scope) and to present preliminary findings with respect to the geologic characterization. The new data obtained from Borings AKA-8 through AKA-13 coupled with a recently-located historical photograph depicting the pre-development topography suggested an alternative model of landsliding within the East Canyon, which could not be confirmed or refuted with the information available to us at that time. As a result of this meeting, Task 7 was expanded to include a series of subtasks:

Scope of Services – Task 7

Task No.	Subtask Description
7	Offsite Geologic Reconnaissance and Mapping
	Test Pits TP-1 through TP-4
	Borings AKA-14 through AKA-16
	Petrographic Analysis
	Analyses and Reporting

1.05 Project Team

This report was prepared by the firms of Alan Kropp & Associates (AKA) and William Lettis & Associates (WLA) as part of a project-specific joint effort. Our study was directed and managed by Mr. Wayne Magnusen of AKA (GE 2705) in association with Mr. John Baldwin (CEG 2167) of WLA. Our consultant team included Dr. Jonathan Bray, professor of geoengineering at UCB, who provided specialized consultation to AKA on earthquake ground motions, slope stability and seismic displacement analyses.

2.00 METHODS OF INVESTIGATION

2.01 Review of Geologic and Historical Information

As part of this and previous LBNL studies, we reviewed and compiled geologic and historical information from a variety of published and unpublished sources. The materials that we reviewed include regional-scale maps and report published by the United States Geological Survey (USGS), official hazard maps issued by the California Geological Survey (CGS), published papers relating to the geology of the Berkeley Hills, unpublished consultant reports pertaining to LBNL geology, and historical photographs of the site and vicinity. The key sources of geologic and historic information used in preparing this report are introduced in the subsections that follow. A more thorough list of compiled sources relevant to our study is presented in the References section (Section 10.00) of this report.

2.01.1 Regional-Scale Geologic Maps

- ***Dibblee 1980*** **-** Dibblee, Thomas W., Jr., 1980, "Preliminary Geologic Map of the Briones Valley Quadrangle, Alameda and Contra Costa Counties, California," U.S. Geological Survey, Open File Report 80-539.

- ***Graymer, et al. 1996*** **-** Graymer, R.W., Jones, D.L., and Brabb, E.E., 1996, "Preliminary Geologic Map Emphasizing Bedrock Formations in Alameda County, California: A Digital Database," U.S. Geological Survey, Open-File Report 96-252.

- ***Graymer 2000*** **-** Graymer, R.W., 2000, "Geologic Map and Map Database of the Oakland Metropolitan Area, Alameda, Contra Costa and San Francisco Counties, California," U.S. Geological Survey, Miscellaneous Field Studies MF-2342.

2.01.2 Publications on Berkeley Hills Geology

- ***Jones and Curtis 1991*** **-** Jones, David L. and Curtis, Garniss, 1991, "Guide to the Geology of the Berkeley Hills, Central Ranges, California," in <u>Geologic Excursions in Northern California: San Francisco to the Sierra Nevada</u>, California Division of Mines and Geology, Special Publication 109.

- ***Lawson and Palache 1901*** **-** Lawson, Andrew C. and Palache, Charles, 1901, "The Berkeley Hills, a Detail of Coast Range Geology," text dated December 1901, The University of California Bulletin of the Department of Geology, Vol.2, No.12, pp-349-450, Plates 1-17, with oversize map dated 1900.

2.01.3 Materials Pertaining to LBNL Geology and Hydrogeology

- ***Converse 1984*** **-** Converse Consultants, 1984, "Hill Area Dewatering and Stabilization Studies," unpublished consulting report prepared for the University of California Department of Facilities Management, dated October 31, 1984.

- ***HLA 1982*** - Harding Lawson Associates (HLA), 1982, "Geology of Lawrence Berkeley Laboratory," unpublished consulting report prepared for the Lawrence Berkeley Laboratory, dated September 28, 1982, HLA Job No. 2000,135.01 (LBNL File No. 42).

- ***LBNL/Parsons 2000*** - Lawrence Berkeley National Laboratory Environmental Health and Safety Division and Earth Sciences Division with Parsons Engineering Science, Inc. (LBNL/Parsons), 2000, "RCRA Facility Investigation Report for the Lawrence Berkeley National Laboratory Environmental Restoration Program," unpublished consulting report dated September 2000 (referred to herein as the "RFI Report").

2.01.4 Landslide Maps

- ***CGS 2003a*** - California Geological Survey (CGS), 2003, "Seismic Hazard Zone Report for the Briones Valley 7.5-Minute Quadrangle, Alameda County, California," Seismic Hazards Zone Report 084.

- ***LBNL 1984*** - Lawrence Berkeley National Laboratory Facilities Division, 1984, "Slope Locations – Stability Evaluations," 1" = 100' scale drawing dated 8/94.

- ***Nilsen 1975*** - Nilsen, T.H., 1975, "Preliminary Photointerpretation Map of Landslide and Other Surficial Deposits of the Briones Valley 7½' Quadrangle, Contra Costa and Alameda Counties, California," U.S. Geological Survey, Open File Map 75-277-08.

2.01.5 Fault and Seismic Source Maps

- ***CDMG 1982a&b*** - California Division of Mines and Geology (CDMG), 1982a, Special Studies Zone Map, Oakland West Quadrangle.

- ***CDMG 1982b*** - California Division of Mines and Geology (CDMG), 1982b, Special Studies Zone Map, Richmond Quadrangle.

- ***ICBO 1998*** - International Conference of Building Officials (ICBO), 1998, "Maps of Known Active Fault Near-Source Zones in California and Adjacent Portions of Nevada," California Division of Mines and Geology.

- ***Lienkaemper 1992*** - Lienkaemper, J.J., 1992, "Map of Recently Active Traces of the Hayward Fault, Alameda and Contra Costa Counties, California," United States Geological Survey, Map MF-2196.

2.01.6 References on Seismicity

- ***Bakun 1999*** - Bakun, W.H., 1999, "Seismic Activity of the San Francisco Bay Region," Bulletin of the Seismological Society of America; June 1999; V.89, No.3, p. 764-784.

- ***WGCEP 2003*** - Working Group on California Earthquake Probabilities, 2003, "Earthquake Probabilities in the San Francisco Bay Region: 2002–2031," USGS Open-File Report 2003-214.

- ***WGCEP 2008*** - Working Group on California Earthquake Probabilities, 2008, "The Uniform California Earthquake Rupture Forecast, Version 2 (UCERF 2): for 2007–2036:" USGS Open-File Report 2007-1437; CGS Special Report 203; and SCEC Contribution #1138.

2.01.7 References on Ground Motions

- ***CGS 2009*** - California Geological Survey, accessed 2009, "Probabilistic Seismic Hazards Ground Motion Page (http://redirect.conservation.ca.gov/cgs/rghm/pshamap/pshamap.asp).

- ***URS 2008*** - URS Corporation, 2008, "Updated Probabilistic Seismic Hazard Evaluation and Development of Seismic Design Ground Motions for the University of California, Berkeley and the Lawrence Berkeley National Laboratory," unpublished consulting report dated 9 September 2008.

- ***USGS 2007*** - United States Geologic Survey, 2007, Seismic Hazard Curves and Uniform Hazard Response Spectra v5.0.8, November 20, 2007 (http://earthquake.usgs.gov/research/hazmaps/design/).

2.02 Field Investigations and Laboratory Analyses

2.02.1 Geologic Field Mapping

In August and September of 2009, WLA geologists performed surface reconnaissance of the East Canyon in order to revise and expand upon the geologic mapping performed as part of previous LBNL studies. The surface reconnaissance included: (1) mapping of geologic deposits, artificial fill, and landslides; (2) collection of structural information (orientation of bedding and discontinuities) from rock exposures and outcrops; (3) evaluation of roads, curbs, and sidewalks to check for indications of slope instability; and (4) identification of possible and preferred exploratory test pit locations to evaluate landslide characteristics in the direct vicinity of Buildings 85 and 85A.

Geologic mapping was performed using a topographic base map constructed from ground conditions surveyed in 2003 by LBNL (hereafter referred to as the "2003 LBNL base map," or simply "base map"). The base map is in the U.C. Grid projection (units in feet), with Grid North oriented about 16.7 degrees west of True North, and includes both 1-foot and 2-foot contour intervals. As part of the mapping, we also reviewed and interpreted: (1) pre-grading topographic maps/plans provided by LBNL or contained within older consultant reports; and (2) recent airborne-collected LiDAR (Light Detection and Ranging) data/maps flown for Alameda County, obtained and processed by AKA.

2.02.2 Borings

This investigation included nine exploratory borings, as summarized in the following table:

Exploratory Borings for This Investigation

Boring ID	Date Completed	Total Depth (feet)	Continuous Sampling Interval(s) (feet)	Drilling Equipment
AKA-8	9/19/08	85	2.5 to 85	Truck-Mounted Rotary Wash
AKA-9	9/25/08	101	3 to 101	Truck-Mounted Rotary Wash
AKA-10	7/14/09	89	15 to 89	Truck-Mounted Rotary Wash
AKA-11	7/13/09	80	20 to 80	Truck-Mounted Rotary Wash
AKA-12	7/8/09	61.5	5 to 35	Truck-Mounted Rotary Wash
AKA-13	7/9/09	60	2 to 60	Truck-Mounted Rotary Wash
AKA-14	10/28/09	35	0 to 35	Hydraulic Portable Auger
AKA-15	10/30/09	25	6 to 25	Hydraulic Portable Auger
AKA-16	10/29/09	43	0 to 27.5 30 to 37.5 40 to 43	Hydraulic Portable Auger

The approximate locations of the borings are indicated on the Site Plan, Figure 2. As-drilled boring locations and elevation data for Borings AKA-8, 9, and 14 through 16 were provided to us by Bates & Bailey Land Surveyors, Inc. (B&B) of Berkeley, California, an LBNL subcontractor. The locations of Borings AKA-10 through 13 were determined using a tape measure and as-drilled elevations were estimated based on the Building 85 plans (upper yard vs. lower yard).

An AKA engineer or WLA geologist, supervised the drilling operations, logged the soils and bedrock encountered, and obtained samples of the subsurface materials for subsequent evaluation and laboratory testing. The field logs and soil/rock samples were reviewed in the laboratory by WLA's lead engineering geologist for the project, Mr. John Baldwin. The logs of Borings AKA-8 through 16 are attached in Appendix A, together with two explanatory figures pertaining to the classification/description of the soil (Figure A1) and rock (Figure A2). The soils are described in general accordance with the Unified Soil Classification System (ASTM D-2487-06).

Samples of soil and weathered bedrock were obtained using: (1) a 1½-inch inside-diameter Standard Penetration Test (SPT) split barrel drive sampler; (2) a 2½-inch inside-diameter Modified California split barrel drive sampler equipped with brass liners; and (3) a "101-type" wireline core barrel sampler. Drive samplers were advanced using a standard automatic 140-pound hammer falling 30 inches. The borings were continuously sampled throughout zones considered to be of geologic interest; borings were generally sampled at about 5-foot vertical intervals outside these targeted zones. The intervals of sampling are shown on the boring logs presented in Appendix A; the depth intervals over which continuous sampling was performed are summarized in the table presented earlier in this section.

2.02.3 Exploratory Excavations

Between October 29 and November 4, 2009, WLA geologists excavated and documented four test pits (TP-1 through TP-4) and a rock cut at the approximate locations shown on the Site Plan presented on Figure 2. The logs of test pits TP-1 through TP-4 and the rock cut are attached in Appendix B.

C&C Excavation (an AKA subcontractor) excavated the test pits and rock cut using a rubber tire backhoe equipped with a 36-inch-wide bucket. At least one wall of each test pit was completely cleaned to expose fresh material. Structural and stratigraphic features were flagged and logged at 1 inch = 2 feet (1:24-scale). Attitudes and orientations of structural features were measured and logged after correlating with similar features on the opposite wall. The test pits were used to characterize the presence or absence of landslide material upslope and downslope of Building 85, and to delineate the contact between the Moraga and Orinda Formations. The test pits were up to about 15 feet long and 15 feet deep.

Prior to excavation, a site-safety meeting was held with WLA, LBNL, and C&C Excavation to review the health and safety plan and to discuss elements of the test pit investigation. The test pits used aluminum hydraulic shoring in accordance with OSHA regulations. Site safety inspections were performed by the WLA competent person prior to entering the trenches. Upon documentation of the test pit exposures, the excavations were backfilled in lifts using a backhoe-mounted sheepsfoot compaction device. The backfill compaction was visually inspected and did not include laboratory or field testing of the backfill conditions. Each test pit area was restored to previous grade using the backhoe equipment. The trench locations were subsequently surveyed by B&B.

2.02.4 Laboratory Testing

Soil and rock samples were examined in our laboratory for more detailed examination and to select specimens for laboratory analyses. The following geotechnical laboratory tests were performed to provide general data on the physical properties of the subsurface materials.

- Water content per ASTM Test Designation D-2216;
- Dry density per ASTM Test Designation D-2937;
- Atterberg Limits per ASTM Test Designation D-4318; and
- Particle Size Analysis per ASTM Test Designation D-422.

The tests were conducted in general accordance with the current edition of the referenced ASTM standards at the time the tests were performed. The results of the tests are presented on the boring logs at the appropriate sample depths. Laboratory test data sheets are attached at the end of Appendix A, where appropriate.

2.02.5 Shear Wave Velocity Measurements

Geophysical methods were used to measure the subsurface distribution of compressional (P-) and shear (S-) seismic velocity within borings AKA-8 and AKA-9. The field work was performed on September 19 and 24, 2008 by our subconsultant Norcal Geophysical Consultants, Inc. (Norcal) of Cotati, California, using a downhole suspension velocity logging system. Norcal's P- and S-Wave Borehole Suspension Logging Report is attached in Appendix C.

2.02.6 Petrographic Analyses

Six representative bedrock samples were submitted to an independent testing laboratory for petrographic analysis in order to substantiate our classification of onsite sedimentary and volcanic rocks. The results of the petrographic analyses are attached in Appendix D.

2.03 Compilation and Review of Existing Subsurface Data

2.03.1 Unpublished Consulting Reports by Others

This investigation included compiling and reviewing relevant existing subsurface data from unpublished geotechnical and geologic reports prepared by others. These sources of data and information included:

> ***D&M 1960*** - Dames & Moore (D&M), 1960, "Foundation Investigation, Health Physics Building, Lawrence Radiation Laboratory, Berkeley, California," report dated July 7, 1960.
>
> ***GRC 1994a*** - Geo/Resource Consultants, Inc. (GRC), 1994a, "Fault Investigation, Building 85, Hazardous Waste Handling Facility," prepared for Lawrence Berkeley National Laboratory, dated March 22, 1994, Job #1746-003 *(LBNL File #340)*.
>
> ***GRC 1994b*** - Geo/Resource Consultants, Inc. (GRC), 1994b, "Geotechnical Investigation, Replacement Hazardous Waste Handling Facility, Building 85," prepared for Lawrence Berkeley National Laboratory, May 2, 1994, Job #1746-006 *(LBNL File #339)*.
>
> ***HLA 1997*** - Harding-Lawson Associates (HLA), 1977, "Foundation Investigation, Cell Culture Facility, Lawrence Berkeley Laboratory, Berkeley, California," HLA Job No. 2000,104.01, unpublished consulting report dated July 27, 1977 *(LBNL File #183)*.
>
> ***HLA 1985*** - Harding-Lawson Associates (HLA) 1985, "Preliminary Geotechnical Evaluation, Proposed East Canyon Corporation Yard Development, Lawrence Berkeley Laboratory, Berkeley, California," report dated January 18, 1985, HLA Project No. 2000.170.01.
>
> ***Kleinfelder 2001*** - Kleinfelder Inc., 2001, "Geotechnical Investigation, Proposed Road and Water Tank, Lawrence Berkeley National Laboratory, Berkeley, California," report dated July 19, 2001, Kleinfelder Job No. 41-7631-01/001 *(LBNL File #384)*.

Selected boring and test pit/trench logs from the above-referenced geotechnical investigations are attached in Appendix E.

2.03.2 Geo-positioning of Subsurface Data

We evaluated the locations and elevations of previous borings, test pits and/or trenches using the reference information provided in the cited report. Where a "site plan" or similar drawing was the sole source of horizontal reference, we evaluated probable data locations by scaling from recognizable site features. The accuracy of this method is necessarily limited by the relative quality of the reference source and should be considered approximate. Elevations of the ground surface at the time that the explorations were performed were typically obtained directly from the logs. The approximate locations and elevations of specific sources of data are shown on the Site Plan (Figure 2).

2.03.3 Geographical Information System Database

Our study included entering new and existing subsurface data into a Geographical Information System (GIS) database, which we developed using industry standard ArcGIS software (by ESRI). For reference purposes, each data source at LBNL that we have evaluated to-date has been assigned a unique GIS reference number. Tabular summaries are provided in Appendix F linking the GIS reference number to the original source information (citation and boring, test pit or trench number), consistent with the identifying information shown on the Site Plan (Figure 2).

3.00 GEOLOGIC SETTING

3.01 Regional Geology

The San Francisco Bay region lies within a broad region of deformation that defines the boundary between the North American and Pacific tectonic plates. These two plates are currently in motion relative to each other and this relative motion is accommodated, in part, by slip along a series of major active strike-slip faults, which exist over a width of more than 50 miles (Figure 3). At the current time, the Pacific Plate is moving northwest relative to the North American Plate. Consequently, relative motion along the major strike-slip faults is predominantly horizontal with the ground on the opposite side of the fault moving towards the right. The nature of this relative motion is defined as "right-lateral strike-slip."

Among the oldest rocks in the region are highly deformed sedimentary, metamorphic and volcanic rocks of the Franciscan Complex. Franciscan Complex rocks were deposited in a deep ocean floor environment during the late Jurassic and late Cretaceous (159 to 69 million years ago). About 145 million years ago, the plate upon which the Franciscan rocks were deposited (the Farallon Plate) collided with the North American plate. At this time and continuing up to about 30 million years ago, the Farallon Plate (moving in an easterly motion) was subducted below, and in places accreted onto, the crust of the western edge of the North American Plate. About 30 million years ago, after much of the Farallon Plate had been consumed by subduction, the North American Plate came into contact with the Pacific Plate. Subduction ceased at this plate intersection and was replaced by the right-lateral strike-slip faulting that predominates today.

Around the same time that the oceanic Franciscan Complex rocks were being deposited in a marine seafloor environment (159 to 69 million years ago), sedimentary rocks of the Great Valley Sequence were being deposited on a fragment of oceanic crust (the Coast Range Ophiolite) within a marine basin at the western edge of the North American Plate. The Franciscan Complex, Great Valley Sequence and Coast Range Ophiolite have since undergone significant vertical and lateral deformation from tectonic faulting and folding. Relative motion occurring along faults has, over geologic time, resulted in the large-scale dislocation of rock masses throughout the region. Over the past 30 million years (the period of time over which strike-slip faulting has predominated), the coastal terrain west of the San Andreas fault on the Pacific Plate has shifted more than 300 miles to the northwest relative to the North American Plate.

Although much of this movement has occurred along the San Andreas fault, large-scale movements have also occurred along faults on both sides of the Berkeley Hills, such as the Hayward and Calaveras faults. The major active fault of greatest significance to LBNL is the Hayward fault, the location of which is shown on the A-P Zone Map presented on Figure 4. In the vicinity of LBNL, the Hayward fault juxtaposes Franciscan Complex rocks on the west against Coast Range Ophiolite and Great Valley Sequence on the east. The Franciscan Complex and Great Valley Sequence rocks are generally overlain by a diverse sequence of younger Tertiary-age sedimentary and volcanic rocks. The predominant sequence of sedimentary rocks that exists locally (i.e., in the general vicinity of LBNL) was deposited between about 16 and 10 million years ago. The Tertiary-age sedimentary rocks are locally overlain and at times interlayered with volcanic rocks deposited about 10.5 and 8.4 million years ago. These volcanic rocks are among the youngest rocks that exist locally.

In addition to strike-slip movement occurring along northwest-trending faults, the region has also at times been compressed in the northeast-southwest direction. During the late Miocene and early Pliocene (11.2 to 3.6 million years ago) an extended period of compression occurred resulting in folding, faulting and uplift of the Berkeley Hills. The Berkeley Hills are thought to be currently experiencing uplift at a very low rate (as much as 1mm/year) based on geodetic studies (Graymer 2000).

3.02 Regional Active Faults

The San Francisco Bay region currently includes a series of major northwest-trending faults (Figure 3) that are considered active. Faults that are defined as active exhibit one or more of the following: (1) evidence of Holocene-age (within about the past 11,000 years) displacement, (2) measurable aseismic fault creep, (3) close proximity and alignment with linear concentrations or trends of earthquake epicenters, and (4) youthful tectonic-related geomorphology. Faults that are defined as "potentially active" are not known to be Holocene-active but have evidence of Quaternary-age displacement (within about the past 2 million years).

3.02.1 San Andreas Fault System

The San Andreas fault system shown on the Regional Fault Map (Figure 3) is approximately 50 miles wide and within the latitude of LBNL includes (from west to east) the San Gregorio, San Andreas, Hayward, Calaveras, Concord-Green Valley and Greenville faults. In general, the location and activity of these major faults are reasonably well-established from a regional perspective.

In 1998, the International Conference of Building Officials (ICBO) published a convenient book of fault maps (ICBO 1998) to be used in conjunction with the Uniform Building Code. These maps, developed in cooperation with the CGS, delineate Active Fault Near-Source Zones related to seismic activity at depth that differs in some respects from maps depicting surface traces of the fault. Within the San Francisco Bay Region (where the major faults are near-vertical) the most significant distinction involving the ICBO (1998) maps is that they extend the Active Fault Near-Source Zones beneath bodies of water (where surface fault traces have generally not been mapped). The distances and directions from LBNL to the regional active faults depicted on the ICBO (1998) maps are summarized below.

Regional Active Faults, Site to Seismic Source Distances

Seismic Source	Approximate Distance from LBNL	Approximate Direction from LBNL
San Andreas	31 km (~ 19 miles)	Southwest
San Gregorio	33 km (~ 21 miles)	Southwest
Hayward	Proximate	Southwest
Northern Calaveras	21 km (~ 13 miles)	East
Concord-Green Valley	23 km (~ 14 miles)	Northeast
West Napa	34 km (~ 21 miles)	North

3.02.2 The Hayward Fault

The closest known active fault to LBNL is the Hayward fault, which has been mapped by Lienkaemper (1992), WLA (2007) and others based upon exploratory trenching and surface observation of creep-related deformational features. As shown on the current A-P Zone Map (Figure 4), the Hayward fault generally traverses the base of the Berkeley Hills mostly southwest of the LBNL facility. On the UCB Campus the Hayward fault passes through Memorial Stadium and to the east of Bowles Hall, the Greek Theater and the clusters of student housing along Gayley Way and Hearst Avenue. North of Hearst

Avenue, the Hayward fault passes through the western limit of LBNL near the base of the slope west of LBNL Building 88.

The Hayward fault is part of the Hayward-Rogers Creek fault system, which extends approximately 150 kilometers (93 miles) from Fremont on the south to Healdsburg on the north. The Hayward fault extends from near Warm Springs (Fremont) on the south to San Pablo Bay on the north and has a total length of about 87 kilometers (54 miles) ± 10 kilometers (6 miles). The fault is creeping along its entire length (Lienkaemper, et al. 1991; 1997; 2001), although the rate of creep varies along the fault trace. Near U.C. Memorial Stadium the fault is creeping at an average rate of 4.8 mm/yr (McFarland, et al. 2009). Along the length of the fault, the average rate of observed creep is 4 to 5 millimeters per year (mm/yr), with a high of 9 mm/yr observed locally near the southern end of the fault near Fremont. The Holocene slip rate on the Hayward fault is estimated to be about 9 ± 2mm/yr (Lienkaemper and Borchardt 1996; WGCEP 2003).

3.03 <u>Regional Seismicity</u>

3.03.1 Historic Earthquakes

Since 1836, six earthquakes of magnitude 6.5 or greater have occurred in the Bay Area (Bakun 1999); the dates, magnitudes (M) and epicentral locations of these six large earthquakes are summarized below:

Magnitude 6.5 or Greater Earthquakes; 1836-1998 (Bakun 1999)

Date	Magnitude	Epicenter Location
June 10, 1836	6.5	East of Monterey Bay
June 1838	6.8	Peninsula section of the San Andreas fault;
October 8, 1865	6.5	Southwest of San Jose
October 21, 1868	6.8	Southern Hayward fault (Hayward Earthquake)
April 18, 1906	7.8	San Andreas fault (San Francisco Earthquake)
October 18, 1989	6.9	Santa Cruz Mountains (Loma Prieta Earthquake)

Many smaller earthquakes have occurred within the San Francisco Bay region during this same period of time. In general, larger earthquakes are less likely; as illustrated by the "significant" earthquakes tabulated by Bakun (1999), which include: 73 earthquakes of magnitude M4.6 or greater, 13 earthquakes of magnitude M6.2 or greater, 6 earthquakes of magnitude M6.5 or greater, and only 1 earthquake greater than magnitude M7.

3.03.2 Seismicity of the Hayward-Rodgers Creek Fault System

As shown on Figures 3 and 4, LBNL is located along the northern Hayward fault, a segment of the longer Hayward-Rodgers Creek fault system. Recent seismic source characterization of the Hayward-Rodgers Creek fault system considers earthquake rupture models that allow for the possibility of rupture of the entire fault system, as well as individual ruptures along the southern Hayward fault, the northern Hayward fault, and the Rodgers Creek fault (WGCEP 2003). The northern Hayward fault extends from northern Oakland on the south to San Pablo Bay on the north, a distance of approximately 30 kilometers (19 miles). The boundary between the northern and southern Hayward fault is based on the inferred rupture length of the 1868 earthquake, which ruptured the southern Hayward fault (by definition) between Warm Springs in Fremont and about San Leandro, or possibly Rocky Mound in Oakland (WGCEP 2003).

Trenching investigations at Mira Vista Golf Course in El Cerrito (about 5 miles northwest of LBNL) show the most recent event on the northern Hayward fault occurred between AD1640 and AD1776 (the Hayward Fault Paleoearthquake Group [HFPEG] 1999). The study identified at least four and possibly as many as seven, surface fault ruptures during the past approximately 2,100 years and yielded a minimum recurrence between 270 and 210 years (HFPEG 1999). Recent paleoseismic data collected on the southern Hayward fault at Tyson's Lagoon indicate as many as 11 large surface-fault ruptures within the last approximately 1,800 years, and a recurrence interval of 151 ± 23 years (Lienkaemper and Williams, 2006). A review of existing earthquake timing data between the Mira Vista site and the Tyson's Lagoon shows that it is permissible to interpret past ruptures along the entire Hayward fault, as well as separate ruptures constrained to the northern Hayward fault.

3.03.3 Regional Earthquake Probabilities

In 2003, The Working Group on California Earthquake Probabilities (WGCEP 2003), in conjunction with the United States Geological Survey (USGS), published an updated report evaluating the probabilities of significant earthquakes occurring in the Bay Area over the next three decades (2002-2031), which has since been updated on a state-wide scale in 2008 for the time span of 2007-2036. The WGCEP (2008) report indicates that there is a 0.63 (63 percent) probability that at least one magnitude 6.7 or greater earthquake will occur in the San Francisco Bay region before 2037. This probability is an aggregate value that considers seven principal Bay Area fault systems and unknown faults (background values-WGCEP 2003). The findings of the WGCEP (2008) report are summarized in the following table:

WGCEP (2008) Probabilities

Fault System	**Probability of At Least One Magnitude 6.7 or Larger Earthquake in 2007-2036**
Hayward/Rodgers Creek	0.31
San Andreas	0.21
Calaveras	0.07
San Gregorio	0.07
Concord-Green Valley	0.03
Greenville	0.03
Mount Diablo Thrust	0.01
Background (2002-2031)	0.14

The published background values are not explicitly stated in the WGCEP (2008) and thus the WGCEP (2003) values were used. The background values indicate that between 2002 and 2031 there is a 14 percent chance that an earthquake with a magnitude of greater than 6.7 may occur in the Bay Area on a fault system not characterized in the study. It should be noted differences between the 2008 and 2003 WGCEP generally fall within the magnitude of error, and major differences in background values are not expected.

4.00 LOCAL GEOLOGY

4.01 LBNL Geology

LBNL is located along the west side of the northwest-trending Berkeley Hills. Bedrock geology in the Berkeley Hills is structurally complex and includes a variety of moderately to highly deformed (faulted and folded) sedimentary, volcanic and metamorphic rock units that have been subjected to a long history of regional uplift, folding, and mass wasting (landsliding). This section provides an overview of the geology of LBNL based on a review of published geologic information.

4.01.1 Sequence and Ages of Local Bedrock Units

Virtually all of LBNL is situated east of the Hayward fault within a fault-bounded assemblage of rocks designated by Jones and Curtis (1991) as "Subterrane I." The geologic units comprising Subterrane I are introduced in the following table together with information on the age of each unit (Ma signifying millions of years ago).

Subterrane I Stratigraphic Column (Jones and Curtis 1991)

Stratigraphic Unit	Period/Epoch	Age
Bald Peak Formation	Tertiary/Late Miocene	8.5 - 8.4 Ma
Siesta Formation	Tertiary/Late Miocene	8.5 (?) Ma
Moraga Formation	Tertiary/Late Miocene	10.2 - 8.4 Ma
Orinda Formation	Tertiary/Middle to Late Miocene	13.5 - 10.5 Ma
Claremont Shale	Tertiary/Middle Miocene	16 - 13 Ma
Sobrante (?) Formation	Tertiary/Early Miocene ?	~ 23.7 (?) Ma
Eocene Sandstone, Shale	Tertiary/Eocene	49.0 - 33.7 Ma
Great Valley Sequence	Upper Jurassic/Lower Cretaceous	159 - 99 Ma
Coast Range Ophiolite	Early Late Jurassic	~ 150 Ma

At LBNL, rocks of the Jurassic/Cretaceous-age Great Valley Sequence (159-99 Ma) are locally overlain/juxtaposed with younger Tertiary-age rocks (Claremont Shale, Orinda Formation and Moraga Formation) dating from 16 to 8.5 Ma.

4.01.2 Regional Geologic Mapping by Graymer (2000)

The Regional Geologic Map presented on Figure 5 is based on a recent published geologic map of this area from the United States Geological Survey (Graymer 2000). The map shows the geographical distribution of the bedrock units mapped locally, which are identified on the map as Great Valley Group, Claremont Chert, Orinda Formation, and Moraga Volcanics. Graymer (2000) describes these predominant bedrock units at LBNL as follows:

> ***Moraga Formation (map symbol Tmb); late Miocene -*** *Basalt and andesite flows, minor rhyolite tuff, Ar/Ar ages obtained from rocks of this unit range from 9.0+0.3 to 10.2+0.5 Ma.*
>
> ***Orinda Formation (map symbol Tor); late Miocene -*** *Distinctly to indistinctly bedded, nonmarine, pebble to boulder conglomerate, conglomerate sandstone, coarse- to medium-grained lithic sandstone, and green and red siltstone and mudstone.*

***Claremont Chert (map symbol Tcc); late to middle Miocene** - Laminated and bedded chert, minor brown shale, and white sandstone.*

***Great Valley Complex, Unnamed Sedimentary Rocks (map symbol Ku); Late Cretaceous** - Massive to distinctly bedded, biotite-bearing, brown-weathering, coarse- to fine-grained greywacke and lithic wacke, siltstone, and mudstone.*

In addition to bedrock units, the regional geologic mapping by Graymer includes interpreted information pertaining to bedrock structure. The active Hayward fault (not labeled) is shown at the contact between Great Valley Sequence and Franciscan Formation rocks near the western edge of LBNL. A variety of other interpreted faults are mapped throughout LBNL. The structural mapping also shows that within the boundary of LBNL, Tertiary-age sedimentary and volcanic rocks are folded into a south-plunging syncline.

4.01.3 Local Geologic Mapping by Lawson and Palache (1901)

Some of the earliest geologic mapping of the LBNL area is by Andrew Lawson, a former professor of geology at UCB. Andrew Lawson, and his student Charles Palache, collaborated on the original seminal work on Berkeley Hills Geology (Lawson and Palache 1901). This published work included a geologic map and cross sections developed from more than a decade of field reconnaissance at a time when the Berkeley Hills were in an essentially natural condition. Although subsequent research and improved understanding of geologic processes (including the theory of plate tectonics) have added much to our understanding of Berkeley Hills geology, the geologic map and documented observations of Lawson and Palache continue to provide useful reference information on the bedrock geology and pre-development topographic conditions of the Berkeley Hills. A portion of the geologic map presented in the 1901 Lawson and Palache report is reproduced on Figure 6.

The Lawson and Palache report identified many of the key geologic structures in the area that is now LBNL. Of particular interest is the identification and mapping of the structural relationships between volcanic rocks (now Moraga Formation) and fresh-water sedimentary rocks (now Orinda Formation). Lawson and Palache (1901) describe the contact between the volcanic rocks and the fresh-water sedimentary rocks as "interleaved … in the vicinity of Pie Knob and Fog Bluff and in the intervening Wolsey Cañon" (i.e., within the western part of LBNL; Figure 6). This observation generally indicates that the contact between Moraga and Orinda Formation rocks is complex, and that these two bedrock units are, at times, interfingering and contemporaneous in age. This is consistent with the findings of several recent consultant studies at LBNL that indicate the presence of a mixed alluvial unit between the Moraga and Orinda Formation, as well as sedimentary units within the lower section of the Moraga Formation (AKA 2006; WLA 2009).

4.01.4 LBNL Geologic Mapping by HLA (1982)

In 1982, the consultant firm of Harding Lawson Associates (HLA) prepared a 16-page geologic report for LBNL which included a detailed (scale 1" = 200") oversized geologic map of the facility as a whole (HLA 1982). In their 1982 report, HLA provides the following interpretation on the relationship between the Orinda and Moraga Formations:

> "Although overlying the Orinda formation for the most part, Moraga rocks are interbedded with upper Orinda sediments. Apparently the volcanic flows were deposited in the Orinda sedimentary basins which eventually filled with increasing thicknesses of volcanic rocks." (p.9)

Although not explicitly discussed, HLA generally maps higher elevations above the central portion of LBNL as a single laterally continuous volcanic unit (Moraga Formation), whereas lower elevations (between about 700 and 1,100 feet in elevation) are mapped as being substantially more complex and comprise discontinuous bodies of volcanic material surrounded by Orinda Formation.

Similar to Lawson and Palache (1901), HLA (1982) interpret the Moraga Formation being deposited upon an undulating and partially eroded paleosurface comprised of folded and faulted fresh-water sedimentary rocks of the Orinda Formation. HLA (1982) describe folds (anticlines and synclines) at LBNL as generally trending northwest, roughly parallel to the orientation of the Berkeley Hills rangefront and the Hayward fault. In the Pie Knob - Fog Bluff - Wolsey Cañon area discussed by Lawson and Palache (1901), Moraga volcanics and/or interfingered Moraga and Orinda Formation rocks are interpreted as being within two or three roughly parallel northwest-trending troughs (synclines).

4.02 East Canyon Geology

Buildings 85 and 85A are located within the East Canyon of LBNL, which is part of the Strawberry Creek watershed. The axis of the East Canyon is aligned in a north-south direction, roughly perpendicular to the east-west alignment of Strawberry Creek. The head of the canyon is located near Grizzly Peak Boulevard (just below Little Grizzly Peak); from there, water within the canyon flows generally south within two roughly parallel drainages along the canyon margins.

The natural topography of the East Canyon has been extensively modified by grading performed to construct Centennial Drive, Lawrence Road, Calvin Road, the Water Tank road, various parking lots and LBNL buildings 74, 83, 84, 85, 85A, and 86. In addition, the upper part of the canyon has been used to stockpile various amounts of excavation material derived from building projects throughout LBNL. Current and pre-1994 topographic contours of the East Canyon are presented on Figure 7, for comparison purposes.

Buildings 85 and 85A are situated along the western side of the canyon near the former alignment of the western drainage (referred to in this report as Winter Creek). The development of the Building 85/85A site included routing Winter Creek into a culvert, and filling in the former natural creek channel (Figure 7). Currently, Winter Creek flows within a culvert in three locations: (1) beneath the Water Tank road; (2) from above the PG&E Access road to the lower Building 83 parking lot; and (3) beneath the Building 83 parking lot and Centennial Drive Bridge to an offsite outlet within UCB's Mather Grove. Near the head of the East Canyon (north of Building 85A), portions of Winter Creek currently flow within a natural deeply-incised channel that exposes relatively thick quantities of undifferentiated Quaternary colluvium with occasional discontinuous bedrock outcrops.

The eastern and western sides of the canyon are bounded by natural bedrock slopes with average inclinations that range from about 2.5:1 (horizontal to vertical) to as steep as about 1.5:1. The steeper slopes are generally indicative of the more resistant bedrock materials that underlie the ridges on each side of the canyon (Moraga volcanics on the west and Claremont Chert on the east). Regional-scale mapping (Figure 5) generally shows that along the western part of the canyon, Tertiary sedimentary and volcanic rocks are gently folded along a northwest-trending syncline. The syncline appears to be cut by the Wildcat fault near the upper part of the canyon. The northwest-striking Wildcat fault juxtaposes Tertiary Orinda Formation on the west against Tertiary Claremont Chert on the east and demarcates much of the eastern side of the canyon (Figure 5). These general relationships are also shown in the geologic map presented in the RCRA Facilities Investigation (RFI) Report (LBNL/Parsons 2000), which is reproduced in this report as Figure 8.

Prior to development, the canyon floor between the two roughly parallel north/south-trending drainages sloped down toward the south at an average declination of about 5:1 (horizontal to vertical). Much of the East Canyon floor includes a complex mix of landslide debris derived from the Moraga and Orinda Formations and is underlain primarily by Tertiary sedimentary bedrock. Landslide material also exists along the western side of the canyon associated with smaller-scale landsliding adjacent to the former deeply-incised channel of Winter Creek (now buried by fill). Within the lower central portion of the East Canyon is a small hill comprised of resistant Moraga Formation rock, the southern face of which was excavated in the 1800s as part of quarrying operations. Previous researchers and consultants working in this area have speculated as to the origin of this particular topographic high, which has alternatively been interpreted as either: (1) a volcanic vent; (2) a continuation of the northwest-trending Moraga Formation syncline; or 3) Moraga Formation volcanic rock displaced by landsliding.

The Site Geologic Map developed for this study (Figure 9) shows bedrock units and structural data (i.e., strike and dip) as well as bedrock faults and landslide deposits within the East Canyon. As shown on Figure 8, the surficial geology of the East Canyon includes Tertiary sedimentary and volcanic bedrock, unconsolidated to semi-consolidated Quaternary colluvium, debris-flow deposits, landslide deposits, and artificial fill. Note that artificial fill is not shown across the map area because it would obscure the underlying geologic relations interpreted within the canyon. The local geology of the East Canyon is introduced in the subsections that follow. Landsliding within the East Canyon (a focus of this study) is discussed further in Section 5.00.

4.03 Bedrock Units

4.03.1 Claremont Chert (middle to late Miocene) – Symbol Tc

The oldest strata that crop out in the East Canyon are well-bedded, siliceous shale and chert of the Claremont Chert. Also called the Claremont shale, this resistant unit underlies the steep slope on the east side of the canyon, and dips moderately to steeply northeast. It consists of finely laminated and thin beds of blocky fractured chert and shale, and occasional interbeds of sandstone. The unit is bound to the west by the steeply east-dipping Wildcat fault. The chert and shale beds commonly exhibit pinch and swell structures. Where encountered, it consists predominantly of brown to light-brown, thinly bedded chert and siliceous shale with interbeds of sandstone exposed east of the site (Figure 9). These strata generally dip to the southeast. This unit is not present at the Building 85 site.

4.03.2 Orinda Formation (late Miocene) – Symbol To

The Miocene Orinda Formation is a non-marine, well- to poorly-bedded siltstone, claystone, fine lithic sandstone, and pebble conglomerate up to 2400 feet in thickness. The fine-grained units of the Orinda Formation have been heavily secondarily altered and show cataclasis at the microscopic level (see the petrographic report in Appendix D). The conglomerate contains a high percentage of detritus derived from the Franciscan Assemblage, including radiolarian chert, basalt, and mixed sedimentary clasts (Graymer, et al. 1996; petrographic analysis report in Appendix D). The coarse-grained conglomerate was deposited under alluvial fan conditions, while the sandstone, mudstone and finer-grained conglomerate were deposited as flood plain and channel material (Jones and Curtis 1991). In the vicinity of western LBNL, Lawson and Palache (1901) interpret sedimentary lacustrine deposits of the Campan Series (later identified as equivalent with the Orinda Formation by Graymer, 2000) as interfingering with volcanic deposits of the Moraga Formation at or near the interplay between eruptive and fluvial deposition. A similar relation is interpreted by Lawson and Palache (1901) for the Orinda and Moraga Formations located east of the Wildcat fault.

The contact between the Orinda Formation and the overlying Moraga Formation southwest of the Building 85 site is relatively well-defined and underlies a landslide west of the Building 83 parking lot. The Orinda Formation is sheared, fractured, slightly to moderately weathered, and soft to moderately hard. Joint, fracture, and shear partings are planar to irregular, open to tight, and commonly have mineralized (quartzite and calcite) infills. Locally, discontinuities are clay-lined, very closely spaced, or penetrative to the point of brecciation.

The Orinda Formation naturally crops out along the southwestern margin of East Canyon along the north side of Lawrence Road, directly west of the Centennial Drive overpass. The conglomerate exposed along Centennial Drive and Lawrence Road strikes northwest and dips approximately 30° to 40° northeast (Figure 9). A trench exposure located directly west of the parking lot for Building 83 shows bedding in a fine-grained gravel striking N05°W and dipping 25° west (GIS #99; AKA 2006b). However, the overall northeast inclination of the Orinda Formation observed in the LBNL area is interpreted as regional bedding associated with the western arm of a regional northwest-trending syncline that intersects East Canyon. The basis for this syncline is derived primarily from the map pattern of the Orinda and Moraga Formations. The Orinda Formation also underlies the fill, colluvium and landslide deposits mapped in the central axis of East Canyon. To the east, it is in fault contact with the Claremont chert (WLA 2008).

4.03.3 Moraga Formation (late Miocene) – Symbol Tm

Regionally, the Moraga Formation depositionally overlies and locally interfingers with the Orinda Formation. The Miocene Moraga Formation consists of as many as five distinct flows typically defined by basaltic and andesitic composition (Wahrhaftig and Sloan 1989) with coarse fluvial sedimentary interbeds between different volcanic flows. Potassium-argon ages of the volcanic flows vary from 10.2 million years (Ma) to 8.5 Ma (Curtis 1989). The maximum thickness of the Moraga Formation in the vicinity of LBNL is estimated at about 800 to 1000 feet (Lawson and Palache 1901). The source vent has been previously interpreted to be the Round Top volcanic complex located several miles southeast of LBNL. A caldera source or volcanic vent of similar mineral composition to the Red Top eruptive center is hypothesized by Lawson and Palache (1901) to exist west of the Wildcat fault near the abandoned quarry of the East Canyon. Curtis (1989) hypothesizes that the vent (old quarry southeast of Building 85) and Red Top caldera have been displaced right-laterally along the Wildcat fault (now inactive). The Moraga Formation is exposed in multiple cut slopes along Centennial Drive and Grizzly Peak Boulevard north and west of Building 85 as well as within several abandoned quarries at LBNL. Lawson and Palache (1901) describe the quarry volcanics as consisting of mixed vesicular basalt and agglomerate.

In the B85 area, the Moraga Formation consists of andesitic and basaltic flows, tuff, and volcaniclastics (locally described as agglomerate or volcanic breccia). The basal member of the volcanics, defined as an amygdaloidal andesite, is interpreted to have been deposited over a broad alluvial flood plain with later flows and tuffs being confined to narrow channels, ravines and valleys (Lawson and Palache 1901; Wahrhaftig and Sloan 1989). Locally, the Moraga Formation rests depositionally on the Orinda Formation, or is present as translated slide bodies (LBNL/Parsons 2000). In-place massive Moraga

Formation rock is mapped upslope and southwest of Building 85. The bedding of the Moraga Formation and Orinda Formation southwest of Building 85 defines the western limb of a previously mapped northwest-trending syncline (Lawson and Palache 1901). This syncline, may or may not be the same feature (syncline) mapped by Graymer (2000) east of the Wildcat fault that also folds similar Tertiary-aged sedimentary and volcanic rocks. On the basis of stratigraphic and structural relations, Lawson and Palache (1901) argue that the synclines west and east of the Wildcat fault are of different ages, with the syncline beneath much of LBNL being younger.

In-place Moraga Formation is exposed in road cuts for a PG&E utility access road northwest and upslope of Building 85. Mapping of the rock cut along the PG&E access road exposed Moraga volcanics overlain by a thin (1- to 2-foot-thick) veneer of colluvium (Appendix B). The southwestern portion of the exposure is composed of highly fractured angular blocks of andesite and basalt (0-8 feet) that transitions abruptly into agglomerate containing blocks of angular to subrounded andesite with variable fracture patterns. The massive agglomerate is especially chaotic with abrupt changes in clast percentages (matrix vs. clast supported) and clast angularity and exhibits very little discernable stratification. Weak bedding can be inferred from the dip of large andesite blocks and alignment of andesite clasts suggesting a northwest dip, but this dip is highly speculative. Minor bedrock faults and fractures strike northwest and dip both northeast and southwest and are generally tight indicating a stable hillside. Trench exposures below the access road expose Moraga Formation volcanic rocks consisting of ash, agglomerate, tuff, andesite and basalt striking between N60°W to N80°W and steeply north-dipping (WLA 2008).

Volcanic rocks within the lower part of East Canyon, found in limited outcroppings (e.g. at the old quarry southeast of Building 85) and in borings and previous cut slopes, have a less certain origin, and have previously been interpreted as displaced through landsliding (AKA 2006b) or as in-place vent rocks (Lawson and Palache 1901). Moraga Formation rocks found in the central portion of the East Canyon (including the old quarry) appear to lie structurally below the main outcrop belt of Moraga Formation rocks located upslope and to the northwest of Building 85. Previous geologic mapping in the canyon shows a linear north/south-trending belt of Moraga Formation that has been interpreted to be either a fault-bounded block (e.g. Collins 1993), or part of a planar block landslide deposit (e.g. LBNL/Parsons 2000; AKA 2006b). Previous studies by AKA and WLA have demonstrated that: (1) the fault mapped along the western margin of the canyon does not exist as mapped, and (2) the block of volcanics in the floor of the valley upslope (north) of the old quarry is likely composed of multiple displaced blocks of Orinda and Moraga Formation with the dimensions and boundaries of the blocks being highly complex and poorly defined.

4.04 Quaternary Deposits

Quaternary colluvium, minor clay-rich alluvium, and debris-flow deposits exist within various portions of the East Canyon. The former drainage of Winter Creek that passes beneath or near the eastern margins of Buildings 85 and 85A contains variable amounts of Quaternary colluvium, alluvium and landslide debris primarily derived from areas upslope to the west and north of the site. Some of these materials are currently buried by artificial fill. The undifferentiated Quaternary material and artificial fill are not shown everywhere on the geologic map for clarity. Of primary importance to the Building 85 study is the presence of landslides within East Canyon, which are discussed in the following section (Section 5.00).

4.05 Bedrock Faults

LBNL contains numerous mapped and inferred faults that are not zoned by the State of California as active. The RFI Report (LBNL/Parsons 2000) discusses three such features that exist within the East Canyon: (1) the Wildcat fault; (2) the locally named East Canyon feature/fault; and (3) an unnamed fault at the contact between the Orinda Formation and the Great Valley Sequence. All three features, which are mapped as faults on the RFI Geologic Map (Figure 8), are also shown on the Site Geologic Map (Figure 9).

4.05.1 Wildcat Fault

The approximately 20- to 25-km-long Wildcat fault is located within the Berkeley Hills and extends northwest-southeast from Richmond to Oakland, subparallel to the Hayward fault (Figure 5; Graymer 2000). The Wildcat fault was first identified by Lawson and Palache (1901), and was later named by Untermann (1935) who identified the fault in the Claremont and San Pablo water tunnels. In the tunnel exposures, the fault offsets the Monterey Formation (Claremont tunnel), and both the Orinda Formation (west) and Monterey Formation (east) (San Pablo tunnel). Untermann (1935) interpreted the fault as accommodating both strike-slip and vertical components of displacement. More recent studies by Curtis (1989) characterize the Wildcat fault as a right-lateral strike-slip fault that dips near-vertical to steeply southwest. The fault is interpreted to have accommodated as much as 7 km of horizontal displacement over the last 9.6 million years (Ma) (Curtis 1989). Jones and Curtis (1992) later characterize the fault, in the region of LBNL, as a laterally continuous thrust fault between Berkeley and Oakland.

As shown on the Site Geologic Map (Figure 9), the Wildcat Fault is mapped as two roughly parallel traces striking north-northwest near Building 74. A west/southwest-trending cross fault is mapped beneath Building 74 and terminating before reaching a previous exploratory trench (GIS ID# 85; Figure 10). In the vicinity of Building 74, the Wildcat fault generally juxtaposes Claremont chert (Tc) on the east against Orinda Formation on the west. As mapped within the LBNL and UCB campus, the Wildcat fault has never been included as part of an Earthquake Fault Zone. In addition, recent subsurface exploration of the fault along the east side of the East Canyon southeast of LBNL Building 74 also interpreted the absence of Holocene activity (WLA 2008).

4.05.2 East Canyon Feature

The East Canyon feature is mapped as passing through Building 85. The East Canyon feature was first postulated to be a fault by Borg (1991) based on an alignment of historical springs depicted in an historical 1875 (Soulé 1875) map, subtle morphology, and apparent right-lateral displacement of Tertiary bedrock units in upper East Canyon. The alignment of the apparent fault-related features was interpreted to represent a near-vertical, right-lateral strike-slip fault oriented north-south to N10°E along the west side of East Canyon. This alignment approximately coincides with the base of the volcanic layer mapped by Lawson and Palache (1901) along this same alignment of springs.

Based on the recent findings of a surface-fault rupture investigation of the East Canyon feature southwest of Building 85, the hypothesized fault has been demonstrated to not exist as mapped, and thus has been reclassified as a feature rather than a tectonic fault and if it exists, occurs east of the previous investigation performed by WLA (2008a). Multiple trenches that intersect the mapped location, as well as reasonable orientations for the feature, provide direct evidence on the absence of a laterally continuous bedrock fault as mapped previously by others (Borg 1991; Collins 1993; Graymer, et al. 2000; Parsons 2000; and Collins 2007).

It is not known whether a buried north-south striking fault exists beneath the floor of the East Canyon, however, it is permissible to interpret that such a fault could exist east of the trenching study and within East Canyon. A north-striking East Canyon fault can be inferred at or near the location of Winter Creek based on changes in the elevation of the bedrock contact between the Moraga and Orinda Formations observed in boreholes, trenches and test pits from the Building 83 (U5) parking lot area; however, alternatively these vertical elevation changes can be explained by undulations in the paleosurface of the Orinda Formation prior to deposition of the Moraga Formation. Inferring the existence of such a fault at this juncture would be purely speculative and there is no evidence to suggest that such fault, if it exists, would be Holocene-active.

4.05.3 Tertiary/Cretaceous Contact (i.e., Chicken Creek fault of AKA 2008)

The previously-identified unnamed fault strikes northwest across LBNL and juxtaposes Great Valley Sequence on the southwest against Orinda Formation rocks on the northeast. The fault is located in the southernmost part of East Canyon. Numerous investigators have interpreted a northwest-striking bedrock fault at the contact between Tertiary and Cretaceous rocks (e.g. HLA 1982; Graymer, et al. 1996; Graymer 2000; LBNL/Parsons 2000; Jordan and Javandel 2007). The fault is approximately 5 miles long and dips northeast between 16° and 70° (Jordan and Javandel 2007; HLA 1975). It has been previously referred to as the Chicken Creek fault (AKA 2008).

The fault generally passes through the areas currently occupied by LBNL Buildings 66, 10 (User Support Building), 29 (Guest House), and 51 (former Bevatron). Because the contact is inclined (i.e., dipping towards the northeast into the hill) the surface trace of the fault is curvilinear across topographic elevation changes. The Tertiary/Cretaceous contact has been directly observed in exploratory trenches near LBNL Building 66; in other areas the location of the surface trace has been inferred from surface observations, subsurface data from boreholes and/or various geometric constructs. Consequently, maps depicting surface traces of the contact and the related inferred fault at LBNL vary (HLA 1975 and 1979; Converse Consultants 1984; Graymer, et al. 1996; Kleinfelder 2002 and 2003; Jordan and Javandel 2007). In general, more recent maps prepared by onsite researchers and consultants (LBNL/Parsons 2000; Jordan and Javandel 2007; AKA 2008) are generally thought to more accurately represent the true location of the Tertiary/Cretaceous contact as they are based on more complete datasets (e.g. new borings at LBNL Building 10) as well as new observational data (direct observation of the contact at LBNL Building 29).

Near Building 66, the contact is expressed as a broad (approximately 50 feet wide) zone of steep east-dipping shears, with slickensides trending N40°W and dipping northeast. This feature was interpreted by HLA as a fault. A trench excavated across the fault exposed a thin (greater than 3 feet thick) veneer of colluvium unfaulted across a distinct zone of clay shears (HLA 1975). HLA (1975) concluded that the fault was "ancient" and that it represented no threat to the proposed construction of Building 66. Converse Consultants (1984) reviewed the work of HLA (1975) and performed field reconnaissance, and similarly concluded that the fault was not active.

4.06 <u>Hydrogeologic Conditions</u>

4.06.1 Hydrogeologic Characterization by LBNL/Parsons (2000)

The RFI report (LBNL/Parsons 2000) describes geologic and hydrogeologic investigations performed to evaluate geometric relationships and material properties affecting the movement of groundwater and groundwater contaminants. Accordingly, the subsurface investigations described are concentrated geographically in areas with known or potential importance to contaminant investigations. These specific areas of focus are generally located within or downgradient of developed areas of the facility that, in some cases, coincide with those areas characterized in the RFI report as paleolandslides.

Consistent with the interpretation of previous consultants working for UCB and LBNL, the RFI report identifies the contrast in permeability between Moraga and Orinda Formation rock as a predominant structural control on groundwater flow. Average permeabilities between these two geologic units are thought to vary by several orders of magnitude; the Moraga formation being far more permeable due to the widespread fracturing that exists within the unit. The Moraga Formation overlies Orinda Formation rocks that are far less permeable. Consequently, groundwater preferentially moves through the Moraga Formation and flows into and through troughs (synclines) and localized "bowls" that exist on the top of the Orinda Formation.

The Bedrock Geologic Map presented in the RFI Report (Figure 8) shows the upslope areas directly north and northwest of Buildings 85 and 85A capped by Moraga Formation bedrock of great areal extent. This mapping is generally consistent with the regional syncline mapped by Graymer (2000) and Lawson and Palache (1901) (presented on Figures 5 and 6, respectively). The southeastern limit of the Moraga Formation rock is proximate to LBNL Buildings 85 and 85A and generally corresponds to the near-linear alignment of historical springs depicted in the historical 1875 map by Soulé (shown on Figure 8).

4.06.2 Hydrogeologic Characterization by Outside Consultants

In the late 1960s through the early 1980s there was significant interest in the sources and mechanisms of groundwater flow in the hill areas of LBNL, largely due to slope instability concerns. During this period of time: (1) Centennial Drive was extended from the UCB Botanical Gardens to Grizzly Peak Boulevard (which included the construction of the Lawrence Road overcrossing); (2) UCB's Space Sciences Laboratory and the Lawrence Hall of Science (LHS) were developed along the upper portions of Centennial Drive; and (3) landsliding occurred during the winters of 1962-63, 1968-69, 1972-73, 1981-82 and 1982-83. In the early 1980s LBNL and UCB retained various outside consultants for the purposes of addressing slope stability concerns. Since the landslides occurring at the time were triggered by rises in groundwater levels, these studies all addressed groundwater and hydrogeologic conditions to some degree.

The UCB-commissioned report titled "Hill Area Dewatering and Stabilization Studies" (Converse 1984) provides an overview of events and work performed during this period. A focus at the time was to address slope movements that had occurred upslope of LBNL Building 77 (about 1,000 feet west-northwest of Building 85) and in the area of the Centennial Drive-Lawrence Road overcrossing (about 300 feet south of Building 85). Efforts were therefore made to drain subsurface water from areas upslope, which in both cases involve drainage beneath the ridgeline northwest of Buildings 85 and 85A. This ridgeline, which extends up to Little Grizzly Peak, is underlain by permeable Moraga Formation rocks that are part of the regional syncline interpreted by Graymer (2000), Lawson and Palache (1901) and others. The accounts presented in the Converse (1984) report include the following discussion of horizontally-drilled drains (hydraugers) and vertically-drilled wells installed to tap Moraga Formation rocks within this regional syncline:

> ***General*** *- As part of University contract work, numerous hydraugers were installed in the hill area by Lennart and Associates. These included hydraugers installed in the Corporation Yard slope* (now northeast and upslope of Building 77) *in 1968, Hydraugers Nos. 1 and 2 and two others installed in the overpass/Botanical Garden area installed in 1969, and Hydraugers 789-A and 789-B installed in the Poultry Husbandry area* (now west and downslope of LBNL Building 62) *in 1979...(p. 5-6)*

Hydraugers Nos. 1 and 2 *- Hydrauger Nos. 1 and 2 were installed to lower groundwater levels in the overpass area. Both drains exited in Mather Grove south of the overpass and west of Mather Creek* (aka Winter Creek). *In addition, a 27-foot-deep subdrain was installed on the north side of Cyclotron Road* (now Lawrence Road) *terminating at a vertical well connected to Hydrauger No.1. (p. 5-6)*

Hydraugers Nos. 789-A and 789-B *- Hydrauger Nos. 789-A and 789-B were drilled in 1979 to lengths of approximately 2,100 and 910 feet, respectively. Hydrauger No. 789-A was drilled with the intent of dewatering the Moraga flow rocks located in the syncline postulated by Lennert... According to Lennert, aquifers were encountered between 1,057 and 1,092 feet and at approximately 1,780 feet (horizontal distance). Maximum initial water flows from these aquifers were on the order of 100 and 1,100 gpm* (gallons per minute), *respectively, dropping off substantially with time to flows at the pipe presently on the order of 4 to 12 gpm. Hydrauger No. 789-A was intended to intersect Test Well 789-1, but it cannot be determined how close to the well the hydrauger is actually located. (p.5-7)*

Test Well 789-1 *- Test Well No. 789-1 was drilled in 1979 to a depth of 667 feet on a knoll* (now the location of the radio antenna south of the UCB Space Sciences Laboratory) *southeast of Shively Well No. 1. The well was intended to complement the Shively Well in dewatering the Moraga volcanic flow rocks in the postulated underlying syncline. The well could not be developed, however and currently functions only as an observation well. (p. 5-8)*

Shively Well No. 1 *- Shively Well No. 1 was installed by Ben Lennert in the spring of 1975 adjacent to the dirt road near the south end of the Space Sciences Laboratory parking lot. The well was intended to help lower the groundwater level in the rock structure underlying the ridge and to improve stability conditions in the LHS and Corporation Yard* (now LBNL Building 77) *areas. The well was drilled to a depth on the order of 400 feet. A boring log for this well could not be found... Pump flow readings (in gpm) in the Shively Well were taken by Lennert between the time of installation to the end of 1979. His detailed records, if any, were not found, but his past correspondence with the University indicated that the well was pumping about 31 gpm in late 1975, and between 8 and 15 gpm between April, 1978 and July, 1979. (p. 5-5)*

A March 3, 1969 letter by Lennert discusses efforts intended to prevent failure of the Centennial Drive overcrossing of Lawrence Road in which subsurface drainage measures were discussed, including: (1) "installation of a trench subdrain on the northerly side of the road and east of the overpass;" (2) "drilling-in the outlet drain for the trench subdrain from the slope area southerly of the overpass structure;" and (3) "two hydrauger subdrains...drilled into the rock structure northerly and easterly of the overpass area." The "rock structure" appears to refer to the old quarry southeast of Building 85; a hydrauger outlet pipe currently exists on the north side of Lawrence Road south of the quarry from which water continues to drain.

5.00 EAST CANYON LANDSLIDES

5.01 Previous Landslide Mapping by Others

5.01.1 USGS Regional Landslide Mapping

In 1975, the United States Geological Survey (USGS) published a series of 7½-minute quadrangle maps depicting landslides and other surficial deposits (Nilsen 1975, various), which were published at a scale of 1:24,000 (1 inch = 2,000 feet). The mapping by Nilsen includes landslides known to be recently active. LBNL's East Canyon is situated at the junction of two 7½-minute quadrangles (Briones Valley and Oakland East). Both maps refer to a separate USGS publication (Miscellaneous Field Studies Map MF-493; Nilsen 1973) for a more detailed explanation of map symbols. As appropriate for regional-scale landslide mapping, the landslides depicted on the 1:24,000 (1 inch = 2,000 feet) maps are generally at least 200 feet in longest dimension (Nilsen 1973).

The photointerpretive mapping by Nilsen depicts two moderate-sized landslides along the western wall of the East Canyon. The northern landslide is situated in the upper reaches of the canyon north of the water tank, whereas the southern landslide is mapped in the general vicinity of Buildings 85 and 85A. The entire East Canyon valley floor is broadly mapped by Nilsen (1975) as colluvium.

5.01.2 CGS Landslide Inventory Mapping

The California Geological Survey (CGS) published a series of seismic hazard zone reports as part of their work under the Seismic Hazard Mapping Act (SHMA) of 1990. Each seismic hazards zone report includes a landslide inventory map; the methodology used to develop the landslide inventory maps is described by the CGS as follows (CGS 2003):

> "As part of the geologic data compilation, an inventory of existing landslides in Berkeley and Oakland was prepared by field reconnaissance, analysis of stereo-paired aerial photographs, and review of published landslide mapping (Nilsen 1975). Landslides were mapped at a scale of 1:24,000. For each landslide included on the map a number of characteristics (attributes) were compiled. These characteristics include the confidence of the interpretation (definite, probable and questionable) and other properties such as activity, thickness, and associated geologic units."

The CGS landslide inventory map for the Briones Valley 7½-minute quadrangle shows two landslides within the East Canyon. The larger of the two mapped landslides is mapped within the East Canyon floor and extends from near Little Grizzly Peak (above Grizzly Peak Boulevard) south to near the location of the old quarry (above Lawrence Road and Centennial Drive). A moderate-size landslide is also depicted along the western wall of the East Canyon north of the water tank (similar to the northern slide mapped by Nilsen).

5.01.3 LBNL and Consultant Landslide Maps

Detailed maps depicting the locations of historic slope stability concerns at LBNL are maintained by the lab's onsite facilities personnel (e.g. LBNL 1984), typically at a scale of 1 inch = 100 feet. These LBNL maps have been developed in parallel with work by the lab's geotechnical and geologic consultants, who have also developed various geologic maps depicting landslides and other surficial deposits.

The 1982 geologic map by HLA shows a number or relatively small historically active landslides distributed throughout LBNL. Within the East Canyon, HLA maps two small active landslides northwest and southeast of the Centennial Drive overpass. Broad areas of colluvium are mapped in areas throughout the East Canyon floor that are occasionally interrupted by localized "islands" of material mapped as bedrock. Relative to the location of the current Building 85 and 85A site, HLA (1982) maps Moraga Formation rock: (1) beneath the ridge directly west and northwest of the site; and (2) east of Winter Creek in the general area surrounding the old quarry. HLA maps colluvium along the west side of Winter Creek and throughout much of the remainder of the valley floor. Within the western wall of the East Canyon, the contact between colluvium and Moraga Formation bedrock is mapped as passing through the current location of Buildings 85 and 85A. Colluvium, as defined by HLA (1982), includes slope wash, ravine deposits as well as landslide deposits of incoherent soil and rock.

A subsequent geologic map by Lou Gilpin (Gilpin 1994) presents an alternative interpretation of landsliding within East Canyon, reportedly based (in part) on "subsurface conditions encountered during the construction of the Hazardous Waste Handling Facility (HWHF) crib wall and retaining walls." This interpretive map broadly maps landslide deposits throughout the East Canyon floor that extend beneath the old quarry and the Centennial Drive overpass and into (or entirely beneath) Mather Grove. The western margin of the landslide deposits mapped by Gilpin roughly coincides with the natural alignment of Winter Creek, which is mapped as being partially overlain/infilled with colluvium and debris flow deposits.

5.01.4 Paleolandslide Deposits Interpreted by LBNL/Parsons (2000)

In the 1990s, LBNL geologists participated in the preparation of a Resource Conservation and Recovery Act (RCRA) Facility Investigation report, pursuant to the permitting requirements of the California Environmental Protection Agency (Cal-EPA) and Department of Toxic Substances Control (DTSC). The resulting report (LBNL/Parsons 2000), commonly referred to as the "RFI Report," is a public document that includes detailed information pertaining to the geology and hydrogeology of LBNL. The RFI report proposes the following interpretation of large-scale landsliding at LBNL:

> *Numerous isolated masses comprised of Moraga Formation rock underlie the developed portions of LBNL at lower elevations than the main Moraga Formation outcrop belt. The rock at the contact between these masses and the Orinda Formation is often composed of slickensided, volcaniclastic/sedimenticlastic rocks that have been informally denoted as a "Mixed Unit." These masses are interpreted to be paleolandslide deposits that are younger than the Moraga Formation but older than historically active landslides at LBNL. - p. A-3 RFI Report Module A*

The RFI geologic map presented on Figure 8 (LBNL/Parsons 2000) shows the ridge area north and northwest of Building 85 as part of the main Moraga Formation outcrop belt. LBNL/Parsons 2000 maps the central portion of the East Canyon (i.e., between the two roughly-parallel historic drainages) as a "paleolandslide deposit composed of Moraga Formation rocks." As mapped by LBNL/Parsons, the paleolandslide deposit is several hundred feet wide, more than 2,000 feet long and extends from near the head of the East Canyon down to the creek that flows along the north side of the UCB Botanical gardens (south of Centennial Drive). Similar to Gilpin (1994), LBNL/Parsons (2000) interprets the old quarry to be with the area mapped as a landslide deposit. The RFI Report provides the following information on the interpreted age of the paleolandslides:

Several historic landslides composed of these rocks have moved since development of LBNL, and appear to represent reactivated segments of the paleolandslides...The present existence of slopes sufficiently unstable to allow reactivation of the paleolandslide blocks suggests that original displacement of the paleolandslides may have occurred relatively late in the development of the present day topography (i.e. later than 5 Ma). However most of the paleolandslide blocks do not exhibit evidence of recent movement, and currently underlie promontories, ridgelines, or benches, suggesting that they were at least old enough for the surrounding, more erodible Orinda Formation rocks to waste away. Therefore displacement primarily took place primarily prior to the Holocene (i.e. more than 11,000 years ago). *- p. 4-10 RFI Report*

5.02 Previous Landslide Mapping by AKA and WLA

Landslide deposits in the East Canyon are extensive, and are derived from several types of materials, including: (1) reworked Quaternary deposits, (2) deposits containing mixed blocks of Orinda and Moraga Formation, and (3) homogeneous blocks of Moraga Formation or Orinda Formation (AKA 2006a; AKA 2006b). In general, the results of previous subsurface investigations and geologic field mapping indicate that sliding within East Canyon is complex and in places consists of nested sequences of distinct slide masses. Individual slide masses have typically not been delineated within areas broadly mapped as landslides due to the absence of present-day geomorphic features (having been previously removed by grading) as well as the need to rely upon existing subsurface data, which are often limited by their quality, location and/or depth. Generalized descriptions of our previous mapping of landslide deposits within the East Canyon follow.

5.02.1 Historically Active Landslides

Two historically active landslide bodies are known to exist within the lower East Canyon, both are shown on the Site Geologic Map presented on Figure 9.

Landslide 40 - A map prepared by LBNL's Facilities Division entitled "Slope Locations – Stability Evaluations" identifies areas of slope stability concerns by number. On this map (LBNL 1984), a landslide is shown northwest of the Centennial Bridge that is identified as Landslide 40. Landslide 40 extends from the PG&E access road west of Building 85 to the southeast toward Winter Creek. Landslide 40 is designated as a "creep slide" by Lennert (1969) and mapped as a "possible slope creep zone" by HLA (1978). In general, previous boreholes drilled within Landslide 40 encountered between about 18 and 28 feet of soil over material logged as Orinda Formation. Slope indicator data from 1982-1983 show indications of movement down to a depth of about 45 to 50 feet within the Orinda Formation and at the Orinda Formation/colluvial contact (AKA 2009). As shown on Figure 10, Landslide 40 is interpreted to be approximately 550 feet long and 230 feet wide at its maximum extent. Landslide 40 appears for the most part to have been relatively stable during historic time under static (non-earthquake) conditions, experiencing only slow creep-type movements during periods of high groundwater, and possible reactivation of the toe region at or near Winter Creek in 1907 (AKA 2009).

1907 Landslide - In 1907, a large earthflow (landslide) occurred in the region of Winter Creek between the old quarry and Mather Grove (see Figure 9). On the basis of a review of historical photographs, geologic mapping and interpretation of borehole data, the headwall of the 1907 landslide occurred within the Building 83 parking lot. Vertical scarps at the head of the landslide are interpreted to have been 10 or more feet high, based on the height of fence posts that can be seen on the 1907 photographs within and surrounding the down-dropped portions of the landslide. In addition, the photographs appear to show that much of the landslide headscarp material consists of an upper fine-grained colluvium and lower coarse-grained colluvium or alluvium. As shown on the Site Geologic Map presented on Figure 9, the 1907 Landslide is interpreted to be an irregularly-shaped landslide with multiple lobes; the largest (almost 400 feet long and 200 feet wide) being on the east side of Winter Creek. The 1907 landslide has not been shown on previous geologic maps and its existence appears not to have been recognized prior to the recent evaluation of the Centennial Bridge (AKA, 2009).

Active landsliding has also occurred in areas of the upper East Canyon, mostly as a result of excavation cuts made to construct Calvin Road and the Water Tank road (Figure 9). In general, these known upcanyon landslides were subsequently repaired or retained as part of subsequent site development activities.

5.02.2 Previously-Interpreted East Canyon Landslide

Landslide debris has been noted in previous consultant reports for Building 83 (HLA 1977), Buildings 85 and 85A (GRC 1994b; AKA 2007), Building 85B (SCI 1996) and Building 86 (AKA 2006). Previous mapping by HLA (1982) and Gilpin (1994) show extensive large-scale deposits of colluvium and/or Quaternary landslide materials occupying the floor of the East Canyon. Both HLA and Gilpin mapped the western margin of these deposits in the vicinity of Winter Creek. The RFI Final Report (LBNL/Parsons 2000) also maps most of the East Canyon floor as a "paleolandslide deposit composed of Moraga Formation rocks" (Figure 8). In general, the previous mapping of landslide deposits in the area of the East Canyon floor by AKA, WLA and others has been based upon: (1) valley morphology, (2) interpretation of historical photography, (3) landslide-related deposits encountered during grading activities, and/or (4) geological and geophysical features encountered during previous subsurface investigations. In this and previous reports, we generally refer to the postulated very large landslide previously interpreted as occupying virtually the entire canyon floor as the "East Canyon Landslide."

Based in part on borings drilled in the direct vicinity of Buildings 85, 85A and 86, previous studies by AKA and WLA delineated an East Canyon Landslide comprised of undifferentiated Quaternary material, Moraga Formation-derived volcanic breccia (Qls[m]) and areas of mixed Orinda Formation and Moraga Formation (Qls[m/o]). As previously mapped, the East Canyon Landslide encompassed most of the East Canyon floor both within and below the LBNL campus (similar to the paleolandslide deposit mapped by LBNL/Parsons [2000] that is shown on Figure 8). The maximum depth of landsliding was poorly constrained based on the available data; however, features were identified at depth in several borings that made it permissible to interpret depths of landsliding greater than 60 feet. Landsliding occurring at this depth was interpreted to necessarily extend beneath the seemingly intact Moraga Formation block within the central portion of the East Canyon at the location of the old quarry. Several shallower nested landslides were interpreted to exist within the boundaries of the large-scale feature.

The deposits associated with the hypothetical East Canyon Landslide were interpreted to be mostly confined between two stream channels that historically followed the east and west sides of the valley (see previous topography shown on Figure 7). Upper and lower limits (the head scarp and toe regions) of the large-scale landslide deposits approximately coincided with the broad, curvilinear head of the East Canyon floor and the downslope extent of broad, hummocky topography near the confluence of the East Canyon drainages. The hummocky, lobate morphology of the canyon floor seen in pre-grading topographic maps and historical oblique and aerial photographs was interpreted to support a Quaternary age for these deposits (younger than about 1.6 Million years). However, it was noted that the feature mapped as the East Canyon Landslide (or similar) may not have moved downslope as a coherent unit in Holocene time (within the last 11,000 years) and that there is no evidence that suggests the feature mapped as the East Canyon Landslide moved as a coherent unit in historic time (i.e., since the late 1800s).

6.00 FINDINGS OF DATA COMPILATION AND SUBSURFACE INVESTIGATION

6.01 Overview of Updated Geologic Interpretation

In the following sections, we discuss the findings of our geologic reconnaissance and subsurface investigation together with information obtained from review of published and unpublished sources, including geologic, geotechnical and environmental consulting reports. In general, our findings can be summarized in the following statements:

- Extensive complex Quaternary landslide deposits (Qls-1 and the 1907 landslide) occupy much of the East Canyon floor upslope and downslope of the old quarry;
- Multiple smaller landslide deposits rim the west margin of the East Canyon (Qls-2 through Qls-4; and Landslide 40);
- Maximum depth of landsliding in the vicinity of Building 85 is probably on the order of 30 to 40 feet;
- The old quarry does not appear to have experienced significant translational displacement associated with landsliding; and
- Within the lower East Canyon, the geologic contact between the Moraga and Orinda Formations is complex, includes interfingering between the two geologic formations, and possibly is related to a pre-depositional undulatory surface and/or post-depositional tectonic deformation (faulting, folding).

6.02 Conceptual Geologic Model

The Site Geologic Map presented on Figure 9 presents our updated interpretation of the surficial geology within the East Canyon. The Site Geologic Map focuses upon bedrock units and landslide deposits within the East Canyon; other Quaternary surficial deposits (including artificial fill) are purposely not shown in their entirety so that underlying bedrock and landslide relations can be better displayed.

As discussed in Section 5.02.2, previous studies (e.g. LBNL/Parsons 2000; AKA 2006a; AKA 2006b) mapped virtually the entire canyon floor both within and below the LBNL campus as a landslide (the East Canyon Landslide). This very large landslide was interpreted to include undifferentiated Quaternary material, Moraga Formation-derived volcanic breccia (Qls[m]) and areas of mixed Orinda Formation and Moraga Formation (Qls[mo]). Based on several boreholes that encountered features inferred as landslide-related at depths exceeding 60 feet, it was initially interpreted that the East Canyon Landslide could extend beneath the old quarry and the eastern portion of the Centennial Drive Bridge. However, investigations performed for this study coupled with our concurrent investigations for the Centennial Drive Bridge, geologic reconnaissance, review of newly-acquired historic photographs, and re-interpretation of pre-grading topography allow us to revise our initial conceptual geologic model of landsliding within the East Canyon. The most significant of these revisions include the: (1) identification of multiple shallow slides within the valley floor (Qls-1 and the 1907 landslide); (2) identification of multiple shallow slides along the western valley margin (Qls-2, Qls-3, and Qls-4), and (3) absence of deep-seated landsliding. This model rests on several key observations and conclusions outlined in the bulleted items in Section 6.01, which are elaborated upon below.

First, the interpretation of newly-acquired historical photographs and pre-development topographic maps has helped define the historic boundaries of pre-existing landslides that are now obscured by artificial fill or have otherwise been altered by grading. Interpretation of maps and historical photographs suggests the western margin of the valley is rimmed by several east-directed slides bound on the east by Winter Creek. This model is generally similar to and consistent with the mechanisms of landsliding found in our recent Centennial Drive Bridge assessment, which suggests that Landslide No. 40 and the 1907 landslide tend to be limited in lateral extent by the presence of Winter Creek. We adopt a similar model for the landscape in the region of Buildings 85 and 85A, where Winter Creek presently exists in a buried culvert beneath the eastern side of the site.

Second, recent test pits (AKA TP-2 and TP-4), as well as exploratory borehole AKA-16 indicate that the bedrock topographic high preserved at the old quarry is very likely in place and not entrained as part of a large, hypothetical deep-seated (~60 feet deep) East Canyon Landslide. In particular, AKA-16 drilled close to the center of the topographic high extended to 43 feet in depth, crossed the Moraga and Orinda Formation contact, and did not encounter evidence for deep-seated landsliding. Furthermore, other recent deep boreholes (AKA-10 and AKA-11) did not encounter a laterally continuous deep landslide deposit at depth(s) as inferred in previous cores and studies. These data suggest that the previously interpreted large East Canyon Landslide is actually composed of multiple smaller and shallower slides both upslope (Landslide Qls-1) and downslope (1907 landslide) of the old quarry. The majority of the subsurface geologic data support shallow (25-40 feet thick) landsliding consistent with the mapped boundaries determined from pre-development topography. Lastly, the absence of displaced Moraga Formation blocks south of the old quarry strongly suggests steady long-term transport of Moraga-derived landslide material, as required in the previous East Canyon Landslide model, is unsubstantiated. The revised conceptual geologic model for landsliding shown on Figure 9 depicts Landslide Qls-1 as bounded on its southern margin by the in-place topographic high, which also serves to redirect the landslide movement towards the southeast (i.e., in the direction of Building 83 and the former natural drainage associated with East Creek).

Third, these key points support a geologic and geomorphic model that includes feedback between incision/erosion along Winter Creek, and active mass wasting along the western margin of the canyon. The coincidence of Winter Creek with toes of landslides Qls-2, Qls-3, Qls-4 and Landslide 40 and the western lateral margin of Landslide Qls-1 suggests that incision by paleo-Winter Creek may have greatly influenced mass wasting processes within the East Canyon. Hydrogeologically, the presence of substantial surface and subsurface water along the lower portion of the western canyon wall and in the vicinity of Winter Creek is well-documented, beginning with the map of historical springs by Soulé (1875). In summary, active incision related to past wet and saturated conditions is interpreted as having produced rapid downcutting along Winter Creek creating unstable free faces and landsliding within the upslope colluvium and Tertiary bedrock.

6.03 East Canyon Geomorphology

The natural geomorphology of the East Canyon can be visualized and inferred by reviewing historic photographs (Figures 10 and 11) as well as the pre-construction topographic contours shown on old LBNL maps (Figure 7). The axis of East Canyon is generally aligned in a north-south direction and, from the head of the canyon, water flows generally south within two roughly parallel drainages. The slopes along the east side of the canyon are interrupted by several tributary drainages that enter the canyon from the northeast; the ridgelines between these drainages are generally oriented northeast-southwest and can be seen on the left-hand side of Figure 10 and the right-hand side of Figure 11. More subtle ridgeline topography exists along the western side of the East Canyon; the lower portions of two generally west/east-trending ridges can be seen along the right-hand side of Figure 10. Buildings 85 and 85A are currently located in the area just beyond these two ridges; an area that is mostly obscured in the southeast-facing photograph on Figure 10. This area can be seen directly in the photograph presented on Figure 11; however, the absence of shadows on the northwest-facing image make it difficult to visually resolve some of the more subtle aspects of the surface topography.

The valley floor below the bedrock quarry was occupied by Such Dairy and several wood barn- and house-like structures. During 1885 to 1907, most of East Canyon consisted of grasslands with the occasional riparian habitat bordering the lower reaches of Winter, East, and Botanical Garden Creeks (south of the old quarry). Various dairy buildings existed at that time, all of which were located upon gently rolling to hummocky terrain within the valley floor south of the old quarry. The old quarry during this time was being used to access a shallow spring noted by water pipes that can be seen in old maps (Soulé 1875) and historic photographs.

The southeast-facing view (Figure 10) shows the former meanders and creek bends along the lower reaches of Winter Creek at or near the current location of Building 85. The creek is deeply incised west of the old quarry near the western margin of the canyon floor. Topographic maps of the area that predate the construction of Buildings 85 and 85A show the present-day site formerly existed as a relatively flat, gently-sloping topographic bench (Figure 7). On Figure 10, a relatively broad and gently east-dipping surface can be inferred west of Winter Creek that presumably matches the flattened and gently sloping topography depicted on the pre-construction topographic maps. In addition, the creek meanders observed in the photograph can be correlated with similar meanders of the pre-construction topography indicating Winter Creek had not been heavily modified between the time of the historical photograph and development of the site.

6.04 Landslide Assessment

Physical and operational constraints associated with Buildings 85 and 85A, existing underground utilities, and extensive slope modifications (i.e., cutting and filling) make direct geologic observation of the lateral margins of landsliding in this area difficult. However, the results of our data compilation, interpretation of pre-development photographs and topographic maps, site reconnaissance and subsurface borehole and test pit information provide some constraints on the inferred lateral extent and depth of landslides Qls-1 to Qls-4. Field reconnaissance provided evidence of recent slope movement (e.g. cracking of curbs and roads) associated only with Landslide Qls-2 (not proximate to the Building 85 and 85A site). Relatively shallow and localized zones of reactivation have previously developed within the Landslide Qls-1 as a result of previous site grading activities (i.e., Calvin Road expansion to the water tank above Building 85A; cut slope grading for Building 83).

Our landslide assessment is heavily influenced by the findings of our recent investigation of Centennial Drive Bridge that documents the presence of multiple smaller to moderate-sized earthflows and landslides within the valley floor and western margin of East Canyon (AKA 2009) and the conceptual geologic model described earlier. Figure 12 shows the approximate outline of mapped landslides Qls-1 through Qls-4 on the pre-1994 topographic map presented previously on Figure 7. Figures 13 and 14 present six interpretive cross sections (A-A' through F-F') that provide information on the underlying geologic conditions within East Canyon at or near Buildings 85 and 85A. The locations of the cross sections are shown on both the Site Plan (Figure 2) and Site Geologic Map (Figure 9) and were selected for the purposes of depicting the geometric relationships between the landslides and Buildings 85 and 85A. Cross Sections A-A' through F-F' (Figures 13 and 14) are presented with no vertical exaggeration and depict bedrock units, undifferentiated Quaternary colluvium and alluvium (shown as colluvium), and artificial fill. Our interpretations of probable and possible landslide slip surfaces are shown on the cross sections in red. The interpretations of landslides Qls-1 to Qls-4 are discussed further below.

6.04.1 Landslide Qls-1

Landslide Qls-1 is the largest landslide of the four documented in the direct vicinity of Buildings 85 and 85A. The landslide is broadly defined by the hummocky topography occupying the valley floor shown in historical photographs and maps of East Canyon. Pre-development photographs taken from near Little Grizzly Peak depict a headwall region comprised of large angular blocks of displaced volcanic material (Figure 10; Historic Photograph - Looking Southeast). The eastern and western lateral margins of the landslide coincide with the deeply incised East and Winter Creeks, respectively. The downslope extent of the landslide appears to be controlled in part by the bedrock ridge of Moraga Formation agglomerate that occupies the central part of the canyon floor (surrounding the old quarry). Colluvium and landslide deposits abut the incised and eroded eastern slope of the bedrock topographic high.

The dimensions of Landslide Qls-1 are estimated from compiling geologic, geophysical, and geomorphic data, coupled with the findings of this subsurface investigation. On the basis of these data, Landslide Qls-1 is up to about 1140 feet long and 300 to 400 feet wide (Figure 9). All margins associated with Landslide Qls-1 should be considered approximately located. The lateral and vertical extent of Landslide Qls-1 is depicted in Cross Sections A-A' to D-D' (Figures 13 and 14). The geologic composition of Landslide Qls-1 is highly variable ranging from unconsolidated clayey colluvium mixed with gravel and blocks of weathered and fractured volcanic rock to claystone, siltstone, and sandstone. Landslide Qls-1 debris ranges from dark brown to reddish brown and bluish gray in color, is moderately to extremely weathered, friable to moderately hard, and is often highly fractured and sheared. The base of the landslide deposit frequently contains multiple zones of subplanar to gently dipping, highly plastic clay and intensely fractured (brecciated to crushed) rock that range in thicknesses from less than 1 inch to about 1 foot. Previous borings (AKA-1, AKA-4, AKA-6 and AKA-7) drilled in the canyon for the ACF and Building 85 landslide study, with the possible exception of boring AKA-3, clearly penetrate Landslide Qls-1 and encounter the basal slide plane either as soft to stiff clay layers and highly fractured and brecciated zones in the Orinda Formation, or it occurs near the contact between the Moraga and Orinda Formations. Recent exploratory borehole AKA-9, near the upper reaches of the landslide, encountered a very distinct basal slide plane consisting of disrupted and sheared 'mixed' Orinda/Moraga formation approximately between 45.5 to 46.5 feet in depth.

6.04.2 Longitudinal Profiles of Landslide Qls-1

Cross Sections A-A' and B-B' trend subparallel to one another along the central axis of Landslide Qls-1. Cross Section A-A' projects southeast through Building 83 whereas Cross Section B-B' trends more south-southwesterly through the bedrock quarry and Centennial Drive Bridge. Both sections show the headwall defined by a smoothed interpretation of the more gently inclined, lobate topography present in the upper reaches of East Canyon consistent with pre-development topography and historical photography. Between borehole AKA-9 and directly downslope of the PG&E tower, Landslide Qls-1 is as much as 45 to 50 feet thick and is comprised of mixed blocks of Orinda and Moraga-derived material (see borehole AKA-9). In the region of the ACF and Building 85, grading for the construction of Calvin Road has reduced the slide mass to a thickness of about 30 feet or less. Near Building 85B, Cross Section A-A' bends southeast and directly behind (northeast) the bedrock quarry to capture (1) a shallow landslide previously reported and mitigated by HLA (1977) during construction of Building 83, as well as (2) a weakly constrained deeper slide plane projecting toward paleo-East Creek. Constraints on the downslope limits of landsliding are derived from the geologic model in which the in-place bedrock quarry acts as a "back stop" prompting the landslide toe to either surface upslope of the quarry or deflect to the southeast toward Building 83. This interpretation is consistent with grading observations during construction of Calvin Road, utitlity trenches along the road, and the cuts made for the ACF. We tentatively infer at least two landslide toe regions: (1) an upper toe located between the Animal Care Facility and Building 83, and (2) a lower toe located downslope of Building 83 approximately coinciding with the former location of East Creek. Borehole data indicate a general thickened mass of colluvial, alluvial and loose landslide deposits behind the bedrock topographic high that project southeast toward Building 83 (see Cross Section B-B; Figure 13).

The lower half of Cross Section B-B' extends from Building 85B in a southerly direction through the quarry and Mather Grove. Consistent with previous geologic studies (AKA 2006), a landslide toe is inferred as roughly projecting beneath the ACF and terminating at or near the north side of the in-place quarry hill. Downslope of the old quarry, near the Building 83 (U5) parking lot, Cross Section B-B' intersects the headwall region of the 1907 landslide that was previously assessed for the Centennial Drive Bridge project (AKA 2009). The geometry of the 1907 landslide shown in Cross Section B-B' is based on: (1) review of multiple historical photographs taken in 1907; (2) tonal lineaments observed in 1939 stereo-paired aerial photographs; (3) patterns of ground cracking reportedly observed following the grading and paving of the U5 parking lot; and (4) subtle geomorphology observed from site reconnaissance. This landslide is interpreted to be irregularly-shaped with multiple lobes – the largest (as much as 400 feet long and nearly 200 feet wide) situated on the east side of Winter Creek. Vertical scarps at the head of the 1907 landslide are interpreted to have been 10 feet or higher. Borehole data suggest a translational slide mass composed of weak colluvial material and weathered Orinda Formation bedrock.

Lastly, Cross Section B-B' shows the approximate limits of the 1982 landslide within the eastern approach fill of Centennial Drive Bridge. The landslide occurred primarily within artificial fill where it intersects the 1907 landslide mass. The failure surface is confirmed by slope indicators (GIS #304 to 306) installed within the fill and eastern extent of the 1907 landslide. Data from slope indicator readings generally show up to several inches of downslope movement extending to depths of about 40 to 45 feet. We interpret the 1982 landslide as reactivating the portion of the older 1907 landslide upon which it was built. Neither the 1907 landslide or 1982 landslide directly impact Buildings 85 and 85A.

6.04.3 Cross-Sectional Profiles of Landslide Qls-1

The eastern margin of Landslide Qls-1 is based on interpreting landslide morphology from pre-grading topographic maps, locating historic landslide failures (e.g. Harza 1995), compiling engineering geologic observations of utility trenches excavated along Calvin Road (Exposure E8-94d), as well as recent observations from research trenches excavated by LBNL geologists. Evidence for the western lateral margin is limited to Building 85A retaining wall construction observations (Exposures E10 and E11-94d), and the inference that the margin coincides closely with the historical margin of Winter Creek. Recent boreholes drilled as part of the Building 85 study, coupled with re-interpretation of previous geologic and geotechnical data from the site vicinity, provide supporting evidence for this interpretation. For example, borings AKA-5 and 5a indicate the geometry of western margin of Landslide Qls-1 is roughly coincident with Winter Creek (see Cross Section C-C'). Previously, the western margin of the hypothetical large and deep East Canyon landslide was interpreted further west of Winter Creek; however, as shown in Figures 12 and 14 (Sections C-C', D-D', E-E'), we now interpret multiple smaller landslide bodies (Qls-2 to Qls-4) projecting into East Canyon from west of Winter Creek. The eastern margin is generally inferred to be closely aligned with paleo East Creek. A recent research on the Wildcat fault by LBNL geologists located east of boring AKA-9 exposed Orinda Formation juxtaposed against Claremont Chert across the fault, however, no landslide deposits were encountered. The trench exposure therefore places the eastern margin west of this trench.

6.04.4 Landslide Qls-2

The dimensions of Landslide Qls-2 are estimated primarily from the compilation of trenching data and geologic mapping of landslide-related geomorphology from pre-development topographic maps. Landslide Qls-2 is constrained to the western margin of East Canyon and is bound to the east by Winter Creek. The landslide is approximately 340 feet wide and 140 feet long (Figure 9). Landslide Qls-2 is composed of landslide material derived from primarily Moraga Formation located to the west and undifferentiated colluvium and alluvium derived from Winter Creek. The northern margin of the landslide appears to be underlain by a thick fill prism associated with the road leading to the water tank. No subsurface data exists on the depth of slide material; however, based on geometric relations we infer the slide plane to be as deep as 20 feet and extending across the Moraga and Orinda Formation geologic contact. A shallower slide plane at or near the Moraga and Orinda Formation contact is also plausible. Geomorphic relations interpreted from pre-development topography suggest that the landslide toes out at or near Winter Creek where it is likely buried by as much as 10 feet of undifferentiated alluvium and colluvium. Landslide Qls-2 appears to be located directly north of Building 85A and thus does not underlie Buildings 85 or 85A.

Limited subsurface information from previous Trench T-1B (GIS # 70) of GRC (1994) and test pit TP-3 of this recent study are used to provide some constraint on the landslide material and geometrical relations near Building 85A (Figure 14). Trench T-1B, located upslope of Building 85A, intersects the southwestern margin of Landslide Qls-2 along a trend of N80°E. The landslide margin trends approximately N85°W and is delineated by highly dilated Moraga Formation and poorly consolidated silty clay (colluvium) separated by a thin grayish brown silty clay (e.g. the southern slide margin of Qls-2). Portions of Landslide Qls-2 appear to have been reactivated recently as evidenced by: (1) youthful appearance of a small headwall nested within the older, more subdued larger slide, (2) bedrock relations exposed in trench T-1B (GIS # 70), and, (3) dilated and fractured pavement of the PG&E access road at the intersection with the landslide margin. Test Pit TP-3 located upslope of Building 85A and directly south of the region of road distress exposed intact Moraga Formation overlain by a steeply-dipping colluvium confirming the southwestern limits of Landslide Qls-2. Relative elevations of the bedrock-colluvial contact across the trench (i.e., a paleo-ground surface defined by the northeasterly dip of colluvium) suggest the presence of a buried southwest-trending ridge bordered on the north by a colluvial hollow associated in part with Landslide Qls-2. No landsliding was interpreted in test pit TP-3.

6.04.5 Landslide Qls-3

Landslide Qls-3 is a small inferred slope failure located primarily in the region of Building 85A. It appears to intersect landslides Qls-2 and Qls-4 to the north and south, respectively (Figures 9 and 14). The characterization of Landslide Qls-3 is based on a compilation of previous trenching information and descriptions of construction excavations as well as geologic mapping of landslide-related geomorphology from pre-development historical topography. Pre-construction topography define the western slopes bordering Winter Creek as a gentle southeast-dipping ground surface with a moderately steep north to northeast-trending headwall. The odd configuration of the landslide suggests that it is either an individual slide mass as mapped, or alternatively represents a piece of a larger ancient slide that has been truncated.

Landslide Qls-3 is mapped as being approximately 80 feet long and 100 feet wide (Figure 9). The inferred overall thickness of the landslide mass at or near the headwall and central portion of the slide have been significantly reduced (from as much as 30 feet to 15-20 feet thick) from construction-related grading of Building 85A and the steep rock cut west of the building (see Cross Section C-C'; Figure 14). As shown in Cross Sections C-C' and F-F', Landslide Qls-3 is between 15-20 feet thick and involves a thick section of colluvium overlying the Moraga and Orinda Formations. The northern and southern margins of the slide are inferred from historical topography, and anomalous meanders and resistant knobs or blocks within the Winter Creek drainage. Landslide Qls-3 is well-constrained along the western margin (see discussion below) yet poorly constrained along the eastern margin along the historic thalweg of Winter Creek.

The western margin of Landslide Qls-3 is constrained by exposures described during grading operations for Building 85A and interpretation of cut-slope excavations for the present-day retaining walls north of and on the southeast side of Building 85A. The keyway cut north of Building 85A exposed a 1- to 24-inch-thick zone of stiff clay gouge within volcanic rock striking N11°-19°W and a subvertical-steep easterly dip (Exposure E4-94d). This gouge zone is interpreted as the western margin of Landslide Qls-3.

Sketches of the excavation for the retaining wall along the southeast side of Building 85A show several features consistent with landslide debris and a north-trending landslide margin (e.g. Exposures E10-94d and E11-94d; or GIS# 65 and 64, respectively). The sketch logs developed by LBNL geologists depict colluvium and dilated and weathered basalt (Moraga Formation) subhorizontally overlying weathered and tilted siltstone and sandstone (Orinda Formation) at the southwestern end of the excavation. The northeast end of the retaining wall excavation exposed sheared Orinda Formation (siltstone/sandstone) and a subvertical to moderately east-dipping curvelinear contact between the Orinda and Moraga Formation. Thin, discontinuous ash layers were present near the contact and within a dilated basalt mass at the contact. We interpret the retaining wall excavation sketches from southwest to northeast to represent: (1) Moraga Formation in depositional contact over Orinda Formation; (2) sheared and deformed Orinda Formation delineating the western margin of Landslide Qls-3; and (3) a displaced and rotated depositional contact between the Moraga Formation and Orinda Formation with minor landslide-related mixing between the two bedrock units and colluvium within Landslide Qls-1. The presence of sheared Orinda Formation and a displaced but otherwise preserved depositional contact between Moraga Formation and Orinda Formation is similar to the bedrock discontinuities and bedding observed in previous borings AKA-5A and AKA-5 (GIS# 338 and 337) located directly east of the retaining wall. (Note that the location of GIS # 338 and 337 data points lie close to the thalweg of paleo-Winter Creek and either represent the projection of the toe of Landslide Qls-3 within Winter Creek or the western margin of Landslide Qls-1. We tentatively interpret these borings as within the slide mass of Qls-1.)

Lastly, a gouge zone (excavation E4-94d or GIS # 66) within the Moraga Formation that was observed in a keyway cut directly north of Building 85A lies along projection with the shearing observed within Orinda Formation in the retaining wall exposure (Exposures E10-94a and E11-94d). These features are used, coupled with the pre-grading topography, to delineate Landslide Qls-3. As shown in this section, the slide is composed predominantly of displaced Moraga Formation, a thick section of Winter Creek undifferentiated colluvium and alluvium, and a lesser amount of Orinda Formation near the basal contact. At Winter Creek the landslide toe intersects the inferred western margin of Landslide Qls-1, and has been altered through grading of Calvin Road and placement of fill within the paleo-Winter Creek corridor.

6.04.6 Landslide Qls-4

Landslide Qls-4 is expressed geomorphically in the pre-grading topography of the Building 85 site as a broad and gentle southeast sloping surface. The arcuate headwall aligns closely with a spring reported in a trench at the site, whereas the toe roughly coincides with Winter Creek (Figures 12 and 14). The southern margin is constrained partly by borehole data and pre-grading geomorphic expression. The northern margin of the landslide intersects Landslide Qls-3 between Buildings 85 and 85A. The dimensions of Landslide Qls-4, represented schematically in Cross Sections E-E' and F-F', are based on pre-grading topography, test pit, trench and borehole data. The landslide is up to 170 feet wide and 130 feet long and underlies the northern half of Building 85 (Figures 9 and 14). The landslide is comprised of undifferentiated colluvium and alluvium overlying Moraga Formation, and lesser components of Orinda Formation. Construction-related grading for Building 85 has removed the upper part of the landslide whereas significant fill (up to 24 feet) has been placed within Winter Creek acting as a buttress for the landslide toe.

As discussed above and below and shown on Cross Sections D-D' and E-E', the extent and depth of Landslide Qls-4 is constrained by historical geomorphic mapping, trench data (GRC 1993) and multiple boreholes. Trench T-2 (GIS # 61) of GRC (1993) exposed the inferred headwall of Landslide Qls-2. GRC (1993) describe a possible landslide headscarp shear trending N5°W and dipping 50-20° NE within the Moraga Formation and log an anomalous 2-foot vertical step in the basal contact of colluvium with bedrock. The bedrock type exposed in the trench is similar to the bedrock encountered upslope along the PG&E access road (e.g. basalt, andesite and agglomerate with little or no bedding).

Multiple recent exploratory boreholes AKA-10 through AKA-12 provide vertical and lateral constraints on Landslide Qls-4. Borehole AKA-12, located near the headwall of the landslide and within the former northwest-trending swale, appears to have encountered about 14 feet of fill overlying about 8 feet of undifferentiated coarse clayey alluvium and colluvium. Between 22 and 26 feet in depth the borehole intersects highly weathered Moraga Formation with a clay-rich matrix. Below a depth of 26 feet the bedrock transitions into Orinda Formation siltstone with minor amounts of volcanic material that is suggestive of interfingering. At 22 feet, a fat clay seam interpreted as a landslide shear plane was encountered between the Moraga Formation and overlying colluvium. Because of the clay-rich nature of the weathered and weak Moraga volcanics below this clay seam, it is possible that the entire package of Moraga Formation and colluvium has been translated by landsliding, suggesting the basal plane may be at about 26 feet in depth.

Similarly, AKA-11 is located within Landslide Qls-4 and provides evidence of landslide-related deposits. Borehole AKA-11 encountered about 18 feet of fill overlying 4 to 5 feet of undifferentiated alluvium of Moraga Formation affinity and highly weathered Moraga Formation bedrock. At or near the contact between the Moraga Formation and Orinda Formation (approximately 22 feet) a clay seam dipping 30 to 40 degrees and containing subhorizontal straie is inferred to represent the basal slide plane as it approaches Winter Creek. Below the inferred slide plane the bedrock becomes a hard compentent siltstone with large interbeds of claystone, sandstone and siltstone of the Orinda Formation dipping between 20 and 30 degrees.

Borehole AKA-10 is located south of AKA-11 at or near the paleo-drainage associated with Winter Creek and just south of the geomorphic expression of Landslide Qls-4. This borehole encountered an approximately 26-foot-thick fill prism that is underlain by undifferentiated alluvium consisting of clayey gravel with Moraga and Orinda-dervied clasts. Definitive sandy siltstone bedrock is present at 44.5 feet in depth. Of the samples retrieved from AKA-10, there was no evidence of definitive landslide material of similar appearance or composition to the landslide features in the other boreholes extending through Landslide Qls-4. Multiple ¼- to 1-inch clay seams, dipping 35 to 40 degrees, were present at about 42.5 feet; however these stiff seams do not appear to be related to Landslide Qls-4 and are inferred to be related to older geologic processes.

A compilation of older boreholes and test pits by GRC (1994) help to infer the arcuate geometry of the basal slideplane shown on Cross Section D-D'. Interestingly, previous boreholes B-1, B-2, and test pit TP-2 identified very similar alluvium and colluvium over Moraga Formation, but did not identify clay shears or discontinuities indicative of landslide margins. These data require the landslide boundary be located below the total depths of these test pits and boreholes, thus requiring an arcuate landslide geometry.

7.00 GEOTECHNICAL ENGINEERING EVALUATIONS

7.01 Overview of Stabilization Approach

7.01.1 Project Objectives

As part of the geologic assessment, we have interpreted that landslide deposits exist in many areas of the East Canyon and that landslide deposits extend beneath portions of Buildings 85 and 85A (Figure 9). The geometry of landsliding in the direct vicinity of these two buildings is complex. However, based on the data developed for this study, we interpret that:

1. A very large north/south-trending landslide (identified as Landslide Qls-1) exists within the upper portion of the East Canyon that extends beneath Buildings 83, 85B and 86 but not beneath the hill south of these three buildings, within which the old quarry is located. The western lateral limit of Landslide Qls-1 is interpreted to be roughly coincident with the former historic drainage of Winter Creek. This very large north/south-trending landslide does not underlie Building 85 or 85A.

2. About the northeastern two-thirds of Building 85A is underlain by a separate northwest/southeast-trending landslide (identified as Landslide Qls-3) within the lower western wall of the canyon. The maximum thickness of Landslide Qls-3 appears to be about 20 feet.

3. About the northern two-thirds of Building 85 is underlain by landslide deposits associated with a northwest/southeast-trending landslide within the lower western wall of the canyon. This landslide (identified as Landslide Qls-4) is about 30 feet in maximum thickness.

The objective of the project is to protect Building 85, Building 85A and the emergency generator pad located between these buildings from unacceptable ground deformations that might otherwise occur during a large earthquake. The analyses and recommendations presented in this report are based on our understanding that: (1) calculated median seismic displacements of 2 inches or less are considered "acceptable" for the "design-level" earthquake shaking; and (2) the "design-level" earthquake shaking is defined at the 10 percent probability of exceedance in 50 years, which is equivalent to the ground motion intensity with a 475-year return period.

We note that the 2 inches or less "acceptable" level of calculated median seismic displacement is a stringent criterion; SP 117A (CGS 2008) states that "Newmark displacements of 0 to 15 cm [0 to 6 inches] are unlikely to correspond to serious landslide movement and damage."

7.01.2 Slope Displacement Mechanics

The results of the geologic assessment generally indicate that the landslide deposits that underlie Buildings 85 and 85A are stable under normal static (i.e., non-earthquake) conditions. This study focuses on slope displacements that may occur under earthquake conditions. The mechanics of earthquake-induced slope displacements examined in this study are as follows:

1. Slope stability analyses performed for this study demonstrate that the largest of the three landslides (Qls-1) cannot be considered stable in a design-level seismic event. In a future earthquake, some or all of the region mapped as Landslide Qls-1 (Figure 9) may move incrementally downslope. Although the upper portion of Landslide Qls-1 is generally aligned

north-south, in the general vicinity of Buildings 85 and 85A, downslope movement of Landslide Qls-1 is redirected towards the southeast by the in-place quarry hill (Figure 12). Cross Section A-A'', presented on Figure 13, illustrates the downward-sloping basal geometry of sliding in the southeast direction.

2. Movement of Landslide Qls-1 towards the southeast has the potential to remove support from the toe region of Landslides Qls-3 and Qls-4, thereby decreasing their stability. Slope stability analyses performed for this study demonstrate that an additional resisting force is needed to limit earthquake-induced displacements of Landslides Qls-3 and Qls-4 following the loss of toe support. Cross sections C-C' and D-D' presented on Figure 14 illustrate the interpreted basal geometries of Landslides Qls-3 and Qls-4, respectively, as well as their relationships to Landslide Qls-1.

7.01.3 Design Approach

As currently envisioned, the project will involve the installation of new below-grade structural elements (e.g. drilled piers, cap beams and tiebacks) designed to limit seismic ground deformations in the area of Buildings 85 and 85A. The drilled piers and tiebacks will extend below/through underlying landslide deposits to be anchored in bedrock. Key geotechnical relationships are illustrated on the Engineering Plan, Section and Loading Diagrams presented on Figure 15.

The project design is primarily intended to restrain Landslides Qls-3 and Qls-4, while limiting seismic displacements associated with these two landslides to "acceptable" levels (i.e., calculated 2-inch median displacements). The project design is not intended to restrict the movement of Landslide Qls-1, which will potentially pull away from and/or slide past the below-grade face of the vertical stabilizing elements (drilled piers). Figure 15 shows the general locations of four zones (designated Zones A1, A2, B1 and B2) in which the drilled piers will be installed. Figure 15 also presents an engineering cross section that generally coincides with the drilled pier alignment (Cross Section G-G'). The drilled piers are proximate to the former Winter Creek channel and are intended to isolate Buildings 85 and 85A from the body of Landslide Qls-1. We note, however, that marginal piece of the mapped Qls-1 landslide will be captured within the drilled pier alignment as shown on the Engineering Plan and Cross Section G-G' presented on Figure 15.

This design approach necessarily requires that tiebacks be installed that extend beneath Buildings 85 and 85A. Both of these existing buildings are supported upon drilled pier foundations, the locations of which are shown on plans available from LBNL. The tiebacks that are to be installed as part of this project will therefore be located so that the drilling for the tiebacks will not encounter the existing piers that support these two buildings. In addition, the drilled piers, tiebacks, cap beams and associated excavations required for their construction will be designed to not interfere with critical subsurface utilities that service Buildings 85 and 85A.

7.02 <u>Overview of Geotechnical Engineering Analyses</u>

7.02.1 General Analysis Objectives and Approach

The primary objective of our geotechnical engineering analyses was to evaluate the lateral forces that the new below-grade structural elements (drilled piers, tiebacks and cap beams) would need to resist. This involved what was essentially a two-step process:

1. Demonstrating that Landslide Qls-1 is not seismically stable and predicting order-of-magnitude downslope movements that might occur during a design-level earthquake event; and

2. Evaluating the lateral forces needed to maintain stability and limit deflections of Landslides Qls-3 and Qls-4 should Landslide Qls-1 pull away from the new below-grade structural restraints.

Our analytical approach was based upon the official State of California guidelines presented in SP 117A (CGS 2008). Our evaluations of earthquake-induced slope displacements were performed using the methods outlined in the professional paper "*Simplified Procedure for Estimating Earthquake-Induced Deviatoric Slope Displacements*" by Bray and Travasarou (2007).

7.02.2 Displacement Analysis Methodology

Bray and Travasarou (2007) utilizes a Newmark-type model for evaluating seismic performance of slopes and was developed based on the results of nonlinear, fully coupled sliding block analyses using a database of horizontal components of recorded ground motions from 41 earthquakes. The Bray and Travasarou (2007) procedure includes the following steps:

1. The yield coefficient of the landslide is evaluated using conventional geotechnical analysis methods (e.g. commercially available slope stability analysis software). The yield coefficient (k_y) is equal to the fractional proportion of the acceleration of gravity (g) which, when applied horizontally at the centroid of the landslide body, produces a calculated pseudostatic factor of safety (FS) equal to one.

2. Earthquake displacements are evaluated using plot of yield acceleration versus displacement, which is generated using an Excel spreadsheet published by the authors. The plot is based on a statistical analysis using the database of input ground motions and presents median as well as 84^{th} and 16^{th} percentile displacements. It has been noted that the 84^{th} and 16^{th} percentile displacements are commonly about two times and half, respectively, of the median displacement values.

To analyze the displacement of Landslide Qls-1 (as discussed further in Section 7.03), the landside's yield coefficient was evaluated based on the current slope geometry for two possible groundwater levels. The Bray and Travasarou (2007) plot was then used directly to evaluate seismic slope displacements.

To analyze the lateral forces needed to maintain stability and limit deflections of Landslides Qls-3 and Qls-4 (as discussed further in Section 7.04), a vertical step was created in the slope stability model at the approximate location of the vertical stabilizing elements (drilled piers). With this step, the slope is no longer stable under static (non-earthquake) conditions and therefore a resisting force is needed to bring the retained landslide back into equilibrium. Under design-level earthquake loadings, increasingly higher resisting forces are needed to produce lower deflections. The methodology that we used to evaluate the relationship between resisting forces and deflections is described briefly below.

First, we used the Bray and Travasarou (2007) plot developed for Landslides Qls-3 and Qls-4 to evaluate the yield coefficients needed to produce a range of target deformations (2, 4 and 6 inches). Then, the slope stability model was used to calculate the required resisting force (total horizontal force applied per unit width of the slide body) to produce the yield coefficients associated with the target deformations. Within the bodies of the landslides, two possible groundwater levels were modeled; we ignored the stabilizing effect of any groundwater that might remain downslope of the step in our lateral force analysis.

Finally, we developed a plot of total required resisting force versus median displacements by combining the Bray and Travasarou (2007) and slope stability analysis results.

7.02.3 Simplifying Assumptions

We performed our slope stability modeling using conventional 2-dimensional (2D) analysis methods based on the geologic interpretations presented on the Site Geologic Map (Figure 9) and the geologic cross sections (Figures 13 and 14). As previously noted, the conditions within the study area are geometrically complex and a variety of simplifying assumptions were made in our evaluations of seismic displacements and forces. For example, landslides were modeled based on a typical cross section oriented upslope-downslope within the central portion of the landslide body. This methodology does not capture variations in cross-sectional geometry (or the resulting lateral forces) that occur across the width of the landslide. However, given the accuracy and detail by which specific subsurface features can be resolved based on available data, 2D methods were judged to be generally reasonable and appropriate for the purposes of our engineering analyses.

Similarly, it was our objective to develop geotechnical engineering recommendations for the structural design of below-grade stabilizing elements in areas where limited "deep" subsurface data exists. In developing our design recommendations, it was our intent to capture the likely vertical and horizontal extent of the landslide deposits to be retained by the below-grade stabilizing elements. The geologic interpretations presented on the Site Geologic Map (Figure 9) and geologic cross sections (Figures 13 and 14) generally show curvilinear surfaces at the boundary of landslides. However, recognizing the approximate nature of the geologic interpretation and for the purposes of simplicity, we developed our geotechnical recommendations using a simplified engineering framework that envelops but does not necessarily follow the curvilinear surfaces depicted in the geologic figures.

Finally, in preparing our recommendations for the design of below-grade stabilizing elements, it was necessary to evaluate the direction (vector) of seismically-induced landslide loading. In general, we assumed that landslide movement would occur in the general directions shown on Figure 15. For Landslide Qls-4 it was assumed that the lateral force/displacement vector would be oriented perpendicular to the long axis of Building 85. The orientation of the lateral force/displacement vector for Landslide Qls-3 is less well-constrained based on the available data and was interpreted as roughly parallel to the displacement vectors of Qls-2 and Qls-4 (Figures 12 and 15).

7.02.4 Seismic Analysis Parameters

The key parameters used in our seismic analyses include: (1) yield coefficient (k_y); (2) initial fundamental period (T_s); (3) moment magnitude (M_w); and (4) spectral acceleration (Sa). The methods used to evaluate these analysis parameters are briefly described below.

> ***Yield Coefficient (k_y) -*** We used the computer program SLIDE, version 5.037 (October 2008) and Spencer and Bishop Simplified Methods to calculate yield coefficients using simplified "pseudostatic" methods. SLIDE is a commercially available geotechnical software package that uses conventional two-dimensional limit-equilibrium analysis methods to evaluate slope stability. The yield coefficient value varies for each of the landslides and groundwater cases analyzed. Graphical output for each case is attached in Appendix F.

Initial Fundamental Period (T_s) - We estimated the initial fundamental period of landslide masses using the relationship: $T_s = 4H/V_s$, where H is the height (thickness) of the landslide and V_s is the average shear wave velocity of the landslide mass. We used an average shear wave velocity of 700 feet per second (fps) for all of our analyses, which is based on shear wave velocity data from Borings AKA-8 and AKA-9 (Appendix C). The height of the landslide (H) was scaled, as appropriate, for each landslide case.

Moment Magnitude (M_w) - An average mean magnitude of 7.1 was obtained from published data on the Hayward fault and was used for the moment magnitude, M_w, for all analysis cases.

Spectral Acceleration (Sa) - We obtained spectral acceleration values using the Uniform Hazard Spectra (UHS) for the LBNL Rock Site developed by URS Corporation (Figure 21 in URS 2008). This UHS is for a 10 percent probability of exceedence in 50 years level-of-hazard (475-year return period). The UHS was developed for use throughout LBNL and is the same for all three analysis cases. The specific spectral acceleration value used in the Bray and Travasarou (2007) analysis corresponds to the "degraded period", which is defined numerically as 1.5 times the initial fundamental period (1.5 T_s) and therefore varied based on landslide thickness.

The yield coefficient, when multiplied by the acceleration due to gravity (g), is termed the "yield acceleration." The yield acceleration is also commonly viewed as the horizontal acceleration at which the landslide just starts to move.

7.02.5 Slope Stability Modeling

The key inputs to our slope stability model include: (1) slope geometry; (2) slide plane geometry; (3) slide plane material strength; (4) landslide unit weight; and (5) groundwater level. We generally modeled the slope as a single-layer system with the landslide slip surface explicitly specified. Brief descriptions of the methods used to evaluate these modeling inputs follow; these inputs are also shown on the graphical output from the slope stability model (Appendix F).

Slope Geometry - We developed an idealized cross section for each analysis case that was generally oriented along the primary axis of landsliding. We generally used geologic Cross Section A-A' (Figure 13) to model Landslide Qls-1. Although geologic Cross Sections C-C' and D-D' cut through Landslides Qls-3 and Qls-4 (respectively), they do not coincide with the principal axes of the landslides; we therefore developed additional cross sections (engineering Cross Sections H-H' and I-I' on Figure 15) for our Qls-3 and Qls-4 analyses. The surface topography on all three cross sections is based on recent LBNL surveys and is intended to be generally representative of current conditions.

Slide Plane Geometry - We modeled slide plane geometry for Landslide Qls-1 using the landslide slip surfaces shown on geologic Cross Section A-A' (Figure 13). We modeled slide plane geometry for Landslides Qls-3 and Qls-4 using the landslide slip surfaces shown on engineering Cross Sections H-H' and I-I', respectively (Figure 15).

Slide Plane Material Strength - Previous AKA studies within the East Canyon (AKA 2006a; AKA 2006b) have included laboratory evaluations of residual shear strength using torsional ring shear apparatus. We also performed torsional residual ring shear tests for the Helios project, which was to be located within Chicken Creek Canyon, about 1,000 feet to the west of Building 85. All of these tests were preformed for the purposes of evaluating the residual shear strength of known or suspected slide plane materials. Based on these data, we generally used residual friction angles between 20 and 22 degrees (with no cohesion) in our slope stability modeling.

Landslide Unit Weight - We used a uniform unit weight of 120 pounds per cubic foot (pcf) in our slope stability modeling.

Groundwater Level (Qls-1) - In our analysis of Qls-1, we modeled "high" groundwater conditions assuming a groundwater surface generally coincident with the bases of the cut slopes that exist along the cross section alignment. We modeled "low" groundwater conditions using a surface that was approximately 15 feet lower.

Groundwater Level (Qls-3 and Qls-4) - In our analysis of Qls-3 and Qls-4, we modeled "high" groundwater conditions assuming a groundwater surface about 5 to 10 feet below the current ground surface. We modeled "low" groundwater conditions based on a hypothetical "with drainage" model using a surface that was approximately 10 to 15 feet lower.

7.03 Displacement Analysis – Landslide Qls-1

Landslide Qls-1 does not directly underlie Buildings 85 or 85A; however earthquake-induced downslope movement of Landslide Qls-1 has the potential to remove support from and destabilize the two smaller landslides (Qls-4 and Qls-3, respectively) that underlie these two buildings. The primary purpose of the displacement analysis described in this section was to evaluate how far downslope Landslide Qls-1 might move during a design-level earthquake in order to qualitatively assess potential effects caused by the landslide moving past or pulling away from the new below-grade structural elements.

As discussed in previous sections, Landslide Qls-1 is interpreted to be comprised of multiple landslide bodies as well as debris flow deposits that have been shed from areas upslope and deposited upon the canyon floor. The surface topography of Landslide Qls-1 has also been extensively modified by grading as shown qualitatively on Figure 7 and in greater detail on the interpretive cross sections (Figures 13 and 14). In some locations, excavation cuts have lowered grades by 30 or more feet (as shown on Figure 13; cross sections A-A' and B-B') nearly cutting through Landslide Qls-1. However, many of the major cuts and fills within the East Canyon are at an oblique angle to the upslope-downslope axis of Qls-1 and sections taken elsewhere would reveal different geometric relationships. In our analyses, which are based on cross section A-A', we examined two possible failure modes for Landslide Qls-1:

Upcanyon Slide - An upcanyon failure that "toes out" at the base of the deep cut made to construct the water tank access road (i.e., near GIS ID#284 on cross section A-A' [Figure 13]); and

Fill Slide - A full reactivation of Landslide Qls-l as a whole, which would toe out east of Building 83 near the former (now buried) location of East Creek.

We evaluated yield coefficients and seismic displacements for both failure modes for two possible groundwater elevations:

High Groundwater - An upper bound condition generally limited by the presence of excavation cuts along the cross section alignment; and

Low Groundwater - An intermediate groundwater elevation intended to be generally representative of "typical" long-term groundwater conditions.

In our analysis of Landslide Qls-1 we used a residual shear strength value of 22 degrees to model the existing slide plane material (use of a lower shear strength would generally produce greater displacements). The results of our analyses are presented in Appendix F and summarized below.

Calculated Yield Accelerations and Displacements – Landslide Qls-1

Case	Groundwater Condition	Yield Acceleration	Median Displacement
Upcanyon Slide	High	0.02	8.5 feet
	Low	0.13	2.6 feet
Full Slide	High	0.04	7.2 feet
	Low	0.14	2.4 feet

The calculated median displacements reported above should be considered a relative index of seismic slope performance; actual displacements can be thought of as being as little as half or up to about two times the calculated median displacements. This approximate relationship is illustrated by the 16th and 84th percentile lines on the yield acceleration versus displacement plot for Cross Section A-A' (in Appendix F).

7.04 Earthquake-Induced Lateral Forces – Landslides Qls-3 and Qls-4

Landslides Qls-3 and Qls-4 are significantly smaller than Landslide Qls-1 and have vectors of downslope movement oriented in a southeast direction (Figure 15). Both landslides, as depicted on Cross Sections C-C' and D-D', are interpreted as distinct landslide bodies based, in part, upon direct observations of well-developed slide planes in excavation cuts (for Qls-3) and a test pit (for Qls-4). The interpreted lateral extents of both landslides are shown in plan view, in cross section and in profile on Figure 15.

We used the Bray and Travasarou (2007) spreadsheet to calculate the yield accelerations that would be needed to produce median displacements of 1.5, 3 and 6 inches for each landslide. We then evaluated the lateral resisting forces needed to produce the target median displacement values. Two possible groundwater elevations were considered:

High Groundwater - A groundwater condition intended to model long-term high groundwater levels recognizing that the site is located in an area where natural springs and high groundwater flows are known to exist; and

Low Groundwater - An artificially-created groundwater condition modeled for the purposes of evaluation of the effects of subsurface drainage upon resisting forces.

In our analysis of Landslides Qls-3 and Qls-4 we used a residual shear strength value of 20 degrees to model the existing slide plane material (use of a higher shear strength would generally produce lesser resisting forces, which was judged to be less than conservative given the available data). The results of our analyses are presented in Appendix F and include a combined plot of median displacement versus total required resisting force for each landslide.

In consultation with the design team and LBNL, an "allowable" median displacement value of 2 inches has been selected for use in project design. The following table summarizes the approximate lateral resisting force needed to produce this allowable median displacement value for each landslide under two groundwater conditions.

Calculated Landslide Forces for 2-inch Median Displacement – Landslides Qls-3 and Qls-4

Case	Groundwater Condition	Total Landslide Force (per one-foot width)
Qls-3	High	70 kips
	Low	58 kips
Qls-4	High	158 kips
	Low	140 kips

Lateral resisting forces needed to produce other median displacements can be evaluated using the plots presented in Appendix F.

7.05 Lateral Resisting Force Analysis

7.05.1 Existing Building Piers

The plans for Building 85 show that the building is supported upon piers that are 3 feet in diameter and include twelve vertical #10 reinforcing bars. As designed, these existing drilled piers are sufficiently deep to penetrate the slip surface of Landslide Qls-4 and extend into bedrock interpreted as "in-place." We conducted simplified engineering analyses intended to evaluate the lateral capacity of the existing building piers, which can be used to help resist the earthquake-induced lateral forces discussed in the previous section (Section 7.04).

We used the computer program LPILE (v 5) to evaluate the lateral capacity of the existing building piers. The program includes an option that allows the user to input a specified amount of soil deflection into the pier; using this option we were able to check shear and moments within a "typical" 35-foot-long drilled pier for specified 1 and 2 inches of soil movement. In our single analysis case, we modeled 15 feet of pier embedment into rock (which corresponds to 20 feet of soil movement) and a fixed head condition; we neglected any structural loads applied to the pier. Using the available soil sampling data, we estimated undrained shear strengths of 1700 and 5200 pounds per square foot for soil and rock, respectively; groundwater was modeled at a depth of 10 feet (below the top of the soil layer). The structural properties of the pile were modeled using an EI of ½ the gross sectional value; pier moment capacity was estimated for the case of no axial pile load using a simple pile interaction diagram computer program. For these conditions, the results were:

1. Without any reduction for group effects, it appears that the piers could provide up to about 140 to 190 kips of resistance to the slide mass (for 1" and 2" movement, respectively). Numerically, this is the maximum shear on the pile and occurs at the bottom of the presumed slide mass.

2. At 2 inches of soil movement, the moment capacity of the pile has been reached.

Generally similar resistance values were obtained for a "pinned" head condition at a slightly greater deflection (2.5 inches vs. 2 inches). The LPILE analysis was performed with unfactored soil and pile properties (i.e., a presumed factor of safety of 1.0).

In our simplified analyses, we estimated that a typical 20-foot-wide "bay" of Building 85 includes seven piers, of which only two or three are not within a group in the direction of motion. In evaluating group effects, we considered a "Pmultiplier" value of 0.6 to be generally appropriate (i.e., conservative) for a 3- to 5-pier group. Accordingly, the actual resistance of the piles within the group can be approximated as about 60 percent of the values previously presented for a single pile. Assuming that the "average" pier may only provide 60 percent of the resistance of a single pier, for 2 inches of deflection, we calculate an average lateral resistance of about 800 kips (190 kips/pier × 7 piers × 0.6) per 20-foot-wide bay. This corresponds to an average resisting force across the width of the landslide of about 40 kips per lineal foot.

7.05.2 Pressures Acting on the Downslope Face of Stabilized Zone

In our evaluations of the earthquake-induced lateral forces imposed by Landslides Qls-3 and Qls-4 (Section 7.04), we assumed that a gap will open up between the outside faces of the drilled piers and the adjacent ground due to the west-to-east component of movement within Landslide Qls-1. However, the magnitude of seismic landslide movement at the western slide margin (and, consequently, the width/depth of the gap) cannot be accurately predicted. It has been suggested that it may be overconservative to assume that Qls-1 will move entirely away from the vertical stabilizing elements as it is considered likely that the crack will be partially infilled with soil (e.g. by coincident back-sliding or a *graben*) as it develops. Our criteria, therefore, allows the application of a resisting lateral pressure on the downslope side of vertical stabilizing elements over the lower portion of the retained height. For this analysis, we judged that the height of infilling could reasonably be estimated as about one-half of the slide thickness.

7.06 <u>Construction Considerations</u>

7.06.1 Project Constraints

Buildings 85 and 85A provide services that are critical to the operation of LBNL as a whole. For this reason, it is our understanding that the Building 85/85A facility will need to remain functional throughout the period of construction. The contractor should anticipate that LBNL will likely place significant constraints on the project, which may include (but not necessarily be limited to) the following:

- Limitations pertaining to schedule, sequencing and work hours;
- Limitations on areas available for construction, laydown and staging;
- Limitations involving onsite subsurface utilities;
- Requirements involving excavations and drilling;
- Requirements involving soil stockpiling and/or disposal;
- Requirements involving the handling, containerization and disposal of drilling fluids;
- Requirements involving stormwater protection and spill control;
- Requirements involving construction noise and/or vibrations;
- Requirements involving the restoration of existing below-slab membranes; and
- Stringent health and safety protocols.

It is the contractor's responsibility to understand, acknowledge and fully comply with all of the limitations, requirements and protocols set forth by LBNL throughout the period of contract performance.

7.06.2 Pier Drilling

We judge that bedrock materials that underlie the site are likely able to be penetrated with conventional heavy drilling equipment; however, zones of relatively hard rock could be encountered. The contractor should be prepared to utilize suitable hard rock drilling techniques, if necessary. Special drilling procedures and/or equipment may also be required to: (1) safely accomplish ground penetrations in areas with active utilities, and (2) maintain vibrations from drilling to within acceptable limits.

If water accumulates in the holes, it should be removed by pumping or bailing prior to concrete placement unless tremie methods are used. Also, drilling for piers may encounter soils and/or fractured bedrock material that may cave. The drilled pier contractor should anticipate having to drill with slurry and/or case pier holes, as appropriate.

7.06.3 Excavations and Shoring

We anticipate soil and rock materials at the site can be excavated with conventional heavy earth-moving equipment (e.g. a large excavator equipped to be capable of breaking concrete). The existing fill materials at the site may include subsurface obstructions and it is possible that zones of hard rock could be encountered that would require jack-hammering or hoe-ramming to excavate. In addition, all excavations deeper than 4 feet that will be entered by workers should be shored or sloped for safety in accordance with the California Occupational Safety and Health Administration (Cal-OSHA) standards. In general, the stability of site shoring and all temporary construction slopes as well as the protection of nearby site improvements during construction are responsibilities of the contractor.

We suggest that the contractor thoroughly document the condition of nearby buildings, pavements and storm drains by video or other means prior to excavation. The contractor should also perform regular surveys during excavation to monitor for deflection of nearby site improvements.

7.06.4 Temporary Dewatering

The site is located in an area of known natural springs and high groundwater flows. It is therefore possible that some site excavations could extend below groundwater, particularly if the work is performed during or shortly after the winter rainy season. Although low-permeability clayey soils exist over much of the site, higher-permeability zones may exist that would produce higher groundwater flows. The types of higher-permeability materials that are anticipated include sandy or gravelly alluvial/colluvial soils within former drainages and fractured bedrock comprising the excavation bottom. However, other seepage zones or locally perched groundwater conditions could also be encountered.

The control of groundwater during construction is the responsibility of the contractor. Possible groundwater control methods include the installation of low-permeability shoring or cut-off walls at the excavation perimeter, pumping from sumps at low points within excavations, horizontal drains and dewatering wells. The design, permitting, installation, monitoring, and abandonment of site dewatering and discharge systems are the contractor's responsibility. These responsibilities also include any special regulatory or health and safety requirements that may be associated with the disposal and/or discharge of construction water.

7.06.5 Wet Weather Construction

Although it is possible for construction to proceed during or immediately following the wet winter months, a number of geotechnical problems may occur which may increase costs and cause project delays. The water content of onsite soils may increase during the winter and rise significantly above optimum moisture content for compaction of subgrade or backfill materials. If this occurs, the contractor may be unable to achieve the specified levels of compaction. Dewatering requirements will potentially increase due to rainfall, surface runoff, seepage and rises in groundwater level. The stability of temporary slopes will decrease, potentially increasing the lateral extent of excavation required. If excavation trenches are open during winter rains, caving of the trench walls may occur. In general, we note that it has also been our experience that increased clean-up costs may be incurred, and greater safety hazards may exist, if the work proceeds during the wet winter months.

8.00 GEOTECHNICAL RECOMMENDATIONS

8.01 General

8.01.1 Structural Design

The project envisioned herein involves a variety of design complexities that should be most familiar to designers of slope and/or cut retention projects. For this reason, we recommend that the project Design Engineer have experience in the successful implementation of slope and/or cut retention projects of generally similar scale and complexity.

The project structural design should be per the 2007 California Building Code (CBC [CBSC 2007]). The geotechnical factors that may influence the selection of a structural design approach and appropriate load combinations include the following:

- The Design Landslide Loads presented in Section 8.02.2 of this report are associated with "design earthquake" shaking defined at the 10 percent probability of exceedence in 50 years level and a statistically-determined median displacement value of 2 inches.
- Drilled piers will not be load tested. Associated uncertainties involving the actual axial and lateral resistance of drilled piers should therefore be considered in the project structural design.
- All tiebacks will be load tested. The magnitude of the load test can be up to 80 percent of the specified minimum tensile strength of the tendon. The actual axial (tensile) resistance of the tieback is therefore known to be at least as high as the test load.

8.01.2 Project Layout

New below-grade structural elements should be located to avoid conflicts with critical subsurface utilities and the drilled piers that support Buildings 85 and 85A. The locations of specific elements that need to be protected in the project design and construction should be clearly identified by LBNL. We recommend that LBNL provide the project design team (and Design Engineer) with the relevant as-built construction drawings and utility plans and that the locations of these critical elements be confirmed by new onsite surface and subsurface (i.e., utility locating) surveys before the construction documents are finalized.

8.01.3 Contractors

We recommend that the contractors that install the drilled piers and tiebacks have demonstrated experience in the successful implementation of slope and/or cut retention projects of this relative scale and complexity. We strongly suggest that only pre-qualified specialty contractors have the opportunity to bid on the project; provided that this type of contracting approach is acceptable to LBNL. We recommend that AKA have the opportunity to provide input during the contractor pre-qualification process to the extent that is considered appropriate by LBNL and the project design team.

Contractors responsible for the geotechnical aspects of the project (e.g. pier drilling, tieback installation, excavation, subsurface utility relocation) should become familiar with the contents of this report and acknowledge:

- The site conditions, as described in this report and the attached Appendices;
- The construction considerations discussed in Section 7.06 of this report; and
- All applicable LBNL requirements pertaining to the project.

These and all other contractor responsibilities should be clearly defined in the project plans and specifications.

8.02 Earthquake-Induced Landslide Loads

8.02.1 Basis of Lateral Load Recommendations

The lateral load recommendations presented in this Section are based on the analyses previously described in Sections 7.04 and 7.05. The direct landslide loads are for a "high" groundwater level; which is considered appropriate for existing conditions. Although considered by the design team, preliminary (December 2009) plans for the project do not include a deep subsurface drainage system, which would be needed to warrant use of direct landslide loads calculated for "low" groundwater conditions. In general, the lateral loads in this Section are unfactored (i.e., have not been increased by a factor of safety).

8.02.2 Design Landslide Loads

Figure 15 identifies four zones in which drilled piers are to be installed (Zones A1, A2, B1 and B2). The design landslide force within Zones A1 and A2 is equal to the calculated Qls-3 landslide force associated with a median displacement value of 2 inches. The design landslide force within Zone B1 is equal to the calculated Qls-4 landslide force associated with a median displacement value of 2 inches. The design landslide force within Zone B2 is equal to the calculated Qls-4 landslide force associated with a median displacement value of 2 inches *minus* the estimated lateral resistance provided by the existing piers beneath Building 85. These total lateral forces to be resisted (per 1-foot width perpendicular to the direction of loading) are summarized in the following table:

Direct Landslide Forces – 2-inch Median Displacement

Retention Zone	Direct Landslide Force	Landslide Force Zone Location (Elevation)
A1	70 kips	above +860 feet
A2	70 kips	above +860 feet
B1	158 kips	above +850 feet
B2	118 kips	above +850 feet

Direct landslide forces should be distributed over the height (H) of the landslide force zones shown in the above table (also on Figure 15, Table 1). As shown on the loading diagram presented on Figure 15, we recommend that lateral forces be redistributed as either a uniform lateral pressure, or (alternatively) a trapezoidal lateral pressure distribution.

The lateral forces in the above table should be applied in accordance with the directions of loading shown on the plan view presented on Figure 15 (the direction of loading for Zones A1, A2 and B1 is at a skew angle to the zone alignment whereas the direction of loading for Zone B2 is perpendicular to the zone alignment. At one location (between the Zone B1 and B2 systems) the gap between drilled piers will be slightly larger in order to accommodate subsurface utilities that service Building 85. We consider it acceptable to neglect the increases in load that would be distributed across the adjacent piers due to the wider pier spacing at this specific location.

8.02.3 Landslide Shear Loads

Due to the orientation of the Zone A1 and A2 alignment, lateral restraining elements within these two zones will need to be designed to resist lateral shear forces associated with Landslide Qls-1 sliding past the outside face of the retention zone. Within Zones A1 and A2, landslide shear represents an alternate mode of failure that would not occur simultaneously with the direct landslide forces of the previous section (Section 8.02.2). The area over which shear forces should be applied are shown on Cross Section G-G' on Figure 15. Note that: (1) the overall height of the landslide shear zone is greater than the height (H) of the landslide force zone presented in the previous section; and (2) the landslide shear zone is vertically segmented into zones that generally correspond to soil and translated rock.

A shear load (in pounds per square foot [psf]) should be applied over the full vertical area defined by the outboard faces of the drilled piers. The vertically-segmented landslide shear zones shown in the table below and on Figure 15 (Table 1) can be used for design.

Landslide Shear Forces
(applicable to Zones A1 and A2, only)

Retention Zone	Shear Parallel to Retention Zone	Landslide Shear Zone Location (Elevation)
A1	2000 psf	above +870 feet
	3000 psf	+860 feet to +870 feet
A2	2000 psf	above +867 feet
	3000 psf	+850 to +867 feet

Design lateral forces within the lower translated rock zone can be reduced from 3,000 psf to 2,000 psf if a significant fraction of the rock within the lower zone is replaced with soil (i.e., by drilling or excavating). The orientation of the landslide shear load should be taken as coincident with the outer faces of the drilled piers; this orientation is shown schematically on Figure 15.

We recommend that the piers within Zones A1 and A2 be installed along a linear alignment; individual piers that protrude farther into Landslide Qls-1 would need to be designed to resist greater loads. Similarly, we recommend that the northernmost pier be installed as close to Building 85A as practical, in order to minimize direct loads from Landslide Qls-1 on this "lead" pier. Where this is the case, the direct Qls-1 landslide force acting on the lead pier can be neglected (assumed equal to zero). In the shear failure mode, landslide materials south of the southernmost pier will pull away and should therefore _not_ be included in either: (1) the calculation of lateral shear forces; or (2) the available resisting forces at the south end of the Zone A2 pier group.

8.03 Drilled Piers

8.03.1 Basis of Drilled Pier Recommendations

As shown on the December 2009 preliminary plans, large (approximately 5-foot-diameter) drilled piers will be installed within Zones A1, A2, B1 and B2 that will be restrained near their tops by tiebacks. As shown schematically on Figure 15:

- The Zone A1 and A2 piers will extend from near the southeast corner of Building 85A to near the eastern corner of the emergency generator pad. Tiebacks in Zones A1 and A2 will be oriented towards the northwest, at a skew angle to the pier alignment.
- The Zone B1 piers will extend from near the eastern corner of the emergency generator pad south to the northeast corner of Building 85A; tiebacks in Zone B1 will also be oriented at a skew angle to the pier alignment.
- The Zone B2 piers will be approximately parallel to the face of Building 85; tiebacks in Zone B2 will be oriented approximately perpendicular to the pier alignment. Where adjacent to Building 85, the drilled piers will be spaced on 10-foot centers (approximately 5 feet clear between piers) so that tiebacks installed through the piers will not intersect the existing drilled piers that support Building 85.

All of the drilled piers will extend through the landslide materials a minimum distance into in-place bedrock. Drilled piers will be designed to resist the downward component of the tieback loads through skin friction. All piers will be designed to achieve a ductile response.

8.03.2 Passive Resistance in Bedrock

Passive resistance within in-place bedrock can be evaluated using the loading diagram presented on Figure 15, which includes a factor of safety. The diagram includes two components of passive resistance: (1) a minimum passive resistance value of 1,000 pounds per square foot (psf) that starts at the bedrock surface; plus (2) an equivalent fluid pressure that increases at a rate of 450 psf per foot of depth below the bedrock surface. The above passive resistance can be considered "allowable" values under short-term loading conditions and include a factor of safety of at least 1.5, as summarized in the following table.

Drilled Piers – Passive Resistance in Bedrock

Condition	Uniform Lateral Pressure	Equivalent Fluid Weight	Factor of Safety
Allowable – Seismic	1000 psf	450 pcf	1.5
Ultimate	1500 psf	675 pcf	1

Passive resistance can be applied over two (horizontal) pier diameters starting at the "top of passive resistance" elevations shown in the following table below.

Top of Passive Resistance

Retention Zone	Passive Resistance Zone Location (Elevation)
A1	Below +860 feet
A2	Below +850 feet
B1	Below +850 feet
B2	Below +850 feet

All piers should be designed to extend at least 10 feet below the top of passive resistance zone elevations shown in the above table. AKA should observe during pier drilling to check that adequate penetration into "in-place" bedrock is achieved.

Passive resistance should be reduced for piers in Zones A1 and A2 when evaluating resistance to the landslide shear load (Section 8.02.3), which is in the direction of the pier group alignment. We recommend using 60 percent of the total passive resistance (Pmultiplier = 0.6) to account for group effects for this load case.

8.03.3 Drilled Pier Axial Capacity

Drilled piers can be designed to resist axial loads through skin friction in soil and bedrock. We recommend that any contribution to axial capacity from end bearing in bedrock be ignored due to difficulties associated with obtaining and confirming adequate cleanout at the bottom of pier holes. For the portion of the pier that is within bedrock, skin friction should be applied over the full pier diameter. For the portion of the pier within the retained zone (i.e., above bedrock) skin friction can be applied over one-half of the pier diameter. We recommend that skin friction above the uppermost row of tiebacks be ignored. The axial capacity of drilled piers can be evaluated using the skin friction values presented in the following table:

Drilled Piers – Skin Friction in Soil and Bedrock

Condition	Skin Friction in Soil*	Skin Friction in Bedrock	Factor of Safety
Allowable – Static	750 psf	1500 psf	2.0
Allowable – Seismic	1000 psf	2000 psf	1.5
Ultimate	1500 psf	3000 psf	1

*Can be applied over ½ pier diameter below upper row of tiebacks

For design purposes, the bedrock surface should be taken as the bottom of the retention zone (Elevation +860 feet in Zone A and Elevation +850 feet in Zones B1 and B2). We recommend that design assumptions regarding bedrock support be checked during pier drilling based on the subsurface conditions encountered.

8.03.4 Drilled Pier Installation

It is the drilled pier contractor's responsibility to verify that no utilities or other subsurface elements to be protected are present at planned pier hole locations prior to the start of pier drilling. All of the drilled pier contractor's onsite activities should be performed in strict accordance with the applicable LBNL restrictions, regulations, protocols and guidelines.

Holes for drilled piers and soldier piles should be drilled straight and plumb (within 1 percent of vertical) and should be cleaned of loose soil and rock fragments. We judge that the holes can likely be drilled using heavy auger drilling equipment; however, zones of relatively hard rock could be encountered. The contractor should be prepared to utilize suitable hard rock drilling techniques, if necessary. The contractor should also anticipate that drilling for piers could encounter subsurface materials that may cave or squeeze (e.g. granular drainage materials, fractured bedrock and/or soft clays) and should be prepared to case pier holes or drill using slurry, as appropriate.

Concrete placement should start as soon as possible after the drilling and cleanout is complete. In all cases, holes for drilled piers should be concreted on the day they are drilled. Following placement of the reinforcing steel, holes should be concreted from the bottom up in a single operation. If water or slurry is present in the hole, tremie methods should be used; the tremie pipe should be constantly maintained at least 5 feet below the surface of the concrete during casting of the pier. As the concrete is placed, any casing used to stabilize the hole should be withdrawn. The bottom of the casing should be maintained not more than 5 feet or less than 1 foot below the surface of the concrete. The tops of the pier holes should be vibrated as concrete placement is completed.

Drilled piers should be installed by a qualified drilling contractor with demonstrated experience on projects of similar complexity and scale. We recommend that AKA observe during pier installation to confirm that subsurface conditions are as anticipated and that the drilled piers are constructed in accordance with the recommendations presented in this report.

8.04 Tiebacks

8.04.1 Basis of Tieback Recommendations

High-capacity multi-strand anchors (tiebacks) will be installed that will extend through the landslide materials a minimum distance into in-place bedrock. As shown on the December 2009 preliminary plans, up to three tiebacks will be installed, per pier. Each tieback array will be vertically splayed to provide suitable anchorage; the arrays being oriented in a manner so as to not intersect the existing piers that underlie Buildings 85 and 85A. Tiebacks will be locked off at a fraction of their "design" load, which will be determined, in part, based on the recommendations previously presented in Section 8.02 (Earthquake-Induced Landslide Loads). Special procedures (spacers) will be employed to appropriately "set" the wedges for strand anchors, after which the spacers will be removed to slacken the anchors to achieve the specified lock-off criteria.

8.04.2 Tieback Design

The tieback contractor should be responsible for providing tiebacks that meet all of the requirements specified by the project Design Engineer. These requirements should include (but not necessarily be limited to) the following:

1. All tiebacks should be appropriately protected to resist corrosion. We recommend that strand anchors be equipped, from the factory, with double corrosion protection. Appropriate permanent corrosion protection should also be designed and specified for the area of tieback stressing tail and anchorage.

2. All tiebacks should be inclined downward at an angle of at least 10 degrees below the horizontal and should be designed to be anchored within in-place bedrock below the depth of landsliding. All tiebacks should have a bond zone length of at least 20 feet and portions of tiebacks that are not within the anchorage zone should be designed to be unbonded.

3. The contractor should be required to provide tiebacks of the design capacities specified by the project Design Engineer. Design capacities should be confirmed by load testing; the contractor should be responsible for providing additional tiebacks (at no extra cost) for all tiebacks that fail to meet the load test acceptance criteria specified by the project Design Engineer.

4. Tiebacks should be sized so that neither the design load nor test load exceed 80 percent of the guaranteed ultimate tensile strength of the strands.

For preliminary design purposes, the location of the tieback anchorage zone can be estimated using the interpreted elevation contours presented on Figure 15 (Plan View). We recommend that care be exercised if the engineering cross sections shown on Figure 15 are used for this purpose; particularly in the case of engineering Cross Section H-H', which is at a skew angle to the drilled pier alignment. The ultimate skin friction values presented below can be used by the project Design Engineer to preliminarily estimate the lengths of tiebacks post-grouted under pressure.

Post-Grouted Tiebacks – Skin Friction in Bedrock

Condition	Skin Friction	Factor of Safety
Ultimate	4000 psf	1

The above "ultimate" value is intended to be used by the project Design Engineer for the sole purpose of developing preliminary estimates of tieback length. Actual "design" skin friction values should be proposed by the contractor based upon the geotechnical data coupled with experience, judgment and their specific proprietary materials and methods. The tieback contractor should submit, prior to ordering materials, a detailed submittal that includes: (1) their proposed materials methods; and (2) calculations and assumptions used as a basis for their proposed tieback design. AKA and the project Design Engineer should both review the tieback contractor's submittal(s) to check consistency with the intent of the project design and the geotechnical conditions.

8.04.3 Tieback Testing, Lock-Off and Corrosion Protection

All tiebacks should be proof tested by the contractor to verify that they meet the acceptance criteria specified by the Design Engineer. AKA should observe during proof testing to verify that load tests are performed in accordance with the specifications and provide geotechnical consultation and recommendations for any tiebacks that fail to meet the acceptance criteria. During proof testing: (1) the magnitude of the applied test loads should be determined with a calibrated pressure gauge or a load cell; and (2) movements of the end of the tieback should be monitored to the nearest thousandths (0.001) of an inch relative to an independent fixed reference point. Proof test loads should be applied in pre-determined increments in general accordance with the load test procedures outlined in the Post Tensioning Institute's publication "*Recommendations for Prestressed Rock and Soil Anchors.*" Tiebacks that meet the specified acceptance criteria should be permanently locked off in accordance with the requirements specified by the Design Engineer. Following lock-off, appropriate permanent corrosion protection should be provided at the tieback anchorage.

The contractor should be responsible for designing an appropriate load test setup and for the protection of existing improvements and new structural elements (including factory installed corrosion protection) during load testing and lock-off. We recommend that the contractor prepare detailed submittals describing their proposed materials and methods for load testing, lock-off and contractor-installed permanent corrosion protection, which AKA and the project Design Engineer should review prior to the start of load testing.

8.05 Resistive Earth Loads

8.05.1 Basis of Resistive Earth Load Recommendations

We judge that it is permissible to interpret that resistive earth loads may be applied at the face of the retained zones that act in the direction opposite to the movement of Landslides Qls-3 and Qls-4. The resistive earth loads presented in this section are based on the assumptions that: (1) the downslope movement of Landslide Qls-1 will be accompanied by sloughing and back-failures that will partially fill the gap that opens up at the face of the stabilized zones(s); and (2) the high groundwater level assumed in the earthquake-induced displacement/force analyses will result in groundwater being present within the gap to the depth of infilling.

We anticipate, even with what might be viewed as favorable assumptions, the overall effect of resisting earth loads will be small relative to the Design Landslide Load recommendations presented in Section 8.02.2.

8.05.2 Resistive Earth Pressure Distribution

The effects of resistive earth loads can be evaluated using a triangular pressure distribution corresponding to an equivalent fluid weighing 80 pounds per cubic foot (pcf). The 80 pcf value was developed as an active pressure ($K_A \sim 0.3$) with groundwater present up to the top of the infilled soil mass.

$$80 \text{ pcf} = 62.4 \text{ pcf} + 0.3\ (120-62.4 \text{ pcf})$$

For design purposes, the surface of the infilled soil and groundwater can be taken as Elevation +865 feet (in all zones). The resistive earth pressures allowed in this section do not include a factor of safety and should therefore be considered ultimate resistance values.

8.06 Earthwork and Pavements

8.06.1 Basis of Earthwork and Pavement Recommendations

The existing sitework that surrounds Buildings 85 and 85A includes asphalt concrete (AC) pavement; a Portland cement concrete (PCC) pavement and a complex array of existing subsurface utilities. The installation of drilled piers and tiebacks will require that certain elements be removed and replaced, whereas any critical elements will need to be protected throughout the period of construction. On this basis, we anticipate that the geotechnical aspects of the project will include: (1) removing and replacing pavements; (2) excavating and replacing soil; and (3) removing and re-routing subsurface utilities. The recommendations presented in this Section are generally based on the assumption that the existing pavements and underlying subgrade materials can essentially be replaced "in-kind" and that new designs for AC or PCC pavements will not be included in the contract documents. In addition, we have assumed that any "special" requirements involving pavements, excavations, subsurface utilities, underslab barriers, stockpiling/disposal of excavated materials, health/safety and the like will be provided directly to the project design team by LBNL.

8.06.2 Site Preparation

Prior to the cutting and removal of existing pavements, all active subsurface utilities in and immediately surrounding the construction area should be located and marked. Any utilities to be protected as well as any utilities that are found to exist at locations not shown on the project plans should be clearly identified and brought to the attention of the project Design Engineer (in writing). It is the contractor's responsibility to protect any and all existing subsurface utilities not specifically designated for removal throughout the period of construction.

Pavements, aggregate base, slabs-on-grade, curbs, gutters, and other near-surface improvements within the area designated for excavation and/or pier drilling should be removed. Any soils within these areas containing vegetation or organic matter should be stripped. Stripped materials are not suitable for re-use as engineered fill and should be removed from the site. Pavements, aggregate base, broken concrete, and other cleared improvements should be removed from the site or stockpiled for later use, subject to the approval of AKA and LBNL.

8.06.3 Excavation

Site excavations should be performed in accordance with the design drawings and any additional requirements set forth by LBNL. AKA should observe during excavations to check that subsurface conditions are as anticipated and to assist in the identification and segregation of excavated materials that are considered unsuitable for re-use as engineered fill. Soil subgrades within excavated areas that will support construction equipment (e.g. tieback drilling equipment) should be: (1) protected throughout the period prior to backfilling; and/or (2) overexcavated to expose firm undisturbed soil prior to backfilling. The cost of any additional excavation and fill placement needed to remediate soil subgrades disturbed by the contractor's activities should be borne by the contractor.

Excavation cuts deeper than 4 feet will need to be laid back or shored in accordance with Cal-OSHA requirements. Temporary shoring will be required where safe cutback slopes are not possible, or where the protection of adjacent utilities, structures or other improvements is necessary. Temporary dewatering may also be needed depending upon the depths of planned excavations, groundwater conditions and runoff. The design, installation and maintenance of temporary slopes, shoring and dewatering and the protection of workers, utilities and adjacent improvements during construction are responsibilities of the contractor.

We recommend that the contractor document the location and condition of nearby buildings, pavements, and utilities in as thorough a manner as is practical prior to the commencement of site excavation. The contractor should also perform regular and frequent surveys during excavation and construction to monitor and document any observed settlement or deflection of nearby utilities, structures or other site improvements.

8.06.4 Fill Materials

General fill can be used as engineered fill, except where non-expansive fill is specifically required. General fill material should have an organic content of less than 3 percent by volume and should not contain rocks or lumps larger than 6 inches in greatest dimension. The soil and rock obtained from site excavations are generally suitable for re-use as fill provided that they meet, or can be processed (i.e., by crushing and/or blending) to meet the requirements for general fill.

Non-expansive fill material should conform to the following requirements:

- Have an organic content of less than 3 percent, by volume;
- Be generally free of rocks or lumps larger than 6 inches in greatest dimension;
- Have a Plasticity Index of 12 or less; and
- Have a Liquid Limit of 40 or less.

Non-expansive fill can be comprised of: (1) onsite materials that meet or can be processed to meet the above requirements; or (2) import materials that meet the above requirements and are free of environmental contaminants. All proposed fill materials should be approved by AKA prior to their use; import material should be evaluated by our firm prior to its importation to the site.

8.06.5 Fill Placement

The upper 18 inches of fill beneath pavements and slabs-on-grade should be comprised of non-expansive fill material. Any aggregate base or drain rock beneath the pavement/slab section can be considered part of the 18-inch non-expansive layer.

Areas to receive fill should be generally firm and non-yielding and fill should be placed in layers such that the surface of each layer is nearly level. We recommend that fill be spread in uniform layers not exceeding 8 inches in loose thickness and compacted using mechanical means in a uniform and systematic manner based on the following requirements (per ASTM D-1557 Test Methods):

- Predominantly cohesive general fill materials should be moisture conditioned to at least 3 percent over optimum moisture content and compacted to between 90 and 95 percent relative compaction.

- Predominantly cohesive non-expansive fill should be moisture conditioned to above optimum moisture content and compacted to at least 90 percent relative compaction.

- Low cohesion (predominantly granular) fill materials should be moisture conditioned to near optimum moisture content and compacted to at least 95 percent relative compaction.

- The upper 12 inches of non-expansive fill directly beneath the pavement/slab/aggregate section should be compacted to at least 95 percent relative compaction.

AKA should observe during construction to check that: (1) subgrades to receive fill are firm and non-yielding; and (2) engineered fill is appropriately placed and compacted in accordance with our geotechnical recommendations.

8.06.6 Utility Trenches

Utility trenches should be backfilled with fill placed in lifts not exceeding 8 inches in uncompacted thickness. Trenches should be filled by placing a granular shading layer beneath and around the pipe, and then 6 to 12 inches of shading should be carefully placed and tamped above the pipe. The remaining portion of the trench should be backfilled with onsite or import soil. The backfill (above shading layers) should be placed and compacted to a minimum relative degree of compaction of 90 percent based on ASTM D-1557; predominantly granular backfill materials should be compacted to at least 95 percent relative compaction. The compaction requirements given above should be considered minimum recommended requirements. If LBNL, manufacturer, and/or utility company specifications require more stringent backfill requirements, those specifications should be followed.

If imported granular soil is used, sufficient water should be added during the trench backfilling operations to prevent the soil from "bulking" during compaction. All compaction operations should be performed by mechanical means only. We recommend against jetting.

Where granular backfill is used in utility trenches, we recommend an impermeable plug or mastic sealant be used where utilities enter the building to minimize the potential for free water or moisture to enter below the building. Finally, we recommend the contractor carefully evaluate the stability of all trenches and use temporary shoring, where appropriate. The design and installation of the temporary shoring should be wholly the responsibility of the contractor. In addition, all LBNL regulations governing safety around such excavations should be carefully followed.

8.07 Future Geotechnical Services

8.07.1 Design Consultation and Plan Reviews

We recommend that we continue to provide geotechnical consultation to LBNL and the project team during the design phase in order to: (1) check that the design recommendations presented in this report are appropriately incorporated into the project plans and specifications; and (2) provide supplemental geotechnical recommendations, as needed. We recommend that we review the project plans and specifications as they are being developed so that we may provide timely input. We should also perform a general review of the geotechnical aspects of the final plans and specifications, the results of which we should document in a formal plan review letter.

8.07.2 Review of Contractor Requests and Submittals

During the bidding and construction phases, we should review all Requests for Clarification (RFCs) and Requests for Information (RFIs) that are geotechnical in nature. We recommend that we also review all geotechnical submittals from the contractor, including (but not necessarily limited to) those pertaining to drilled piers, tiebacks, excavation, subsurface utility installations and geotechnical materials.

8.07.3 Construction Observation and Testing

The analyses and recommendations submitted in this report are based in part upon the data obtained from our geologic mapping, test borings and data review. These analyses rely upon direct observations of surface conditions and discrete data points; the nature and extent of subsurface variations may therefore not become evident until construction. If variations then become apparent, it will be necessary to re-examine the recommendations of this report.

It is critical that we be retained to provide geotechnical engineering services during the construction phases of the work in order to observe compliance with the design concepts, specifications, and recommendations and to allow design changes in the event that subsurface conditions differ from those anticipated prior to the start of construction. The scope of our construction-phase observation and testing services should include (but not necessarily be limited to) site preparation, excavation, drilled pier installation, tieback installation and testing, pavement and slab-on-grade subgrade preparation, aggregate base, and utility installation.

9.00 LIMITATIONS

This report has been prepared for the exclusive use of LBNL and their consultants for specific application to the proposed Building 85 Slope Stabilization Project in accordance with generally accepted soil and foundation engineering practices. No other warranty, expressed or implied, is made. Note that the findings presented in this report are based, in part, upon data collected by previous investigators. We cannot accept responsibility for the accuracy of the data obtained from others or (consequently) for interpretations that we have made based on existing available data. In the event that any changes in the nature or design of the project are planned, the conclusions and recommendations contained in this report should not be considered valid unless the changes are reviewed and the conclusions of this report are modified or verified in writing.

The findings of this report are valid as of the present date. However, the passing of time will likely change the conditions of the existing property due to natural processes or the works of man. In addition, due to legislation or the broadening of knowledge, changes in applicable or appropriate standards may occur. Accordingly, the findings of this report may be invalidated, wholly or partly, by changes beyond our control. Therefore, this report should not be relied upon after a period of three years without being reviewed by this office.

10.00 REFERENCES

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10.02 <u>Consulting Reports</u>

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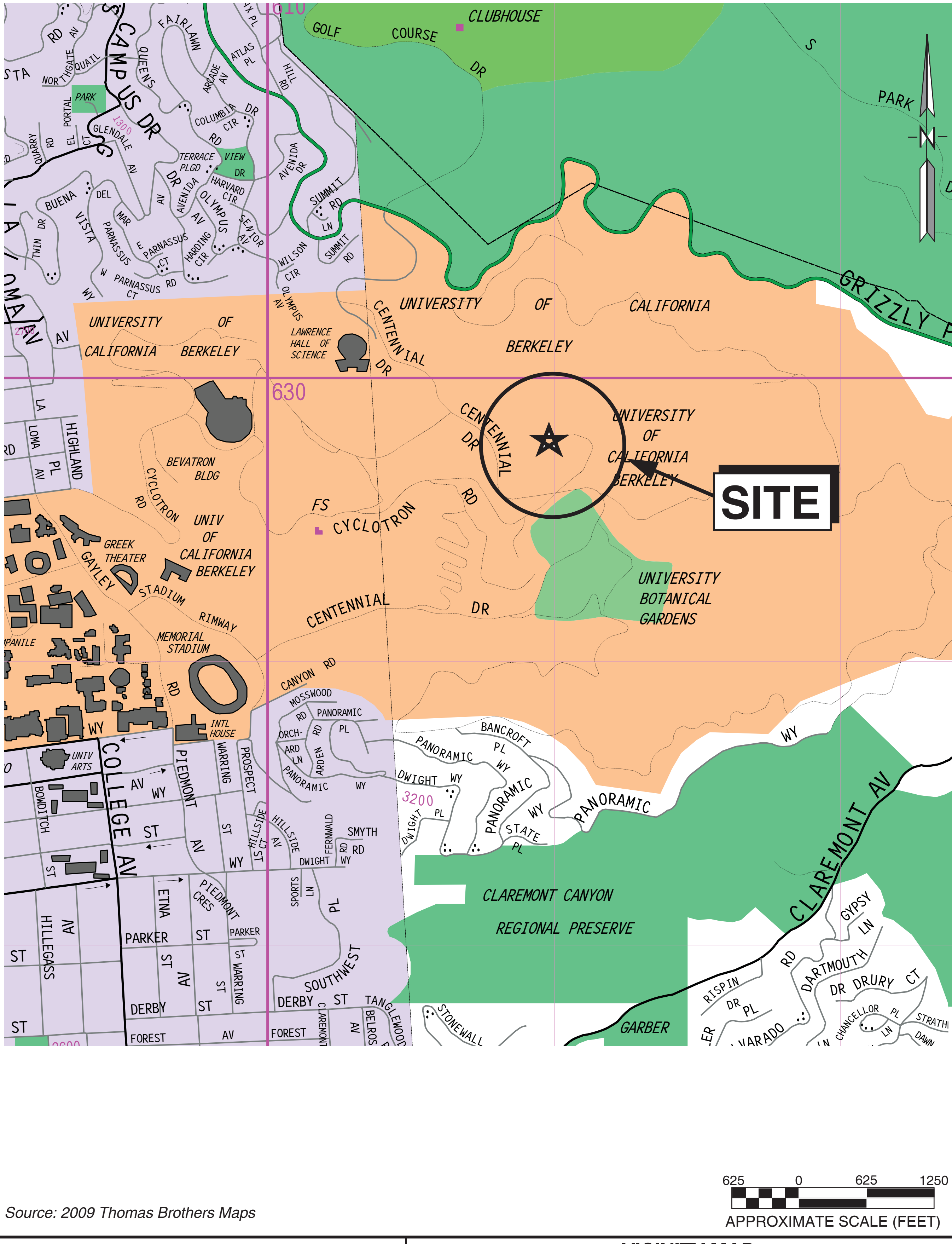
10.03 Aerial Photographs

Type	Date	Scale	Photo No.	Source
Black and White,	08/02/39	1:20,000	BUT-BUU-289-67, 68	United States Soil Stereo Pair Conservation Service



Source: 2009 Thomas Brothers Maps

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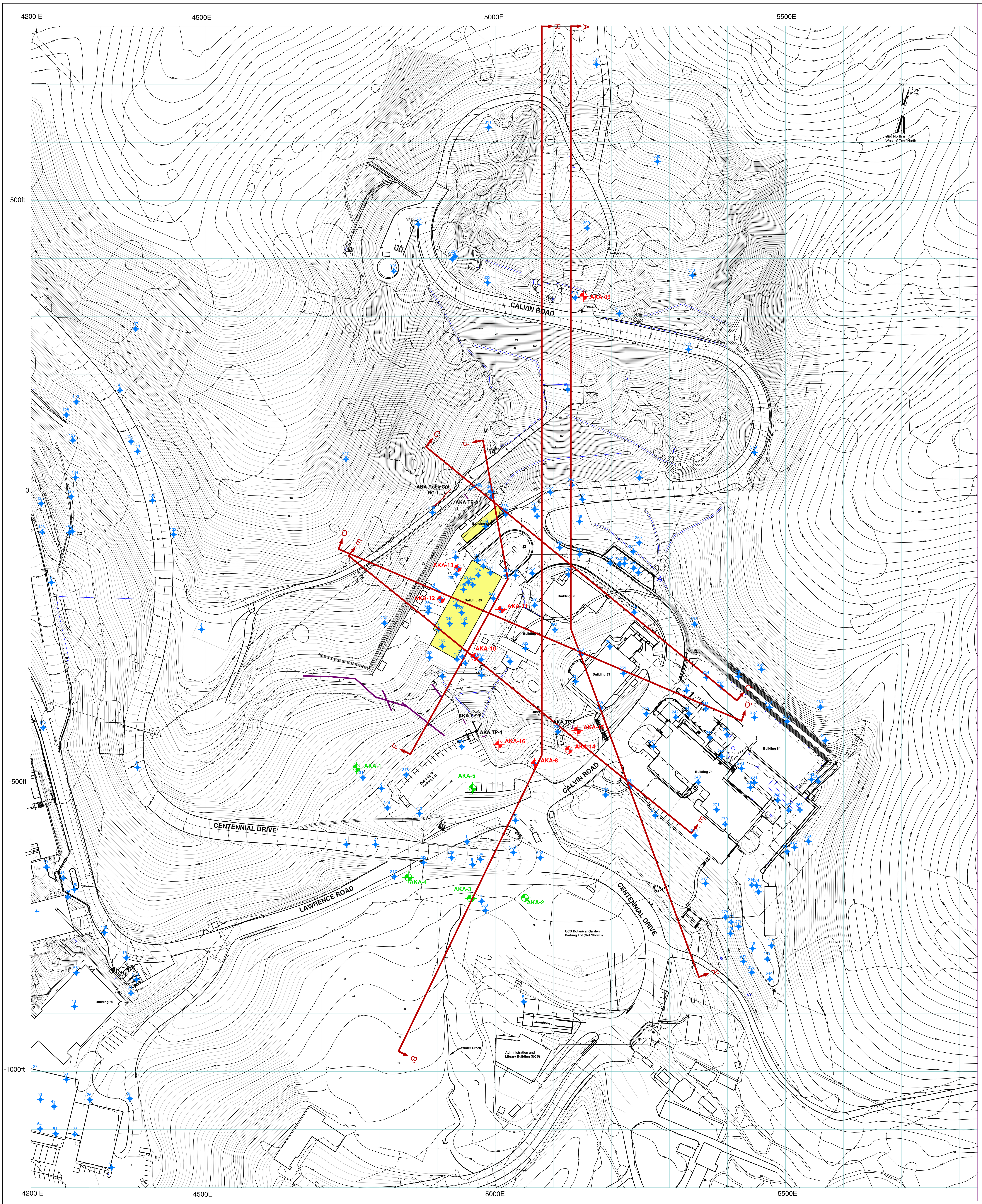
Geotechnical Consultants

VICINITY MAP		
LBNL BUILDING 85 Berkeley, California		
PROJECT NO.	DATE	FIGURE 1
2335-7B	April 2010	



LEGEND

- AKA-1 (red) — Approximate location of boring by Alan Kropp and Associates (Current Study - Appendix A)
- AKA-1 (green) — Approximate location of boring by Alan Kropp and Associates in 2009 (Cenntennial Drive Study)
- TP-1 — Approximate location of test pit by William Lettis and Associates (Current Study - Appendix B)
- RC -1 — Approximate location of rock cut by William Lettis and Associates in 2009 (Current Study - Appendix B)
- 234 — Approximate location of previous boring or slope indicator with GIS identification number
- A A' — Approximate location of cross-section
- T99 — Approximate location of previous exploratory trench with GIS identification number

25 0 50 100
APPROXIMATE SCALE FEET

Base: "q196.dwg," "q197.dwg," "q174.dwg," "q175.dwg," "q152," "q153.dwg," received from LBNL October 2008.

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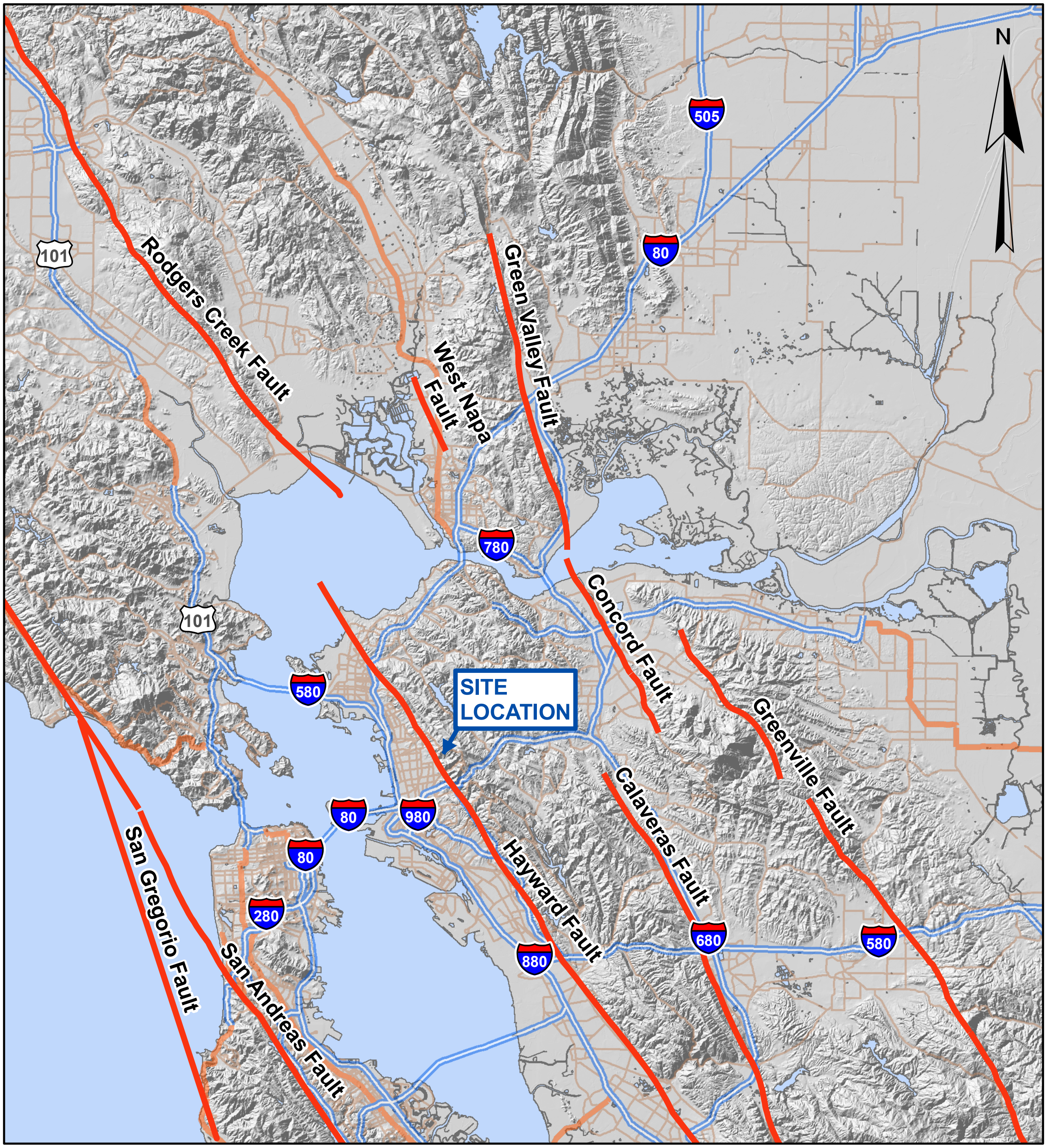
SITE PLAN		
LBNL BUILDING 85 Berkeley, California		
PROJECT NO.	DATE	FIGURE 2
2335-7B	April 2010	



LEGEND

"Active" Regional Faults (Surface Displacement within the Last 11,000 years)

0 5 10 20 Miles

Sources: 1) The California Geological Survey, 2001, CD's 2001-04, 2001-05, and 2001-06: GIS Files of Official Alquist-Priolo Earthquake Fault Zones (http://www.consrv.ca.gov/CGS/geologic_hazards/regulatory_hazard_zones/ap_cd_htm.htm).
2) Jennings, 1994, "Fault Activity Map of California and Adjacent Areas," CDMG, Geologic Data Map No. 6
3) California Division of Mines and Geology, 1997, "Maps of Known Active Fault Near-Source Zones in California and Adjacent Portions of Nevada."
4) Background data: USGS 10m DEM.

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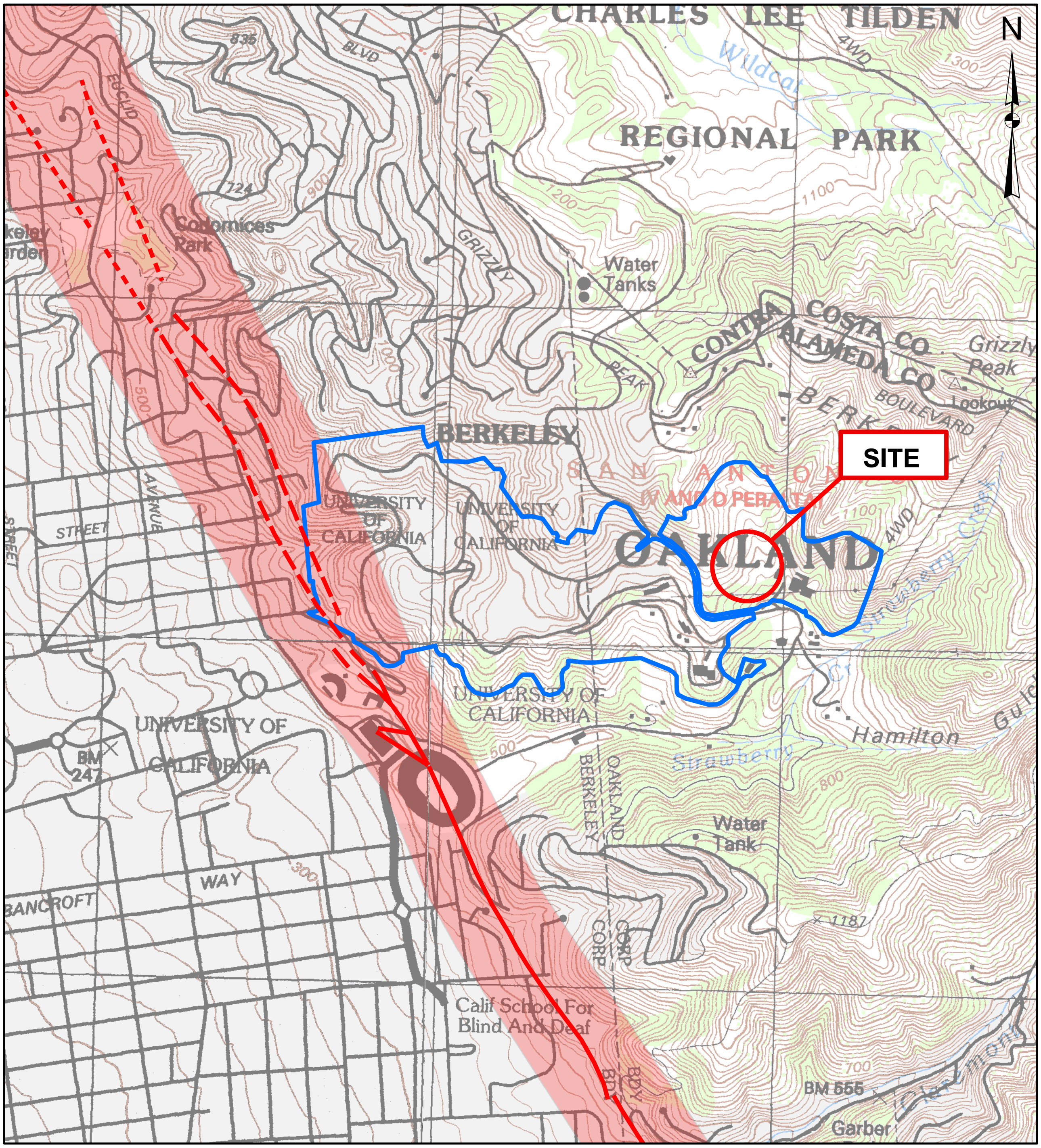
REGIONAL FAULT MAP		
LBNL BUILDING 85 Berkeley, California		
PROJECT NO.	DATE	FIGURE 3
2335-7B	**April 2010**	



LEGEND

Approximate location of LBNL site boundary

Source: The California Geological Survey, 2001, CD's 2001-04, 2001-05, and 2001-06: GIS Files of Official Alquist-Priolo Earthquake Fault Zones (http://www.consrv.ca.gov/CGS/geologic_hazards/regulatory_hazard_zones/ap_cd_htm.htm).

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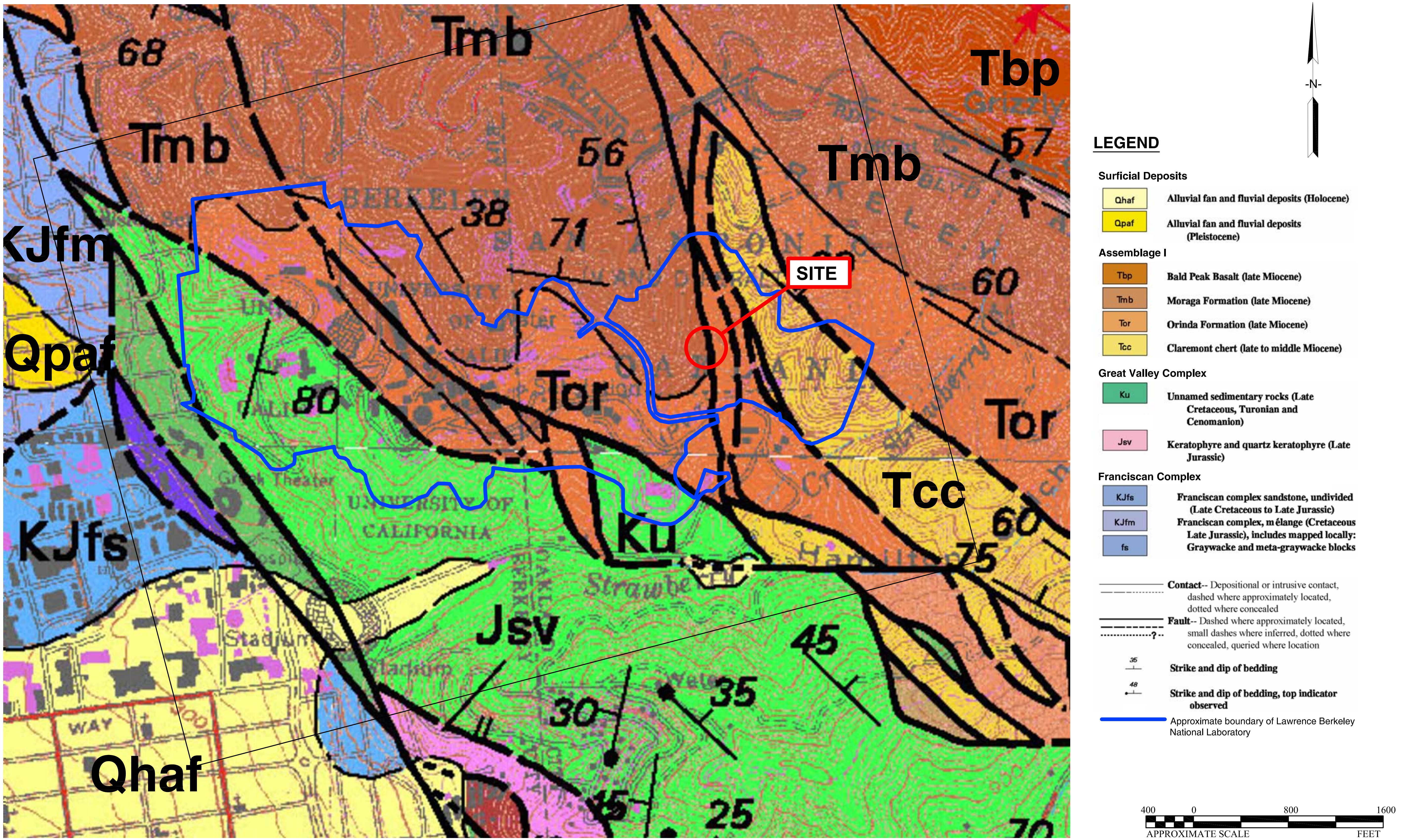
AP FAULT ZONE MAP		
LBNL BUILDING 85 Berkeley, California		
PROJECT NO.	DATE	FIGURE **4**
2335-7B	**April 2010**	



Base: "Geologic Map and Map Database of the Oakland Metropolitan Area, Alameda, Contra Costa and San Francisco Counties, California" by Graymer, R.W., U.S. Geological Survey, Miscellaneous Field Studies MF-2342, 2000.

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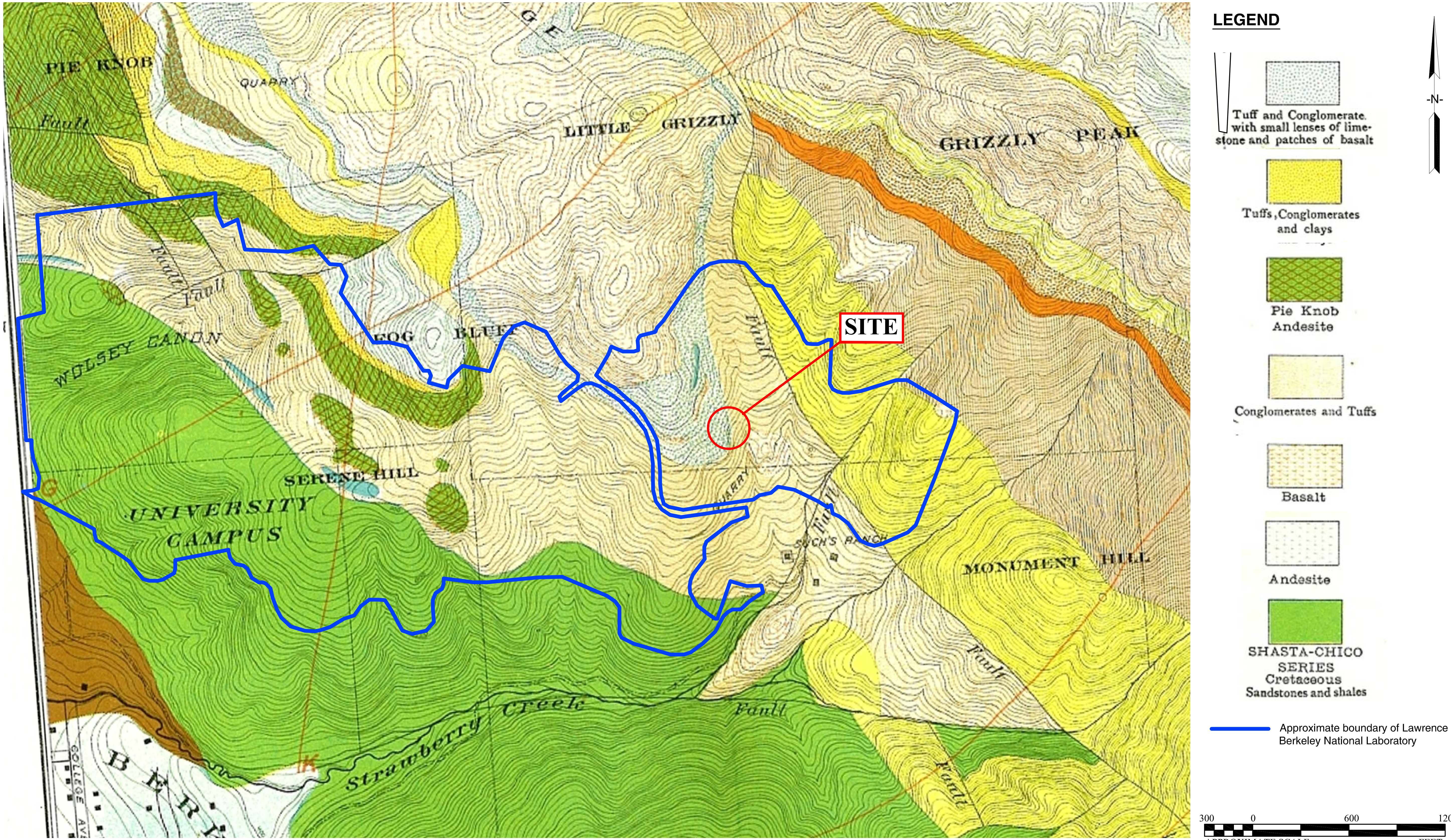
REGIONAL GEOLOGIC MAP

LBNL BUILDING 85
Berkeley, California

PROJECT NO.	DATE	FIGURE 5
2335-7B	**April 2010**	



Base: *"Berkeley Hills Geologic Map," by Lawson & Palache, dated 1901.*

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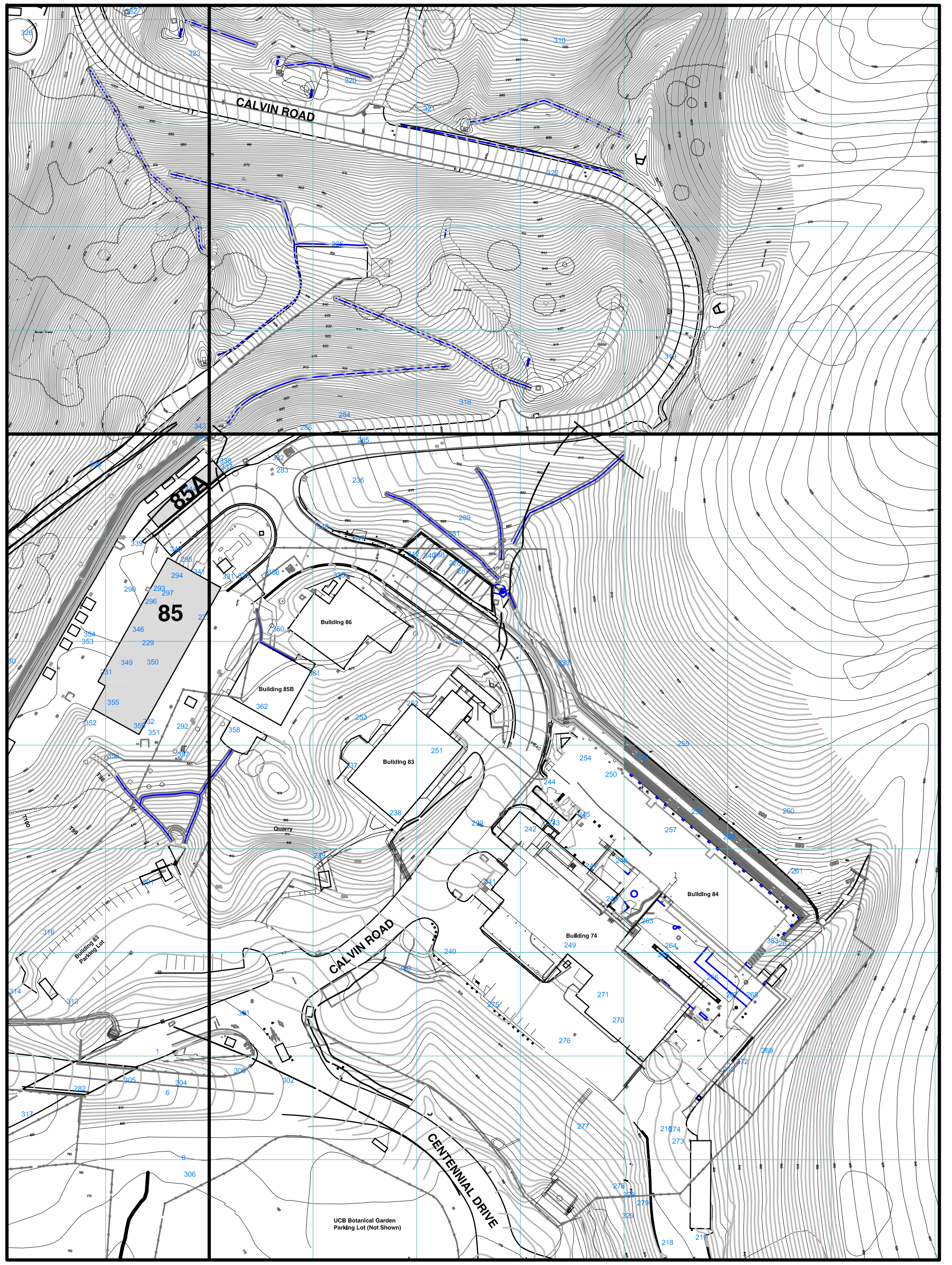
HISTORIC GEOLOGIC MAP

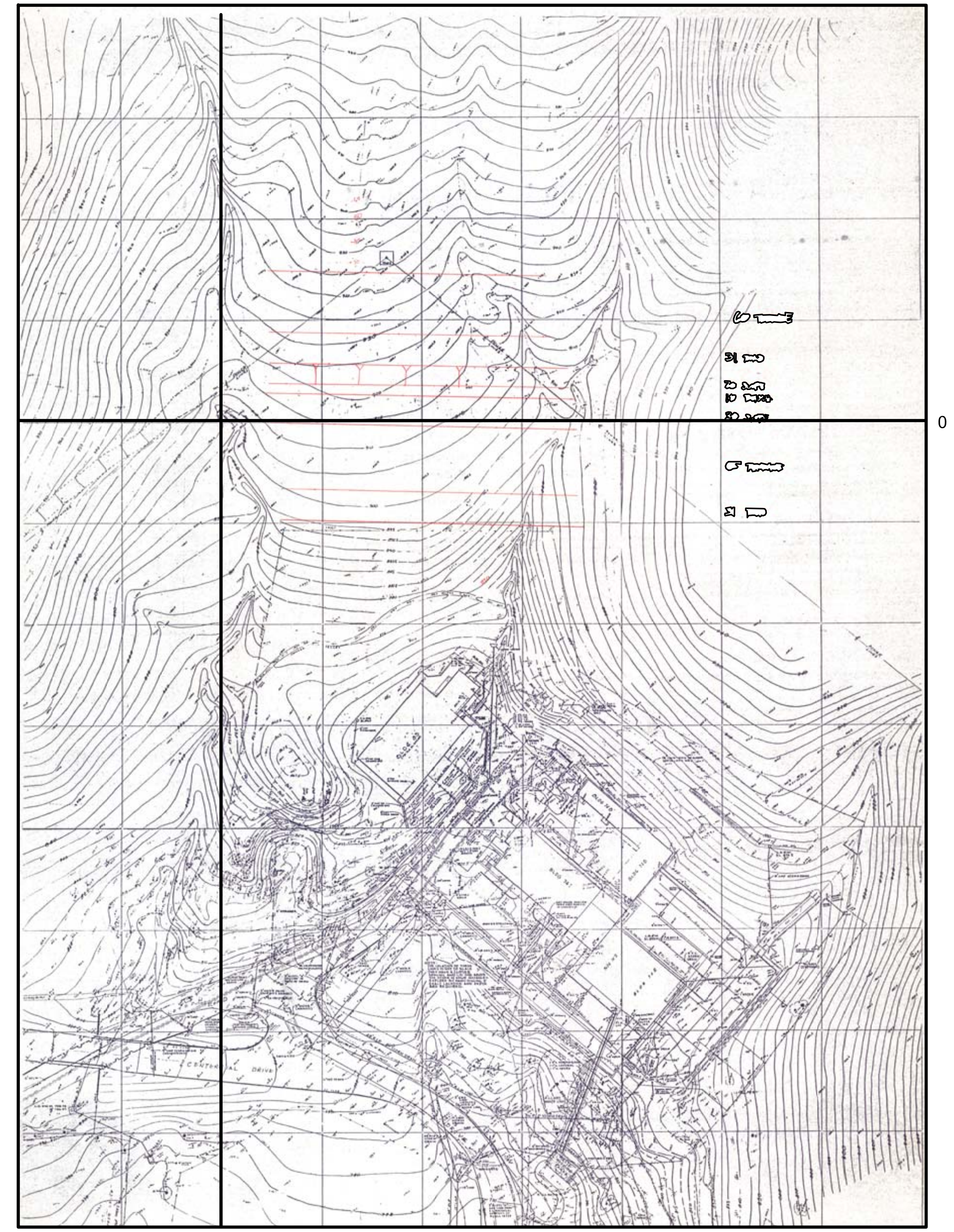
LBNL BUILDING 85
Berkeley, California

PROJECT NO.	DATE	FIGURE 6
2335-7B	**April 2010**	



Current Topography

Base: "q196.dwg," "q197.dwg," "q174.dwg," "q175.dwg," "q152," "q153.dwg," received from LBNL October 2008.



Pre-1994 Topography

Base: Undated LBNL topographic map with redlined notations.

75 0 150 300
APPROXIMATE SCALE FEET

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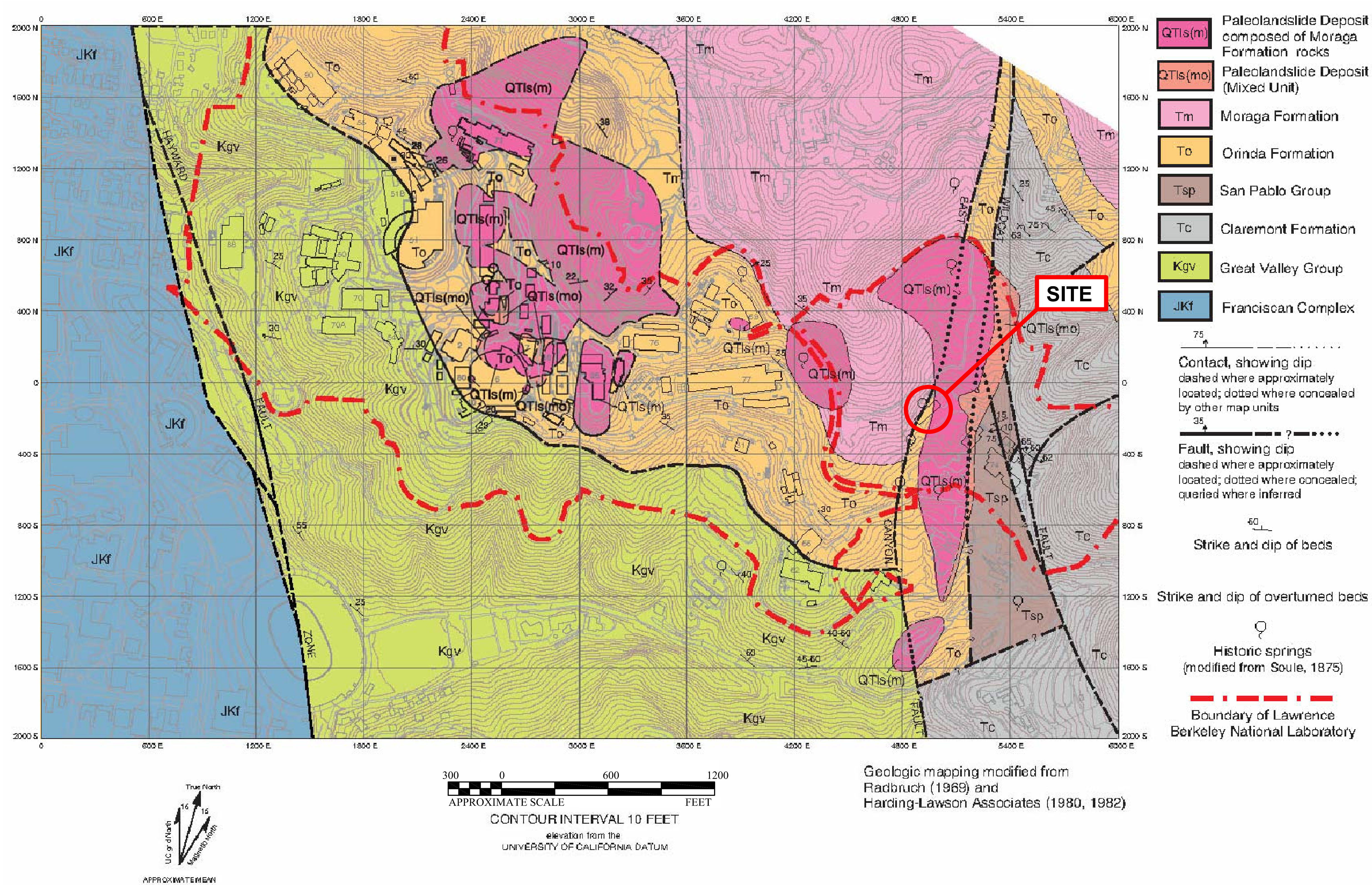
Geotechnical Consultants

EAST CANYON TOPOGRAPHY		
LBNL BUILDING 85 Berkeley, California		
PROJECT NO. **2335-7B**	DATE **April 2010**	FIGURE **7**



Geologic mapping modified from Radbruch (1969) and Harding-Lawson Associates (1980, 1982)

Base: "Bedrock Geologic Map, Lawrence Berkeley National Laboratory," Figure A2.1-2, by Lawrence Berkeley National Laboratory, dated 9/27/2000.

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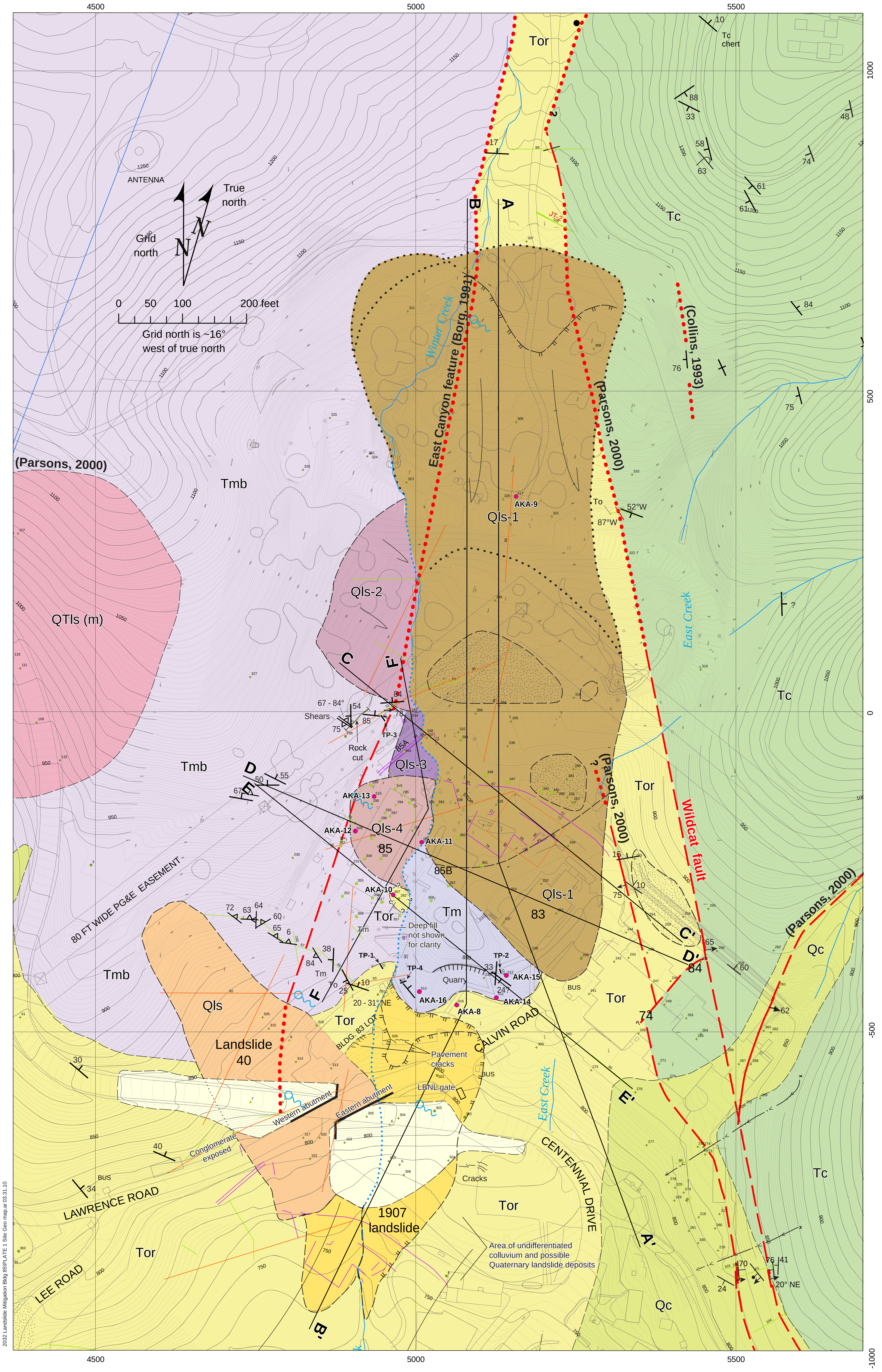
RFI GEOLOGIC MAP

LBNL BUILDING 85
Berkeley, California

PROJECT NO.	DATE	FIGURE
2335-7B	**April 2010**	**8**



Explanation

Unit Descriptions

- Fill
- Qc — Quaternary colluvium/alluvium
- QTls(m) — Moraga paleolandslide unit
- Tmb — Miocene Moraga Formation (volcanics)
- Tor — Miocene Orinda Formation (sandstone-siltstone conglomerate)
- Tc — Miocene Claremont Formation (chert-shale)

- Repaired landslide
- 1907 landslide
- Landslide 40
- Qls-1 - Quaternary landslide deposits
- Qls-2- Quaternary landslide deposits
- Qls-3- Quaternary landslide deposits
- Qls-4- Quaternary landslide deposits

Symbols

- Contour, 10-foot interval (2003)
- Contour, 2-foot interval (2003)
- Contact; dashed where approximate dotted where concealed
- Scarp morphology from 1907 photographs
- ? Fault projected verticle from depth, dashed where approximate, dotted where concealed and uncertain
- 84 Strike and dip of bedding
- Overturned strike and dip
- Fault strike and dip
- 24 Shear
- Syncline
- Anticline
- Buildings, roads, vegetation (2003)
- Spring (Parsons, 2000)
- Stream (LBNL, 2003)

GIS Data Point ID

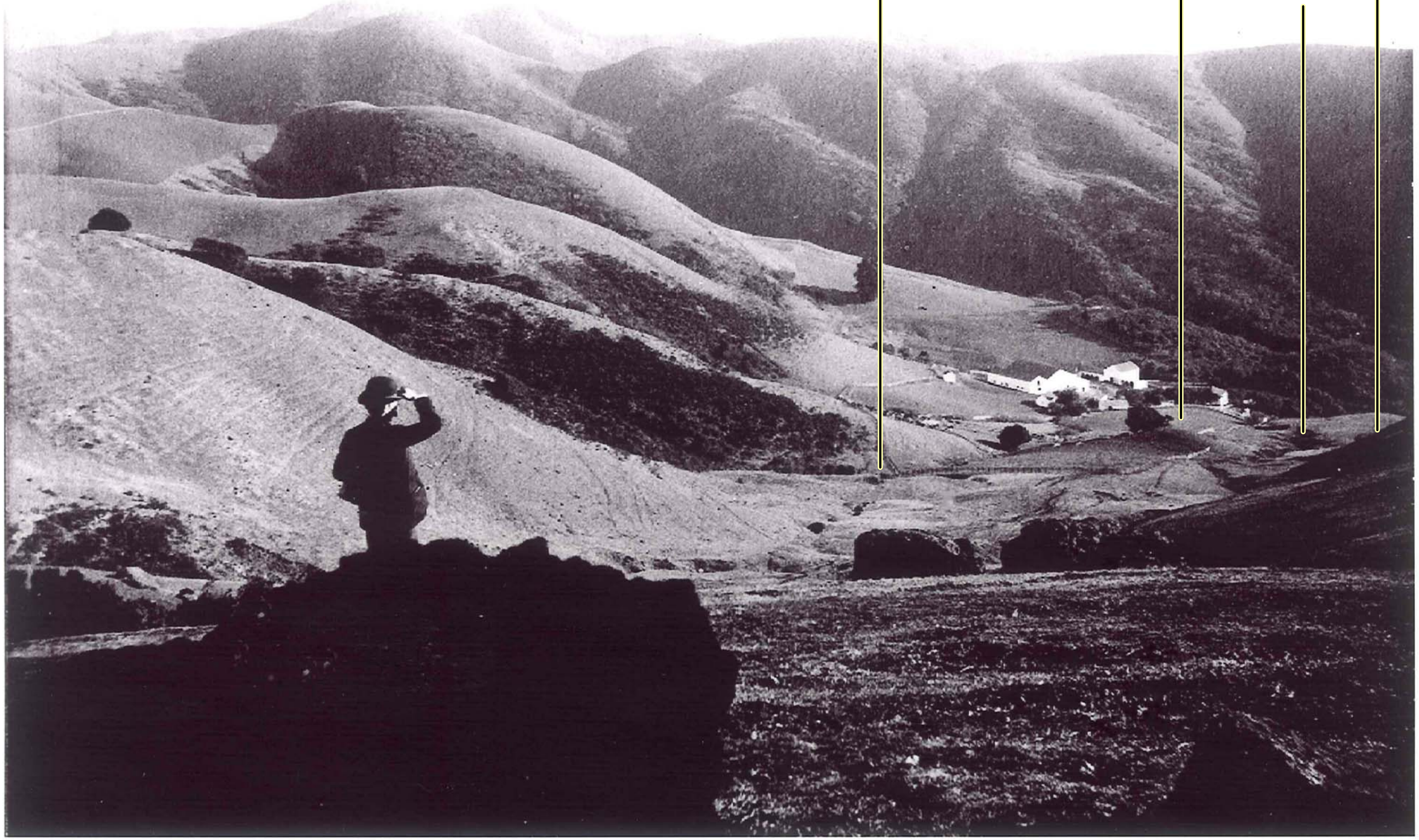
- AKA-8 to AKA-16 — Boring (this study)
- 24 — Boring
- 294 — Pier hole
- 72 — Slope indicator boring
- 4 — Piezometer
- 283 — Monitoring well
- 164 — Well boring
- 352 — Test pit
- 103 — Borehole-hydrograph

GIS Data Line ID

- 60 — Hydrauger
- 34 — Seismic line
- 22 — Trench or test pit
- 72 — Cut wall

Notes: 1. Coordinate system is the University of California Grid system.
2. Mapping is based on field reconnaissance and compilation of previous studies.
3. The location accuracy of all data is only as good as the source location information. Georeferencing error can be as much as +/- 10 feet.

Site Geologic Map
FIGURE 9



Base: *Photograph obtained from Berkeley Historical Society, date uncertain (c. 1900).*

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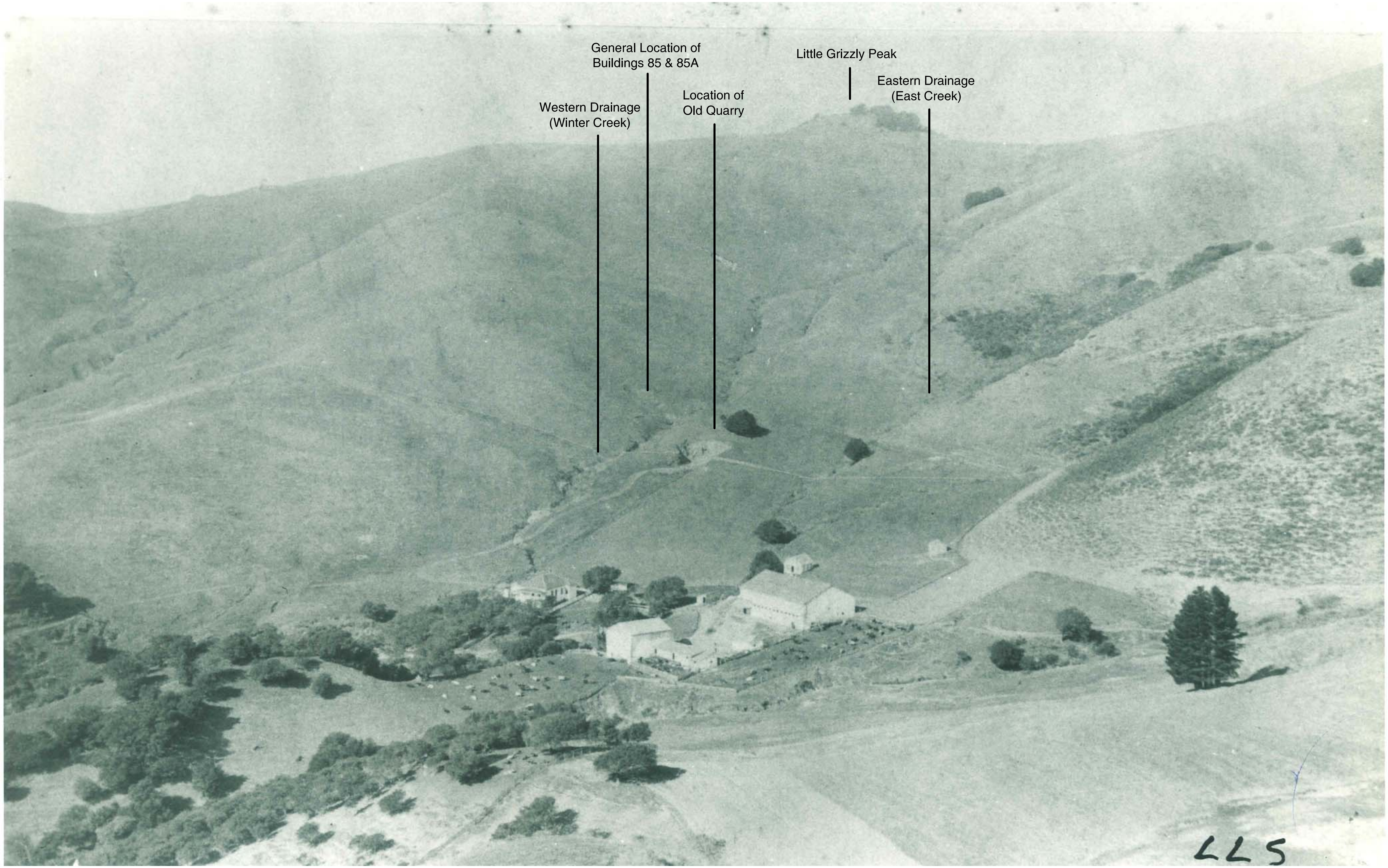
HISTORIC PHOTOGRAPH - LOOKING SOUTHEAST

LBNL BUILDING 85
Berkeley, California

PROJECT NO.	DATE	FIGURE
2335-7B	**April 2010**	**10**



Base: Photograph obtained from Berkeley Historical Society, date uncertain (c. 1903).

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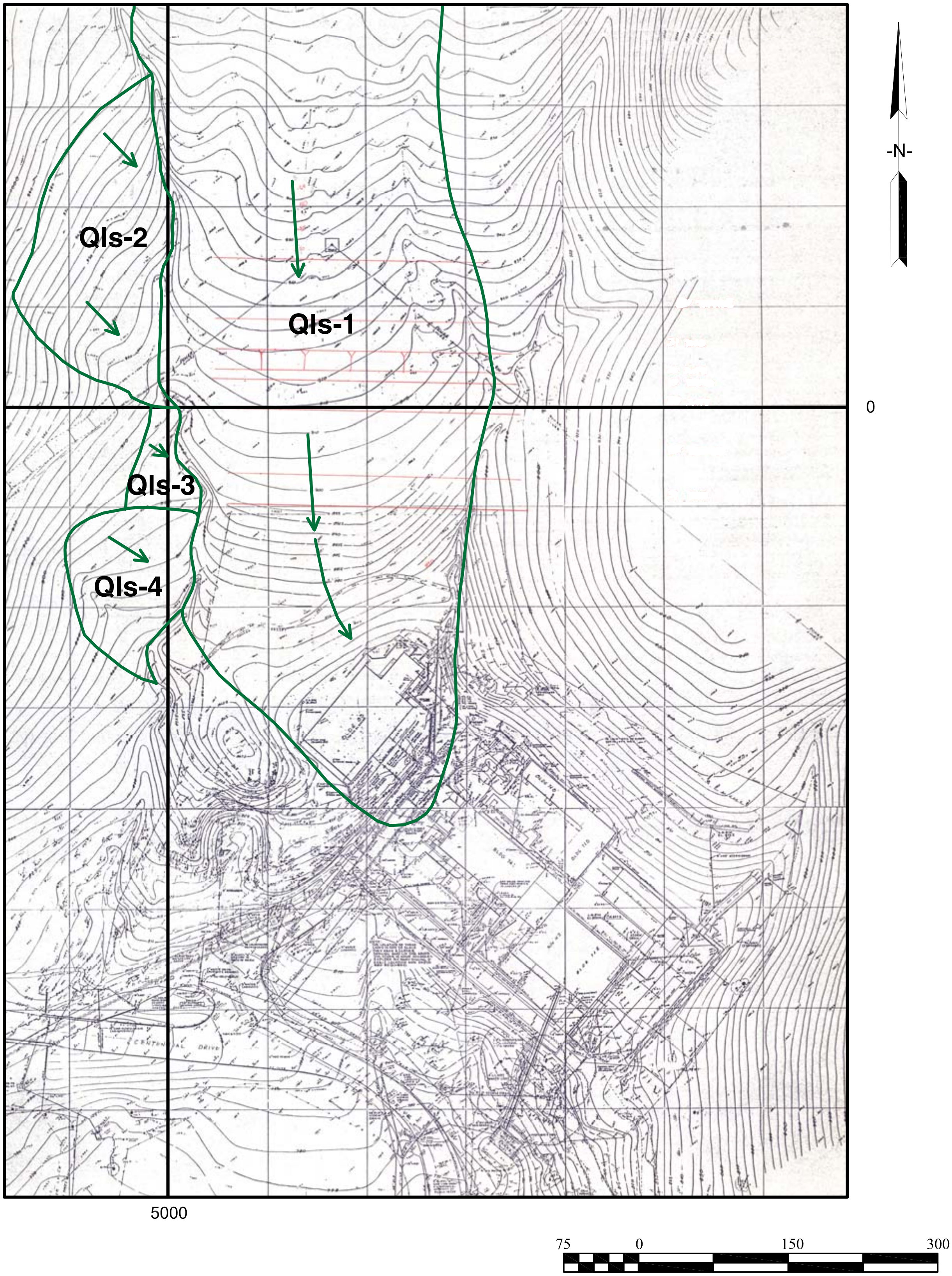
HISTORIC PHOTOGRAPH - LOOKING NORTHWEST

LBNL BUILDING 85
Berkeley, California

PROJECT NO.	DATE	FIGURE 11
2335-7B	**April 2010**	



Base: Undated LBNL topographic map with redlined notations.

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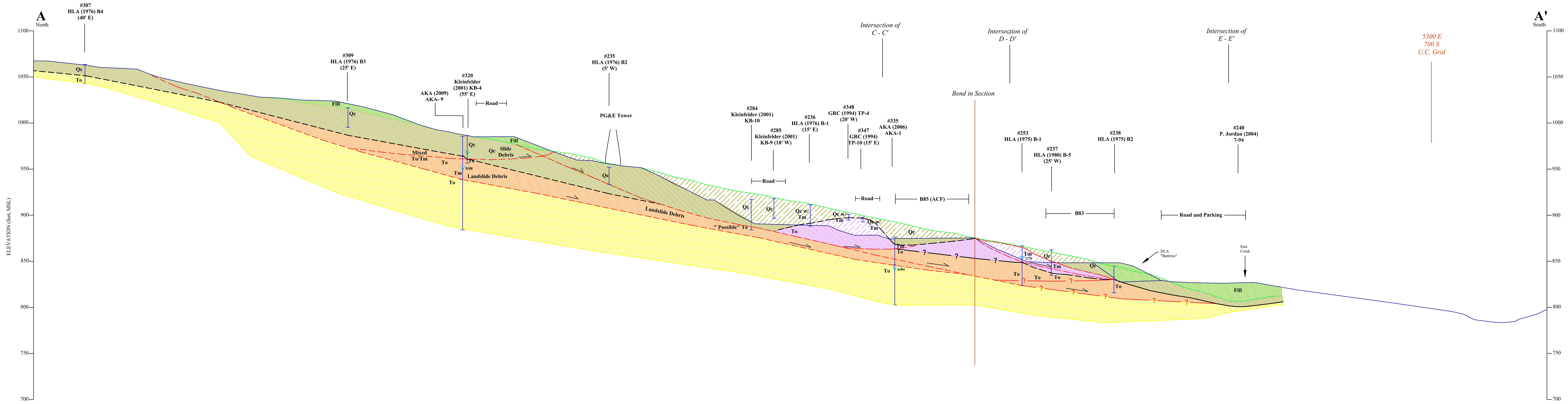
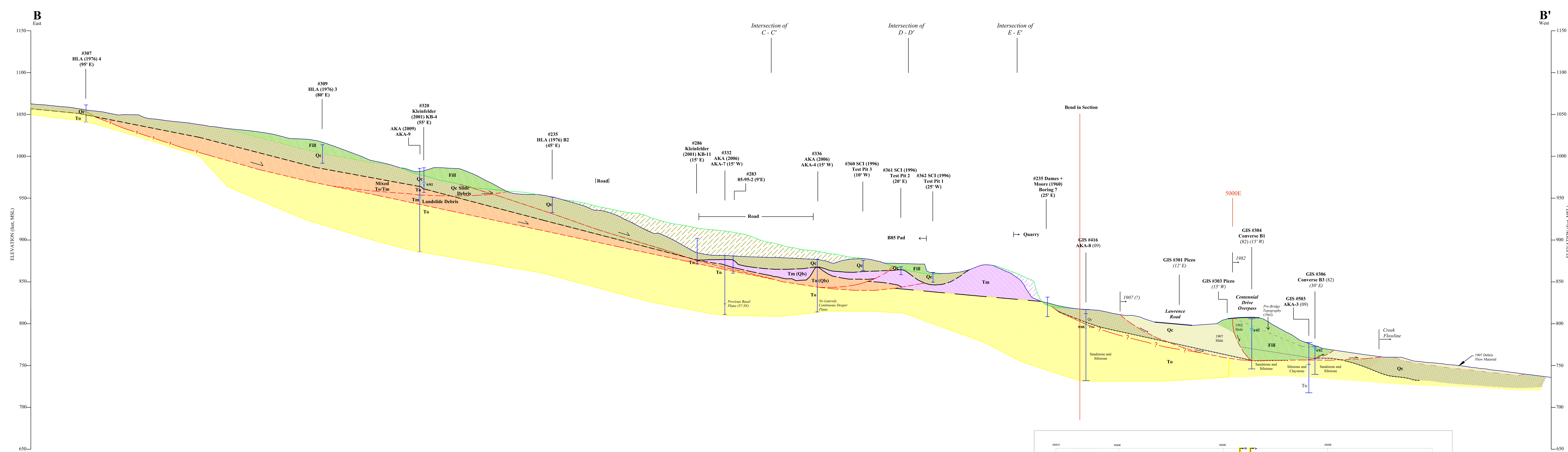
PRE-DEVELOPMENT TOPOGRAPHY WITH LANDSLIDE INTERPRETATION

LBNL BUILDING 85
Berkeley, California

PROJECT NO.	DATE	FIGURE 12
2335-7B	**April 2010**	





CROSS SECTION MAP KEY

LEGEND:

- Current Ground Surface
- Original Ground Surface
- Interpreted Landslide Slip Surface
- Measured Groundwater Level
- Fill
- Qc, Colluvium
- Qc, Colluvium - Removed From Previous Grading
- Qc, Colluvium within (1907 Slide)
- Tm, Moraga Formation - Removed From Previous Grading
- Tm, Moraga Formation
- To / Tm, Orinda - Moraga Formation Mix
- To, Orinda Formation

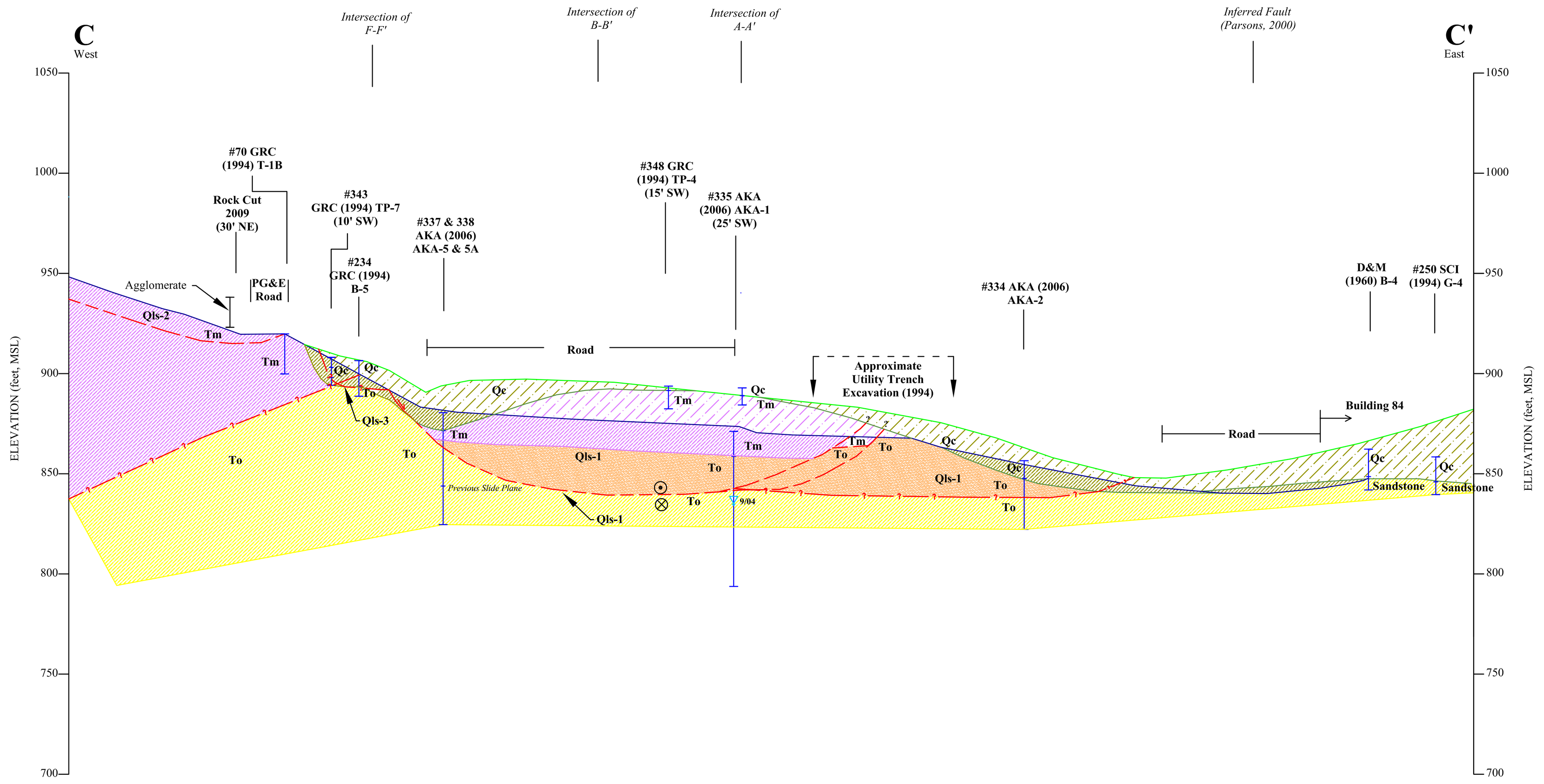
25 0 50 100
APPROXIMATE SCALE FEET

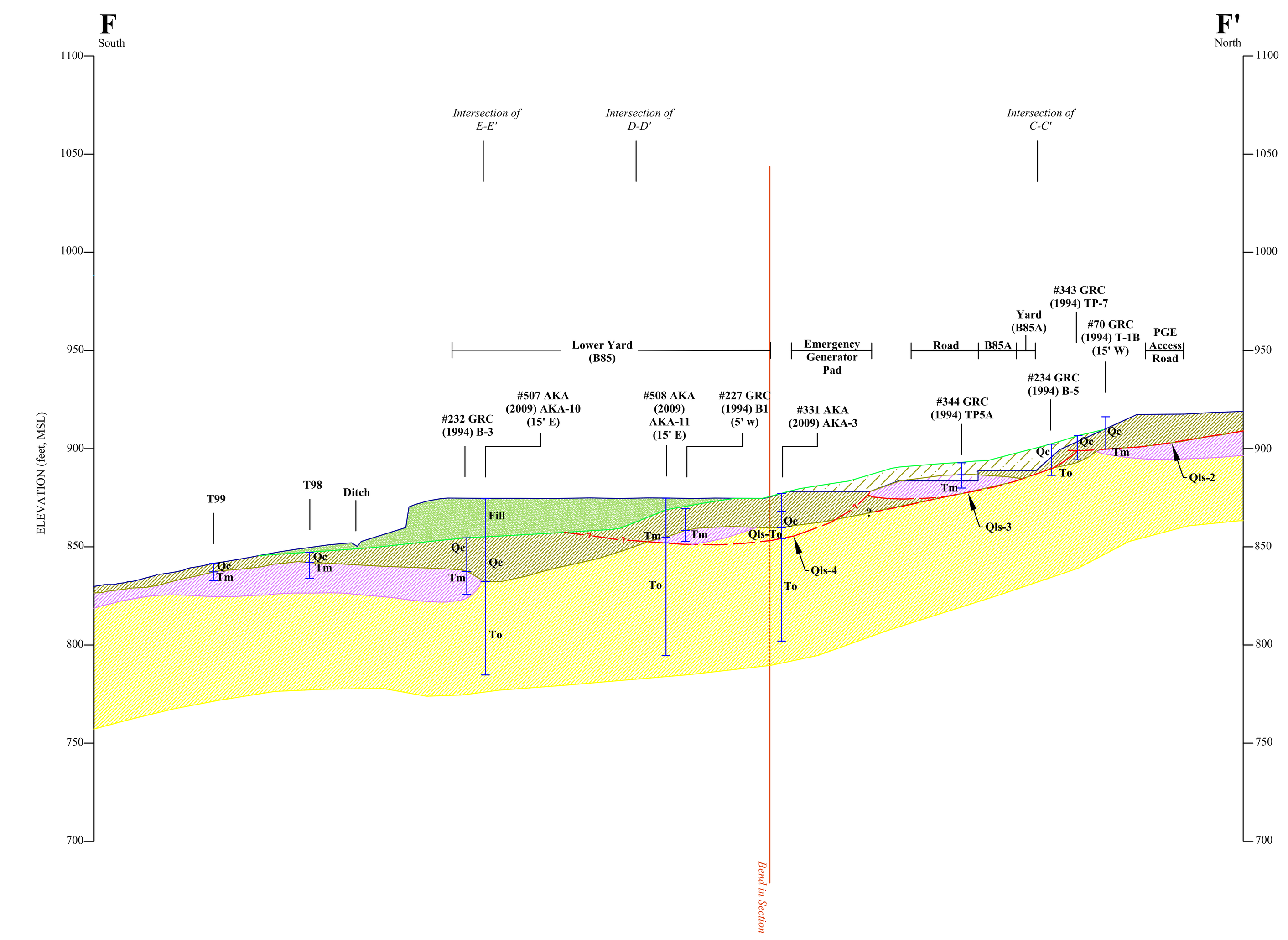
ALAN KROPP & ASSOCIATES
Geotechnical Consultants

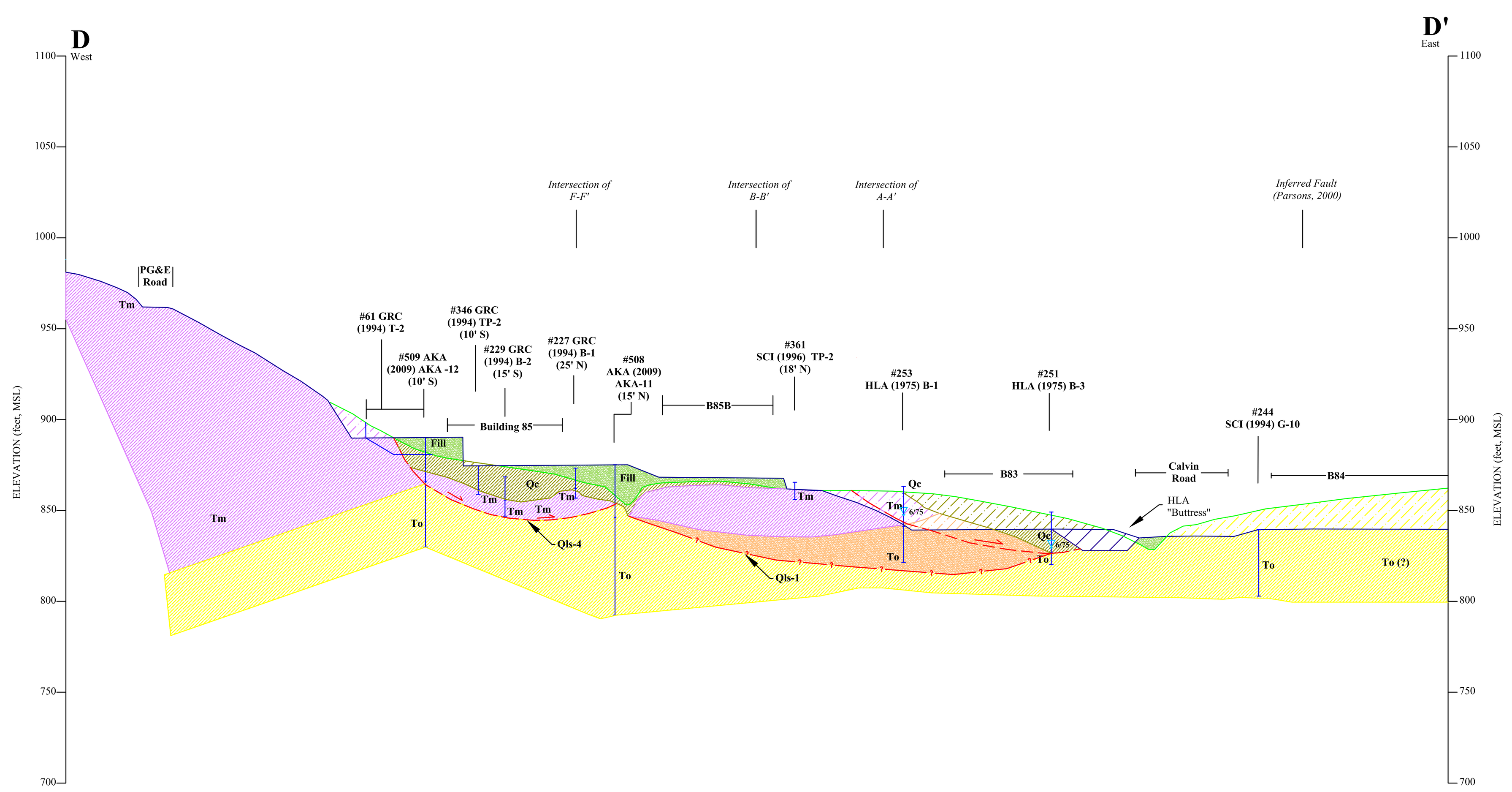
CROSS SECTIONS A-A' and B-B'

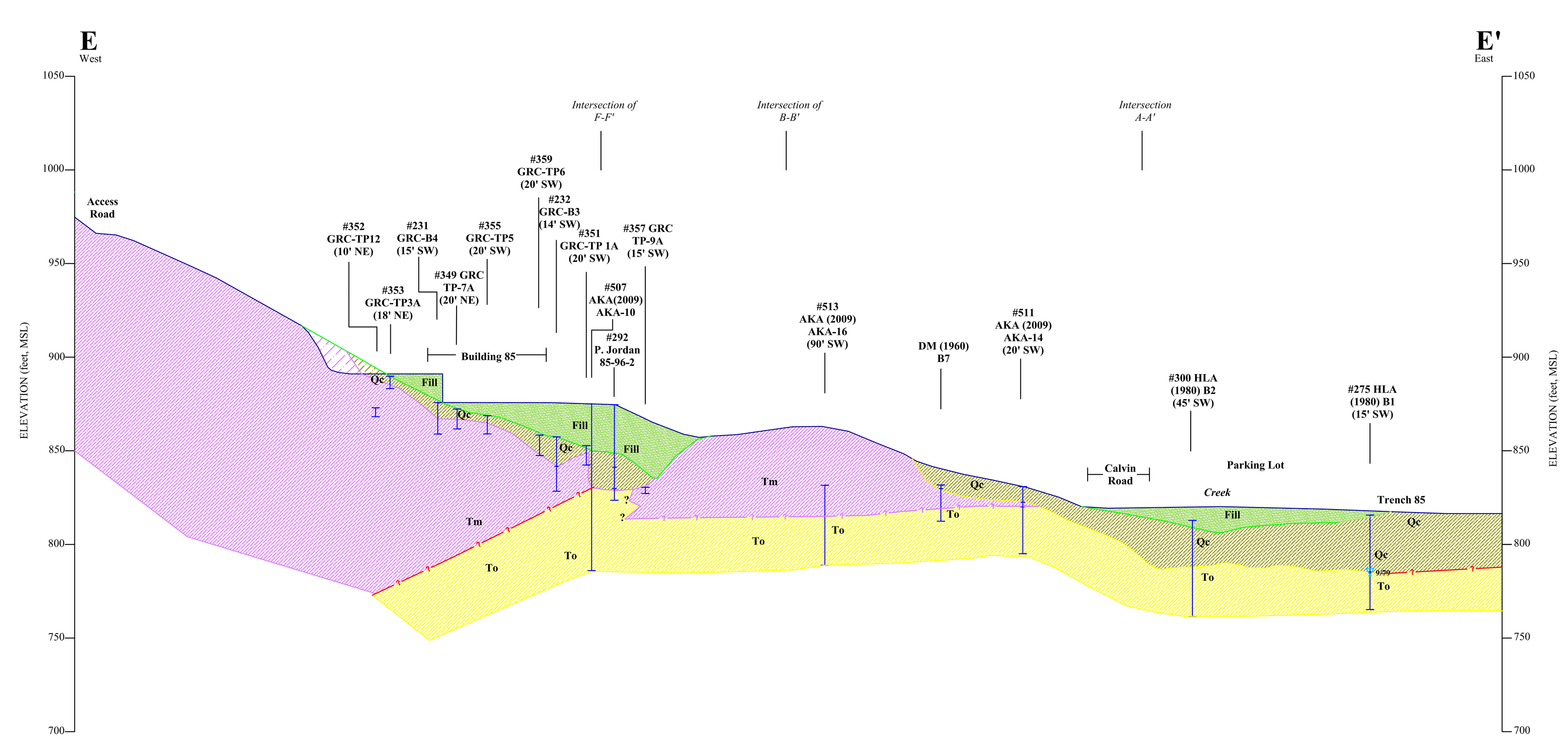
LBNL BUILDING 85
Berkeley, California

PROJECT NO.	DATE	FIGURE 13
2335-7B	April 2010	









LEGEND:

- Current Ground Surface
- Original Ground Surface
- Interpreted Landslide Slip Surface
- Measured Groundwater Level
- Fill
- Qc, Colluvium
- Qc, Colluvium - Removed From Previous Grading
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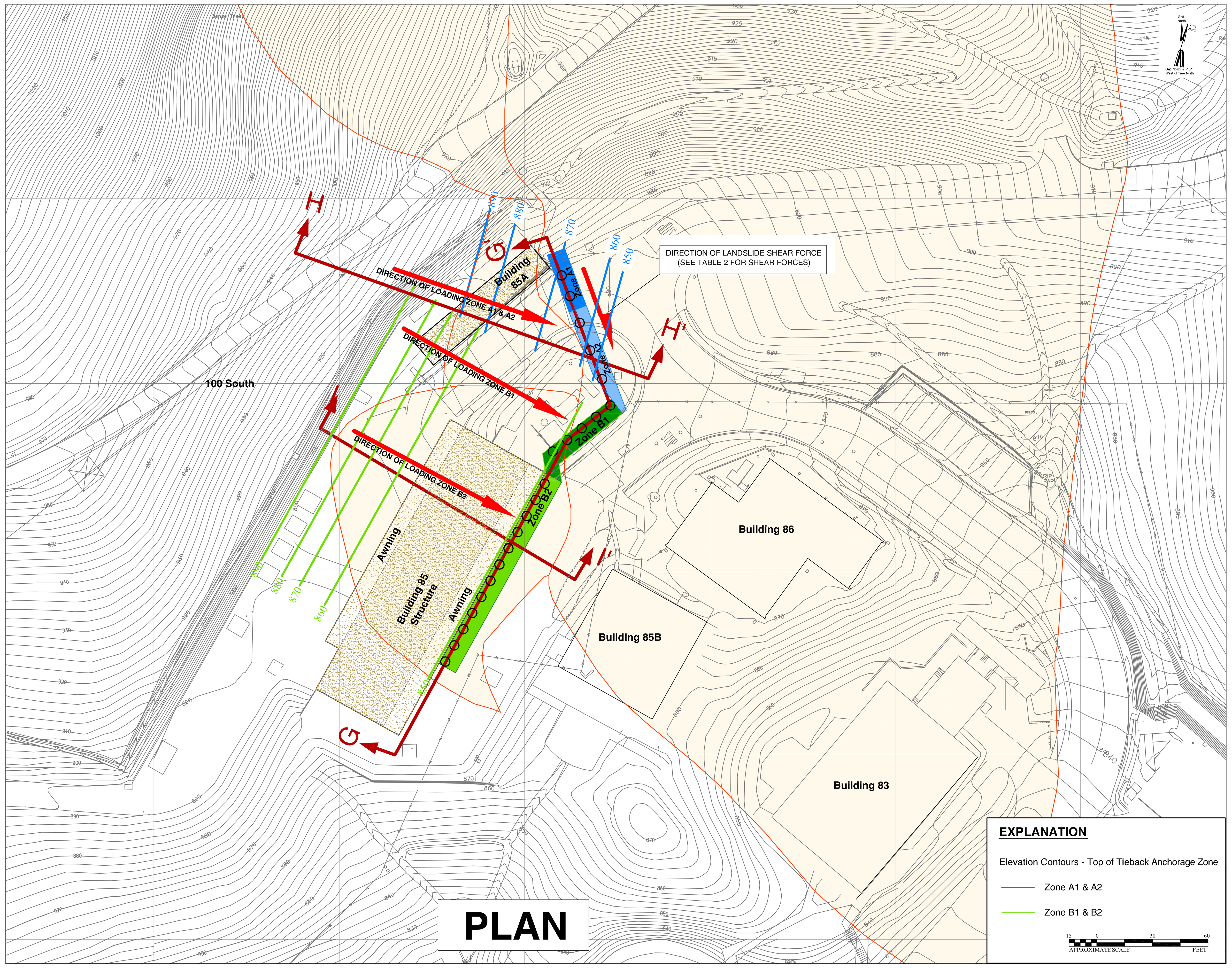
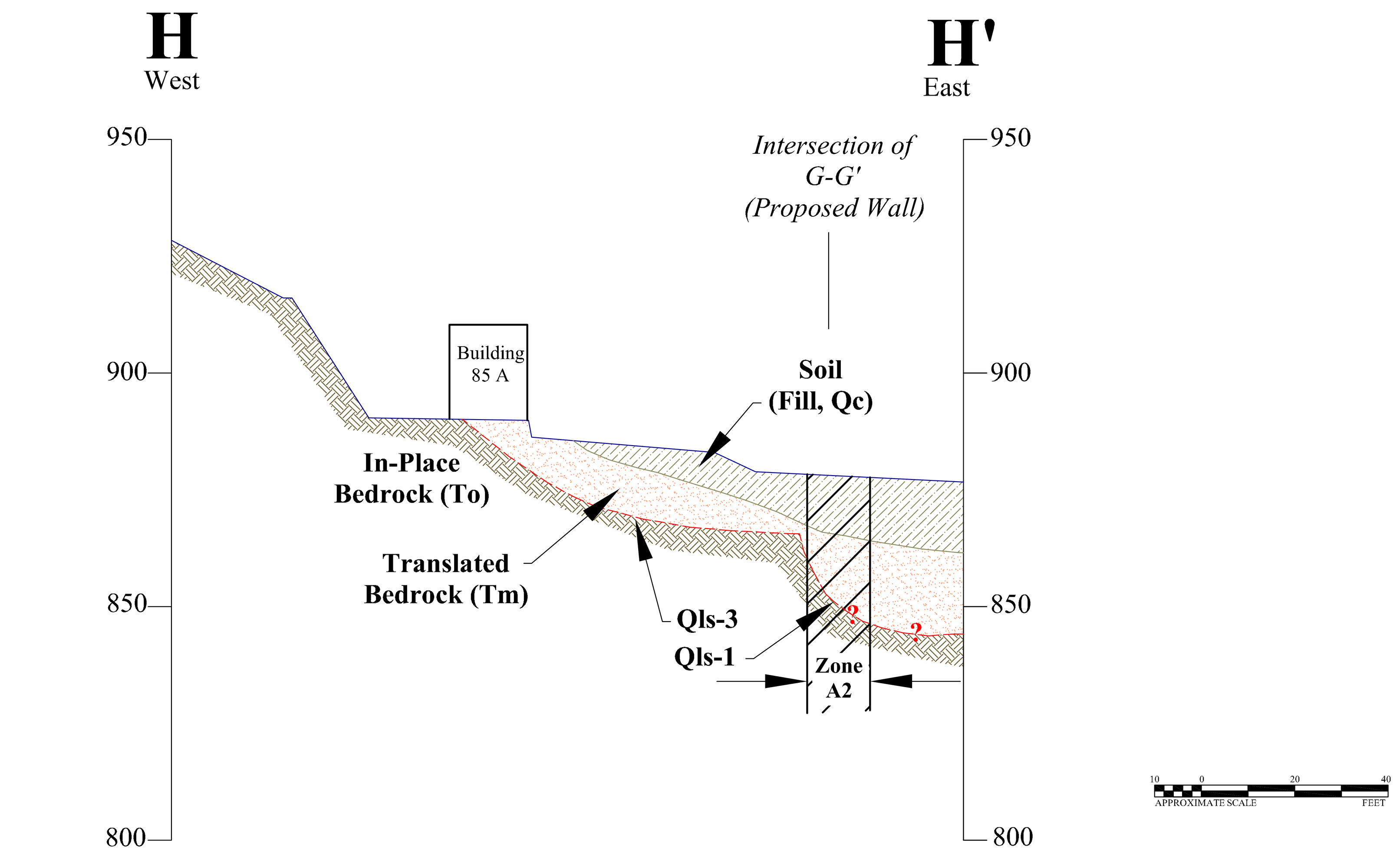
- Tm, Moraga Formation - Removed From Previous Grading
- Tm, Moraga Formation
- To / Tm, Orinda - Moraga Formation Mix
- To, Orinda Formation

25 0 50 100
APPROXIMATE SCALE FEET

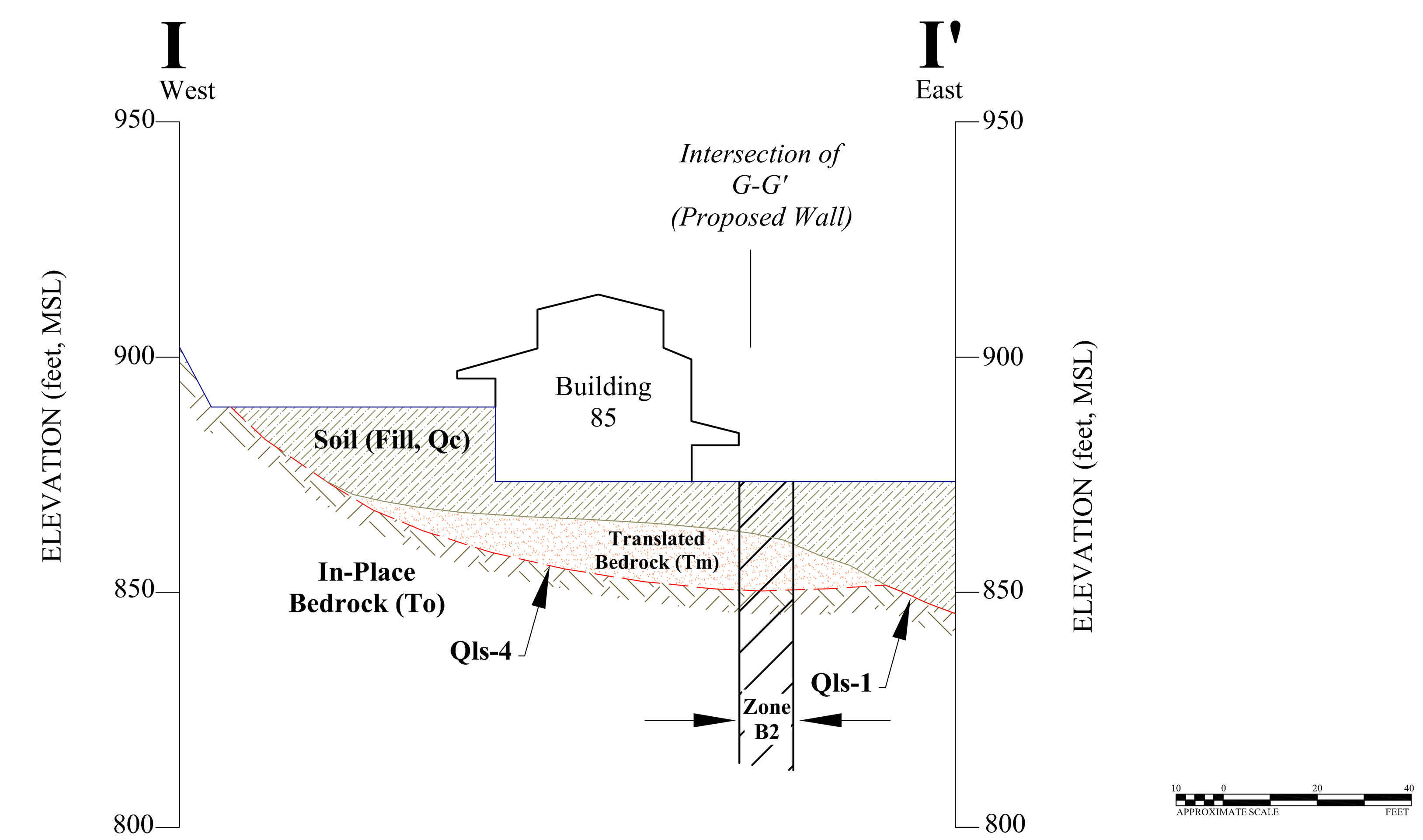
ALAN KROPP & ASSOCIATES Geotechnical Consultants	CROSS SECTIONS C-C', D-D', E-E', and F-F'		
	LBNL BUILDING 85 Berkeley, California		
	PROJECT NO.	DATE	FIGURE 14
	2335-7B	April 2010	



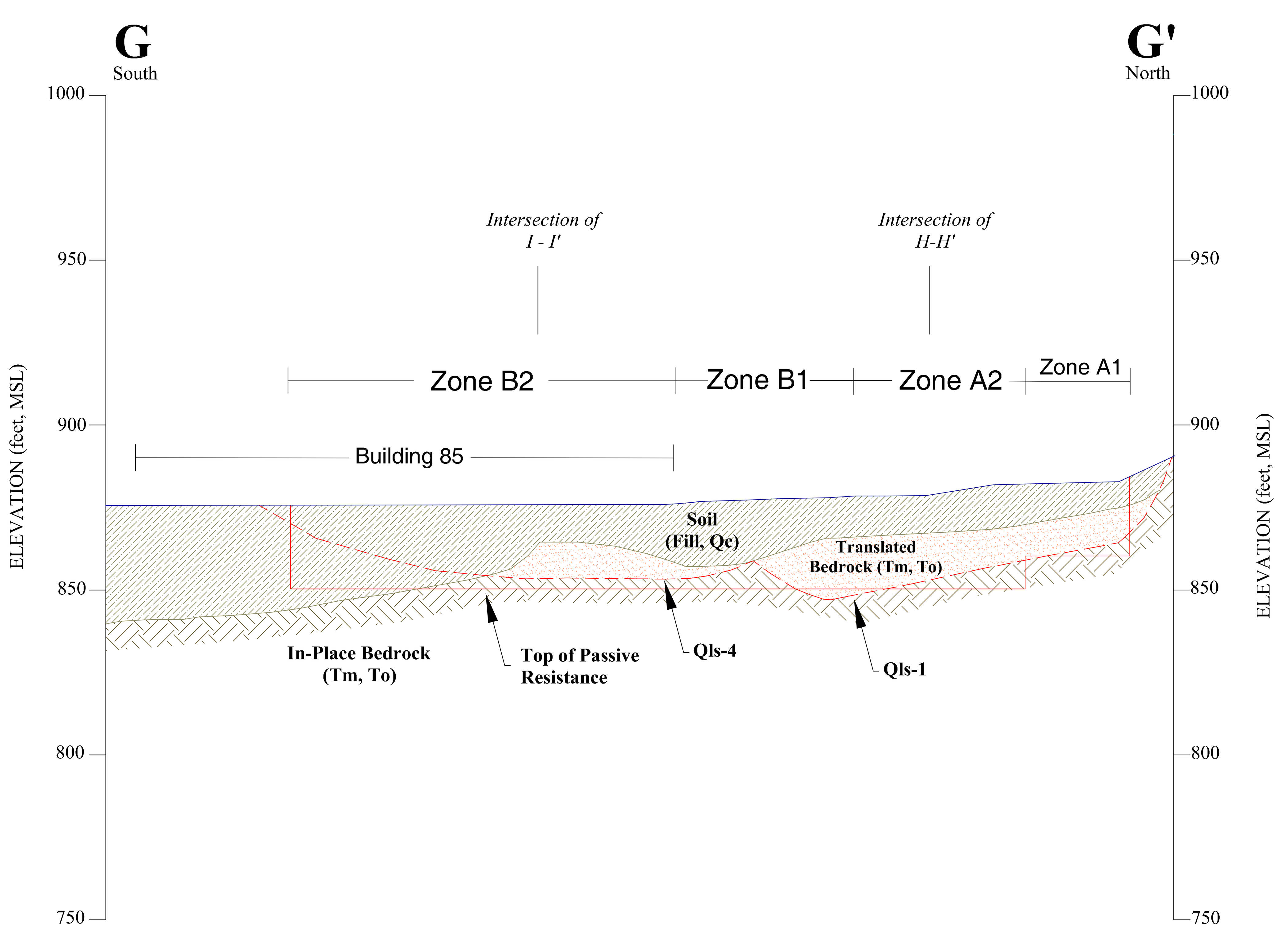
PLAN



ENGINEERING CROSS SECTION H-H'



ENGINEERING CROSS SECTION I-I'

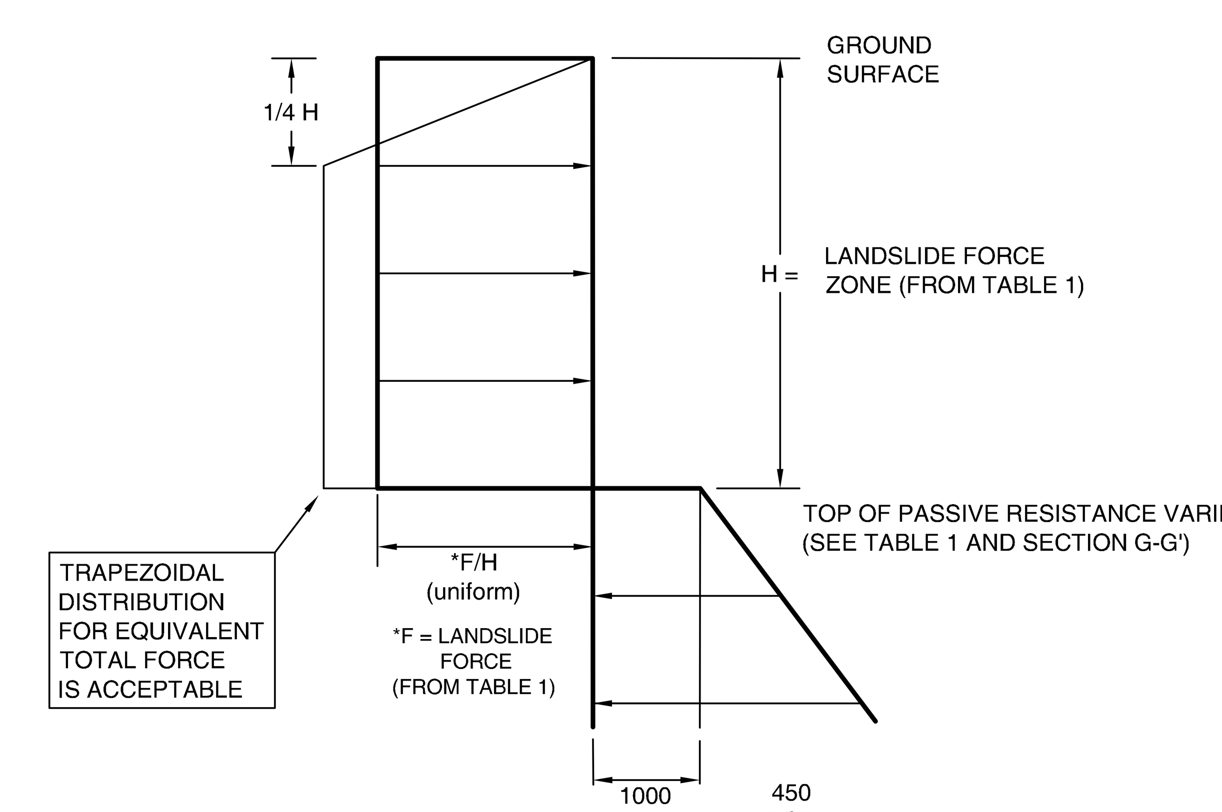


ENGINEERING CROSS SECTION G-G'

TABLE 1 – Direct Landslide Forces			
Retention Zone	Direct Landslide Force	Landslide Force Zone Location (Elevation)	Top of Passive Resistance (Elevation)
A1	70 kips	above +860 feet	+860 feet
A2	70 kips	above +860 feet	+850 feet
B1	158 kips	above +850 feet	+850 feet
B2	118 kips*	above +850 feet	+850 feet

TABLE 2 – Shear Forces (Zones A1 and A2 only)			
Retention Zone	Shear Parallel to Retention Zone	Landslide Shear Zone Location (Elevation)	Top of Passive Resistance (Elevation)
A1	2000 psf	above +870 feet	+860 feet
	3000 psf	+860 feet to +870 feet	
A2	2000 psf	above +867 feet	+850 feet
	3000 psf	+850 to + 867 feet	

*Zone B2 includes reduction in total landslide force due to existing building 85 piers that penetrate slide plane



LOADING DIAGRAM

NOTES:

1. Plan view should be used to evaluate directions of loading (direct and shear) and location of tieback anchorage zones. Boring and test pits shown on the Site Plan (Figure 2) and the Site Geologic Map (Figure 9) have been omitted on this figure for clarity.
2. Engineering Cross Section G-G' corresponds to the planned drilled pier alignments.
3. Loading Diagram is presented for illustrative purposes only and shows unfactored Direct Landslide Loads and allowable Passive Resistance values for Drilled Piers in Bedrock. Structural Design should be per the recommendations presented in Section 8.01 through 8.05 of the report.

ALAN KROPP & ASSOCIATES
Geotechnical Consultants

ENGINEERING PLAN, SECTIONS AND LOADING DIAGRAM
LBNL BUILDING 85
Berkeley, California

PROJECT NO.	DATE	FIGURE
2335-7B	April 2010	15

APPENDIX A

Logs and Photographs of Borings

Photograph A-1. Core from boring AKA-8 at 17.5 feet showing possible bedding noted by seam.

Photograph A-2. Core from boring AKA-8 at 44 feet showing clay seams within the Orinda Formation.

Photographs of AKA Boring Cores

Photograph A-3. Core from boring AKA-9 at 30.5 feet showing a steeply inclined contact within the Orinda Formation.

Photograph A-4. Core from boring AKA-9 at 45.5 to 46.5 feet showing approximate contact and shear between Moraga and Orinda Formations.

Photographs of AKA Boring Cores

Photograph A-5. Core from boring AKA-10 at 42.5 feet showing clay laminations. Note the laminations are similar to bedding (red vs. gray units).

Photograph A-6. Core from boring AKA-11 at 22 feet showing inclined seam with Moraga Formation above and Orinda Formation below.

Photographs of AKA Boring Cores

Photograph A-7. Sample from boring AKA-12 at 25 feet showing clay seam and weathered and mixed Moraga Formation.

Photograph A-8. Core from boring AKA-12 at 27 to 30 feet showing mixed Moraga (reddish) and Orinda Formation siltstone (gray).

Photographs of AKA Boring Cores

Photograph A-9. Core from boring AKA-13 at 20 feet showing gravelly Moraga Formation overlying Orinda Formation siltstone along a "seamy" contact.

Photograph A-10. Core from boring AKA-14 at 9 to 11 feet showing Moraga Formation (far left) and Orinda Formation (grayish color).

Photographs of AKA Boring Cores

FUGRO

Photograph A-11. Core from boring AKA-15 at 8 feet showing approximate contact between Moraga volcanics (blocky brownish color) and Orinda Formation (light gray).

Photograph A-12. Core from boring AKA-16 at 17.5 feet showing contact between Moraga and Orinda Formations along steeply inclined plane.

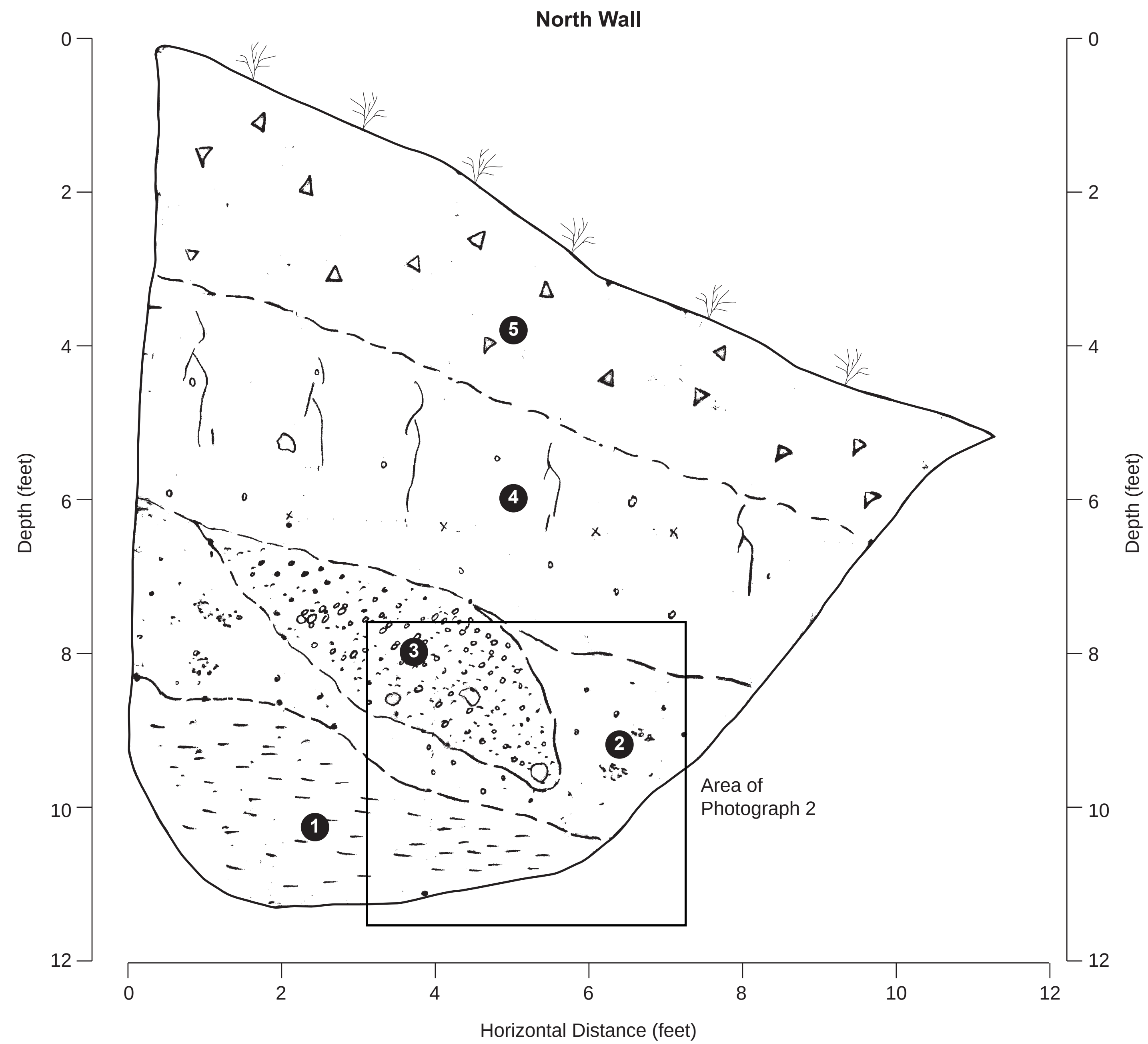
Photograph A-13. Core from boring AKA-16 at 25 feet showing 1/4 inch thick clay seam within siltstone of Orinda Formation.

Photographs of AKA Boring Cores

APPENDIX B

Logs of Test Pits and Rock Cut

Photograph 1. View to west showing location of test pit TP-1.



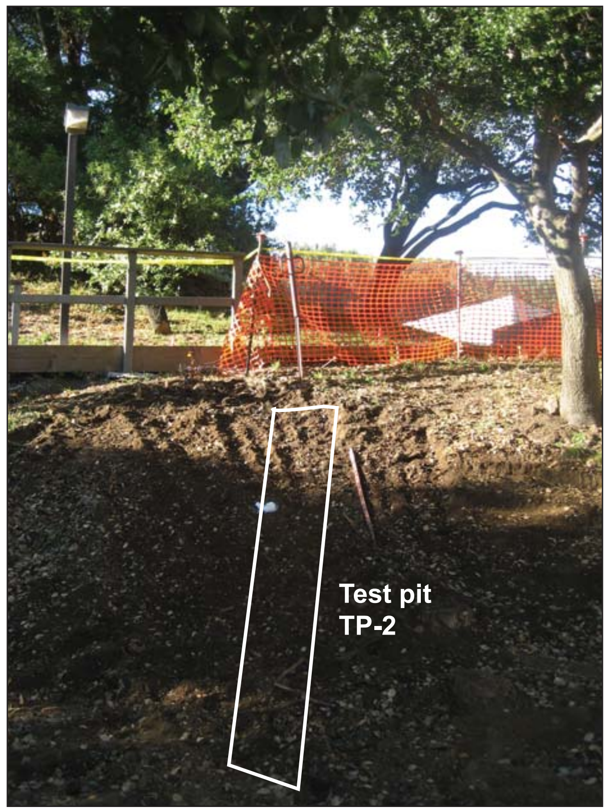
Unit Descriptions

- **5** Artificial Fill
- **4** Dark brown gravelly clay; stiff; massive; 10 to15% fine to coarse gravel of Moraga and Orinda origin; soil tongues; moist [colluvium]
- **3** Light yellowish brown gravelly clay with coarse-grained sand; poorly sorted with no bedding; gravel clasts 3 to 5 inches in diameter; predominantly Moraga-derived with occasional Orinda Formation clasts; moist [paleo Winter Creek channel deposits]
- **2** Reddish brown to brown sandy silt with gravel; 10% fine gravel; faintly mottled with gray zones; moist [colluvium to alluvium]
- **1** Strong reddish brown mottled siltstone; highly weathered to competent; 10 to 20% very fine sand in places making it occasionally friable; no fractures or shears; becomes more competent with depth [Orinda Formation]

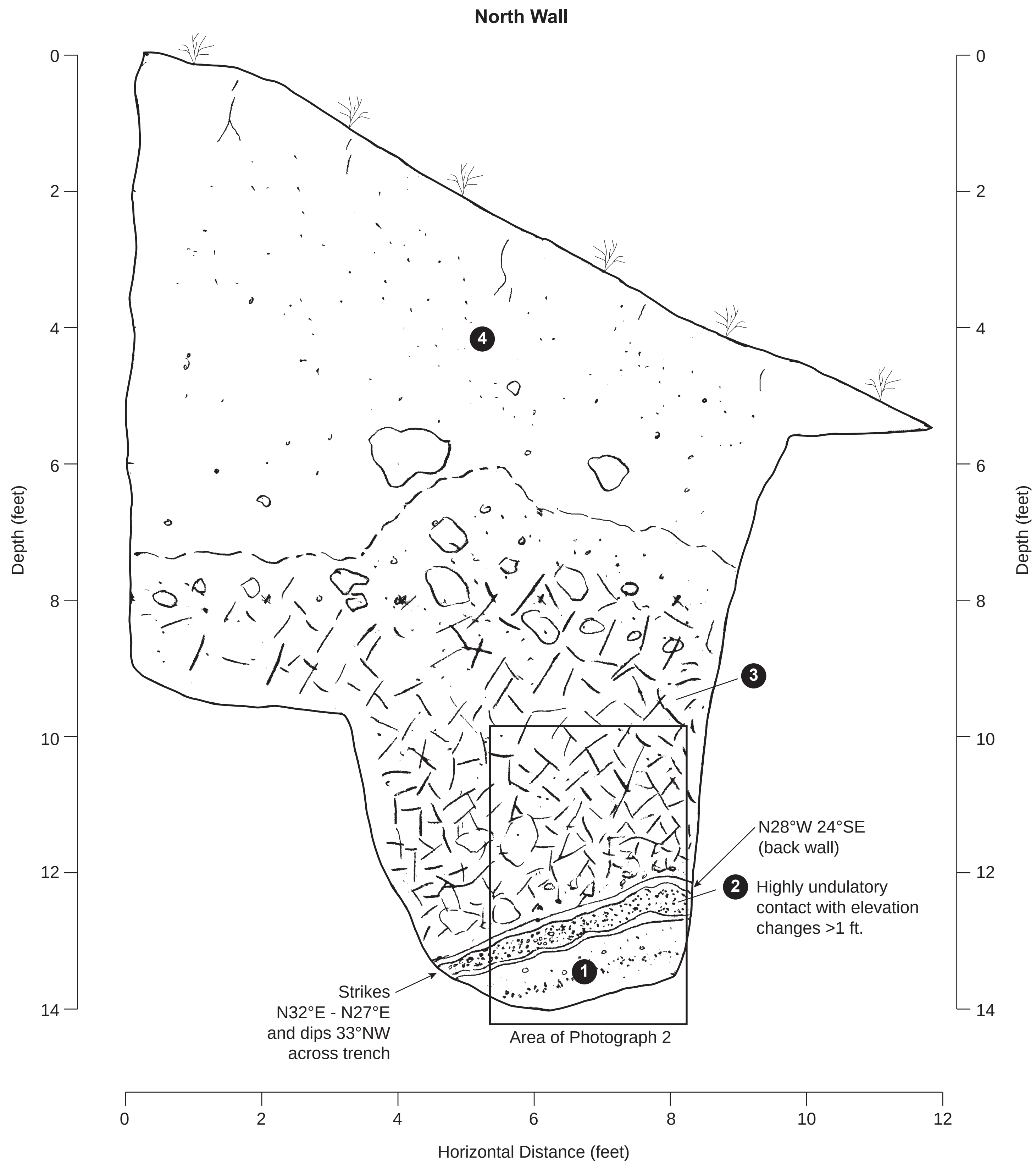
Photograph 2. View to north wall showing relations of base of test pit TP-1.

Graphics, Active Projects, 2032.000 Building 85 Landslide Mitigation, Modified 12.22.09

Test Pit TP-1



Photograph 1. View to northwest showing location of test pit TP-2 along east side of old quarry.



Unit Descriptions

4 Dark brown to brown silty sand with 10 to15% gravel; loose to friable; rootlets and krotovinas abundant; dry [fill/colluvium]

3 Yellow-brown highly weathered volcanic rock; angular blocks of basalt, tuffaceous agglomerate in gravelly to sand matrix; becomes stiffer with depth but overall loose and very weathered [Moraga Formation]

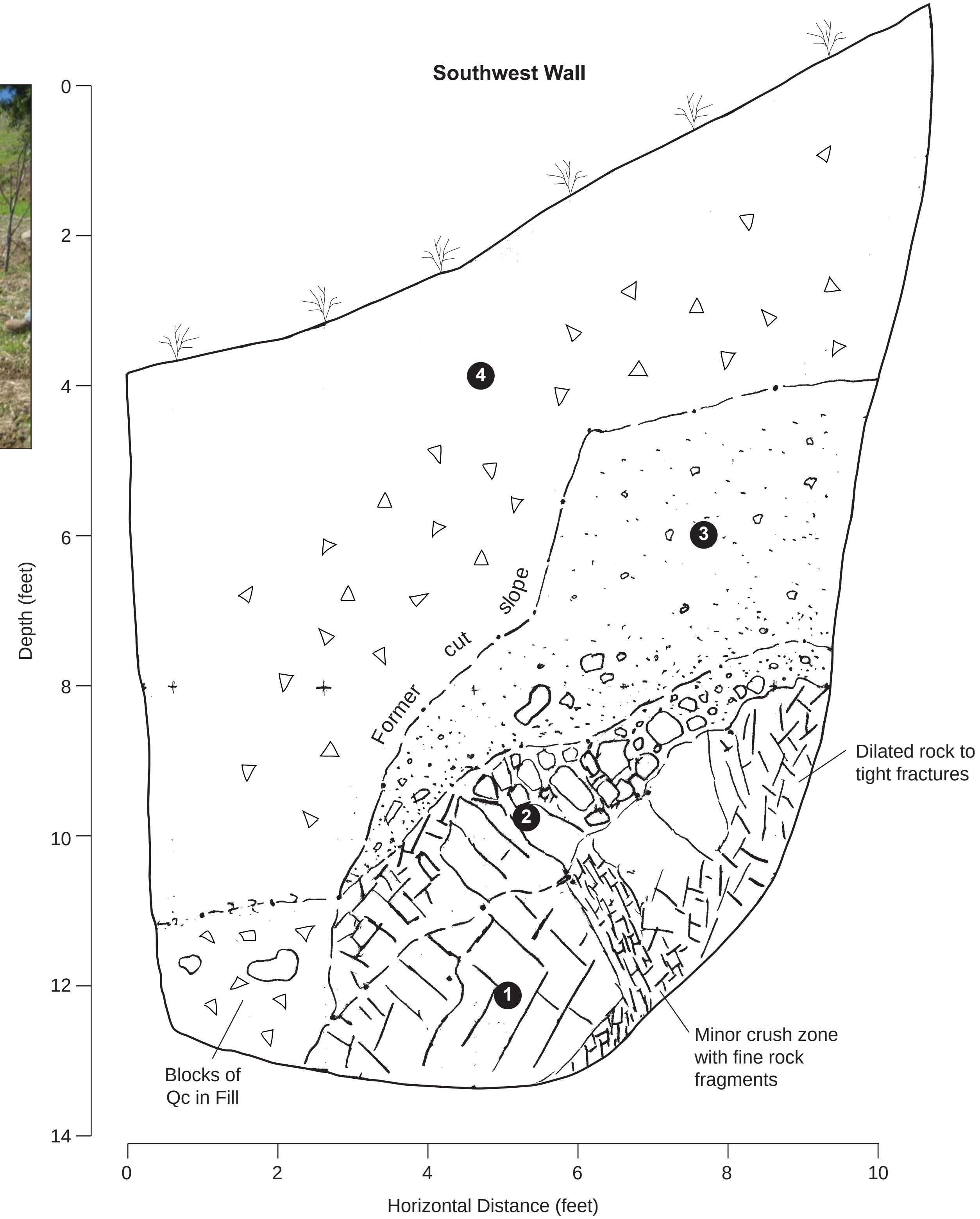
2 Reddish brown clayey silt with gravel; very irregular and undulating, laminations of clayey silt with mixed zones of gravel and siltstone and sandstone; abrupt to distinct contact with 10 to 15% clay [mixed Moraga and Orinda Formation]

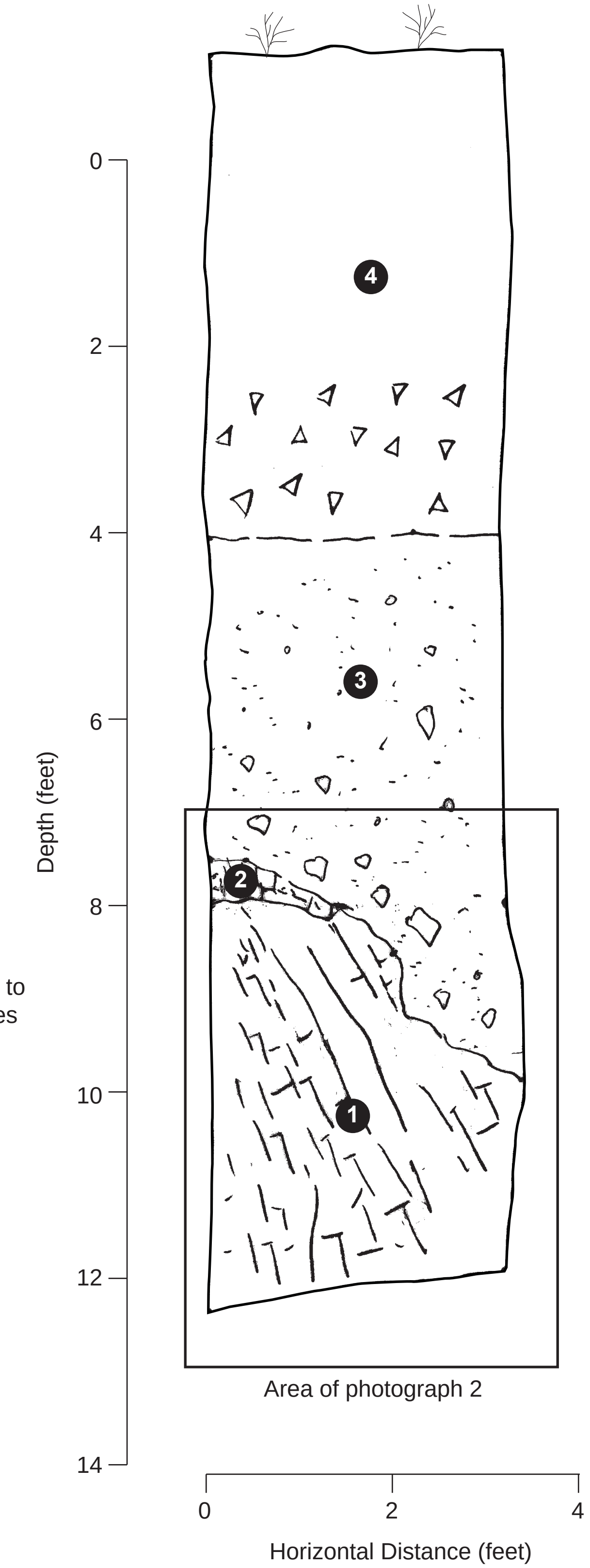
1 Grayish gravelly sandstone; bedded with thin laminations [Orinda Formation]

Photograph 2. View of north wall of test pit TP-2. Blue flags at base of Unit 3.

Test Pit TP-2

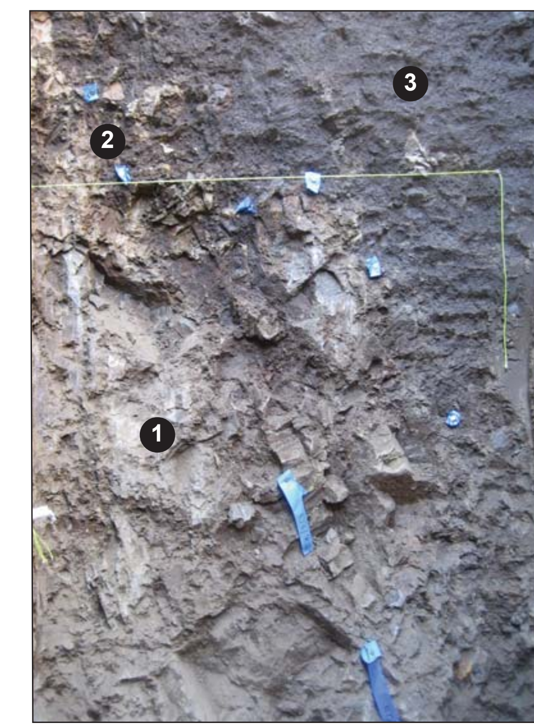
Photograph 1. View to west - southwest of test pit TP-3 location. Fence line borders PG&E access.





Unit Descriptions

- **4** Artificial fill
- **3** Dark grayish brown sandy clay with gravel 10 to 15% fine- to medum-grained sand and 15 to 25% fine gravel; massive; damp to moist; dips to north-northeast toward old ravine [colluvium]
- **2** Light brown, weathered volcanic bedrock comprised of basalt [Moraga Formation]
- **1** Light brown fine angular blocks of fine-grained microcrystalline andesite with blocks of basalt [Moraga Formation]

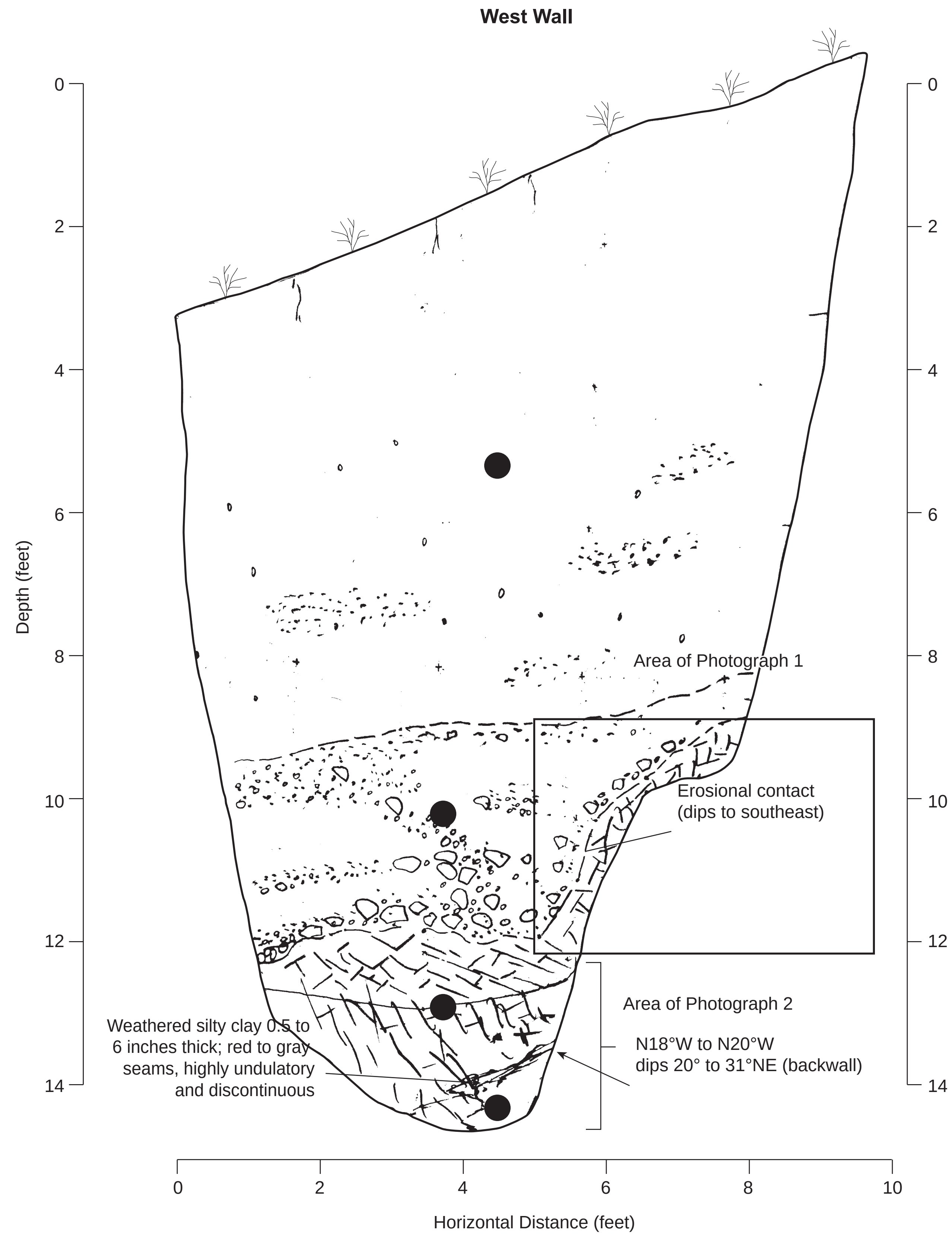


Photograph 2. View of northwest wall (back wall) showing stratigraphic relations and dip of colluvium to northeast.

Graphics, Active Projects, 2032.000 Building 85 Landslide Mitigation, Modified 12.22.09

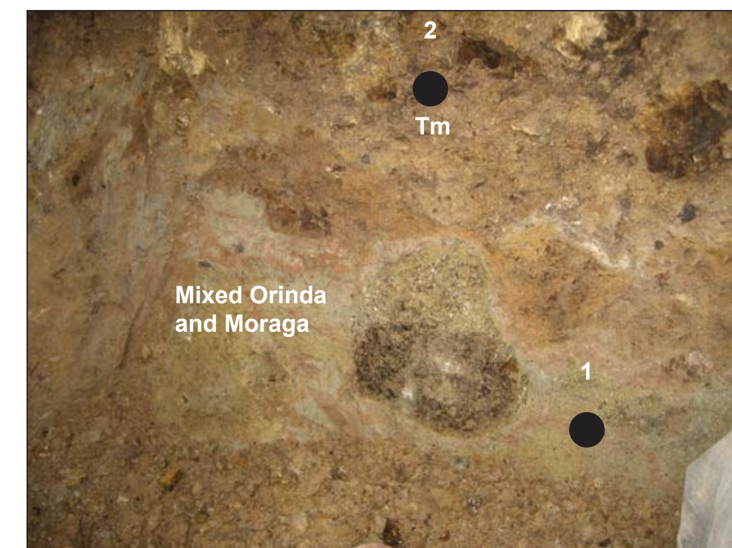
Test Pit TP-3

channel associated with paleo Winter Creek.



Unit Descriptions

- Dark brown silt and clay with pockets of gravel, moist, massive with weak bedding increasing with depth [colluvium]
- Brown to yellow-brown clayey gravel to gravelly clay; discontinuous lenses of basalt clasts weakly bedded; yellowish siltstone clasts rare; erosional contact with Moraga volcanics [alluvium]
- Black to grayish brown weathered basalt; occurs as large resistant angular blocks highly fractured iron-stained [Moraga Formation]
- Reddish brown siltstone [Orinda Formation]



mixed nature of Moraga and Orinda Formations.

Test Pit TP-4

Photomosaic of Rock Cut along PG&E Access Road

FIGURE B-5

APPENDIX C

Borehole Suspension Logging Report

October 10, 2008

Mr. Wayne Magnusen
Alan Kropp and Associates
2140 Shattuck Avenue, Suite 910
Berkeley, CA 94704

Subject: P-and S-Wave Borehole Suspension Logging Report
Building 85
Lawrence Berkeley Laboratory
Berkeley, CA
NORCAL Job No. 08-778.04B

Mr Magnusen:

This report presents the findings of a borehole geophysical survey performed by NORCAL Geophysical Consultants, Inc. The survey was performed in two boreholes designated as AKA-8 and 9. Boring AKA-8 was situated downslope of Building 85, whereas Boring AKA-9 was situated up slope of Building 85.

The geophysical survey consisted of measuring the subsurface distribution of compressional (P-) and shear (S-) seismic velocity using a downhole suspension velocity logging system. The field work was performed on September 19 and 24, 2008 by NORCAL geophysicist, William Henrich. Background information and logistical support were provided by Ms. Kate Krug of William Lettis and Associates.

1.0 PURPOSE

The purpose of the seismic suspension logging survey was to measure the distribution P-wave and S-wave velocities below the natural hillside. These data will aid in evaluating hillside stability and detect potential landslide features.

2.0 METHODOLOGY

We used an OYO-Robertson Model 3403 digital suspension logging system to measure downhole compressional (P-) and shear (S-) velocities. The suspension logging system consists of a control console, four-conductor winch and downhole probe. The probe is equipped with a dipole seismic energy source located near the base of the probe and a pair of geophones (detectors) located at the upper end. A schematic showing the probe configuration and equipment attachments is shown in Appendix A. The distance from the energy source to the first geophone was 7.02 feet (2.13 meters). The in-line distance between the geophone pair is 3.28 feet (1.0 meter). Each geophone contains one horizontal and one vertical oriented element. The horizontal phone elements preferentially record the shear wave. The vertical geophone elements record first arriving P-wave energy.

Suspension seismic data are collected at discrete depths in a fluid-filled borehole. At each measurement depth, the energy source is activated via commands from the surface control console. This activation causes a metal solenoid to strike a plate (anvil) mounted inside the probe housing. This energy transmits through the fluid to the borehole wall which produces a seismic wave ("flexure") in the adjacent formation. As this wave propagates radially in the formation away from the source, a seismic interaction between the seismic wave and the borehole wall creates tube waves together with a compressional P-wave that travels up the borehole to the two recording geophones.

P-wave arrival times are identified as the first break on the vertical geophone seismic records. Tube wave arrivals are later arriving seismic events and are recorded on the horizontal geophones. The identification of the tube wave arrival times are facilitated by recording seismic records from two opposite directions of solenoid impacts. By superimposing these two seismic records, the onset of the tube wave/S-wave arrival time is usually identified as a higher amplitude and phase reversal event. The velocity of the tube wave is very close (90 percent) to that of the S-wave. Hence, we report tube wave velocities as seismic S-wave velocities.

When assembled, the suspension logging tool measures approximately 19 feet in length. The measuring point of the tool is taken at the center of the pair of geophones. This measuring point is approximately 11 feet from the bottom of the probe. Therefore, the maximum depth of our survey will always be reported 11 feet from the total depth of the borehole.

4.0 DATA ACQUISITION

The boreholes were drilled with a rotary core method using a four-inch diameter drill bit. Total depths of Borings AKA-8 and AKA-9 ranged from 83 to 102 feet below ground surface (bgs), respectively.

We measured seismic suspension velocities at one- to two-foot intervals beginning at 15 feet below ground surface down to the bottom of each well. At each measurement station, we cycled the energy source to fire 3 to 5 times in succession into each geophone element. This cycling stacks seismic records to achieve better signal to noise ratios. We also recorded S-wave data using a 1.2 KHz low pass filter. This filtering reduces high frequency interference from the onset of earlier arriving P-wave modes. The downhole tool did not encounter any obstructions and as a result, we were afforded more time to record additional measurement stations up the boring such that the final sampling interval was one-half to one foot over critical borehole sections.

5.0 DATA ANALYSIS

Seismic P- and S-wave velocities were calculated with the interpretation computer software Glog SUS, Version 1.12 published by Oyo Corporation (2000). A typical interpreted seismic record is presented in Appendix B. This record shows six geophone traces. Traces H1 and H2 are horizontal geophone elements which are preferentially aligned to record S-waves. H1 is the geophone nearest to the source, H2 is the farthest from the source. V1 and V2 are the vertical geophone elements which are preferentially aligned to record P-waves. The horizontal geophone elements (H1 and H2) show a total of four S-wave arrival times; two arrival times identified at each geophone are referenced as “up” and “down” breaks. The ”up” and “down” breaks are the result of two separate and oppositely directed (180 degrees) solenoid impacts by the energy source. As the example record illustrates, these opposing impacts produce amplitude phase reversals which identifies the on set of the S-wave energy. All seismic records were analyzed for P- and S- arrival time in this manner. Seismic velocities are calculated by dividing the geophone spacing interval (1 meter) by the interpreted interval travel times in microseconds to yield seismic velocities in meters per second. Two S-wave velocities are calculated at each depth measurement station. We averaged the results of two S-wave interval velocities and presented a single S-wave value at each measurement station.

The interval velocity calculation method is the preferred reduction technique, however, we have noticed problems as some first arrival times (first breaks) within a set of measured waveforms are not always in phase. These mismatches cause significant velocity deviations at some depth measurement stations when compared to nearest neighbors. To help flag these mismatches we performed direct velocities calculations from the arrival times. That is, we divide the travel distance from the source to the detectors by the arrival times (see report graphic regarding the probe geometry). These direct arrival times velocities are compared to the interval velocities. When we see velocity discrepancies we reinterpret arrival times in the Glog-SUS program so that the interval velocities approximately correspond to the direct velocity calculation. It should be noted that the direct velocity calculation though useful can not substitute for an interval velocity because the delay times due to instrumental and probe standoff are not known precisely.

6.0 RESULTS

The results of our velocity interpretation are graphically presented on Plates 1 and 2. The P- and S-wave velocities were converted to English units in feet per second (fps). Note, the horizontal velocity scale for the S-wave velocity is one half value that of the P-wave velocity scale. The reason for this more sensitive S-wave scale is to show small magnitude velocities variations with depth.

7.0 INTERPRETATION

Our analysis showed the subsurface P-wave and S-wave velocities ranged from 5000 to 8400 and from 700 to 1950 fps, respectively. These velocity ranges represents alluvium and bedrock. The alluvium consists of stiff clay. The bedrock consists of shale and sandstones in various states of saturation, weathering and consolidation. It should be noted that the lower velocity measurement limit of the suspension logging technique with respect to first arriving P-waves is 5000 fps. This is due to the fact that the tool operates in a fluid column which has a P-wave velocity of approximately 5000 fps. Therefore, P-wave energy emitted by the source will travel directly up the borehole fluid column and arrive at the geophone detectors earlier than any P-waves induced in comparable or lower velocity geologic materials between the source and detector.

S-wave velocities are not subject to the above P-wave limitation and provide a useful comparative velocity profile of the subsurface. Low S-wave velocities less than 1000 fps usually indicate unconsolidated alluvium or highly weathered shale and sandstone. Higher S-wave velocities above 1500 fps usually indicated less weathered and fracture bedrock. Exact correlation of our S-wave velocity profiles to lithology can be made with correlation to geologic core logs. However, it is within our scope to distinguish major changes in the S-wave that may have significance in terms of lithologic or mechanical deformation within the same lithology. This is briefly discussed in the following paragraphs.

Borehole AKA-8 velocity profile (Plate 1) indicates velocity step changes at 23, 40 and 50 feet bgs. S-wave velocity increases with depth suggesting more stiffer alluvium down to 50 feet bgs. Per discussions with the field geologist, the transition at 50 feet bgs represents a lithology change from alluvium (stiff clay) to bedrock. Bedrock below 50 feet shows a S-wave velocity ranging from 1400 to 1920 fps.

The S-wave profile of Borehole AKA-9 (Plate 2) shows velocity changes at 31, 47 and 77 feet bgs. The change at 31 feet bgs based on S-velocity may represent a transition from alluvium to bedrock. A very significant low velocity S-wave and P-wave anomaly is shown between 44 and 51 feet bgs. This zone could represent highly fractured or sheared bedrock. A minor four-foot thick S-wave velocity anomaly is centered at 77 feet bgs. Since the change in S-wave velocity is small (300 fps), this zone may be related to changes in lithology.

8.0 STANDARD CARE AND WARRANTY

The scope of NORCAL's services for this project consisted of using geophysical methods to characterize the subsurface. The accuracy of our findings is subject to specific site conditions and limitations inherent to the techniques used. We performed our services in a manner consistent with the standard of care ordinarily exercised by members of the profession currently employing similar methods. No warranty, with respect to the performance of services or products delivered under this agreement, expressed or implied, is made by NORCAL.

We appreciate having the opportunity to provide you with this information.

Respectfully,

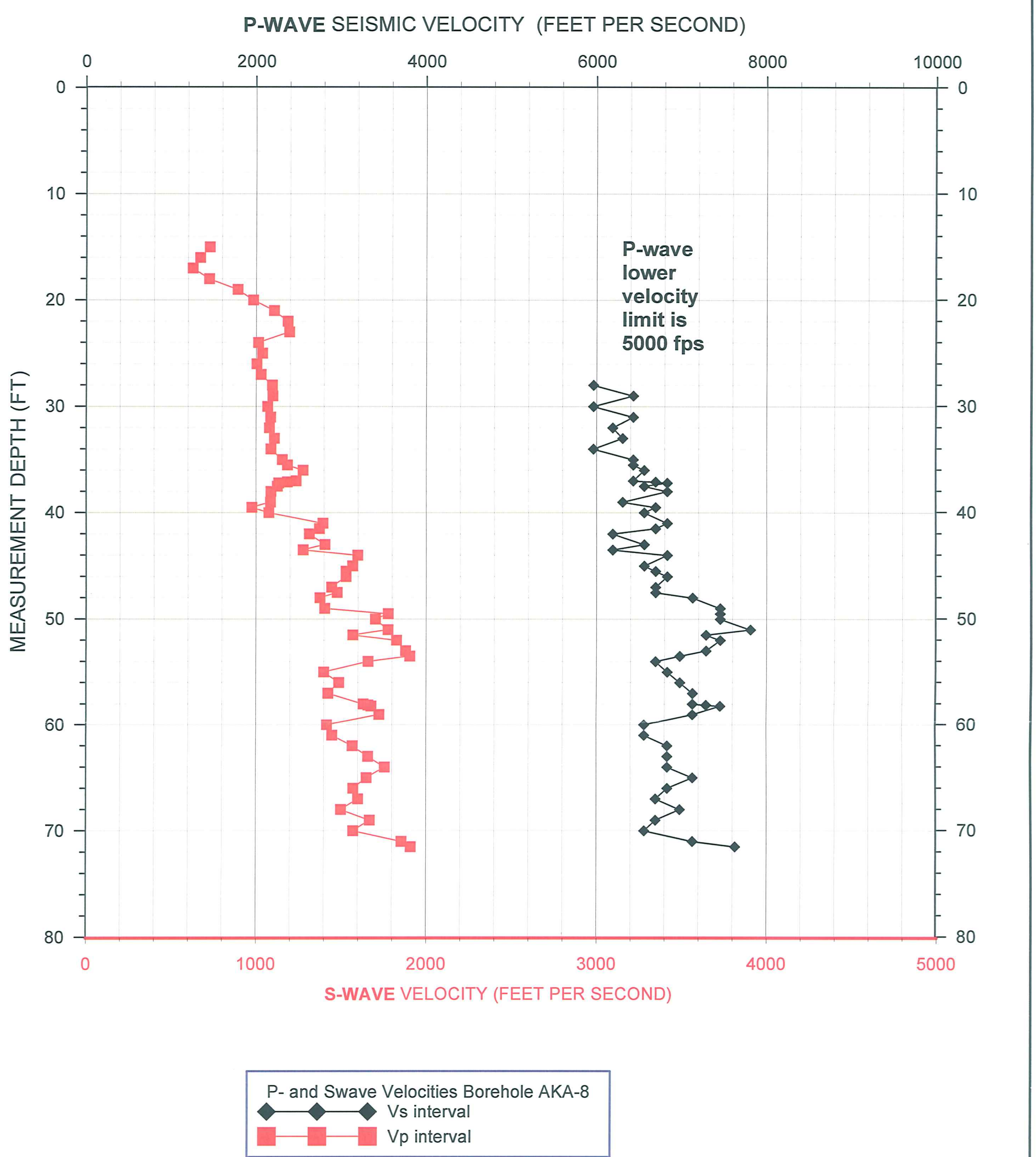
NORCAL Geophysical Consultants, Inc.

William J. Henrich
Geophysicist, GP-893

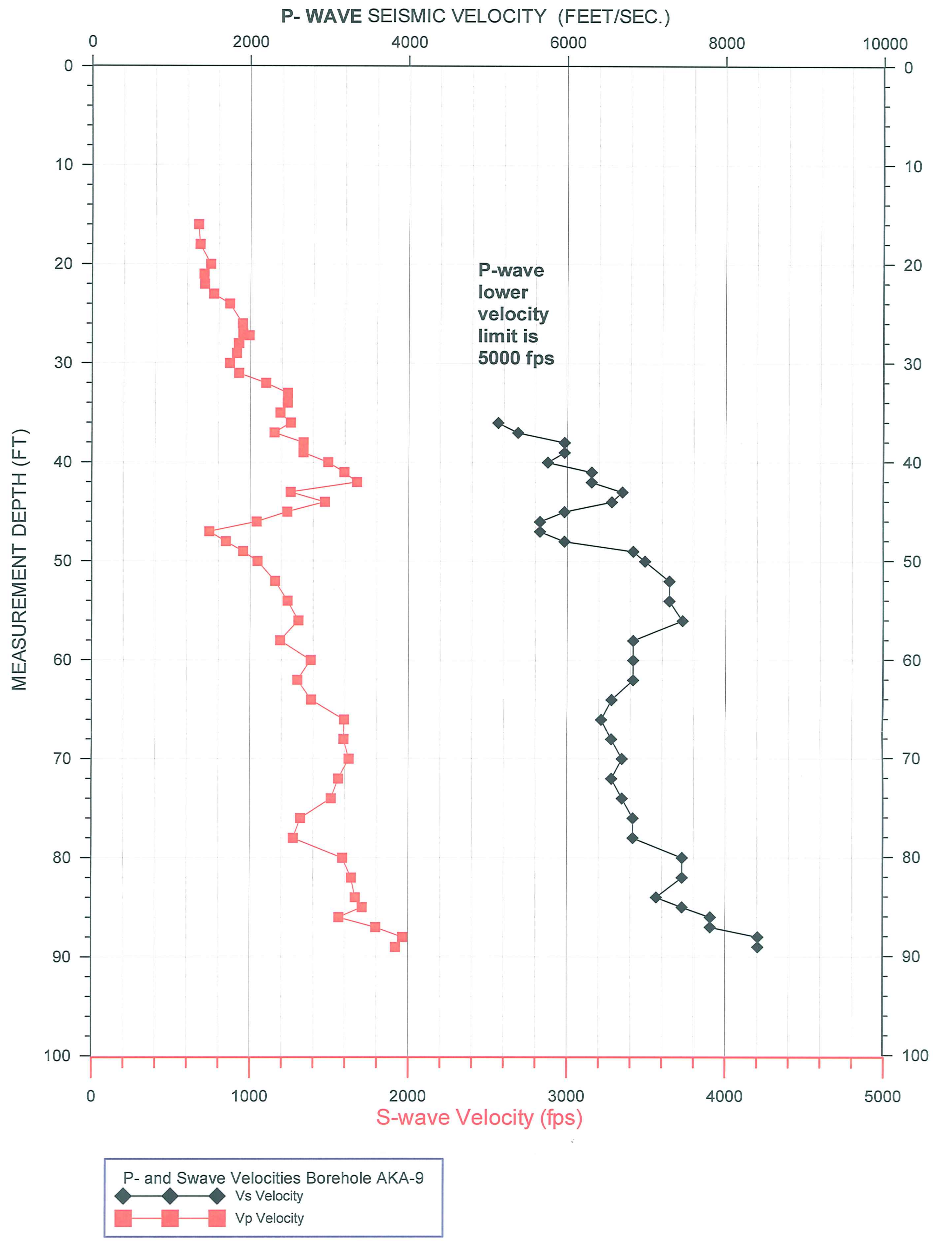
Attachments: PLATES 1 AND 2

Appendix A: Suspension Logging Probe and System Schematic
Appendix B: Example Seismic Suspension Record

WJH/tt



NORCAL	BORING AKA-8 SUSPENSION LOGGING SURVEY P- AND S-WAVE VELOCITY PLOT
	LOCATION: LBL-BUILDING 85
	CLIENT: ALAN KROPP ASSOCIATESES
JOB #: 08-778.04B	NORCAL GEOPHYSICAL CONSULTANTS INC.
DATE: OCT. 2008	DRAWN BY: W. HENRICH / APPROVED BY: WJH
PLATE 1	

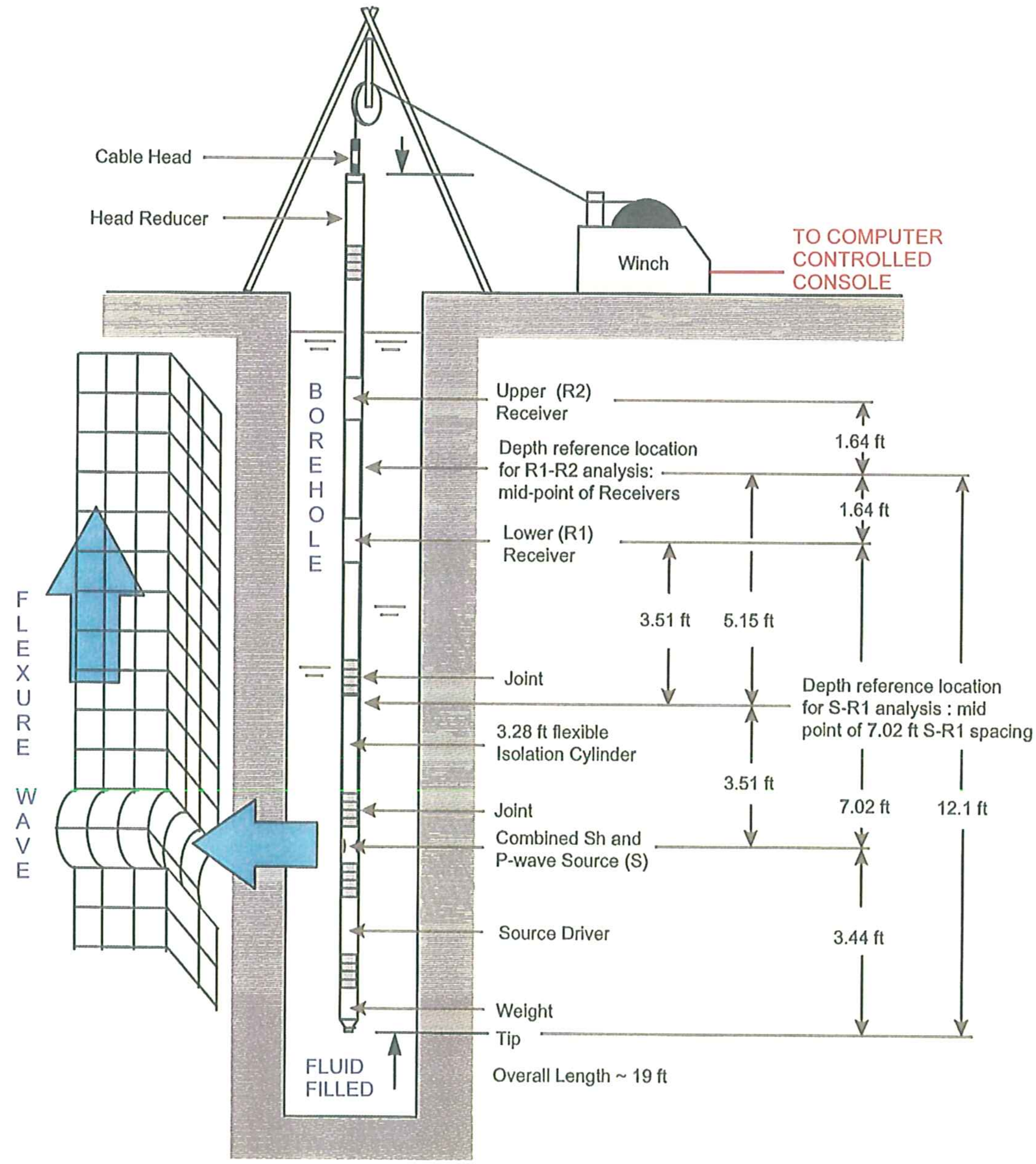


NORCAL	BORING AKA-9 SUSPENSION LOGGING SURVEY P- AND S-WAVE VELOCITY PLOT		
	LOCATION: LBL-BUILDING 85		
	CLIENT: ALAN KROPP ASSOCIATESES		PLATE
JOB #: 08-778.04B	NORCAL GEOPHYSICAL CONSULTANTS INC.		2
DATE: OCT. 2008	DRAWN BY: W. HENRICH	APPROVED BY: WJH	

APPENDIX A

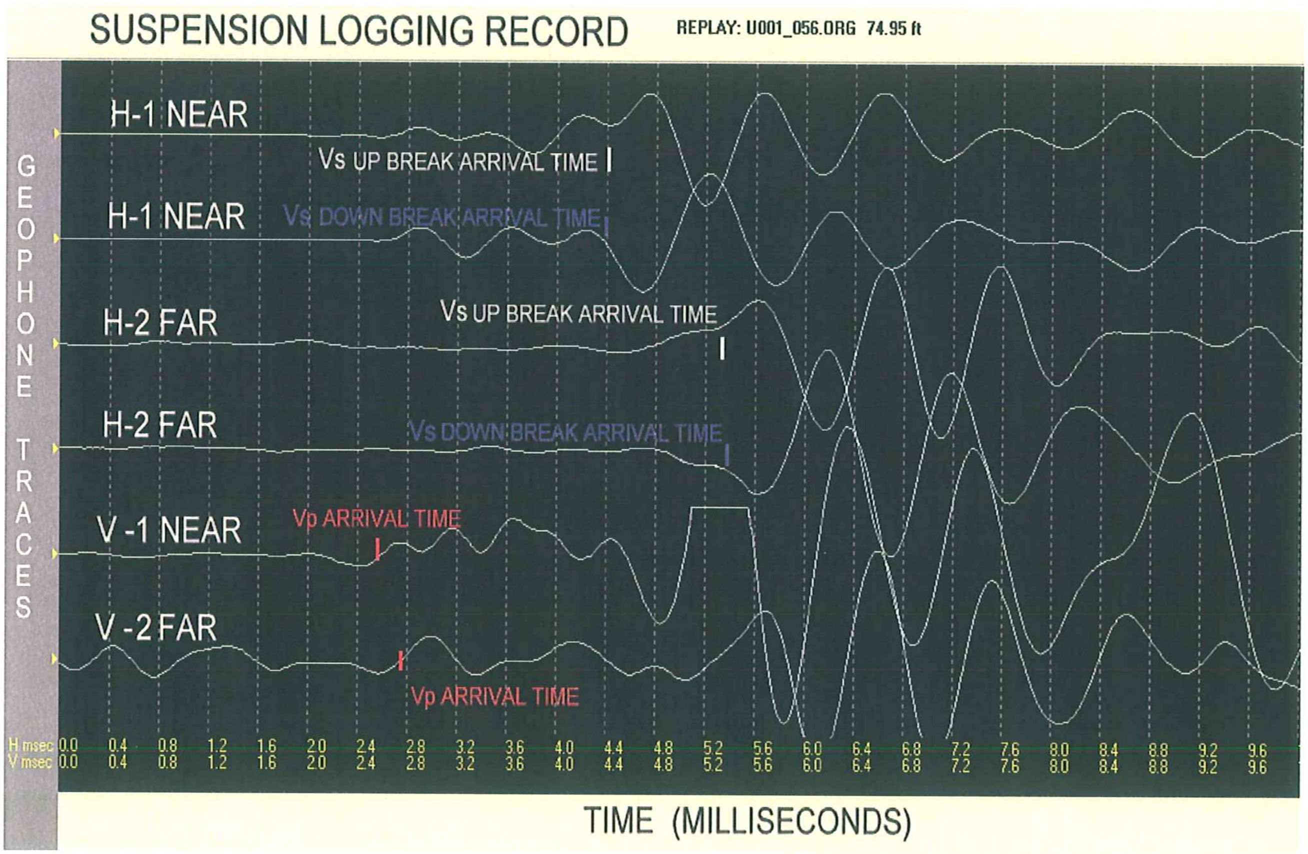
Suspension Logging Probe and System Schematic

SUSPENSION LOGGING PROBE AND EQUIPMENT CONFIGURATION



Appendix B:

Example Seismic Suspension Record



SUSPENSION LOGGING RECORD
REPLAY: U001_056.ORG 74.95 ft
H-1 NEAR
Vs UP BREAK ARRIVAL TIME
H-1 NEAR
Vs DOWN BREAK ARRIVAL TIME
H-2 FAR
Vs UP BREAK ARRIVAL TIME
H-2 FAR
Vs DOWN BREAK ARRIVAL TIME
V -1 NEAR
Vp ARRIVAL TIME
V -2 FAR
Vp ARRIVAL TIME
GEOPHONE TRACES
H msec 0.0 0.4 0.8 1.2 1.6 2.0 2.4 2.8 3.2 3.6 4.0 4.4 4.8 5.2 5.6 6.0 6.4 6.8 7.2 7.6 8.0 8.4 8.8 9.2 9.6
V msec 0.0 0.4 0.8 1.2 1.6 2.0 2.4 2.8 3.2 3.6 4.0 4.4 4.8 5.2 5.6 6.0 6.4 6.8 7.2 7.6 8.0 8.4 8.8 9.2 9.6
TIME (MILLISECONDS)

APPENDIX D

Petrographic Analysis Report

Project No. 2335-7B

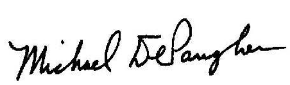
Petrographic Report #XNZ

October 12, 2009

for

George Hu
Wayne Magnusen
Alan Kropp & Associates
2140 Shattuck Ave., Suite 910
Berkeley, CA 94704

by



Michael DePangher, Ph.D.
Spectrum Petrographics, Inc.

3315 NE 112th Ave., Suite B98 Vancouver, WA 98682-8733 U.S.A. (877)-838-2950 www.petrography.com

Key to Petrographic and Photomicrographic Descriptions

Clay minerals common in altered rocks must often be identified by X-ray diffraction either because their optic properties are not diagnostic or because they are too fine grained to be reliably identified by optical methods. The term "clay" is used herein to denote fine grained phyllosilicates in general. Under ideal conditions, it is often possible to optically discriminate between 4 major groups: kaolinite, smectite, mica (including illite), and chlorite. This is done whenever conditions permit.

The term "sericite" is applied to fine grained colorless phyllosilicates that show upper 2nd order maximum interference colors. These could include muscovite, illite, paragonite, lepidolite, margarite, clintonite, pyrophyllite, and talc. The term "intermediate clay" is applied to fine grained very pale or colorless phyllosilicates that show upper 1st order maximum interference colors. These are probably dominated by chlorite, smectite, and mixed-layer illite/smectite.

The term "opaques" is used to refer to all materials opaque (and sometimes semi-opaque) to transmitted light. The term "FEOH" is herein used to indicate fine grained, yellowish to reddish brown, earthy materials of varying opacity in transmitted light. FEOH is probably mostly Fe oxy-hydroxides but may sometimes include sphalerite, realgar, orpiment, jarosite, a number of Mn oxy-hydroxides, and organic matter.

Particle size distributions are given as (A-B μm), where A and B are the median and largest particle sizes, respectively, in microns. A question mark (?) in the position of A or B indicates that the value of A or B was indeterminate, probably because of excessively large or small particle size or statistically insignificant numbers of particles.

Mineral abundances are visual estimates. For multi-lithologic materials (cuttings, etc...), mineralogy, textures, and alteration are described only for the dominant lithology.

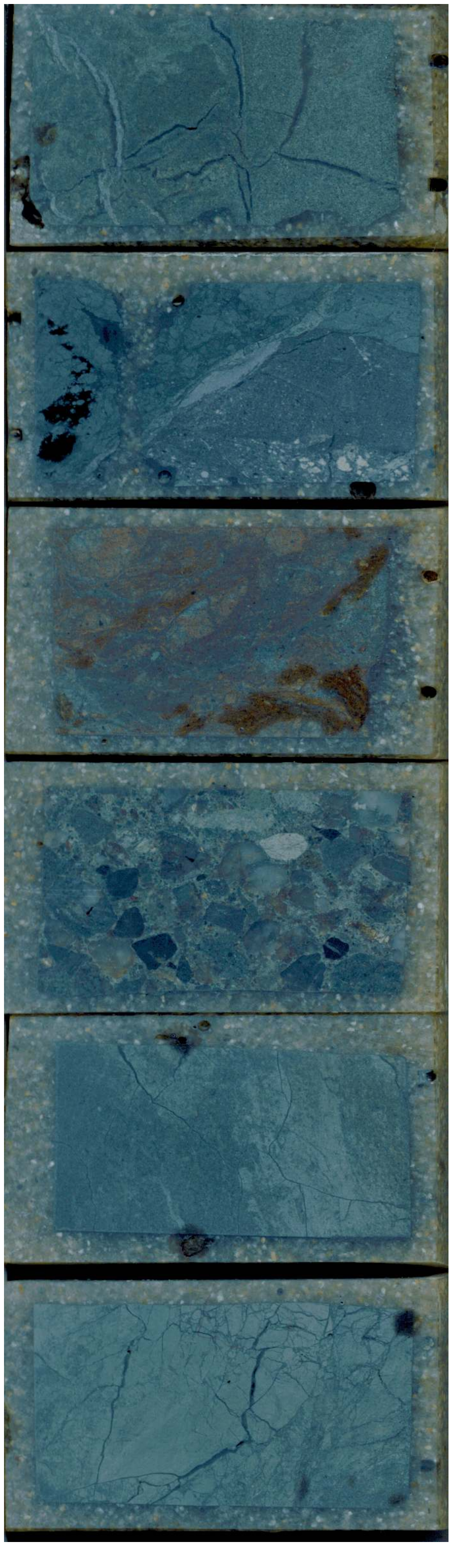
Section preparation codes are as follows: (1) Format: 27 x 46 mm, 51 x 76 mm, or 1" round; (2) Finish: standard lapping (STD) or polished (POL); (3) Stains: sodium cobaltinitrite (SCN), alizarin red S (ARS), potassium ferricyanide (PF), and barium chloride + potassium rhodizonate (BCPR); and (4) Cover: none, permanent Loctite acrylic (PLA), or removable Canada Balsam (RCB).

Photomicrograph captions/labels contain the following items of information in consecutive order separated by forward slashes: (1) sample identification; (2) film roll number; (3) frame number; (4) illumination; (5) field of view (FOV); and (6) the job identification number. "PPL" indicates plane-polarized light; "XPL indicates cross-polarized light; "R" indicates reflected light. "550" means that a 550 nanometer wavelength plate was inserted in the light path. "C" indicates that the substage condenser was in (sometimes used for Fe-oxides). "O" indicates substage condenser in an oblique position. These various illuminations can be combined. "CON" indicates conoscopic illumination. POL means that a polarizing filter was used with the lens, and DAY means the sample was photographed in diffused daylight.

Features on photomicrographs are indicated by the number of the feature in the ALTERATION section of the text or by a mineral name abbreviation: **Q**uartz, **P**lagioclase, **K**-feldspar, **b**io**t**ite, **mu**scovite, **chl**orite, **garn**et.

A question mark after a rock or mineral name in a petrographic description means that there is uncertainty about the identification of that rock or mineral.

Comments



11@26'

12@56'

8@17.5

6@84'

11@71'

5@41'

SAMPLE # **11@26'** October 10, 2009

ROCK NAME ALTERED SANDSTONE -- probably formed by alteration (secondary dolomite) of a very fine arkose (McBride, 1963) protolith.

MINERALS [Quartz + plagioclase] (55%) + clay (26%) + K-feldspar (12%) + dolomite (4%) + clinozoisite (1%) + actinolite (1%) + opaques (1%) + biotite (<1%) + sphene (<1%) + zircon (<1%).

TEXTURES Clastic sedimentary, non-directed fabric.

Detrital Framework Grains (75%) are subangular, 70-1080 µm, monocrystalline [quartz + plagioclase] (55%) + K-feldspar (12%) + clinozoisite (1%) + actinolite (1%) + biotite (<1%) + sphene (<1%) + zircon (<1%)] + lithic fragments of polycrystalline quartz (6%). Contacts between grains are tangential.

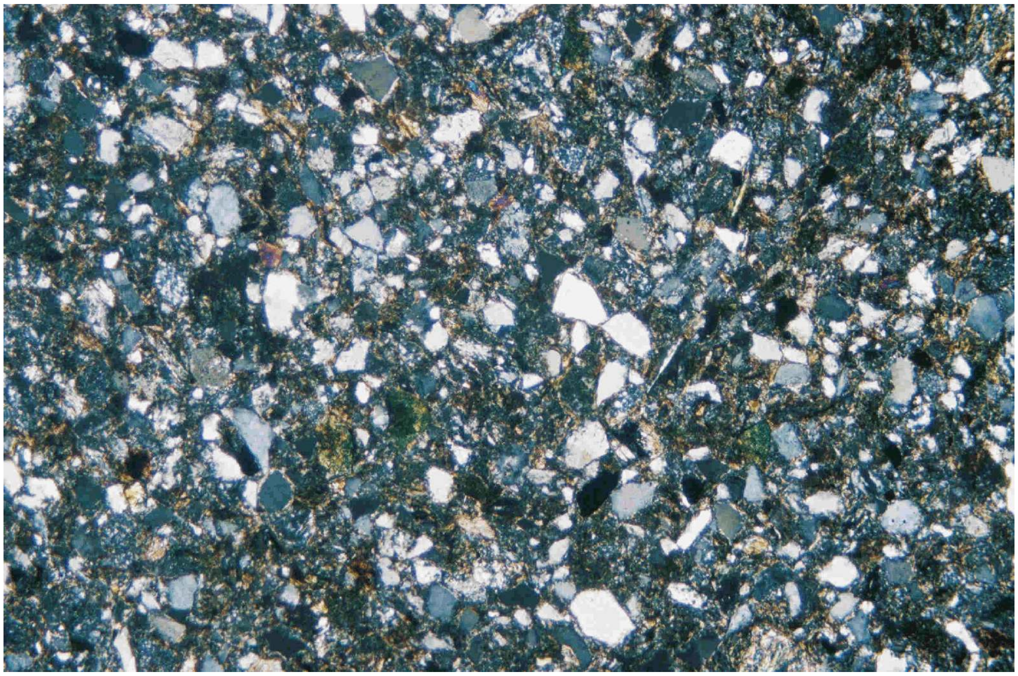
Matrix (26%) is composed of clay (includes at least some chlorite).

Cement (4%) is composed of dolomite.

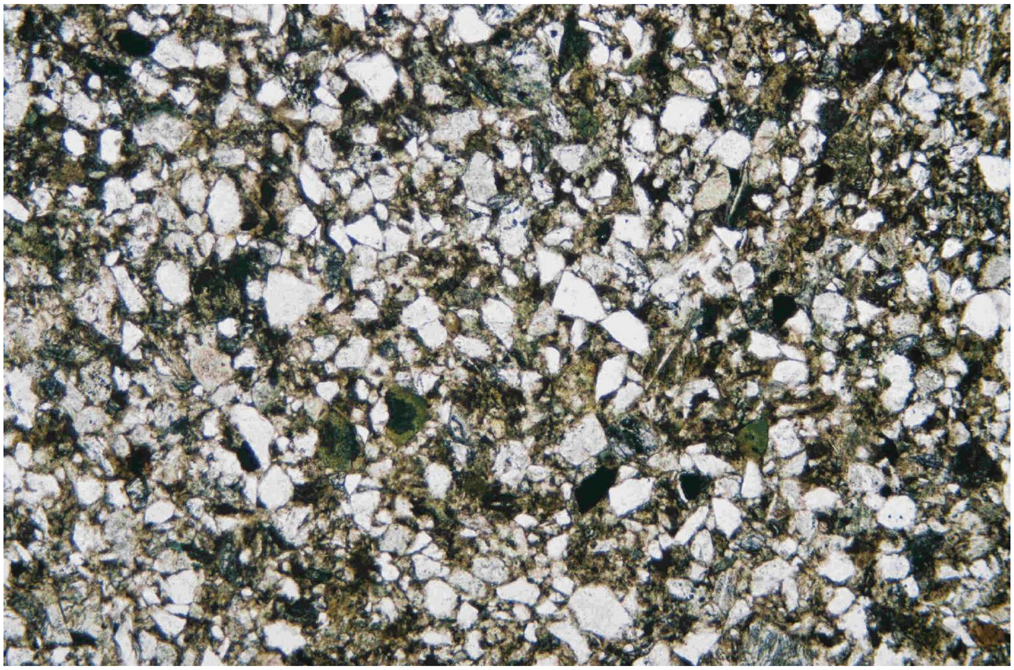
ALTERATION Alteration features in relative chronological order from oldest to youngest are: (1) veins of dolomite.

SECTIONING Format: 27 x 46 mm Finish: STD Stains: SCN (top ½) + [ARS + PF] (right ½) Cover: PLA

IMAGES 11@26' 09031_05.jpg/XPL/FOV = 1.85 x 2.69 mm/XNZ ALTERED SANDSTONE showing typical appearance of detrital framework grains in a clay matrix (same view as 09031_06.jpg).



11@26' 09031_06.jpg/PPL/FOV = 1.85 x 2.69 mm/XNZ ALTERED SANDSTONE showing typical appearance of detrital framework grains in a clay matrix (same view as 09031_05.jpg).



SAMPLE # **12@56'** October 10, 2009

ROCK NAME MUDSTONE/CLAYSTONE CATACLASITE -- probably formed by alteration (secondary dolomite) and cataclasis of dominantly claystone and sandy dolomite protoliths.

MINERALS Dolomite (35%) + clay (32%) + [quartz + plagioclase] (25%) + K-feldspar (5%) + opaques (2%) + clinozoisite (<1%) + actinolite (<1%).

TEXTURES Cataclasis has produced a weakly directed fabric.

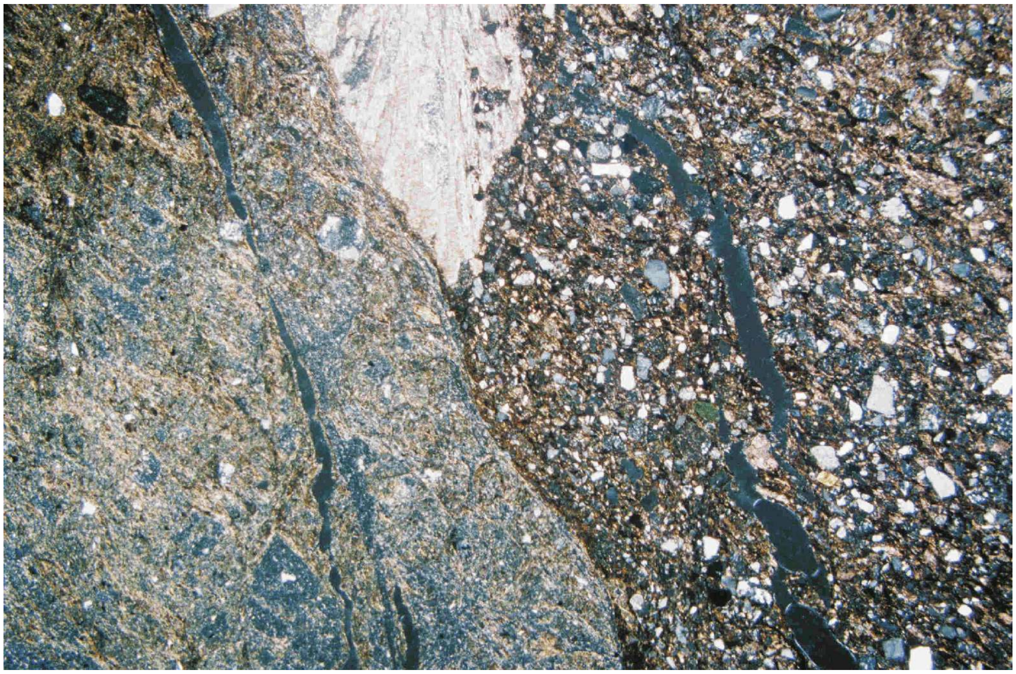
Porphyroclasts (ind.%) are subround, ?-800 µm lithic fragments of claystone + sandy dolomite with minor [polycrystalline quartz + altered basalt]. Contacts between porphyroclasts are mostly curved.

Matrix (ind.%) is composed of clay.

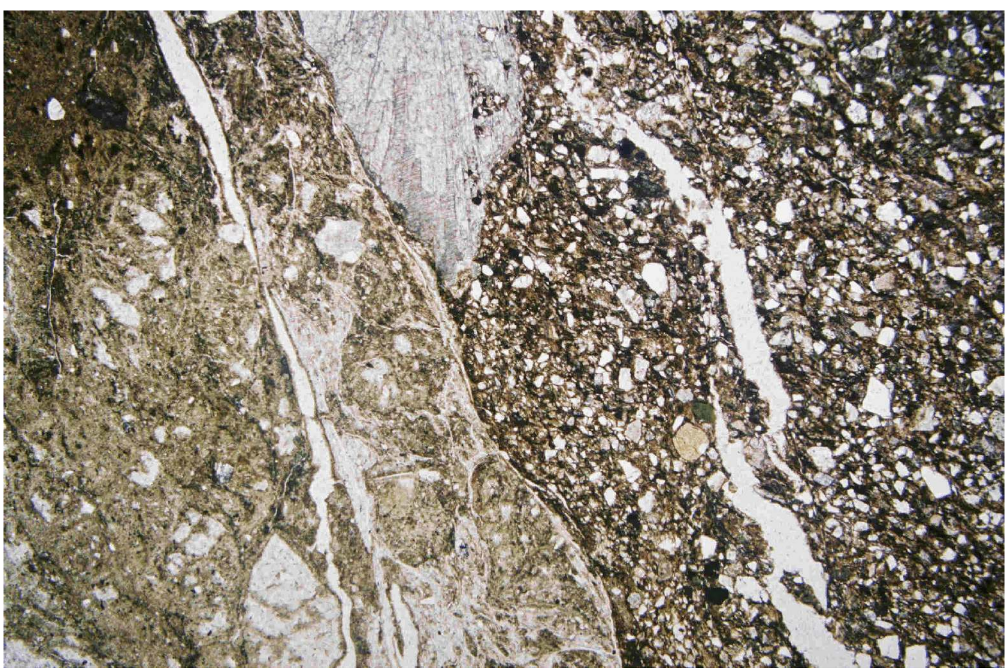
ALTERATION Alteration features in relative chronological order from oldest to youngest are: (1) veins of dolomite; and (2) cataclasis.

SECTIONING Format: 27 x 46 mm Finish: STD Stains: SCN (top 1/2) + [ARS + PF] (right 1/2) Cover: PLA

IMAGES 12@56' 09031_07.jpg/XPL/FOV = 4.00 x 5.83 mm/XNZ MUDSTONE/CLAYSTONE CATACLASITE showing typical appearance (same view as 09031_08.jpg).



12@56' 09031_08.jpg/PPL/FOV = 4.00 x 5.83 mm/XNZ MUDSTONE/CLAYSTONE CATACLASITE showing typical appearance (same view as 09031_07.jpg).



SAMPLE # **8@17.5** October 10, 2009

ROCK NAME MUDSTONE CATACLASITE -- probably formed by alteration (secondary sericite + clinozoisite) and cataclasis of a mudstone protolith.

MINERALS Clay (50%) + [quartz + plagioclase] (38%) + K-feldspar (10%) + sericite (1%) + opaques (1%) + clinozoisite (<1%) + actinolite (<1%) + sillimanite (?) (<1%).

TEXTURES Cataclasis has produced a weakly directed fabric.

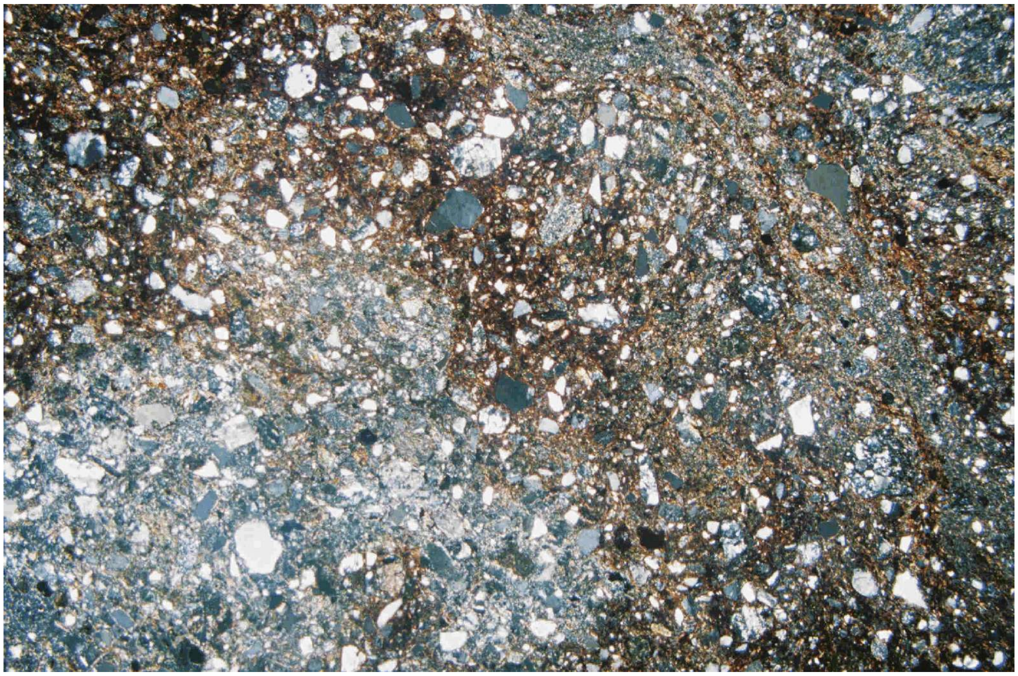
Porphyroclasts (ind.%) are subround, ?-4400 µm lithic fragments of monocrystalline [quartz + plagioclase + K-feldspar] + polycrystalline lithic fragments of [quartz + eutectic granite + quartz-sillimanite (?) schist + quartz-sericite schist]. Contacts between porphyroclasts are mostly curved.

Matrix (ind.%) is composed of clay.

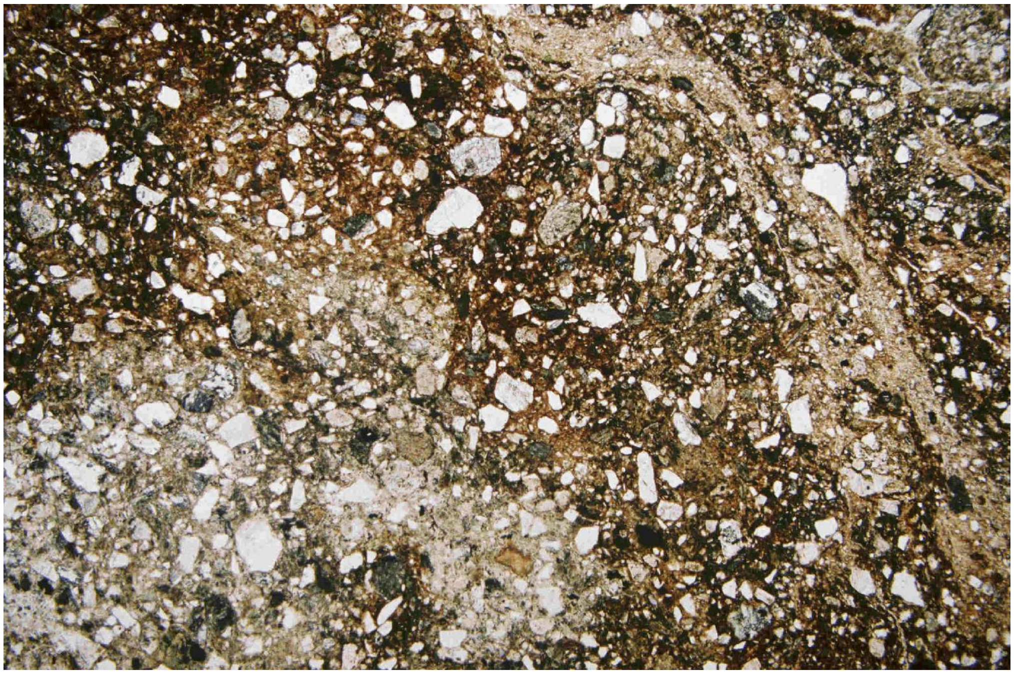
ALTERATION Alteration features in relative chronological order from oldest to youngest are: (1) plagioclase weakly altered to sericite + clinozoisite; and (2) cataclasis.

SECTIONING Format: 27 x 46 mm Finish: STD Stains: SCN (top 1/2) + [ARS + PF] (right 1/2) Cover: PLA

IMAGES 8@17.5 09031_09.jpg/XPL/FOV = 4.00 x 5.83 mm/XNZ MUDSTONE CATACLASITE showing typical appearance (same view as 09031_10.jpg).



8@17.5 09031_10.jpg/PPL/FOV = 4.00 x 5.83 mm/XNZ MUDSTONE CATACLASITE showing typical appearance (same view as 09031_09.jpg).



SAMPLE # **6@84'** October 10, 2009

ROCK NAME ALTERED CONGLOMERATE -- probably formed by alteration (secondary sericite + dolomite) and weak cataclasis of a granule litharenite (McBride, 1963) conglomerate protolith.

MINERALS Quartz (50%) + clay (30%) + sericite (6%) + plagioclase (5%) + dolomite (3%) + opaques (1%) + FEOH (<1%) + gypsum (<1%) + andalusite (<1%).

TEXTURES Clastic sedimentary; non-directed fabric.

Detrital Framework Grains (97%) are subround, 3.5-8 mm, lithic fragments strongly dominated by polycrystalline metamorphic quartz with minor sandstone + radiolarian chert + basalt + claystone + mudstone + diorite. Contacts between grains are curved.

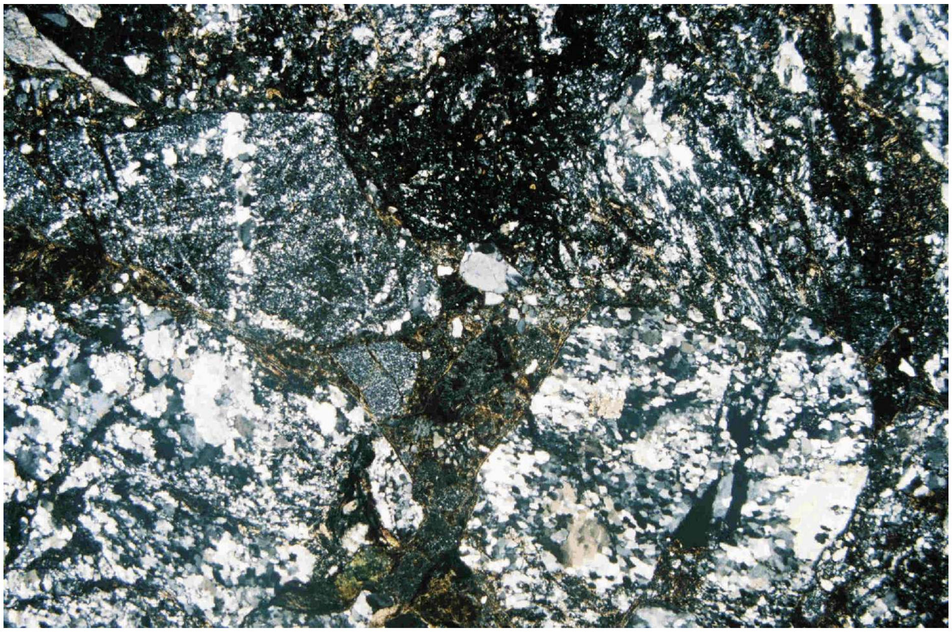
Matrix (0%) was not observed.

Cement (3%) is composed of dolomite.

ALTERATION The following alteration features are present but of indeterminate relative ages: (1) cementation by dolomite; (2) weak cataclasis; and (3) plagioclase weakly altered to sericite.

SECTIONING Format: 27 x 46 mm Finish: STD Stains: SCN (top 1/2) + [ARS + PF] (right 1/2) Cover: PLA

IMAGES 6@84' 09031_11.jpg/XPL/FOV = 4.00 x 5.83 mm/XNZ ALTERED CONGLOMERATE showing typical appearance dominated by framework grains composed of metamorphic polycrystalline quartz (same view as 09031_12.jpg).



6@84' 09031_12.jpg/PPL/FOV = 4.00 x 5.83 mm/XNZ ALTERED CONGLOMERATE showing typical appearance dominated by framework grains composed of metamorphic polycrystalline quartz (same view as 09031_11.jpg).

SAMPLE # **11@71'** October 10, 2009

ROCK NAME SANDSTONE CATACLASITE -- probably formed by cataclasis of a very fine arkose (McBride, 1963) protolith.

MINERALS [Quartz + plagioclase] (52%) + clay (25%) + K-feldspar (20%) + clinozoisite (1%) + actinolite (1%) + opaques (1%) + ferroan dolomite (<1%).

TEXTURES Cataclasis has produced a non-directed fabric.

Porphyroclasts (ind.%) are lithic fragments of very fine arkose. Contacts between porphyroclasts are indeterminate.

Matrix (ind.%) is composed of clay.

ALTERATION Alteration features in relative chronological order from oldest to youngest are: (1) cataclasis.

SECTIONING Format: 27 x 46 mm Finish: STD Stains: SCN (top 1/2) + [ARS + PF] (right 1/2) Cover: PLA

IMAGES

11@71' 09031_13.jpg/XPL/FOV = 4.00 x 5.83 mm/XNZ SANDSTONE CATACLASITE showing typical appearance (same view as 09031_14.jpg).

11@71' 09031_14.jpg/PPL/FOV = 4.00 x 5.83 mm/XNZ SANDSTONE CATACLASITE showing typical appearance (same view as 09031_13.jpg).

SAMPLE # **5@41'** October 10, 2009

ROCK NAME MUDSTONE/CLAYSTONE CATACLASITE -- probably formed by cataclasis of dominantly claystone and mudstone protoliths.

MINERALS Clay (86%) + [quartz + plagioclase] (10%) + K-feldspar (3%) + opaques (1%).

TEXTURES Cataclasis has produced a weakly directed fabric.

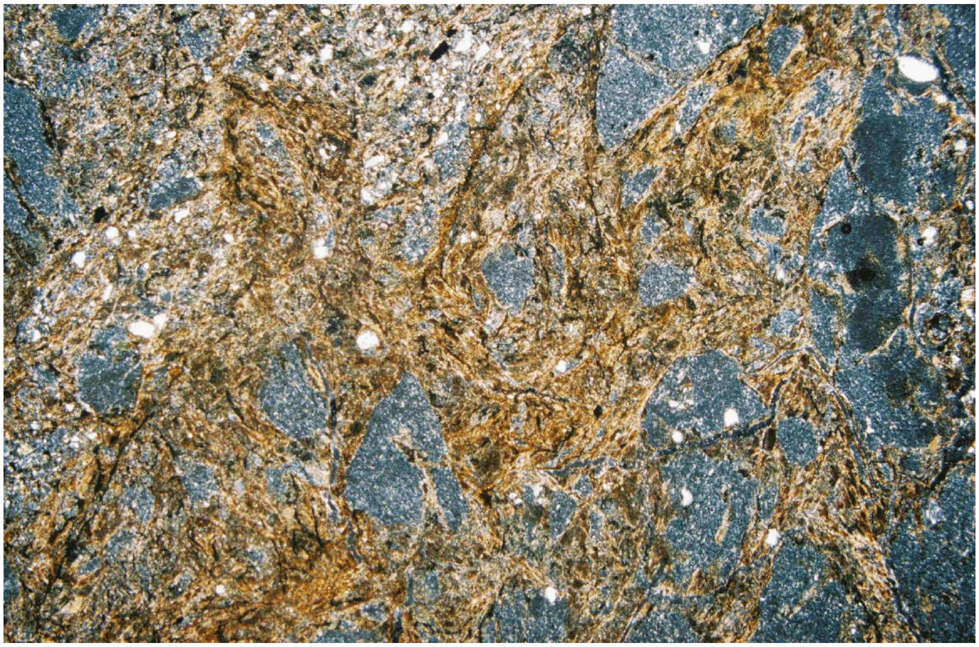
Porphyroclasts (ind.%) are lithic fragments of claystone with minor mudstone. Contacts between porphyroclasts are mostly curved.

Matrix (ind.%) is composed of the comminuted equivalent of the clasts.

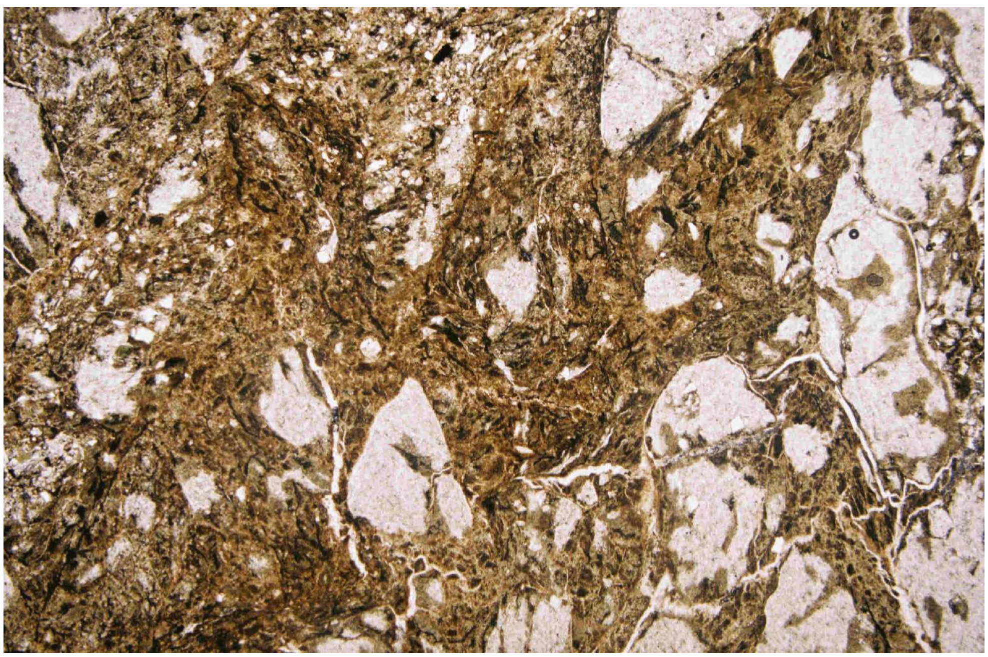
ALTERATION Alteration features in relative chronological order from oldest to youngest are: (1) cataclasis.

SECTIONING Format: 27 x 46 mm Finish: STD Stains: SCN (top 1/2) + [ARS + PF] (right 1/2) Cover: PLA

IMAGES 5@41' 09031_15.jpg/XPL/FOV = 4.00 x 5.83 mm/XNZ MUDSTONE/CLAYSTONE CATACLASITE showing typical appearance (same view as 09031_16.jpg).



5@41' 09031_16.jpg/PPL/FOV = 4.00 x 5.83 mm/XNZ MUDSTONE/CLAYSTONE CATACLASITE showing typical appearance (same view as 09031_15.jpg).



APPENDIX E

Logs of Explorations Shown on Cross Sections

Cross - Section A - A'

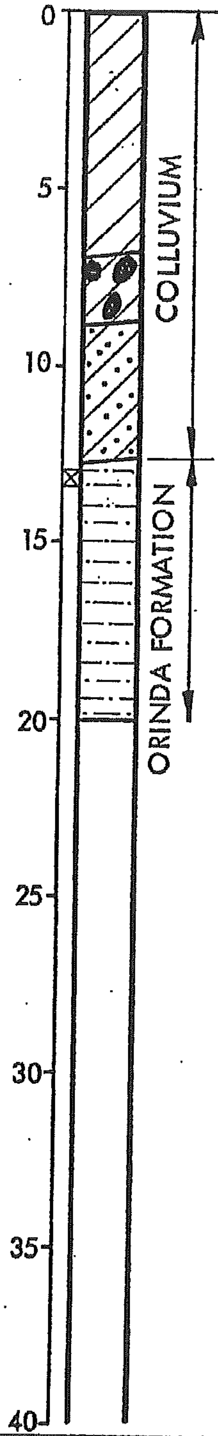
GIS #	BORING #	ORIGINAL SOURCE
307	B4	HLA (1976) - East Canyon - Biomedical Area Lawrence Berkeley Laboratory
309	B3	HLA (1976) - East Canyon - Biomedical Area Lawrence Berkeley Laboratory
417	AKA-9	AKA (2009) - Current Study
320	KB-4	Kleinfelder (2001) - LBNL Tank Road
235	B2	HLA (1976) - East Canyon - Biomedical Area Lawrence Berkeley Laboratory
284	KB-10	Kleinfelder (2001) - LBNL Tank Road
285	KB-9	Kleinfelder (2001) - LBNL Tank Road
236	B-1	HLA (1976) - East Canyon - Biomedical Area Lawrence Berkeley Laboratory
348	TP-4	GRC (1989) - Replacement of Hazardous Waste Handling Facility
347	TP-10	GRC (1989) - Replacement of Hazardous Waste Handling Facility
335	AKA-1	AKA (2006) - LBNL Animal Care Facility
253	B-1	HLA (1975) - Proposed Biodynamic Building
237	B-5	HLA (1977) - Cell Culture Building
238	B2	HLA (1975) - Proposed Biodynamic Building

LOG OF BORING 4

Shear Strength (lbs/sq ft) | Moisture Content (%) | Dry Density (pcf) | Depth (ft) | Sample

Equipment: Spin Auger

Elevation: 1062   Date: 12/5/75



DARK BROWN SANDY CLAY (CL)
stiff, moist, with occasional rock fragments

ORANGE-BROWN CLAYEY GRAVEL (GC) - stiff, wet

MOTTLED GRAY-BROWN CLAYEY SAND (SC)

GRAY-GREEN SANDY SILTSTONE
low hardness, weak, deeply weathered
change to moderately weathered moderately strong

(no free water encountered)

HARDING - LAWSON ASSOCIATES
Consulting Engineers and Geologists

Job No. 2000,106.01   Appr: JRK   Date 1/7/76

LOG OF BORING 4

East Canyon - Biomedical Area
Lawrence Berkeley Laboratory

PLATE 6

022_00012

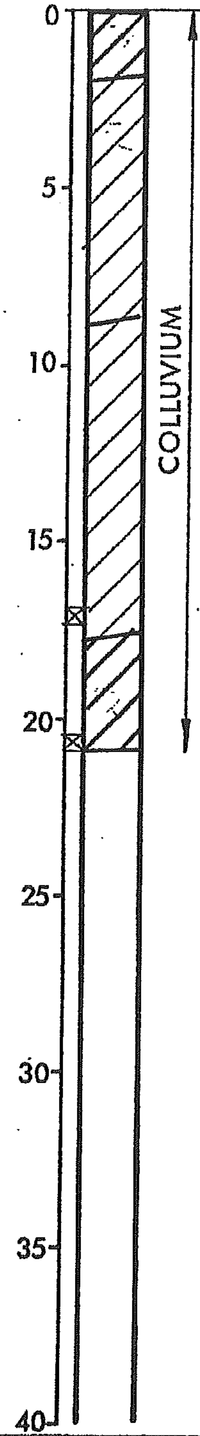
Shear Strength (lbs/sq ft)

Moisture Content (%) | Dry Density (pcf) | Depth (ft) | Sample

LOG OF BORING 3

Equipment: Spin Auger

Elevation: 1012 Date: 12/5/75



BLACK SILTY CLAY (CH)
medium stiff, wet

DARK BROWN GRAVELLY CLAY (CL) - stiff, wet

RED-BROWN GRAVELLY CLAY (CL)
medium stiff, wet

DARK GRAY CLAY (CH)
stiff, wet, with abundant small rock fragments

(no free water encountered)

HARDING - LAWSON ASSOCIATES
Consulting Engineers and Geologists

Job No. 2000,106.01 Appr: SRK Date 1/7/76

LOG OF BORING 3

East Canyon - Biomedical Area
Lawrence Berkeley Laboratory

PLATE
5

DRILL RIG: CME-55, Rotary Wash	**SURFACE ELEVATION:** 985.6 (see notes)	**LOGGED BY:** KDK
DEPTH TO GROUNDWATER: 36 feet (see notes)	**BORING DIAMETER:** 4 3/4" inches	**DATE DRILLED:** 9/22/08

DESCRIPTION AND REMARKS	COLOR	CONSISTENCY	SOIL TYPE	DEPTH (ft)	SAMPLER TYPE	SAMPLER BLOW COUNTS	MOISTURE CONTENT (%)	DRY DENSITY (pcf)	OTHER TESTS
CLAY, Lean - with gravel, dry, few organics (Qc)	Black	Stiff	CL						
				1					
				2					
				3					PP = 4.5 tsf
				4					
						14			
-moist, pea size gravel or smaller	Dark Brown			5					PP = >4.5 tsf
-less gravel, increase plasticity	Brown			6					
						12			
				7					PP = 4.0 tsf
				8					PP = 4.5 tsf
						11			PP = 1.5 tsf
				9					PP = 4.0 tsf
				10					
-increase silt, dry, increase gravel, Orinda Formation clasts									PP = 3.0 tsf
				11					PP = 3.5 tsf
				12					
-clast reduction	Dark Reddish Brown			13					PP = 3.5-4.0 tsf
				14					
-silty, moist				15					PP = 3.0 tsf
				16					
									PP = 2.5 tsf
-clasts of shale and siltstone, fining downward and fewer clasts				17					PP = >4.5 tsf
				18					
-19.4': 30 degree dipping contact between colluvium and Orinda Formation, wavy, no visible shearing, no clay gouge				19					PP = 4.5 tsf
	Greenish Gray		CL/ML						

(Continued on Next Page)

ALAN KROPP & ASSOCIATES
Geotechnical Consultants

EXPLORATORY BORING LOG
LBNL BUILDING 85
Berkeley, California

PROJECT NO.	DATE	SHEET	BORING
2335-7B	**April 2010**	**1 of 5**	**AKA-9**

DESCRIPTION AND REMARKS	COLOR	CONSISTENCY	SOIL TYPE	DEPTH (ft)	SAMPLER TYPE	SAMPLER BLOW COUNTS	MOISTURE CONTENT (%)	DRY DENSITY (pcf)	OTHER TESTS
(Continued from Previous Page)									
CLAY/SILTSTONE - jumbled Orinda siltstone and silty clay, fine grained, sheared Orinda Formation (Qls)	Greenish Gray		CL/ML						
				21					PP = 4.5 tsf
-22': 20 degree bedding, wavy and andulatory shears both inside and outside of clay seams				22					
				23					PP = 3.0 tsf
-wet, no discernable bedding structure, Orinda sandstone	Blue, Green, Yellow, Red			24					
-displaced Orinda, moist, hard, friable, fine-grained siltstone, massive to fine bedding, oxide staining	Greenish Gray			25					
				26					
				27					
-28': 60 degree contact, < 1cm thick clayey shear				28					
-28.5': 50 degree clear contact, CaCO3 deposits, increasing clay along boundary but not sharp, polished slicks, possible slide plane				29					
				30					
-30.3': 60-70 degree sharp contact, 0.1' thick clayey shear, separates dark gray from greenish gray siltstone, pebbles below	Dark Gray			31					
CLAY/SILT/CLASTS OF MORAGA - silt and clay with lenses of black hard volcanic rock	Red and Light Green		CL/GC	32					
-almost entirely Tm clasts supported in silt/clay matrix				33					
-mixed clasts of Tm supported by clayey silt matrix				34					
-crystaline Tm rock crushed with clay intermixed				35					
-35.2' - 35.5': very soft, moist, fat clay seam, slide plane	Reddish Brown			36					▼
-crystaline rock	Black								
-clasts of Tm in silty clay matrix, wet, loose, fine grained, medium plasticity	Dark Brown			37					
				38					
				39					
-Tm with MnO2 staining				40					
				41					
-below 41.2' matrix becomes more sandy, clay color lightens				42					

(Continued on Next Page)

(Continued from Previous Page)

DESCRIPTION AND REMARKS	COLOR	CONSISTENCY	SOIL TYPE	DEPTH (ft)	SAMPLER TYPE	SAMPLER BLOW COUNTS	MOISTURE CONTENT (%)	DRY DENSITY (pcf)	OTHER TESTS
-displaced Tm (Qls)	Light Brown		CL/GC	43					
				44					
-crystaline rock fragments and clay	Reddish Brown			45					
-45.5' - 46.5': basal shear zone, separates Tm from Tor, very distict zone of disruption bounded by reddish brown clay seams				46					PP = 3.5 tsf
CLAYSTONE/SILTSTONE - moist, low plasticity, massive to finely bedded, contains gravel, Orinda Formation	Dark Reddish Brown and Dark Greenish Gray		BED ROCK	47					
-47.5': 0.01' thick clay seam, 50 degree dip, minor Qls basal shear				48					
-49': 40 degree dipping shear, minor Qls basal shear				49					PP = 4.0 tsf
-50.2': clay seam, 0.1' thick, subvertical within siltstone	Yellow/Brown/Green/Red			50					
				51					PP = >4.5 tsf
-51.3': 0.1' thick gravel lense with sharp boundaries marked by clay bedding -dry, sub-horizontal partings, calcite stingers and nodules present	Green Yellow/Blue/Green/Red			52					
				53					
-53.3': 40-50 degree clay seam, coarse sandstone above siltstone -53.5 - 54': coarsened by high concentration of calcite crystals, 20% fine sand, heavily mottled	Greenish Gray			54					
				55					
-harder, paler				56					
				57					
-57.6' - 58.5': sub-horizontal clay seams bounding siltstone both sides				58					
-58.7': CaCO3 reminents and nodules -59' - 60': vertical clay seams				59					
-dry, hard, no discernable bedding (sub-horizontal partings), colors mix in fluid contact, heavily weathered	Dark Reddish Brown and Dark Greenish Gray			60					
				61					
				62					
				63					
-becomes harder, partings with polished surfaces				64					
				65					

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DESCRIPTION AND REMARKS	COLOR	CONSISTENCY	SOIL TYPE	DEPTH (ft)	SAMPLER TYPE	SAMPLER BLOW COUNTS	MOISTURE CONTENT (%)	DRY DENSITY (pcf)	OTHER TESTS
CLAYSTONE/SILTSTONE - similar to above, Orinda Formation	Dark Reddish Brown and Dark Greenish Gray		BED ROCK	66					
-66.5' - 67': dark reddish brown CLAY, moist, medium plasticity, calcite nodules present, subangular clasts, no discrete planes	Red and Green			67					
-moist to dry, friable, massive				68					
-70.4': CaCO3 subangular nodules/clasts				70					
-71.4': bedding dip, 60 degrees				71					
-massive, fine-grained, calcite rich, more sandy than above	Dark Greenish Gray			72–73					
-60 degree fracture, CaCO3 coated, <0.01' thick				74–75					
-77.2 - 77.6': sub-horizontal banding with 0.01' thick red clay lenses (varves)	Green			77					
-becomes sandier, sub-vertical CaCO3 seam				78–79					
-81.2': CacO3 nodules				81					

Depth scale (ft): 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88

(Continued on Next Page)

DESCRIPTION AND REMARKS (Continued from Previous Page)	COLOR	CONSISTENCY	SOIL TYPE	DEPTH (ft)	SAMPLER TYPE	SAMPLER BLOW COUNTS	MOISTURE CONTENT (%)	DRY DENSITY (pcf)	OTHER TESTS
CLAYSTONE/SILTSTONE - similar to above, Orinda Formation	Green and Red		BED ROCK	89					
				90					
-sub-horizontal red clay bands				91					
				92					
-harder, more cemented				93					
				94					
				95					
				96					
-96.9': conglomerate, clasts of CaCO3 (<1cm dia)	Dark Greenish Gray			97					
SANDSTONE - poorly sorted, fine-medium grained, matrix supported, well cemented, reacts to Hcl, sub-horizontal interbeds, Orinda Formation	Dark Greenish Gray			98					
SILTSTONE - massive, finely bedded with fractures dominating structure (non-linear and pervasive), no reaction to Hcl, polished surfaces on fractures, Orinda Formation	Dark Gray with Dark Greenish Gray			99 100					
				101					

Bottom of boring at 101.0 feet.

NOTES:

1. Groundwater was encountered at approximately 36 feet at the time of drilling and the boring was backfilled immediately after drilling. (See report for discussion.)
2. Stratification lines represent the approximate boundaries between material types and the transitions may be gradual.
3. Penetration resistance values (blow counts) marked with an asterisk (*) are not standard penetration resistance values.
4. Elevations were measured by LBNL personnel.
5. Approximate unconfined compressive strength values were recorded in the field using a pocket penetrometer. These values are shown on the logs and are preceded by the symbol "PP".
6. Blow counts have not been corrected for hammer energy.

ALAN KROPP & ASSOCIATES
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EXPLORATORY BORING LOG LBNL BUILDING 85 Berkeley, California			
PROJECT NO.	DATE	SHEET	BORING **AKA-9**
2335-7B	**April 2010**	**5 of 5**	

Other Laboratory Tests	Dry Density (pcf)	Moisture Content (%)	Sample Interval (feet)	Blows/ Foot *	DEPTH (FEET)	Description
						EQUIPMENT: **Morooka MST 600** ELEVATION: **985.0 ****
						LOGGED BY: **Ted Crump** START DATE: **2-26-01**
						STATION: **9+00** FINISH DATE: **2-26-01**
				24	0	DARK BLACKISH BROWN SANDY CLAY (CH), very stiff, wet with fine roots and some reddish brown rock fragments (Colluvium)
LL=66PL=25PI=41 UC 2045	95	27.7		29	5	Becomes brown in color and hard with small gravel and apparent charcoal pieces (Colluvium)
				37	10	LIGHT BROWN SANDY CLAY (CL), hard, moist with small angular rock fragments (Colluvium)
LL=40,PL=23,PI=17				38	15	
	106	20.6		50+	20	Some small reddish fragments
					25	Soft wet sandy clay observed in auger cuttings
				50+		DARK GRAY BEDROCK OF THE ORINDA FORMATION, closely fractured, low hardness, moderately weathered

BOTTOM OF BORING 29.5 FEET
Groundwater Encountered 21 Feet and 22 Feet

* Converted to equivalent standard penetration blow counts.

** Existing ground surface at time of drilling.

KLEINFELDER
Geotechnical, Materials and Environmental Engineering

PROJECT NUMBER **41-7631-01-001** DATE **JUN 2001**

LOG OF BORING KB-4

LBNL TANK ROAD

Berkeley, California

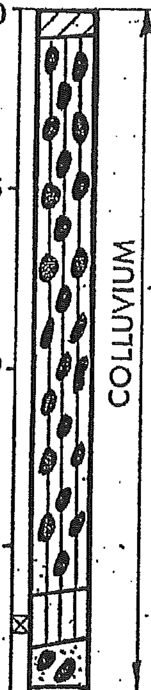
PLATE **A-6**

LOG OF BORING 2

Equipment: Spin Auger
Elevation: 952 Date: 12/5/75

Shear Strength (lbs/sq ft) | Moisture Content (%) | Dry Density (pcf) | Depth (ft) | Sample

Depth (ft): 0, 5, 10, 15, 20, 25, 30, 35, 40



DARK BROWN SANDY CLAY (CL)
medium stiff, moist, with occasional rock fragments

LIGHT BROWN SILTY SANDY GRAVEL (GM) - medium dense, dry, with abundant weathered volcanic rock fragments
hole caving at 6' and at 15'

GRAY SANDY SILT (ML)
soft, moist, with shear planes, decayed vegetation

BROWN GRAVEL (GP)
loose, moist

(no free water encountered)

HARDING - LAWSON ASSOCIATES
Consulting Engineers and Geologists

Job No. 2000,106.01 Appr: SRK Date 1/7/76

LOG OF BORING 2
East Canyon - Biomedical Area
Lawrence Berkeley Laboratory

PLATE 4

022_00010

Other Laboratory Tests	Dry Density (pcf)	Moisture Content (%)	Sample Interval (feet)	Blows/ Foot *	DEPTH (FEET)
				42	
				45	
				50+	

EQUIPMENT: Morooka MST-600 ELEVATION: 912.0 **
LOGGED BY: Ted Crump START DATE: 3-27-01
STATION: 1+10 L20 FINISH DATE: 3-27-01

0 DARK BROWN SANDY GRAVELLY CLAY (CL), medium stiff, moist with abundant angular gravels (Colluvium)

DARK BROWN SANDY CLAY (CH), hard, moist with some small angular gravels and light blue clay seams

MOTTLED LIGHT BLUE AND GRAY CLAY SAND GRAVEL (GC), very dense, wet (Possible Orinda formation bedrock interface with colluvium)

BOTTOM OF BORING 33.5 FEET
No Groundwater Encountered

* Converted to equivalent standard penetration blow counts.
** Existing ground surface at time of drilling.

KLEINFELDER
Geotechnical, Materials and Environmental Engineering

PROJECT NUMBER 41-7631-01-001 DATE JUN 2001

LOG OF BORING KB10

LBNL TANK ROAD
Berkeley, California

PLATE A-12

EQUIPMENT: **Morooka MST 600**		ELEVATION: **912.0 ****
LOGGED BY: **Steve Carroll**		START DATE: **2-27-01**
STATION: **1+30 R10**		FINISH DATE: **2-27-01**

Other Laboratory Tests	Dry Density (pcf)	Moisture Content (%)	Sample Interval (feet)	Blows/ Foot *	DEPTH (FEET)	Description
					0	LIGHT BROWN SANDY CLAY (CL), medium stiff, moist, porous with roots and angular gravels and bedrock fragments (Colluvium)
				31		Becomes hard and yellow brown in color
					5	
				31		
				50+	10	
TxUU 4441(1000)	113	16.2		50+		Becomes light brown to brown in color
					15	
				50+		MOTTLED LIGHT BROWN, BROWN AND BLACK CLAYEY GRAVEL (GC), very dense, moist, (Colluvium)
						BOTTOM OF BORING 19.1 FEET No Groundwater Encountered

* Converted to equivalent standard penetration blow counts.

** Existing ground surface at time of drilling.

KLEINFELDER
Geotechnical, Materials and Environmental Engineering

PROJECT NUMBER **41-7631-01-001** DATE **JUN 2001**

LOG OF BORING KB-9

LBNL TANK ROAD

Berkeley, California

PLATE **A-11**

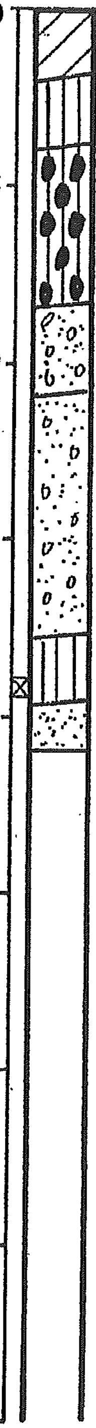
LOG OF BORING 1

Equipment: Spin Auger

Elevation: 905 Date: 12/5/75

Shear Strength (lbs/sq ft) | Moisture Content (%) | Dry Density (pcf) | Depth (ft) | Sample

Depth (ft): 0, 5, 10, 15, 20, 25, 30, 35, 40



MORAGA FORMATION AND/OR COLLUVIUM

DARK BROWN SANDY CLAY (CL)
stiff, moist, with occasional rock fragments

BROWN GRAVELLY SILT (ML)
stiff, dry, with occasional volcanic rock fragments

BROWN SANDY GRAVEL (GM)
dense, dry, (weathered volcanic agglomerate), moderately hard, moderately strong, deeply weathered

GRAY BROWN AGGLOMERATE
closely fractured, moderately hard, moderately strong, moderately weathered, with occasional andesite fragments

LIGHT BROWN AND YELLOW TUFFACEOUS AGGLOMERATE
moderately hard, moderately strong, moderately weathered slightly moist

ORINDA FORMATION

MOTTLED GREEN-BROWN CLAYEY SILT (ML) – stiff, moist, with rock fragments

GREEN SILTY SANDSTONE
low hardness, friable, deeply weathered

(no free water encountered)

HARDING - LAWSON ASSOCIATES
Consulting Engineers and Geologists

Job No. 2000,106.01 Appr: ??? Date 1/7/76

LOG OF BORING 1
East Canyon – Biomedical Area
Lawrence Berkeley Laboratory

PLATE 3

LOG OF TEST PIT TP-3

Equipment: Backhoe

Elevation: ±897 Date: 8-9-88

Depth (ft.)	Description
0	DARK BROWN SILTY CLAY (CH) Slightly moist, stiff
	VERY DARK BROWN CLAY (CH) Very moist, very stiff, contains small weathered gravel clasts
5	DARK BROWN CLAY (CL) Contains large gravel clasts
	DARK GRAY ANDESITE (Moraga Fm) Hard and strong where fresh, closely fractured, moderately weathered contains clay and loose material in fractures
10	Total Depth: 9 ft. No Free Water
15	

LOG OF TEST PIT TP-4

Equipment: Backhoe

Elevation: ±895 Date: 8-9-88

Depth (ft.)	Description
0	BROWN SILTY CLAY (CL-ML) contains gravel
	GRAY ANDESITE (Moraga Fm) closely fractured, mod. hard, mod. strong weathered, little to moderately weathered
5	
	more weathered below 8 ft.
10	Total Depth: 10 ft. No Free Water
15	

Geo/Resource Consultants, Inc.
Consulting Engineers, Geologists, Geophysicists

Job No. 1393-00 Appr: Date 10/16/89

LOGS OF TEST PITS TP-3 & TP-4

REPLACEMENT OF HAZARDOUS WASTE HANDLING FACILITY AT LAWRENCE BERKELEY LABORATORY BERKELEY, CALIFORNIA

FIGURE A-2

LOG OF TEST PIT TP- 9

Equipment Backhoe

Depth (ft.) Elevation ±888 Date 8-10-88

Depth (ft.)	Description
0	DARK BROWN SILTY CLAY (CH) moist, very stiff
	BROWN GRAVELLY SANDY CLAY (CL) moist, very stiff contains clasts of andesite, friable sandstone (debris flow deposit)
5	BROWN CLAY (CL) moist, very stiff to hard contains small clasts of decomposed sandstone, some chert
10	GRAVELLY CLAY (CL-GC) wet, very stiff contains chert clasts
	Total Depth: 11.5 ft No Free Water
15	

LOG OF TEST PIT TP- 10

Equipment Backhoe

Depth (ft.) Elevation ±893 Date 8-11-88

Depth (ft.)	Description
0	DARK BROWN SILTY CLAY (CH) moist, very stiff
	BROWN GRAVELLY CLAY (CL) moist, very stiff to hard
5	ANDESITE (Moraga Fm) closely fractured with intensely fractured zones moderately weathered with deeply weathered zones hard, strong on fresh surfaces fractures stained and contain clay
	Total Depth: 7.5ft No Free Water
10	
15	

Geo/Resource Consultants, Inc.
Consulting Engineers, Geologists, Geophysicists

Job No: 1393-00 Appr: ______ Date 10/16/89

LOGS OF TEST PITS TP-9 & TP-10
REPLACEMENT OF HAZARDOUS WASTE HANDLING FACILITY AT LAWRENCE BERKELEY LABORATORY BERKELEY, CALIFORNIA

FIGURE A-5

DRILL RIG: Rotary Wash	SURFACE ELEVATION: ± 872 feet	LOGGED BY: JP
DEPTH TO GROUNDWATER: See Notes	BORING DIAMETER: 5 inches	DATE DRILLED: 08-16-04

DESCRIPTION AND REMARKS	COLOR	CONSISTENCY	SOIL TYPE	DEPTH (feet)	SAMPLER	BLOWS / FT	MOISTURE CONTENT (%)	DRY DENSITY (pcf)	OTHER TESTS
SILTSTONE to SANDSTONE, fine-grained, highly weathered, fractured, silty clay matrix along larger blocks; (LANDSLIDE DEBRIS), (continued from previous sheet)	Dark Reddish Brown	Soft Hardness	ROCK	21					
-21-22': less fractured -22.5': contact dips 25°-30° between upper dark reddish brown clay rich siltstone and distinct bluish gray siltstone, pervasive blocky fractures	Bluish Gray			22		[37]			
				23		23			
CLAY, slickensides, dips 20°, (interpreted slide plane)	Bluish Gray	Soft	CH	24					
SILTSTONE, abundant clay, blocky to seamy fractures, with anastomosing fabric, shiny surfaces, strongly sheared to crushed bluish gray siltstone;(LANDSLIDE DEBRIS)	Dark Reddish Brown to Bluish Gray	Stiff	ROCK	25					
				26					
-transition landslide to bedrock (LANDSLIDE DEBRIS ↑)				27		[73]			
SILTSTONE, highly weathered, fractured, less clay rich and losing seamy fabric, still abumdant fractures, becoming blue in color	Dark Reddish Brown	Soft Hardness	BED-ROCK	28					
-29.5-31.5': solid blocky fractures, no clay seams, fracture spacing 1 to 2 inches and blocky, no apparent bedding	Bluish Gray			29		77			
				30					
				31					
				32					
	Reddish Brown			33		[94]			
-34-37.5': weak to moderately strong material, fracture spacing 2 to 3 inches	Grayish Reddish Brown			34		82			
				35					
				36					⊻ 16 hours after drilling
				37		[50]/5"			
SANDSTONE, very-fine-grained, silty, large blocky fractures, no clay seams, bedding dip 20°-40°, weak to moderately strong -39': prominent steep 60° dipping tight fracture, subhorizontal reddish brown weathered zone (continued on next sheet)	Bluish Gray	Moderate Hardness	BED-ROCK	38					
				39					
				40					

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EXPLORATORY BORING LOG

LBNL ANIMAL CARE FACILITY
Berkeley, California

PROJECT NO.	DATE	SHEET	BORING NO.
2335-2	September 2004	2 of 4	1

DRILL RIG: Rotary Wash	SURFACE ELEVATION: ± 872 feet	LOGGED BY: JP
DEPTH TO GROUNDWATER: See Notes	BORING DIAMETER: 5 inches	DATE DRILLED: 08-16-04

DESCRIPTION AND REMARKS	COLOR	CONSISTENCY	SOIL TYPE	DEPTH (feet)	SAMPLER	BLOWS / FT	MOISTURE CONTENT (%)	DRY DENSITY (pcf)	OTHER TESTS
SANDSTONE, very-fine-grained, silty, large blocky fractures, no clay seams, bedding dip 15°-20°, moderate to hard strong, thin sandy laminations (continued from previous sheet)	Dark Gray to Light Gray	Moderate Hardness	BED-ROCK	41					
				42					
				43					
				44					
-44.5-45': highly fractured and crushed sandstone, with fine gravels, fractures at 45 feet, widely spaced with minor displacement (?)				45					
				46					
-47': very-fine-to-medium-grained sandstone, fractured with mineralization dip 45°-50°, very small micro-faults, bedding dip between units 45°-50°	Bluish Gray Green to Brown			47					
				48					
				49					
-50': siltstone with cemented gravel and coarse sand, erosional contact (paleochannel?) moderate to strong, few fractures tight				50					
				51					
				52					
-finer grained at 53' -53-53.5': thin lense of cemented fine gravel, fractures at 1" spacing	Gray			53					
-54': bedding dip 20° -54-56': excellent interbeds of cross-bedded and laminated sand and silt to claystone (erosional contacts)	Gray to Brown			54					
				55					
-56-60': prominent sandstone and siltstone interbeds, interbedded siltstone bedding dips 20°, stong to very strong	Gray			56					
				57					
				58					
				59					
(continued on next sheet)				60					

ALAN KROPP & ASSOCIATES
Geotechnical Consultants

EXPLORATORY BORING LOG

LBNL ANIMAL CARE FACILITY
Berkeley, California

PROJECT NO.	DATE	SHEET	BORING NO.
2335-2	September 2004	3 of 4	1

DRILL RIG: Rotary Wash	SURFACE ELEVATION: ± 872 feet	LOGGED BY: JP
DEPTH TO GROUNDWATER: See Notes	BORING DIAMETER: 5 inches	DATE DRILLED: 08-16-04

DESCRIPTION AND REMARKS	COLOR	CONSISTENCY	SOIL TYPE	DEPTH (feet)	SAMPLER	BLOWS / FT	MOISTURE CONTENT (%)	DRY DENSITY (pcf)	OTHER TESTS
SANDSTONE, very-fine-grained, large blocky fractures, no clay seams, bedding dip 15°-20°, moderate to hard strong, thin sandy laminations (continued from previous sheet)	Gray	Moderate Hardness	BED-ROCK	61					
-62-65': interbedded siltstone to claystone and sandstone, very blocky, very hard, numerous sealed microfaults, highly fractures	Brown			62, 63, 64					
-65': very-fine-grained-sandstone with steep fractures, interbedded fine to coarse sand, dipping 15°, abundant sealed microfaults, highly fractured	Bluish Gray			65, 66, 67					
-68-69': fracture dipping 45°	Brown to Gray			68, 69					
CLAYSTONE, abundant blocky seamy fractures, very weak to weak, no clay seams along fractures	Dark Brown with Gray	Soft Hardness	BED-ROCK	70, 71					
-70-72': pulverized and crushed									
SANDSTONE, very-fine-grained, moderate to strong, bedding dip with claystone 30°	Gray	Hard Hardness	BED-ROCK	72, 73					

Bottom of boring at 74 feet

NOTES

1. Groundwater was encountered at a depth of about 36 feet 16 hours after drilling. The boring was grouted following drilling. (See text for discussion.)
2. Stratification lines represent the approximate boundaries between material types and the transitions may be gradual.
3. Penetration resistance values (blow counts) enclosed in brackets ([ ]) were recorded with a 3.0-inch O.D. Modified California sampler; these are not standard penetration resistance values.
4. Elevations were determined from topographic map supplied by LBNL Facilities Department, 2004.

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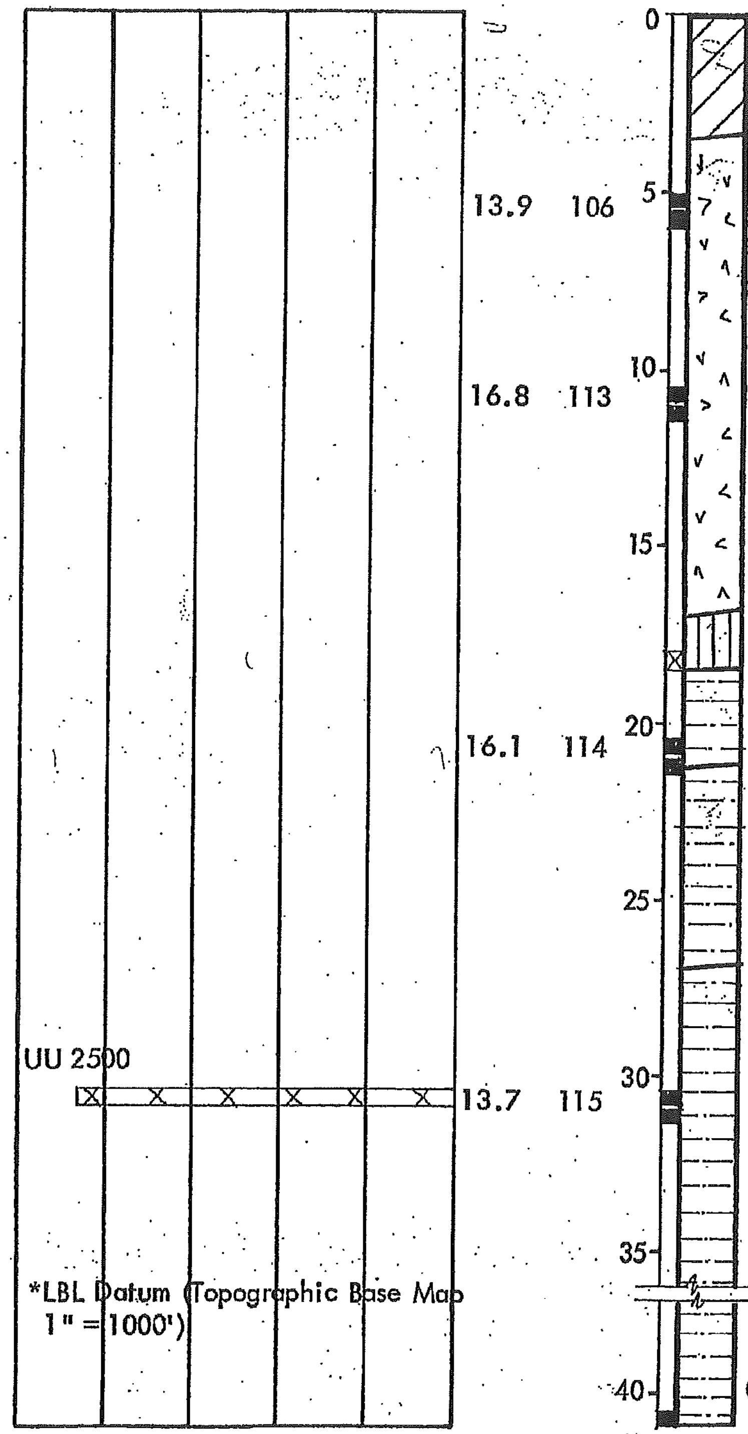
EXPLORATORY BORING LOG

LBNL ANIMAL CARE FACILITY
Berkeley, California

PROJECT NO.	DATE	SHEET	BORING NO.
2335-2	September 2004	4 of 4	1

LOG OF BORING 1

Equipment: Hollow Stem Auger
Elevation: 862 *   Date: 6/21/75



Moisture Content (%)	Dry Density (pcf)	Depth (ft)
		0
13.9	106	5
16.8	113	10
		15
16.1	114	20
		25
13.7	115	30
		35
		40

Colluvium

BROWN SILTY CLAY (CL)
medium stiff, moist, with small angular rock fragments

MORAGA FORMATION

GRAY-BROWN ANDESITE
intensely fractured, moderately hard, moderately strong, deeply weathered

water level 6/24/75

ORINDA FORMATION

GRAY-GREEN CLAYEY SILT (ML)
soft, moist

GRAY-GREEN SANDY SILTSTONE
low hardness, weak, moderately weathered

RED-BROWN CLAYSTONE
low hardness, weak, moderately weathered

GRAY-GREEN SILTSTONE
low hardness, weak, moderately weathered

becoming sandy, little weathered, massive
(2" diameter plastic pipe placed in hole after completion of drilling)

HARDING - LAWSON ASSOCIATES
Consulting Engineers and Geologists

Job No. 2000,104.01   Appr: SRK   Date 7/11/75

LOG OF BORING 1
Proposed Biodynamic Building
Lawrence Berkeley Laboratory

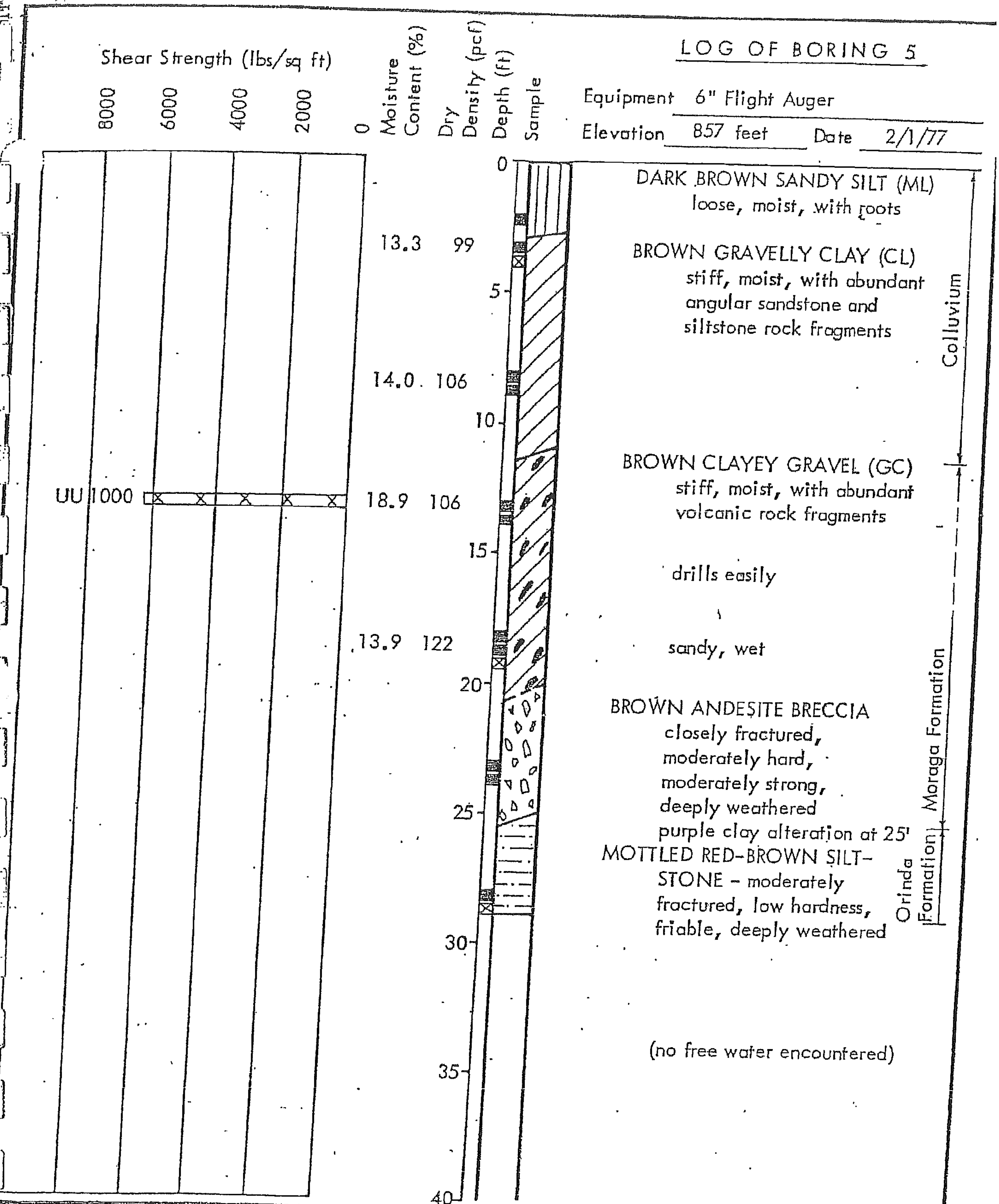
PLATE 2

029_00007

LOG OF BORING 5

Equipment 6" Flight Auger

Elevation 857 feet Date 2/1/77



HARDING - LAWSON ASSOCIATES

Consulting Engineers and Geologists

No. 2000,104.01 Appr: JB Date 4/8/77

LOG OF BORING 5

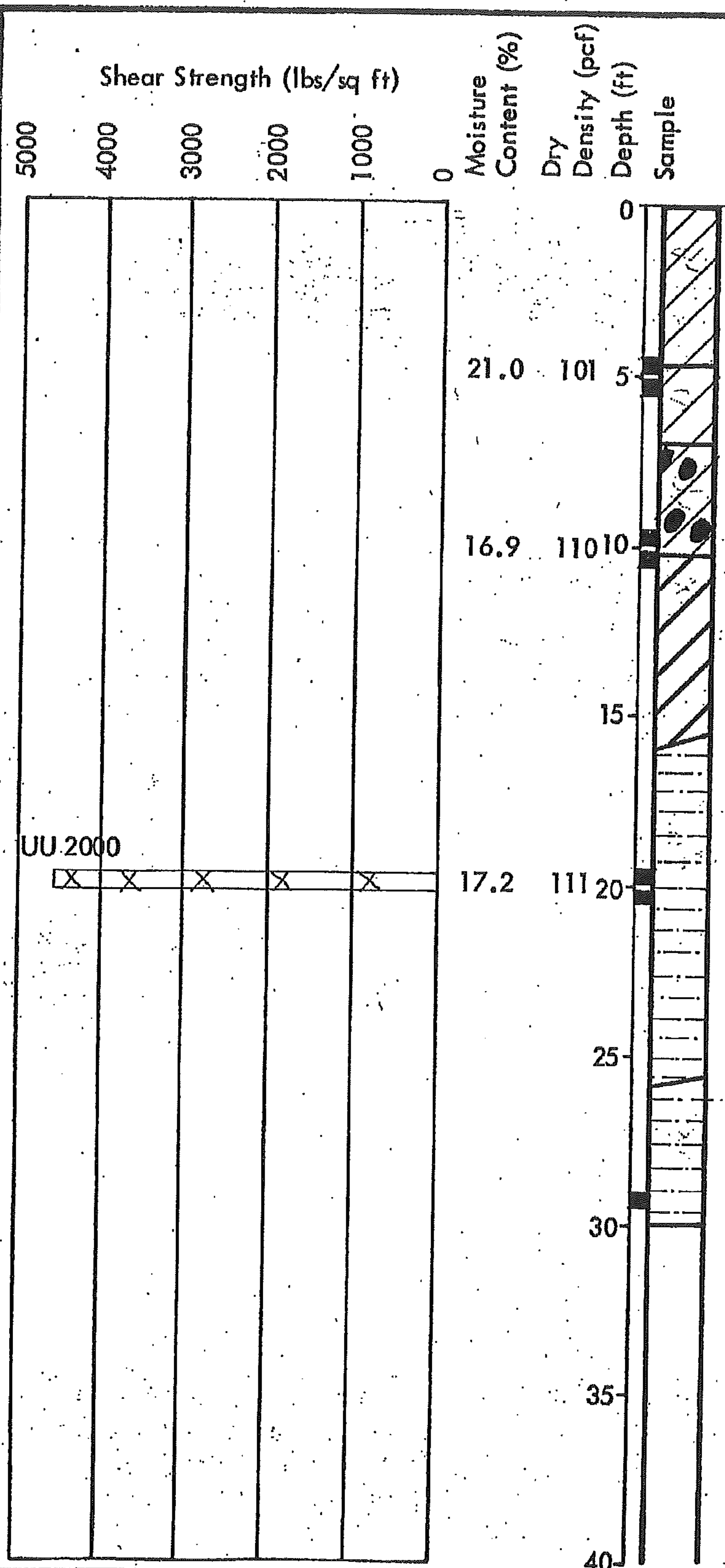
Cell Culture Building
Lawrence Berkeley Laboratory

PLATE 6

RFII

LOG OF BORING 2

Equipment: Hollow Stem Auger
Elevation: 840 Date: 6/21/75



DARK BROWN SANDY CLAY (CL) stiff, dry

MOTTLED BROWN SANDY CLAY (CL) - stiff, moist, with abundant angular rock

BROWN CLAYEY GRAVEL (GC) dense, moist (Predominantly Andesite Fragments)

RED-BROWN SILTY CLAY (CH) stiff, moist, with occasional rock fragments

MOTTLED RED-BROWN & GREEN CLAYSTONE - crushed and sheared, soft, weak, deeply weathered

GRAY-GREEN SANDY SILTSTONE - moderately fractured, low hardness, weak, little weathered

(no free water encountered)

(2" diameter plastic pipe placed in hole after completion of drilling)

HARDING - LAWSON ASSOCIATES
Consulting Engineers and Geologists

Job No. 2000,104.01 Appr: SRK Date 7/11/75

LOG OF BORING 2
Proposed Biodynamic Building
Lawrence Berkeley Laboratory

PLATE 3

029_00008

Cross - Section B - B'

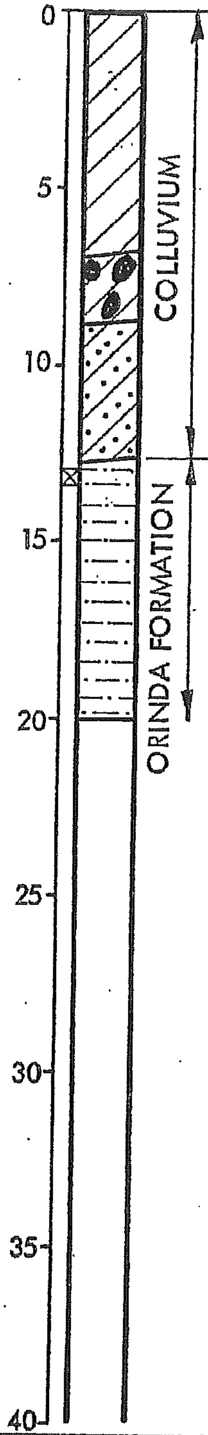
GIS #	BORING #	ORIGINAL SOURCE
307	B4	HLA (1976) - East Canyon - Biomedical Area Lawrence Berkeley Laboratory
309	B3	HLA (1976) - East Canyon - Biomedical Area Lawrence Berkeley Laboratory
417	AKA-9	AKA (2009) - Current Study
320	KB-4	Kleinfelder (2001) - LBNL Tank Road
235	B2	HLA (1976) - East Canyon - Biomedical Area Lawrence Berkeley Laboratory
286	KB-11	Kleinfelder (2001) - LBNL Tank Road
332	AKA-7	AKA (2006) - LBNL Buildings 85 and 85A
336	AKA-4	AKA (2006) - LBNL Buildings 85 and 85A
360	TP 3	SCI (1996) - Building 85 Modular Office Pad
361	TP 2	SCI (1996) - Building 85 Modular Office Pad
362	TP 1	SCI (1996) - Building 85 Modular Office Pad
235	B7	D&M (1960) - First Increment, Proposed Animal Bioradiological Laboratory
416	AKA-8	AKA (2009) - Current Study
304	B1	CWDD (2004) - Centennial Drive Overpass Landslide
503	AKA-3	AKA (2009) - Centennial Bridge
306	B3	CWDD (2004) - Centennial Drive Overpass Landslide

LOG OF BORING 4

Shear Strength (lbs/sq ft) | Moisture Content (%) | Dry Density (pcf) | Depth (ft) | Sample

Equipment: Spin Auger

Elevation: 1062 Date: 12/5/75



DARK BROWN SANDY CLAY (CL)
stiff, moist, with occasional rock fragments

ORANGE-BROWN CLAYEY GRAVEL (GC) - stiff, wet

MOTTLED GRAY-BROWN CLAYEY SAND (SC)

GRAY-GREEN SANDY SILTSTONE
low hardness, weak, deeply weathered
change to moderately weathered moderately strong

(no free water encountered)

HARDING - LAWSON ASSOCIATES
Consulting Engineers and Geologists

Job No. 2000,106.01 Appr: JRK Date 1/7/76

LOG OF BORING 4
East Canyon - Biomedical Area
Lawrence Berkeley Laboratory

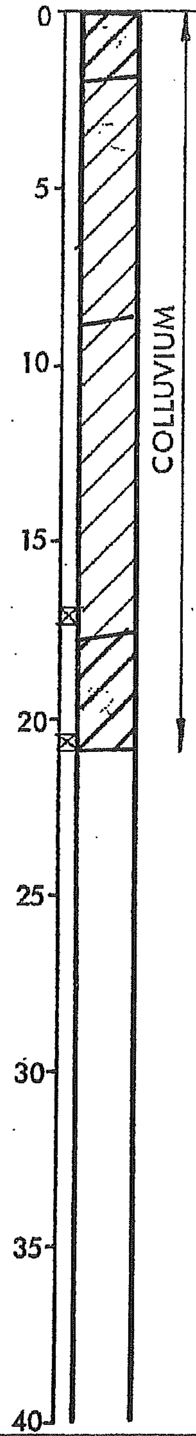
PLATE 6

022_00012

LOG OF BORING 3

Shear Strength (lbs/sq ft)	Moisture Content (%)	Dry Density (pcf)	Depth (ft)	Sample

Equipment: Spin Auger
Elevation: 1012   Date: 12/5/75



BLACK SILTY CLAY (CH)
medium stiff, wet

DARK BROWN GRAVELLY CLAY (CL) - stiff, wet

RED-BROWN GRAVELLY CLAY (CL)
medium stiff, wet

DARK GRAY CLAY (CH)
stiff, wet, with abundant small rock fragments

(no free water encountered)

HARDING - LAWSON ASSOCIATES
Consulting Engineers and Geologists

Job No. 2000,106.01 Appr: SRK Date 1/7/76

LOG OF BORING 3
East Canyon - Biomedical Area
Lawrence Berkeley Laboratory

PLATE 5

022_00011

DRILL RIG: CME-55, Rotary Wash	**SURFACE ELEVATION:** 985.6 (see notes)	**LOGGED BY:** KDK
DEPTH TO GROUNDWATER: 36 feet (see notes)	**BORING DIAMETER:** 4 3/4" inches	**DATE DRILLED:** 9/22/08

DESCRIPTION AND REMARKS	COLOR	CONSISTENCY	SOIL TYPE	DEPTH (ft)	SAMPLER TYPE	SAMPLER BLOW COUNTS	MOISTURE CONTENT (%)	DRY DENSITY (pcf)	OTHER TESTS
CLAY, Lean - with gravel, dry, few organics (Qc)	Black	Stiff	CL						
				1					
				2					
				3					PP = 4.5 tsf
				4					
						14			
-moist, pea size gravel or smaller	Dark Brown			5					PP = >4.5 tsf
-less gravel, increase plasticity	Brown			6					
						12			
				7					PP = 4.0 tsf
				8					PP = 4.5 tsf
						11			PP = 1.5 tsf
				9					PP = 4.0 tsf
				10					
									PP = 3.0 tsf
-increase silt, dry, increase gravel, Orinda Formation clasts				11					PP = 3.5 tsf
				12					
-clast reduction	Dark Reddish Brown			13					PP = 3.5-4.0 tsf
				14					
-silty, moist				15					PP = 3.0 tsf
				16					
									PP = 2.5 tsf
-clasts of shale and siltstone, fining downward and fewer clasts				17					PP = >4.5 tsf
				18					
-19.4': 30 degree dipping contact between colluvium and Orinda Formation, wavy, no visible shearing, no clay gouge				19					PP = 4.5 tsf
	Greenish Gray		CL/ML						

(Continued on Next Page)

ALAN KROPP & ASSOCIATES
Geotechnical Consultants

EXPLORATORY BORING LOG			
LBNL BUILDING 85, Berkeley, California			
PROJECT NO.	DATE	SHEET	BORING **AKA-9**
2335-7B	**April 2010**	**1 of 5**	

DESCRIPTION AND REMARKS	COLOR	CONSISTENCY	SOIL TYPE	DEPTH (ft)	SAMPLER TYPE	SAMPLER BLOW COUNTS	MOISTURE CONTENT (%)	DRY DENSITY (pcf)	OTHER TESTS
(Continued from Previous Page)									
CLAY/SILTSTONE - jumbled Orinda siltstone and silty clay, fine grained, sheared Orinda Formation (Qls)	Greenish Gray		CL/ML	21					PP = 4.5 tsf
-22': 20 degree bedding, wavy and andulatory shears both inside and outside of clay seams				22					
				23					PP = 3.0 tsf
-wet, no discernable bedding structure, Orinda sandstone	Blue, Green, Yellow, Red			24					
-displaced Orinda, moist, hard, friable, fine-grained siltstone, massive to fine bedding, oxide staining	Greenish Gray			25					
				26					
				27					
-28': 60 degree contact, < 1cm thick clayey shear				28					
-28.5': 50 degree clear contact, CaCO3 deposits, increasing clay along boundary but not sharp, polished slicks, possible slide plane				29					
				30					
-30.3': 60-70 degree sharp contact, 0.1' thick clayey shear, separates dark gray from greenish gray siltstone, pebbles below	Dark Gray			31					
CLAY/SILT/CLASTS OF MORAGA - silt and clay with lenses of black hard volcanic rock	Red and Light Green		CL/GC	32					
-almost entirely Tm clasts supported in silt/clay matrix				33					
-mixed clasts of Tm supported by clayey silt matrix				34					
-crystaline Tm rock crushed with clay intermixed				35					
-35.2' - 35.5': very soft, moist, fat clay seam, slide plane	Reddish Brown								
-crystaline rock	Black			36					▼
-clasts of Tm in silty clay matrix, wet, loose, fine grained, medium plasticity	Dark Brown			37					
				38					
				39					
-Tm with MnO2 staining				40					
				41					
-below 41.2' matrix becomes more sandy, clay color lightens				42					

(Continued on Next Page)

DESCRIPTION AND REMARKS	COLOR	CONSISTENCY	SOIL TYPE	DEPTH (ft)	SAMPLER TYPE	SAMPLER BLOW COUNTS	MOISTURE CONTENT (%)	DRY DENSITY (pcf)	OTHER TESTS
(Continued from Previous Page)									
-displaced Tm (Qls)	Light Brown		CL/GC	43					
				44					
-crystaline rock fragments and clay	Reddish Brown			45					PP = 3.5 tsf
-45.5' - 46.5': basal shear zone, separates Tm from Tor, very distict zone of disruption bounded by reddish brown clay seams				46					
CLAYSTONE/SILTSTONE - moist, low plasticity, massive to finely bedded, contains gravel, Orinda Formation -47.5': 0.01' thick clay seam, 50 degree dip, minor Qls basal shear	Dark Reddish Brown and Dark Greenish Gray		BED ROCK	47 48					
-49': 40 degree dipping shear, minor Qls basal shear				49					PP = 4.0 tsf
-50.2': clay seam, 0.1' thick, subvertical within siltstone	Yellow/Brown/Green/Red			50					
-51.3': 0.1' thick gravel lense with sharp boundaries marked by clay bedding -dry, sub-horizontal partings, calcite stingers and nodules present	Green Yellow/Blue/Green/Red			51 52					PP = >4.5 tsf
-53.3': 40-50 degree clay seam, coarse sandstone above siltstone -53.5 - 54': coarsened by high concentration of calcite crystals, 20% fine sand, heavily mottled	Greenish Gray			53 54 55					
-harder, paler				56 57					
-57.6' - 58.5': sub-horizontal clay seams bounding siltstone both sides				58					
-58.7': CaCO3 reminents and nodules -59' - 60': vertical clay seams				59					
-dry, hard, no discernable bedding (sub-horizontal partings), colors mix in fluid contact, heavily weathered	Dark Reddish Brown and Dark Greenish Gray			60 61 62 63					
-becomes harder, partings with polished surfaces				64 65					

(Continued on Next Page)

ALAN KROPP & ASSOCIATES
Geotechnical Consultants

EXPLORATORY BORING LOG
LBNL BUILDING 85
Berkeley, California

PROJECT NO.	DATE	SHEET	BORING
2335-7B	**April 2010**	**3 of 5**	**AKA-9**

DESCRIPTION AND REMARKS	COLOR	CONSISTENCY	SOIL TYPE	DEPTH (ft)	SAMPLER TYPE	SAMPLER BLOW COUNTS	MOISTURE CONTENT (%)	DRY DENSITY (pcf)	OTHER TESTS
(Continued from Previous Page)									
CLAYSTONE/SILTSTONE - similar to above, Orinda Formation -66.5' - 67': dark reddish brown CLAY, moist, medium plasticity, calcite nodules present, subangular clasts, no discrete planes -moist to dry, friable, massive	Dark Reddish Brown and Dark Greenish Gray Red and Green		BED ROCK	66 67 68 69 70					
-70.4': CaCO3 subangular nodules/clasts				71					
-71.4': bedding dip, 60 degrees				72					
-massive, fine-grained, calcite rich, more sandy than above	Dark Greenish Gray			73 74					
-60 degree fracture, CaCO3 coated, <0.01' thick				75 76					
-77.2 - 77.6': sub-horizontal banding with 0.01' thick red clay lenses (varves)	Green			77 78					
-becomes sandier, sub-vertical CaCO3 seam				79 80					
-81.2': CacO3 nodules				81 82 83 84 85 86 87 88					

(Continued on Next Page)

DESCRIPTION AND REMARKS (Continued from Previous Page)	COLOR	CONSISTENCY	SOIL TYPE	DEPTH (ft)	SAMPLER TYPE	SAMPLER BLOW COUNTS	MOISTURE CONTENT (%)	DRY DENSITY (pcf)	OTHER TESTS
CLAYSTONE/SILTSTONE - similar to above, Orinda Formation	Green and Red		BED ROCK	89					
				90					
-sub-horizontal red clay bands				91					
				92					
-harder, more cemented				93					
				94					
				95					
				96					
-96.9': conglomerate, clasts of $CaCO_3$ (<1cm dia)	Dark Greenish Gray			97					
SANDSTONE - poorly sorted, fine-medium grained, matrix supported, well cemented, reacts to Hcl, sub-horizontal interbeds, Orinda Formation	Dark Greenish Gray			98					
SILTSTONE - massive, finely bedded with fractures dominating structure (non-linear and pervasive), no reaction to Hcl, polished surfaces on fractures, Orinda Formation	Dark Gray with Dark Greenish Gray			99, 100					
Bottom of boring at 101.0 feet.				101					

NOTES:

1. Groundwater was encountered at approximately 36 feet at the time of drilling and the boring was backfilled immediately after drilling. (See report for discussion.)
2. Stratification lines represent the approximate boundaries between material types and the transitions may be gradual.
3. Penetration resistance values (blow counts) marked with an asterisk (*) are not standard penetration resistance values.
4. Elevations were measured by LBNL personnel.
5. Approximate unconfined compressive strength values were recorded in the field using a pocket penetrometer. These values are shown on the logs and are preceded by the symbol "PP".
6. Blow counts have not been corrected for hammer energy.

EQUIPMENT: Morooka MST 600 ELEVATION: 985.0 **

LOGGED BY: Ted Crump START DATE: 2-26-01

STATION: 9+00 FINISH DATE: 2-26-01

Other Laboratory Tests	Dry Density (pcf)	Moisture Content (%)	Sample Interval (feet)	Blows/ Foot *	DEPTH (FEET)	Description
					0	DARK BLACKISH BROWN SANDY CLAY (CH), very stiff, wet with fine roots and some reddish brown rock fragments (Colluvium)
				24		
LL=66PL=25PI=41 UC 2045	95	27.7		29	5	Becomes brown in color and hard with small gravel and apparent charcoal pieces (Colluvium)
				37	10	LIGHT BROWN SANDY CLAY (CL), hard, moist with small angular rock fragments (Colluvium)
LL=40,PL=23,PI=17				38	15	
	106	20.6		50+	20	Some small reddish fragments
					25	Soft wet sandy clay observed in auger cuttings
				50+		DARK GRAY BEDROCK OF THE ORINDA FORMATION, closely fractured, low hardness, moderately weathered

BOTTOM OF BORING 29.5 FEET
Groundwater Encountered 21 Feet and 22 Feet

* Converted to equivalent standard penetration blow counts.

** Existing ground surface at time of drilling.

KLEINFELDER
Geotechnical, Materials and Environmental Engineering

PROJECT NUMBER 41-7631-01-001 DATE JUN 2001

LOG OF BORING KB-4

LBNL TANK ROAD

Berkeley, California

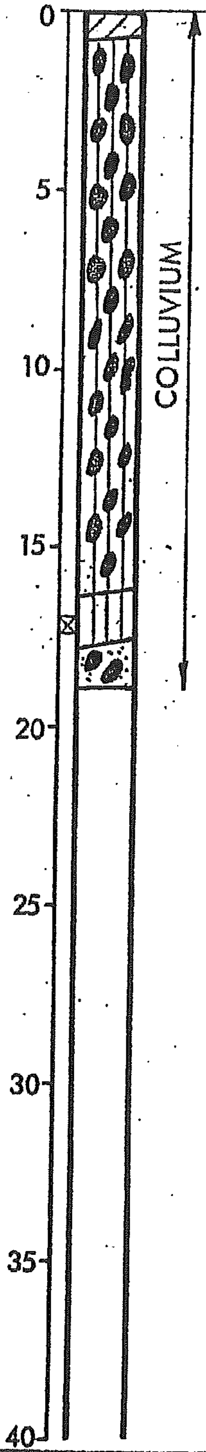
PLATE A-6

Shear Strength (lbs/sq ft) | Moisture Content (%) | Dry Density (pcf) | Depth (ft) | Sample

LOG OF BORING 2

Equipment Spin Auger

Elevation 952 Date 12/5/75



DARK BROWN SANDY CLAY (CL)
medium stiff, moist, with occasional rock fragments

LIGHT BROWN SILTY SANDY GRAVEL (GM) - medium dense, dry, with abundant weathered volcanic rock fragments
hole caving at 6' and at 15'

GRAY SANDY SILT (ML)
soft, moist, with shear planes, decayed vegetation

BROWN GRAVEL (GP)
loose, moist

(no free water encountered)

HARDING - LAWSON ASSOCIATES
Consulting Engineers and Geologists

Job No. 2000,106.01 Appr: SRK Date 1/7/76

LOG OF BORING 2
East Canyon - Biomedical Area
Lawrence Berkeley Laboratory

PLATE 4

Other Laboratory Tests	Dry Density (pcf)	Moisture Content (%)	Sample Interval (feet)	Blows/ Foot *	DEPTH (FEET)

EQUIPMENT: **Morooka MST-600** ELEVATION: **900.0 ****

LOGGED BY: **Ted Crump** START DATE: **3-27-01**

STATION: **0+80 L10** FINISH DATE: **3-27-01**

Depth (feet)	Blows/Foot *	Description
0		YELLOW BROWN SANDY GRAVELLY CLAY (CL), medium stiff with angular rock fragments (Colluvium)
		Probe to Bedrock
5		Abundant Gravels
10		
15		
20		
25		Easy drilling at 25 feet
		GRAY-BROWN CLAYEY SANDY GRAVEL (GC), very dense, wet (Possible Orinda formation bedrock interface with colluvium)
	50+	
		BOTTOM OF BORING 30 FEET No Groundwater Encountered

* Converted to equivalent standard penetration blow counts.

** Existing ground surface at time of drilling.

KLEINFELDER
Geotechnical, Materials and Environmental Engineering

PROJECT NUMBER **41-7631-01-001** DATE **JUN 2001**

LOG OF BORING KB11

LBNL TANK ROAD

Berkeley, California

PLATE **A-13**

ROCK LOG - Boring No. AKA-7

Project Name and Job Number LBNL BUILDINGS 85 AND 85A WLA: 1717-B, AKA: 2335-4a			WLA
Type and Diameter of Boring Rotary wash, 4 7/8-inch diameter	Boring Location In road, 50 feet east of north corner, Building 85A		Total Depth 69.5 feet
Drilling Contractor and Rig Pitcher Drilling, Inc., Faeling 1500	Elevation and Datum 880.5 feet MSL	Ground Water Depth ---	Depth to Bedrock 58 feet
Casing Size and Depth 5-inch diameter, 6.5 feet	Length of Core Barrel and Bit 8 feet with bit; 5-ft. inner barrel	No. of Core Boxes ---	Date Started 3/8/06
	Borehole Inclination 90°	Logged by J. Goodman (AKA)	Date Completed 3/9/06

Reviewed by/Date JNB 3/20/06

Depth (feet.)	Drill Rate (min/ft)	Run No.	Recovery/Cut	RQD	Weathering	Strength	Soil Samples/ Borehole Tests	Discontinuity Log	Discontinuity Description	Lithology	Remarks	Elevation (feet.)
0–2.5										Asphalt pavement 4 inches thick over CLAY; with medium to coarse sand and fine subangular gravel; firm; increase in gravel content below 1 foot, moist [Artificial fill]	Pilot hole hand augered to 5 feet below grade and subsequently reamed	880.5
2.5–5									2.2 to 4.2 feet numerous mechanical breaks	CLAY; orange to red-brown; abundant fine angular gravel; trace fine sand; moist [Landslide debris - shallow landslide]		875.5 (5 ft)
5–6.5	Interval not sampled										6.5 to 8.5 feet: caving	
6.5–8.5	2	P1	2.0/2.0		HW	R1				Mafic volcanic rock; reddish brown; crushed; with randomly oriented clay along fragments; crudely layered [Moraga Formation-derived landslide debris - shallow landslide]	P1: 50 - 100 psi	
8.5–9	Interval not sampled											
9–11	4	P2	1.5/2.0							color change to olive-brown; increase in clay content; minor medium to coarse sand and charcoal (?) crumbly to crushed mafic volcanic gravel	P2: 100 - 500 psi	870.5 (10 ft)
11–12	2	P3	0.67/1.0						stiff clay marks distinct contact between volcanics and siltstone; no evidence of recent shearing	11.2 - 11.5 feet: CLAY; dark brown; very stiff [older slide plane?] CLAYSTONE; olive-brown and gray-green; locally sandy [Orinda Formation-derived landslide debris - shallow landslide]	P3: 500 psi	
12–13.5	6	P4	1.5/1.5		MW-HW	R2			10° - 35° dark brown clay seam, 1 inch thick, stiff, polished, but no straie	SANDSTONE; dark gray; locally clayey; weaky cemented	P4: 600 psi	
13.5–15	8	P5	0.75/1.5		SW-MW	R2				13.3 feet: series of very thin clay seams; subparallel to bedding; appear to offset a thin gray-white sandstone bed	P5: 1100 psi	865.5 (15 ft)

Handwritten: Tm (at ~10.7 ft), To (at ~13.5 ft)

See page 2 for abbreviations of terms related to weathering, strength, and sample method.

ROCK LOG - Boring No. AKA-7

Project Name and Job Number
LBNL BUILDINGS 85 AND 85A
WLA: 1717-B, AKA: 2335-4a

WLA

Depth (feet.)	Drill Rate (min/ft)	Run No.	Recovery/Cut	RQD	Weathering	Strength	Remarks
15–17.5	4	P_6	2.0/2.0		MW-HW	R1	P_6: 600 psi
17.5–20	13	P_7	1.5/2.5		HW	R1	P_7: 1200 psi
20–21.5	6	P_8	1.75/1.5		MW	R1-R2	P_8 : 1200 psi
21.5–23	4	P_9	1.33/1.5		SW	R1-R2	P_9: 1100 psi
23–25	7	P_{10}	1.16/2.0		HW	R1	P_{10}: 800 psi
25–26.5	7	P_{11}	1.08/1.5		MW	R1	P_{11}: 800 psi
26.5–28	3	P_{12}	1.08/1.5		MW	R1	P_{12}: 600 psi
28–29.5	2	P_{13}	1.5/1.5		MW	R1	P_{13}: 600 psi
29.5–30	4	P_{14}	1.0/1.5				P_{14}: 1000 psi

Elevation (feet.): 865.5 (15 ft); 860.5 (20 ft); 855.5 (25 ft); 850.5 (30 ft)

Discontinuity Description

- 16 ft: 2- to 4-inch thick clay seam with crushed clasts, stiff, dry
- contact is irregular/erosive
- 5°: 1-inch thick clay seam
- 60°: lithologic contact, slightly irregular
- 45°: competent SANDSTONE bedding?
- 60°: brown clay seam, slightly mineralized
- rock mass becomes increasinly fractured, numerous high angle fractures
- 30°: bedding, brown clay layer
- 40°: bedding brown clay layer
- 40°: lamination

Lithology

- Fine to coarse SANDSTONE; mottled; moderately cemented with pockets of stiff clay and 2-inch diameter rounded gravel clasts; chaotic appearance; disaggregated
- CLAY; gray; stiff; 2 to 4 inches thick with crushed clasts [Landslide plane?]
- CLAYSTONE with interbedded clayey SILTSTONE [Landslide debris]
- CLAY; dark brown; stiff; 1-inch thick [Landslide plane?]
- CLAYSTONE, SILTSTONE and fine SANDSTONE; gray; brown; and reddish brown [Landslide debris - lower landslide]
- CLAYSTONE and SILTSTONE; gray to gray-brown; increasingly crushed and sheared with clay-rich fractures
- 26.5 to 27 feet: clay-filled fractures [older shear zone?]
- CLAYSTONE; dark brown

Undisturbed sample
S = Shelby, P = Pitcher, C = rock core

Driven (2.5 to 3.0 inch) with liners
MC = Modified California, O = other

Standard Penetration Test (SPT) sampler

Weathering: Fr - Fresh, Sl - Slight, Mo - Moderate, Se - Severe, and VS - Very Severe. Strength: R6 - Extremely strong, R5 - Very strong, R4 - Strong, R3 - Medium strong, R2 - Weak, R1- Very weak, and R0 - Extremely weak. Lithologic Description: Rock type, color, texture, grain size, etc. Discontinuities: Be - Bedding, Fa - Fault, Fo - Foliation, Jo - Joint, Me - Mechanical break, Sh - Shear, and Ve - Vein. Joint Descriptions: Dip, Surface shape (Pl - Planar, St - Stepped, or Wa - Wavy), Roughness (Sm - Smooth, Sl - Slightly Rough, Ro - Rough, and VR - Very Rough), Aperture (Fi - Filled, He - Healed, Op - Open and Ti - Tight), type and amount of infilling, slickensides, etc. Remarks: Drill water return and losses, drill water color, drill cuttings, rapid or slow drilling, etc.

ROCK LOG - Boring No. AKA-7

Project Name and Job Number
LBNL BUILDINGS 85 AND 85A
WLA: 1717-B, AKA: 2335-4a

WLA

Depth (feet.)	Drill Rate (min/ft)	Run No.	Recovery/Cut	RQD	Weathering	Strength	Soil Samples/ Borehole Tests	Discontinuity Description	Lithology	Remarks	Elevation (feet.)
30	4	P_{14}	1.0/1.5								850.5
31–32.5	?	P_{15}	2.0/1.5		MW	R1		70°: clay seam 60°: joint; adjacent material is crushed with angular blocks/ fragments	color change to dark brown	P_{15}: 800psi	
32.5–35.5	6	P_{16}	2.5/3.0		MW	R2			very fine sandy SILTSTONE bed; dark gray; weakly to moderately cemented	P_{16}: 800psi	845.5 (at 35)
35.5–38	6	P_{17}	2.5/2.5		MW / HW	R1			rock mass becomes increasingly weathered	P_{17}: 800 psi	
38–40	4	P_{18}	1.5/2.0		HW	R1				P_{18}: 600 psi	840.5 (at 40)
40–42	8	P_{19}	2.5/2.0		HW	R1		clay seam, subhorizontal, irregular surface, slickensided	1-inch thick layer of CLAY; brown; very stiff, encapsulating rock fragments	P_{19}: 600 psi	
42–43.5	6	P_{20}	1.5/1.5			R1				P_{20}: 1000 psi	
43.5–45	9	P_{21}	1.84/2.0		SW	R2-R3		no clay gouge or shears at contact 55° to 60° - quartz veins, subparallel	Fine SANDSTONE; brown; well sorted; moderately cemented	P_{21}: 700 psi	835.5 (at 45)

Undisturbed sample S = Shelby, P = Pitcher, O = other

Driven (2.5 to 3.0 inch) with liners MC = Modified California, O = other

Standard Penetration Test (SPT) sampler

Weathering: Fr - Fresh, Sl - Slight, Mo - Moderate, Se - Severe, and VS - Very Severe. Strength: R6 - Extremely strong, R5 - Very strong, R4 - Strong, R3 - Medium strong, R2 - Weak, R1- Very weak, and R0 - Extremely weak. Lithologic Description: Rock type, color, texture, grain size, etc. Discontinuities: Be - Bedding, Fa - Fault, Fo - Foliation, Jo - Joint, Me - Mechanical break, Sh - Shear, and Ve - Vein. Joint Descriptions: Dip, Surface shape (Pl - Planar, St - Stepped, or Wa - Wavy), Roughness (Sm - Smooth, Sl - Slightly Rough, Ro - Rough, and VR - Very Rough), Aperture (Fl - Filled, He - Healed, Op - Open and Ti - Tight), type and amount of infilling, slickensides, etc. Remarks: Drill water return and losses, drill water color, drill cuttings, rapid or slow drilling, etc.

ROCK LOG - Boring No. AKA-7

Project Name and Job Number
LBNL BUILDINGS 85 AND 85A
WLA: 1717-B, AKA: 2335-4a

WLA

Depth (feet.)	Drill Rate (min/ft)	Run No.	Recovery/Cut	RQD	Weathering	Strength	Soil Samples/ Borehole Tests	Discontinuity Description	Lithology	Remarks	Elevation (feet.)
45		P_{21}							same as above		835.5
46	5	P_{22}	2.0/1.5		SW	R2-R3		40°: joint; rough; clay lined with slickensides		P_{22}: 600 psi	
47								contact is crushed with fractures and polishing, no clay gouge,	Clayey SILTSTONE; green; sheared; numerous very thin shears - old tectonic features?		
48	8	P_{23}	2.0/2.5		MW	R1		70°: 1/8-inch thick clay seams; very closely spaced		P_{23}: 1200 psi	
49									Silty fine SANDSTONE; gray to greenish gray; moderately cemented; rock is generally highly fractured		
50	10	P_{24}	2.5/2.0		SW	R2-R3		50°: brown clay seam		P_{24}: 1600 psi	830.5
51									increase in weathering; numerous subvertical fractures; some with recrystallization; no distinct clay seams		
53	10	P_{25}	2.33/3.0		HW	R1-R2				P_{25}: 1500 psi	
54								52°: clay seam, tight 45°: quartz vein			
55	9	P_{26}	2.42/1.5		HW	R1		25° - 35°: lithologic contact	CLAYSTONE and SILTSTONE; green; sheared; with mineralized veins	P_{26}: 1300 psi	825.5
57	10	P_{27}	2.25/2.0						CLAY; reddish brown; with rock fragments; medium stiff with some soft zones; within fracture clasts [Landslide plane]	P_{27}: 1600 psi 57.5 ft. - driller reports soft zone	
58								45°: quartz vein	Fine SANDSTONE with SILTSTONE; gray, weakly cemented [Orinda Formation]		
59	6	P_{28}	2.08/2.5		SW			45°: quartz vein	clean SANDSTONE; tight and competent; no dilation; coarsens with depth	P_{28}: 500 psi	
60											820.5

Undisturbed sample S = Shelby, P = Pitcher, C = rock core
Driven (2.5 to 3.0 inch) with liners MC = Modified California, O = other
Standard Penetration Test (SPT) sampler

Weathering: Fr - Fresh, Sl - Slight, Mo - Moderate, Se - Severe, and VS - Very Severe. Strength: R6 - Extremely strong, R5 - Very strong, R4 - Strong, R3 - Medium strong, R2 - Weak, R1- Very weak, and R0 - Extremely weak. Lithologic Description: Rock type, color, texture, grain size, etc. Discontinuities: Be - Bedding, Fa - Fault, Fo - Foliation, Jo - Joint, Me - Mechanical break, Sh - Shear, and Ve - Vein. Joint Descriptions: Dip, Surface shape (Pl - Planar, St - Stepped, or Wa - Wavy), Roughness (Sm - Smooth, Sl - Slightly Rough, Ro - Rough, and VR - Very Rough), Aperture (Fi - Filled, He - Healed, Op - Open and Ti - Tight), type and amount of infilling, slickensides, etc. Remarks: Drill water return and losses, drill water color, drill cuttings, rapid or slow drilling, etc.

ROCK LOG - Boring No. AKA-7

Project Name and Job Number
LBNL BUILDINGS 85 AND 85A
WLA: 1717-B, AKA: 2335-4a

WLA

Depth (feet)	Drill Rate (min/ft)	Run No.	Recovery/Cut	RQD	Weathering	Strength	Soil Samples/ Borehole Tests	Discontinuity Log	Discontinuity Description	Lithology	Remarks	Elevation (feet)
60		P_{28}								same as above		820.5
61–62.5	10	P_{29}	2.16/2.0		HW	R1			45°: quartz vein; 25°: joint, planar, smooth	CLAYSTONE; sheared with numerous slickensides, no gouge	P_{29}: 1500 psi	
62.5–65	10	P_{30}	2.42/2.5						55°: bedding; 63°: quartz vein	Fine SANDSTONE and SILTSTONE; dark gray, weakly cemented with well-cemented zones at fractures; isolated layers of green CLAYSTONE; no gouge; fractures show occasional polished faces	P_{30}: 1000 psi	815.5 (at 65)
65–67.5	11	P_{31}	2.75/2.5		HW	R1-R2					P_{31}: 1600 psi	
67.5–69.5	7	P_{32}	2.16/2.0		MW	R3					P_{32}: 700 psi	
69.5										Bottom of hole at 69.5 feet.		810.5 (at 70)

Undisturbed sample S = Shelby, P = Pitcher, C = rock core; Driven (2.5 to 3.0 inch) with liners MC = Modified California, O = other; Standard Penetration Test (SPT) sampler

Weathering: Fr - Fresh, Sl - Slight, Mo - Moderate, Se - Severe, and VS - Very Severe. Strength: R6 - Extremely strong, R5 - Very strong, R4 - Strong, R3 - Medium strong, R2 - Weak, R1- Very weak, and R0 - Extremely weak. Lithologic Description: Rock type, color, texture, grain size, etc. Discontinuities: Be - Bedding, Fa - Fault, Fo - Foliation, Jo - Joint, Me - Mechanical break, Sh - Shear, and Ve - Vein. Joint Descriptions: Dip, Surface shape (Pl - Planar, St - Stepped, or Wa - Wavy), Roughness (Sm - Smooth, Sl - Slightly Rough, Ro - Rough, and VR - Very Rough), Aperture (Fi - Filled, He - Healed, Op - Open and Ti - Tight), type and amount of infilling, slickensides, etc. Remarks: Drill water return and losses, drill water color, drill cuttings, rapid or slow drilling, etc.

ROCK LOG - Boring No. AKA-4

Project Name and Job Number: LBNL Building 85, WLA: 1717-B, AKA: 2335-4a			WLA
Type and Diameter of Boring: Rotary wash, 4 7/8-inch diameter	Boring Location: In road, ~50 feet east of northeast corner of Building 85		Total Depth: 62.5 feet
Drilling Contractor and Rig: Pitcher Drilling, Inc., Faeling 1500	Elevation and Datum: 877.5 feet MSL	Ground Water Depth: ---	Depth to Bedrock: >62.5 feet
Casing Size and Depth: 5-inch diameter, advanced to 12 feet	Length of Core Barrel and Bit: 8 feet with bit; 5-ft. inner barrel	No. of Core Boxes: ---	Date Started: 9/24/05
	Borehole Inclination: 90°	Logged by: J. Goodman (AKA)	Date Completed: 9/24/05

Reviewed by/Date JNB 3/20/06

Depth (feet)	Drill Rate (min/ft)	Run No.	Recovery/Cut	RQD	Weathering	Strength	Discontinuity Description	Lithology	Remarks	Elevation (feet)
0–2								Asphalt pavement over brown aggregate base rock [Artificial fill]		877.5
2–4		S1	1.1/2.0				2.2 to 4.2 feet numerous mechanical breaks	Gravelly lean CLAY with fine to coarse sand, dark brown, very stiff; gravel is angular and grades from fine to cobble-sized; moisture content increases with depth [Quaternary alluvium]	S1: tip of Shelby tube is bent	
4–7		P2	1.5/3.0					1-inch thick dark brown fat CLAY layer	P2: 200 psi	872.5
7–8.5	3	P3	1.3/1.5					Clayey fine to coarse SAND, and fine to coarse sandy CLAY, dark brown, loose to medium dense/firm, with isolated soft zones, trace angular fine gravel, wet	P3: 100 - 125 psi; loss of fluid circulation	
8.5–10.4	3	S4	0.6/2.0						S4: 50 - 225 psi	867.5
10.4–10.9		S5	0.5/0.5				10.4 to 11.0 feet numerous horizontal mechanical breaks	SILTSTONE clast, dark gray, in tip of Shelby tube	S5: 225 psi; loss of fluid circulation	
10.9–11.5	Interval not sampled								casing pushed to 12 feet	
11.5–13.5	6	P6	2.0/2.0		HW	R1-R2		SILTSTONE, CLAYSTONE, and SANDSTONE, dark brown to gray-brown, highly weathered, crude bedding [Landslide debris - shallow landslide]	P6: 250 - 200 psi	
13.5–15	2	P7	1.4/1.5				44° lithologic contact dark brown SILTSTONE over gray-brown SAND-STONE		P7: 250 psi	862.5

Handwritten annotations: "Tm?" (at ~10.4 ft), "Tm?/Tb?" (at ~12 ft)

See page 2 for abbreviations of terms related to weathering, strength, and sample method.

ROCK LOG - Boring No. AKA-4

Project Name and Job Number
LBNL BUILDINGS 85 AND 85A
WLA: 1717-B, AKA: 2335-4a

WLA

Depth (feet.)	Drill Rate (min/ft)	Run No.	Recovery/Cut	RQD	Weathering	Strength	Soil Samples/ Borehole Tests	Discontinuity Description	Lithology	Remarks	Elevation (feet.)
15–17.5	4	P_8	2.2/2.5		HW	R1			same as above 2-inch thick CLAYSTONE layer, brown, polished, intensely fractured, free water visible on fracture planes	P_8: 250 - 300 psi	862.5 (at 15)
17.5–19.5	3	P_9	2.1/2.0					parting face has slickensides and polishing 80°: clay-filled joint; tight	SANDSTONE, clayey, dark brown and gray; material has mixed texture	P_9: 250 - 300 psi	
19.5–21	5	P_{10}	1.7/1.5		HW	R1-R2		30°: clay-filled joint; tight		P_{10}: 300 psi	857.5 (at 20)
21–23.5	7	P_{11}	1.9/2.5					~50°: clay-filled joint; tight		P_{11}: 300 - 400 psi	
23.5–25	7	P_{12}	1.5/1.5							P_{12}: 300 - 500 psi	852.5 (at 25)
25–27.5	6	P_{13}	2.1/2.5		HW	R2		50°: clay horizon, polished to striated	gravel-sized clasts of basalt mixed with SANDSTONE	P13: 250 - 400 psi driller reports hard layer	
27.5–28	10	P_{14}	0.5/0.5					50°: 0.3-inch clay seam at fine sandstone over siltstone contact	zone of clay seams		
28–30	20	C_{15}	2.5/2.5		MW-HW	R2		30° - 35°: healed joint with mineralized infilling; underlain by a well-cemented zone	Fine SANDSTONE, silty, slightly mottled brown, gray, and blue-gray; contact demarcated by a 4-inch thick well cemented zone	C_{15}: 200 - 225 psi	847.5 (at 30)

Undisturbed sample S = Shelby, P = Pitcher, C = rock core
Driven (2.5 to 3.0 inch) with liners MC = Modified California, O = other
Standard Penetration Test (SPT) sampler

Weathering: Fr - Fresh, SW - Slight, MW - Moderate, HW - Highly, CW - Completely, and RS - Residual soil. Strength: R6 - Extremely strong, R5 - Very strong, R4 - Strong, R3 - Medium strong, R2 - Weak, R1- Very weak, and R0 - Extremely weak.

ROCK LOG - Boring No. AKA-4

Project Name and Job Number
LBNL BUILDINGS 85 AND 85A
WLA: 1717-B, AKA: 2335-4a

WLA

Depth (feet.)	Drill Rate (min/ft)	Run No.	Recovery/Cut	RQD	Weathering	Strength	Soil Samples/ Borehole Tests	Discontinuity Log	Discontinuity Description	Lithology	Remarks	Elevation (feet.)
30	5	C_{15}								same as above		847.5
30.5–31	6				MW	R2					switch to Pitcher barrel	
31–31.5		P_{16}	1.0/2.0								P_{16}: 350 - 425 psi	
32	16				HW				35°: joint, smooth, highly weathered	color change to dark gray		
33	15								55°: clay seam 1/4-inch thick; high plasticity, sticky, separates yellow-brown siltstone and blue-gray to reddish brown siltstone	CLAYSTONE, mottled blue-gray, red-brown, and dark brown with poorly to moderately cemented fine sand and silt horizons, highly weathered	switch to rock coring	
34	4	C_{17}	3.5/4.0		HW	R1-R2					C_{17}: 200 - 250 psi	
35	7								45°: planar to stepped clay film on hard cemented discontinuous surface			842.5
36	11											
37									25°: contact of slide-plane clay over bluish gray siltstone	Gravelly, sandy CLAY, reddish brown to blue-gray, volcanic and sandstone clasts; 37.0 - 37.2 feet: CLAY with minor silt, dark gray to brown, soft [Landslide plane]		
37.5					HW	R1						
38	4									CLAYSTONE and SILTSTONE, dark gray, bluish gray, over CLAYSTONE, highly fractured/ crushed, angular to subrounded gravel, soft rock fragments with lighter gray/greenish gray matrix; highly weathered to moderately weathered [Landslide debris - deep landslide]		
39	9	C_{18}	2.9/5.0		MW	R1-R2					C_{18}: 150 - 250 psi	
40	10											837.5
41	5											
42	16	C_{19}	0/1.5								C_{19}: no recovery	
42.5	8											
43	8										driller reports loss of fluid circulation	
44	6	C_{20}	0.8/3.0		MW	R1-R2					C_{20}: 200 psi	
45												832.5

Undisturbed sample S = Shelby, P = Pitcher, C = rock core
Driven (2.5 to 3.0 inch) with liners MC = Modified California, O = other
Standard Penetration Test (SPT) sampler

Weathering: Fr - Fresh, SW - Slight, MW - Moderate, HW - Highly, CW - Completely, and RS - Residual soil. Strength: R6 - Extremely strong, R5 - Very strong, R4 - Strong, R3 - Medium strong, R2 - Weak, R1- Very weak, and R0 - Extremely weak.

ROCK LOG - Boring No. AKA-4

Project Name and Job Number
LBNL BUILDINGS 85 AND 85A
WLA: 1717-B, AKA: 2335-4a

WLA

Depth (feet.)	Drill Rate (min/ft)	Run No.	Recovery/Cut	RQD	Weathering	Strength	Soil Samples/ Borehole Tests	Discontinuity Description	Lithology	Remarks
45–46	5	C_{20}							same as above	poor recovery with rock coring
46–47.5		MC_{21}			SW-MW	R2		45°: bedding? zone of very closely spaced, tight fractures	SILTSTONE and very fine SANDSTONE; notable increase in rock strength and coherence	good recovery below 47.5 feet with Pitcher barrel
47.5–50		P_{22}	2.4/2.5		SW	R3		polishing and faint slickensides on fracture faces		P_{22}: 250 - 400 psi
50–52.5	3	P_{23}	2.6/2.5						Fine SANDSTONE, gray, weakly cemented, slightly silty, locally graded	P_{23}: 300 - 450 psi
52.5–54.5	2	P_{24}	2.0/2.0					60°: joint		P_{24}: 300 - 450 psi
54.5–57	10	P_{25}	2.5/2.5		SW	R3		54 to 57 feet: joint set, randomly oriented, open with some mineralized infilling - some - 40° to 50°		P_{25}: 300 - 400 psi
57–59.5	5	P_{26}								P_{26}: 300 - 550 psi
59.5–60	6	P_{27}								P_{27}: 300 - 450 psi

Elevation (feet.): 832.5 at 45 ft; 827.5 at 50 ft; 822.5 at 55 ft; 817.5 at 60 ft

Undisturbed sample S = Shelby, P = Pitcher, C = rock core
Driven (2.5 to 3.0 inch) with liners MC = Modified California, O = other
Standard Penetration Test (SPT) sampler

Weathering: Fr - Fresh, SW - Slight, MW - Moderate, HW - Highly, CW - Completely, and RS - Residual soil. Strength: R6 - Extremely strong, R5 - Very strong, R4 - Strong, R3 - Medium strong, R2 - Weak, R1- Very weak, and R0 - Extremely weak.

ROCK LOG - Boring No. AKA-4

Project Name and Job Number
LBNL BUILDINGS 85 AND 85A
WLA: 1717-B, AKA: 2335-4a

Depth (feet.)	Lithology	Drill Rate (min/ft)	Run No.	Recovery/Cut	RQD	Weathering	Strength	Soil Samples/ Borehole Tests	Discontinuity Log	Discontinuity Description	Lithology	Remarks	Elevation (feet.)
60			P_{27}	1.5/1.5						48°: parting	same as above		817.5
61			P_{28}										
62.5											Bottom of hole at 62.5 feet.		
65													812.5
75													

Undisturbed sample S = Shelby, P = Pitcher, C = rock core

Driven (2.5 to 3.0 inch) with liners MC = Modified California, O = other

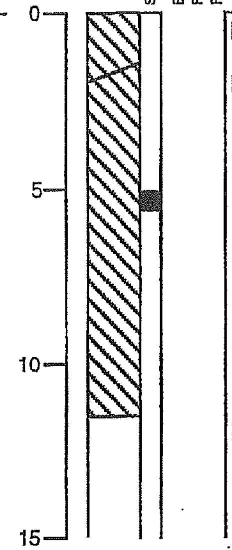
Standard Penetration Test (SPT) sampler

Weathering: Fr - Fresh, SW - Slight, MW - Moderate, HW - Highly, CW - Completely, and RS - Residual soil. Strength: R6 - Extremely strong, R5 - Very strong, R4 - Strong, R3 - Medium strong, R2 - Weak, R1- Very weak, and R0 - Extremely weak.

LOG OF TEST PIT 3

EQUIPMENT: BACKHOE (30" BUCKET)
DATE EXCAVATED: JUNE 5, 1996
ELEVATION: 873 FEET (MSL DATUM)

LABORATORY TESTS	MOISTURE CONTENT (%)	DRY DENSITY (PCF)	OVM (PPM)	DEPTH (FEET)	SAMPLE	BLOWS PER FOOT	DESCRIPTION
				0			BROWN SILTY CLAY (CH) soft, dry, with roots (colluvium)
							BROWN SILTY CLAY (CH) medium stiff, moist (colluvium)
	22.3	91		5	■		
				10			
							No groundwater encountered
				15			



Subsurface Consultants	BUILDING 85 MODULAR OFFICE PAD LAWRENCE BERKELEY NATIONAL LABORATORY			PLATE
	JOB NUMBER 658.040	DATE 8/19/96	APPROVED [signature]	3

355_00022

LOG OF TEST PIT 1

EQUIPMENT: BACKHOE (30" BUCKET)
DATE EXCAVATED: JUNE 5, 1996
ELEVATION: 862 FEET (MSL DATUM)

LABORATORY TESTS	MOISTURE CONTENT (%)	DRY DENSITY (PCF)	OVM (PPM)	DEPTH (FEET)	SAMPLE	BLOWS PER FOOT
				0		
	28.7	93				
	27.7	93				
				5		
				10		
				15		

BROWN SILTY CLAY (CH)
soft, dry, with roots (colluvium)
BROWN SILTY CLAY (CH)
medium stiff, moist (colluvium)

BROWN SILTY CLAY (CL)
stiff, moist, with cobbles (colluvium)

No groundwater encountered

LOG OF TEST PIT 2

EQUIPMENT: BACKHOE (30" BUCKET)
DATE EXCAVATED: JUNE 5, 1996
ELEVATION: 867 FEET (MSL DATUM)

LABORATORY TESTS	MOISTURE CONTENT (%)	DRY DENSITY (PCF)	OVM (PPM)	DEPTH (FEET)	SAMPLE	BLOWS PER FOOT
				0		
	26.3	97				
				5		
	21.6	102				
				10		
				15		

BROWN SILTY CLAY (CH)
soft, dry, with roots (colluvium)
BROWN SILTY CLAY (CH)
medium stiff, moist (colluvium)
RED-GRAY-BROWN AGGLOMERATE
intensely fractured, friable, weak, deep weathering

No groundwater encountered

Subsurface Consultants

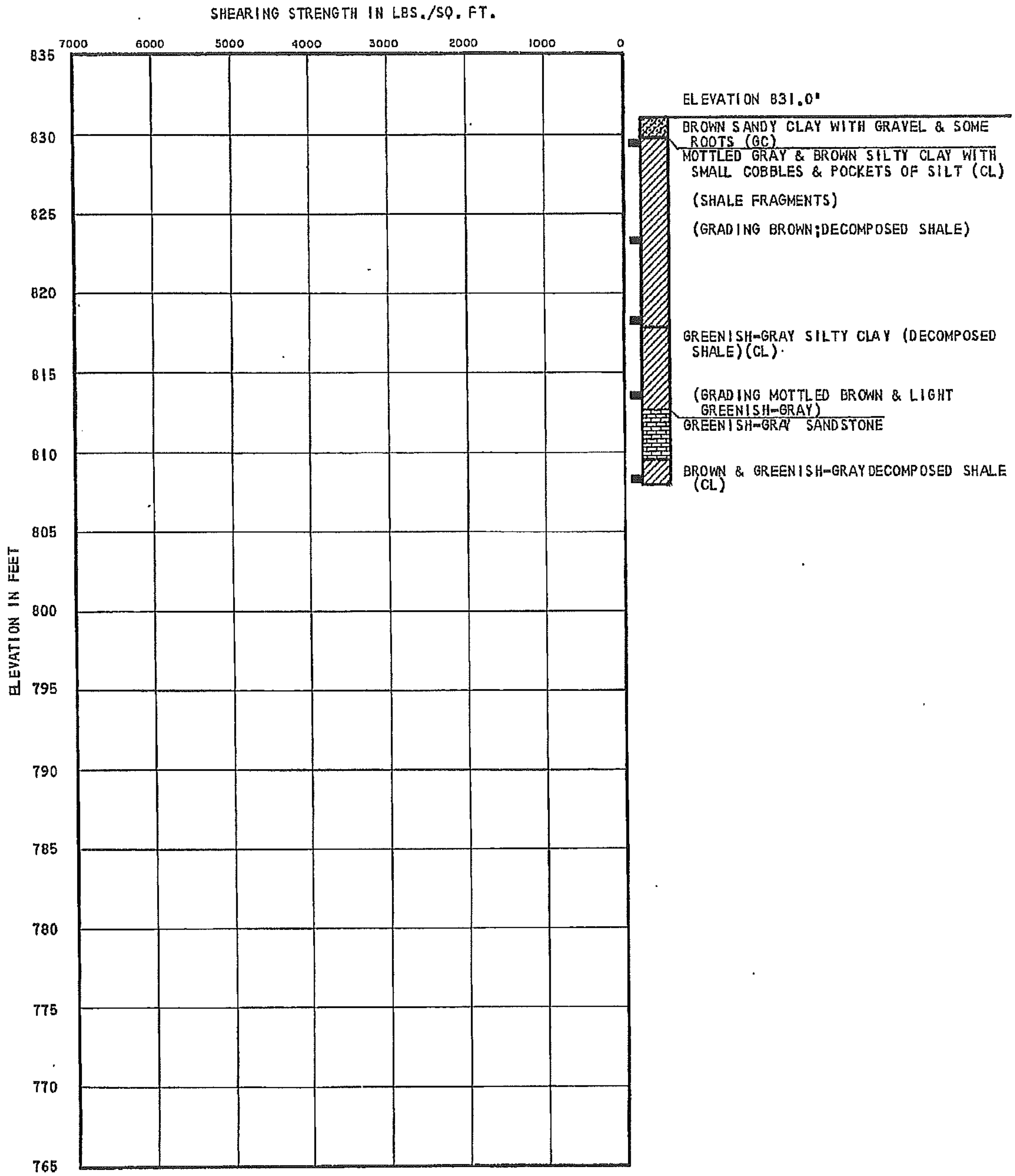
BUILDING 85 MODULAR OFFICE PAD
LAWRENCE BERKELEY NATIONAL LABORATORY

JOB NUMBER 658.040 | DATE 8/19/96 | APPROVED [signature]

PLATE 2

BORING 7

DRILLED 4-8-60



LOG OF BORING

DAMES & MOORE
SOIL MECHANICS ENGINEERS

PLATE A10

236_00020

DRILL RIG: CME-55, Rotary Wash	SURFACE ELEVATION: 816 (see notes)	LOGGED BY: KDK
DEPTH TO GROUNDWATER: 22 feet (see notes)	BORING DIAMETER: 4 3/4" inches	DATE DRILLED: 9/17/08

DESCRIPTION AND REMARKS	COLOR	CONSISTENCY	SOIL TYPE
CLAY, Lean - with silt and sand, some subangular gravel, dry (FILL) FILL ↑	Brown	Firm	CL
GRAVEL, Poorly Graded - volcanic breccia with cobble-sized rocks, reacts to Hcl, no joints (Qc) -4.5': siltstone clast/cobble (Orinda?) -4.8': 2.5" layer of silty/clayey gravel -5': Orinda Formation rock and cobbles	Bluish Green/Greenish Gray	Medium Dense to Dense	GP
CLAY, Lean - with silt and angular clasts of Tm, moist to wet, (Possible Qc mixed with Tm but primarily clay suggesting completely weathered To with Tm clasts)	Greenish Gray	Firm to Stiff	CL
CLAY, Lean - clay with completely weathered To; no Tm clasts below 9.5'	Blue, Green, Gray	Stiff	CL
		Very Stiff	
-with gravel, moist to wet	Dark Greenish Brown		
-14.5' - 16': silty with some very fine sand (10-15 %), moist	Greenish Gray		
-16': with silt, moist -17.4': 3-inch clay seam, very abrupt contact, strong color change, polished slickened sides, shear fabric extends below clay into lower siltstone, sub-horizontal contact, < 20 degree dip, possible slide plane	Dark Grayish Brown		
	Red/Green		BED ROCK
SILTSTONE - clayey, moist, friable, weak, Orinda Formation -19.6': sharp 50 degree contact with thin	Greenish Gray		

DEPTH (ft)	SAMPLER BLOW COUNTS	MOISTURE CONTENT (%)	DRY DENSITY (pcf)	OTHER TESTS
1				
2				
3				
4				
5				
5.5	[69]			
6				
6.5				PP = 1.5 tsf
7	[23]			
8				PP = 2.5 tsf
9				
9.5	[11]			PP = 3.5 tsf
10				PP = 4.0 tsf
11	[12]			PP = 4.0 tsf
12				
12.5	[26]			PP = 4.3 tsf
13				
14	[23]			PP = 3.5 tsf
14.5				PP = >4.5 tsf
15				
15.5	[25]			PP = 3.0 tsf
16				PP = 4.5 tsf
17	[23]			PP = 4.0 tsf
18				PP = 4.5 tsf
19				PP = >4.5 tsf

(Continued on Next Page)

DESCRIPTION AND REMARKS (Continued from Previous Page)	COLOR	CONSISTENCY	SOIL TYPE	DEPTH (ft)	SAMPLER TYPE	SAMPLER BLOW COUNTS	MOISTURE CONTENT (%)	DRY DENSITY (pcf)	OTHER TESTS
clay seam separating weathered Tor from harder Tor, steep brecciated and fractured contact with healed zones	Greenish Gray		BED ROCK	21					
SILTSTONE - moist, friable to weak, uncemented, sub-vertical fractures lined with clay, massive bedding, reacts slightly with Hcl, CaCO3 along fractures, Orinda Formation	Red/Green			22					▼
-21': sandy siltstone with fracturing at 50 degrees, healed fracture zone				23					PP = >4.5 tsf
-22' - 24.5': red clay matrix around clasts of green siltstone				24					
-23.5' - 24.5': clay lined fracture with CaCO3, 35-40 degree dip	Black to Green			25					
-24.5': red clay no longer dominant, siltstone with large calcite crystals.	Red/Green			26					
-25.5': red clay matrix around clasts of green siltstone, oxidized zone				27					PP = 4.0 tsf
-27.2': 1-inch thick silty clay seam dipping 35 degrees, CaCO3 along fracture, weak zone, doesn't separate different rock material, not breaking along primary shear				28					PP = >4.5 tsf
-28': decreasing clay content, dry, hard				29					PP = >4.5 tsf
				30					
SILTSTONE/CLAYSTONE - moist, friable, no joints, massive, Orinda Formation	Greenish Gray/Dark Greenish Brown			31					PP = >4.5 tsf
-harder, less clay, fine grained				32					PP = >4.5 tsf
				33					
				34					
				35					PP = >4.5 tsf
				36					
-high concentration of vertical/sub-vertical calcite veins/stringers, no distinctive bedding, dipping 60 degrees				37					PP = >4.5 tsf
-38': increase clay content	Reddish Brown and Oxidized			38					
-38' - 38.5': 6-inch thick clayey silt to clay seam, somewhat brecciated, random slicks and mullions, upper seam 40 degree dip, lower seam 70 degree dip	Greenish Gray			39					PP = >4.5 tsf
SILTSTONE - moist, no joints, massive bedding, sub-vertical calcite veins, good solid rock, Orinda Formation				40					
	Red/Green			41					PP = >4.5 tsf
-42' - 42.5': thin seams of soft clay-rich material with siltstone, multiple				42					

(Continued on Next Page)

(Continued from Previous Page)

DESCRIPTION AND REMARKS	COLOR	CONSISTENCY	SOIL TYPE	DEPTH (ft)	SAMPLER TYPE	SAMPLER BLOW COUNTS	MOISTURE CONTENT (%)	DRY DENSITY (pcf)	OTHER TESTS
sub-horizontal seams <15 degrees and undulatory, do not separate different rock types, not breaking along individual shears			BED ROCK	43					PP = 4.0 tsf
-44': 3-inch thick soft brown clay seam, platey siltstone fabric below, dips <10 degrees, possible slide plane but material same on both sides of shear, possible bedding but very weak clay, does not break along seams				44					PP = 2.0 tsf PP = 3.5 tsf
	Red/Brown/Green			45					PP = >4.5 tsf
CLAYSTONE/SILTSTONE - friable to weak, partings/decompression cracks, 45 degree bands of clay, Orinda Formation				46					PP = >4.5 tsf
-46.4' - 46.5': clay rich zone, 50 degree dip, appears to be associated with old tectonic shears				47					PP = >4.5 tsf
-47.5': becoming grayer with depth, finer grained material, more cemented				48					
SILTSTONE/CLAYSTONE - hardness increase, fine-grained, massive, no discernable bedding, vertical calcite stringers, moderately weathered, well cemented, Orinda Formation	Dark Greenish Gray			49					
				50					
				51					
				52					
				53					
				54					
				55					
				56					
				57					
				58					
-59': 1/2-inch thick, dark reddish brown, clay lined fracture, 60-70 degree dip, same rock on both sides				59					
CLAYSTONE/SILTSTONE - fine bedding, wet, moderately to deeply weathered, weak and fractured, Orinda Formation				60					
				61					
-more competent, harder, less bedding breaks				62					
-62.2' - 63': multiple bands of red clay, appear to be bedding and zones of weakness with breaking along clay seams				63					
				64					
-64.5': lense of fine grained gray sandstone with trace coarse clasts and calcite				65					

(Continued on Next Page)

DESCRIPTION AND REMARKS	COLOR	CONSISTENCY	SOIL TYPE	DEPTH (ft)	SAMPLER TYPE	SAMPLER BLOW COUNTS	MOISTURE CONTENT (%)	DRY DENSITY (pcf)	OTHER TESTS
(Continued from Previous Page)									
CLAYSTONE/SILTSTONE - Orinda Formation, similar to above	Reddish Gray		BED ROCK	66					
				67					
-clay rich, soft, no distinct bedding	Red/Green/Yellow			68					
				69					
				70					
-fine grained, massive, no distinct bedding, dry to moist	Dark Gray			71					
				72					
				73					
	Dark Greenish Gray			74					
				75					
				76					
				77					
				78					
				79					
				80					
-82': coarser, highly reactive to Hcl, conglomerate, predominantly light-colored clasts, <5% dark clasts, 15% very fine sand, schist and granite (?), bedding variable 10-25 degrees				81					
				82					
-83': conglomerate with silt matrix, well cemented, subrounded to angular clasts, slight reaction with Hcl	Dark Green			83					
				84					
Bottom of boring at 85.0 feet.				85					

NOTES:

1. Groundwater was encountered at approximately 22 feet at the time of drilling and the boring was backfilled immediately after drilling. (See report for discussion.)
2. The stratification line represents the approximate boundary between material types and the transition may be gradual.

(Continued on Next Page)

DESCRIPTION AND REMARKS	COLOR	CONSISTENCY	SOIL TYPE	DEPTH (ft)	SAMPLER TYPE	SAMPLER BLOW COUNTS	MOISTURE CONTENT (%)	DRY DENSITY (pcf)	OTHER TESTS

(Continued from Previous Page)

3. Penetration resistance values (blow counts) marked with an asterisk (*) are not standard penetration resistance values.
4. Elevation taken off October 2008 LBNL topographic map.
5. Approximate unconfined compressive strength values were recorded in the field using a pocket penetrometer. These values are shown on the logs and are preceded by the symbol "PP".
6. Blow counts have not been corrected for hammer energy.

LOG OF BORING NO. 1

DATE DRILLED: 4/9/82

THIS SUMMARY APPLIES ONLY AT THE LOCATION OF THIS BORING AND AT THE TIME OF DRILLING. SUBSURFACE CONDITIONS MAY DIFFER AT OTHER LOCATIONS AND MAY CHANGE AT THIS LOCATION WITH THE PASSAGE OF TIME. THE DATA PRESENTED IS A SIMPLIFICATION OF ACTUAL CONDITIONS ENCOUNTERED.

ELEVATION: 806± EQUIPMENT: 5" Rotary Wash Drill

DEPTH m.	DEPTH ft.	SAMPLES	Moisture	Consistency	Color	Description		BLOWS/FT.	FIELD MOISTURE % DRY WEIGHT	DRY DENSITY LB./CU. FT.	TESTS
						4.5" ASPHALT CONCRETE					
			slightly moist	medium dense	brown	SILTY SAND tr. gravel	SM				
1		D	moist	medium to stiff	purple gray	CLAYEY SILT (fill) trace fine rock fragments, trace to some sand	CL	10	14.6	111	
	5	B			gray						
2											
		D						12	17.1	110	tx
3	10										
			▽ 4/10								
4						wood fragments					
	15	D		very stiff	gray brown	asphalt fragments		13	11.6	120	
5					purple gray						
			moist	medium	dark gray	SILTY CLAY trace rock fragments	CL				
6	20	S						push	26.6	94	tx
7					gray						
	25	D	very moist	loose	gray	SANDY SILT	ML	9	27.6	94	
8											
			moist	stiff	gray brown	SILTY CLAY	CL				
9	30	S	moist	stiff	brown	SANDY CLAY	CL	push			
10			moist	stiff	gray	SILTY CLAY	CL				
	35	D	moist	loose	dark gray	SANDY SILT occasional clay lenses	ML	19	32.0	88	
11											
				stiff							
12	40	D			bl. gray			28	18.9	111	

CENTENNIAL DRIVE OVERPASS LANDSLIDE
University of California, Berkeley

Project No. 81-04139-04

ConverseWardDavisDixon Geotechnical Consultants

Drawing No. 2-2

LOG OF BORING NO. 1 (cntd)

DATE DRILLED:

THIS SUMMARY APPLIES ONLY AT THE LOCATION OF THIS BORING AND AT THE TIME OF DRILLING. SUBSURFACE CONDITIONS MAY DIFFER AT OTHER LOCATIONS AND MAY CHANGE AT THIS LOCATION WITH THE PASSAGE OF TIME. THE DATA PRESENTED IS A SIMPLIFICATION OF ACTUAL CONDITIONS ENCOUNTERED.

ELEVATION: EQUIPMENT:

DEPTH m.	DEPTH ft.	SAMPLES	SYMBOL	Moisture	Consistency	Color	Description	BLOWS/FT.	FIELD MOISTURE % DRY WEIGHT	DRY DENSITY LB./CU.FT.	TESTS
13		D		moist	stiff	light gray	SANDY SILT ML little clay, rock fragments				
14	45	D		moist	stiff	mottled purple gray	CLAYEY SILT ML	37	19.6	110	tx
15–16	50	D		moist	hard	mottled purple brown	SANDSTONE and SILTSTONE (Orinda Formation) weathering decreasing with depth	68	14.3	122	
17	55	D				gray brown		92			
18		D				gray		130/ 11"			
19–24	60–80						Bottom of Boring 60'				

CENTENNIAL DRIVE OVERPASS LANDSLIDE
University of California, Berkeley

Project No. 81-04139-04

ConverseWardDavisDixon Geotechnical Consultants

Drawing No. 2-3

DRILL RIG: Track Rig, Rotary Wash	SURFACE ELEVATION: 775.0 (see notes)	LOGGED BY: AL
DEPTH TO GROUNDWATER: (see notes)	BORING DIAMETER: 4 7/8 inches	DATE DRILLED: 7/16/09

DESCRIPTION AND REMARKS	COLOR	CONSISTENCY	SOIL TYPE	DEPTH (ft)	SAMPLER TYPE	SAMPLER BLOW COUNTS	MOISTURE CONTENT (%)	DRY DENSITY (pcf)	OTHER TESTS
CLAY, Lean - some silt, with fine to coarse gravel (FILL)	Dark Brown with Yellowish Brown and Greenish Gray	Very Stiff	CL	1 2 3 4					
-some silt, with some fine gravel, some coarse sands, low to medium plasticity, moist (FILL)	Dark Brown with Yellowish Brown and Gray			5 6 7 8		[32]	16.6	112	PP = >4.5 tsf
-some silt, trace coarse gravel, black angular Moraga volcanic pieces, some coarse sands, medium plasticity (FILL)	Dark Gray, Bluish Gray, Black, Reddish Yellowish Brown			9 10 11 12 13 14		[26]	19.9	106	PP = 3.5 tsf LL = 47.7, PL = 20.2
-some silt, with some coarse sand to fine gravel, claystone pieces and Moraga volcanics, low plasticity, moist (FILL)	Bluish Gray with Light Gray, Yellowish Brown, Reddish Brown, Black			15 16 17 18 19		[37]	16.7	115	PP = >4.5 tsf
-with siltstone fragments, trace roots, trace gravels (FILL)	Mottled Reddish Brown, Yellowish Brown, Greenish Gray			20					

(Continued on Next Page)

DESCRIPTION AND REMARKS	COLOR	CONSISTENCY	SOIL TYPE	DEPTH (ft)	SAMPLER TYPE	SAMPLER BLOW COUNTS	MOISTURE CONTENT (%)	DRY DENSITY (pcf)	OTHER TESTS
(Continued from Previous Page)									
-(continued from previous page)				22					
SILT - with siltstone, reconstructed fill (FILL)	Greenish Gray	Very Stiff	ML	23					
-25': piece of fabric at top of sample (filter fabric from slide repair) FILL				24					
SILTSTONE - deeply weathered with clay along fractures, soft to low hardness, friable to plastic, crushed, moist, some fine gravels, faint iron-oxide modeling (ORINDA)	Greenish-Bluish Gray		BED ROCK	25, 26, 27, 28					Gravel = 1.4%, Sand = 8.3%, Silt =- 76.6%, Clay = 13.7% LL = 41.3, PI = 26.8
-29'-30.5': fine grained silty sandstone with gravel, very moist, soft, friable				29					
SILTSTONE - low hardness, friable to weak, deeply weathered (ORINDA)	Bluish Gray with Yellowish Mottling			30, 31					
-32'-34': clayey siltstone, massive, fractured and weathered, weak, moist	Bluish Gray			32, 33, 34					
-35': changes to reddish brown clayey siltstone across low angle (<10 degrees) contact, no shearing, weak and soft, becomes darker with depth	Reddish Brown			35, 36					
-37' - 37.5': clay rich zone, depositional contact, no shearing, dips about 20 degrees				37					
SILTSTONE/CLAYSTONE - low hardness, friable to weak, moderately weathered, hard siltstone fragments with siliceous coating (ORINDA)	Brown and Bluish Gray			38, 39, 40					
-40.5' - 42': No recovery, very hard drilling at 40.5'				41					
-42' - 42.5': fine to coarse sized metamorphic gravels with silt and clay, wet (at top of SPT sample)	Gray and Brown			42, 43					
-43.5' - 44.5': metamorphic cobbles with clay				44		46			
CLAYSTONE - some silt, low hardness,	Brown and Gray								

(Continued on Next Page)

DESCRIPTION AND REMARKS	COLOR	CONSISTENCY	SOIL TYPE	DEPTH (ft)	SAMPLER TYPE	SAMPLER BLOW COUNTS	MOISTURE CONTENT (%)	DRY DENSITY (pcf)	OTHER TESTS
(Continued from Previous Page) weak, moderate to little weathering, moist, competent rock (ORINDA)			BED ROCK	46					
CLAYSTONE - (continued from previous page)				47 48 49					
SILTSTONE - low hardness, weak, moderately weathered, moist, abundant microfractures with mineralization of veins common, fractures healed and very thin, massive with no bedding, competent rock (ORINDA)	Brown and Greenish Gray			50 51 52 53					
-54' - 55': "old" soft and dark reddish brown clay fracture, 1/2" wide, dips 60 degrees, mineralization along fracture				54 55 56 57					
-increase in fine sand with depth, sandy siltstone at 59.5' to 60'				58 59 60					

Bottom of boring at 60.5 feet.

NOTES:

1. Groundwater was obscured due to rotary wash drilling method.
2. Stratification lines represent the approximate boundaries between material types and the transitions may be gradual.
3. Penetration resistance values (blow counts) enclosed in brackets ([ ]) were recorded with a 3.0-inch O.D. Modified California sampler; these are not standard penetration resistance values.
4. Elevations were approximately measured in the field using a hand level.
5. Approximate unconfined compressive strength values were recorded in the field using a pocket penetrometer. These values are shown on the logs and are preceded by the symbol "PP".

LOG OF BORING NO. 3

DATE DRILLED: 4/26/82

THIS SUMMARY APPLIES ONLY AT THE LOCATION OF THIS BORING AND AT THE TIME OF DRILLING. SUBSURFACE CONDITIONS MAY DIFFER AT OTHER LOCATIONS AND MAY CHANGE AT THIS LOCATION WITH THE PASSAGE OF TIME. THE DATA PRESENTED IS A SIMPLIFICATION OF ACTUAL CONDITIONS ENCOUNTERED.

ELEVATION: 773± EQUIPMENT: 6" Solid Auger

DEPTH m.	DEPTH ft.	SAMPLES	SYMBOL	Moisture	Consistency	Color	Description	BLOWS/FT.	FIELD MOISTURE % DRY WEIGHT	DRY DENSITY LB./CU.FT.	TESTS
							CRUSHED ROCK BASE				
				moist	medium	black	SILTY CLAY CH				
1		D		▽ 4/29 moist	medium	purple-brown	CLAYEY SILT ML trace fine sand	13	22.2	90	
2	5			moist	stiff	gray-brown	SILTY CLAY CL				
3	10	D				green-gray	trace rock fragments	19	20.2	104	
4				moist	stiff	red-brown	SILTY CLAY CH trace fine rock fragments				
5	15	D		dry	hard	olive green	SANDSTONE and SILTSTONE (Orinda Formation)	69/11"	9.9	122	
6	20	D				gray		90/9"	8.3	133	
7	25	D						77			
8, 9	30	D						88	9.1	132	
10		D						100/5"			
11, 12	35, 40						Bottom of Boring 33.5'				

CENTENNIAL DRIVE OVERPASS LANDSLIDE
University of California, Berkeley

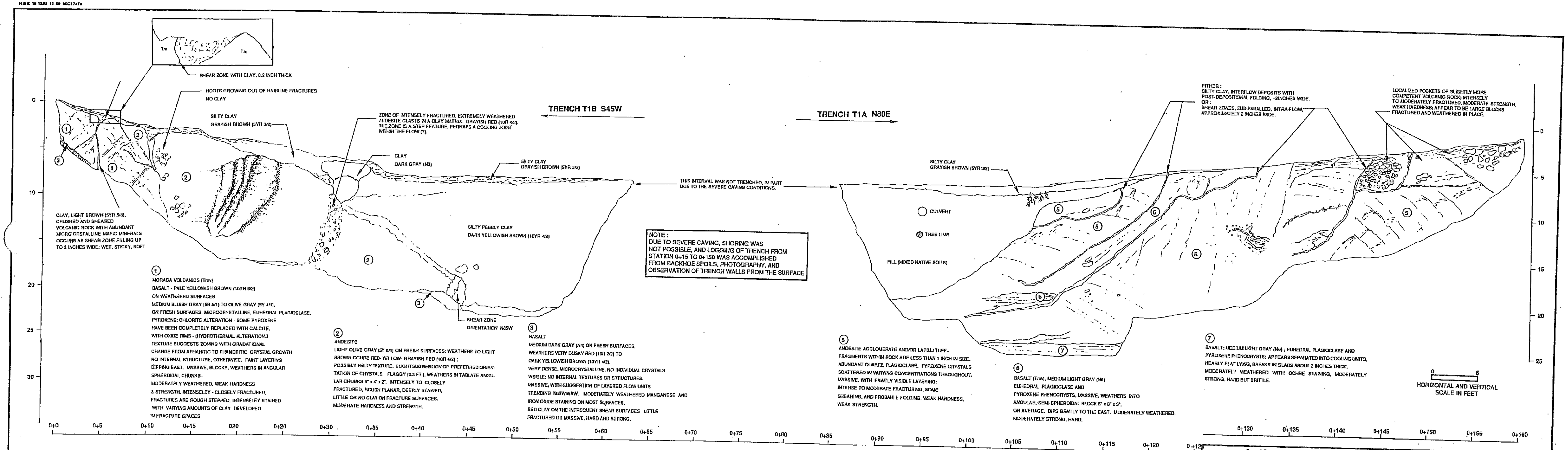
Project No. 81-04139-04

ConverseWardDavisDixon Geotechnical Consultants

Drawing No. 2-6

Cross - Section C - C'

GIS #	BORING #	ORIGINAL SOURCE
70	T-1B	GRC (1993)- Building 85 Fault Investigation
343	TP-7	GRC (1994) - Replacement of Hazardous Waste Handling Facility
234	B-5	GRC (1994) - Replacement of Hazardous Waste Handling Facility
337	AKA-5	AKA (2006) - LBNL Buildings 85 and 85A
338	AKA-5A	AKA (2006) - LBNL Buildings 85 and 85A
348	TP-4	GRC (1994) - Replacement of Hazardous Waste Handling Facility
335	AKA-1	AKA (2006) - LBNL Animal Care Facility
334	AKA-2	AKA (2006) - LBNL Animal Care Facility
-	B-4	D&M (1960) - First Increment, Proposed Animal Bioradiological Laboratory
250	G-4	SCI (1994) - LBL Human Genome Laboratory



Geo/ Resource Consultants, Inc.
GEOLOGISTS / ENGINEERS / ENVIRONMENTAL SCIENTISTS
505 BEACH STREET, SAN FRANCISCO, CALIFORNIA 94133

Job No. 1746-003 Appr. ________ Date 4/29/93

TRENCH No.1
LAWRENCE BERKELEY LABORATORY
BUILDING 85
FAULT INVESTIGATION
BERKELEY, CALIFORNIA

FIGURE 2

340_00019

LOG OF TEST PIT TP-7

Equipment: Backhoe

Elevation: ±909 Date: 8-9-88

Depth (ft.)

Depth (ft.)	Description
0	**VERY DARK BROWN SILTY CLAY (CH)** Moist, very stiff
	BROWN GRAVELLY CLAY (CL-CH) Moist, very stiff to hard
5	**SANDY CLAYEY GRAVEL (GC)** Moist, dense, angular chunks of friable tan sandstone (Debris flow deposit)
	DARK BROWN CLAY (CH) Slightly moist, stiff
10	**MEDIUM BROWN CLAY (CL)** Slightly moist, very stiff, contains gravel
15	Total Depth: 12 ft. No Free Water

Geo/Resource Consultants, Inc.
Consulting Engineers, Geologists, Geophysicists

Job No. 1393-00 Appr: ESJ Date 10/16/89

LOGS OF TEST PITS TP-7 & TP-8
REPLACEMENT OF HAZARDOUS WASTE HANDLING FACILITY AT LAWRENCE BERKELEY LABORATORY
BERKELEY, CALIFORNIA

FIGURE A-4

LOG OF BORING B-5

* = 3.0" O.D. Modified California Sampler w/140 lb. hammer* falling 30".

Equipment: hollow stem auger

Elevation: 907 feet Date: 8/11/88

Laboratory Analyses	Blows/ft.	Moisture Content (%)	Dry density (pcf)	Depth (ft.)	Description
				0	DARK BROWN SILTY CLAY (CH) moist, stiff; grades a little more sandy & gravelly
	41			5	BROWN CLAYEY SILT (ML) slightly moist, dense gravelly
TXUU 5,600 (1,000)	27	15.8	99.0	10	BROWN SILTY CLAY (CL-CH) moist, very stiff
					BLUE GRAY SANDSTONE (Orinda Fm) friable, weak moderately weathered
	90			15	Bottom of hole 16'
				20	
				25	
				30	
				35	
				40	

Geo/Resource Consultants, Inc.
Consulting Engineers, Geologists, Geophysicists

Job No. 1393-00 Appr: ESJ Date 10/16/89

LOG OF BORING B-5
REPLACEMENT OF HAZARDOUS WASTE HANDLING FACILITY AT LAWRENCE BERKELEY LABORATORY
BERKELEY, CALIFORNIA

FIGURE A-16

ROCK LOG - Boring No. AKA-5

Project Name and Job Number LBNL BUILDINGS 85 AND 85A WLA: 1717-B, AKA: 2335-4a			WLA
Type and Diameter of Boring HQ wireline	**Boring Location** In road, ~8 feet off southeast corner of Building 85A		**Total Depth** 53.1 feet
Drilling Contractor and Rig Pitcher Drilling, Inc. Faeling 1500	**Elevation and Datum** 882.5 feet (LBNL, 2003)	**Ground Water Depth** ---	**Depth to Bedrock** 36.3 feet
Casing Size and Depth 4.5-inch diameter, 7 feet	**Length of Core Barrel and Bit** 3 feet Pitcher and 5 feet coring	**No. of Core Boxes** ---	**Date Started** 9/24/05
	Borehole Inclination 90°	**Logged by** SCT (WLA)	**Date Completed** 9/24/05

Reviewed by/Date JNB 3/20/06

Depth (feet.)	Drill Rate (min/ft)	Run No.	Recovery/Cut	RQD	Weathering	Strength	Discontinuity Description	Lithology	Remarks	Elevation (feet.)
0								Asphalt over GRAVEL; with sand (GP); gray-brown [Artificial fill]	Asphalt road surface	882.5
2							2.2 to 4.2 feet numerous mechanical breaks	CLAY; gravelly with sand (CH); dark yellowish brown to brown; 10 to 30% subangular to subrounded volcanic and sandstone clasts [Quaternary alluvium and possible landslide debris]		
2.5–5		S1	1.0/2.5							
5–7	3:08/2.0 feet	P2	0.9/2.0					6 to 7 feet: same as above with angular gravel in clay matrix, clasts moderately to severely weathered volcanics [Landslide debris - shallow landslide]	some circulation loss extend casing to 7 feet; hard drilling - Pitcher tube bent on rock	877.5
7					HW	R1-R2	fractures, rough, very close, open			
7–8	Interval not sampled								7 to 8 feet: drill advanced under own weight in soft material	
8–8.5		P5	0.3/0.5	0	MW	R3	fractures, rough, close to very close, open	MAFIC VOLCANIC ROCK; very dark brown; weathers to reddish brown with clasts of blue, olive, red, gray, purple; basalt and volcaniclastic rock with sandy matrix [Moraga Formation - derived landslide debris - shallow landside]		
8.5–11	17:30/2.5 feet	C4	2.2/2.5	0	MW	R3	50° joint, rough, wavy; crushed zone; 50° joint, rough			872.5
10.5					MW	R2	fractures close to very close			
11–14	27:30/3.0 feet	C5	2.8/3.0	1.2/2.8	MW		40° joint, rough, wavy, tight; 40° joint, rough, wavy, tight			
13					SW	R3	35° joint, rough, wavy, tight; 55° joint, rough			
14–15		C6		0	MW	R3	50° joints, rough; crushed zone			867.5

See page 2 for abbreviations of terms related to weathering, strength, and sample method.

ROCK LOG - Boring No. AKA-5

Project Name and Job Number
LBNL BUILDINGS 85 AND 85A
WLA: 1717-B, AKA: 2335-4a

WLA

Depth (feet.)	Drill Rate (min/ft)	Run No.	Recovery/Cut	RQD	Weathering	Strength	Discontinuity Description	Lithology	Remarks	Elevation (feet.)
15	15:00/4.0 feet	C_6	2.3/4.0	0				15 to 16 feet: CLAY with gravel (CL); dark brown to dark bluish gray; subangular to subrounded gravel; fine-grained volcanics [Base of Moraga Formation - derived landslide debris]	soft drilling 16 to 18 feet; poor recovery missing Tm/To contact	867.5
18	31:00/5.0 feet	C_7	2.1/5.0	1.1/2.1	SW; MW; HW	R1; R0	25° 1-inch clay seam; 80° joint; 40° fracture, tight; 40° bedding?, tight; 60° joint, wavy, rough, open	SANDSTONE and SILTSTONE; bluish gray; fine sand [Orinda Formation-derived landslide debris - deep landslide] coarsens to medium sand, well graded, with subrounded to subangular coarse sand and fine gravel, dark grayish brown	soft drilling 18 to 22 feet; some circulation loss (~20%)	862.5 (at 20)
23	23:50/5.0 feet	C_8	4.7/5.0	4.2/4.7	SW-MW; MW-HW	R1; R0	crushed rock zone, 1-inch thick, subhorizontal; 45° joint, wavy, rough, open; 50° shear, wavy, very rought, open, some polished and striated surfaces	fine- to medium-grained SANDSTONE; dark brown; in steeply dipping to irregular depositional contact with SILTSTONE; CLAYSTONE and SILTSTONE, dark reddish brown to purple and bluish gray; with local subrounded to subangular "clasts" (corestones?) of siltstone	some circulation loss (~20%)	857.5 (at 25)
28		C_9			MW	R0	10° fracture, wavy, very rough, open			
30										852.5

Undisturbed sample S = Shelby, P = Pitcher, C = rock core
Driven (2.5 to 3.0 inch) with liners MC = Modified California, O = other
Standard Penetration Test (SPT) sampler

Weathering: Fr - Fresh, SW - Slight, MW - Moderate, HW - Highly, CW - Completely, and RS - Residual soil. Strength: R6 - Extremely strong, R5 - Very strong, R4 - Strong, R3 - Medium strong, R2 - Weak, R1- Very weak, and R0 - Extremely weak.

ROCK LOG - Boring No. AKA-5

Project Name and Job Number
LBNL BUILDINGS 85 AND 85A
WLA: 1717-B, AKA: 2335-4a

WLA

Depth (feet.)	Drill Rate (min/ft)	Run No.	Recovery/Cut	RQD	Weathering	Strength	Discontinuity Description	Lithology	Remarks	Elevation (feet.)
30	23:50/5.0 feet	C_8	4.7/5.0	4.2/4.7				same as above		852.5
								SILTSTONE to fine SAND-STONE; minor claystone interbeds; bluish gray		
31					MW	R0	60° joint, planar, mineralized filling			
									slight circulation loss	
							60° joint, tight			
32					SW	R1				
							45° joint/fracture			
33	11:00/5.0 feet	C_{10}	4.6/5.0	4.0/4.6	MW					
							fracture: several orientations, tight, closely spaces			
34					SW		subhorizontal interbed contacts			
						R1				
35					MW			SANDSTONE; fine; reddish, grayish brown		847.5
							45° fractures, tight, very thin mineralization			
36						R0	20° bedding contacts			
								CLAY (CH); dark reddish brown; 3 to 4 inches thick; moist [Landslide plane]		
37					MW	R0	fractures, tight, closely spaced	SILTSTONE; bluish gray; subangular; gravel-sized clasts of siltstone; either old; annealed; breccia zone or corestones from in-situ weathering [Orinda Formation]		
38	24:40/5.0 feet	C_{11}	4.4/5.0	4.4/4.4			fractures, several orientations, tight, closely spaced			
39							55° bedding?	CLAYSTONE to SILTSTONE; reddish brown to bluish gray; moderately bedded with minor fine sandstone beds		
					MW	R0	50° bedding?			
40							fractures, several orientations, tight			842.5
					SW	R1				
41							40° bedding, facies contact			
							80° joint/fracture, tight			
42					SW		45° bedding, facies contact			
						R0	30° bedding			
43		C_{12}								
44							45° bedding			
						R1	fractures, many orientations, tight to open, few polished surfaces			
45										837.5

Undisturbed sample
S = Shelby, P = Pitcher, C = rock core

Driven (2.5 to 3.0 inch) with liners
MC = Modified California, O = other

Standard Penetration Test (SPT) sampler

Weathering: Fr - Fresh, SW - Slight, MW - Moderate, HW - Highly, CW - Completely, and RS - Residual soil. Strength: R6 - Extremely strong, R5 - Very strong, R4 - Strong, R3 - Medium strong, R2 - Weak, R1 - Very weak, and R0 - Extremely weak.

ROCK LOG - Boring No. AKA-5

Project Name and Job Number
LBNL BUILDINGS 85 AND 85A
WLA: 1717-B, AKA: 2335-4a

WLA

Depth (feet.)	Drill Rate (min/ft)	Run No.	Recovery/Cut	RQD	Weathering	Strength	Discontinuity Description	Lithology	Remarks	Elevation (feet.)
45								same as above		837.5
46–48	22:50/5.0 feet	C12	4.1/5.0	<2/4.1		R0-R1	fracture, low angle, tight, very closely spaced			
48					SW			with fine sandstone interbeds 1 to 6 inches thick		
48–53	30:00/5.0 feet	C13	5.1/5.0	4/5.1		R1	35° bedding, planar to irregular, smooth to rough, open		slight circulation loss	832.5
52.5					SW	R1				
53.1								Bottom of hole 53.1 feet.		829.4

Depth scale: 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60

Undisturbed sample S = Shelby, P = Pitcher, O = other

Driven (2.5 to 3.0 inch) with liners MC = Modified California, O = other

Standard Penetration Test (SPT) sampler

Weathering: Fr - Fresh, SW - Slight, MW - Moderate, HW - Highly, CW - Completely, and RS - Residual soil. Strength: R6 - Extremely strong, R5 - Very strong, R4 - Strong, R3 - Medium strong, R2 - Weak, R1 - Very weak, and R0 - Extremely weak.

ROCK LOG - Boring No. AKA-5A

Project Name and Job Number LBNL BUILDINGS 85 AND 85A WLA: 1717-B, AKA: 2335-4a	WLA		
Type and Diameter of Boring HQ wireline	Boring Location In road, ~7 feet off southeast corner of Building 85A		Total Depth 25 feet
Drilling Contractor and Rig Pitcher Drilling, Inc. Faeling 1500	Elevation and Datum 882 feet, MSL	Ground Water Depth ---	Depth to Bedrock >25 feet
Casing Size and Depth 4.5-inch diameter, 5 feet	Length of Core Barrel and Bit 3 feet Pitcher	No. of Core Boxes ---	Date Started 3/10/06
	Borehole Inclination 90°	Logged by J. Goodman (AKA)	Date Completed 3/10/06

Reviewed by/Date JNB 3/20/06

Depth (feet)	Lithology	Drill Rate (min/ft)	Run No.	Recovery/Cut	RQD	Weathering	Strength	Soil Samples/ Borehole Tests	Discontinuity Log	Discontinuity Description	Lithology	Remarks	Elevation (feet)
0													882.5
5													877.5
7												Drilling advanced to 12.5 feet to sample basalt-siltstone contact zone	
10													872.5
12.5–13.5		3	P_1	1.0/1.0		HW	R1			fractures abundant, clay-lined	MAFIC VOLCANIC ROCK; heavily fractured/crushed in a matrix of angular gravel and fine to coarse sand; crude layering; moist [Moraga Formation - Landslide debris - shallow landslide]	600 psi	
13.5–15		4	P_2	1.7/2.0						30° joint, planar, slightly rough 45° bedding, reddish-yellowish brown silt (ash)	CLAY with variable amounts of sand and silt; colors range from pale yellow to brown to olive; soft; highly mixed [Landslide debris - shallow landslide]	soft drilling at 13.5 feet 400 psi	
15													867.5

See page 2 for abbreviations of terms related to weathering, strength, and sample method.

ROCK LOG - Boring No. AKA-5A

Project Name and Job Number
LBNL BUILDINGS 85 AND 85A
WLA: 1717-B, AKA: 2335-4a

WLA

Depth (feet)	Drill Rate (min/ft)	Run No.	Recovery/Cut	RQD	Weathering	Strength	Discontinuity Description	Lithology	Remarks	Elevation (feet)
15		P2					60° bedding	SAND; clayey; black; 10% fine gravel; some white calcium carbonate nodules [Paleosol and landslide debris - shallow landslide]		867.5
16–17	6	P3	1.75/2.0	0			subhorizontal contact, Paleosol over siltstone	16.5 to 18.7 feet: SILTSTONE with CLAY SEAMS; red to gray; medium to high plasticity [Landslide shear zone]	400 psi	
18	3	P4	0.8/1.0		HW	R1	<5° shear, 1.5 inches soft clay; 12° shear, 1.5 inches stiff clay, old slide plane	18 feet: CLAY; dark brown; soft; 1.5 inches thick [Landslide plane]; 18.7 feet: CLAY; stiff; 1.5 inch thick [Old landslide plane]	500 psi	
19	4	P5	1.6/1.5		MW	R2	bedding, irregular, subhorizontal	SANDSTONE; greenish gray; fine to medium; weakly cemented; [Landslide debris - deep landslide]	1000 psi	
20								coarse sand and fine gravel		862.5
21	4	P6	0.9/1.5	1.1/2.1	HW-SW	R2	55° bedding	SILTSTONE, clayey to sandy, crushed		
22–23									not sampled below 21.5 feet	
25								Bottom of hole at 25 feet.		857.5
30										852.5

Undisturbed sample S = Shelby, P = Pitcher, O = other

Driven (2.5 to 3.0 inch) with liners MC = Modified California, O = other

Standard Penetration Test (SPT) sampler

Weathering: Fr - Fresh, SW - Slight, MW - Moderate, HW - Highly, CW - Completely, and RS - Residual soil. Strength: R6 - Extremely strong, R5 - Very strong, R4 - Strong, R3 - Medium strong, R2 - Weak, R1- Very weak, and R0 - Extremely weak.

LOG OF TEST PIT TP-3

Equipment: Backhoe

Elevation: ±897 Date: 8-9-88

Depth (ft.)	Description
0	DARK BROWN SILTY CLAY (CH) Slightly moist, stiff
	VERY DARK BROWN CLAY (CH) Very moist, very stiff, contains small weathered gravel clasts
5	DARK BROWN CLAY (CL) Contains large gravel clasts
	DARK GRAY ANDESITE (Moraga Fm) Hard and strong where fresh, closely fractured, moderately weathered contains clay and loose material in fractures
10	Total Depth: 9 ft. No Free Water
15	

LOG OF TEST PIT TP-4

Equipment: Backhoe

Elevation: ±895 Date: 8-9-88

Depth (ft.)	Description
0	BROWN SILTY CLAY (CL-ML) contains gravel
	GRAY ANDESITE (Moraga Fm) closely fractured, mod. hard, mod. strong weathered, little to moderately weathered
5	
	more weathered below 8 ft.
10	Total Depth: 10 ft. No Free Water
15	

Geo/Resource Consultants, Inc.
Consulting Engineers, Geologists, Geophysicists

Job No. 1393-00 Appr: ESJ Date 10/16/89

LOGS OF TEST PITS TP-3 & TP-4

REPLACEMENT OF HAZARDOUS WASTE HANDLING FACILITY AT LAWRENCE BERKELEY LABORATORY BERKELEY, CALIFORNIA

FIGURE A-2

DRILL RIG: Rotary Wash	SURFACE ELEVATION: ± 872 feet	LOGGED BY: JP
DEPTH TO GROUNDWATER: See Notes	BORING DIAMETER: 5 inches	DATE DRILLED: 08-16-04

DESCRIPTION AND REMARKS	COLOR	CONSISTENCY	SOIL TYPE	DEPTH (feet)	SAMPLER	BLOWS / FT	MOISTURE CONTENT (%)	DRY DENSITY (pcf)	OTHER TESTS
Asphaltic Concrete ~ 6 inches Baserock ~ 6.5 inches	--	--	--						
VOLCANICS, severely weathered, highly fractured, iron staining on partings; (LANDSLIDE DEBRIS)	Brown	Soft Hardness	ROCK	1					
-micro-chrystalline structure, interlocking, fractured 1-2 mm wide, stained, highly weathered, volcanics - basalt or andesite	Dark Gray to Brown			5–6		[34]			
-clay-rich matrix, highly fractured, weathered bedrock	Dark Brown to Olive Brown			7–8		[35]			
	Light Brown			9–10		19			
-crushed bedrock, 40°dip, interpreted slide plane at 10.5 feet, noted by yellowish brown clay, dip 40°	Dark Reddish Brown to Yellowish Brown			10–12					
-highly fractured bedrock with clay seams									
SILTSTONE, tight fractured with iron staining, no clay seams, fractures pervasive; (LANDSLIDE DEBRIS)	Greenish Gray	Moderate Hardness	ROCK	13–14		[53]			
-highly fractured siltstone with clay along seams, no apparent bedding, contact dip between color change 40° -carbonate along seams	Dark Brown			14–16					
SILTSTONE to SANDSTONE, fine-grained, highly weathered, tight fractures; (LANDSLIDE DEBRIS)	Gray to Grayish Brown	Moderate Hardness	ROCK	16–17		[44]			
-reddish brown siltstone, tight fractures with clayey seams				18–19		32			
-19-21': highly weathered and fractured siltstone, silty clay matrix along larger blocks	Dark Reddish Brown	Soft Hardness		19–20					

(continued on next sheet)

ALAN KROPP & ASSOCIATES
Geotechnical Consultants

EXPLORATORY BORING LOG

LBNL ANIMAL CARE FACILITY
Berkeley, California

PROJECT NO.	DATE	SHEET	BORING NO.
2335-2	September 2004	1 of 4	1

DRILL RIG: Rotary Wash	SURFACE ELEVATION: ± 872 feet	LOGGED BY: JP
DEPTH TO GROUNDWATER: See Notes	BORING DIAMETER: 5 inches	DATE DRILLED: 08-16-04

DESCRIPTION AND REMARKS	COLOR	CONSISTENCY	SOIL TYPE	DEPTH (feet)	SAMPLER	BLOWS / FT	MOISTURE CONTENT (%)	DRY DENSITY (pcf)	OTHER TESTS
SILTSTONE to SANDSTONE, fine-grained, highly weathered, fractured, silty clay matrix along larger blocks; (LANDSLIDE DEBRIS), (continued from previous sheet)	Dark Reddish Brown	Soft Hardness	ROCK	21					
-21-22': less fractured -22.5': contact dips 25°-30° between upper dark reddish brown clay rich siltstone and distinct bluish gray siltstone, pervasive blocky fractures	Bluish Gray			22 23		[37]			
				24		23			
CLAY, slickenslides, dips 20°; (interpreted slide plane)	Bluish Gray	Soft	CH						
SILTSTONE, abundant clay, blocky to seamy fractures, with anastomosing fabric, shiny surfaces, strongly sheared to crushed bluish gray siltstone;(LANDSLIDE DEBRIS)	Dark Reddish Brown to Bluish Gray	Stiff	ROCK	25 26 27					
-transition landslide to bedrock (LANDSLIDE DEBRIS ↑)				28		[73]			
SILTSTONE, highly weathered, fractured, less clay rich and losing seamy fabric, still abumdant fractures, becoming blue in color	Dark Reddish Brown	Soft Hardness	BED-ROCK	29		77			
-29.5-31.5': solid blocky fractures, no clay seams, fracture spacing 1 to 2 inches and blocky, no apparent bedding	Bluish Gray			30 31 32					
	Reddish Brown			33		[94]			
-34-37.5': weak to moderately strong material, fracture spacing 2 to 3 inches	Grayish Reddish Brown			34 35		82			
				36					∇ 16 hours after drilling
				37		[50]/5"			
SANDSTONE, very-fine-grained, silty, large blocky fractures, no clay seams, bedding dip 20°-40°, weak to moderately strong -39': prominent steep 60° dipping tight fracture, subhorizontal reddish brown weathered zone (continued on next sheet)	Bluish Gray	Moderate Hardness	BED-ROCK	38 39 40					

ALAN KROPP & ASSOCIATES
Geotechnical Consultants

EXPLORATORY BORING LOG

LBNL ANIMAL CARE FACILITY
Berkeley, California

PROJECT NO.	DATE	SHEET	BORING NO.
2335-2	September 2004	2 of 4	1

DRILL RIG: Rotary Wash	SURFACE ELEVATION: ± 872 feet	LOGGED BY: JP
DEPTH TO GROUNDWATER: See Notes	BORING DIAMETER: 5 inches	DATE DRILLED: 08-16-04

DESCRIPTION AND REMARKS	COLOR	CONSISTENCY	SOIL TYPE	DEPTH (feet)	SAMPLER	BLOWS / FT	MOISTURE CONTENT (%)	DRY DENSITY (pcf)	OTHER TESTS
SANDSTONE, very-fine-grained, silty, large blocky fractures, no clay seams, bedding dip 15°-20°, moderate to hard strong, thin sandy laminations (continued from previous sheet)	Dark Gray to Light Gray	Moderate Hardness	BED-ROCK	41, 42, 43					
-44.5-45': highly fractured and crushed sandstone, with fine gravels, fractures at 45 feet, widely spaced with minor displacement (?)				44, 45, 46					
-47': very-fine-to-medium-grained sandstone, fractured with mineralization dip 45°-50°, very small micro-faults, bedding dip between units 45°-50°	Bluish Gray Green to Brown			47, 48, 49					
-50': siltstone with cemented gravel and coarse sand, erosional contact (paleochannel?) moderate to strong, few fractures tight				50, 51, 52					
-finer grained at 53' -53-53.5': thin lense of cemented fine gravel, fractures at 1" spacing	Gray			53					
-54': bedding dip 20° -54-56': excellent interbeds of cross-bedded and laminated sand and silt to claystone (erosional contacts)	Gray to Brown			54, 55					
-56-60': prominent sandstone and siltstone interbeds, interbedded siltstone bedding dips 20°, stong to very strong	Gray			56, 57, 58, 59, 60					

(continued on next sheet)

ALAN KROPP & ASSOCIATES
Geotechnical Consultants

EXPLORATORY BORING LOG

LBNL ANIMAL CARE FACILITY
Berkeley, California

PROJECT NO.	DATE	SHEET	BORING NO.
2335-2	September 2004	3 of 4	1

DRILL RIG: Rotary Wash	SURFACE ELEVATION: ± 872 feet	LOGGED BY: JP
DEPTH TO GROUNDWATER: See Notes	BORING DIAMETER: 5 inches	DATE DRILLED: 08-16-04

DESCRIPTION AND REMARKS	COLOR	CONSISTENCY	SOIL TYPE	DEPTH (feet)	SAMPLER	BLOWS / FT	MOISTURE CONTENT (%)	DRY DENSITY (pcf)	OTHER TESTS
SANDSTONE, very-fine-grained, large blocky fractures, no clay seams, bedding dip 15°-20°, moderate to hard strong, thin sandy laminations (continued from previous sheet)	Gray	Moderate Hardness	BED-ROCK	61					
-62-65': interbedded siltstone to claystone and sandstone, very blocky, very hard, numerous sealed microfaults, highly fractures	Brown			62 63 64					
-65': very-fine-grained-sandstone with steep fractures, interbedded fine to coarse sand, dipping 15°, abundant sealed microfaults, highly fractured	Bluish Gray			65 66 67					
-68-69': fracture dipping 45°	Brown to Gray			68 69					
CLAYSTONE, abundant blocky seamy fractures, very weak to weak, no clay seams along fractures	Dark Brown with Gray	Soft Hardness	BED-ROCK	70 71					
-70-72': pulverized and crushed									
SANDSTONE, very-fine-grained, moderate to strong, bedding dip with claystone 30°	Gray	Hard Hardness	BED-ROCK	72 73					

Bottom of boring at 74 feet

NOTES

1. Groundwater was encountered at a depth of about 36 feet 16 hours after drilling. The boring was grouted following drilling. (See text for discussion.)

2. Stratification lines represent the approximate boundaries between material types and the transitions may be gradual.

3. Penetration resistance values (blow counts) enclosed in brackets ([ ]) were recorded with a 3.0-inch O.D. Modified California sampler; these are not standard penetration resistance values.

4. Elevations were determined from topographic map supplied by LBNL Facilities Department, 2004.

DRILL RIG: Rotary Wash	SURFACE ELEVATION: ± 858 feet	LOGGED BY: JP
DEPTH TO GROUNDWATER: See Notes	BORING DIAMETER: 5 inches	DATE DRILLED: 08-18-04

DESCRIPTION AND REMARKS	COLOR	CONSISTENCY	SOIL TYPE	DEPTH (feet)	SAMPLER	BLOWS / FT	MOISTURE CONTENT (%)	DRY DENSITY (pcf)	OTHER TESTS
CLAY, silty, sandy, with fine to coarse gravels, dry; (LANDSLIDE DEBRIS)	Brown	Stiff	CL	0					
-highly weathered translated bedrock in clay matrix, material appears to be weathered sandstone				2.5–4					
- Andesite fragments in clay matrix; (Qc/Qls debris)	Yellowish Brown			4–5.5		[27]			
CLAYSTONE, severely weathered, fractured, iron staining on partings; (POSSIBLE LANDSLIDE DEBRIS)	Brown	Soft Hardness	BED-ROCK	8					
- rock fragments in a clayey matrix, sandstone, fractured; (weathered bedrock or landslide debris)	Reddish Brown			10–11.5		34			
- dark rock (basalt?) fragments with some clay, possible base of weathered bedrock, highly fractured; (Qc)	Black			15–15.5		50"/3			
(POSSIBLE LANDSLIDE DEBRIS ↑)									
SANDSTONE, very fine grained, moderately weathered, fractured, with clay matrix	Gray	Hard Hardness	BED-ROCK	18					
(continued on next sheet)				20					

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EXPLORATORY BORING LOG

LBNL ANIMAL CARE FACILITY
Berkeley, California

PROJECT NO.	DATE	SHEET	BORING NO.
2335-2	September 2004	1 of 2	2

DRILL RIG: Rotary Wash	SURFACE ELEVATION: ± 858 feet	LOGGED BY: JP
DEPTH TO GROUNDWATER: See Notes	BORING DIAMETER: 5 inches	DATE DRILLED: 08-18-04

DESCRIPTION AND REMARKS	COLOR	CONSISTENCY	SOIL TYPE	DEPTH (feet)	SAMPLER	BLOWS / FT	MOISTURE CONTENT (%)	DRY DENSITY (pcf)	OTHER TESTS
SANDSTONE, very-fine-grained, moderately weathered, fractured, with angular clasts of grayish brown fractured sandstone; (weathered bedrock) (continued from previous sheet)	Bluish Gray to Gray Black	Hard Hardness	BED-ROCK	21, 22, 23, 24		[50]/5" 50/1"			
- very-fine-to-medium-grained SANDSTONE	Gray			25, 26, 27, 28, 29		50/2"			
- predominately fine-to-medium-grained SANDSTONE, laminated with fine-grained sandstone and siltstone, bedding dipping 35°, gravel lense with coarse sand between overlying fine sand and underlying coarse sand (31.5')	Grayish Light Brown			30, 31, 32					

Bottom of boring at 33 feet

NOTES

1. No groundwater was encountered at the time of drilling and the boring was grouted following drilling. (See text for discussion.)
2. Stratification lines represent the approximate boundaries between material types and the transitions may be gradual.
3. Penetration resistance values (blow counts) enclosed in brackets ([ ]) were recorded with a 3.0-inch O.D. Modified California sampler; these are not standard penetration resistance values.
4. Elevations were determined from topographic map supplied by LBNL Facilities Department, 2004.

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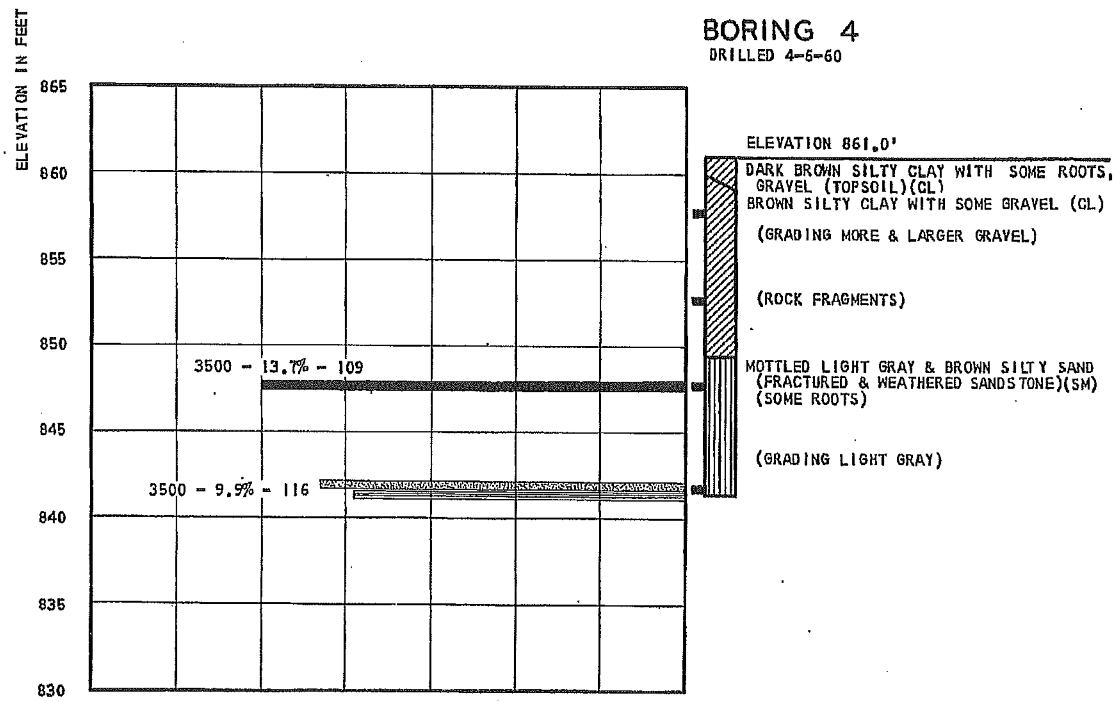
Geotechnical Consultants

EXPLORATORY BORING LOG			
LBNL ANIMAL CARE FACILITY Berkeley, California			
PROJECT NO.	DATE	SHEET	BORING NO. 2
2335-2	September 2004	2 of 2	



LOG OF BORINGS

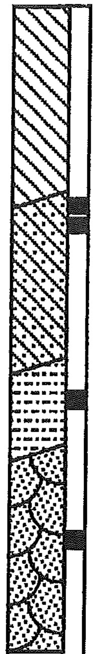
DAMES & MOORE
SOIL MECHANICS ENGINEERS

PLATE A1B

LOG OF TEST BORING G-4

EQUIPMENT 3" Solid Flight Auger
DATE DRILLED 3/17/94
ELEVATION 857 feet

LABORATORY TESTS	MOISTURE CONTENT (%)	DRY DENSITY (PCF)	OVM (PPM)	DEPTH (FEET)	SAMPLE	BLOWS PER FOOT	
				0			MOTTLED BROWN SANDY CLAY (CL) 10YR 3/4 soft, moist, with organic matter and gravel (fill)
	15.2	90		5	■	50	MOTTLED YELLOW BROWN AND RED BROWN CLAYEY SAND (SC) 10YR 6/6 & 2.5YR 4/4 stiff, damp, with dark gray chert fragments (fill)
				10	■	52**	MOTTLED BROWN CLAYSTONE/ SILTSTONE 10YR 5/3 very thin bedded, weak to friable, low hardness, crushed, deep weathering, with clasts of dark gray chert
				15	■	50/ 5"**	MOTTLED YELLOW BROWN AND LIGHT GRAY BROWN SILTY SANDSTONE 10YR 5/6 very thin bedded, intensely fractured, friable, moderately to deeply weathered refusal at 18.5 feet
						50/ 0"**	
				20			GROUNDWATER NOT ENCOUNTERED DURING DRILLING
				25			
				30			
				35			
				40			

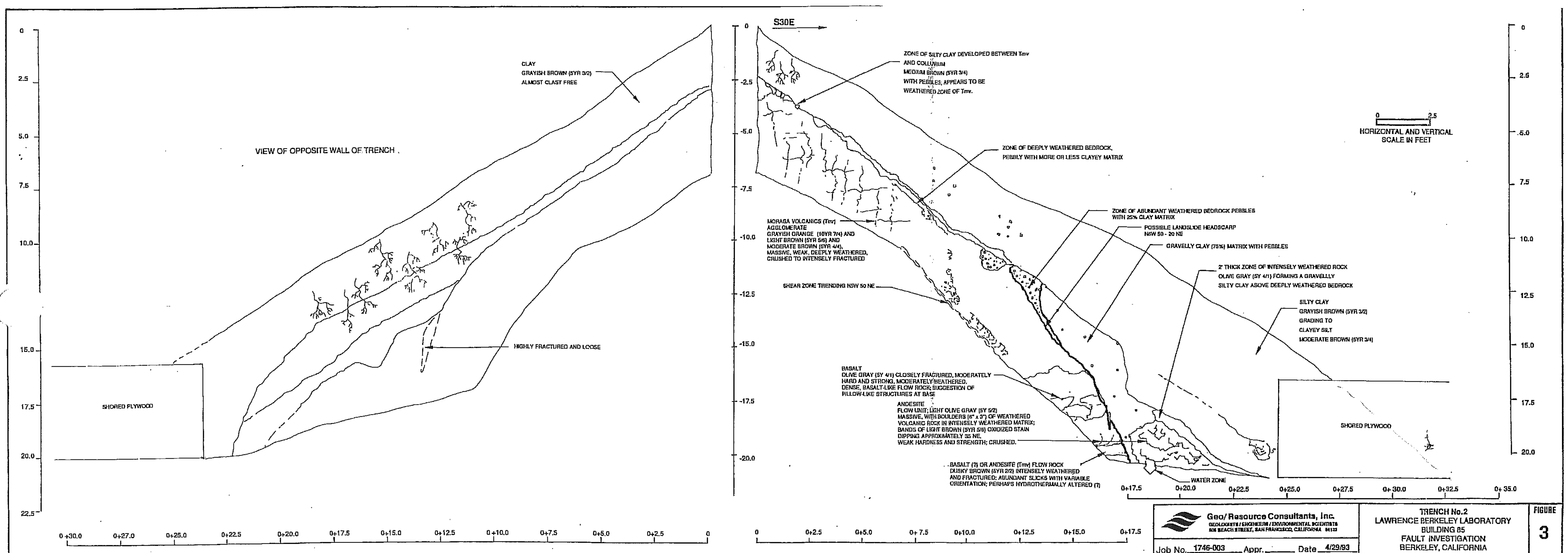


HAMMER WEIGHT: 70 pounds
HAMMER DROP: 30 inches

Subsurface Consultants	LBL HUMAN GENOME LABORATORY - BERKELEY			PLATE
	JOB NUMBER 658.025	DATE 3/28/94	APPROVED PFE	5

Cross - Section D - D'

GIS #	BORING #	ORIGINAL SOURCE
61	T-2	GRC (1994) - Building 85 Fault Investigation
509	AKA-12	AKA (2009) - Current Study
346	TP-2	GRC (1994) - Replacement of Hazardous Waste Handling Facility
229	B-2	GRC (1994) - Replacement of Hazardous Waste Handling Facility
227	B-1	GRC (1994) - Replacement of Hazardous Waste Handling Facility
508	AKA-11	AKA (2009) - Current Study
361	TP-2	SCI (1996) - Building 85 Modular Office Pad
253	B-1	HLA (1975) - Cell Culture Building
251	B-3	HLA (1975) - Cell Culture Building
244	G-10	SCI (1994) - LBL Human Genome Laboratory



Geo/Resource Consultants, Inc.
GEOLOGISTS / ENGINEERS / ENVIRONMENTAL SCIENTISTS
505 BEACH STREET, SAN FRANCISCO, CALIFORNIA 94133

Job No. 1746-003 Appr. ______ Date 4/29/93

TRENCH No.2
LAWRENCE BERKELEY LABORATORY
BUILDING 85
FAULT INVESTIGATION
BERKELEY, CALIFORNIA

FIGURE 3

340_00020

DRILL RIG: Fraste Multidrill XL, Rotary Wash	**SURFACE ELEVATION:** 890 (see notes)	**LOGGED BY:** GH
DEPTH TO GROUNDWATER: (see notes)	**BORING DIAMETER:** 4 7/8 inches	**DATE DRILLED:** 7/8/09

DESCRIPTION AND REMARKS	COLOR	CONSISTENCY	SOIL TYPE	DEPTH (ft)	SAMPLER BLOW COUNTS	MOISTURE CONTENT (%)	DRY DENSITY (pcf)	OTHER TESTS
8" concrete slab with 1/8" thick impermeable seal over 8" AB				1				
CLAY, Lean - with large gravels, some fine gravels, low to moderate plasticity, moist (FILL)	Mottled Brown, Dark Gray, Blue, Olive	Stiff	CL/GC	2		20.3	100	PP = 2.3 tsf PP = 3.6 tsf
-large Moraga Formation clasts, bluish gray volcanic rock in bottom liner and shoe of sample at 3' (hard, strong, moderate to little weathering), increase plasticity in fines (FILL)		Very Stiff		3 4 5	[18] [26]			PP = 4.5 tsf PP = 4.5 tsf
GRAVEL, Clayey - fine to coarse gravels in clay matrix, moderate to high plasticity in clay (FILL)		Medium Dense	GC	6 7				
-no recovery in 8' to 10' sample. Cuttings are coarse sands to fine gravels with clay (FILL)	Gray with Red		SC/GC	8 9 10				
GRAVEL, Clayey - with large yellowish clasts of Orinda Formation sandstone (moderately hard, moderately strong, little weathering), wood at top of sample, wet (FILL)	Yellowish Brown to Dark Gray		GC	11 12 13				
-cuttings have fibers, clay, and debris **FILL** ↑	Bluish Gray			14				
CLAY, Lean to Fat - trace medium to coarse grained sand, large root (1" diameter, 6-7" long) in bottom of sample, moist to wet (Qc)	Blue Gray to Gray	Very Stiff	CL/CH	15 16 17				
CLAY, Lean - silty, fine to coarse siltstone clasts (20-25%), few CaCO3 nodules, becomes softer with depth, dryer than above, moist (Qc)	Olive Gray Brown	Stiff	CL	18 19				PP = 3.0 tsf

(Continued on Next Page)

DESCRIPTION AND REMARKS *(Continued from Previous Page)*	COLOR	CONSISTENCY	SOIL TYPE	DEPTH (ft)	SAMPLER TYPE	SAMPLER BLOW COUNTS	MOISTURE CONTENT (%)	DRY DENSITY (pcf)	OTHER TESTS
CLAY, Lean - silty, fine to coarse siltstone clasts (20-25%), few CaCO3 nodules, becomes softer with depth, dryer than above, moist (Qc)	Olive Gray Brown	Stiff	CL	21		[17]			
CLAY, Fat - with weathered rock/landslide debris 1 to 6 inches thick	Brown, Reddish Brown, Gray	Firm	CH	22					LL=69 PI=46 -200=77%
MORAGA FORMATION - soft to low hardness, friable to weak, deeply to moderately weathered -23.5': 2" clay seam 23' to 26': very weak and highly weathered clayey gravel with abundant clasts of Moraga affinity. Interpreted as possible lighly weathered Moraga Formation -25': well developed clay seam -25' - 26': deeply weathered and oxidized -26': Orinda Formation - reddish brown siltstone	Mottled Bluish Gray, Reddish Brown Bluish Gray Reddish Brown to Olive Gray to Yellowish Brown		BED ROCK	23 24 25 26 27		[18] [17] [25]			
-deeply weathered, soft hardness -28': possible layer of Moraga volcanics, 1"-2" thick suggesting some interbedding or mixed zone	Reddish Brown with Yellowish Brown Gray			28 29					
-soft with few low hardness pieces, plastic to friable, deeply weathered, very little fracturing	Bluish Gray			30 31					
-low hardness, friable, moderately weathered				32					
-32.7': very clay rich 2" to 3" zone of weak clay with siltstone -33': interbedded contact dips 10 to 15 degrees	Reddish Gray Gray			33 34 35 36 37 38 39					
-soft to low hardness, plastic, deeply to moderately weathered; grades to low hardness, friable, moderate weathering, intensely fractured, competent rock	Bluish Gray			40 41 42		45			

(Continued on Next Page)

(Continued from Previous Page)

DESCRIPTION AND REMARKS	COLOR	CONSISTENCY	SOIL TYPE	DEPTH (ft)	SAMPLER TYPE	SAMPLER BLOW COUNTS	MOISTURE CONTENT (%)	DRY DENSITY (pcf)	OTHER TESTS
			BED ROCK	43					
				44					
-low hardness, friable to weak strength, moderately weathered, intensely fractured	Bluish Gray with Reddish Brown Seams			45					
				46		43			
				47					
				48					
				49					
CLAYSTONE to SILTSTONE - low hardness, friable to weak, some plastic seams, moderately weathered, intensely fractured to crushed, Orinda Formation, competent rock	Bluish Gray			50					
				51		50			
				52					
				53					
				54					
SILTSTONE to CLAYSTONE - low hardness, friable to weak strength, moderately weathered, intensely fractured, competent rock, Orinda Formation	Bluish Gray with White Seams			55					
				56		53			
				57					
				58					
				59					
				60					
				61		67			

Bottom of boring at 61.5 feet.

NOTES:

1. No groundwater was encountered at the time of drilling and the boring was grouted immediately after drilling. (See report for discussion.)
2. Stratification lines represent the approximate boundaries between material types and the transitions may be gradual.
3. Penetration resistance values (blow counts) enclosed in brackets ([ ]) were recorded with a 3.0-inch O.D. Modified California

(Continued on Next Page)

DESCRIPTION AND REMARKS	COLOR	CONSISTENCY	SOIL TYPE	DEPTH (ft)	SAMPLER TYPE	SAMPLER BLOW COUNTS	MOISTURE CONTENT (%)	DRY DENSITY (pcf)	OTHER TESTS

(Continued from Previous Page)

sampler; these are not standard penetration resistance values.

4. Elevations were taken from June 1994 Plans for Building 85 and 85A by Brown and Caldwell Consultants.

5. Approximate unconfined compressive strength values were recorded in the field using a pocket penetrometer. These values are shown on the logs and are preceded by the symbol "PP".

6. Blow counts have not been corrected for hammer energy.

LOG OF TEST PIT TP-2

Equipment: Backhoe

Elevation: ±875 Date: 8-9-88

Depth (ft.): 0, 5, 10, 15

DARK BROWN SILTY CLAY (CH)
Slightly moist, very stiff

DARK BROWN GRAVELLY CLAY (CH-CL)
Moist, very stiff, contains clasts of angular weathered tuff, andesite

BROWN GRAVELLY CLAY (CL-GC)
Coarse clasts of volcanic rock

DARK BROWN CLAY (CL)
Less gravelly than above

LIGHT BROWN GRAVELLY CLAY (CL)
Coarse rock clasts

DARK BROWN CLAY (CL)
Moist, very stiff, some small weathered gravel clasts

GRAY AGGLOMERATE (Moraga Fm)
Moderately strong, friable to mod. hard, mod. weathered, closely to mod. fractured

Total Depth: 14.5 ft. No Free Water

Geo/Resource Consultants, Inc.
Consulting Engineers, Geologists, Geophysicists

Job No. 1393-00 Appr: ESr Date 10/16/89

LOGS OF TEST PITS TP-1 & TP-2
REPLACEMENT OF HAZARDOUS WASTE HANDLING FACILITY AT LAWRENCE BERKELEY LABORATORY BERKELEY, CALIFORNIA

FIGURE A-1

LOG OF BORING B-2

* = 3.0" O.D. Modified California Sampler w/140 lb. hammer * falling 30".

Equipment: hollow stem auger

Elevation: 868 feet Date: 8/11/88

Laboratory Analyses	Blows/ft.	Moisture Content (%)	Dry density (pcf)	Depth (ft.)	Description
				0	DARK BROWN SILTY CLAY (CH) slightly moist, stiff
				5	BROWN SILTY CLAY (CL-CH) moist, very stiff contains friable sandstone and siltstone clasts
TXUU 7,800 (500)	34				
				10	BROWN GRAVELLY CLAY (CL) moist, very stiff contains andesite fragments
	30				
				15	
	39				GRAY AGGLOMERATE (Moraga Formation) soft, weak, closely to intensely fractured deeply weathered becomes reddish brown, harder
				20	
	90				
					Bottom of hole 21' 6"
				25	
				30	
				35	
				40	

Geo/Resource Consultants, Inc.
Consulting Engineers, Geologists, Geophysicists

Job No. 1393-00 Appr: ES Date 10/16/89

LOG OF BORING B-2
REPLACEMENT OF HAZARDOUS WASTE HANDLING FACILITY AT LAWRENCE BERKELEY LABORATORY
BERKELEY, CALIFORNIA

FIGURE A-13

LOG OF BORING B-1

* = 3.0" O. D. Modified California Sampler w/140 lb. hammer* falling 30".

Equipment: hollow stem auger

Elevation: 873 feet Date: 8/11/88

Laboratory Analyses	Blows/ft.	Moisture Content (%)	Dry density (pcf)	Depth (ft.)	Description
Atterberg Limits L.L. = 54, P.I. = 21	20	21.0		0–5	DARK BROWN SILTY CLAY (CH) dry to slightly moist
	31	15.1	95.6	5–7	BROWN SILTY CLAY (CL) moist, very stiff - contains clasts of friable sandstone
				7–11	LIGHT BROWN CLAYEY GRAVEL (GC) contains moist, dense friable sandstone and hard andesite fragments
	53	10.1	88.9	11–16.5	GRAY AGGLOMERATE (Moraga Formation) weak to moderately strong, friable, moderately weathered, closely fractured
	63			16.5	Bottom of hole 16'6"

Depth scale: 0, 5, 10, 15, 20, 25, 30, 35, 40

Geo/Resource Consultants, Inc.
Consulting Engineers, Geologists, Geophysicists

Job No. 1393-00 Appr: ESJ Date 10/16/89

LOG OF BORING B-1
REPLACEMENT OF HAZARDOUS WASTE HANDLING FACILITY AT LAWRENCE BERKELEY LABORATORY
BERKELEY, CALIFORNIA

FIGURE A-12

DRILL RIG: Fraste Multidrill XL, Rotary Wash	SURFACE ELEVATION: 875 (see notes)	LOGGED BY: GH
DEPTH TO GROUNDWATER: (see notes)	BORING DIAMETER: 4 7/8 inches	DATE DRILLED: 7/13/09

DESCRIPTION AND REMARKS	COLOR	CONSISTENCY	SOIL TYPE	DEPTH (ft)	SAMPLER TYPE	SAMPLER BLOW COUNTS	MOISTURE CONTENT (%)	DRY DENSITY (pcf)	OTHER TESTS
1/8" impermeable layer over 10" concrete slab and 6" of AB				1					
CLAY, Lean, Gravelly - large angular rocks to coarse gravels, some sand and silt, dry to moist (FILL)	Reddish Brown	Very Stiff	CL/GC	2, 3	X	[25]	17.8	90	PP = >4.5 tsf PP = >4.5 tsf
				4, 5, 6					
CLAY, Lean to Fat, Sandy - some medium to coarse gravels, large root at top of 2nd liner, moist (FILL)	Mottled Black, Bluish Gray, Reddish Brown	Very Stiff	CL/CH	7, 8	X	[25]	18.2	95	PP = 4.0 tsf LL=49 PI=47 -200=60% PP = >4.5 tsf
-cuttings are black to yellowish brown angular volcanics, Moraga Formation (FILL)				9, 10, 11					
GRAVEL, Clayey - large Moraga Formation volcanics in lean clay matrix, some sand and silt, moist (FILL)	Black rocks in Mottled Reddish Brown	Dense	GC	12, 13	X	[37]	14.8	118	PP = >4.5 tsf
				14, 15, 16					
-large aphanetic rocks, Moraga Formation with lean clay, moist (FILL)	Black, Reddish Brown	Very Dense		17, 18	X	[69]			
FILL ↑				19					

(Continued on Next Page)

ALAN KROPP & ASSOCIATES
Geotechnical Consultants

EXPLORATORY BORING LOG
LBNL BUILDING 85
Berkeley, California

PROJECT NO.	DATE	SHEET	BORING **AKA-11**
2335-7B	**April 2010**	**1 of 4**	

DESCRIPTION AND REMARKS	COLOR	CONSISTENCY	SOIL TYPE	DEPTH (ft)	SAMPLER TYPE	SAMPLER BLOW COUNTS	MOISTURE CONTENT (%)	DRY DENSITY (pcf)	OTHER TESTS
(Continued from Previous Page)									
VOLCANIC ROCK - Moraga Formation gravel, hard, moderately strong, moderately weathered, with sand (Translated Moraga Formation)	Mottled Black, Brown, Reddish Brown, Gray	Dense	GC						
CLAY, Fat - clay seam with slicks, polished surfaces, Tm over Tor, or slide plane; dips 30 to 40 degrees	Mottled Reddish, Yellowish, Greenish Gray	Firm to Stiff	CH	21					LL=59 PI=40 -200=78%
SILTSTONE - Orinda Formation, moderately hard to hard, weak to moderately strong, moderately weathered	Mottled Reddish, Yellowish, Greenish Gray		BED ROCK	22 23 24					
-25': coarse crushed blocks of siltstone and sandstone	Reddish Brown			25					
SANDSTONE - silty, Orinda Formation	Light Gray grades to Reddish Brown			26 27					
-27' - 28': clayey SILTSTONE	Reddish Brown			28					
SILTSTONE - sandy, Orinda Formation, low hardness, friable, deeply to moderately weathered	Gray			29					
-29' - 30': 70 degree fracture with $CaCO_3$ and calcite mineralization	Reddish Brown Grades Reddish Brown to Greenish Gray			30 31 32					
-black fissures at bottom of sample									
SILTSTONE - low hardness, friable, deeply to moderately weathered, Orinda Formation	Grades Greenish Gray, Bluish Gray to Mottled Reddish Brown, Black, Bluish Gray			33 34					
-34' to 35': interbeds of fine to medium grained with dips of 20-30 degrees, SANDSTONE				35					
CLAYSTONE - soft to low hardness, plastic to friable, deep to moderate weathering, with thin clay seams, Orinda Formation	Reddish Brown			36 37 38					
SANDSTONE - interbed at 39', coarse sand to fine gravel dipping 30 degrees, weak to moderately strong, deeply to moderately weathered, Orinda Formation				39 40					
CLAYSTONE - low to moderately hard, friable, deeply to moderately weathered, Orinda Formation	Mottled Bluish Gray, Reddish Brown, with Reddish Brown seams			41 42					

(Continued on Next Page)

DESCRIPTION AND REMARKS (Continued from Previous Page)	COLOR	CONSISTENCY	SOIL TYPE	DEPTH (ft)	SAMPLER TYPE	SAMPLER BLOW COUNTS	MOISTURE CONTENT (%)	DRY DENSITY (pcf)	OTHER TESTS
CLAYSTONE - low to moderately hard, friable, deeply to moderately weathered, Orinda Formation	Mottled Bluish Gray, Reddish Brown, with Reddish Brown seams		BED ROCK	43 44					
-grades from CLAYSTONE to SILTSTONE to SANDSTONE, low hardness, friable, deeply weathered, Orinda Formation	Mottled Bluish Gray, Reddish Brown			45 46 47 48					
SANDSTONE - low hardnes, friable, deeply weathered, Orinda Formation	Bluish Gray to Light Gray			49 50 51 52					
CLAYSTONE - some silt, low hardness, friable to weak, moderately weathered, Orinda Formation -53' - 55': fracture (70 degree inclination), good competent rock across fracture -56': calcite mineraliztion -58': 2" reddish brown clay seam dipping 50 degrees, very distinct, soft when moist, no brecciation above and below seam, no prominent bedrock change across seam, slicks and seamy when broken open -occasional fractures, rare to occasional mineralization zones	Mottled Bluish Gray, Greenish Gray, Reddish Brown			53 54 55 56 57 58 59 60					
SILTSTONE - low to moderately hard, weak strength, moderate to little weathering, occasionally fractured -below 62': good competent rock with little to no dramatic bedding changes	Bluish Gray mottled slightly with Reddish Brown			61 62 63 64 65					

(Continued on Next Page)

DESCRIPTION AND REMARKS (Continued from Previous Page)	COLOR	CONSISTENCY	SOIL TYPE	DEPTH (ft)	SAMPLER TYPE	SAMPLER BLOW COUNTS	MOISTURE CONTENT (%)	DRY DENSITY (pcf)	OTHER TESTS
CLAYSTONE - Orinda Formation, low to moderate hardness, weak to moderately strong, moderately weathered, very little fracture -66' - 67': mineralization along narrow near vertical fracture	Mottled Bluish Gray, Reddish Brown		BED ROCK	66 67 68					
SILTSTONE - moderate hardness, weak to moderate strength, moderate to little weathering, very little fracture, trace white mineralization, subvertical siliceous veins, Orinda Formation	Bluish Gray with some Reddish Brown in seams			69 70 71 72					
-moderate hardness, weak to moderate strength, little weathering				73 74					
CLAYSTONE - low to moderate hardness, friable, moderately weathered				75 76					
-low hardness, friable to moderately strong, moderate to little weathering, grades to	Greenish Gray to Bluish Gray			77 78					
SILTSTONE - moderate hardness, weak to moderately strong, coarse sand pieces, some white gravels, moderately weathered				79 80					

Bottom of boring at 80.0 feet.

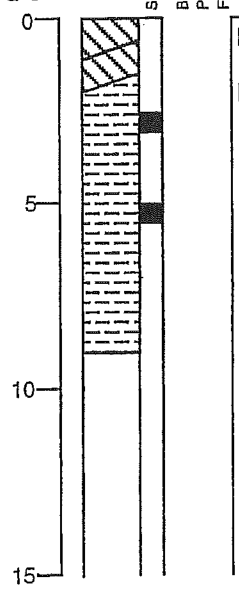
NOTES:

1. No groundwater was encountered at the time of drilling and the boring was grouted immediately after drilling. (See report for discussion.)
2. Stratification lines represent the approximate boundaries between material types and the transitions may be gradual.
3. Penetration resistance values (blow counts) enclosed in brackets ([ ]) were recorded with a 3.0-inch O.D. Modified California sampler; these are not standard penetration resistance values.
4. Elevations were taken from June 1994 Plans for Building 85 and 85A by Brown and Caldwell Consultants.
5. Approximate unconfined compressive strength values were recorded in the field using a pocket penetrometer. These values are shown on the logs and are preceded by the symbol "PP".
6. Blow counts have not been corrected for hammer energy.

LOG OF TEST PIT 2

EQUIPMENT: BACKHOE (30" BUCKET)
DATE EXCAVATED: JUNE 5, 1996
ELEVATION: 867 FEET (MSL DATUM)

LABORATORY TESTS	MOISTURE CONTENT (%)	DRY DENSITY (PCF)	OVM (PPM)	DEPTH (FEET)	SAMPLE	BLOWS PER FOOT	DESCRIPTION
				0			BROWN SILTY CLAY (CH) soft, dry, with roots (colluvium)
							BROWN SILTY CLAY (CH) medium stiff, moist (colluvium)
	26.3	97					RED-GRAY-BROWN AGGLOMERATE intensely fractured, friable, weak, deep weathering
	21.6	102		5			
				10			No groundwater encountered
				15			



Subsurface Consultants

BUILDING 85 MODULAR OFFICE PAD
LAWRENCE BERKELEY NATIONAL LABORATORY

JOB NUMBER	DATE	APPROVED	PLATE
658.040	8/19/96	[signature]	2

LOG OF BORING 1

Equipment: Hollow Stem Auger
Elevation: 862 feet* Date: 6/21/75

Shear Strength (lbs/sq ft): 5000, 4000, 3000, 2000, 1000, 0

Shear Strength	Moisture Content (%)	Dry Density (pcf)	Depth (ft)
	13.9	106	5
	16.8	113	10
	16.1	114	20
UU 2500	13.7	115	30

Depth (ft): 0–40

BROWN SILTY CLAY (CL) — medium stiff, moist, with small angular rock fragments (Colluvium)

GRAY-BROWN ANDESITE — intensely fractured, moderately hard, moderately strong, deeply weathered (MORAGA FORMATION)

water level 6/24/75

GRAY-GREEN CLAYEY SILT (ML) — soft, moist

GRAY-GREEN SANDY SILTSTONE — low hardness, weak, moderately weathered

RED-BROWN CLAYSTONE — low hardness, weak, moderately weathered

GRAY-GREEN SILTSTONE — low hardness, weak, moderately weathered (ORINDA FORMATION)

becoming sandy, little weathered, massive

(2" diameter plastic pipe placed in hole after completion of drilling)

*LBL Datum (Topographic Base Map 1" = 1000')

HARDING-LAWSON ASSOCIATES
Consulting Engineers and Geologists

Job No 2000,104.01 Appr JB Date 7/11/75

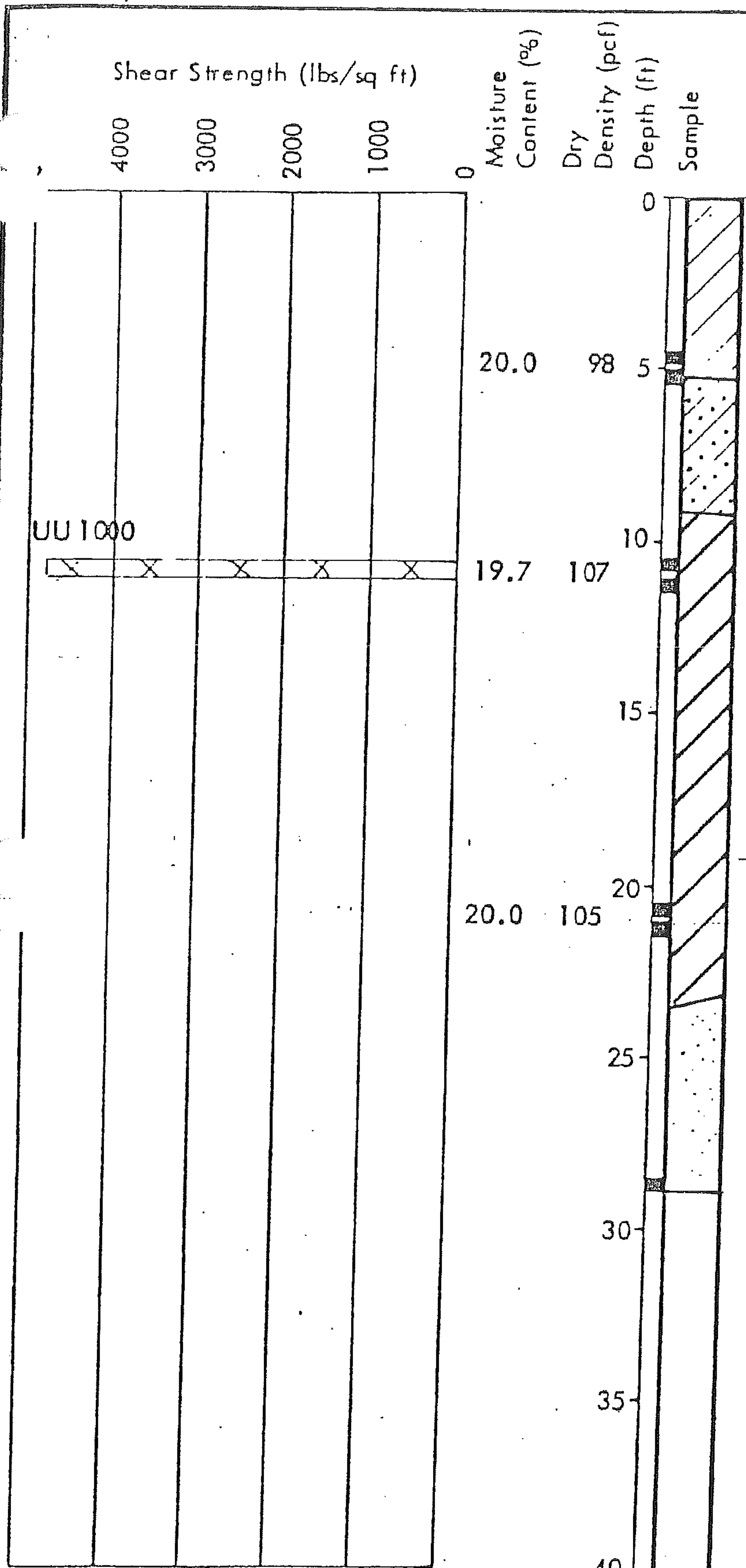
LOG OF BORING 1
Cell Culture Building
Lawrence Berkeley Laboratory

PLATE 2

LOG OF BORING 3

Equipment: Hollow Stem Auger

Elevation: 849 feet Date: 6/21/75



DARK BROWN SILTY CLAY (CL)
loose to medium stiff, moist, with occasional roots

BROWN CLAYEY SAND (SC)
dense, moist (Predominantly Volcanic Rock Fragments)

PROBABLE SLIDE DEBRIS

LIGHT BROWN SANDY CLAY (CH) - stiff, moist, with occasional small angular rock fragments

water level 6/24/75

COLLUVIUM

LIGHT GRAY-BROWN SANDSTONE - low hardness, friable, deeply weathered

ORINDA FM.

(2" diameter plastic pipe placed in hole after completion of drilling)

HARDING - LAWSON ASSOCIATES
Consulting Engineers and Geologists

Job No 2000,104.01 Appr HB Date 7/11/75

LOG OF BORING 3
Cell Culture Building
Lawrence Berkeley Laboratory

PLATE 4

LOG OF TEST BORING G-10

EQUIPMENT: 7" Hollow Stem Auger
DATE DRILLED: 3/17/94
ELEVATION: 838 feet

LABORATORY TESTS	MOISTURE CONTENT (%)	DRY DENSITY (PCF)	OVM (PPM)	DEPTH (FEET)	BLOWS PER FOOT
				0	
				5	75/3"
			18***		
			25***		
				10	75/ 9"***
			10		
			30***		
					86/ 9"***
			610		
	10.3	102		15	50/ 5"***
				20	50/ 5"***
			15		
			95***		
				25	100/ 4"***
			115***		
			5	30	50/ 2.5"***
				35	30/ 0"***
				40	

ASPHALT CONCRETE - 2" thick
GRAY BROWN SANDY GRAVEL (GP)
medium dense, damp
boring hand excavated to 3 feet by LBL
GRAY BROWN AND BROWN SANDSTONE
10YR 6/2 & 10YR 5/3
thin bedded, closely fractured, moderate hardness, moderately strong, little weathering
hydrocarbon odor at 7-7.5 feet
GRAY SANDSTONE/SILTSTONE
7.5YR N5/0
thin bedded, closely fractured, moderate hardness, moderately strong, little weathering
hydrocarbon odor at 10.5 feet
less hard at 12 feet

DARK GRAY CLAYSTONE/SILTSTONE
7.5YR 4/0
thin bedded, closely fractured, moderate hardness, weak, moderate weathering, hydrocarbon odor in rock cuttings
LIGHT GRAY SILTY SANDSTONE 5Y 6/2
thin bedded, closely fractured, moderately strong, moderate hardness, moderate weathering, hydrocarbon odor

refusal at 38 feet
Boring backfilled with cement grout

GROUNDWATER NOT ENCOUNTERED DURING DRILLING

*** OVM READING OF SOIL CUTTINGS

HAMMER WEIGHT: 140 pounds
HAMMER DROP: 30 inches

Subsurface Consultants

LBL HUMAN GENOME LABORATORY - BERKELEY

JOB NUMBER: 658.025 | DATE: 3/28/94 | APPROVED: PFE

PLATE 10

Cross - Section E - E'

GIS #	BORING #	ORIGINAL SOURCE
352	TP-12	GRC (1994) - Replacement of Hazardous Waste Handling Facility
353	TP-3A	GRC (1994) - Replacement of Hazardous Waste Handling Facility
231	B-4	GRC (1994) - Replacement of Hazardous Waste Handling Facility
349	TP-7A	GRC (1994) - Replacement of Hazardous Waste Handling Facility
355	TP-5	GRC (1994) - Replacement of Hazardous Waste Handling Facility
359	TP-6	GRC (1994) - Replacement of Hazardous Waste Handling Facility
232	B-3	GRC (1994) - Replacement of Hazardous Waste Handling Facility
351	TP-1A	GRC (1994) - Replacement of Hazardous Waste Handling Facility
507	AKA-10	AKA (2009) - Current Investigation
357	TP-9A	GRC (1994) - Replacement of Hazardous Waste Handling Facility
513	AKA-16	AKA (2009) - Current Investigation
-	B-7	D&M (1960) - First Increment, Proposed Animal Bioradiological Laboratory
511	AKA-14	AKA (2009) - Current Investigation
300	B-2	HLA (1980) - Biomedical Laboratory II Site
275	B-1	HLA (1980) - Biomedical Laboratory II Site

LOG OF TEST PIT TP-12

Equipment: Backhoe

Elevation: ±872 Date: 8-12-88

Depth (ft.)	Description
0–5	ANDESITE (MORAGA Fm) Hard, strong, moderately fractured with some closely fractured zones.
5–15	Total Depth: 5 ft. No Free Water

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Consulting Engineers, Geologists, Geophysicists

Job No. 1393-00 Appr: [signature] Date 10/16/89

LOGS OF TEST PITS TP-11&TP-12
REPLACEMENT OF HAZARDOUS WASTE HANDLING FACILITY AT LAWRENCE BERKELEY LABORATORY BERKELEY, CALIFORNIA

FIGURE A-6

LOG OF TEST PIT TP-3A

Equipment: Case 580E Backhoe

Elevation: ±889.5 Date: 7/17/89

Depth (ft.)	Description
0	**BROWNISH BLACK CLAY (CL)** dry to moist, stiff, contains numerous roots (Topsoil)
	MODERATE BROWN SANDY GRAVELLY CLAY (CL) moist, very stiff
5	**ANDESITE (Moraga FM)** moderate brown, intensely fractured, friable to low hardness, friable to weak strength, moderately weathered, contains some resistent nodules and calcium carbonate coatings.
	Total Depth: 7 ft. No Free Water
10	
15	

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LOG OF TEST PITS TP-3A & TP-4A

REPLACEMENT OF HAZARDOUS WASTE HANDLING FACILITY AT LAWRENCE BERKELEY LABORATORY BERKELEY, CALIFORNIA

FIGURE A-8

* = 3.0"O.D. Modified California Sampler w/140 lb. hammer* falling 30".

LOG OF BORING B-4

Equipment: hollow stem auger

Elevation: 875 feet   Date: 8/11/88

Laboratory Analyses	Blows/ft.	Moisture Content (%)	Dry density (pcf)	Depth (ft.)	Description
				0	DARK BROWN SILTY CLAY (CH) slightly moist, stiff
					BROWN SILTY CLAY (CL) slightly moist, stiff
	19			5	
					BROWN AGGLOMERATE (Moraga Formation) friable to mod. hard, weak to mod. strong mod. to deeply weathered closely to intensely fractured
	47			10	
					ANDESITE mod. hard to hard, mod. strong closely to intensely fractured mod. weathered
	76			15	
					Bottom of hole at 16'
				20	
				25	
				30	
				35	
				40	

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Consulting Engineers, Geologists, Geophysicists

Job No. 1393-00   Appr: ES   Date 10/16/89

LOG OF BORING B-4
REPLACEMENT OF HAZARDOUS WASTE HANDLING FACILITY AT LAWRENCE BERKELEY LABORATORY
BERKELEY, CALIFORNIA

FIGURE A-15

LOG OF TEST PIT TP-7A

Equipment: Case 580E Backhoe

Elevation: ±871.5 Date: 7/18/89

Depth (ft.)	Description
0	BLACKISH BROWN CLAY (CL) dry to moist, stiff, moderately plastic (Topsoil)
	MODERATE BROWN SANDY CLAY (CL) moist, very stiff, randomly oriented slickensides throughout, occasional gravel-sized rock fragments
5	
	AGGLOMERATE (Moraga FM) moderate brown, soft to friable hardness, friable strength, deeply weathered
10	
	Total Depth: 11ft. No Free Water
15	

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LOG OF TEST PITS TP-7A & TP-8A

REPLACEMENT OF HAZARDOUS WASTE HANDLING FACILITY AT LAWRENCE BERKELEY LABORATORY BERKELEY, CALIFORNIA

FIGURE A-10

LOG OF TEST PIT TP-5

Equipment: Backhoe

Elevation: ±868 Date: 8-9-88

Depth (ft.)	Description
0	DARK BROWN SILTY CLAY (CH) slightly moist, stiff
	CLAYEY GRAVEL (GC)
5	AGGLOMERATE (Moraga Fm) moderately hard, weak to moderately strong, closely fractured with intensely fractured zones, moderately weathered with deeply weathered zones
10	Total Depth: 10 ft. No Free Water
15	

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Job No. 1393-00 Appr: ES Date 10/16/89

LOGS OF TEST PITS TP-5 & TP-6

REPLACEMENT OF HAZARDOUS WASTE HANDLING FACILITY AT LAWRENCE BERKELEY LABORATORY BERKELEY, CALIFORNIA

FIGURE A-3

LOG OF TEST PIT TP-6

Equipment: Backhoe

Elevation: ±858 Date: 8-10-88

Depth (ft.)	Description
0 – approx. 2.5	**DARK BROWN SILTY CLAY (CH)** Moist, very stiff, contains eucalyptus roots
approx. 2.5 – 5	**BROWN CLAY (CL)** Moist, very stiff to hard
5 – 11.5	**SANDY CLAY (CL)** Moist, very stiff to hard, grades more gravelly with depth
11.5 – 15	Total Depth: 11.5 ft No Free Water

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LOGS OF TEST PITS TP-5 & TP-6
REPLACEMENT OF HAZARDOUS WASTE HANDLING FACILITY AT LAWRENCE BERKELEY LABORATORY
BERKELEY, CALIFORNIA

FIGURE A-3

LOG OF BORING B-3

Equipment: hollow stem auger

Elevation: 857 feet Date: 8/11/88

* = 3.0" O.D. Modified California Sampler w/140 lb. hammer * falling 30".

Laboratory Analyses	Blows/ft.	Moisture Content (%)	Dry density (pcf)	Depth (ft.)	Description
Atterberg Limits L.L.= 65 P.I. = 23 UC 2,920	23	26.0	95.8	0	DARK BROWN SILTY CLAY (CH) moist, very stiff
	24	22.4	98.0	5	BROWN SILTY CLAY (CL) moist, very stiff contains some gravel grades more gravelly
	23	17.4	94.3	10	grades to light brown contains fragments of weathered andesite and siltstone
	60			15	BROWN AGGLOMERATE (Moraga Formation) soft, weak, moderately weathered
	29			20	becomes gray, softer, more weathered becomes harder, stronger
	91			25	
				30	Bottom of hole at 28'4"
				35	
				40	

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Job No. 1393-00 Appr: ES Date 10/16/89

LOG OF BORING B-3
REPLACEMENT OF HAZARDOUS WASTE HANDLING FACILITY AT LAWRENCE BERKELEY LABORATORY
BERKELEY, CALIFORNIA

FIGURE A-14

LOG OF TEST PIT TP-1A

Equipment: Case 580E Backhoe

Elevation: ±852 Date: 7/17/89

Depth (ft.)	Description
0	BROWN BLACK CLAY (CL-CH) dry to moist, very stiff, contains numerous roots (Topsoil)
	MODERATE BROWN SANDY CLAY (CL) moist, very stiff, randomly oriented slickensides
5	AGGLOMERATE (Moraga FM) moderate brown, intensely to closely fractured, friable hardness and strength, moderately to deeply weathered, randomly oriented slickensides
10	slightly less weathered and increased hardness and strength
	Total Depth: 11 ft. No Free Water
15	

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Job No. 1393-00 Appr: ESJ Date 10/16/89

LOG OF TEST PITS TP-1A & TP-2A

REPLACEMENT OF HAZARDOUS WASTE HANDLING FACILITY AT LAWRENCE BERKELEY LABORATORY BERKELEY, CALIFORNIA

FIGURE A-7

DRILL RIG: Fraste Multidrill XL, Rotary Wash	**SURFACE ELEVATION:** 875 (see notes)	**LOGGED BY:** GH
DEPTH TO GROUNDWATER: (see notes)	**BORING DIAMETER:** 4 7/8 inches	**DATE DRILLED:** 7/14/09

DESCRIPTION AND REMARKS	COLOR	CONSISTENCY	SOIL TYPE	DEPTH (ft)	SAMPLER TYPE	SAMPLER BLOW COUNTS	MOISTURE CONTENT (%)	DRY DENSITY (pcf)	OTHER TESTS
10" concrete slab with 1/8" impermeable layer over about 4" AB				1					
CLAY, Lean - with silt and fine to coarse sized gravels and pieces of asphalt, moist (FILL)	Reddish Brown w/ Yellowish Brown Pockets	Stiff	CL	2 3 4					
CLAY, Lean - mixed with fat clay, Moraga volcanics and Orinda sandstone. pieces of wood and roots, some fine gravels that appear to be Orinda Formation, dry to moist (FILL) -large rock at 6' (>3" diameter)	Mottled Black, Bluish Gray Brown, Yellowish Brown, Reddish Brown, Black	Very Stiff	CL/CH	5 6 7 8 9		[27]	15.8	92	
GRAVEL, Clayey - moderately plastic clay, fine to coarse subangular gravel, some fine to medium grained sand, moist, some organics and roots (FILL)	Black w/ Bluish Gray	Medium Dense	GC	10 11 12 13 14		[33]	19.9	101	LL=43 PI=26 -200=47%
CLAY, Lean - with black angular, coarse gravel sized Moraga Volcanics, some roots (FILL)	Black w/ Bluish Gray and Yellowish Brown Pockets	Very Stiff	CL	15 16 17		[32]	21.9	100	PP = 3.75 tsf PP = >4.5 tsf
	Mottled Olive, Bluish Gray, Yellowish Brown	Stiff to Very Stiff		18 19		18 [31]			PP = >4.5 tsf

(Continued on Next Page)

ALAN KROPP & ASSOCIATES

Geotechnical Consultants

EXPLORATORY BORING LOG			
LBNL BUILDING 85 Berkeley, California			
PROJECT NO.	DATE	SHEET	BORING **AKA-10**
2335-7B	**April 2010**	**1 of 5**	

DESCRIPTION AND REMARKS	COLOR	CONSISTENCY	SOIL TYPE	DEPTH (ft)	SAMPLER TYPE	SAMPLER BLOW COUNTS	MOISTURE CONTENT (%)	DRY DENSITY (pcf)	OTHER TESTS
(Continued from Previous Page)									
		Stiff to Very Stiff							
CLAY, Lean - some silt, large rocks and coarse gravels and sands (FILL)	Mottled Black, Greenish Gray, Yellowish Brown Rocks		CL	21		13	25.2	93	PP = 3.25 tsf
				22					PP = >4.5 tsf
		Very Stiff				[21]			
				23					
-some roots, chunks of various rock debris (FILL)	Mottled Black, Bluish Gray, Greenish Gray			24		20			PP = 3.25 tsf
				25					
FILL						[25]			
				26					
CLAY, Lean - with large angular rock pieces, occasional fine gravel sized reddish siltstone clasts, with coarse sands, some roots, silt, moist (Qc)	Gray Brown/Olive Brown with Reddish clasts	Stiff	CL						
				27		17	19.9	100	PP = >4.5 tsf
				28					PP = 4.1 tsf
						[18]			
				29					
GRAVEL, Clayey - fine to coarse subangular gravel, with fine to medium grained sand (Qc) -bottom liner has large rock, shoe has large angular pieces of Moraga Volcanics (weathered bedrock or colluvium?) (inaccurate blow count?) -no recovery at 31.5' -no recovery at 33'	Reddish Brown w/ Yellow Brown, White, Red spots	Medium Dense	GC	30		20			LL=42 PI=25 -200=38% PP = 4.2 tsf
				31					
						[70]			
				32					
				33		16			
				34					
						[27]			
CLAY, Lean - with silt, with coarse sands, trace fine gravels, possible buried A-horizon; no internal shears; (Qc)	Grayish Brown to Black	Firm	CL	35					
CLAY, Lean - with coarse sand size pieces of yellowish brown, black and white (Qc) -no recovery at 36' ~ 37.5'	Reddish Brown	Stiff to Very Stiff	CL	36		10			
				37					
						[23]			
	Olive Brown	Stiff		38					
-gravelly clay, 10-15% angular clasts	Mottled Olive Brown, Reddish Brown			39		12			
-block of siltstone at 40'				40					
						[32]			
	Mottled Reddish Brown, Black, Yellowish Brown bluish gray.			41					
				42					
-42.5': multiple thin 1/4" to 1" - thick clay seems; dip 35-40 degrees									

(Continued on Next Page)

DESCRIPTION AND REMARKS	COLOR	CONSISTENCY	SOIL TYPE	DEPTH (ft)	SAMPLER TYPE	SAMPLER BLOW COUNTS	MOISTURE CONTENT (%)	DRY DENSITY (pcf)	OTHER TESTS
(Continued from Previous Page)									
SILTSTONE/CLAYSTONE - deeply weathered, soft to low hardness, plastic to friable; at 44.5' bedding dips 30 degrees	Reddish Brown		BED ROCK	43					
				44					
				45					
SILTSTONE - some clay, soft to low hardness, plastic to friable, moderate weathering	Mottled Reddish Brown, Blue			46					
				47					
				48					
				49					
CLAYSTONE - soft to low hardness, plastic to friable, moderate weathering, 20-30 degree contact.	Gray			50					
				51					
SANDSTONE - low hardness, friable, moderate weathering, gravelly	Bluish Gray			52					
				53					
				54					
				55					
-56' - 56.5': slight weak zone with clay, no shearing				56					
-fine sand at 57'				57					
-silty at 58'				58					
-gravelly at 59'				59					
SILTSTONE - low hardness, friable, moderate weathering (distinct contact-no shear)	Reddish brown			60					
-60' - 62': steep micro faults, 1-2 inches displacement				61					
				62					
-62.5': gravelly sand seam with clay, 1-3" wide (drilling fluids?)				63					
-63'-64': old fracture or fault	Bluish Gray			64					
-competent rock below 65', moderate hardness, friable, moderate weathering, Orinda Formation	Reddish Brown			65					

(Continued on Next Page)

(Continued from Previous Page)

DESCRIPTION AND REMARKS	COLOR	CONSISTENCY	SOIL TYPE	DEPTH (ft)	SAMPLER TYPE	SAMPLER BLOW COUNTS	MOISTURE CONTENT (%)	DRY DENSITY (pcf)	OTHER TESTS
-66': white coarse gravels in soft silt, increase in medium sand	Reddish Brown		BED ROCK	66					
				67					
-68': 30 degree fracture/fault -68' - 69': fine sandstone	Bluish Gray			68					
CLAYSTONE - soft to low hardness, plastic to friable, deep to moderate weathering, Orinda Formation -with trace coarse sands, low to moderate hardness, friable to weak, moderately weathered				69					
				70					
				71					
				72					
SILTSTONE - trace coarse gravels and sands, moderately hard, weak, moderate to little weathering	Mottled Bluish Gray, Reddish Brown			73					
				74					
				75					
-76.5': 40-50 degree tight annealed fracture, good competent rock, crystallized veins along fracture				76					
CLAYSTONE - moderately hard, weak to moderately strong, moderate to little weathering -77.5': conglomerate zone with fine gravels and clay -79': conglomerate zone with coarse white gravels and clay, zone of mineralization	Mottled Reddish Brown, Bluish Gray			77					
				78					
				79					
CLAYSTONE - some coarse gravels, moderately hard, weak to moderately strong, moderate to little weathering				80					
-81' - 82': 70-80 degree fracture, no clay gouge				81					
				82					
SILTSTONE - moderately hard to hard, moderate strength, little weathering				83					
				84					
CLAYSTONE - moderately hard to hard, moderate strength, moderate to little weathering, occasionally to moderately fractured				85					
				86					
				87					
				88					

(Continued on Next Page)

ALAN KROPP & ASSOCIATES
Geotechnical Consultants

EXPLORATORY BORING LOG
LBNL BUILDING 85
Berkeley, California

PROJECT NO.	DATE	SHEET	BORING AKA-10
2335-7B	April 2010	4 of 5	

DESCRIPTION AND REMARKS (Continued from Previous Page)	COLOR	CONSISTENCY	SOIL TYPE	DEPTH (ft)	SAMPLER TYPE	SAMPLER BLOW COUNTS	MOISTURE CONTENT (%)	DRY DENSITY (pcf)	OTHER TESTS
Bottom of boring at 89.0 feet.				89					

NOTES:

1. No groundwater was encountered at the time of drilling and the boring was grouted immediately after drilling. (See report for discussion.)
2. Stratification lines represent the approximate boundaries between material types and the transitions may be gradual.
3. Penetration resistance values (blow counts) enclosed in brackets ([ ]) were recorded with a 3.0-inch O.D. Modified California sampler; these are not standard penetration resistance values.
4. Elevations were taken from June 1994 Plans for Building 85 and 85A by Brown and Caldwell Consultants.
5. Approximate unconfined compressive strength values were recorded in the field using a pocket penetrometer. These values are shown on the logs and are preceded by the symbol "PP".
6. Blow counts have not been corrected for hammer energy.

LOG OF TEST PIT TP-9A

Equipment: Case 580E Backhoe

Elevation: ± 830   Date: 7/19/89

Depth (ft.)	Description
0	COBBLES
	MODERATE BROWN CLAY (CL)
	AGGLOMERATE (Moraga FM) intensely to closely fractured, soft to friable hardness, friable strength, deeply weathered
5	Total Depth: 3 ft. No Free Water
10	
15	

Geo/Resource Consultants, Inc.
Consulting Engineers, Geologists, Geophysicists

Job No. 1393-00   Appr: ESJ   Date 10/16/89

LOG OF TEST PIT TP-9A

REPLACEMENT OF HAZARDOUS WASTE HANDLING FACILITY AT LAWRENCE BERKELEY LABORATORY BERKELEY, CALIFORNIA

FIGURE A-11

DRILL RIG: Minuteman, Solid Flight Auger	**SURFACE ELEVATION:** 831.5 (see notes)	**LOGGED BY:** GV (WLA)
DEPTH TO GROUNDWATER: (see notes)	**BORING DIAMETER:** 3 inches	**DATE DRILLED:** 10/29/09

DESCRIPTION AND REMARKS	COLOR	CONSISTENCY	SOIL TYPE	DEPTH (ft)	SAMPLER TYPE	SAMPLER BLOW COUNTS	MOISTURE CONTENT (%)	DRY DENSITY (pcf)	OTHER TESTS
SILT - with sand, dry, soft to firm, very mottled with small oxidized clasts, many roots and organics, very fine grained sand (Qc)	Brown and Dark Yellowish Brown		ML	1		[4]			
-clasts of Basalt, dark gray, angular, from 1 to several inches				2					
CLAY, Lean - ~50% silt, 10-20% fine angular gravel, predominantly Tm clasts (Qc)	Olive Brown/Dark Brown		CL	3 4		[11] 8			
SILT - with sand and gravel, dry, stiff to very stiff, very mottled, gravels are subrounded to subangular basalt and tuff, low plasticity, low dry strength, 20-30% fine gravel (Qc)	Dark Yellowish Brown to Dark Reddish Brown		ML	5 6 7 8		[29] [22]			
GRAVEL, Silty - with sand; dry; dense; fine subrouned to subangular gravels of basalt, andesite, and tuff; very mottled; moderately well sorted (Qc)	Light Yellowish Brown		GM	9 10 11		14 [31]			
-11.5': increase in large basalt clasts, matrix supported				12		[33]			
-zones of strong reddish-orange weathered basalt, fractured, open, and infilled with soil (Weathered Rock to Qc)				13		37			
BASALT - moderately weathered, weak, oxidation staining on surfaces, fractured into angular gravels, with silt and sand (Moraga Formation)	Dark Brown		BED ROCK	14 15 16 17		[50/6"] [45] 31			
-17.7' - 18.1': bake/flow zone to very old tectonic (?) contact, very stiff and dry zone of alternating thin red seams of silt and clay, 70 degree dip, no clear deFormation above or below this contact suggesting bake/flow layer									
SANDSTONE - dry, dense, moderately	Light Yellowish Brown and Dark Reddish Brown		BED ROCK	18 19		[49]			

(Continued on Next Page)

(Continued from Previous Page)

DESCRIPTION AND REMARKS	COLOR	CONSISTENCY	SOIL TYPE	DEPTH (ft)	SAMPLER TYPE	SAMPLER BLOW COUNTS	MOISTURE CONTENT (%)	DRY DENSITY (pcf)	OTHER TESTS
weathered very weak, very fine grained sand with silty interbeds, few calcite stringers, rootlet at 20', Orinda Formation -massive	Light Olive		BED ROCK	21		[46]			
CLAYSTONE - 22' - 22.7': dry, little weathering, weak, few coarse sand clasts intermixed, Orinda Formation	Dark Olive			22		75			
SILTSTONE - conglomerate, little weathering, friable, fine gravel sized reworked siltstone clasts, subangular, very mottled appearance, Orinda Formation	Dark Reddish Brown and Olive			23		[50/6"]			
				24		[50/6"]			
-25': 1/2 - 1/4-inch thick banded siltstone with clay seams, stiff, upper planar and intersected by 45-60 degree dipping clay seam, zone of whitish gray siltstone between shears				25		50/6"			
				26		[50/6"]			
-tight fractures, healed and some lined with CaCO3	Light Olive Gray			27		[50/6"] 50/6"			
				28					
				29					
				30					
				31					
-31.5': becomes weaker and more mottled, open and porous, suggestive of a buried paleosol (O-A horizon) or ancient shrink-swell feature	Reddish Brown			32		[87]			
				33		[90]			
				34					
-35': few calcite veins				35		77			
-36': frequent hairline shears, some lined with stiff clay	Reddish Brown with Bluish Gray			36		[50/6"]			
				37		[50/6"] 50/6"			
				38					
				39					
-increasing abundancy of bluish-gray color									
-41' - 41.5': SANDSTONE lense, fresh, very weak, massive, fine grained, few siltstone interbeds, with calcite veins, contact <30 degrees	Light Bluish Gray			40					
-41.5': fresh, very weak, fairly massive with weak mottling of blue and red siltstone, calcite veins, cemented	Dark Reddish Brown and Light Bluish Gray			41		[50/6"] [50/6"]			
				42					

(Continued on Next Page)

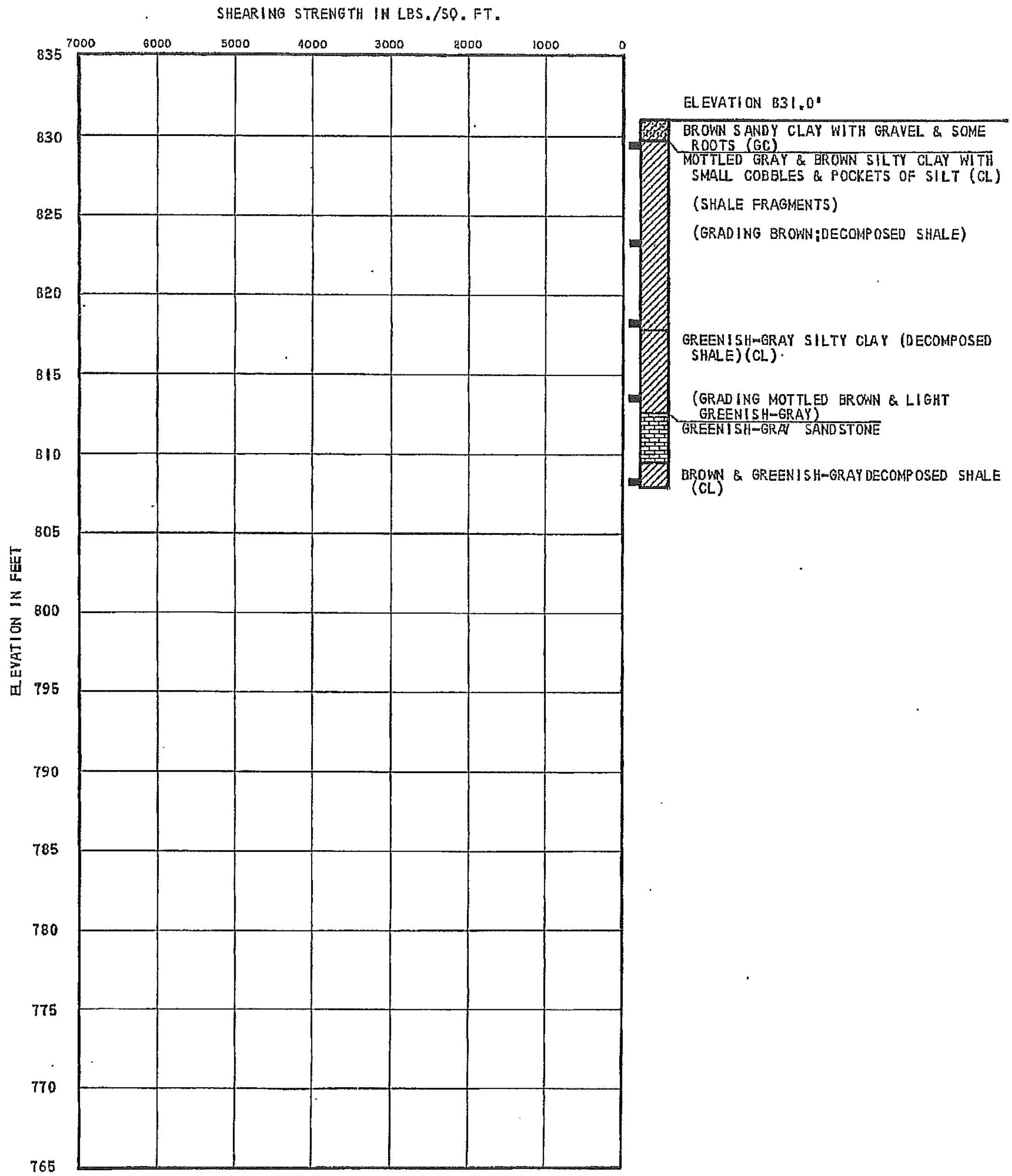
DESCRIPTION AND REMARKS	COLOR	CONSISTENCY	SOIL TYPE	DEPTH (ft)	SAMPLER TYPE	SAMPLER BLOW COUNTS	MOISTURE CONTENT (%)	DRY DENSITY (pcf)	OTHER TESTS
(Continued from Previous Page)									
Bottom of boring at 43.0 feet.				43		50			

NOTES:

1. No groundwater was encountered at the time of drilling and the boring was grouted immediately after drilling. (See report for discussion.)
2. Stratification lines represent the approximate boundaries between material types and the transitions may be gradual.
3. Penetration resistance values (blow counts) enclosed in brackets ([ ]) were recorded with a 3.0 or 2.5-inch O.D. sampler without liners; these are not standard penetration resistance values.
4. Elevations were measured by LBNL personnel.
5. Blow counts have not been corrected for hammer energy.

BORING 7

DRILLED 4-8-60



LOG OF BORING

DAMES & MOORE

SOIL MECHANICS ENGINEERS

PLATE A10

REVISIONS BY ____ DATE ____ BY ____ DATE ____ PLATE ____ OF ____

FILE ____ BY ____ DATE ____ CHECKED BY ____ DATE ____

DRILL RIG: Minuteman, Solid Flight Auger	SURFACE ELEVATION: 830.5 (see notes)	LOGGED BY: GV (WLA)
DEPTH TO GROUNDWATER: (see notes)	BORING DIAMETER: 3 inches	DATE DRILLED: 10/28/09

DESCRIPTION AND REMARKS	COLOR	CONSISTENCY	SOIL TYPE	DEPTH (ft)	SAMPLER TYPE	SAMPLER BLOW COUNTS	MOISTURE CONTENT (%)	DRY DENSITY (pcf)	OTHER TESTS
SAND, Poorly Graded - some silt, dry, loose, mottled, few yellowish tuffaceous gravels and andesite, roots in upper few feet, grading more silty with depth, gravel 25-35% and fine (1/4") (Qc)	Dark Yellowish Brown		SP	1					
				2		[6]			
-with O-A horizon									
-3' - 5': weak B horizon				3		[6]			
				4		7			
SAND, Silty to SILT, Sandy - fine gravel clasts within a brown matrix, volcanics and tuffaceous andesite and sandstone intermixed within a dark brown clayey silt matrix (Qc)	Light Yellowish Brown, Brown and Dark Brown		SM/ML	5					
				6		[20]			
				7					
-silty with small tuff aceous clasts intermixed	Dark Brown			8		[29]			
BASALT - highly weathered, fractured, Fe-oxide staining, soil matrix, mixed contact with siltstone below, no clay gouge or distinct young landslide features, dry, not soft; friable and weak zone throughout, no slicks, or polished surfaces (Tm)	Light Yellowish Brown with Reddish Brown clasts		BED ROCK	9		22			
				10					
SILTSTONE - dry, moderately weathered, weak to friable, fairly massive, mottled, fine sand with volcanic gravels, burned roots, Orinda Formation	Gray to Light Yellowish Brown		BED ROCK	11		[48]			
				12		[25]			
				13		30			
				14					
				15		[65]			
-15.4': depositional contact (<30 degrees), weathered, friable, fractured, pockets of fine grained sand				16		[35]			
				17					
-18' - 18.3': well cemented				18		37			
				19					
-19.5' - 21': massive, with few mottles of	Dark Reddish					[85]			

(Continued on Next Page)

DESCRIPTION AND REMARKS	COLOR	CONSISTENCY	SOIL TYPE	DEPTH (ft)	SAMPLER TYPE	SAMPLER BLOW COUNTS	MOISTURE CONTENT (%)	DRY DENSITY (pcf)	OTHER TESTS
(Continued from Previous Page)									
gray sand, tight to slightly open fine fractures, siltstone is porous and similar to a buried soil or weak fractured zone, no clay gouge or shearing	Brown			21		[38]			
				22					
-well cemented, hard, clayey siltstone, tight fractures abundant, breaks easily along partings						67			
				23		[50/6"]			
				24		[50/8"]			
				25					
				26		72			
-more open and porous, more mottled with rare sub-horizontal laminations, abundant fine rootlets				27		[50/6"]			
				28		[39]			
-siltstone with clay				29					
-29' - 29.2': clay filled fractures dipping 60 degrees, randomly oriented, very stiff and reddish brown, in places depositional	Dark Reddish Brown and Olive			30		68			
-moderate to little weathering, friable, mottled, few fine angular gravels, rootlets in very thin steeply dipping fractures	Gray			31		[50/6"]			
SANDSTONE - little weathering, weak to friable, massive, fine grained, Orinda Formation	Dark Reddish Brown and Olive			32		[50/6"]			
SILTSTONE - moderate to little weathering, friable, mottled, trace gravels and calcite, Orinda Formation				33		84/9"			
				34		[50/6"]			
						[50/5"]			
Bottom of boring at 35.0 feet.				35		50/4"			

NOTES:

1. No groundwater was encountered at the time of drilling and the boring was grouted immediately after drilling. (See report for discussion.)
2. Stratification lines represent the approximate boundaries between material types and the transitions may be gradual.
3. Penetration resistance values (blow counts) enclosed in brackets ([ ]) were recorded with a 3.0 or 2.5-inch O.D. sampler without liners; these are not standard penetration resistance values.
4. Elevations were measured by LBNL personnel.
5. Blow counts have not been corrected for hammer energy.

LOG OF BORING 2.145

Equipment: 6 inch flight auger
Elevation: 813 feet Date: 9/20/79

Depth (ft)	Shear Strength (lbs/sq ft)	Blows/foot (N)	Moisture Content (%)	Dry Density (pcf)	Description
0–4 (FILL)		27			RED-BROWN SANDY SILT (ML) - stiff, dry to moist containing roots and sandstone rock fragments
4–11 (COLLUVIUM)	* Atterberg Limits: liquid limit = 54, plastic limit = 29, plasticity index = 25	13	17.7	88 *	DARK BROWN SANDY CLAY (CH) stiff, moist with abundant small weathered rock fragments
11–15	UU 1000	19			DARK BROWN SANDY SILT (ML) stiff, moist
15–18		43			LIGHT BROWN SANDY CLAY (CL) very stiff, moist
18–33		49	12.1	117	RED-BROWN CLAYEY SILT (ML) very stiff, moist with siltstone fragments
		50/4.5"	16.0	94	with abundant large siltstone fragments at 26 feet
33–35		100/6"			BROWN SILTY CLAY (CL) - stiff, moist
35–37					GRAY - GREEN SILTSTONE - fragments

(Continuation of Log)

Depth (ft)	Shear Strength (lbs/sq ft)	Blows/foot (N)	Moisture Content (%)	Dry Density (pcf)	Description
40–51	UU 3400	46			DARK BROWN SANDY CLAY (CH) very stiff, moist
		70			with occasional gray siltstone fragments
		41			

No free water encountered

HARDING-LAWSON ASSOCIATES
Consulting Engineers and Geologists

Job No. 2000,145.01 Appr: [signature] Date 1/21/80

LOG OF BORING 2.145
BIOMEDICAL LABORATORY II SITE
Lawrence Berkeley Laboratory

PLATE 6

LOG OF BORING 1.145

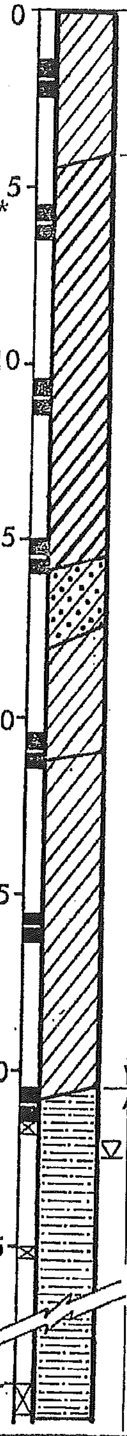
Equipment: 6 inch flight auger

Elevation: 816 feet* Date: 9/20/79

Shear Strength (lbs/sq ft): 8000, 6000, 4000, 2000, 0

Depth (ft)	Blows/foot (N)	Moisture Content (%)	Dry Density (pcf)	Shear Strength (lbs/sq ft)
~1	26	16.6	99	
~5	21	15.5	88 **	
~10	25			
~15	46			UU 1200
~20	26			
~25	17			UU 2000
~30	65	11.8	125	
~35	50/3"			
~40	60			

** Atterberg Limits:
liquid limit = 57
plastic limit = 27
plasticity index = 30



0–4 ft (FILL): MOTTLED BROWN SANDY CLAY (CL)
stiff, moist containing angular gravels and roots.

4–30 ft (COLLUVIUM):

DARK BROWN SANDY CLAY (CH)
stiff, moist, containing angular gravels and abundant roots.

with occasional small rock fragments

BROWN CLAYEY SAND (SC)
dense, moist with occasional small angular gravel

BROWN SILTY CLAY (CL)
medium stiff, moist, wet

BLUE GRAY SANDY CLAY (CL)
medium dense, moist

30 ft and below (ORINDA FM.): GRAY-GREEN SANDY SILTSTONE
intensely fractured, low hardness weak, moderately weathered friable to

water level 9/21/79

* LBL Datum

HARDING-LAWSON ASSOCIATES
Consulting Engineers and Geologists

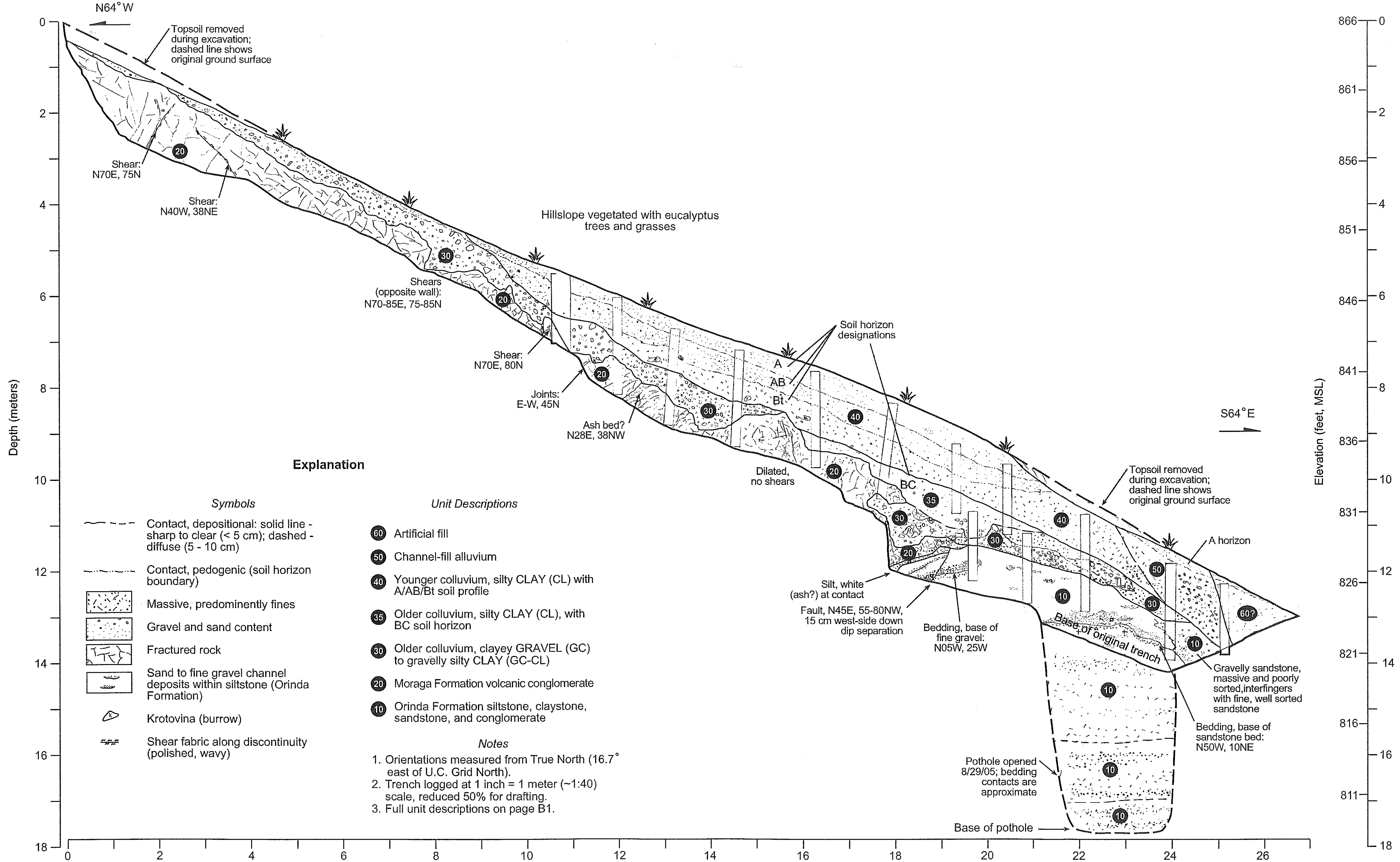
Job No. 2000,145.01 Appr: SRK Date 1/21/80

LOG OF BORING 1.145
BIOMEDICAL LABORATORY II SITE
Lawrence Berkeley Laboratory

PLATE 5

Cross - Section F - F'

GIS #	BORING #	ORIGINAL SOURCE
99	WLA-2	AKA (2006) - LBNL Buildings 85 and 85A
98	WLA-1	AKA (2006) - LBNL Buildings 85 and 85A
232	B-3	GRC (1994) - Replacement of Hazardous Waste Handling Facility
507	AKA-10	AKA (2009) - Current Investigation
508	AKA-11	AKA (2009) - Current Investigation
227	B-1	GRC (1994) - Replacement of Hazardous Waste Handling Facility
331	AKA-3	AKA (2006) - LBNL Buildings 85 and 85A
344	TP 5A	GRC (1994) - Replacement of Hazardous Waste Handling Facility
234	B-5	GRC (1994) - Replacement of Hazardous Waste Handling Facility
343	TP-7	GRC (1994) - Replacement of Hazardous Waste Handling Facility
70	T-1B	GRC (1994) - Building 85, Fault Investigation

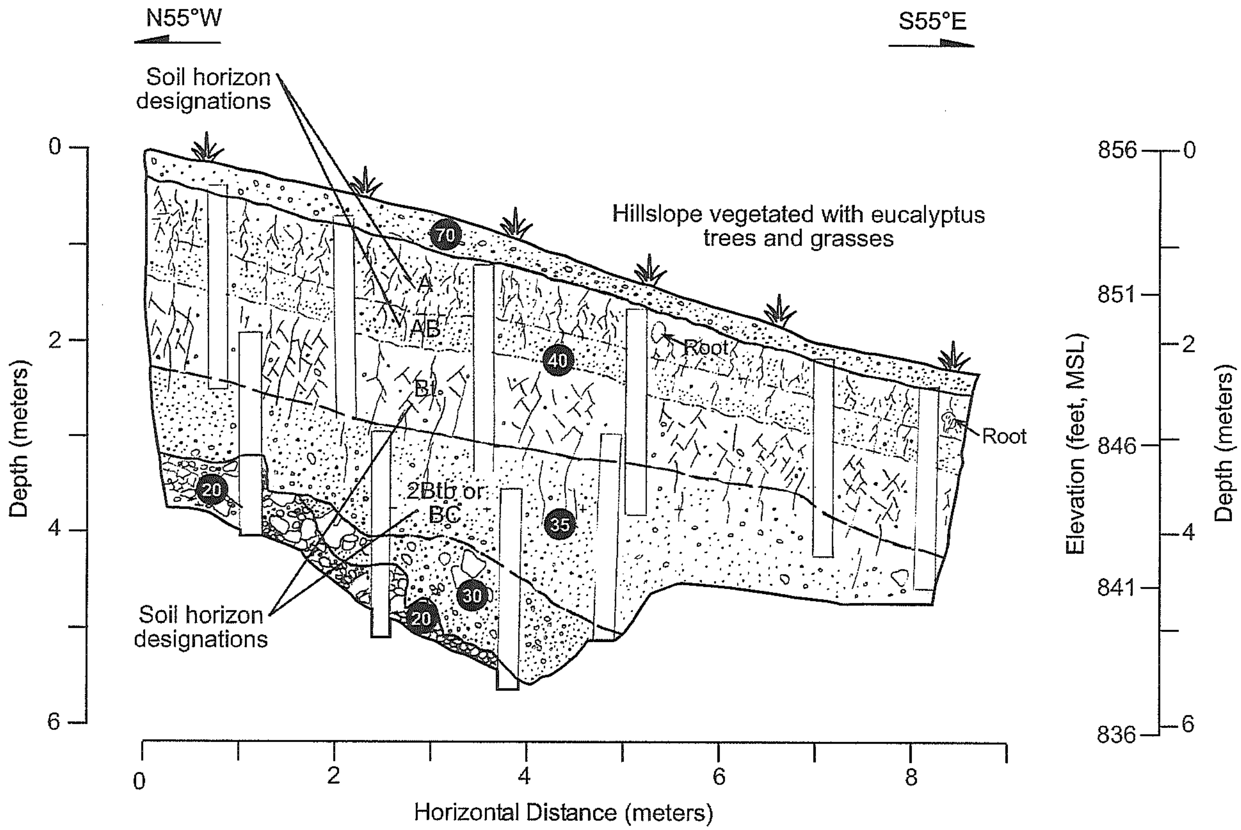


LBNL BUILDINGS 85 AND 85A

Log of Trench WLA-2, Northeast Wall

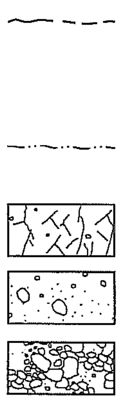
WLA — WILLIAM LETTIS & ASSOCIATES, INC. | Figure B2

Revised 3/14/07



Explanation

Symbols



Contact, depositional: solid line - sharp to clear (<5 cm); dashed - diffuse (5 - 10 cm)

Contact, pedogenic (soil horizon boundary)

Prismatic to blocky soil structure

Gravel and sand content

Fractured volcanic conglomerate

Unit Descriptions

70 Artificial fill

40 Younger colluvium, silty CLAY (CL) with A/AB/Bt soil profile

35 Older colluvium, silty CLAY (CL) with 2Btb or BC soil horizon

30 Older colluvium, clayey GRAVEL (GC)

20 Moraga Fm. volcanic conglomerate

Notes

1. Orientations measured from True North (16.7° east of U.C. Grid North).
2. Trench logged at 1 inch = 1 meter (~1:40) scale, reduced 50% for drafting.
3. Full unit descriptions on page B1.

L B N L B U I L D I N G S 8 5 A N D 8 5 A

Log of Trench WLA-1
Northeast Wall

WLA William Lettis & Associates, Inc. | Figure B1

Revised 3/14/07

1717 LBNL

LOG OF BORING B-3

* = 3.0" O.D. Modified California Sampler w/140 lb. hammer* falling 30".

Equipment: hollow stem auger

Elevation: 857 feet Date: 8/11/88

Laboratory Analyses	Blows/ft.	Moisture Content (%)	Dry density (pcf)	Depth (ft.)	Description
Atterberg Limits L.L.= 65 P.I. = 23 UC 2,920	23	26.0	95.8	0–4.5	DARK BROWN SILTY CLAY (CH) moist, very stiff
	24	22.4	98.0	4.5–16	BROWN SILTY CLAY (CL) moist, very stiff contains some gravel
					grades more gravelly
	23	17.4	94.3		grades to light brown contains fragments of weathered andesite and siltstone
	60			16–28.3	BROWN AGGLOMERATE (Moraga Formation) soft, weak, moderately weathered
	29				becomes gray, softer, more weathered
					becomes harder, stronger
	91				
				28.3	Bottom of hole at 28'4"

Depth scale (ft.): 0, 5, 10, 15, 20, 25, 30, 35, 40

Geo/Resource Consultants, Inc.
Consulting Engineers, Geologists, Geophysicists

Job No. 1393-00 Appr: ES Date 10/16/89

LOG OF BORING B-3
REPLACEMENT OF HAZARDOUS WASTE HANDLING FACILITY AT LAWRENCE BERKELEY LABORATORY
BERKELEY, CALIFORNIA

FIGURE A-14

DRILL RIG: Fraste Multidrill XL, Rotary Wash	**SURFACE ELEVATION:** 875 (see notes)	**LOGGED BY:** GH
DEPTH TO GROUNDWATER: (see notes)	**BORING DIAMETER:** 4 7/8 inches	**DATE DRILLED:** 7/14/09

DESCRIPTION AND REMARKS	COLOR	CONSISTENCY	SOIL TYPE	DEPTH (ft)	SAMPLER TYPE	SAMPLER BLOW COUNTS	MOISTURE CONTENT (%)	DRY DENSITY (pcf)	OTHER TESTS
10" concrete slab with 1/8" impermeable layer over about 4" AB									
CLAY, Lean - with silt and fine to coarse sized gravels and pieces of asphalt, moist (FILL)	Reddish Brown w/ Yellowish Brown Pockets	Stiff	CL	1–4					
CLAY, Lean - mixed with fat clay, Moraga volcanics and Orinda sandstone. pieces of wood and roots, some fine gravels that appear to be Orinda Formation, dry to moist (FILL) -large rock at 6' (>3" diameter)	Mottled Black, Bluish Gray Brown, Yellowish Brown, Reddish Brown, Black	Very Stiff	CL/CH	5–9		[27]	15.8	92	
GRAVEL, Clayey - moderately plastic clay, fine to coarse subangular gravel, some fine to medium grained sand, moist, some organics and roots (FILL)	Black w/ Bluish Gray	Medium Dense	GC	10–14		[33]	19.9	101	LL=43 PI=26 -200=47%
CLAY, Lean - with black angular, coarse gravel sized Moraga Volcanics, some roots (FILL)	Black w/ Bluish Gray and Yellowish Brown Pockets	Very Stiff	CL	15–17		[32]	21.9	100	PP = 3.75 tsf PP = >4.5 tsf
	Mottled Olive, Bluish Gray, Yellowish Brown	Stiff to Very Stiff		18–19		18 [31]			PP = >4.5 tsf

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DESCRIPTION AND REMARKS	COLOR	CONSISTENCY	SOIL TYPE	DEPTH (ft)	SAMPLER TYPE	SAMPLER BLOW COUNTS	MOISTURE CONTENT (%)	DRY DENSITY (pcf)	OTHER TESTS
		Stiff to Very Stiff							
CLAY, Lean - some silt, large rocks and coarse gravels and sands (FILL)	Mottled Black, Greenish Gray, Yellowish Brown Rocks		CL	21		13	25.2	93	PP = 3.25 tsf PP = >4.5 tsf
				22					
		Very Stiff		23		[21]			
-some roots, chunks of various rock debris (FILL)	Mottled Black, Bluish Gray, Greenish Gray			24		20			PP = 3.25 tsf
FILL ↑				25		[25]			
CLAY, Lean - with large angular rock pieces, occasional fine gravel sized reddish siltstone clasts, with coarse sands, some roots, silt, moist (Qc)	Gray Brown/Olive Brown with Reddish clasts	Stiff	CL	26					
				27		17	19.9	100	PP = >4.5 tsf PP = 4.1 tsf
				28		[18]			
				29					
GRAVEL, Clayey - fine to coarse subangular gravel, with fine to medium grained sand (Qc) -bottom liner has large rock, shoe has large angular pieces of Moraga Volcanics (weathered bedrock or colluvium?) (inaccurate blow count?) -no recovery at 31.5' -no recovery at 33'	Reddish Brown w/ Yellow Brown, White, Red spots	Medium Dense	GC	30		20			LL=42 PI=25 -200=38% PP = 4.2 tsf
				31		[70]			
				32					
				33		16			
				34		[27]			
CLAY, Lean - with silt, with coarse sands, trace fine gravels, possible buried A-horizon; no internal shears; (Qc)	Grayish Brown to Black	Firm	CL	35					
CLAY, Lean - with coarse sand size pieces of yellowish brown, black and white (Qc) -no recovery at 36' ~ 37.5'	Reddish Brown	Stiff to Very Stiff	CL	36		10			
				37		[23]			
	Olive Brown	Stiff		38					
-gravelly clay, 10-15% angular clasts	Mottled Olive Brown, Reddish Brown			39		12			
-block of siltstone at 40'				40		[32]			
	Mottled Reddish Brown, Black, Yellowish Brown bluish gray.			41					
-42.5': multiple thin 1/4" to 1" - thick clay seems; dip 35-40 degrees				42					

(Continued on Next Page)

ALAN KROPP & ASSOCIATES
Geotechnical Consultants

EXPLORATORY BORING LOG
LBNL BUILDING 85
Berkeley, California

PROJECT NO.	DATE	SHEET	BORING
2335-7B	**April 2010**	**2 of 5**	**AKA-10**

DESCRIPTION AND REMARKS (Continued from Previous Page)	COLOR	CONSISTENCY	SOIL TYPE	DEPTH (ft)	SAMPLER TYPE	SAMPLER BLOW COUNTS	MOISTURE CONTENT (%)	DRY DENSITY (pcf)	OTHER TESTS
SILTSTONE/CLAYSTONE - deeply weathered, soft to low hardness, plastic to friable; at 44.5' bedding dips 30 degrees	Reddish Brown		BED ROCK	43					
				44					
				45					
SILTSTONE - some clay, soft to low hardness, plastic to friable, moderate weathering	Mottled Reddish Brown, Blue			46					
				47					
				48					
				49					
				50					
CLAYSTONE - soft to low hardness, plastic to friable, moderate weathering, 20-30 degree contact.	Gray			51					
				52					
SANDSTONE - low hardness, friable, moderate weathering, gravelly	Bluish Gray			53					
				54					
				55					
-56' - 56.5': slight weak zone with clay, no shearing				56					
-fine sand at 57'				57					
-silty at 58'				58					
-gravelly at 59'				59					
SILTSTONE - low hardness, friable, moderate weathering (distinct contact-no shear)	Reddish brown			60					
-60' - 62': steep micro faults, 1-2 inches displacement				61					
				62					
-62.5': gravelly sand seam with clay, 1-3" wide (drilling fluids?)				63					
-63'-64': old fracture or fault	Bluish Gray			64					
-competent rock below 65', moderate hardness, friable, moderate weathering, Orinda Formation	Reddish Brown			65					

(Continued on Next Page)

ALAN KROPP & ASSOCIATES
Geotechnical Consultants

EXPLORATORY BORING LOG
LBNL BUILDING 85
Berkeley, California

PROJECT NO.	DATE	SHEET	BORING
2335-7B	April 2010	3 of 5	AKA-10

DESCRIPTION AND REMARKS (Continued from Previous Page)	COLOR	CONSISTENCY	SOIL TYPE	DEPTH (ft)	SAMPLER TYPE	SAMPLER BLOW COUNTS	MOISTURE CONTENT (%)	DRY DENSITY (pcf)	OTHER TESTS
-66': white coarse gravels in soft silt, increase in medium sand	Reddish Brown		BED ROCK	66					
				67					
-68': 30 degree fracture/fault	Bluish Gray			68					
-68' - 69': fine sandstone									
CLAYSTONE - soft to low hardness, plastic to friable, deep to moderate weathering, Orinda Formation -with trace coarse sands, low to moderate hardness, friable to weak, moderately weathered				69					
				70					
				71					
				72					
SILTSTONE - trace coarse gravels and sands, moderately hard, weak, moderate to little weathering	Mottled Bluish Gray, Reddish Brown			73					
				74					
				75					
-76.5': 40-50 degree tight annealed fracture, good competent rock, crystallized veins along fracture				76					
CLAYSTONE - moderately hard, weak to moderately strong, moderate to little weathering	Mottled Reddish Brown, Bluish Gray			77					
-77.5': conglomerate zone with fine gravels and clay				78					
-79': conglomerate zone with coarse white gravels and clay, zone of mineralization				79					
CLAYSTONE - some coarse gravels, moderately hard, weak to moderately strong, moderate to little weathering				80					
-81' - 82': 70-80 degree fracture, no clay gouge				81					
				82					
SILTSTONE - moderately hard to hard, moderate strength, little weathering				83					
				84					
CLAYSTONE - moderately hard to hard, moderate strength, moderate to little weathering, occasionally to moderately fractured				85					
				86					
				87					
				88					

(Continued on Next Page)

DESCRIPTION AND REMARKS	COLOR	CONSISTENCY	SOIL TYPE	DEPTH (ft)	SAMPLER TYPE	SAMPLER BLOW COUNTS	MOISTURE CONTENT (%)	DRY DENSITY (pcf)	OTHER TESTS
(Continued from Previous Page)									
Bottom of boring at 89.0 feet.				89					

NOTES:

1. No groundwater was encountered at the time of drilling and the boring was grouted immediately after drilling. (See report for discussion.)
2. Stratification lines represent the approximate boundaries between material types and the transitions may be gradual.
3. Penetration resistance values (blow counts) enclosed in brackets ([ ]) were recorded with a 3.0-inch O.D. Modified California sampler; these are not standard penetration resistance values.
4. Elevations were taken from June 1994 Plans for Building 85 and 85A by Brown and Caldwell Consultants.
5. Approximate unconfined compressive strength values were recorded in the field using a pocket penetrometer. These values are shown on the logs and are preceded by the symbol "PP".
6. Blow counts have not been corrected for hammer energy.

DRILL RIG: Fraste Multidrill XL, Rotary Wash	SURFACE ELEVATION: 875 (see notes)	LOGGED BY: GH
DEPTH TO GROUNDWATER: (see notes)	BORING DIAMETER: 4 7/8 inches	DATE DRILLED: 7/13/09

DESCRIPTION AND REMARKS	COLOR	CONSISTENCY	SOIL TYPE	DEPTH (ft)	SAMPLER TYPE	SAMPLER BLOW COUNTS	MOISTURE CONTENT (%)	DRY DENSITY (pcf)	OTHER TESTS
1/8" impermeable layer over 10" concrete slab and 6" of AB				1					
CLAY, Lean, Gravelly - large angular rocks to coarse gravels, some sand and silt, dry to moist (FILL)	Reddish Brown	Very Stiff	CL/GC	2					
				3	X	[25]	17.8	90	PP = >4.5 tsf PP = >4.5 tsf
				4					
				5					
				6					
CLAY, Lean to Fat, Sandy - some medium to coarse gravels, large root at top of 2nd liner, moist (FILL)	Mottled Black, Bluish Gray, Reddish Brown	Very Stiff	CL/CH	7					
				8	X	[25]	18.2	95	PP = 4.0 tsf LL=49 PI=47 -200=60% PP = >4.5 tsf
				9					
-cuttings are black to yellowish brown angular volcanics, Moraga Formation (FILL)				10					
				11					
GRAVEL, Clayey - large Moraga Formation volcanics in lean clay matrix, some sand and silt, moist (FILL)	Black rocks in Mottled Reddish Brown	Dense	GC	12					
				13	X	[37]	14.8	118	PP = >4.5 tsf
				14					
				15					
				16					
-large aphanetic rocks, Moraga Formation with lean clay, moist (FILL)	Black, Reddish Brown	Very Dense		17					
				18	X	[69]			
FILL ↑				19					

(Continued on Next Page)

(Continued from Previous Page)

DESCRIPTION AND REMARKS	COLOR	CONSISTENCY	SOIL TYPE	DEPTH (ft)	OTHER TESTS
VOLCANIC ROCK - Moraga Formation gravel, hard, moderately strong, moderately weathered, with sand (Translated Moraga Formation)	Mottled Black, Brown, Reddish Brown, Gray	Dense	GC	21	
CLAY, Fat - clay seam with slicks, polished surfaces, Tm over Tor, or slide plane; dips 30 to 40 degrees	Mottled Reddish, Yellowish, Greenish Gray	Firm to Stiff	CH	22	LL=59 PI=40 -200=78%
SILTSTONE - Orinda Formation, moderately hard to hard, weak to moderately strong, moderately weathered	Mottled Reddish, Yellowish, Greenish Gray		BED ROCK	23 24	
-25': coarse crushed blocks of siltstone and sandstone	Reddish Brown			25	
SANDSTONE - silty, Orinda Formation	Light Gray grades to Reddish Brown			26 27	
-27' - 28': clayey SILTSTONE	Reddish Brown			28	
SILTSTONE - sandy, Orinda Formation, low hardness, friable, deeply to moderately weathered	Gray			29	
-29' - 30': 70 degree fracture with CaCO3 and calcite mineralization	Reddish Brown			30	
	Grades Reddish Brown to Greenish Gray			31 32	
-black fissures at bottom of sample					
SILTSTONE - low hardness, friable, deeply to moderately weathered, Orinda Formation	Grades Greenish Gray, Bluish Gray to Mottled Reddish Brown, Black, Bluish Gray			33 34	
-34' to 35': interbeds of fine to medium grained with dips of 20-30 degrees, SANDSTONE				35	
CLAYSTONE - soft to low hardness, plastic to friable, deep to moderate weathering, with thin clay seams, Orinda Formation	Reddish Brown			36 37 38	
SANDSTONE - interbed at 39', coarse sand to fine gravel dipping 30 degrees, weak to moderately strong, deeply to moderately weathered, Orinda Formation				39 40	
CLAYSTONE - low to moderately hard, friable, deeply to moderately weathered, Orinda Formation	Mottled Bluish Gray, Reddish Brown, with Reddish Brown seams			41 42	

(Continued on Next Page)

(Continued from Previous Page)

DESCRIPTION AND REMARKS	COLOR	CONSISTENCY	SOIL TYPE	DEPTH (ft)	SAMPLER TYPE	SAMPLER BLOW COUNTS	MOISTURE CONTENT (%)	DRY DENSITY (pcf)	OTHER TESTS
CLAYSTONE - low to moderately hard, friable, deeply to moderately weathered, Orinda Formation	Mottled Bluish Gray, Reddish Brown, with Reddish Brown seams		BED ROCK	43 44					
-grades from CLAYSTONE to SILTSTONE to SANDSTONE, low hardness, friable, deeply weathered, Orinda Formation	Mottled Bluish Gray, Reddish Brown			45 46 47 48					
SANDSTONE - low hardnes, friable, deeply weathered, Orinda Formation	Bluish Gray to Light Gray			49 50 51 52					
CLAYSTONE - some silt, low hardness, friable to weak, moderately weathered, Orinda Formation -53' - 55': fracture (70 degree inclination), good competent rock across fracture	Mottled Bluish Gray, Greenish Gray, Reddish Brown			53 54 55					
-56': calcite mineraliztion				56 57					
-58': 2" reddish brown clay seam dipping 50 degrees, very distinct, soft when moist, no brecciation above and below seam, no prominent bedrock change across seam, slicks and seamy when broken open -occasional fractures, rare to occasional mineralization zones				58 59 60					
SILTSTONE - low to moderately hard, weak strength, moderate to little weathering, occasionally fractured -below 62': good competent rock with little to no dramatic bedding changes	Bluish Gray mottled slightly with Reddish Brown			61 62 63 64 65					

(Continued on Next Page)

ALAN KROPP & ASSOCIATES
Geotechnical Consultants

EXPLORATORY BORING LOG
LBNL BUILDING 85
Berkeley, California

PROJECT NO.	DATE	SHEET	BORING
2335-7B	April 2010	3 of 4	**AKA-11**

DESCRIPTION AND REMARKS (Continued from Previous Page)	COLOR	CONSISTENCY	SOIL TYPE	DEPTH (ft)	SAMPLER TYPE	SAMPLER BLOW COUNTS	MOISTURE CONTENT (%)	DRY DENSITY (pcf)	OTHER TESTS
CLAYSTONE - Orinda Formation, low to moderate hardness, weak to moderately strong, moderately weathered, very little fracture -66' - 67': mineralization along narrow near vertical fracture	Mottled Bluish Gray, Reddish Brown		BED ROCK	66 67 68					
SILTSTONE - moderate hardness, weak to moderate strength, moderate to little weathering, very little fracture, trace white mineralization, subvertical siliceous veins, Orinda Formation	Bluish Gray with some Reddish Brown in seams			69 70 71 72					
-moderate hardness, weak to moderate strength, little weathering				73 74					
CLAYSTONE - low to moderate hardness, friable, moderately weathered				75 76					
-low hardness, friable to moderately strong, moderate to little weathering, grades to	Greenish Gray to Bluish Gray			77 78					
SILTSTONE - moderate hardness, weak to moderately strong, coarse sand pieces, some white gravels, moderately weathered				79 80					

Bottom of boring at 80.0 feet.

NOTES:

1. No groundwater was encountered at the time of drilling and the boring was grouted immediately after drilling. (See report for discussion.)
2. Stratification lines represent the approximate boundaries between material types and the transitions may be gradual.
3. Penetration resistance values (blow counts) enclosed in brackets ([ ]) were recorded with a 3.0-inch O.D. Modified California sampler; these are not standard penetration resistance values.
4. Elevations were taken from June 1994 Plans for Building 85 and 85A by Brown and Caldwell Consultants.
5. Approximate unconfined compressive strength values were recorded in the field using a pocket penetrometer. These values are shown on the logs and are preceded by the symbol "PP".
6. Blow counts have not been corrected for hammer energy.

LOG OF BORING B-1

* = 3.0" O. D. Modified California Sampler w/140 lb. hammer* falling 30".

Equipment: hollow stem auger

Elevation: 873 feet Date: 8/11/88

Laboratory Analyses	Blows/ft.	Moisture Content (%)	Dry density (pcf)	Depth (ft.)	Description
Atterberg Limits L.L. = 54, P.I. = 21	20	21.0		0	DARK BROWN SILTY CLAY (CH) dry to slightly moist
	31	15.1	95.6	5	BROWN SILTY CLAY (CL) moist, very stiff - contains clasts of friable sandstone
					LIGHT BROWN CLAYEY GRAVEL (GC) contains moist, dense friable sandstone and hard andesite fragments
	53	10.1	88.9	10	GRAY AGGLOMERATE (Moraga Formation) weak to moderately strong, friable, moderately weathered, closely fractured
	63			15	Bottom of hole 16'6"
				20	
				25	
				30	
				35	
				40	

Geo/Resource Consultants, Inc.

Consulting Engineers, Geologists, Geophysicists

Job No. 1393-00 Appr: ESJ Date 10/16/89

LOG OF BORING B-1

REPLACEMENT OF HAZARDOUS WASTE HANDLING FACILITY AT LAWRENCE BERKELEY LABORATORY BERKELEY, CALIFORNIA

FIGURE A-12

ROCK LOG - Boring No. AKA-3

Project Name and Job Number LBNL BUILDINGS 85 AND 85A WLA: 1717-B, AKA: 2335-4a			
Type and Diameter of Boring HQ wireline	Boring Location Building 85, ~5 feet north of northeast corner		Total Depth 74.5 feet
Drilling Contractor and Rig Pitcher Drilling, Inc.; Faeling 1500	Elevation and Datum 876.5 feet, MSL	Ground Water Depth ---	Depth to Bedrock 65.5 feet
Casing Size and Depth 4.5-inch diameter, 10 feet	Length of Core Barrel and Bit 3 feet Pitcher and 5 feet coring	No. of Core Boxes ---	Date Started 9/1/05
	Borehole Inclination 90°	Logged by STS (WLA)	Date Completed 9/2/05

Reviewed by/Date JNB 3/22/06

Depth (feet.)	Drill Rate (min/ft)	Run No.	Recovery/Cut	Discontinuity Description	Lithology	Remarks	Elevation (feet.)
0						Hand-dug pit to 6 feet to clear utility lines	876.5
1–2						drillers reamed and augered to 6.5 feet	
5							871.5
6.5–9		S1	2.5/2.5		CLAY, with silt, minor fine sand; dark gray to reddish brown; very stiff to stiff; low plasticity; poorly bedded; common calcium carbonated nodules [Artificial fill]	drillers reamed and augered to 6.5 feet dry Shelby tube gradual increase 100 - 350 psi	
9–11.5		P2	2.0/2.5		same as above, with minor amounts of charcoal and rootlets; lenses of sand up to 4 inches thick, grayish	good circulation	866.5 (at 10)
11.5–12.2		P3	1.7/2.5		11.5 to 12.2 feet: CLAY with fine gravel; gravel is gray to reddish brown sandstone	200 - 250 psi	
12.2–14	3:18/2.5 ft.	P3			CLAY; reddish brown with grayish mottles; medium plasticity; white fine nodules of calcium carbonate common at 12.2 feet, rare by 15 feet		
14–15		P4	1.5/1.5	randomly oriented fractures with polished faces	with 10% fine gravel, massive		861.5 (at 15)

Other column headings: Lithology, RQD, Weathering, Strength, Soil Samples/Borehole Tests, Discontinuity Log

See page 2 for abbreviations of terms related to weathering, strength, and sample method.

ROCK LOG - Boring No. AKA-3	Project Name and Job Number LBNL BUILDINGS 85 AND 85A WLA: 1717-B, AKA: 2335-4a

WLA

Depth (feet.)	Drill Rate (min/ft)	Run No.	Recovery/Cut	RQD	Weathering	Strength	Soil Samples/ Borehole Tests	Discontinuity Description	Lithology	Remarks	Elevation (feet.)
15		P_4							same as above		861.5
16	5:18/1.5 ft.	P_5	1.5/1.5					low angle bedding	SAND, gravelly with clay; light gray; bedded with laminated fines; fine subrounded gravel, medium to coarse sand; medium dense; moist		
17–19	4:15/2.2 ft.	P_6	2.2/2.2						CLAY, silty with minor sand; reddish brown to dark gray; medium stiff; low plasticity [Quaternary colluvium and Landslide debris] trace charcoal (?)		
20		P_7	1.7/1.8			R1		45° bedding dips, top and base of claystone bed	SILTSTONE and fine SAND-STONE; reddish brown to gray mottled; appears brecciated and mixed with light yellow pebbles above 21.8 feet; damp [Landslide debris - shallow landslide?]		856.5
21		P_8	1.5/1.5		HW			45° contact, thin clayey silt			
22–23		P_9	2.0/2.0		MW	R2		fractures, high angle, tight, polished faces 60° bedding	CLAYSTONE, laminated; reddish brown [Landslide debris - deep landslide] SILTSTONE to fine SAND-STONE; gray; with minor dark reddish brown siltstone beds		
24–25		P_{10}	2.0/2.0			R1		fractures random, no mineralization 35° bedding	CLAYSTONE to SILTSTONE; reddish brown to pale olive-brown; damp; stiff		851.5
26–27		P_{11}	2.0/2.0		MW	R2 R1		abundant fractures and shears, smooth, polished fracture faces open vertical to subhorizontal 30° clay seam 1/2-inch thick; numerous fractures with polished surfaces		more difficult drilling	
28–29	7:15/1.5 ft.	P_{12}	1.3/1.5		MW SW	R2		30° bedding fractures have mineralization	SILTSTONE to fine SAND-STONE; grayish brown to bluish bray; increase in competence		
29–30		P_{13}	1.2/2.0					abundant fractures			846.5

Undisturbed sample S = Shelby, P = Pitcher, C = rock core — Driven (2.5 to 3.0 inch) with liners MC = Modified California, O = other — Standard Penetration Test (SPT) sampler

Weathering: Fr - Fresh, SW - Slight, MW - Moderate, HW - Highly, CW - Completely, and RS - Residual soil. Strength: R6 - Extremely strong, R5 - Very strong, R4 - Strong, R3 - Medium strong, R2 - Weak, R1- Very weak, and R0 - Extremely weak.

ROCK LOG - Boring No. AKA-3

Project Name and Job Number
LBNL BUILDINGS 85 AND 85A
WLA: 1717-B, AKA: 2335-4a

WLA

Depth (feet.)	Drill Rate (min/ft)	Run No.	Recovery/Cut	RQD	Weathering	Strength	Soil Samples/ Borehole Tests	Discontinuity Description	Lithology	Remarks	Elevation (feet.)
30						R2		abundant fractures, steeply dipping, mineralization	same as above		846.5
31–32.5	4:37/1:5 ft.	P14	1.7/1.5		MW	R1		abundant fracture surfaces, subvertical	SILTSTONE to CLAYSTONE, light gray to reddish brown; very weak		
32.5–34.5	4:05/2.0 ft.	P15	2.0/2.0			R2			SILTSTONE, grayish brown to light greenish gray to reddish brown; weak		
34.5–36	4:39/1:5 ft.	P16	1.5/1.5					CLAY seam, brown, 1-inch thick			841.5 (at 35)
36–37.5	3:27/1:5 ft.	P17	1.5/1.5					fractures, steeply dipping, tight, mineralization			
37.5–39.5	5:35/2.0 ft.	P18	2.0/2.0					<30° CLAY seam, dark grayish brown, 1-inch thick; fractures, random striations, tight, some reddish brown fracture faces; common polished and striated surfaces			
39.5–42		P19	2.5/2.5		MW	R2		brecciated zone			836.5 (at 40)
42–44.5		P20	2.5/2.5					abundant fractures; brecciated zone, steeply dipping, clay seams along zone			
44.5–45								abundant fractures, tight			831.5 (at 45)

Undisturbed sample
S = Shelby, P = Pitcher, C = rock core

Driven (2.5 to 3.0 inch) with liners
MC = Modified California, O = other

Standard Penetration Test (SPT) sampler

Weathering: Fr - Fresh, SW - Slight, MW - Moderate, HW - Highly, CW - Completely, and RS - Residual soil. Strength: R6 - Extremely strong, R5 - Very strong, R4 - Strong, R3 - Medium strong, R2 - Weak, R1- Very weak, and R0 - Extremely weak.

ROCK LOG - Boring No. AKA-3

Project Name and Job Number
LBNL BUILDINGS 85 AND 85A
WLA: 1717-B, AKA: 2335-4a

Depth (feet)	Drill Rate (min/ft)	Run No.	Recovery/Cut	RQD	Weathering	Strength	Soil Samples/ Borehole Tests	Discontinuity Description	Lithology	Remarks	Elevation (feet)
45								50° fractures, tight, polished faces	same as above		831.5
46		P21	2.5/2.5								
47						R2-R3			SILTSTONE, light green-gray to gray-brown		
48		P22	2.5/2.5		MW-SW			fractures, high angle, tight, mineralization			
49								abundant fractures, steeply dipping, tight		9/1/05 stop drilling at 49.5 feet 9/2/05 resume drilling	
50	11:29/2.2 ft.	P23	2.2/2.2					30° contact with brecciated zone			826.5
52	5:13/1:3 ft.	P24	1.3/1.3					fractures, tight			
53		P25	0.3								
54	6:15/1:7 ft.	P26	1.7/1.7					fractures, tight; some polished faces			
55											821.5
56		P27	2.0/2.0		MW-SW	R2		50° fractures, tight, mineralization			
57								fractures, steeply dipping to subvertical, tight, mineralized, polished fracture faces			
58		P28	1.5/1.5								
59		P29	1.8/1.8					fractures, tight			
60											816.5

Undisturbed sample S = Shelby, P = Pitcher, C = rock core
Driven (2.5 to 3.0 inch) with liners MC = Modified California, O = other
Standard Penetration Test (SPT) sampler

Weathering: Fr - Fresh, SW - Slight, MW - Moderate, HW - Highly, CW - Completely, and RS - Residual soil. Strength: R6 - Extremely strong, R5 - Very strong, R4 - Strong, R3 - Medium strong, R2 - Weak, R1- Very weak, and R0 - Extremely weak.

ROCK LOG - Boring No. AKA-3

Project Name and Job Number
LBNL BUILDINGS 85 AND 85A
WLA: 1717-B, AKA: 2335-4a

Depth (feet.)	Drill Rate (min/ft)	Run No.	Recovery/Cut	RQD	Weathering	Strength	Soil Samples/ Borehole Tests	Discontinuity Description	Lithology	Remarks	Elevation (feet.)
60								fractures, tight	same as above		816.5
61	7:10/2.2 ft.	P_{30}	2.2/2.2		MW	R2					
62								45° to 50° faults and shears, tight, in brecciated zone	ferrous oxide-stained breccia zone		
63		P_{31}	1.5/1.5			R2		fractures, tight, with occasional clay seams	brecciated, crushed, gray-brown siltstone		
64	2:59/1.1 ft.	P_{32}	1.1/1.1			R0 R2		30° shear, 1.5 inches clay gouge, soft	at 64 feet: CLAY, soft, 1.5-inch thick [Landslide plane] SILTSTONE, green-gray	slight circulation loss	
65											811.5
66	5:44/1.4 ft.	P_{33}	1.4/1.4		MW	R0 R2		SILTSTONE/CLAY contact is steeply dipping and sheared; lower CLAY/SILTSTONE contact is gradual and contains brecciated siltstone fragments	CLAY, medium bluish gray, soft to very soft; high to medium plasticity [Landslide plane] SILTSTONE, clayey with minor sand; light green-gray to dark gray; hard [Orinda Formation or San Pablo Group]		
67	7:42/2.0 ft.	P_{34}	1.9/2.0					subvertical fractures, polished surfaces			
68								30° fractures, with minor crushing and rare clay seams, polished faces with dip-slip striae	Fine SANDSTONE to sandy SILTSTONE		
69	5:40/1.2 ft.	P_{35}	1.1/1.2							refusal with pitcher barrel; switched to rock coring at 69.7 feet	
70									SILTSTONE, light greenish gray to gray		806.5
71								~75° bedding, on pebble bed	zones of fine gravel, subrounded		
72	26:07/4.8 ft.	C_{36}	4.8/4.8		SW	R3					
73									fine SANDSTONE to SILTSTONE, competent		
74.5									Bottom of hole 74.5 feet.		
75											801.5

Undisturbed sample
S = Shelby, P = Pitcher, C = rock core

Driven (2.5 to 3.0 inch) with liners
MC = Modified California, O = other

Standard Penetration Test (SPT) sampler

Weathering: Fr - Fresh, SW - Slight, MW - Moderate, HW - Highly, CW - Completely, and RS - Residual soil. Strength: R6 - Extremely strong, R5 - Very strong, R4 - Strong, R3 - Medium strong, R2 - Weak, R1- Very weak, and R0 - Extremely weak.

LOG OF TEST PIT TP-5A

Equipment: Case 580E Backhoe

Elevation: ± 895 Date: 7/18/89

Depth (ft.)	Description
0	**BROWNISH BLACK CLAY (CL)** dry to moist, stiff, contains numerous roots (Topsoil)
	MODERATE BROWN SANDY CLAY (CL) moist, very stiff
5	**AGGLOMERATE (Moraga FM)** moderate brown, closely to intensely fractured, soft to friable hardness, plastic to friable strength, deeply weathered 5-5.5' lense of more resistent rock
10	becomes less weathered with depth, friable to low hardness, weak strength
	Total Depth: 13' No Free Water
15	

LOG OF TEST PIT TP-6A

Equipment: Case 580E Backhoe

Elevation: ± 886 Date: 7/18/89

Depth (ft.)	Description
0	**BROWNISH BLACK CLAY (CL)** dry to moist, stiff, moderately plastic, contains numerous roots (Topsoil)
5	**MODERATE BROWN CLAY (CL)** moist, very stiff to hard, random slickensides throughout, contains some sand and gravel, increased rock fragments with depth
10	
	AGGLOMERATE (Moraga FM) moderate brown, friable hardness and strength, deeply weathered
	SILTSTONE medium greenish grey, intensely fractured, soft and plastic
	Total Depth: 13.5' No Free Water
15	

Geo/Resource Consultants, Inc.
Consulting Engineers, Geologists, Geophysicists

Job No. 1393-00 Appr: [signature] Date 10/16/89

LOG OF TEST PITS TP-5A & TP-6A

REPLACEMENT OF HAZARDOUS WASTE HANDLING FACILITY AT LAWRENCE BERKELEY LABORATORY BERKELEY, CALIFORNIA

FIGURE A-9

* = 3.0" O.D. Modified California Sampler w/140 lb. hammer* falling 30".

LOG OF BORING B-5

Equipment: hollow stem auger

Elevation: 907 feet Date: 8/11/88

Laboratory Analyses	Blows/ft.	Moisture Content (%)	Dry density (pcf)	Depth (ft.)	Sample pnts.	Description
				0		DARK BROWN SILTY CLAY (CH) moist, stiff; grades a little more sandy & gravelly
	41			5		BROWN CLAYEY SILT (ML) slightly moist, dense gravelly
TXUU 5,600 (1,000)	27	15.8	99.0	10		BROWN SILTY CLAY (CL-CH) moist, very stiff
						BLUE GRAY SANDSTONE (Orinda Fm) friable, weak moderately weathered
	90			15		Bottom of hole 16'
				20		
				25		
				30		
				35		
				40		

Geo/Resource Consultants, Inc.
Consulting Engineers, Geologists, Geophysicists

Job No. 1393-00 Appr: ESJ Date 10/16/89

LOG OF BORING B-5
REPLACEMENT OF HAZARDOUS WASTE HANDLING FACILITY AT LAWRENCE BERKELEY LABORATORY, BERKELEY, CALIFORNIA

FIGURE A-16

LOG OF TEST PIT TP-7

Equipment: Backhoe

Elevation: ±909 Date: 8-9-88

Depth (ft.): 0 – 15

VERY DARK BROWN SILTY CLAY (CH)
Moist, very stiff

BROWN GRAVELLY CLAY (CL-CH)
Moist, very stiff to hard

SANDY CLAYEY GRAVEL (GC)
Moist, dense, angular chunks of friable tan sandstone
(Debris flow deposit)

DARK BROWN CLAY (CH)
Slightly moist, stiff

MEDIUM BROWN CLAY (CL)
Slightly moist, very stiff, contains gravel

Total Depth: 12 ft.
No Free Water

LOG OF TEST PIT TP- 8

Equipment: Backhoe

Elevation: ±883 Date: 8-10-88

Depth (ft.): 0 – 15

DARK BROWN SILTY CLAY (CH)
Slightly moist, very stiff

BROWN CLAYEY GRAVEL (GC)
Slightly moist, very stiff

DARK BROWN CLAY (CH)
Slightly moist, very stiff

BROWN CLAY (CL)
Contains more gravel than above

GRAY CLAY (CH)
Less gravelly

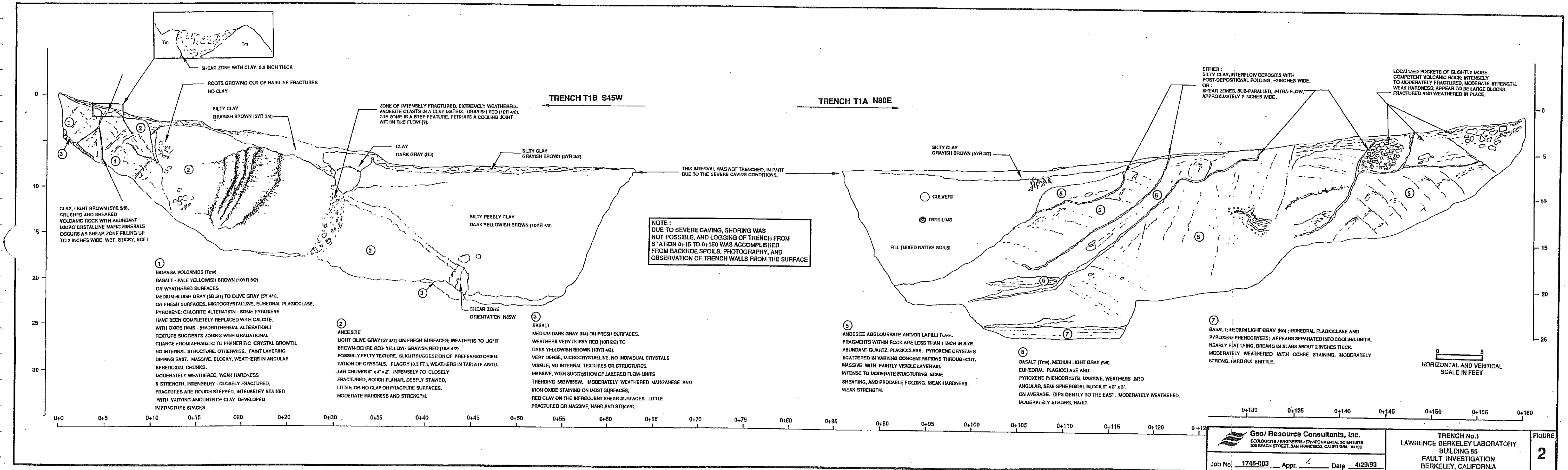
Total Depth: 11.5 ft.
No Free Water

Geo/Resource Consultants, Inc.
Consulting Engineers, Geologists, Geophysicists

Job No. 1393-00 Appr: ESJ Date 10/16/89

LOGS OF TEST PITS TP-7 & TP-8
REPLACEMENT OF HAZARDOUS WASTE HANDLING FACILITY AT LAWRENCE BERKELEY LABORATORY
BERKELEY, CALIFORNIA

FIGURE A-4


Tm
Tm
SHEAR ZONE WITH CLAY, 0.2 INCH THICK
ROOTS GROWING OUT OF HAIRLINE FRACTURES
NO CLAY
SILTY CLAY
GRAYISH BROWN (5YR 3/2)
ZONE OF INTENSELY FRACTURED, EXTREMELY WEATHERED ANDESITE CLASTS IN A CLAY MATRIX. GRAYISH RED (10R 4/2). THE ZONE IS A STEP FEATURE, PERHAPS A COOLING JOINT WITHIN THE FLOW (?).
TRENCH T1B S45W
TRENCH T1A N80E
CLAY
DARK GRAY (N3)
SILTY CLAY
GRAYISH BROWN (5YR 3/2)
THIS INTERVAL WAS NOT TRENCHED, IN PART DUE TO THE SEVERE CAVING CONDITIONS.
SILTY PEBBLY CLAY
DARK YELLOWISH BROWN (10YR 4/2)
CLAY, LIGHT BROWN (5YR 5/6). CRUSHED AND SHEARED VOLCANIC ROCK WITH ABUNDANT MICRO CRSTALLINE MAFIC MINERALS OCCURS AS SHEAR ZONE FILLING UP TO 2 INCHES WIDE; WET, STICKY, SOFT
SHEAR ZONE
ORIENTATION N85W
NOTE :
DUE TO SEVERE CAVING, SHORING WAS NOT POSSIBLE, AND LOGGING OF TRENCH FROM STATION 0+15 TO 0+150 WAS ACCOMPLISHED FROM BACKHOE SPOILS, PHOTOGRAPHY, AND OBSERVATION OF TRENCH WALLS FROM THE SURFACE
CULVERT
TREE LIMB
FILL (MIXED NATIVE SOILS)
SILTY CLAY
GRAYISH BROWN (5YR 3/2)
EITHER :
SILTY CLAY, INTERFLOW DEPOSITS WITH POST-DEPOSITIONAL FOLDING, ~2INCHES WIDE.
OR :
SHEAR ZONES, SUB-PARALLED, INTRA-FLOW, APPROXIMATELY 2 INCHES WIDE.
LOCALIZED POCKETS OF SLIGHTLY MORE COMPETENT VOLCANIC ROCK; INTENSELY TO MODERATELY FRACTURED, MODERATE STRENGTH, WEAK HARDNESS; APPEAR TO BE LARGE BLOCKS FRACTURED AND WEATHERED IN PLACE.
(1) MORAGA VOLCANICS (Tmv)
BASALT - PALE YELLOWISH BROWN (10YR 8/2) ON WEATHERED SURFACES
MEDIUM BLUISH GRAY (5B 5/1) TO OLIVE GRAY (5Y 4/1), ON FRESH SURFACES, MICROCRYSTALLINE, EUHEDRAL PLAGIOCLASE, PYROXENE; CHLORITE ALTERATION - SOME PYROXENE HAVE BEEN COMPLETELY REPLACED WITH CALCITE, WITH OXIDE RIMS - (HYDROTHERMAL ALTERATION.) TEXTURE SUGGESTS ZONING WITH GRADATIONAL CHANGE FROM APHANITIC TO PHANERITIC CRYSTAL GROWTH. NO INTERNAL STRUCTURE, OTHERWISE. FAINT LAYERING DIPPING EAST. MASSIVE, BLOCKY, WEATHERS IN ANGULAR SPHEROIDAL CHUNKS. MODERATELY WEATHERED, WEAK HARDNESS & STRENGTH. INTENSELEY - CLOSELY FRACTURED, FRACTURES ARE ROUGH STEPPED, INTENSELEY STAINED WITH VARYING AMOUNTS OF CLAY DEVELOPED IN FRACTURE SPACES
(2) ANDESITE
LIGHT OLIVE GRAY (5Y 8/1) ON FRESH SURFACES; WEATHERS TO LIGHT BROWN-OCHRE RED- YELLOW- GRAYISH RED (10R 4/2) ; POSSIBLY FELTY TEXTURE. SLIGHTSUGGESTION OF PREFERRED ORIENTATION OF CRYSTALS. FLAGGY (0.3 FT.), WEATHERS IN TABLATE ANGULAR CHUNKS 5" x 4" x 2". INTENSELY TO CLOSELY FRACTURED, ROUGH PLANAR, DEEPLY STAINED, LITTLE OR NO CLAY ON FRACTURE SURFACES. MODERATE HARDNESS AND STRENGTH.
(3) BASALT
MEDIUM DARK GRAY (N4) ON FRESH SURFACES. WEATHERS VERY DUSKY RED (10R 2/2) TO DARK YELLOWISH BROWN (10YR 4/2). VERY DENSE, MICROCRYSTALLINE, NO INDIVIDUAL CRYSTALS VISIBLE; NO INTERNAL TEXTURES OR STRUCTURES. MASSIVE, WITH SUGGESTION OF LAYERED FLOW-UNITS TRENDING N83W55SW. MODERATELY WEATHERED MANGANESE AND IRON OXIDE STAINING ON MOST SURFACES, RED CLAY ON THE INFREQUENT SHEAR SURFACES. LITTLE FRACTURED OR MASSIVE, HARD AND STRONG.
(5) ANDESITE AGGLOMERATE AND/OR LAPILLI TUFF.
FRAGMENTS WITHIN ROCK ARE LESS THAN 1 INCH IN SIZE. ABUNDANT QUARTZ, PLAGIOCLASE, PYROXENE CRYSTALS SCATTERED IN VARYING CONCENTRATIONS THROUGHOUT. MASSIVE, WITH FAINTLY VISIBLE LAYERING: INTENSE TO MODERATE FRACTURING, SOME SHEARING, AND PROBABLE FOLDING. WEAK HARDNESS, WEAK STRENGTH.
(6) BASALT (Tmv), MEDIUM LIGHT GRAY (N6) EUHEDRAL PLAGIOCLASE AND PYROXENE PHENOCRYSTS, MASSIVE, WEATHERS INTO ANGULAR, SEMI-SPHEROIDAL BLOCK 5" x 3" x 3", ON AVERAGE. DIPS GENTLY TO THE EAST. MODERATELY WEATHERED, MODERATELY STRONG, HARD.
(7) BASALT; MEDIUM LIGHT GRAY (N6) ; EUHEDRAL PLAGIOCLASE AND PYROXENE PHENOCRYSTS; APPEARS SEPARATED INTO COOLING UNITS, NEARLY FLAT LYING, BREAKS IN SLABS ABOUT 2 INCHES THICK. MODERATELY WEATHERED WITH OCHRE STAINING, MODERATELY STRONG, HARD BUT BRITTLE.
HORIZONTAL AND VERTICAL SCALE IN FEET
Geo/ Resource Consultants, Inc.
GEOLOGISTS / ENGINEERS / ENVIRONMENTAL SCIENTISTS
505 BEACH STREET, SAN FRANCISCO, CALIFORNIA 94133
Job No. 1746-003 Appr. Date 4/29/93
TRENCH No.1
LAWRENCE BERKELEY LABORATORY
BUILDING 85
FAULT INVESTIGATION
BERKELEY, CALIFORNIA
FIGURE
2

340_00019

APPENDIX F

Stability and Deformation Analyses

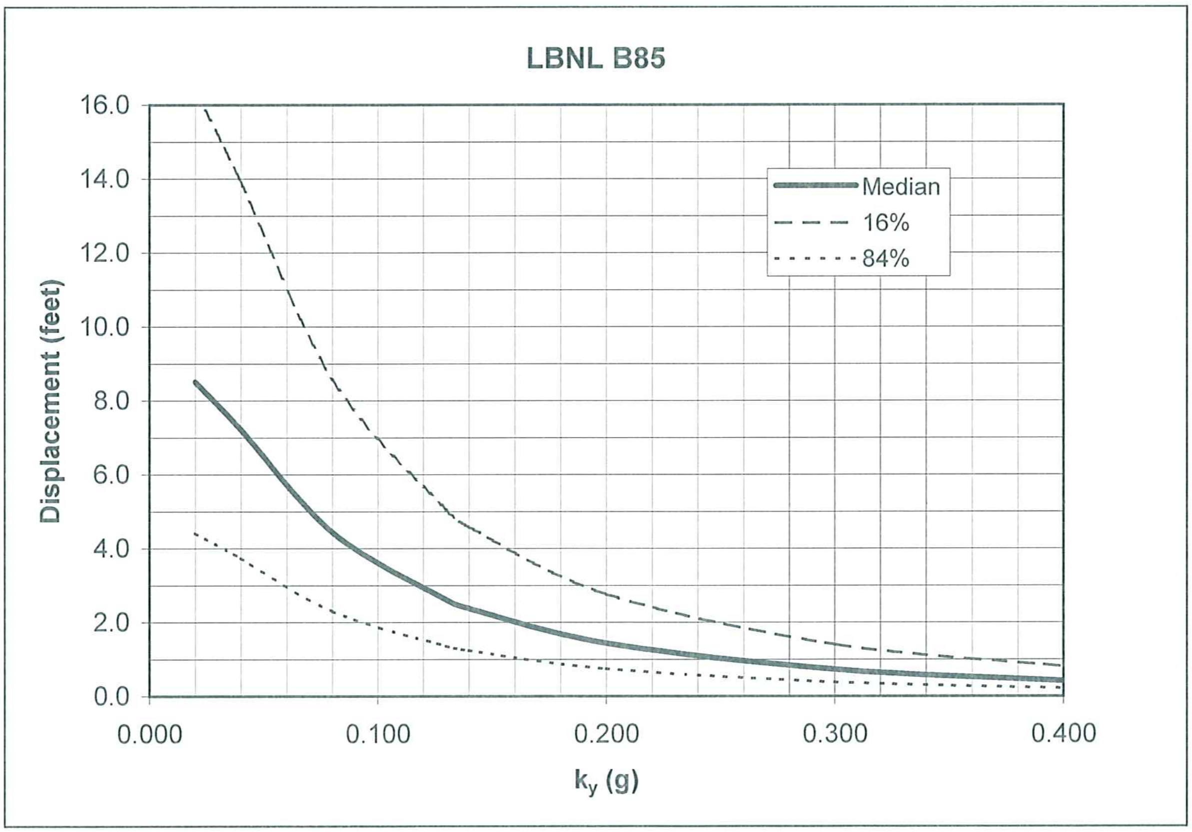
STABILITY AND DEFORMATION ANALYSES

Landslide Qls-1
Cross Section A-A'

LBNL B85
AKA Project # 2335-7B
Qls-1, , Vs=700 ft/s, URS Site Specific Spectra

Simplified Procedure for Estimating Earthquake Induced Deviatoric Slope Displacements
by Jonathan D. Bray and Thaleia Travasarou
Journal of Geotechnical and Geonvironmental Engineering, ASCE, V. 133(4), pp. 381-392, April 2007

ky	Dmedian (cm)	D1 (cm)	D3 (cm)	Dmedian (ft)	D1 (ft)	D3 (ft)
0.020	259.3	499.8	134.5	8.51	16.40	4.41
0.040	220.0	424.0	114.1	7.22	13.91	3.74
0.080	135.5	261.2	70.3	4.45	8.57	2.31
0.130	79.8	153.8	41.4	2.62	5.04	1.36
0.140	72.6	139.9	37.6	2.38	4.59	1.23
0.200	43.7	84.2	22.7	1.43	2.76	0.74
0.300	22.2	42.7	11.5	0.73	1.40	0.38
0.400	12.8	24.6	6.6	0.42	0.81	0.22



Simplified Procedure for Estimating Earthquake Induced Deviatoric Slope Displacements
by Jonathan D. Bray and Thaleia Travasarou
Journal of Geotechnical and Geonvironmental Engineering, ASCE, V. 133(4), pp. 381-392, April 2007

SEE NOTES BELOW FOR GUIDANCE IN THE USE OF SPREADSHEET

Input Parameters			
Yield Coefficient (ky)	0.02		Based on pseudostatic analysis
Initial Fundamental Period (Ts)	0.29	seconds	1D: Ts=4H/Vs 2D: Ts=2.6H/Vs
Degraded Period (1.5Ts)	0.43	seconds	
Moment Magnitude (Mw)	6.9		
Spectral Acceleration (Sa(1.5Ts))	1.47	g	

Additional Input Parameters		
Probability of Exceedance #1 (P1)	84	%
Probability of Exceedance #2 (P2)	50	%
Probability of Exceedance #3 (P3)	16	%
Displacement Threshold (d_threshold)	5	cm

Intermediate Calculated Parameters			
Non-Zero Seismic Displacement Est (D)	259.29	cm	eq. (5) or (6)
Standard Deviation of Non-Zero Seismic D	0.66		

Results			
Probability of Negligible Displ. (P(D=0))	0.000		eq. (3)
D1	134.51	cm	calc. using eq. (7)
D2	259.29	cm	calc. using eq. (7)
D3	499.84	cm	calc. using eq. (7)
P(D>d_threshold)	1.000		eq. (7)

Notes

1. Values highlighted in blue are input parameters
2. Probability of Exceedance is the desired probability of exceeding a particular displacement value.
3. Displacements D1, D2, and D3 correspond to P1, P2, and P3, respectively.
   (e.g., the probability of exceeding displacement D1 is P1)
4. Calculated seismic displacements are due to deviatoric deformation only (add in volumetrically induced movement).
5. ky may range between 0.01 and 0.5, Ts between 0 and 2 s, Sa between 0.002 and 2.7 g, M between 4.5 and 9
6. Rigid slope is assumed for Ts < 0.05 s
7. When a value for D is not calculated, D is < 1cm
8. ky may be estimated using the simplified equations shown below.
9. Examples of how Ts is estimated are shown below.
10. Vs = weighted avg. shear wave velocity for the sliding mass, e.g., for 2 layers, Vs = [(h1)(Vs1) + (h2)(Vs2)]/(h1 + h2)

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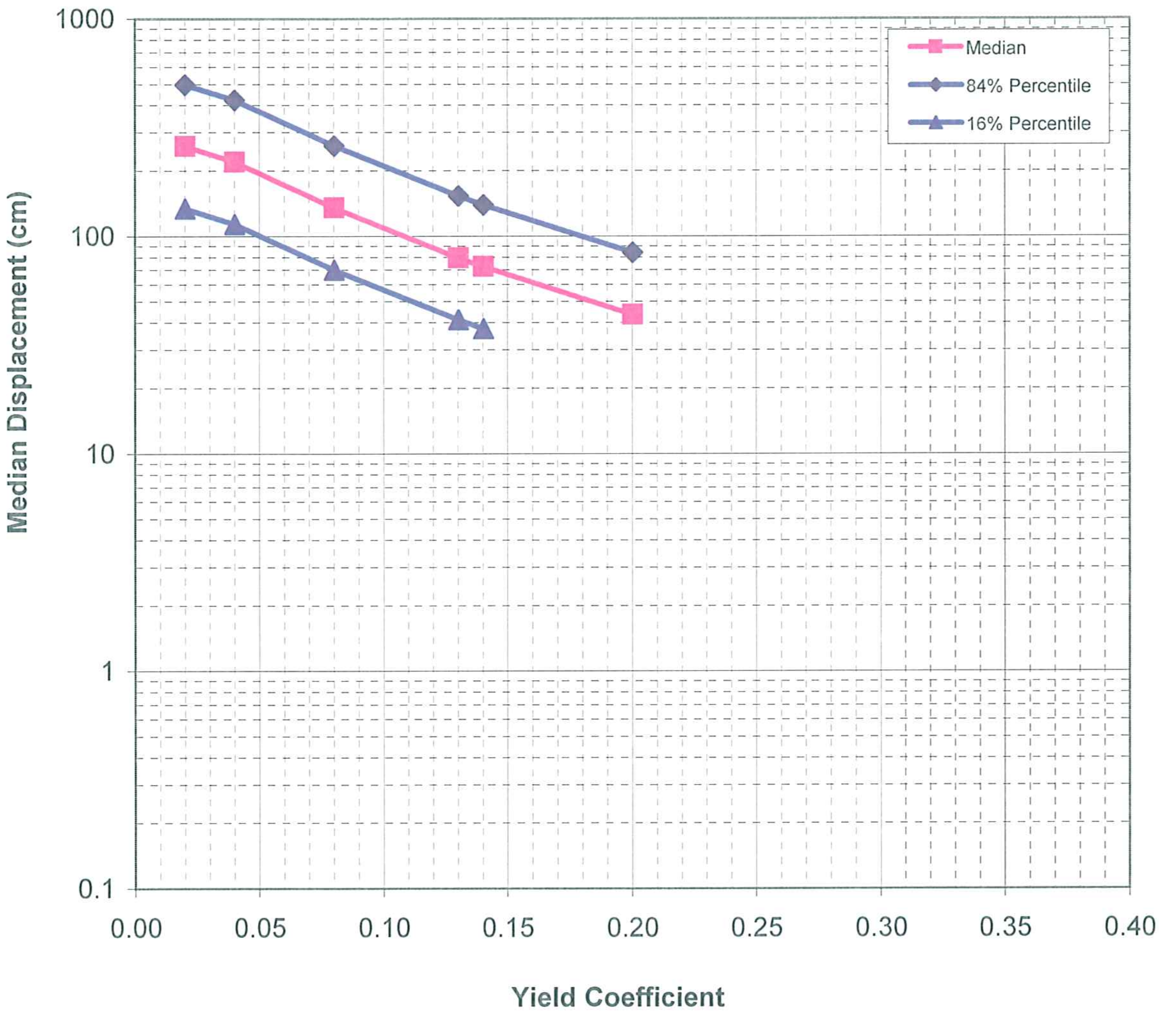
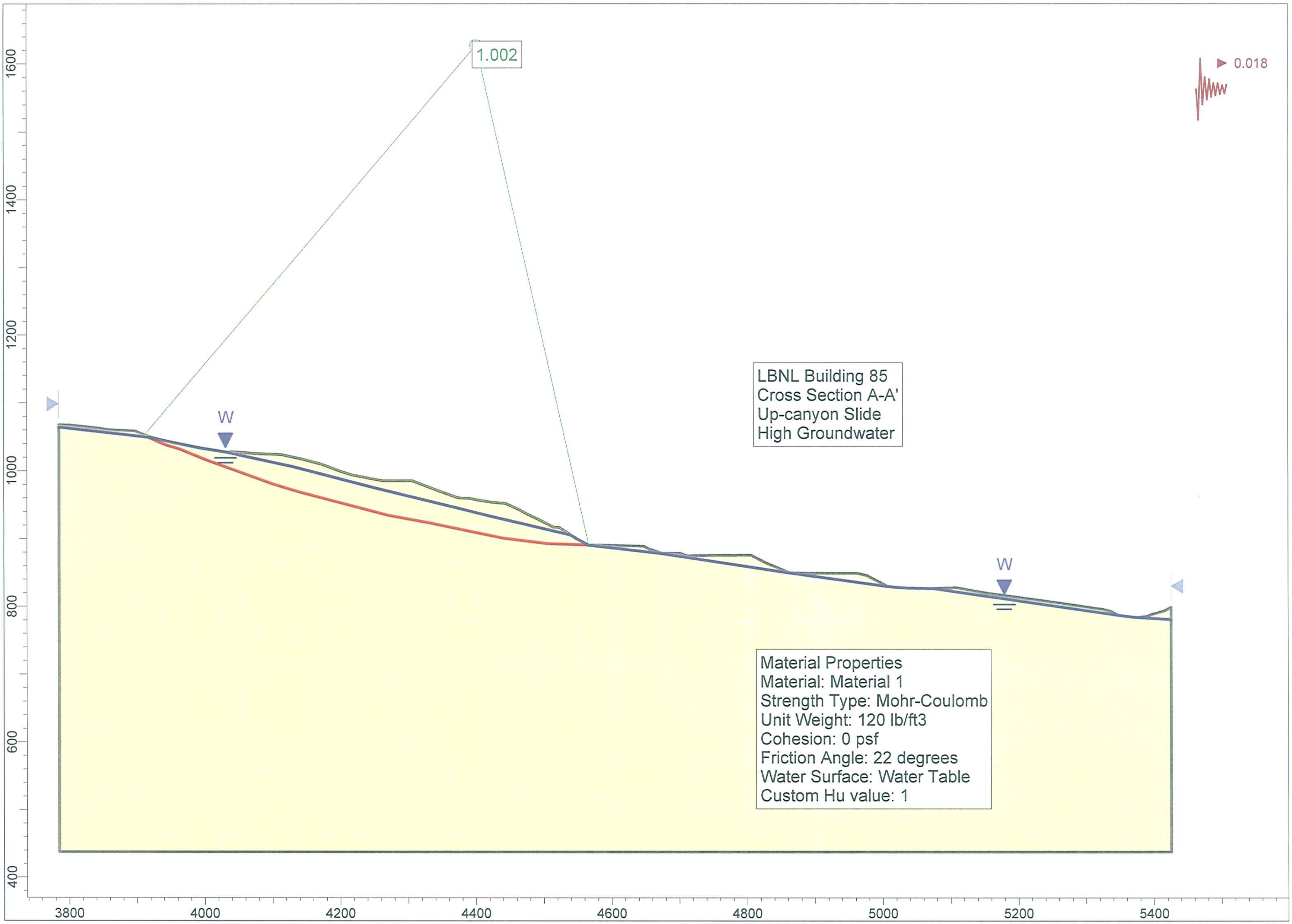
Dependence on ky

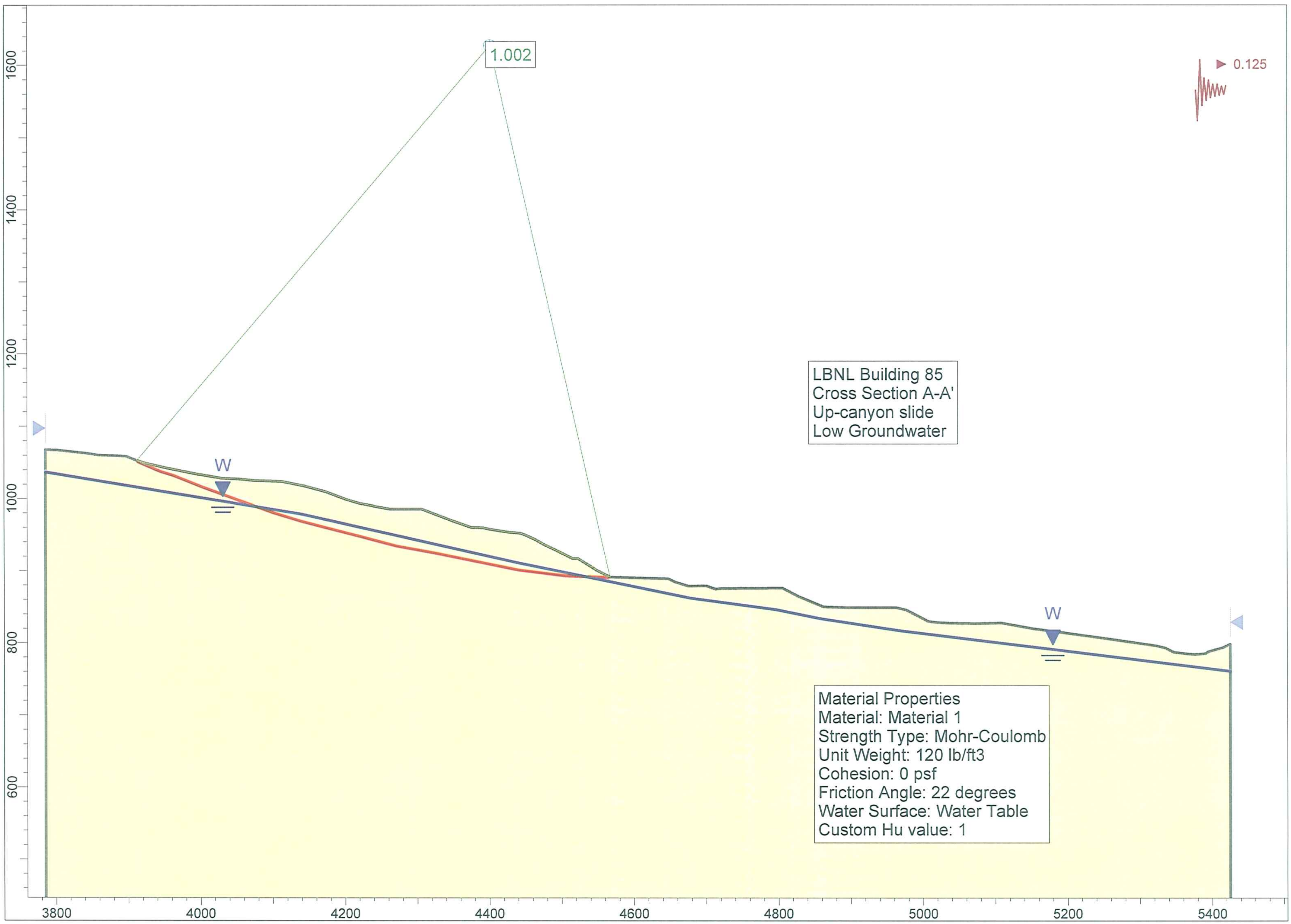
ky	P(D="0")	D (cm)	Dmedian (cm)	D1 (cm)	D3 (cm)
0.020	0.00	259.3	259.3	499.8	134.5
0.04	0.00	220.0	220.0	424.0	114.1
0.08	0.00	135.5	135.5	261.2	70.3
0.13	0.00	79.8	79.8	153.8	41.4
0.14	0.00	72.6	72.6	139.9	37.6
0.2	0.00	43.7	43.7	84.2	22.7
0.3	0.00	22.2	22.2	42.7	11.5
0.4	0.00	12.8	12.8	24.6	6.6

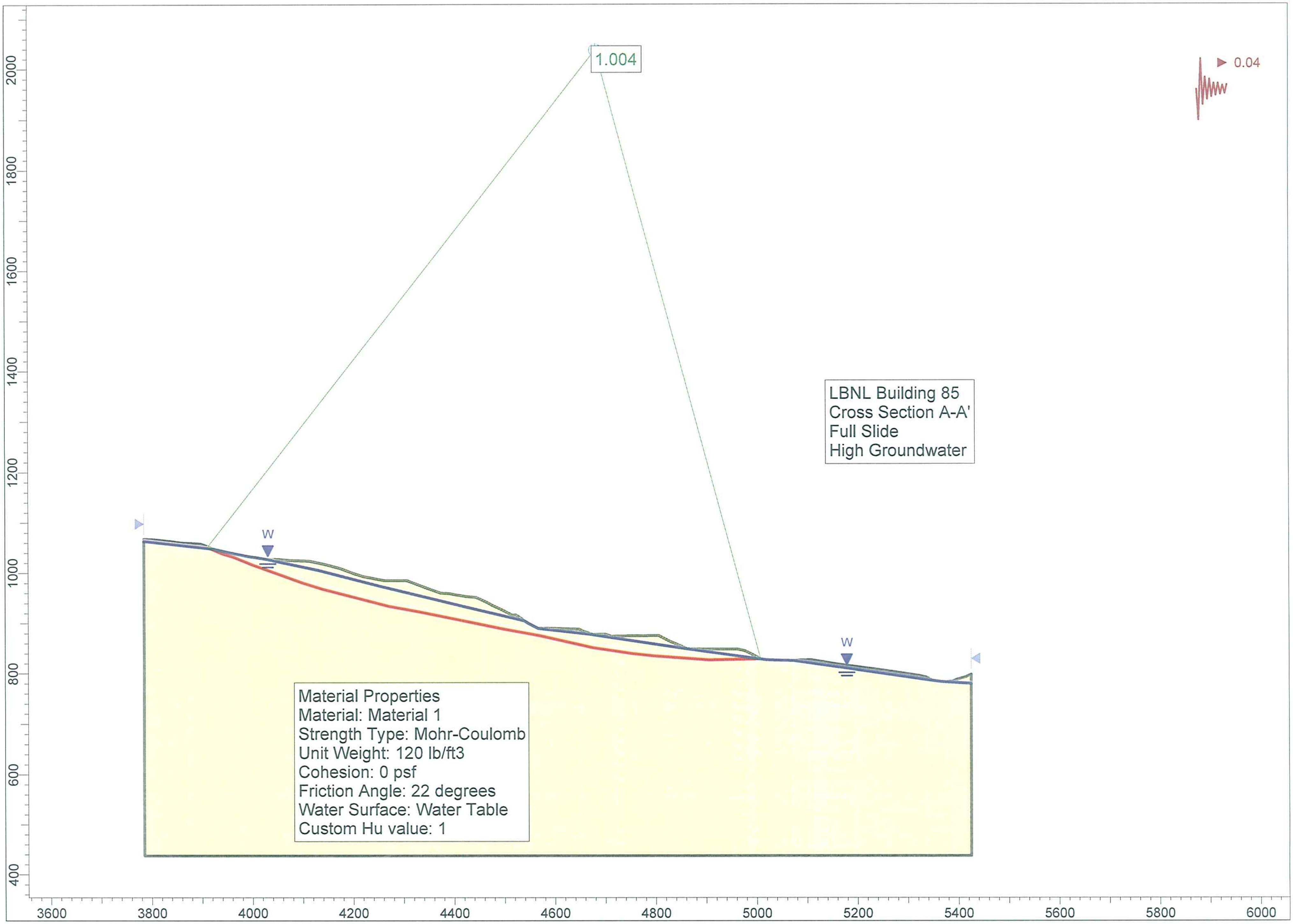


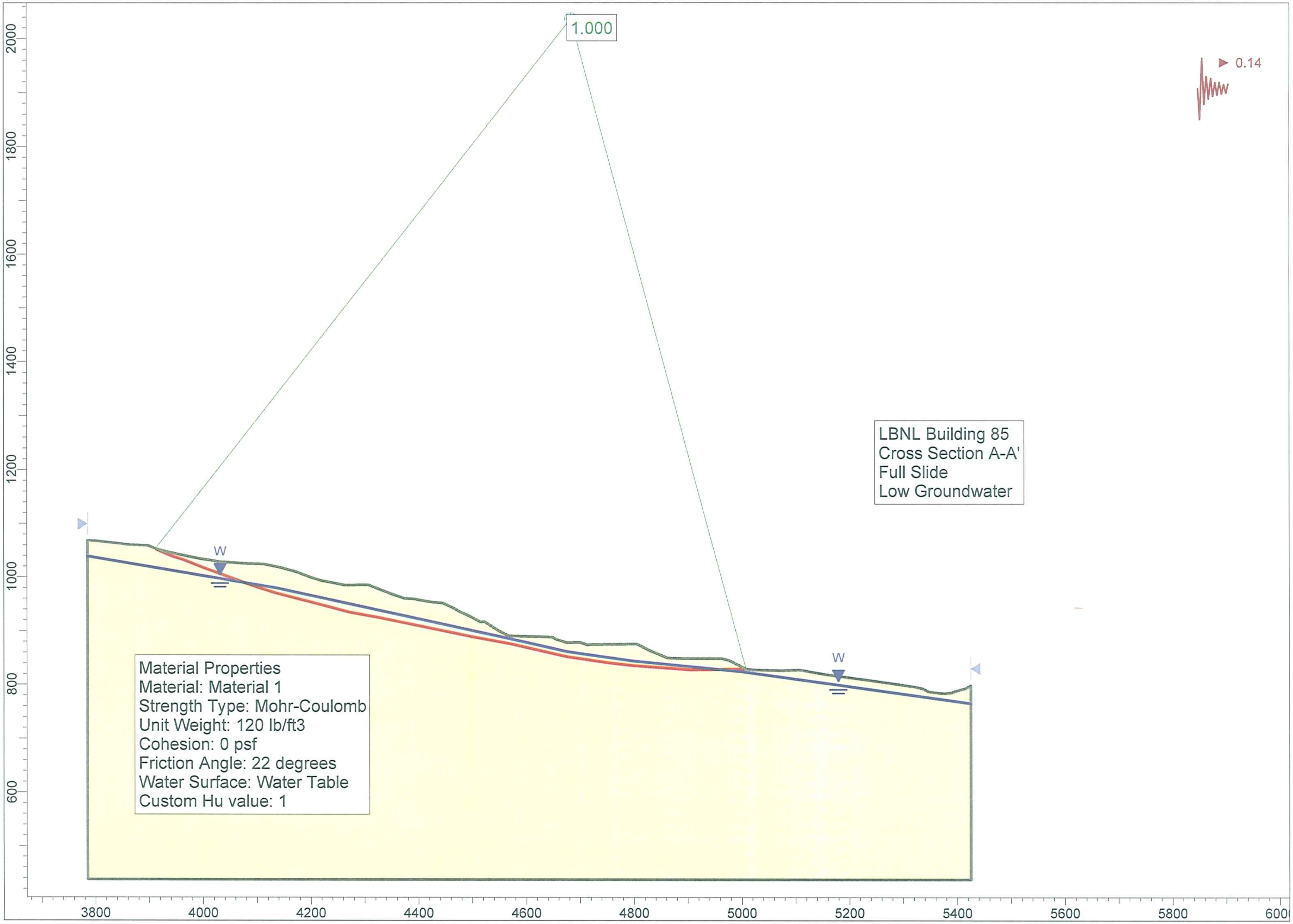
Simplified Procedure for Estimating Earthquake Induced Deviatoric Slope Displacements
by Jonathan D. Bray and Thaleia Travasarou
Journal of Geotechnical and Geonvironmental Engineering, Vol 133, No. 4, pp. 381-392, April 2007



1.002
0.018
LBNL Building 85
Cross Section A-A'
Up-canyon Slide
High Groundwater
W
W
Material Properties
Material: Material 1
Strength Type: Mohr-Coulomb
Unit Weight: 120 lb/ft3
Cohesion: 0 psf
Friction Angle: 22 degrees
Water Surface: Water Table
Custom Hu value: 1
1600
1400
1200
1000
800
600
400
3800
4000
4200
4400
4600
4800
5000
5200
5400

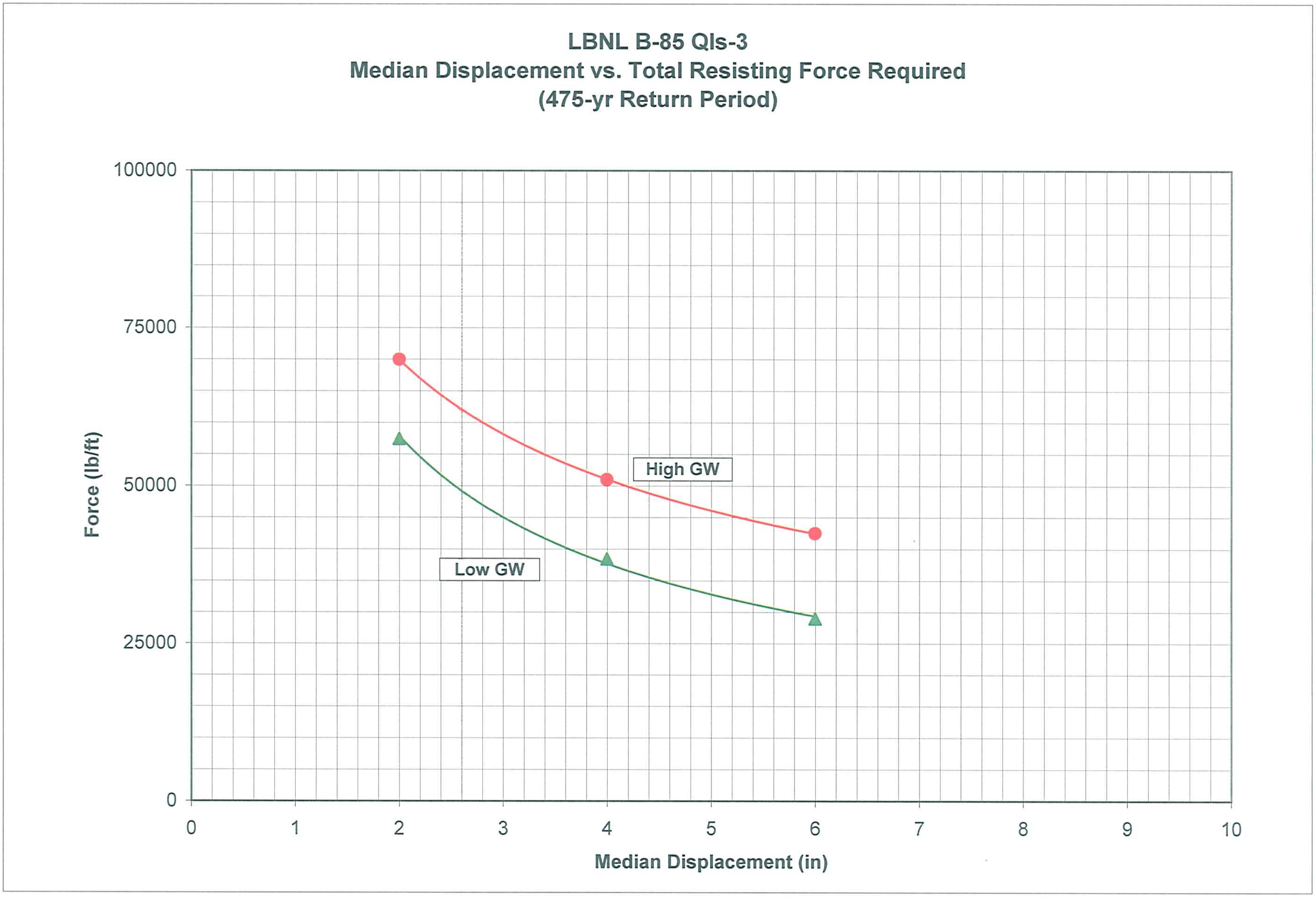

1.002
0.125
LBNL Building 85
Cross Section A-A'
Up-canyon slide
Low Groundwater
W
W
Material Properties
Material: Material 1
Strength Type: Mohr-Coulomb
Unit Weight: 120 lb/ft3
Cohesion: 0 psf
Friction Angle: 22 degrees
Water Surface: Water Table
Custom Hu value: 1
1600
1400
1200
1000
800
600
3800
4000
4200
4400
4600
4800
5000
5200
5400


1.004
0.04
LBNL Building 85
Cross Section A-A'
Full Slide
High Groundwater
W
W
Material Properties
Material: Material 1
Strength Type: Mohr-Coulomb
Unit Weight: 120 lb/ft3
Cohesion: 0 psf
Friction Angle: 22 degrees
Water Surface: Water Table
Custom Hu value: 1
400
600
800
1000
1200
1400
1600
1800
2000
3600
3800
4000
4200
4400
4600
4800
5000
5200
5400
5600
5800
6000

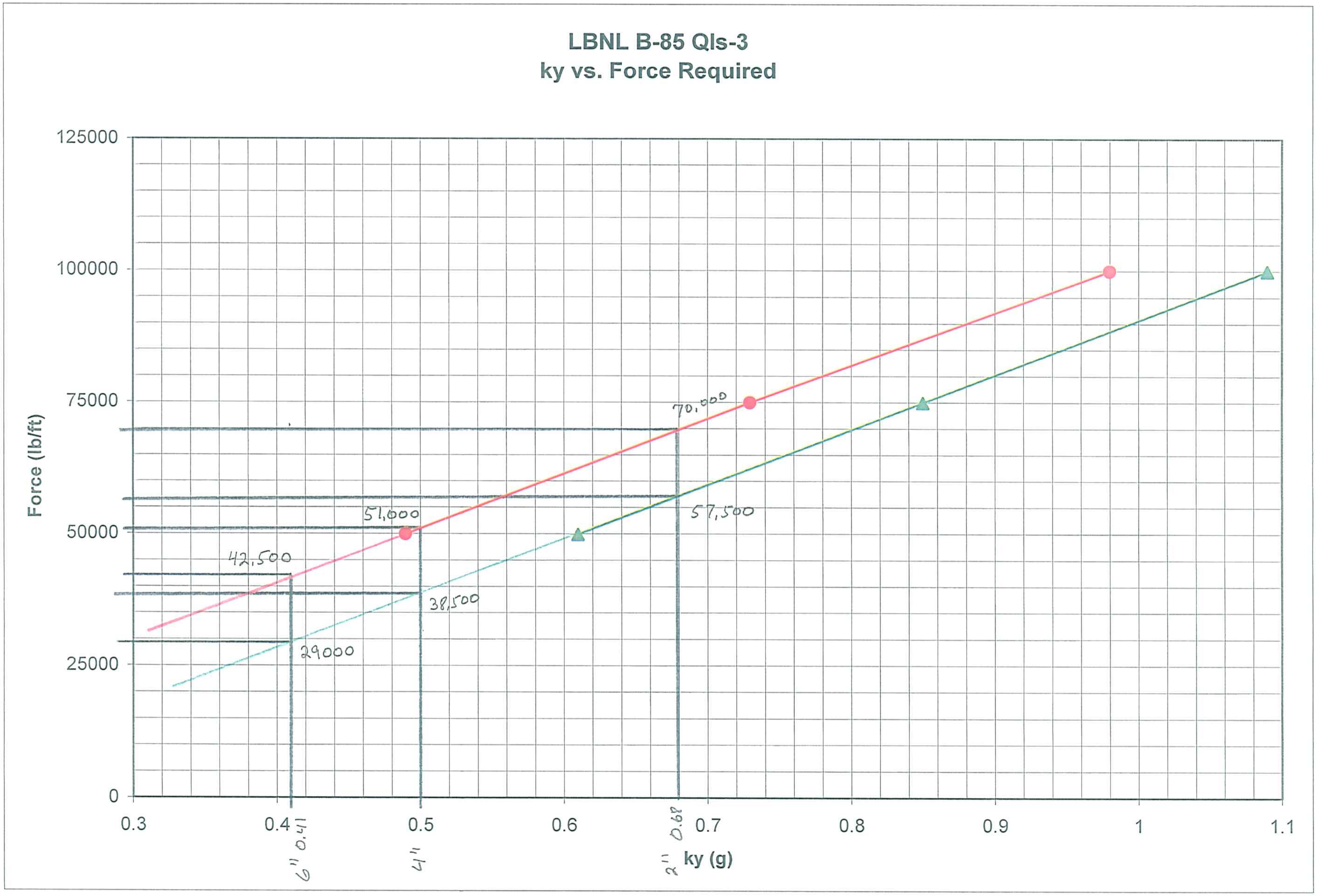

1.000
0.14
LBNL Building 85
Cross Section A-A'
Full Slide
Low Groundwater
W
W
Material Properties
Material: Material 1
Strength Type: Mohr-Coulomb
Unit Weight: 120 lb/ft3
Cohesion: 0 psf
Friction Angle: 22 degrees
Water Surface: Water Table
Custom Hu value: 1
2000
1800
1600
1400
1200
1000
800
600
3800
4000
4200
4400
4600
4800
5000
5200
5400
5600
5800

STABILITY, DEFORMATION AND LATERAL RESISTING FORCE ANALYSES

Landslide Qls-3
Cross Section H-H'
(Zones A1 & A2)



LBNL B-85 Qls-3
Median Displacement vs. Total Resisting Force Required
(475-yr Return Period)
100000
75000
50000
25000
0
Force (lb/ft)
0
1
2
3
4
5
6
7
8
9
10
Median Displacement (in)
High GW
Low GW



LBNL B-85 Qls-3
ky vs. Force Required
125000
100000
75000
50000
25000
0
Force (lb/ft)
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
ky (g)
70,000
57,500
51,000
42,500
38,500
29000
6" 0.41
4"
2" 0.68

LBNL B85
AKA Project # 2335-7B
Qls-3, Vs=700 ft/s, URS Site Specific Spectra, H=15'

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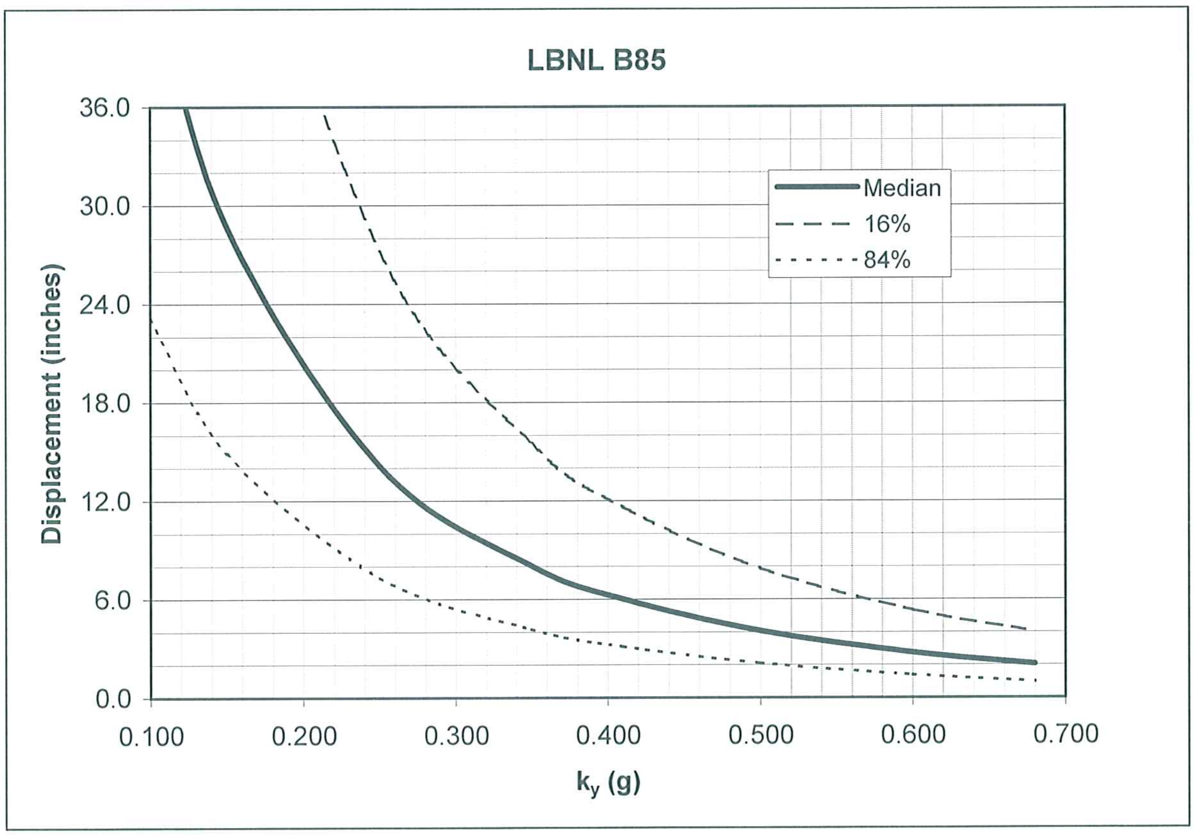
by Jonathan D. Bray and Thaleia Travasarou
Journal of Geotechnical and Geonvironmental Engineering, ASCE, V. 133(4), pp. 381-392, April 2007

ky	Dmedian (cm)	D1 (cm)	D3 (cm)	Dmedian (in)	D1 (in)	D3 (in)
0.100	113.1	218.0	58.7	44.52	85.82	23.09
0.150	72.9	140.5	37.8	28.69	55.31	14.89
0.250	35.9	69.1	18.6	14.12	27.22	7.32
0.350	20.4	39.4	10.6	8.05	15.51	4.17
0.410	15.3	29.5	7.9	6.02	11.60	3.12
0.500	10.3	20.0	5.3	4.07	7.86	2.10
0.600	7.0	13.6	3.5	2.75	5.34	1.38
0.680	5.2	10.2	2.5	2.04	4.01	0.97



Simplified Procedure for Estimating Earthquake Induced Deviatoric Slope Displacements
by Jonathan D. Bray and Thaleia Travasarou
Journal of Geotechnical and Geonvironmental Engineering, ASCE, V. 133(4), pp. 381-392, April 2007

SEE NOTES BELOW FOR GUIDANCE IN THE USE OF SPREADSHEET

Input Parameters			
Yield Coefficient (ky)	0.46		Based on pseudostatic analysis
Initial Fundamental Period (Ts)	0.09	seconds	1D: Ts=4H/Vs 2D: Ts=2.6H/Vs
Degraded Period (1.5Ts)	0.13	seconds	
Moment Magnitude (Mw)	6.9		
Spectral Acceleration (Sa(1.5Ts))	1.85	g	

Additional Input Parameters		
Probability of Exceedance #1 (P1)	84	%
Probability of Exceedance #2 (P2)	50	%
Probability of Exceedance #3 (P3)	16	%
Displacement Threshold (d_threshold)	5	cm

Intermediate Calculated Parameters			
Non-Zero Seismic Displacement Est (D)	12.25	cm	eq. (5) or (6)
Standard Deviation of Non-Zero Seismic D	0.66		

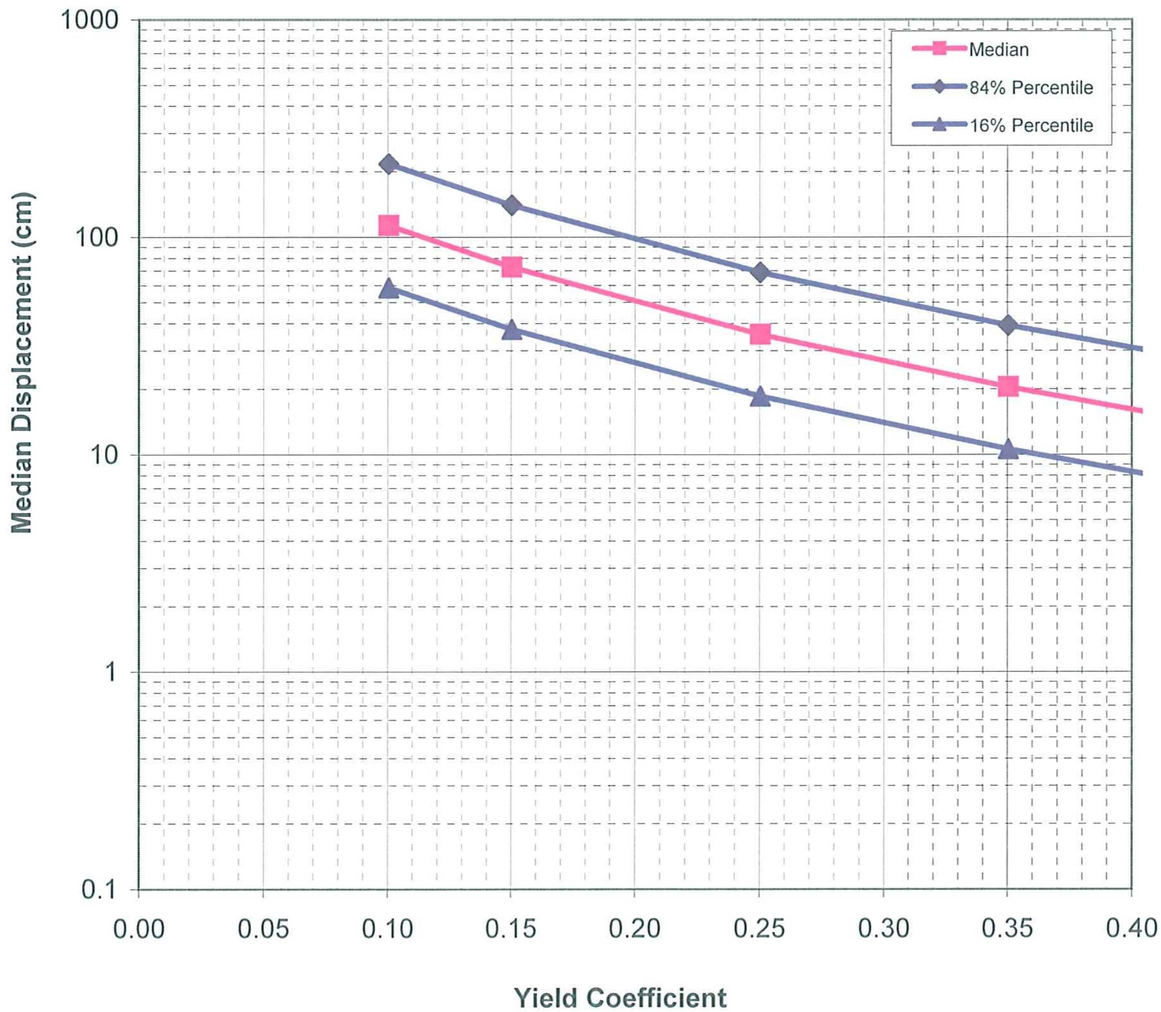
Results			
Probability of Negligible Displ. (P(D=0))	0.002		eq. (3)
D1	6.33	cm	calc. using eq. (7)
D2	12.23	cm	calc. using eq. (7)
D3	23.60	cm	calc. using eq. (7)
P(D>d_threshold)	0.911		eq. (7)

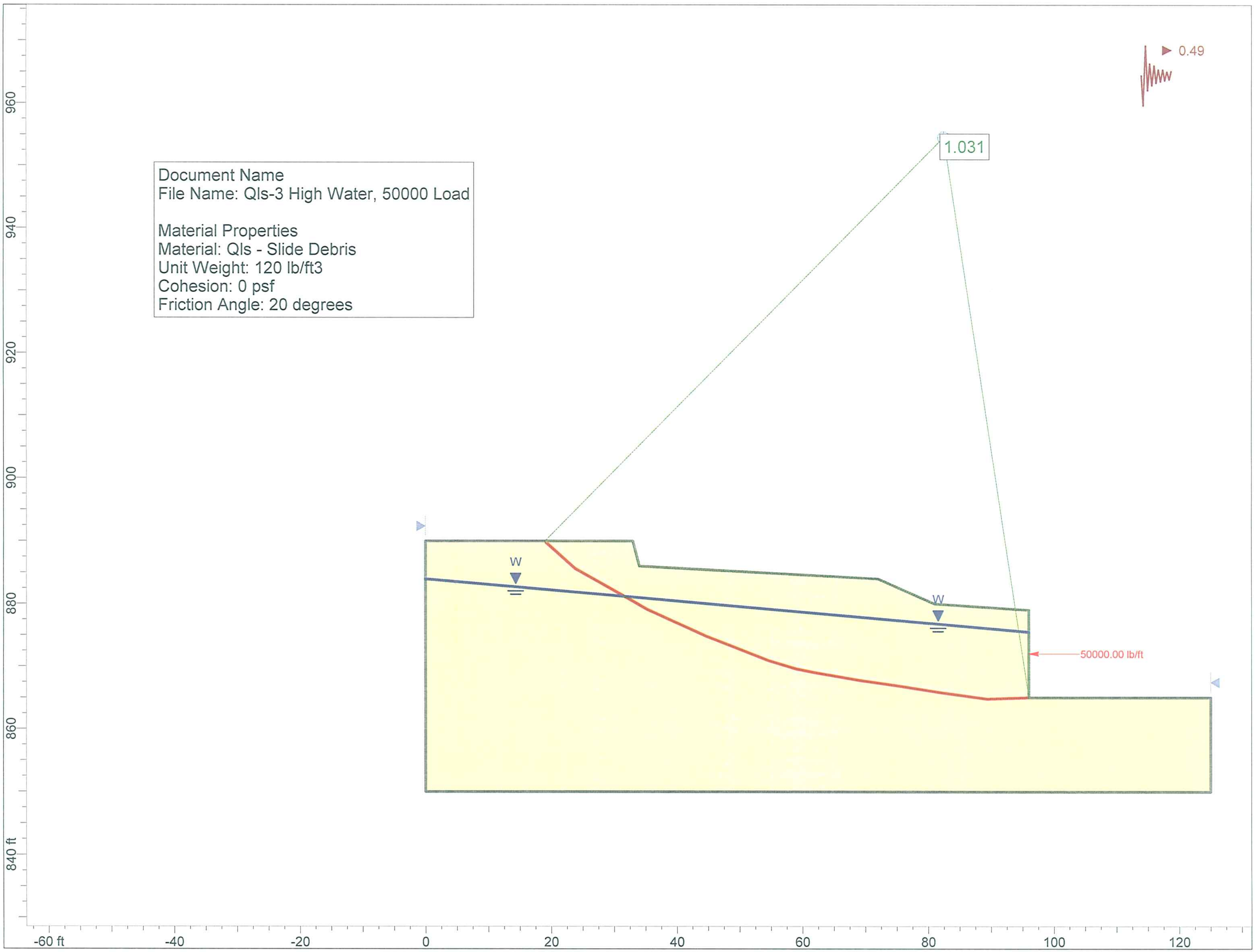
Notes

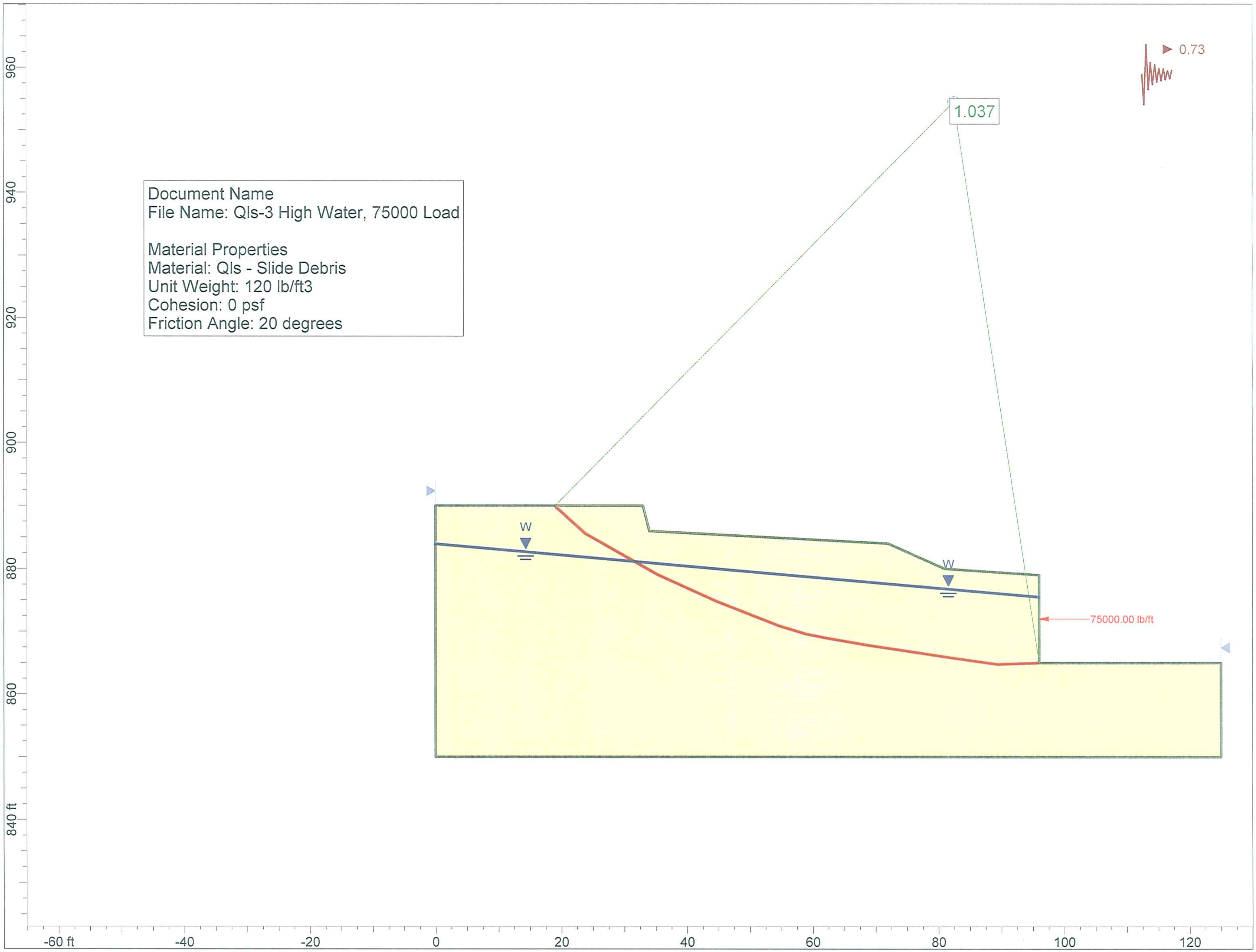
1. Values highlighted in blue are input parameters
2. Probability of Exceedance is the desired probability of exceeding a particular displacement value.
3. Displacements D1, D2, and D3 correspond to P1, P2, and P3, respectively.
   (e.g., the probability of exceeding displacement D1 is P1)
4. Calculated seismic displacements are due to deviatoric deformation only (add in volumetrically induced movement).
5. ky may range between 0.01 and 0.5, Ts between 0 and 2 s, Sa between 0.002 and 2.7 g, M between 4.5 and 9
6. Rigid slope is assumed for Ts < 0.05 s
7. When a value for D is not calculated, D is < 1cm
8. ky may be estimated using the simplified equations shown below.
9. Examples of how Ts is estimated are shown below.
10. Vs = weighted avg. shear wave velocity for the sliding mass, e.g., for 2 layers, Vs = [(h1)(Vs1) + (h2)(Vs2)]/(h1 + h2)

Dependence on ky

ky	P(D="0")	D (cm)	Dmedian (cm)	D1 (cm)	D3 (cm)
0.100	0.00	113.1	113.1	218.0	58.7
0.15	0.00	72.9	72.9	140.5	37.8
0.25	0.00	35.9	35.9	69.1	18.6
0.35	0.00	20.4	20.4	39.4	10.6
0.41	0.00	15.3	15.3	29.5	7.9
0.5	0.00	10.4	10.3	20.0	5.3
0.6	0.02	7.1	7.0	13.6	3.5
0.68	0.05	5.4	5.2	10.2	2.5

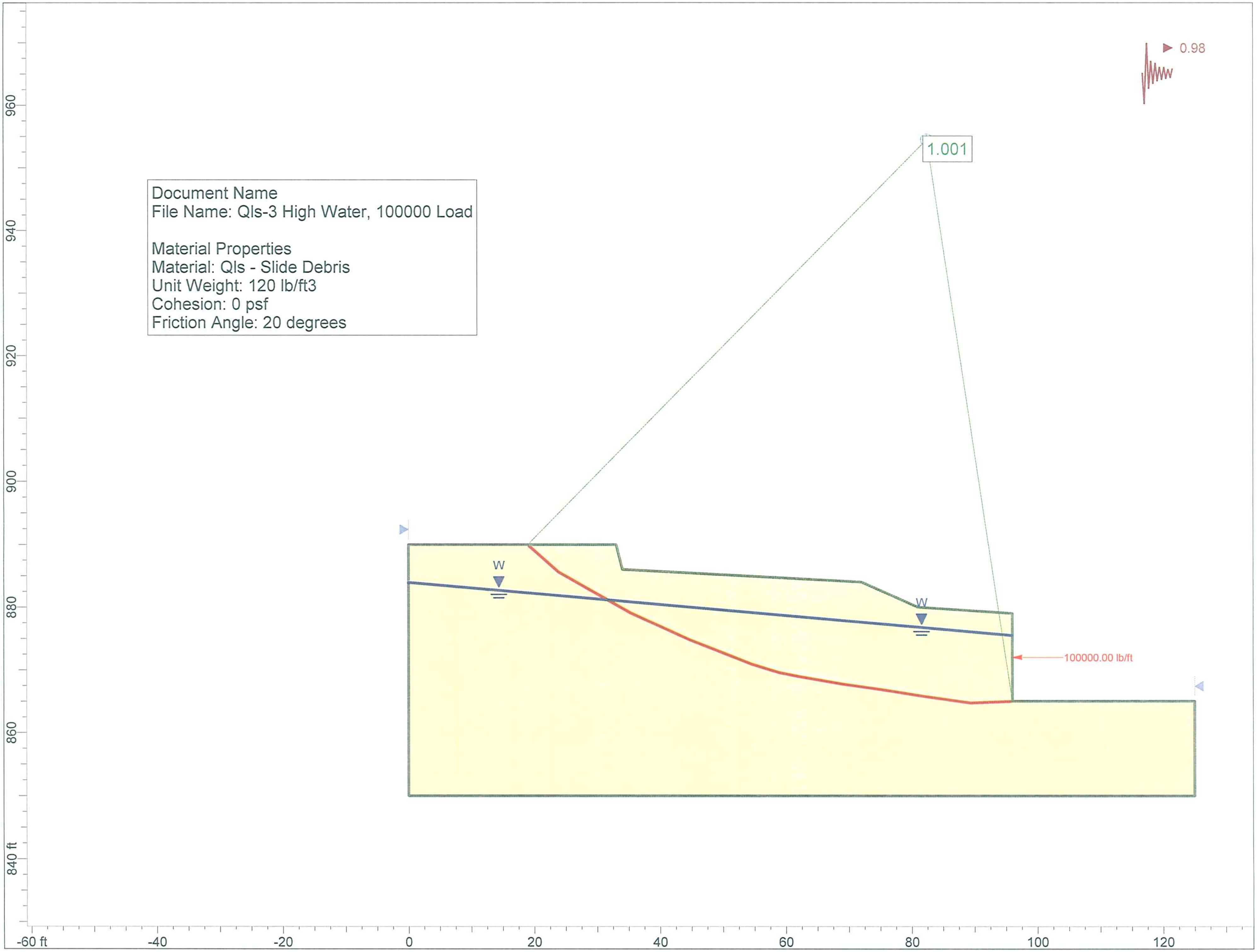



Document Name
File Name: Qls-3 High Water, 50000 Load
Material Properties
Material: Qls - Slide Debris
Unit Weight: 120 lb/ft3
Cohesion: 0 psf
Friction Angle: 20 degrees
1.031
0.49
W
W
50000.00 lb/ft
960
940
920
900
880
860
840 ft
-60 ft
-40
-20
0
20
40
60
80
100
120



Document Name
File Name: Qls-3 High Water, 75000 Load

Material Properties
Material: Qls - Slide Debris
Unit Weight: 120 lb/ft3
Cohesion: 0 psf
Friction Angle: 20 degrees
1.037
0.73
W
W
75000.00 lb/ft
960
940
920
900
880
860
840 ft
-60 ft
-40
-20
0
20
40
60
80
100
120



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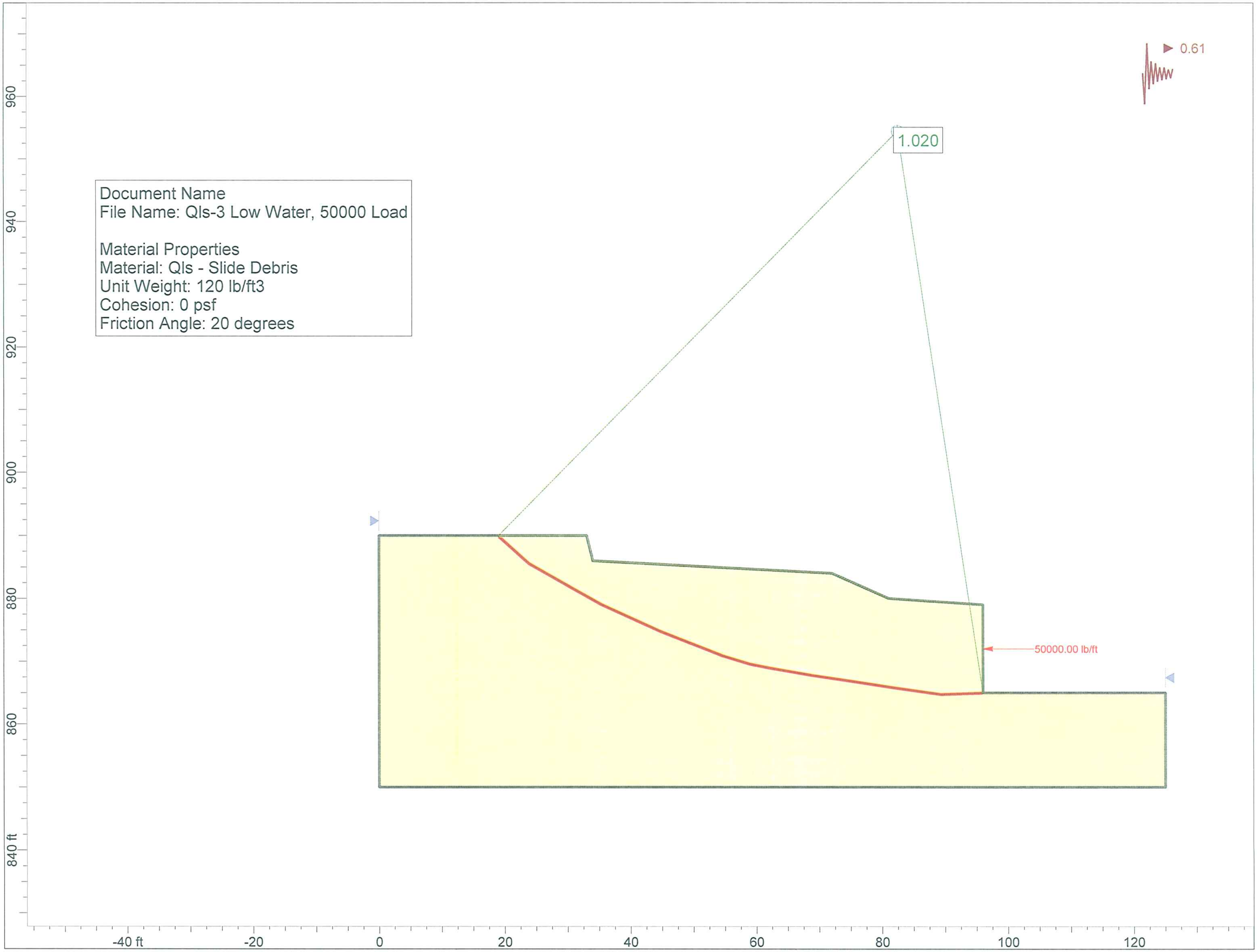
Material Properties
Material: Qls - Slide Debris
Unit Weight: 120 lb/ft3
Cohesion: 0 psf
Friction Angle: 20 degrees
1.001
0.98
100000.00 lb/ft
W
W
960
940
920
900
880
860
840 ft
-60 ft
-40
-20
0
20
40
60
80
100
120


0.61
1.020
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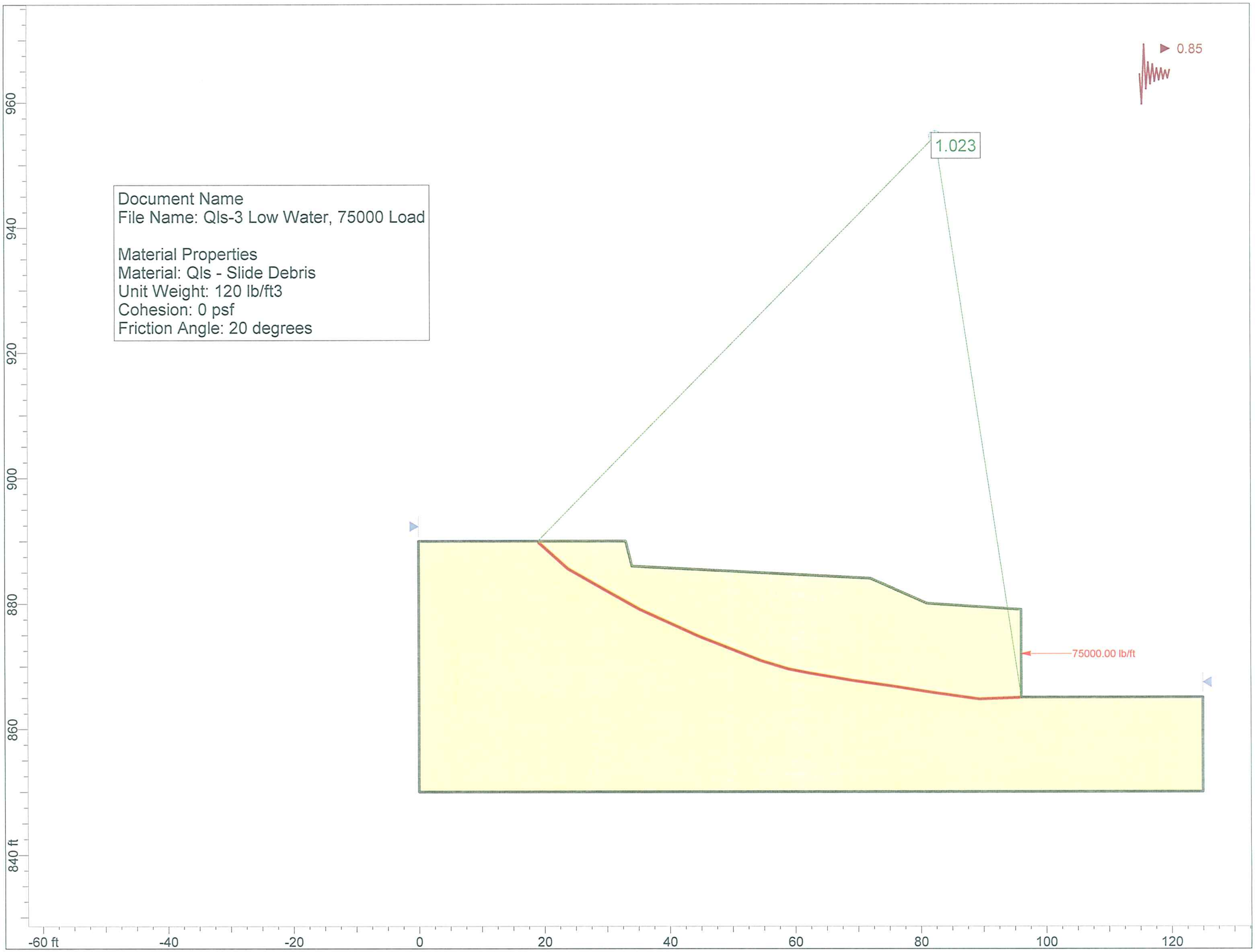
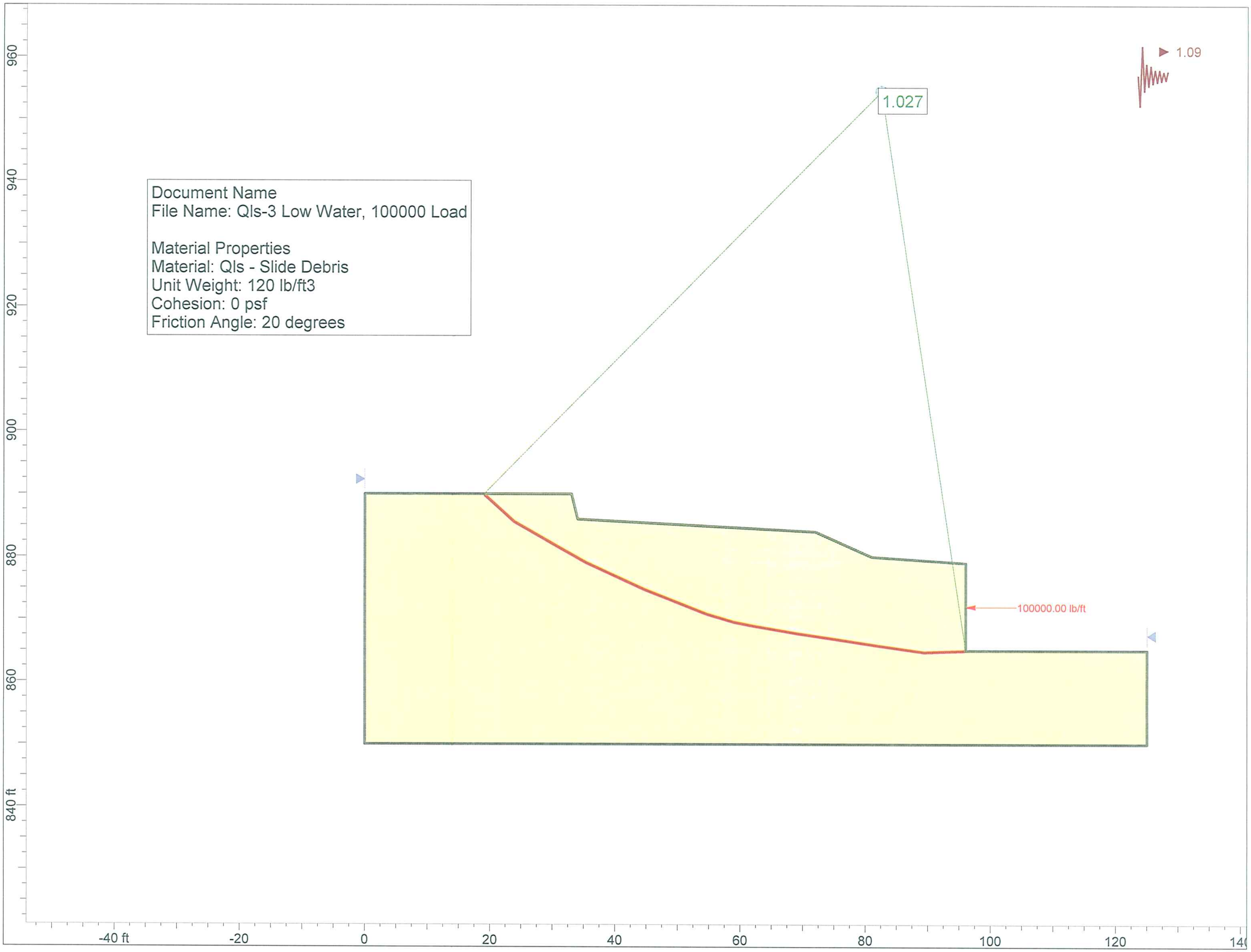
Material Properties
Material: Qls - Slide Debris
Unit Weight: 120 lb/ft3
Cohesion: 0 psf
Friction Angle: 20 degrees
50000.00 lb/ft
960
940
920
900
880
860
840 ft
-40 ft
-20
0
20
40
60
80
100
120

Document Name
File Name: Qls-3 Low Water, 75000 Load

Material Properties
Material: Qls - Slide Debris
Unit Weight: 120 lb/ft3
Cohesion: 0 psf
Friction Angle: 20 degrees

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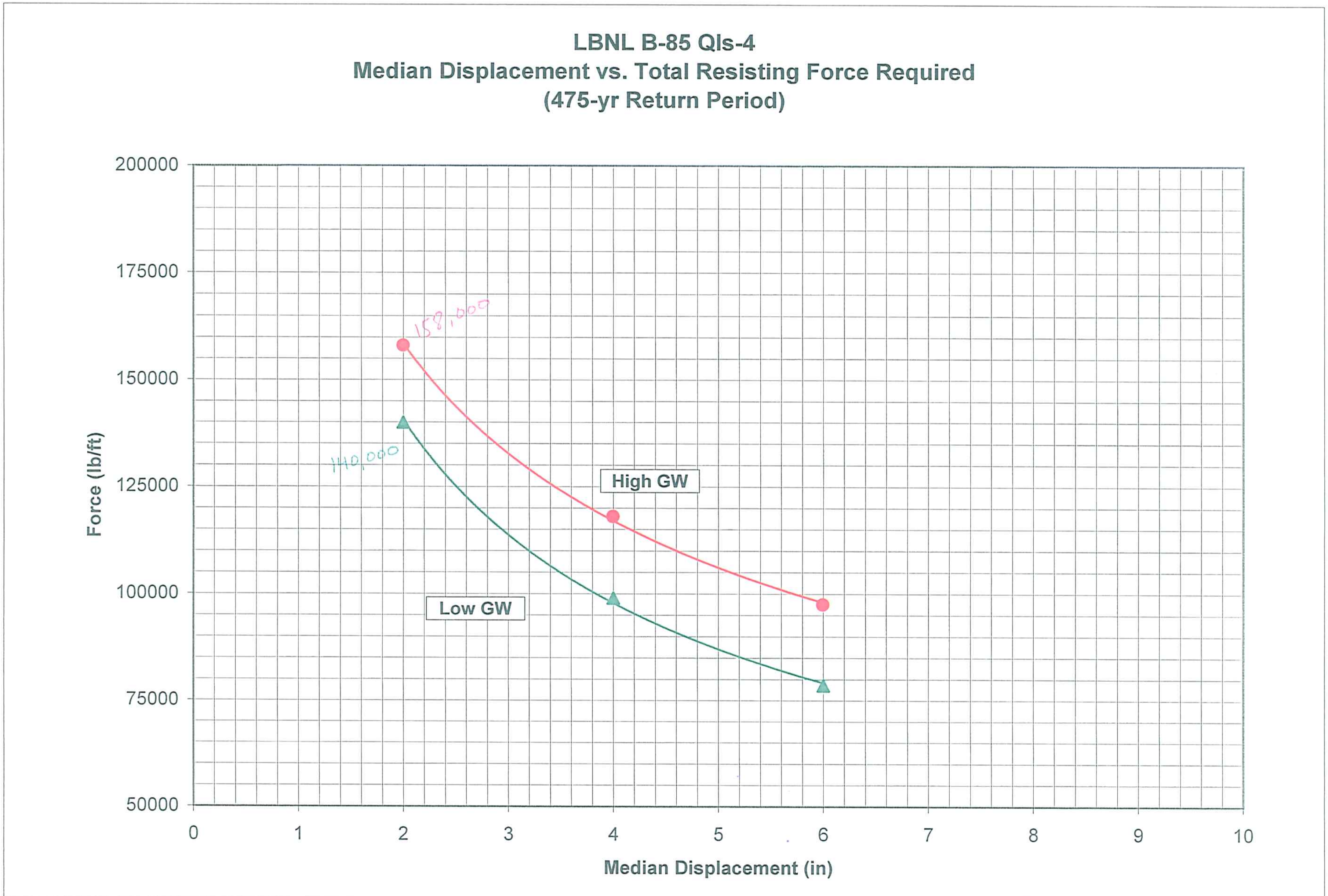
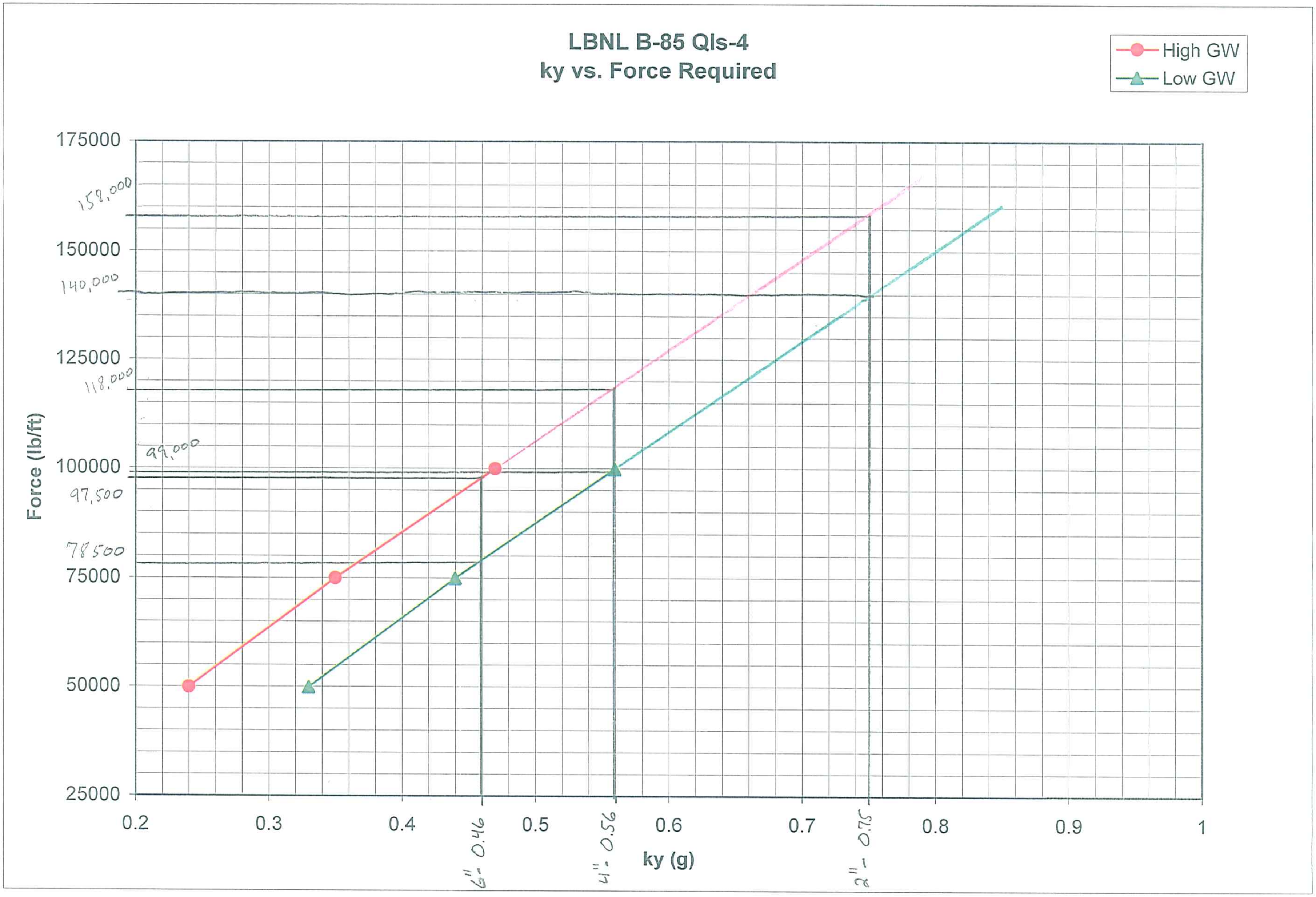
File Name: Qls-3 Low Water, 100000 Load
Material Properties
Material: Qls - Slide Debris
Unit Weight: 120 lb/ft3
Cohesion: 0 psf
Friction Angle: 20 degrees
1.027
1.09
100000.00 lb/ft
960
940
920
900
880
860
840 ft
-40 ft
-20
0
20
40
60
80
100
120

STABILITY, DEFORMATION AND LATERAL RESISTING FORCE ANALYSES

Landslide Qls-4
Cross Section I-I'
(Zones B1 & B2)

$V_s = 700$ ft/s
H = 22' Section I-I' (Qls-4)

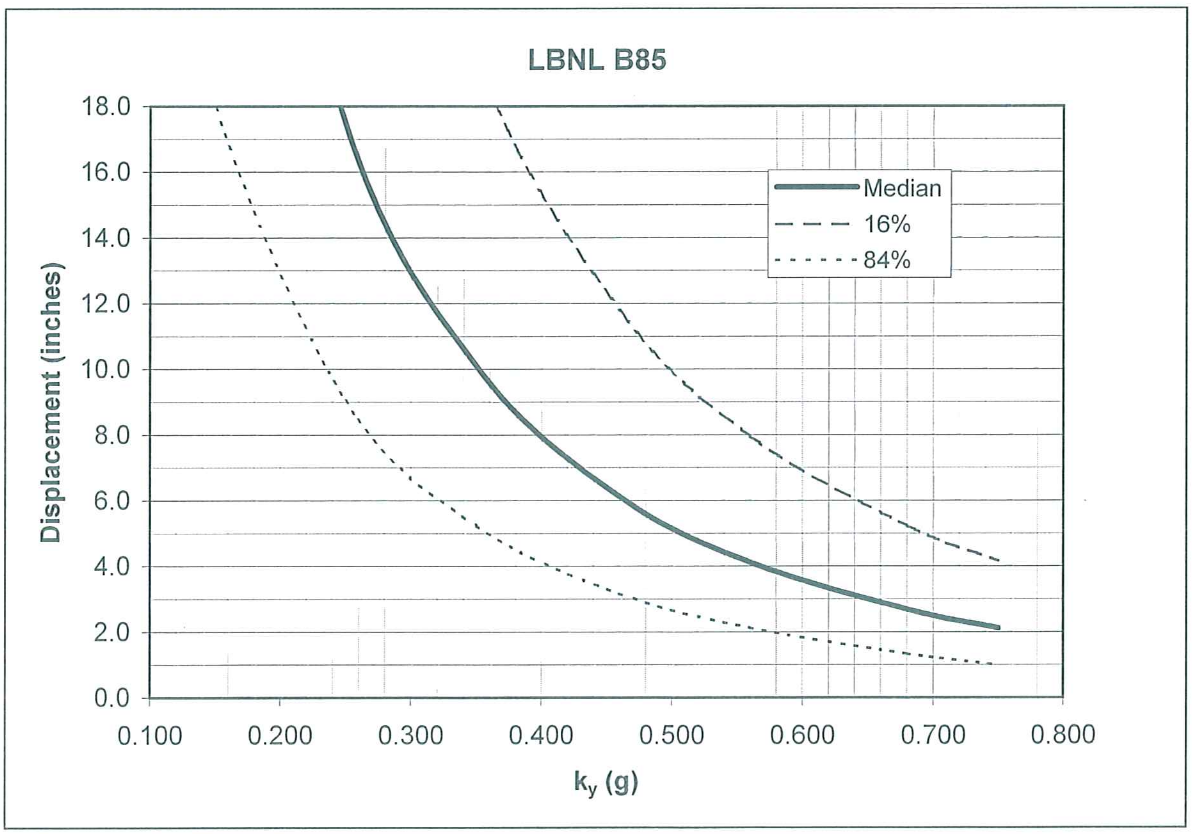



LBNL B-85 Qls-4
ky vs. Force Required
High GW
Low GW
Force (lb/ft)
175000
150000
125000
100000
75000
50000
25000
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
ky (g)
158,000
140,000
118,000
99,000
97,500
78500
6" = 0.46
4" = 0.56
2" = 0.75

LBNL B85
AKA Project # 2335-7B
Qls-4, Vs=700 ft/s, H=22', URS Site Specific Spectra

Simplified Procedure for Estimating Earthquake Induced Deviatoric Slope Displacements
by Jonathan D. Bray and Thaleia Travasarou
Journal of Geotechnical and Geonvironmental Engineering, ASCE, V. 133(4), pp. 381-392, April 2007

ky	Dmedian (cm)	D1 (cm)	D3 (cm)	Dmedian (in)	D1 (in)	D3 (in)
0.100	134.1	258.5	69.6	52.80	101.78	27.39
0.150	88.0	169.6	45.6	34.64	66.78	17.97
0.250	44.3	85.4	23.0	17.43	33.61	9.04
0.350	25.6	49.4	13.3	10.09	19.44	5.23
0.460	15.5	29.9	8.0	6.11	11.79	3.17
0.560	10.5	20.2	5.4	4.12	7.96	2.12
0.680	6.8	13.3	3.4	2.68	5.23	1.34
0.750	5.4	10.6	2.5	2.11	4.16	1.00



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SEE NOTES BELOW FOR GUIDANCE IN THE USE OF SPREADSHEET

Input Parameters			
Yield Coefficient (ky)	0.75		Based on pseudostatic analysis
Initial Fundamental Period (Ts)	0.13	seconds	1D: Ts=4H/Vs 2D: Ts=2.6H/Vs
Degraded Period (1.5Ts)	0.19	seconds	
Moment Magnitude (Mw)	6.9		
Spectral Acceleration (Sa(1.5Ts))	2	g	

Additional Input Parameters		
Probability of Exceedance #1 (P1)	84	%
Probability of Exceedance #2 (P2)	50	%
Probability of Exceedance #3 (P3)	16	%
Displacement Threshold (d_threshold)	5	cm

Intermediate Calculated Parameters			
Non-Zero Seismic Displacement Est (D)	5.61	cm	eq. (5) or (6)
Standard Deviation of Non-Zero Seismic D	0.66		

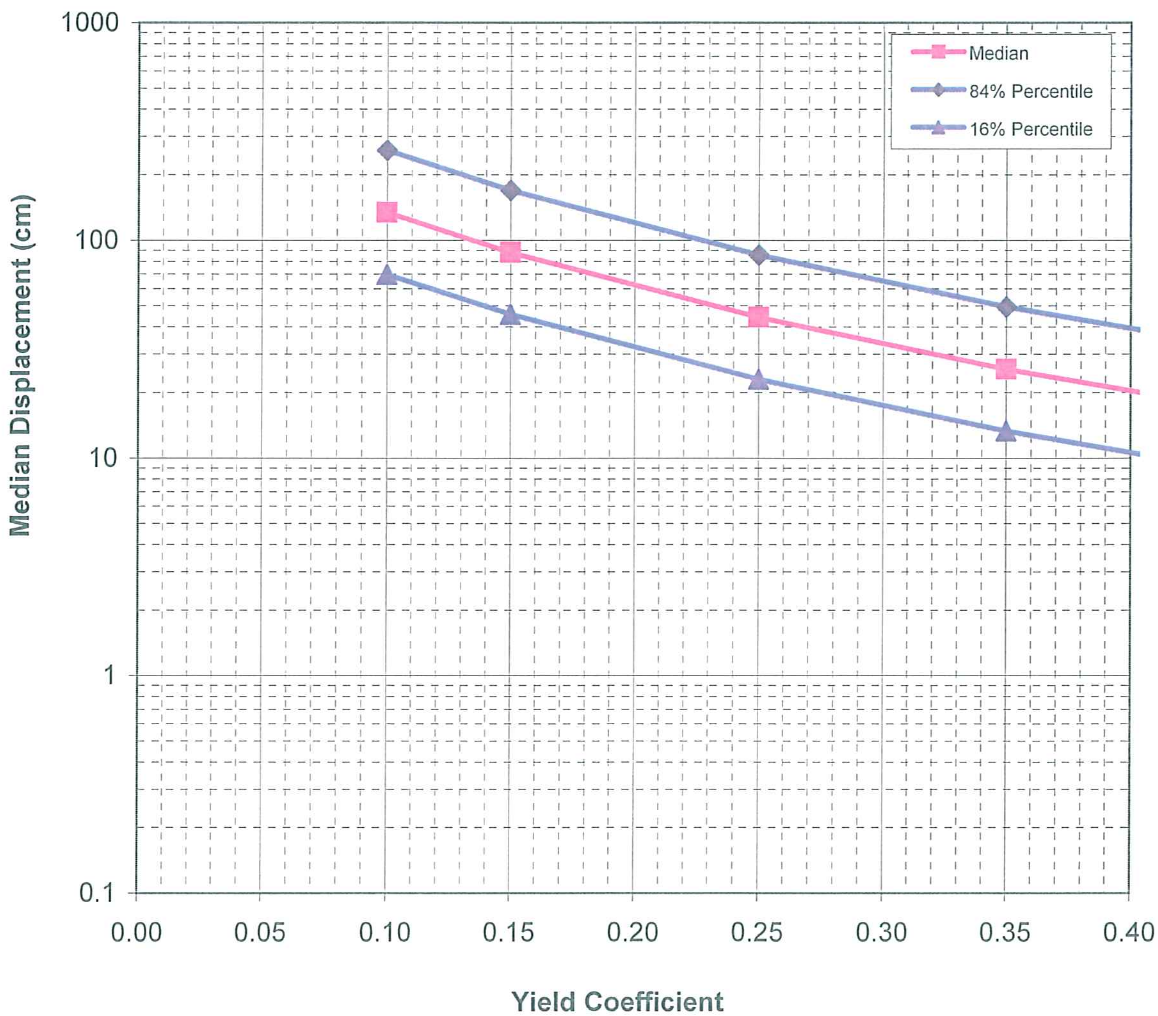
Results			
Probability of Negligible Displ. (P(D=0))	0.052		eq. (3)
D1	2.53	cm	calc. using eq. (7)
D2	5.36	cm	calc. using eq. (7)
D3	10.57	cm	calc. using eq. (7)
P(D>d_threshold)	0.540		eq. (7)

Notes

1. Values highlighted in blue are input parameters
2. Probability of Exceedance is the desired probability of exceeding a particular displacement value.
3. Displacements D1, D2, and D3 correspond to P1, P2, and P3, respectively.
   (e.g., the probability of exceeding displacement D1 is P1)
4. Calculated seismic displacements are due to deviatoric deformation only (add in volumetrically induced movement).
5. ky may range between 0.01 and 0.5, Ts between 0 and 2 s, Sa between 0.002 and 2.7 g, M between 4.5 and 9
6. Rigid slope is assumed for Ts < 0.05 s
7. When a value for D is not calculated, D is < 1cm
8. ky may be estimated using the simplified equations shown below.
9. Examples of how Ts is estimated are shown below.
10. Vs = weighted avg. shear wave velocity for the sliding mass, e.g., for 2 layers, Vs = [(h1)(Vs1) + (h2)(Vs2)]/(h1 + h2)

Dependence on ky

ky	P(D="0")	D (cm)	Dmedian (cm)	D1 (cm)	D3 (cm)
0.100	0.00	134.1	134.1	258.5	69.6
0.15	0.00	88.0	88.0	169.6	45.6
0.25	0.00	44.3	44.3	85.4	23.0
0.35	0.00	25.6	25.6	49.4	13.3
0.46	0.00	15.5	15.5	29.9	8.0
0.56	0.00	10.5	10.5	20.2	5.4
0.68	0.03	7.0	6.8	13.3	3.4
0.75	0.05	5.6	5.4	10.6	2.5



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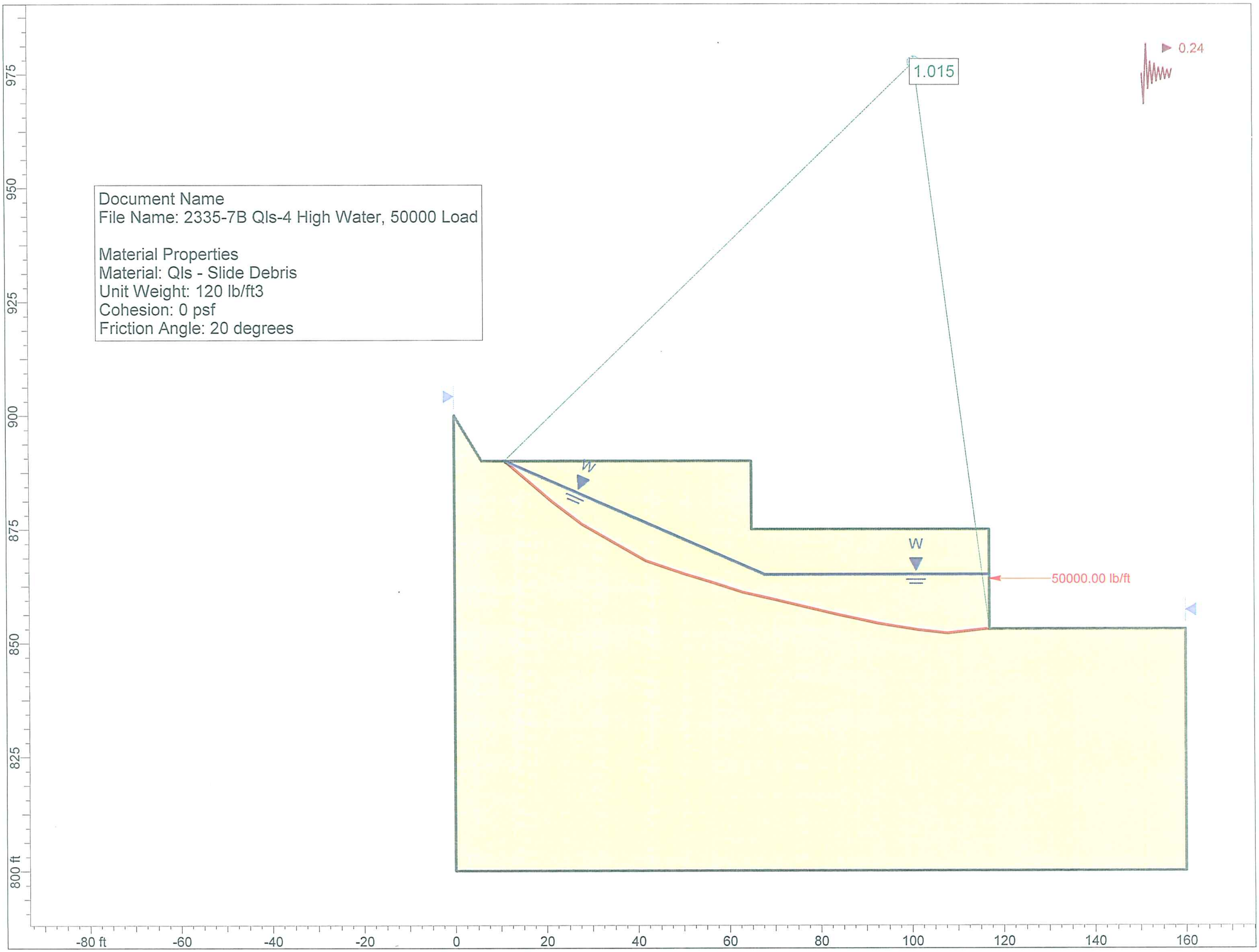
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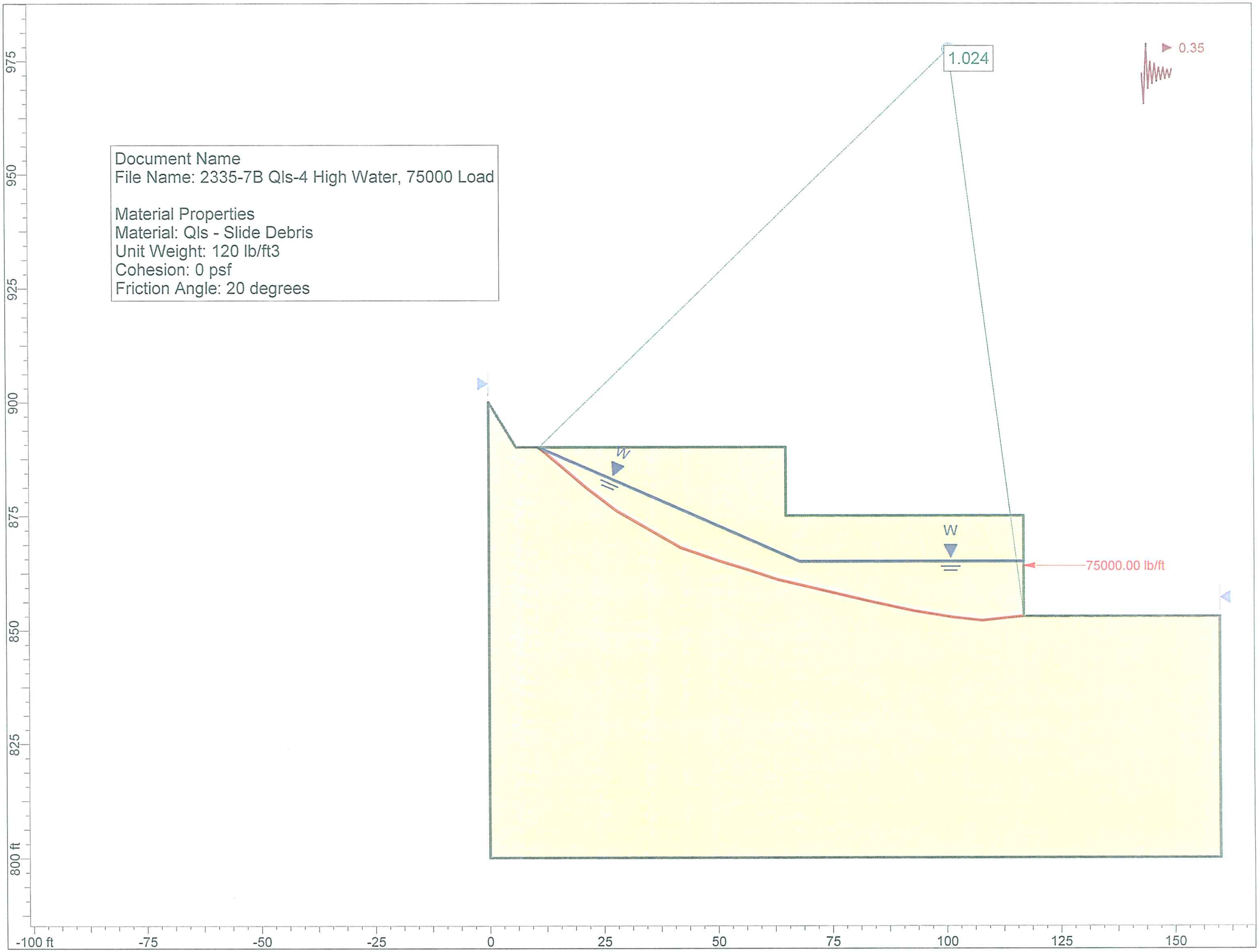
Material: Qls - Slide Debris
Unit Weight: 120 lb/ft3
Cohesion: 0 psf
Friction Angle: 20 degrees
1.015
0.24
W
W
50000.00 lb/ft
975
950
925
900
875
850
825
800 ft
-80 ft
-60
-40
-20
0
20
40
60
80
100
120
140
160



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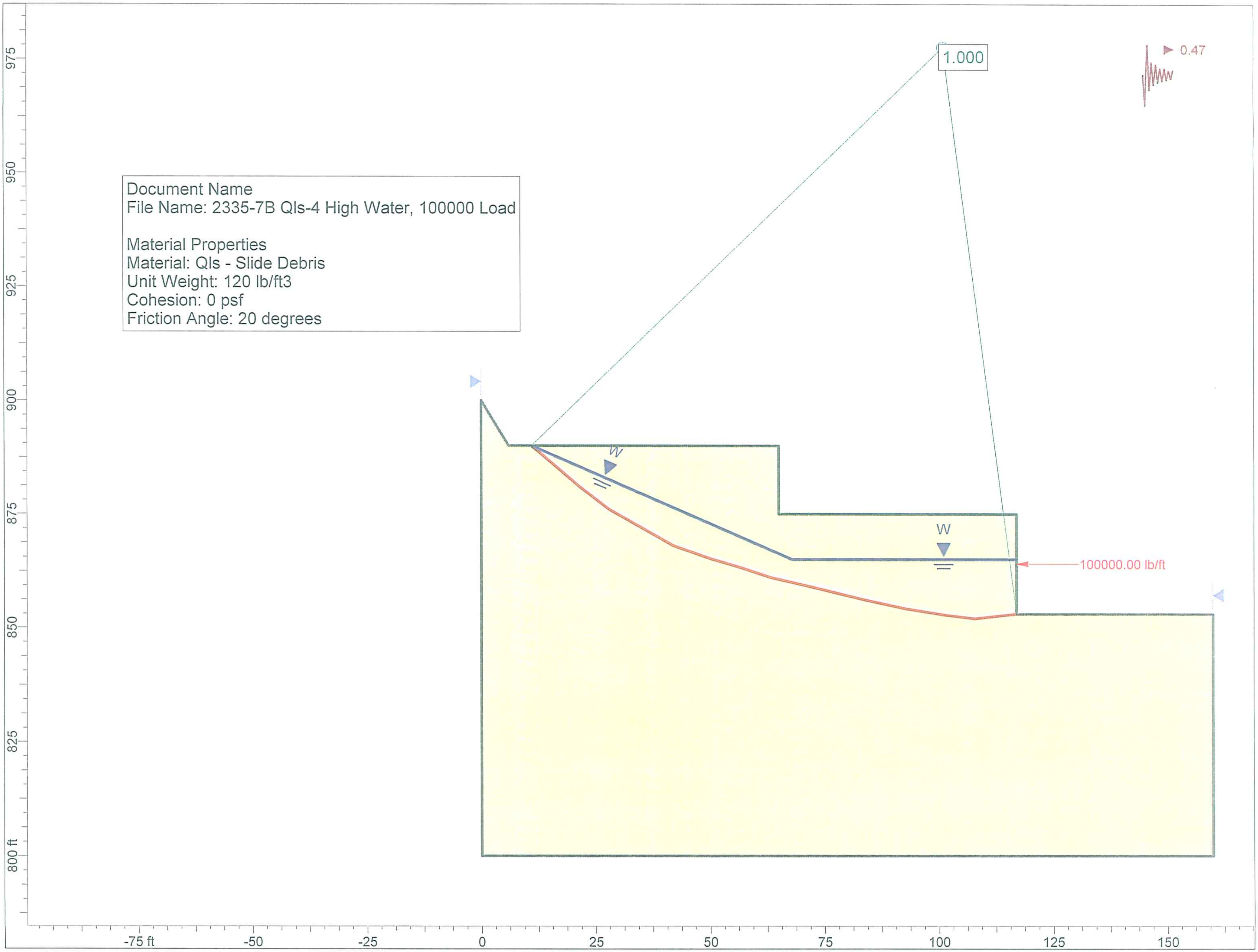
Cohesion: 0 psf
Friction Angle: 20 degrees
1.024
0.35
W
W
75000.00 lb/ft
975
950
925
900
875
850
825
800 ft
-100 ft
-75
-50
-25
0
25
50
75
100
125
150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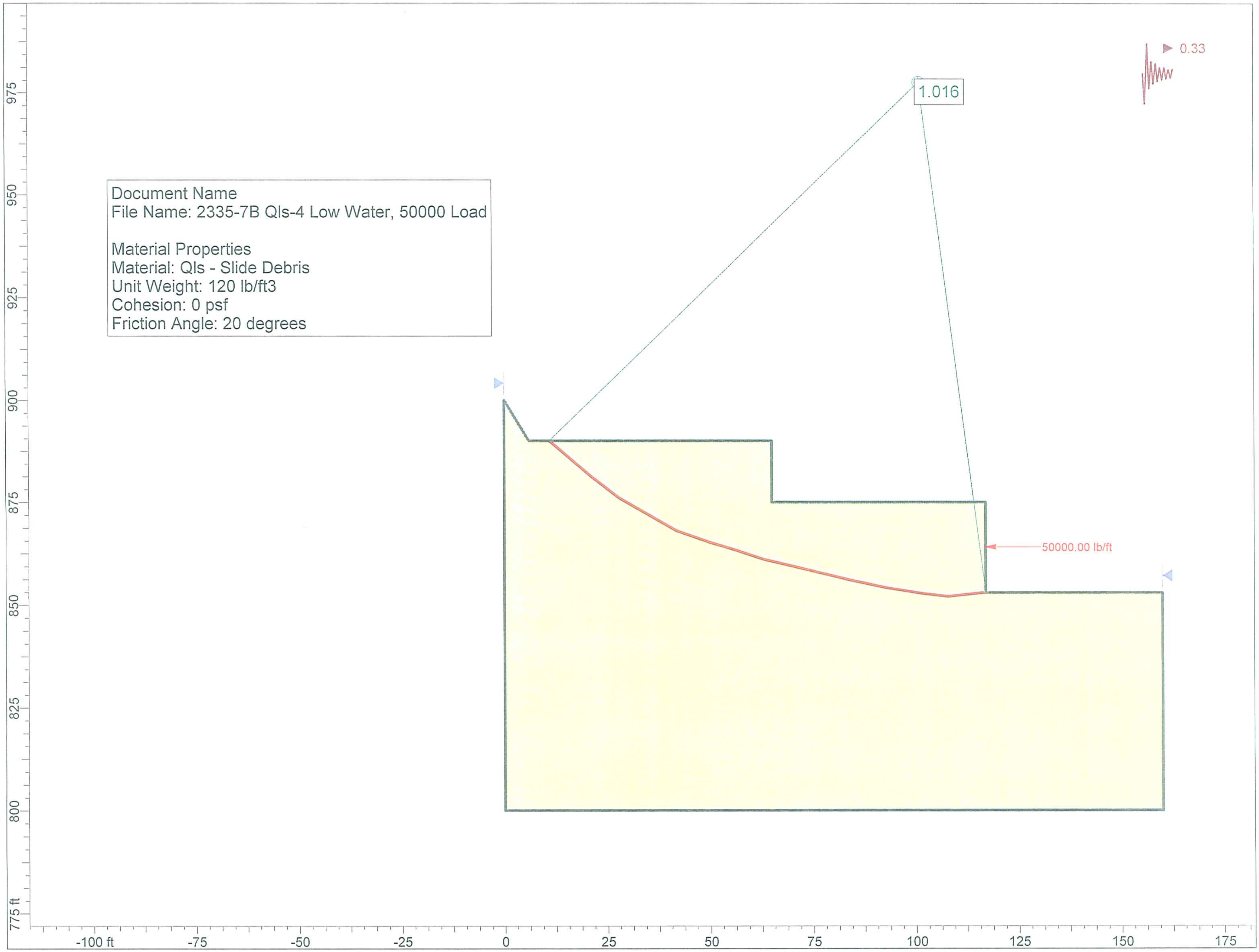
1.000
0.47
W
W
100000.00 lb/ft
975
950
925
900
875
850
825
800 ft
-75 ft
-50
-25
0
25
50
75
100
125
150



0.33
1.016
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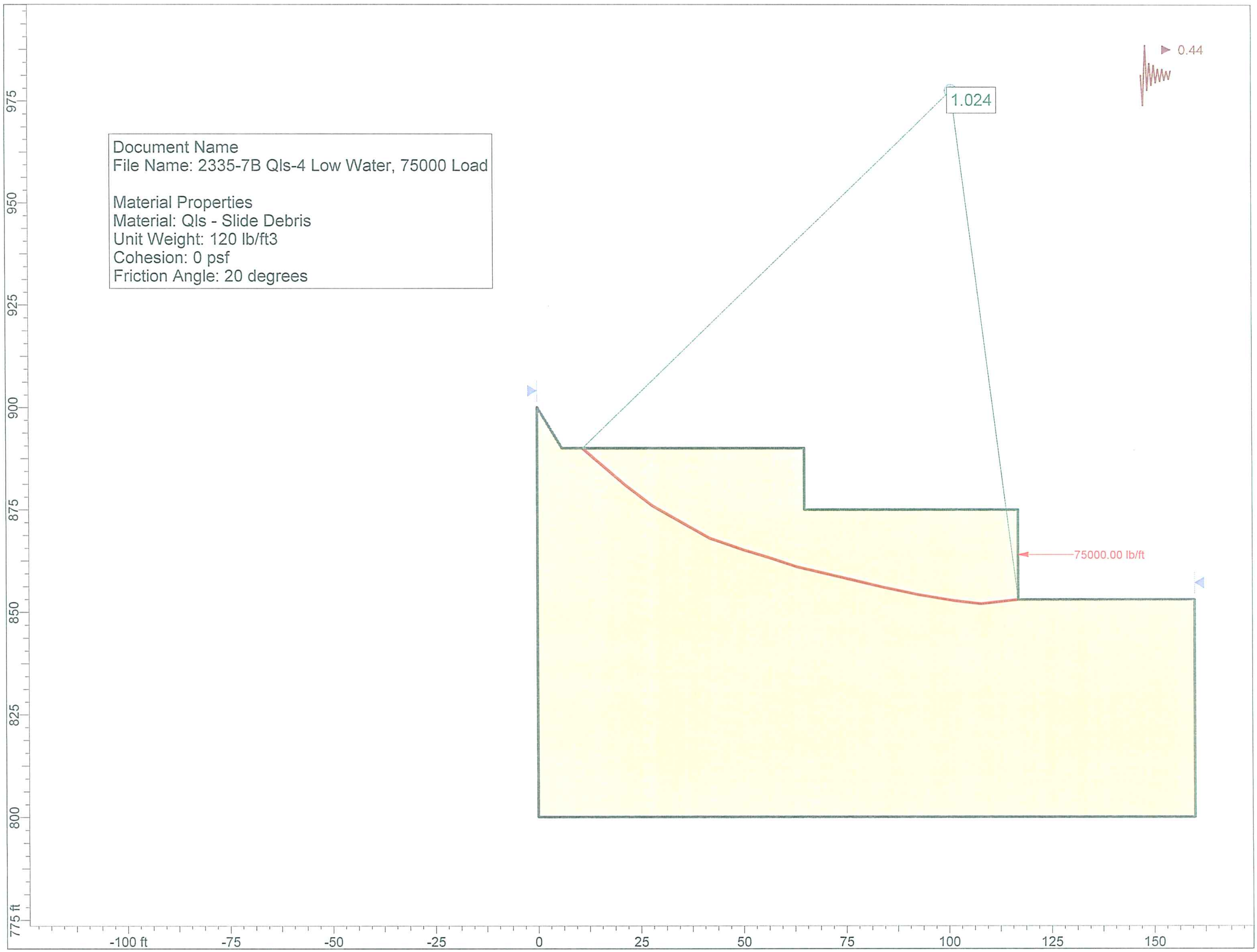
Cohesion: 0 psf
Friction Angle: 20 degrees
50000.00 lb/ft
975
950
925
900
875
850
825
800
775 ft
-100 ft
-75
-50
-25
0
25
50
75
100
125
150
175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Friction Angle: 20 degrees
1.024
0.44
75000.00 lb/ft
975
950
925
900
875
850
825
800
775 ft
-100 ft
-75
-50
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0
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50
75
100
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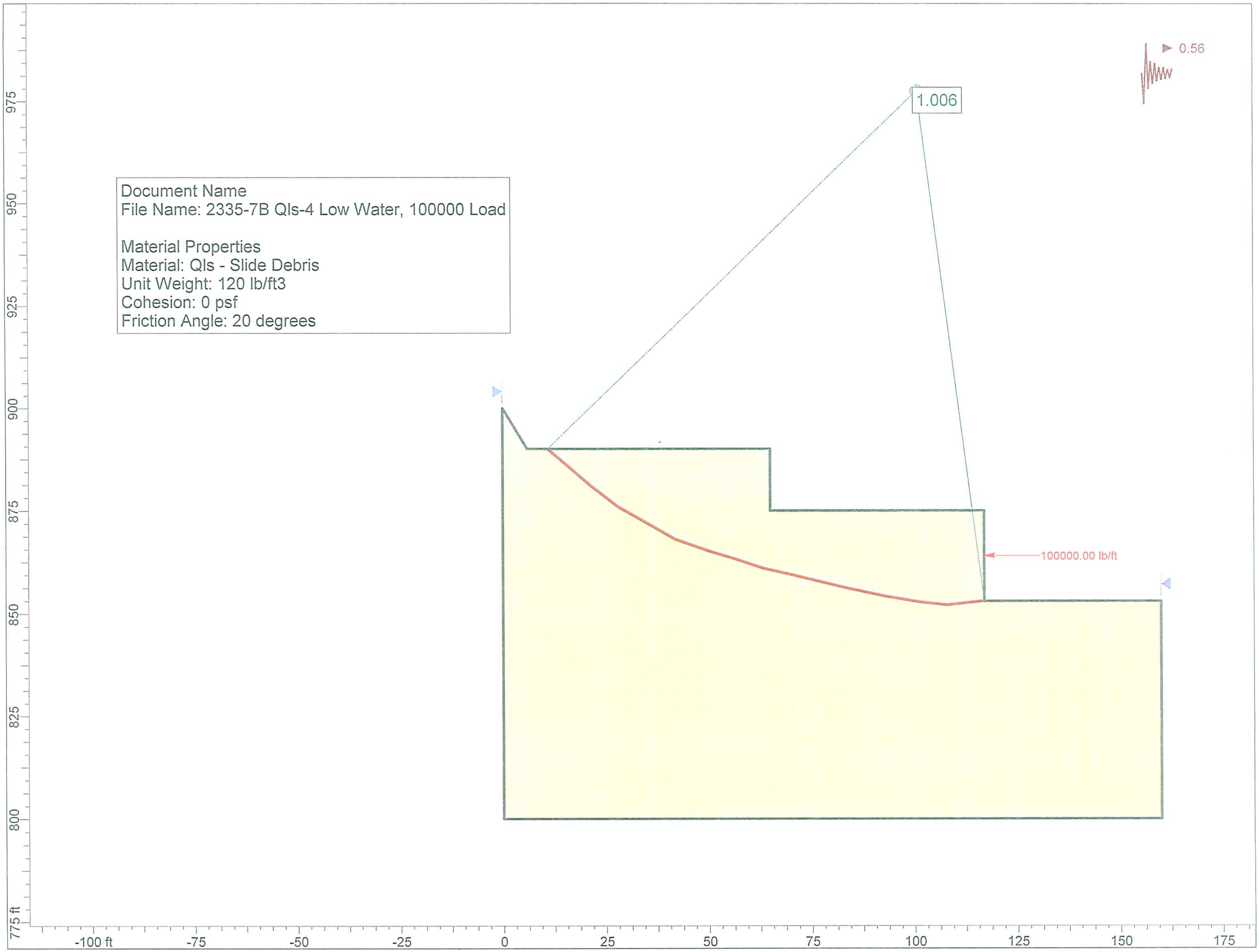
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Cohesion: 0 psf
Friction Angle: 20 degrees
1.006
0.56
100000.00 lb/ft
975
950
925
900
875
850
825
800
775 ft
-100 ft
-75
-50
-25
0
25
50
75
100
125
150
175