Paleolandslide Investigation
Building 25
Lawrence Berkeley National Laboratory
Berkeley, California

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TABLE OF CONTENTS

1.0 Introduction 1
1.1 Project Description 1
1.2 Purpose 2
1.3 Previous AKA/WLA Investigations 2
1.4 Limitations 3
2.0 Scope of Work 4
2.1 Data Review, Site Reconnaissance, and Geologic Mapping 4
2.2 Personal Communications 5
2.3 Subsurface Exploration 5
3.0 Regional Geologic and Seismic Setting 7
3.1 Berkeley Hills Geology 7
3.2 Bay Area Active Faults 7
3.3 Bay Area Seismicity 8
4.0 Local Geologic Conditions 10
4.1 Local Geomorphology 10
4.2 Bedrock Units 11
4.2.1 Cretaceous Great Valley Group 11
4.2.2 Tertiary Orinda Formation 11
4.2.3 Tertiary Moraga Formation 12
4.2.4 Unconsolidated Deposits 13
4.3 Building 25 Geologic Conditions 14
5.0 Origin of Moraga Formation in Old Town 15
5.1 Paleolandsliding 15
5.2 Faulting 17
5.3 Depositional 17
6.0 Results of Subsurface Investigation 18
6.1 Exploratory Trench WLA T-1 18
6.1.1 Stratigraphic Relations in Trench T-1 18
6.1.2 Structural Relations in Trench T-1 19
6.2 Test Pit T-1 20
6.3 Exploratory Trench T-2 20
6.3.1 Stratigraphic Relations of Trench T-2 21
6.3.2 Structural Relations of Trench T-2 22
6.4 Estimated Ages of Deposits 23
7.0 Discussion 25
7.1 Paleolandslide Model 26
8.0 Conclusions 28
9.0 References 29

LIST OF TABLES

Table 1. Aerial Photography Reviewed 4

LIST OF FIGURES

Figure 1. Location Map
Figure 2. Map of Regional Geology
Figure 3. LBNL Geologic Map from the RFI (Parsons, 2000) Report
Figure 4. 1935 Oblique Aerial (View from Southwest) with Primary Local Creeks

Figure 5. 1935 Oblique Aerial Photography Showing Schematic Geology
Figure 6. Historical Seismicity of San Francisco Bay Area
Figure 7. Section A-A'
Figure 8. Section B-B'
Figure 9. Section C-C'
Figure 10. Core Photograph of Borehole 430 (AKA-2)
Figure 11. Core Photographs of Borehole 429 (AKA-1)
Figure 12. Core Photograph Borehole 431 (AKA-3)

LIST OF PLATES

Plate 1. Geologic Map of Building 25 Area
Plate 2. Trench T-1 (South Wall)
Plate 3. Trench T-2 (South Wall)
Plate 4. Test-Pit TP-1 (South Wall)

LIST OF PHOTOGRAPHS

Photograph 1 View to the northwest showing the trench T-1 location in a narrow lawn area sloping southwest toward Building 42 (not shown).
Photograph 2 View to the east showing the location of trench T-1.
Photograph 3 View of the southwall of trench T-1 near Station 16 feet.
Photograph 4 View of the zone of folding and faulting in Tertiary sediments near Station 22 feet.
Photograph 5 Photomosaic of a portion of soil profile SP-1 evaluated at Station 24 feet.

Photograph 6 View of the geologic contact between the Tertiary sediments and sheared Moraga Formation near Station 38 feet in trench T-1.
Photograph 7 View looking west of the abrupt and sheared contact between the Tertiary sediments and the Moraga Formation near Station 38 feet in trench T-1.
Photograph 8 A close-up of calcium carbonate lining the shear zone between the Tertiary sediments and Moraga Formation at Station 42 feet near note b.
Photograph 9 View looking west and upslope toward the southern Building 25 parking lot showing the location of trench T-2.
Photograph 10 View of the geologic contact between Moraga-derived colluvium and Moraga formation and the underlying Orinda Formation near Station 38 feet.
Photograph 11 View of the south wall of trench T-2 showing the geologic contact between the Moraga Formation and the Orinda Formation near Station 34 feet.
Photograph 12 Close-up of the geologic contact between the Moraga and Orinda Formations at Station 34 feet showing the absence of shearing.

LIST OF APPENDICES

Appendix A-Soil Data Sheets SP-1 through SP-4

1.0 INTRODUCTION

William Lettis & Associates, Inc. (WLA), under subcontract to Alan Kropp and Associates, Inc. (AKA), presents the results of a paleolandslide investigation for a proposed redevelopment of the Building 25 area of Lawrence Berkeley National Laboratory (LBNL). The approximate site location is shown on Figure 1 and the site geologic map (Plate 1).

1.1 Project Description

The Building 25 site is located in the "Old Town" area of the LBNL facility in an area of moderately steep slopes. The proposed re-development would include: (1) the demolition of LBNL Buildings 25 and 25A; (2) the construction a General Purpose Laboratory (GPL) building; and (3) a building or building(s) unrelated to the GPL project. The exact location of the proposed building footprints and site improvements are unknown at the time of this report but are assumed to be near Building 25 and its adjacent parking lots.

The "Old Town" area of LBNL includes some of the earliest buildings constructed at the LBNL campus. The natural topography of the area has been extensively modified by grading; however, it is apparent that Building 25 is situated atop a north-south trending ridgeline that extends down into Strawberry Canyon (Figure 1). Old topographic maps of this area generally show the ridgeline and adjacent swales sloping down toward the south at declinations between 2:1 (horizontal to vertical) and 4:1. The general area of Building 25 has been graded to an approximately level pad near Elevation +940 feet (LBNL datum); the nose of the ridgeline intersects the floor of Strawberry Canyon at about 500 feet below the level of the building pad.

Regional geologic mapping and recent subsurface investigations and mapping performed in the general area of Building 25 have encountered volcanic rocks of the Moraga Formation overlying sedimentary rocks of the Orinda Formation (Figure 2; and Plate 1). Previous geotechnical and geologic studies by LBNL consultants have interpreted the contact between these rocks to be depositional. However, the September 2000 (Parsons, 2000) RCRA Facility Investigation (RFI) Report prepared by LBNL's EH&S group presents an alternative interpretation; specifically, that the Moraga Formation rocks have moved downslope as landslide blocks and were deposited on a paleosurface eroded on the Orinda Formation (Figure 3).

The interpreted "paleolandslide" underlying Building 25 (shown as $QTls_{(m)}$ on Plate 1) is a maximum of 80 to 90 feet deep, as depicted in Figure B2.3-9 of the RFI Report (Parsons, 2000) and Figure 2 of AKA (2009a). A "mixed unit" comprised of both types of rocks has been interpreted at the base of the paleolandslide and has shears and slickensided surfaces. The geologic interpretations presented in the RFI Report (Parsons, 2000) were developed as part of a comprehensive environmental study by LBNL's EH&S group that addresses chemically-impacted soils and groundwater on the LBNL

campus.

1.2 Purpose

The purpose of the investigation is to compile existing data on the origin of the volcanic block beneath Building 25, and to assess the presence or absence of paleolandslide features in the subsurface, and if present, assess the activity of the features. The scope of the investigation includes exploratory trenching along the western and eastern margins of the paleolandslide to: (1) establish the presence or absence of the inferred paleolandslide; (2) evaluate the activity and age of the paleolandslide deposits; and (3) compare the rate of activity (i.e., frequency of movement) with the preliminary Newmark analyses derived from an AKA (2009a) initial study of the Building 25 site. The initial findings of the Newmark analysis predicted translation coincident with frequent large magnitude earthquakes on the Hayward fault (AKA, 2009a).

The techniques employed during this study follow the standard procedures used to assess active faulting (i.e., the State's Alquist-Priolo Act). Although, the Building 25 site does not overlie a State-recognized active fault, the techniques used to assess the presence or absence of active faulting are readily applicable to assessing the presence or absence of active landslide-related deformation. For instance, if bedrock shearing is present in the trenches, the recency of landslide deformation can be evaluated by characterizing the upward termination of deformation with respect to the age of the overlying undeformed deposits. The A-P Act defines an active fault as one that has ruptured the ground surface within the past approximately 11,000 years (the Holocene Epoch). Note that no similar age delineation for active landsliding is mandated by State regulation(s).

1.3 Previous AKA/WLA Investigations

The geologic interpretations presented in this study build upon previous investigations conducted by AKA and WLA at other nearby areas within the LBNL facility, such as the Helios site (AKA, 2009b) in Chicken Creek Canyon, and our on-going study at Building 71. Selected AKA/WLA reports used or referred to during this study are listed in Section 9.0 (References). An initial investigation of the Building 25 site performed by WLA and AKA (AKA, 2009a) included a review of existing site data and drilling of several deep boreholes. The preliminary findings from AKA (2009a) suggested that the site geologic conditions encountered below Building 25 were consistent with a paleolandslide hypothesis. Furthermore, simple computer modeling (Newmark analysis) developed from assumptions regarding slide plane geometry and strength parameters indicated the inferred paleolandslide is stable under static conditions, but unstable under dynamic loading resulting from a large earthquake on the active Hayward fault. It was recommended that additional geologic investigation (i.e., trenching) be performed to further evaluate the recency of landslide movement.

1.4 Limitations

This report has been prepared specifically for LBNL and its design consultants for the proposed redevelopment of Building 25, and is to be used solely for its planning purposes. No other warranty, expressed or implied, is made as to the professional advice included in this report. This report has not been prepared for use by other parties, and may not contain sufficient information for the purpose of other parties or other uses. Note that this study does not constitute a geotechnical investigation for foundation design nor an evaluation of other potential geologic hazards (e.g., strong ground motion, liquefaction, landsliding, surface-faulting,) potentially impacting the subject site. These issues should be evaluated in a separate geologic and geotechnical investigation for the site.

2.0 SCOPE OF WORK

Based on a letter of authorization dated July 10, 2009, WLA and AKA were retained by LBNL to evaluate the recency of movement associated with a hypothetical paleolandslide mapped previously beneath the Building 25 site. The investigation focused on new exploratory trenching to complement our previous borehole exploration, as well as a data compilation of nearby previous consultant studies. The scope of work is designed to (1) establish the presence or absence of the inferred paleolandslide; (2) evaluate the activity and age of the paleolandslide deposits; and (3) compare the rate of activity (i.e., frequency of movement). Our scope of work included the following tasks:

- Compilation and review of existing published and unpublished geologic information, including consultants reports, stereo-pair aerial photographs, and oblique historical topographic maps and photographs;
- Site reconnaissance and geologic mapping;
- Excavation and documentation of trenches and a test pit totaling about 170 lineal feet;
- Perform relative age dating of trench deposits using soil profile development;
- Data analysis to assess the location and activity of the inferred paleolandslide;
- Technical peer review of the trenches by LBNL geologist Mr. Preston Jordan, GPL and LBNL stakeholders, Mr. Wayne Magnusen and Ms. Dona Mann of AKA; and Mr. Jeffery Bachhuber (Senior Principal Engineering Geologist) of WLA; and
- Report preparation and submittal.

2.1 Data Review, Site Reconnaissance, and Geologic Mapping

WLA geologists conducted an initial review of pre-construction aerial photographs (Table 1), historical photographs (Figures 4 and 5), topographic maps, geologic and engineering reports, and logs from existing site borings and trenches (Plate 1), field reconnaissance between Building 25 and the Lawrence Hall of Science (LHS) to evaluate local bedrock exposures, surficial deposits, and fault contacts mapped previously (e.g., Clements, 1963; HLA, 1982; Parsons, 2000; Graymer, 2000).

Table 1. Aerial Photography Reviewed

Type	Date	Scale	Photo No.	Source
Black and White, Stereo Pair	08/02/1939	1:20,000	BUT-BUU-289-67,68	United States Soil Conservation Service

Pre-development historic oblique and vertical aerial photographs were examined to check

for geomorphic indicators of landsliding within the area of Building 25. The oldest photograph reviewed was an oblique aerial photograph of the site area from circa 1935, which was obtained from AKA's historical reference library. Representative photographs of the site from 1935 are presented in Figures 4 and 5. The figures are annotated to show the approximate location of the existing Building 25 and key geologic features. The earliest stereo-pair vertical aerial photographs of the site are from 1939 and show the building site consisting of grassy rolling hills in the western and southern part and a eucalyptus grove in the northeastern part of the site vicinity.

We also reviewed published geologic maps and literature pertaining to geologic conditions in the project vicinity. The earliest topographic map reviewed included one with mapped geology in Lawson and Palache (1901). A substantial amount of information exists regarding geotechnical and geologic conditions within the Building 25 area from consulting reports and LBNL environmental documents (i.e. Parsons, 2000). Some of the data contained in the referenced reports was used and relied upon during our initial engineering geologic evaluation of conditions affecting the Building 25 site (AKA, 2009a). The locations of nearby borings, test pits, and trenches used in this report are shown on Plate 1.

2.2 Personal Communications

WLA's engineering geologists contacted Dr. Russell Graymer of the U.S. Geological Survey, on May 29, 2009, through email regarding his geologic mapping of the Berkeley Hills and LBNL area (Graymer et al. 1996; Graymer, 2000). Dr. Graymer is a research geologist and an expert on the local and regional geology and provides an 'independent' perspective on the geologic conditions within the LBNL vicinity. Dr. Graymer stated that he was unaware of any large paleolandslide features in the area, but also acknowledged that he did not necessarily consider this deformation mode during his mapping. Dr. Graymer's maps are small-scale representations of regional-scale stratigraphic and structural bedrock relations in the East Bay Hills (Figure 2).

2.3 Subsurface Exploration

WLA geologists excavated and documented trenches T-1 and T-2, and test pit TP-1 between July 13 and August 2, 2009 (Plate 1). Goebel Paving, Grading, & Underground, Inc. (Goebel) excavated the trenches and test pit using either a track-mounted excavator or rubber tire backhoe equipped with a 36-inch-wide bucket. The south wall of the trenches and test pit were completely cleaned to expose fresh material. Structural and stratigraphic features were flagged and logged at 1 inch = 2 ft (1:24) scale. Attitudes and orientations of structural features and bedding were measured and logged on the south wall after correlating with similar features on the north wall. Detailed soil profiles (SP-1 to SP-4) were prepared by Dr. Janet Sowers of WLA of trenches T-1 and T-2 for age dating purposes (see Appendix A).

Trenches T-1 and T-2 extend generally perpendicular to the previously mapped eastern

and western margins of the inferred paleolandslide (Plate 1). Trench T-1, located between Buildings 4 and 25, crosses the previously mapped western margin of the paleolandslide (Parsons, 2000). The T-1 trench site is a sloping lawn area surrounded by trees, a parking lot, and an adjacent paved access road. Trench T-2, located along a moderately inclined slope (about 15 degrees inclination) on the southeast side and below the southern parking lot of Building 25, intersects the eastern margin of the paleolandslide. A test pit, TP-1, located west of trench T-2, was excavated to assist in properly locating trench T-2.

Prior to excavation, a site-safety meeting was held with WLA, LBNL, and Goebel employees to review the excavation plan and discuss safety elements of the trenching investigation. The trenches used aluminum hydraulic shoring in accordance with OSHA regulations. Daily site safety inspections were performed by the WLA competent person and LBNL safety personnel prior to entering the trenches. The trench locations were approximated in the field using a tape measure and Brunton compass, coupled with a hand-held GPS device. Upon completion of the investigation and a formal review of the findings, trenches were backfilled in 12-inch lifts using a backhoe and/or an excavator-mounted vibratory plate and the addition of water. The trench backfill was confirmed visually without laboratory testing and specified backfill conditions or limits. The site was restored to previous grade using the blade of the backhoe and excavator equipment. Because the trench backfilling was not controlled by a specification and testing, there is a potential for future settlement of backfill soil that needs to be considered with respect to future grading and foundations for the redevelopment of Building 25. The GPS data points of the trench locations have been intergrated into our GIS site map of the area and could help define the limits of the trench for future geotechnical/foundation assessment.

3.0 REGIONAL GEOLOGIC AND SEISMIC SETTING

In the following sections, we summarize the regional geologic and seismic information obtained from our review of published and unpublished geologic information. More detailed discussions of local geologic conditions are presented in Section 4.00, "Local Geologic Conditions."

3.1 Berkeley Hills Geology

The proposed re-development of the Building 25 site is situated at about 940 ft MSL along the west side of the northwest-trending Berkeley Hills, and is characterized by gentle to steep topography. Bedrock geology in the Berkeley Hills is 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 landsliding. These rock units range in age from the Late Jurassic/Cretaceous (135 to 150 million years ago) to the Tertiary (66.5 to 1.6 million years ago).

The regional geology map presented on Figure 2 is based on a published geologic map of this area from the United States Geological Survey (Graymer, 2000). Bedrock units mapped in the site area include the Cretaceous Great Valley Group (Ku), Miocene Orinda Formation (Tor), Miocene Moraga Volcanics (Tmb) and Miocene Claremont Chert (Tcc). Regional geologic mapping shows the Tertiary sedimentary and volcanic rocks are folded into a syncline in the eastern part of LBNL that has been displaced by the inactive Wildcat fault in the East Canyon (Figure 2). The Hayward fault (considered a major active fault) also trends northwest and runs along the western side of the Berkeley Hills near its base (Figures 1 and 2).

3.2 Bay Area Active Faults

The San Francisco Bay Area lies within a broad region of deformation that defines the boundary between the North American and Pacific tectonic plates. This boundary includes a series of major active northwest-trending faults, which include the San Andreas, Hayward, Rodgers Creek, Calaveras, San Gregorio, Concord-Green Valley, West Napa, and Greenville faults. These major faults are near-vertical and generally exhibit right-lateral strike-slip movement (which means that the movement is predominantly horizontal and when viewed from one side of the fault, the opposite side of the fault is observed as being displaced to the right). There are numerous active and potentially active faults within the Bay Area that are secondary to the major strike-slip faults. 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 fault creep, (3) close proximity and alignment with linear concentrations or trends of earthquake epicenters, and (4) tectonic-related geomorphology. Potentially active faults are defined as those that have evidence of Quaternary-age displacement (within about the

past 2 million years), but have not been definitively shown to lack Holocene movement.

Various researchers and government agencies have mapped the locations of active and potentially active faults in California. The closest known active fault to the project site is the Hayward fault, which has been mapped by Lienkaemper (1992), Geomatrix (2006), and WLA (2007) approximately 1,800 feet southwest of the site on the UCB Campus. The State of California has designated official Special Studies Zones (later renamed Earthquake Fault Zones) around known active faults. These official State Earthquake Fault Zones were initially delineated by the State Geologist in conjunction with the California Division of Mines and Geology (CDMG, now the California Geological Survey) as part of the Alquist-Priolo Fault Evaluation Program, and are commonly referred to as A-P Zones. The CGS continues to revise and update the A-P Zone maps. The Building 25 site is not located within a State Earthquake Fault Zone (see Figure 1).

3.3 Bay Area Seismicity

The greater San Francisco Bay Area region is characterized by a high level of seismic activity. Historically, this region has experienced strong ground shaking from large earthquakes, and will continue to do so in the future. A map showing the locations and magnitudes of historical earthquakes in the San Francisco Bay Area is presented in Figure 6. Since 1800, five earthquakes of magnitude (M) 6.5 or greater have occurred in the Bay Area (Bakun, 1999). These include the: 1836 M6.5 event east of Monterey Bay; 1838 M6.8 event on the Peninsula section of the San Andreas fault; 1868 M6.8-7.0 Hayward event on the southern Hayward fault; 1906 M7.9 San Francisco earthquake on the San Andreas fault; and 1989 M6.9 Loma Prieta event in the Santa Cruz Mountains.

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 (WGCEP, 2008). 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, and a 0.31 probability (31 percent) that a M 6.7 or larger earthquake will occur on the Hayward fault in this same time period. A large earthquake on the Hayward fault was used in the preliminary Newmark analysis of the Building 25 site to evaluate the dynamic stability of the inferred paleolandslide shown in Plate 1 (AKA, 2009a).

The Hayward fault accommodates about 25% of the strain associated with the Pacific/North American plate boundary in the San Francisco Bay area. The Hayward fault lies along the southwestern margin of the East Bay Hills and extends from Warm Springs (Fremont) on the south to San Pablo Bay on the north for a distance of about 87 ± 10 km (Figure 1). The fault consists of two major sections: the 30 ±15 km long northern segment, and 55 ± 7.5 km long southern segment, respectively (WGCEP, 2003). The northern Hayward fault also represents the central segment of the 140-km-long Hayward-Rodgers Creek fault (HRCF) system, which according to the latest evaluation by the

Working Group on California Earthquake Probabilities has the highest probability (27%) of the "characterized" faults within the Bay Area capable of producing a **M**≥6.7 earthquake in the next 30 years (2002-2032). 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 mean recurrence interval of 170 ± 82 years (Lienkaemper and Williams, 2007). This short recurrence interval for large earthquakes on the nearby Hayward fault suggests that strong ground shaking-induced slope failures at the Building 25 site should be recorded in the geologic deposits overlying the hypothesized paleolandslide margins.

4.0 LOCAL GEOLOGIC CONDITIONS

In the following sections, we discuss the results of our geologic reconnaissance together with information obtained from our review of published and unpublished sources, including geologic, geotechnical and environmental consulting reports. The introductory discussions presented in this section refer extensively to the Geologic Map presented on Plate 1 and the oblique aerial photographs presented in Figures 4 and 5.

4.1 Local Geomorphology

The Building 25 site is located on the southwest facing slopes of the Berkeley Hills and specifically on a bedrock ridge that has been significantly altered from its original condition. Early maps (Lawson and Palache, 1901) and historical photographs (1935 and 1939) of the site area depict pre-development morphology, and show a gently sloping and rounded north-south trending bedrock ridge with southwest-trending and southeast-trending bedrock spurs. These early depictions show the ridge continuing northward and steepening toward present-day Lawrence Hall of Science (Figure 4). Highly resistant andesitic and basalt units of the Moraga Formation form the steep ridges and cliff faces directly upslope of Building 25 dip northerly into the hillslope, and locally define a north-plunging syncline (Figure 5).

The eastern part of the site is bordered by the headwater of Chicken Creek Canyon whereas the western margin is bounded by a broad west-sloping surface that drains toward Blackberry Creek. The southern part of the site, near Buildings 40 and 41, aligns with the headwaters of Ten-Inch Creek (Figure A2.2-4 of Parsons, 2000) that drains south to Strawberry Creek. An abrupt linear tree line (no longer present) captured in Figure 4 demarcates the Oakland-Berkeley City limits. A south to southeast alignment of vegetation also occupies the southeast spur of the Building 25 site close to the location of trench T-2 excavated during this investigation.

A review of 1939 stereo-paired photography identified a tear-dropped shaped feature suggestive of a shallow landslide located southwest of Building 25 near Buildings 45 and 48 (Plate 1). The approximate location of the shallow landslide is consistent with present-day morphology that depicts an arcuate shaped headwall, stressed and tilted foundations of Buildings 40 and 41, and unstable slopes currently being retained by walls constructed behind Buildings 45 and 48. Lastly, large curvilinear moist zones that coincide with a south-facing break in slope northeast of Building 25 are visible in the 1939 photos and appear to approximate the geologic contact between the Moraga and Orinda Formations. In general, the morphology depicted from the pre-development maps and photography is suggestive of a landscape that is relatively stable with most mass wasting processes confined to existing and pre-existing colluvial hollows and drainages and not ridge tops.

4.2 Bedrock Units

Bedrock within the project area consists of northeast-dipping Cretaceous Great Valley Group and Tertiary Orinda Formation overlain by Moraga Formation (Plate 1). Jordan and Javandel (2007) define the boundary between the Great Valley Group and Orinda Formation at the site as a fault contact. Southeast of the site, the contact is defined, in part, by folded Orinda Formation along a west to northwest-trending anticline (Plate 1). The southwestern limb is cut by an unnamed fault (previously named as the 'Chicken Creek fault' by AKA [2009b]) that juxtaposes Orinda Formation on the northeast against Great Valley Group on the southwest (Jordan and Javandel, 2007).

4.2.1 Cretaceous Great Valley Group

The Cretaceous sedimentary deposits are defined as part of Mesozoic rock complex that includes the Coast Range ophiolite and the Great Valley Group. Although the Great Valley Group is usually separated from the ophiolite, it is known from regional mapping that the Great Valley Group sedimentary rocks were originally deposited on the ophiolitic rocks (Graymer, 2000). This complex represents the accreted and deformed remnants of arc-related Jurassic oceanic crust covered by a thick sequence of turbidites (Graymer, 2000). The sedimentary rocks of this sequence are the oldest strata that crop out in the direct vicinity of the site and consist of sandstone and shale of the Great Valley Group. Based on borehole information acquired and interpreted as part of this study, the middle and lower portions of Chicken Creek Canyon consist of shale, claystone, and siltstone.

Within Chicken Creek Canyon the Great Valley Group strikes northwest and dips 25° to 45° northeast on the east side of the canyon, and increases in inclination to 60° near Centennial Drive and Strawberry Creek. South of the Building 25 site, the Great Valley Group material has been identified as in fault contact with the overlying Miocene Orinda Formation. Great Valley rocks near the fault zone are described as a dark gray to black, sheared and brecciated fine-grained shale and siltstone (Jordan & Javandel, 2007; Kleinfelder, 2004). Although not encountered in boreholes in the Building 25 area, the Great Valley Group would project beneath the site at considerable depth and would lie below the Orinda Formation.

4.2.2 Tertiary Orinda Formation

The Miocene Orinda Formation is a non-marine, well- to poorly-bedded siltstone, claystone, fine lithic sandstone, and pebble conglomerate up to 2400 ft in thickness. The conglomerate contains a high percentage of detritus derived from the Franciscan Assemblage (Graymer, et al., 1996). 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, 1992). In the vicinity of the Building 25 site Lawson and Palache (1901) and Lawson (1900) interpret the sedimentary lacustrine deposits as interfingering with volcanic deposits of the Moraga Formation at or near the interplay between eruptive and fluvial

deposition.

The Miocene Orinda Formation underlies the upper portion of Chicken Creek Canyon and portions of Old Town west of Building 25 (Plate 1). Locally, it consists of well-bedded to massive siltstone and claystone and occasional lenses of coarse-grained sandstone and conglomerate. The top of bedrock consists of fluid-stained, yellowish/reddish brown weathered silty sandstone to siltstone. With increasing depth, the Orinda Formation gradually becomes less weathered and maintains coloration more indicative of the deposit, such as, greenish-gray, gray, olive gray, and grayish-blue colors with discontinuous lenses of sand and gravel lenses.

The coarse-grained assemblage of the Orinda Formation underlies the northern portion of upper Chicken Creek Canyon (i.e. near Buildings 72 and 78) and consists predominantly of fine- and medium-grained sandstone with occasional pebble conglomerates. The sandstone exposed along Cyclotron/Lawrence Road strikes northwest and dips approximately 30° northeast (Plate 1). Exposures in Chicken Creek, at or near the contact with the Great Valley Group, show the inclination within the Orinda Formation to be ~30° south to southwest. The southwest inclination is interpreted as the southwestern limb of a northwest-trending anticline confined to the hanging wall of the Chicken Creek fault (Parsons, 2000).

The Orinda Formation is in fault contact with the Great Valley Group. The fault contact is interpreted as a northwest-striking low to steep east-dipping discontinuity, and is expressed as a brecciated, slickensided sheared zone (Dames and Moore, 1962; Parsons, 2000; Kleinfelder, 2004; Jordan and Javandel, 2007). To the northeast of the site, the Orinda Formation is interpreted to be in a depositional contact with the overlying Moraga Formation (Plate 1 and Figure 2). Based on the geologic and geotechnical data compilation, the anticipated fault contact between the Orinda Formation and Great Valley Group is located southwest of Building 25 and Lawrence Road (Plate 1).

4.2.3 Tertiary Moraga Formation

The Miocene Moraga Formation consists of as many as five distinct flows typically defined by basaltic and andesitic composition (Wahrhaftig and Sloan, 1989). The thickness of the Moraga Formation in the vicinity of LBNL is estimated at about 800 to 1000 ft (Lawson and Palache, 1901). The source vent is believed to be the Round Top volcanic complex located several miles southeast of the site. Early studies by Lawson and Palache (1901) refer to the volcanic deposits in the vicinity of the Building 25 as the Campan series and are described as fresh-water deposits interbedded with lavas and tuffs. Others also describe similar clastic deposits at or near the base of eruptive sequences (Lawson, 1901; Wahrhaftig and Sloan, 1989; and Clements, 1963). The Moraga Formation is exposed in multiple cut slopes along Centennial Drive and Grizzly Peak Blvd north of the site and in several abandoned quarries at LBNL (i.e. northwest of Building 78). Moraga Formation also is exposed in the Lawrence Road cut directly east of Building 48 (south and downslope of Building 25).

In the site area, the Moraga Formation consists of andesitic and basaltic flows, tuff, and volcaniclastics (locally described as agglomerate or volcanic breccia). Potassium-argon ages of the volcanic flows vary from 10.2 million years (Ma) to 8.5 Ma (Curtis, 1989). 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 intact translated slide bodies (Parsons, 2000). At the site, the Moraga Formation typically consists of highly fractured and weathered, subangular to subrounded cobble to large, boulder-size agglomerate to andesite with a predominantly silty to fine gravelly matrix. Minor amounts of weathered and altered ash and tuff also are present.

4.2.4 Unconsolidated Deposits

4.2.4.1 Undifferentiated Natural Surficial Deposits (Quaternary) – Symbol Qu

Quaternary colluvium, minor clay-rich alluvium, and debris-flow deposits have accumulated along the steep to moderate slopes bounding the bedrock ridge of Building 25 (Plate 1) Based on borehole and trench explorations for Building 25 site the unconsolidated colluvial materials are inferred to be as much as 5- to 15-feet-thick.

4.2.4.2 Quaternary Landslide Deposits

Landsliding in this part of Old Town and upslope of Building 25 has occurred at a variety of scales (deep-seated and shallow) and involves a variety of mass-wasting processes. Landslide deposits usually are constrained to the present-day topographic swales and areas of thick colluvium and poorly consolidated deposits of Orinda Formation where slopes have been oversteepened. The landslide deposits are derived from several types of materials: (1) Quaternary colluvium, (2) deposits containing mixed blocks of Orinda and Moraga Formation, and (3) homogeneous blocks of Moraga Formation or Orinda Formation. The mapped landslides depicted on Plate 1 are primarily derived from: (1) valley morphology, (2) landslide-related deposits encountered during grading activities, (3) geological and geophysical features encountered during site investigations, and (4) previously mapped boundaries of landslides.

4.2.4.3 Artificial Fill, Historic

Development within the Old Town area has included the grading of pre-existing topographic highs and filling of topographic lows by placement of artificial fill directly beneath and surrounding portions of Buildings 25 and 25A, including within the former swales and creeks associated with Blackberry Creek and Ten Inch Creek.

4.3 Building 25 Geologic Conditions

Tertiary bedrock units encountered in the Building 25 area include from oldest to youngest: Orinda Formation, Moraga Formation and an inferred Tertiary sedimentary deposit likely close in age to the Moraga Formation (Plate 1). The Geologic Map compiled for this study (Plate 1) shows bedrock units, bedrock faults, and probable deep-seated, bedrock-involved and shallow landslide deposits in the vicinity of Building 25.

In the site vicinity, the Tertiary sedimentary and volcanic rocks are folded along the western limb of a regional south-plunging syncline (Graymer, 2000; Lawson and Palache, 1901) (Figure 2). Local bedding data, compiled borehole information, and geologic reconnaissance also define a north-trending and north-plunging syncline directly upslope of Building 25 (Plate 1). Field reconnaissance of the graded cuts and quarry walls north of Building 25 mapped layered andesite, rhyolite and basalt flows that to the west become interbedded with a pebble conglomerate. Interestingly, trench and borehole data suggest the bedrock ridge occupied by Building 25 consists of an asymmetrical north-south trending synform partly aligned with the syncline north of Building 25 and also having a resistant core of volcanics (see Plate 1 and Figures 7 to 9).

Minor bedrock faults ranging from steep to shallow dipping have been exposed in cut slopes and an abandoned quarry north of Building 25 (Clements, 1963). For instance, Clements (1963) maps a thrust fault along the Orinda and Moraga contact north of LHS and directly west of Building 76 (Plate 1). The fault is mapped as a northwest-southeast striking thrust fault dipping easterly 55 to 65 degrees. To the southeast, Clements (1963) depicts the same contact as depositional and coinciding with the presence of a topographic break in slope (Plate 1). The thrust fault west of Building 76 is mapped as a shallow south dipping fault. A previous slope cut in this area apparently exposed a southeast 20° dipping fault coincident with a four-foot thick gouge zone that separates the Moraga and Orinda Formations (Clements, 1963). Lastly, Clements (1963) maps an east-west striking normal fault displacing Moraga volcanics in the quarry northwest of Building 76. All of these faults are considered inactive and do not fall within a State designated Earthquake Fault Zone (Figure 1).

5.0 ORIGIN OF MORAGA FORMATION IN OLD TOWN

As many as three viable models have been proposed to explain the juxtaposition of various discontinuous Moraga volcanic bodies in the region of Old Town and LHS: (1) paleolandsliding; (2) faulting; and (3) deposition on pre-existing topography and subsequent erosion.

5.1 Paleolandsliding

The Moraga-Orinda contact is defined as an undulatory surface across much of the Old Town area (Parsons, 2000). The Moraga Formation is interpreted as filling former depressions or topographic lows millions of years ago (Figure 3). Present-day morphology indicates many of these former topographic lows currently are expressed as topographic highs, or resistant bedrock ridges comprised of volcanic material, and forming inverted topography. The volcanics are up to 100 ft thick and form a northwest-trending volcanic mass of variable thickness across the Old Town area (Figure 3). Since this massive volcanic block appears to rest structurally below the inferred primary geologic contact between the Moraga and Orinda Formations to the north, previous researchers and consultants have interpreted this northwest-trending block of volcanic material to be displaced by ancient landsliding (HLA, 1983 [near Building 52]; HLA, 1988 [Building 58A]; Parsons, 2000).

The inferred HLA (1983) paleolandslide beneath Building 52 coincides with a thick accumulation of colluvium that buries the inferred headwall of the bedrock paleolandslide (e.g., material shown primarily as Qc in Plate 1). The paleolandslide model of Parsons (2000) infers the contact between the Moraga Formation and underlying Orinda Formation to be an ancient slip surface based on shear planes interpreted from regional boreholes and dissimilar bedding attitudes noted between the underlying Orinda Formation and the overlying "displaced" Moraga volcanic blocks (Parsons, 2000). The paleolandslides are interpreted to have originated after the time of deposition (8 to 10 Ma) or after the tectonic uplift of the Berkeley Hills (5 Ma) (Parsons, 2000).

Cross section B-B′ (Figure 8) intersects one of the hypothetical landslide blocks of Parsons (2000; Figure 3) and provides a schematic representation of the overall geologic conditions at the Building 25 site. This section shows that the Orinda Formation and Moraga Formation are in fault contact to the north along a steeply dipping structure, and that further south the Moraga Formation overlies Orinda Formation along a shallow dipping contact. It also shows the Building 25 site is underlain by a large, lobate mass of volcanic rock (Moraga Formation).

The north end of cross section B-B′ (Station 0 to 220 ft) traverses part of a 50-ft-thick landslide with basal clay gouge that has translated volcanic rock of the Moraga

Formation downslope onto Orinda Formation sandstone and siltstone. The displacement vector for this slide is roughly normal to the cross section alignment.

At Station 400 ft a steeply northeast-dipping (55 to 65 deg) fault intersects the ground surface and places Orinda Formation over and against Moraga Formation in an apparent thrust relationship. The steep dip of this fault was observed in a cut exposure by Clements (1963) during excavation for the Lawrence Hall of Science and is further constrained by documentation of Orinda Formation at the bottom of boring 484 at about 995 ft elevation (Evans, 1963). Multiple clay gouge intervals in boring 484 suggest hanging wall deformation within the Orinda Formation.

Borings 485, 490, 495, 498, 499, and 500 all encountered Moraga Formation volcanic bedrock across the Lawrence Hall spur ridge (Evans, 1963). Map relationships shown on Plate 1 indicate that the Moraga Formation here is roughly 200- to 250-ft-thick and that the basal Moraga Formation contact traverses northwest along the spur ridge at roughly the same elevations as McMillan Road. A roughly 40-ft-thick package of sedimentary rock bracketed above and below by Moraga Formation andesite was mapped along the south face of the Lawrence Hall spur ridge by Clements (1963) and encountered in Borings 498, 495, and 500 (Evans, 1963). Bedding attitudes demonstrated by these strata define a broad, north-plunging synform that projects toward the Building 25 site (Plate 1).

Subsurface data indicate that the Building 25 site is underlain by a lobe of Moraga Formation (volcanic and volcaniclastic rock) up to 70-ft-thick that overlies Orinda Formation siltstone along a concave, roughly south-dipping contact (Figure 8). Absence of Moraga Formation bedrock in borings 429 and 447 demonstrates that the Orinda Formation-Moraga Formation contact below the Building 25 site is not laterally continuous with the Orinda-Moraga contact exposed along McMillan Road. There is little evidence for a vertical structural separation between these two contacts (e.g., east-west oriented faulting or folding). A 4-ft-thick northeast-striking and 20-degree southeast-dipping gouge zone was observed along the Orinda Formation-Moraga Formation contact north of the site by Clements (1963), but the continuation of this feature toward cross section B-B′ is unclear. The feature was not observed in adjacent borings. It also is inconsistent with the north-dipping contact predicted by the north-plunging synform mapped to the northwest along McMillan Road.

Two borings at the Building 25 site (421 and 434) encountered fine-grained tuffaceous sedimentary rock bracketed above and below by volcanic rock. We infer that this package of sedimentary rock may be similar (or equivalent) to the interval mapped by Clements (1963) upslope of the site. In the paleolandslide model, the similarity of these deposits implies that the volcanic rock below the Building 25 site may be derived from upslope during a past sliding event, or is unrelated and represents the Orinda Formation, or separate intra-Moraga sedimentary deposit.

Lastly, our previous exploration of the Building 25 site included drilling three boreholes (429 to 431) along an approximately north-south transect (Plate 1) through the length of

the Parsons (2000) landslide (AKA, 2009a; Figures 10 to 12). Only boring 430 (AKA-2) encountered the Moraga-Orinda contact. The contact was encountered at approximately 91 feet and consisted of soft to medium hard reddish brown 3 to 6 in-thick clay inclined 10 to 15 degrees (Figure 10). Directly overlying the clay shear is fractured and brecciated andesite to tuff (Moraga Formation) and directly below the shear are subhorizontal laminations of clay and siltstone (Orinda Formation) mixed with Moraga volcanic clasts. Borehole 429 (AKA-1) located in the northern parking lot of Building 25 encountered primarily colluvium with weak zones at about 14.5 ft and 21 ft in depth; and Orinda-like deposits between 22 and 25 ft with a clay rich zone at 26 ft associated with slickensides and polished bedrock surfaces. Borehole 431 (AKA-3) is located south of Building 85 and east of Building 48 near the small parking lot north of Lawrence Road. The borehole is located directly south of a steep bedrock ridge of volcanics, however the borehole encountered Orinda Formation siltstone and conglomerate. Anomalous shear zones associated with clay seams (some soft and moist) were noted at various depths and inferred to be possible landslide slip surfaces (22 ft; 41 ft; and 48 ft) (Figure 12). These borings, coupled with the borehole compilation provide information on the depth and approximate geometry of the Moraga block located beneath Building 25. The lobate shape of the volcanic block defined by the borehole data, coupled with the presence of anomalous shears some which occur at the Moraga-Orinda Formational contact, led AKA (2009a) to agree with previous postulations that a large bedrock paleolandslide could potentially exist beneath Building 25.

5.2 Faulting

The tectonic fault model of Graymer (2000) interprets the structural discontinuity between the Moraga blocks southwest and northeast of McMillan Road to be the result of vertical displacement from faulting. The down-dip projection of the fault would presumably merge at depth with the east-dipping inactive Chicken Creek fault located west of the site. Although previous researchers associated with LBNL have interpreted nearly east-west trending faults across the campus, none show a fault located beneath McMillan Road.

5.3 Depositional

Early geologic mapping by Lawson and Palache (1901) of the Berkeley Hills, prior to significant anthropological development and hillside reforestation, does not show a fault (landslide or tectonic) displacing the isolated volcanic blocks of the Old Town area from those beneath the Lawrence Hall of Science. Based on the absence of a fault on the map, it is inferred that Lawson and Palache (1901) interpret the volcanic material as deposited within pre-existing depressions developed on a highly irregular alluvial landscape.

6.0 RESULTS OF SUBSURFACE INVESTIGATION

The results of the investigation consist of geologic description and interpretation of three excavations (T-1, T-2 and TP-1) intersecting the margin of the hypothesized paleolandslide, and mapping of nearby surface and road cut exposures of the Moraga-Orinda contact. Excavation descriptions include the geologic units and their stratigraphic relationships, soil profiles, and documentation of faults, shears, and discontinuities observed. We then interpret the geologic data in light of the paleolandslide hypothesis of Parsons (2000). Collectively, the geologic data provide direct evidence for the presence of undisplaced Quaternary colluvium and paleosol horizons overlying bedrock shears and the Moraga-Orinda formational contact.

The geologic materials encountered in the subsurface investigation are divided into five geologic units: (1) Orinda Formation (2) an unnamed Tertiary sedimentary unit possibly contemporaneous with the Moraga Formation, (3) Moraga Formation, (4) Late Pleistocene to Holocene colluvium, and (5) artificial fill. These units are further divided into numbered subunits (e.g. units 10, 11, 12 etc.; see Plates 2 to 4).

Graphic logs of trenches WLA T-1 to T-2 are provided in Plates 2 and 3, and the log of test-pit TP-1 is presented in Plate 4. Detailed descriptions of geologic materials and soil characteristics observed in trenches are provided on the trench logs, as well as the soil profile descriptions in Appendix A. Discussion of the age of these units is in Section 6.3.

6.1 Exploratory Trench WLA T-1

Trench T-1 was excavated on a gentle to moderately inclined, south sloping hillside southeast of Building 25 (Plate 1, Photographs 1 and 2). Trench T-1 exposed four primary units, which from oldest to youngest include the (1) Miocene Moraga Formation (Tm); (2) an inter-Moraga Formation deposit of sedimentary origin (Tms); Late Pleistocene to Holocene colluvium (Hc), and artificial fill (Fill).

6.1.1 Stratigraphic Relations in Trench T-1

In general, the trench encountered a massive fine-grained colluvium overlying a very dense, reddish brown to gray, coarse-to fine-grained Tertiary alluvium, and andesite of the Moraga Formation. All of these deposits are overlain by about three feet of artificial fill emplaced when the area was first developed in the 1940's to 1950's. The trench exposes bedrock faults displacing Tertiary fluvial sediments and volcanic rocks. A thick, well-developed soil with clay films and calcium carbonate nodules mantles the Tertiary bedrock units and is undeformed across the zones of bedrock shearing. The soil is well developed throughout the trench, and extends well into the weathered bedrock.

Andesite and andesitic agglomerate of the Moraga Formation are exposed in the western end of trench T-1 between stations 38 and 52 (Plate 2). The andesite consists of medium

to large angular blocks bounded by intersecting planar fractures. Strong iron oxide and manganese staining coats the fracture faces. The fractures are open to tight, randomly oriented and do not exhibit kinematic indicators.

Directly overlying the Moraga Formation along an undulatory to wavy abrupt contact is a reddish-orange brown sedimentary conglomerate with sand and clay matrix that is interbedded with siltstone to claystone (Photographs 3 and 4). The sedimentary deposits are weakly to moderately consolidated, highly oxidized and contain calcium carbonate filaments and nodules. The coarse-grained sediments are poorly to moderately bedded with crude cross-beds and fining upward sequences, and contain clasts of Orinda, Moraga and Franciscan origin. The siltstone is massive, highly fractured near its base with tight, closely spaced fractures with a trace of rounded pebbles.

Two massive colluvial units consisting of very dark gray clay overlie the Tertiary deposits. The lowermost colluvium (unit 60) contains a trace of Moraga-derived clasts randomly dispersed throughout the unit with a minor concentration in the eastern part of the trench. The colluvial contacts are wavy and gradational, and have been overprinted by pedogenesis. The upper clay-rich colluvial unit (unit 70) is massive, slightly mottled, and is characterized by vertical pedogenic fractures. Calcium carbonate nodules and fine filaments are present in the lower part of the colluvium. An approximately three foot thick layer of artificial fill overlies the colluvium.

A well-developed soil profile is developed in the colluvium and into the underlying siltstone bedrock (Photograph 5). The upper part of soil is a dark gray A-horizon formed from the decomposition and incorporation of organic material in colluvium derived from the Tertiary bedrock. The traces of gravel found in the soil, especially the A horizon, are assumed to be derived partly from the coarser interbeds within the silt, and partly from colluvium derived from basalt and andesite upslope. The A-horizon grades downward into a reddish brown Bt-horizon, the upper portion of which contains prominent whitish nodules of carbonate (Photograph 5, near the white flag). The Bt horizon is developed in the bedrock and its red color is inherited from the reddish siltstone.

The soil profile encountered in trench T-1 formed from long-term weathering and pedogenic processes acting on the weakly indurated siltstone as it underlay the hillside. Horizon boundaries are sub-parallel to the ground surface, dissimilar to the orientation of the fault plane or to the bedding in the coarser grained Tertiary alluvial units displaced by the fault. Thus, the soil has formed in association with the present hillside.

6.1.2 Structural Relations in Trench T-1

A prominent shear zone occurs at the boundary between the Moraga Formation and an overlying Tertiary sedimentary unit (Tms) in the western end of the trench (Photograph 6). This bedrock fault zone predominantly dips east, however, moving west along the trench wall, it becomes highly undulatory and less well organized as a subhorizontal clay seam (Photographs 7 and 8). The primary fault zone is three to four feet wide, composed

of completely altered andesite bedrock, anastomozing shear fabric, crushed and brecciated rock, and multiple subparallel east-dipping shears between stations 36 and 40 ft that strike northwest between 290°and 314° and dip 30° to 50° NE. The shears are less than 0.5 cm wide and are coated with calcium carbonate deposits and a light-gray to whitish clay-rich material. The thinning of the Tertiary sedimentary units and appearance of Moraga Formation volcanics suggests an apparent west-side-up vertical separation. West of station 40 ft. the shear zone thins dramatically to a grayish white several inch thick shear of calcium carbonate-lined stiff clay with highly variable dip directions of 33°, 21° NW, 321°, 8°N, and 267°, 30°N. Measurements of the fault orientations were made by either by cleaning a clay-rich surface, or projecting the fault zone across the trench. No kinematic indicators were observed.

The western fault zone of trench T-1 does not offset or deform the overlying colluvium or well-developed pedogenic horizons. A prominent soil horizon with pedogenic nodules of calcium carbonate (Btk on soil descriptions, unit 45 on Plate 2), projects nearly straight across the fault zone indicating the fault has not displaced this horizon and thus pre-dates its formation. The age of this horizon is at least late Pleistocene (≥ 10,000 yrs) to early Holocene (10,000 to 8,000 years), and thus demonstrates inactivity.

In the central part of trench T-1, at station 26 ft, a secondary west-dipping fault is located in the hanging wall of the primary western fault zone. The west-dipping fault appears to exhibit west-side down vertical separation as noted by the tilted and folded lower Tertiary sedimentary units and thinning of an overlying siltstone across the zone of faulting. The fault zone is composed of thin fractures and fine pulverized sedimentary laminations. The fault becomes highly weathered and obscured upsection but does not offset the overlying well-developed calcic soil horizons or Holocene colluvium, and thus is inactive.

6.2 Test Pit T-1

Test Pit TP-1 was excavated prior to the excavation of Trench T-2 for the primary purpose of assessing whether the Orinda-Moraga contact lay upslope or downslope. The test pit was 16 feet long and up to 13 ft deep, and located on the slope southeast of Building 25. The trench pit was backfilled up to about 6 ft bgs prior to entry because of the loose and weathered bedrock condition encountered.

Test Pit T-1 exposed Moraga volcanic rock beneath colluvium derived from volcanic rock, thus the contact with the Orinda Formation was determined to be in the downslope direction. Based on this information, trench T-2 was excavated beginning near the downslope end of the test pit. Colluvial and bedrock units in test pit TP-1 (Plate 4) are logged as extensions of the units in trench T-2 (Plate 3).

6.3 Exploratory Trench T-2

Trench T-2 was excavated on a moderate slope (about 15 degrees) on the southeast side of Building 25 approximately 15 ft west of Glaser Road (Plate 1, Photograph 9). The

slope is semi-natural with the upper part modified by fill placed during construction of Building 25. The slope is covered with dry grass and a cluster of large Monterey pines. Similar to trench T-1, trench T-2 exposes Tertiary fluvial and volcanic bedrock overlain by colluvium. The trench is oriented N76°E and intersects the previously mapped boundary between the Moraga and Orinda Formations, at the eastern margin of the hypothesized paleolandslide. The maximum depth of trench T-2 is approximately 10 ft and a length of about 65 feet. A small extension of the trench, offset to the north 3 feet, was excavated at the east end to avoid a large buried pine tree stump. Groundwater was not encountered in any excavation. No fill was present except at the far eastern end.

6.3.1 Stratigraphic Relations of Trench T-2

Trench T-2 exposes Tertiary Orinda Formation sedimentary deposits (Tor) and Moraga Formation volcanics (Tm) along a west-dipping geologic contact (Plate 3). Both Tertiary units are overlain by Holocene colluvium derived from Orinda and Moraga materials. The Orinda Formation consists of poorly bedded fluvial conglomerate (Unit 11) interfingering with massive siltstone (unit 10) and is exposed in the eastern and central part of the trench. At station 30 ft, near the western end of the trench, the Orinda Formation is in an abrupt contact with the overlying Moraga Formation (Photographs 10 to 12). Bedding in the Orinda Formation, as well as the overlying contact with the Moraga Formation, dip gently (up to 20°) to the west. The siltstone is massive, moderately weathered and very weak. Occasional lenses of fine gravel occur within the siltstone indicating a temporary shift in depositional environment or an increase in fluvial energy. The conglomerate beds are generally thin and interfinger with the more massive siltstone. The conglomerates have slightly more rock strength than the siltstone, but have similar moderate weathering. Clasts are subangular to subrounded, up to 2 inches in diameter.

The Moraga Formation volcanics exposed in the western portion of trench T-2 were deposited sequentially as layers of a volcanic eruption sequence (ashflows and lappilli tuff to andesite). The lapilli tuff unit (lower portion of unit 20) is a pyroclastic deposit of pea-sized ignimbrite fragments of ash and rock in a finer tuff matrix. As observed, the unit is moderately well consolidated and appears intact as deposited. Overlying the lapilli tuff is the upper portion of unit 20 containing subangular andesitic blocks intermixed within stiff ash matrix and lapilli grains. The contact between the two volcanic units is diffuse over 1 to 2 inches. Multiple units of blocky andesitic flows (unit 21) overlie the pyroclastic sequence. The blocky andesite contains clay films developed on the fracture surfaces indicating some in-situ weathering has occurred.

The basal contact of the Moraga Formation is sharp, wavy and undulatory with the overlying lapilli tuff filling lows within the Orinda Formation. There are no shears or fractures within the lapilli tuff or in the vicinity of the contact (Photographs 11 and 12). The basal contact of the Moraga Formation is marked by a very thin (0.8-1.3 cm) seam or lamination of moderately plastic clay that is continuous and present on both trench walls. This clay is interpreted to represent a thin volcanic ash that has been altered to clay after

interacting with groundwater. No straie, moullins, or brecciated zones occur along the contact. The minimal thickness of the clay and the lack of observed kinematic indicators and deformation, argue against this lamination being associated with landslide movement.

Two primary colluvial units mantle the Moraga and Orinda bedrock. Unit 30 is a colluvium derived primarily from the Moraga andesite/ignimbrite flows of unit 20 in the western portion of the trench. The clasts are highly weathered (smaller clasts can be cut with a knife) and all clasts are coated with distinct clay films. Because this degree of weathering is similar to the in-place exposure, it is likely that these features are for the most part inherited from the in-place weathering of the ignimbrite. The upper portion of this unit may still be in active transport.

A younger colluvial unit (units 31 and 32) extends the length of the trench mantling all lower units, and hosts a fairly thick organic-rich A-horizon. The colluvium is a silt with 10% to 50% gravel The presence of this moderately thick soil horizon indicates the hillslope is not eroding rapidly and instead is relatively stable.. Similar to the soils in trench T-1, the T-2 soils have been relatively stable throughout the Holocene with the slow rates of erosion keeping pace with the rates of weathering and pedogenesis.

6.3.2 Structural Relations of Trench T-2

The trench T-2 investigation encountered no positive evidence of a landslide margin at the Moraga-Orinda bedrock contact. The bedrock strata exposed in trench T-2 show a clear volcanic eruption sequence overlying Orinda Formation siltstone formed on Tertiary floodplains and alluvial fans. This unique time sequence of deposits is not deformed, mixed, or brecciated, suggesting an absence of landslide processes in the area of the trench exposure. Furthermore, any movement at this contact would have disrupted the fragile lapili tuff unit (lower part of unit 20) lying at the base of the Moraga Formation, or the overlying colluvial deposits. As mentioned above, a thin clay lamination was observed at this bedrock contact, but the minimal thickness and lack of observed kinematic indicators argue against this unit being associated with landslide movement.

Trench T-2 encountered a Tertiary-age bedrock fault that offsets Orinda Formation siltstone and conglomerate members, as well as an isolated Moraga volcanic block (Plate 3). The fault zone is very diffuse and poorly developed, and has been obscured by pedogenic and weathering processes-all of which suggest significant antiquity. Projected upsection, the fault zone does not offset older colluvium (unit 12) or the sequence of younger overlying Holocene colluvial units (units 30, 31, and 32). Exposure of the fault on both the north and south walls is very weak with no observed kinematic indicators. The bedrock fault trends N19°E, with a measured dip of 76°SE, based on exposures on both trench walls and across the trench floor. Apparent near-vertical displacement down-to-the-east is interpreted from the juxtaposition of various Tertiary siltstone and conglomerate units, as well as the Moraga Formation. The conglomerate beds west of the

fault zone exhibit substantial drag folding that are indicative of vertical displacement down-on-the-east. An apparent change in dip direction across the fault further supports this sense of displacement. It is unclear if the block of Moraga Formation (unit 22) is correlative with volcanic material to the west (units 20 and 21) because of several stratigraphic inconsistencies, however, if they are assumed to be correlative, the Moraga-Orinda bedrock contact is displaced about 7 to 9 feet in a dip-slip sense of displacement.

The age of faulting is considered to be pre-Holocene due to the highly weathered and diffuse nature of the zone, lack of distinct shear planes, and upward termination of the fault zone in deeply weathered colluvial deposits derived from the Orinda Formation (unit 12). This Orinda-derived colluvium (unit 12) contains no clasts of Moraga Formation that dominate the younger colluvium, and was probably emplaced shortly after cessation of faulting. The fault is likely a sympathetic structure related to the regional uplift of the Berkeley Hills during the late Tertiary.

6.4 Estimated Ages of Deposits

A key means of assessing fault activity is to estimate the ages of deposits that overlie a fault trace. Age estimates can be made by: (1) direct dating of materials sampled from within the deposit (e.g. radiocarbon dating of charcoal); (2) dating of deposits based on fossil assemblages; (3) correlating deposits with deposits of known age in the site vicinity based on lithologic characteristics and geomorphology; or (4) evaluating the degree of soil profile development in the deposits. We use detailed soil profiles and models of depositional processes and paleo-landscapes to evaluate the ages of colluvium and pedogenic soil horizons in trenches T-1 and T-2 because detrital charcoal and fossils were not found.

The trenches are excavated on hillslopes where slow weathering, soil profile development, and erosion are the dominant geomorphic processes. As the Tertiary bedrock is weathered, it is loosened by bioturbation, and transported downslope as colluvium. The colluvium forms a mantle over the weathered bedrock, and itself undergoes continued weathering and pedogenesis along with the underlying bedrock, even as it slowly creeps down the hillslope. Soil profiles, a vertical sequence of horizons that reflect soil processes such as addition of organic material from plants, translocation and accumulation of clay and other weathering products in the subsoil, are indicators of relative landscape stability. When little erosion or deposition is taking place, the soil horizons become more well-developed. The degree of maturity of the soil profile can be an indication of the degree of landscape stability.

Trench T-1 exposes a mature soil profile developed on weathered Tertiary bedrock overlain by somewhat less mature upper horizons developed in the colluvial mantle. The soil profile is parallel to the ground surface, thus its features are presumed to be associated with weathering of the present hillslope. The older soil includes a horizon with carbonate nodules that accumulated during a drier climate consistent with the late Pleistocene interglacial (e.g. 100,000 to about 10,000 years ago). The carbonate nodules are now degraded and coated with clay films and reside within the argillic horizon of the

soil. Based on geomorphology and soil characteristics in trench WLA T-1, the pedogenic carbonate horizons that are developed in the Tertiary siltstone are interpreted to be late Pleistocene in age. The moderately-thick hillside soil profile present in trench T-2 formed from long-term weathering and pedogenic processes acting on the weakly indurated Tertiary siltstone. The soil horizon boundaries noted in Plate 2 are sub-parallel to the ground surface, dissimilar to the orientation of the fault plane or to the bedding in the coarser grained Tertiary alluvial units displaced by the fault. Thus, the soil and associated horizons formed in association with the present hillside. The present-day geomorphic setting, coupled with the thick soil, clay and carbonate accumulation argues for some antiquity to the soil profile and colluvial deposits. The hillside is interpreted to have attained its present shape by late Pleistocene and to have been relatively stable throughout the Holocene, the rates of weathering and pedogenesis keeping pace with a slow rate of hillslope erosion.

Trench T-2 likewise exposes a mature soil profile developed on a combination of weathered Tertiary bedrock and colluvium derived from Tertiary bedrock units upslope. Tertiary sediments, volcaniclastics, and volcanic rocks are gradually being weathered and transported downslope as colluvium. The presence of clay films and highly weathered clasts in the colluvium of trench T-2 are not good indicators of age for these deposits because they are derived from weathering of the original bedrock. The weathering of the small clasts in the colluvium, however, may reflect weathering within the colluvium as they are too fragile to have survived transport in their present state. The presence of the A-horizon is moderately well developed and thick considering the hillslope environment. Similar to the soils in trench T-1, the trench T-2 soils have developed through the late Pleistocene and have been relatively stable throughout the Holocene with the slow rates of erosion keeping pace with the rates of weathering and pedogenesis. Therefore, the fault located in the eastern end of the trench is not Holocene active. In addition, the geologic contact between the Moraga and Orinda Formations also has not been the focus of differential displacement as noted by the undisplaced overlying colluvial units.

7.0 DISCUSSION

WLA excavated two trenches near and across the eastern and western margins of the hypothetical paleolandslide projected beneath Building 25. The trenches exposed sheared Tertiary sedimentary and volcanic material along northwest-striking and northeast-striking faults, as well as undeformed depositional bedrock contacts striking approximately N30W. All of these bedrock contacts are overlain by unfaulted colluvium ranging in age from late Pleistocene to Holocene indicating the features have not been active in thousands, and some likely in millions of years.

The data collected to date are insufficient to definitively determine the placement of the lobate-shaped Moraga Formation block beneath the Building 25 site. The origin of the block of Moraga Formation is equivocal. The data analyzed both support and contradict the presence of a large ancient landslide at the site. The trenches either intersect the previously mapped landslide margins or cross key bedrock contacts hypothesized by Parsons (2000), and also likely lie close to any previously unknown main margin(s). However, regardless of the origin and placement of the volcanics, information obtained from the shears encountered in the trenches provides direct evidence for the absence of deformation for thousands of years, as well as millions of years for some of the bedrock shears. Furthermore, one of the trenches demonstrates that the geologic contact between the Moraga and Orinda Formations is depositional and lacks bedrock shearing in contrast to that postulated by Parsons (2000). Whether any of the structures encountered in the trenches represent the main paleolandslide margin(s), the features likely are in close proximity to the margin. For instance, based on the dip directions being preferentially aligned, the shears should have undergone triggered slip during displacement of the hypothesized paleolandslide during one or more large events on the Hayward fault during the Holocene Epoch. As noted previously the shearing does not offset paleosol horizons or overlying colluvium. Collectively, this study indicates that the Moraga Formation block previously characterized as a paleolandslide has been stable for many thousands of years and has undergone tens of large magnitude earthquakes on the Hayward fault without notable displacement.

Although there remain other viable explanations for the origin of the Moraga Formation blocks in the Old Town area, such as ancient tectonic faulting and volcanic deposition on a highly undulatory paleotopography, these other models suffer from a paucity of data. The tectonic fault model of Graymer (2000) hypothesizes that the structural discontinuity is a result of a northwest-striking fault beneath McMillan Road. The geologic cross section B-B' prepared to evaluate the paleolandslide model partly supports a south-dipping fault; however, other than the observation that the Moraga Formation appears displaced across McMillan Road, no geologic evidence was discovered from a review of previous consultant reports to support this fault model. Furthermore, this model does not explain the Moraga/Orinda Formation undulations to the southwest of McMillan Road that have amplitudes on the order of 100 feet.

Under the depositional model, the highly undulatory boundary between the Moraga and Orinda Formations that has been previously delineated from borehole data would reflect paleotopography and not landsliding. This pre-eruptive landscape (many millions of years ago) would have had to consist of narrow and deep ravines and valleys that became subsequently buried by ten(s) to hundred(s) of feet of volcanic debris. Similar, to the faulting hypothesis there is no overwhelming geologic data to support this model. Proving this hypothesis would require a systematic evaluation of the Moraga-Orinda geologic contact across the Old Town area, such as (1) documenting the existence of coarse-grained fluvial deposits (i.e., buried channels) or buried paleosols directly beneath the formational contact to demonstrate the lavas were filling an irregular ground surface, and (2) the absence of shearing across the contact. It is interesting to note that trench T-2 identified a clear depositional contact between the Moraga and Orinda Formations, whereas boring 430 (AKA-2) encountered a strong reddish brown (baked zone?), clay rich feature at the contact that is consistent with shearing. It may be that none of the three models by themselves explains the structural anomaly of the Moraga volcanics, and it can best be reconciled as a combination of two or more processes.

7.1 Paleolandslide Model

The paleolandslide model of Parsons (2000) considers a large block of Moraga volcanics breaking free from the steep ridge north of the site and translating downslope to its current position. The vertical and lateral displacement is on the order of several hundred feet or greater. Interpretation of geologic cross-section B-B' indicates it is permissible to retrodeform the lobate volcanic mass and tuffaceous siltstone beneath Building 25 with the steep ridge of "intact" Moraga Formation north of the site (Figure 8). The geologic cross section supports the paleolandslide hypothesis. However, we note that there is no geomorphic expression of an east-or west-trending arcuate headscarp traversing the bedrock ridge. The absence of the headscarp either suggests the landslide does not exist or the previous topography associated with landsliding has been removed by erosion and weathering. Considering the absence of such features, coupled with the rounded and subdued ridge of Building 25, if a paleolandslide does exist, it is geologically stable.

Exposures in trenches T-1 and T-2 provide further support for the presence of a stable landscape over much of the Holocene. The stratigraphic and structural relations exposed in trench T-1 indicate that Holocene colluvial deposits and late Pleistocene pedogenic horizons overlying the bedrock shears provide evidence for long-term stability and the absence of recent deformation along the hypothesized western margin. We acknowledge that the margin could project between the west end of trench T-1 and borehole 476 and thus would be consistent with the paleolandslide model of Figure 3 (e.g., Moraga Formation overlying Orinda Formation along an east-dipping contact). However, even if the main landslide margin lies directly west of trench T-1, the prominent bedrock shearing and folding documented in trench T-1 would likely undergo sympathetic secondary displacement and/or rotation during large-scale translation. As noted previously, the colluvium and well developed soil profiles are undeformed across the shear zones. Lastly, a more westerly located shear plane invokes a very narrow and discontinuous Moraga block as the controlling landslide margin.

Trench T-2 located across the eastern margin of the hypothetical paleolandslide provides direct evidence for the absence of shearing along the inferred slide plane between the Moraga and Orinda Formations. The trench exposed a west-dipping geologic contact strongly suggestive of an eruptive sequence (air fall tuff followed by andesitic flows) deposited on the Orinda Formation. The geologic contact lacks the shearing and internal deformation expected along a landslide margin translated hundreds of feet from its origin. Lastly, the overlying Holocene colluvial deposits do not show evidence of repeated deformation across this contact.

Deciphering the structural geology in the Old Town area is very complicated due to a number of factors: (1) the absence of numerous bedrock exposures; (2) limited bedding information for the Orinda and Moraga Formations; (3) significant anthropogenic landscape alterations, and (4) interbedded fluvial deposits within the Moraga Formation closely resemble Orinda Formation deposits possibly leading to incorrect bedrock classifications by others. Individual borehole observations (some at five foot sampling intervals or greater) interpreted from pervious investigations provide only a limited perspective of the subsurface conditions. Trenches excavated for this study clearly demonstrate the complexity in the bedrock shears and stratigraphy across a short lateral distance. Despite the difficult geologic conditions and scarcity of high-quality data from Old Town, we believe the subsurface investigation and geomorphic evaluation of evidence supporting recent landslide movement, indicate that if a paleolandslide exists beneath the site it is geologically stable under present-day conditions.

8.0 CONCLUSIONS

Based on the findings of this study, we conclude that the Building 25 site is suitable for redevelopment assuming the recommendations provide below are considered. The paleolandslide investigation conducted for this study provides evidence that indicates if a paleolandslide exists beneath the site it is geologically stable as previously mapped. The initial engineering geologic characterization of the paleolandslide and assumed strength and geometrical boundary conditions that suggested frequent large translations from major earthquakes on the Hayward fault were based on geologic assumptions (e.g. overall paleolandslide geometry and residual shear strengths) that are no longer considered valid. The trench and geomorphic data provide evidence for long-term (thousands of years) stability of the bedrock ridge.

The following recommendations are based on this investigation:

- Prior to final design of new major structures, site-specific geotechnical and/or geologic investigations should be performed to assess the soil and bedrock conditions, minor slope instabilities, site grading and loading, strong ground shaking, and surface fault rupture potential.
- Avoid future development in the area of Buildings 40 and 41 (southwest of Building 25) without characterization of the upslope limits of historical landsliding.
- The trenches were not backfilled to engineering design specifications. Any proposed buildings or structures that intersect the trenches should include removal and re-compaction of the trench backfill.

9.0 REFERENCES

Bakun, W.H., 1999, "Seismic Activity of San Francisco Bay region" Bulletin of the Seismological Society of America (June 1999), 89(3), p 764-784.

California Division of Mines and Geology (CDMG), 1974, Official map of Special Studies Zones, Richmond Quadrangle.

California Division of Mines and Geology (CDMG), 1982, Special Studies Zone Map, Oakland West Quadrangle.

California Division of Mines and Geology (CDMG), 1997, Special Publication 117, "Guidelines for Evaluating and Mitigating Seismic Hazards in California".

Curtis, G.H., 1989, Berkeley Hills, in Wahrhaftig, C., and Sloan, D., eds., Geology of San Francisco and vicinity, Field Trip Guide Book T105, 28th International Geological Congress, American Geophysical Union, Washington D.C. p. 47-52.

Graymer, R.W., 2000, Geologic map and map database of the Oakland metropolitan area, Alameda, Contra Costa, and San Francisco Counties, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-2342.

Graymer, R.W., Jones, D.L., and Brabb, E.E., 1996, Preliminary geologic map emphasizing bedrock formations Alameda County, California: a digital database: U.S. Geological Survey Open-File Report 96-252.

Jones, David L. and Curtis, Garniss, 1992, "Guide to the Geology of the Berkeley Hills, Central Ranges, California," in "Geologic Excursions in Northern California: San Francisco to the Sierra Nevada," California Division of Mines and Geology, Special Publication 109.

Lawson, Andrew, C. 1900, "Geologic Map of a Portion of the Berkeley Hills," Scale 1:12,000.

Lawson, A.C., and Palache, C., 1900, The Berkeley Hills: A detail of Coast Range geology, Bulletin of the Department of Geology, University of California, V. 2, p. 349-450.

Lienkaemper, J. and P. Williams, 2007, A record of large earthquakes on the southern Hayward fault for the past 1800 years, Bull Seis. Soc. Am. 97, 1803-1819. http://quake.wr.usgs.gov/research/geology/docs/Tyson2_BSSA07.pdf.

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.

Nilsen, T.H., 1975, "Preliminary Photo interpretation 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.

Wahrhaftig, C. and Sloan, D., 1989, Geology of the San Francisco and Vicinity, San Francisco Bay Region, California, July 1-7, 1989, Field Trip Guide Book T105, pages T105-47-54.

Working Group on California Earthquake Probabilities (WGCEP), 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.

Working Group on California Earthquake Probabilities (WGCEP), 2003, "Earthquake Probabilities in the San Francisco Bay Region: 2002 to 2031," U.S. Geological Survey, Open File Report 03-214.

9.01 Consulting Reports

Alan Kropp & Associates, 2009a, Slide Investigation Building 25 Area Project (LBNL Subcontract No 6881630), unpublished consulting memorandum with 3 pages and 3 figures; no LBNL file number.

Alan Kropp & Associates, 2009b, Geologic and Geotechnical Investigation Report, Helios Energy Research Facility, University of California, Berkeley, California (UCB Project 12313A), unpublished consulting report; no LBNL file number.

Borg, S.G., 1991, Geology of Lawrence Berkeley Laboratory, unpublished report prepared by the Earth Science Division, Lawrence Berkeley Laboratory, Berkeley, California.

Clements, T., 1963, Geology of the Site for the Lawrence Memorial Hall of Science, University of California, Berkeley, California, LBNL # 253.

Collins, L.M., 1993, Geology of the East Canyon and the proposed hazardous waste handling facility, Lawrence Berkeley Laboratory, unpublished report prepared by the Earth Science Division, Lawrence Berkeley Laboratory, Berkeley, California. LBNL File # not assigned.

Converse Consultants, 1984, "Hill Area Dewatering and Stabilization Studies," Lawrence Berkeley Laboratory, Berkeley, CA, October 1984, Project No. 82-4160.

Dames and Moore, 1962, "Engineering Geology of the Lawrence Radiation Laboratory Area, Berkeley, California," December 1962, LBNL # 277 and 171, Project No. 234-083-03.

Dunn, R.J., 1976, "Landslides and Engineering Geology of the Lawrence Berkeley Laboratory", December 7, 1976, LBNL#320.

L.T. Evans, Inc., 1963, A Site Study, University of California Lawrence Memorial Hall, Berkeley, California, November 26, 1963, LBNL # 251.

Geomatrix Consultants, 1994, "Geotechnical Study for the Environmental Health and Safety Building: Strawberry Canyon Facility, Berkeley, California," April 1994, Project No. 2501, LBNL # 351.

Harding-Lawson Associates (HLA), 1964, "Report: Consultation Regarding Foundations Building 62, Lawrence Radiation Laboratory, Berkeley, California," March 1964, Project No. 2000.170.

Harding-Miller-Lawson Associates (HLA), 1967, "Report-Investigation and Consultation Landslide Near Building 76, Lawrence Berkeley Laboratory, Berkeley, California," May 22, 1967; LBNL # 168.

Harding-Lawson Associates (HLA), 1975, "Preliminary Soil Investigation – Proposed Additions Building 62, Lawrence Berkeley Laboratory, Berkeley, California," July 1975, Project No. 2000.100.01.

Harding-Lawson Associates (HLA), 1979, "Geologic Reevaluation Building 62-72 Area, Lawrence Berkeley Laboratory, Berkeley, California," February 1979, Project No. 2000.138.01.

Harding-Lawson Associates (HLA), 1982, "Geology of LBNL, Lawrence Berkeley Laboratory, Berkeley, California," August 14, 1981, Project No. 2000.135.

Harding-Lawson Associates (HLA), 1983, "Geotechnical Investigation, Building 17 and 25A Road Realignment, Lawrence Berkeley Laboratory, Berkeley, California," March 4, 1983; LBNL # 404

Harding-Lawson Associates (HLA), 1988, "Foundation Investigation Building 26 Addition, Lawrence Berkeley Laboratory, Berkeley, California," October 31, 1981; LBNL # 269.

Harding-Lawson Associates (HLA), 1988, "Final Report-Geotechnical Investigation Building 58A Roadway, Lawrence Berkeley Laboratory, Berkeley, California," May 20, 1988, LBNL #117.

Holland, P., and Wollenberg, H., 1992, "Initial Appraisal of the Geologic Controls of Groundwater Occurrence and Movement in the "Grizzly" Area of Lawrence Berkeley Laboratory, Berkeley, California," February 1992, LBL #1852.

Holland, P., 1992, "Initial Appraisal of the Geologic Controls of Groundwater Occurrence and Movement in the "Old Town" Area of Lawrence Berkeley Laboratory, Berkeley, California," February 1992, LBL #293.

Hugh M. O'Neil Company, 1966, "Report of Slope Instability Investigation for the Proposed New Craft Storage Building No. 78, Lawrence Radiation Laboratory, University of California, Berkeley, California", May 27, 1966, LBNL # 182.

Jordan, P. and Javandel, I., 2007, "Hydrogeology and Tritium Transport in Chicken Creek Canyon, Lawrence Berkeley National Laboratory, Berkeley, California," October 2007, LBL #63557.

Kleinfelder Inc., 2002, "Geotechnical Investigation, Proposed Molecular Foundry Building, Lawrence Berkeley Laboratory, Berkeley, California," January 29, 2002, Project No. 41-7702-01, LBL #382.

Kleinfelder Inc., 2003, "Summary of Geotechnical Documents, Planned Molecular Foundry Building 67, Lawrence Berkeley Laboratory, Berkeley, California," October 22, 2003, File No. 20258, LBL #398 and #402.

Kleinfelder Inc., 2004, "Summary Overview and Observation, Shoring Wall, Foundation Piers and Slope Reconstruction, Building 67, Molecular Foundry, Lawrence Berkeley Laboratory, Berkeley, California," December 6, 2003, File No. 20258, LBL #416.

Lennert & Associates, 1978, "Geotechnical Consultation, Hill Area Dewatering, Lawrence Berkeley Laboratory, Berkeley, California," December 17, 1978, Job No. 789.

Lennert & Associates, 1979, "Geologic Consultation, Hillside Access Road, Lawrence Berkeley Laboratory, Berkeley, California," December 1978 (LBNL revceieved1979), Job No. 789.

Parsons Engineering Science, Inc., 2000, "draft final RCRA Facility Investigation Report for the Lawrence Berkeley National Laboratory Environmental Restoration Program" Prepared for Lawrence Berkeley National Laboratory, dated September 29, 2000.

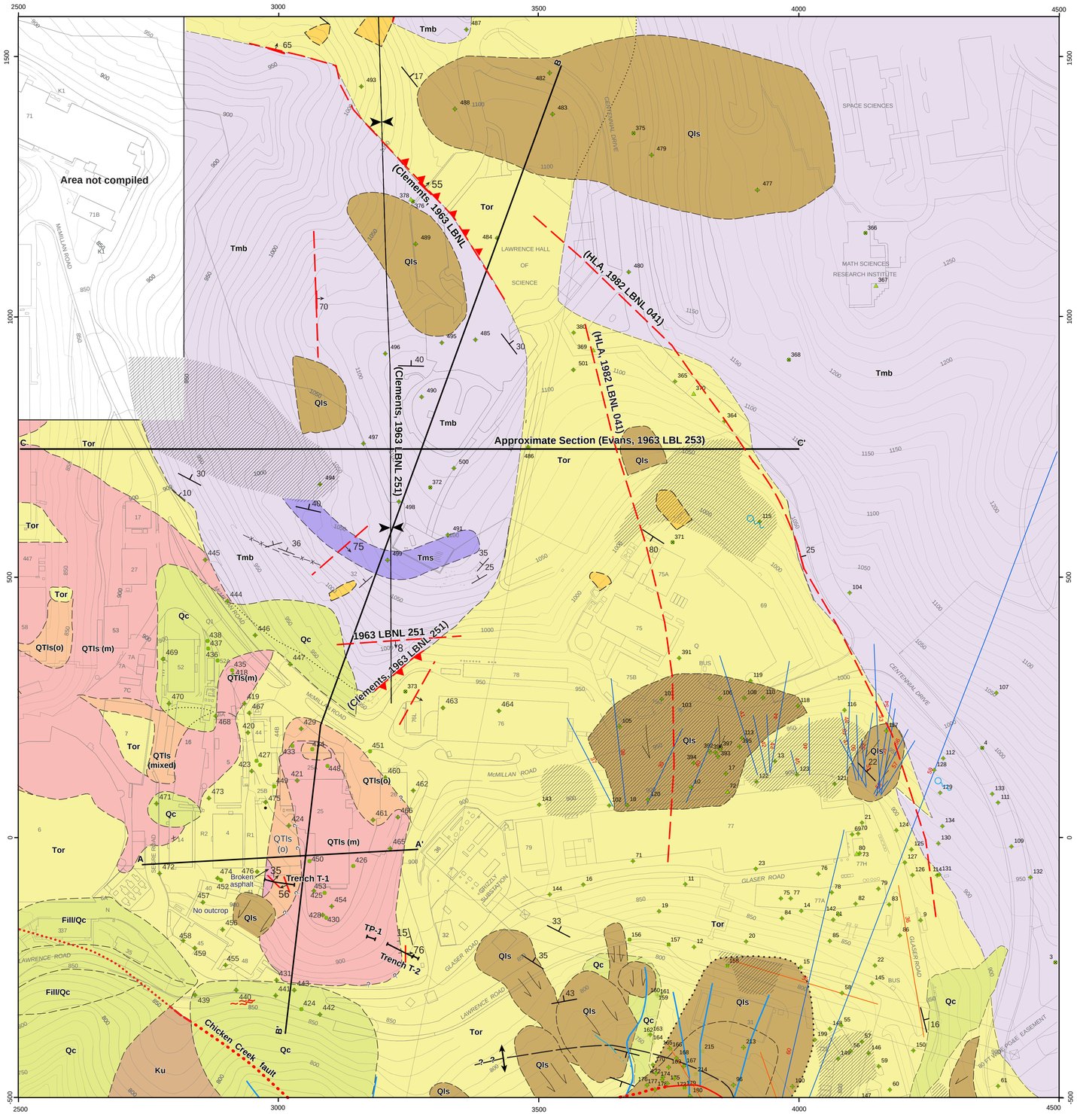
Subsurface Consultants, 1987, Consultation Building 62 Addition, Lawrence Berkeley Laboratory, Berkeley, California," November 1987, Project No. 364.002.

Subsurface Consultants, 1991, "Slope Stability Investigation Four Unstable Slopes, , Lawrence Berkeley Laboratory, Berkeley, California," December 30, 1991; LBNL # 285.

William Lettis & Associates, Inc., 2007, Surface-Fault Rupture Hazard Evaluation, Proposed Haas School Executive Education Building, University of California, Berkeley, Berkeley, California: unpublished consulting report to URS Corporation, dated November, 2007, 54 p. plus figures, plates, and appendices.

FIGURES

PLATES



Explanation

Map Symbols

- Contour, 10-foot interval (2003)
- Contact, dashed where approximate dotted where concealed
- Fault, dashed where approximate, dotted where concealed and uncertain
- 84 — Attitude bedding
- Overturned bedding
- Fault with dip angle and direction
- Syncline
- Anticline
- Buildings, roads, vegetation (2003)
- Spring (Parsons, 2000)
- Stream (LBNL, 2003)
- Road-parallel cracks
- Trench
- Active or former location of slide, which has been removed or mitigated
- Approximate extent of repaired slope/landslide
- Potentially active Quaternary landslide
- Qls — Quaternary landslide deposits with minimum (dashed) landslide extent (may or may not have been mitigated)

Geologic Units

Qc	Quaternary colluvium
QTls(m)	Hypothesized Moraga paleolandslide unit (see report)
QTls(o)	Hypothesized Orinda paleolandslide unit (see report)
Tmb	Miocene Moraga Formation (volcanics)
Tms	Miocene Moraga Formation (volcaniclastic siltstone/sandstone)
Tor	Miocene Orinda Formation (sandstone, siltstone, and conglomerate)
Ku	Cretaceous Great Valley Group (sandstone and shale)

Subsurface Data
(numbers refer to GIS database)

GIS Data Point ID	
24	Boring
294	Pier hole
72	Slope indicator boring
4	Piezometer
283	Monitoring well
164	Well boring
352	Test pit
103	Borehole-hydrograph
60	Hydroauger
34	Seismic line
22	Trench or test pit
72	Cut wall

True north
Grid north

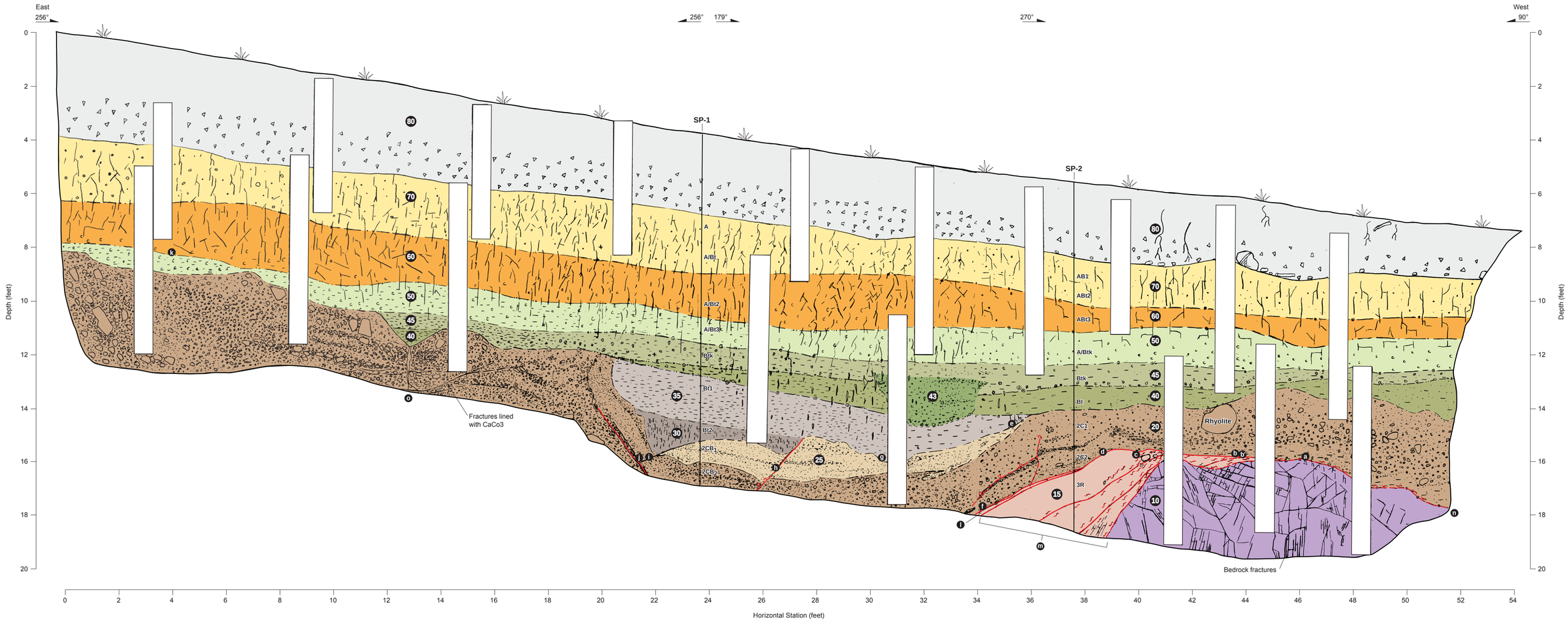
0 50 100 200 feet

Grid north is ~16° west of true north

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 limited to resolution provided in source documents. Georeferencing error maybe up to 10 feet.

Graphics, Active Projects, 2072.001, Modified:08:31:09

GEOLOGIC MAP



Explanation

Symbols

- Soil pattern
- Pedogenic fractures
- Contact, solid where certain, dashed where approximate, dotted where inferred
- Fault, dashed where approximate, queried where uncertain
- Shear fabric
- SP-1 — Soil profile (see Appendix A)
  - A
  - A/Bt
  - A/Bt2

Unit Descriptions

80 — Upper fill: SILT (ML); Very dark gray (10YR 3/1); dry; stiff; 85% silt, 10% very fine sand, 5% clay; High dry strength; high toughness; no dilatancy; low plasticity; block massive structure, abundant roots (1" to 0.5" diameter) and rootlets, common large roots (>1" diameter), basal contact planar to slightly undulatory over 2-3".
Lower fill: Sand with silt and gravel (SW); Light yellowish brown (2.5Y 6/3); dry; dense; 90-95% matrix (matrix: 80% very fine sand, 20% silt), 5-10% gravel; low dry strength; slow to no dilatancy; low toughness; non-plastic; gravel is angular 1" to 3" clasts, gravel clasts are sandstone and are parent material for matrix, rare glass along basal contact, basal contact is planar and sharp [FILL].

70 — CLAY, silty with sand (CL); Very dark gray (10YR 3/1); dry to slightly damp; stiff; 70-80% clay, 20% silt, <10% fine sand, trace coarse sand; medium dry strength; slow dilatancy; medium to high toughness; medium to high plasticity; angular block to weak columnar pedogenic structure, strong brown (.5YR 4/6) mottles coating vertical columnar pedogenic surfaces, moderate to weak clay films coating some coarse sand clasts, common fine pores, common roots and rootlets; weak to no reaction to HCl; massive, angular coarse sand consists primarily of Moraga Formation fragments; slightly wavy diffuse basal contact over ~6" [COLLUVIUM, A and A/Bt pedogenic soil horizon].

60 — CLAY, silty (CL), trace coarse sand; Very dark gray (10YR 3/1); slightly damp; medium stiff; 70-80% clay, 20-30% silty, trace to ≤ 5% coarse sand; low to medium dry strength; no dilatancy; low toughness; medium to high plasticity; angular irregular to massive pedogenic structure; moderate to weak clay films on pedogenic faces and coating coarse sand clasts, weak carbonate (CaCO3) film coating clasts, clasts are weakly effervescent, matrix (clay) does not effervesce with HCl, common roots and rootlets, few fine pores; trace sands are angular and consist of Moraga Formation, coarse sand clasts seem to be associated with areas with higher abundance of roots, lining root casts, diffuse basal contact over ~6", wavy [COLLUVIUM and mixed siltstone bedrock with A/Bt2 soil overprint].

Unit Descriptions (continued)

50 — CLAY, silty with sand (CL-ML), Dark reddish brown (5YR 3/3); dry to slightly damp; medium stiff; 60% clay, 25% silt, 15% fine- to coarse-grained sand; sand is 10% coarse, 5% fine-grained, subrounded to subangular sand of Moraga Formation (Rhyolite and Andesite) and clasts of mixed alluvial bedrock deposited at post/coincident Moraga time (siltstone clasts); medium dry strength; no dilatancy; medium toughness; medium plasticity; irregular angular to very weak blocky pedogenic structure; weak clay films coating clasts; CaCO3 coating clasts, abundant small ~ 1-2 mm rounded carbonate nodules throughout; basal contact is gradational over <4 inches, [BEDROCK, siltstone member of the mixed alluvial bedrock deposited at post/coincident Moraga time, A/Bt3 with minor Btk soil overprint].

45 — CLAY, silty (CL-ML), Dark reddish brown (5YR 3/3); dry; medium stiff; 50-60% clay, 30-40% silt, <10% sand; medium dry strength; no to slow dilatancy; medium toughness; medium plasticity; irregular angular pedogenic structure; clay films on pedogenic surfaces, abundant CaCO3 nodules 1-2.5 cm diameter along the base of the unit, some sub-vertical carbonate stringers, nodules and matrix strongly effervesce; massive; basal contact is gradational over 1-3" [BEDROCK, siltstone member of the mixed alluvial bedrock deposited at post/coincident Moraga time, Btk soil overprint].

43 — CLAY, silty, with gravel clay, Dark reddish brown (5YR 3/3); dry; medium stiff; 30-40% clay, ~20% coarse sand, ~20% fine gravel, 10-20% silt; weakly interbedded channel within Units 40 and 45, poorly defined coarse-grained channel, granular nature of deposit, interbeds within Units 40 and 45, loose CaCO3 precipitations [BEDROCK, interbedded coarse-grained facies of siltstone member of the mixed alluvial bedrock deposited at post/coincident Moraga time, Btk soil overprint].

40 — CLAY, silty (CL-ML), Reddish brown (5YR 4/4); dry to damp; medium stiff; 45-55% clay, 45-55% silt, <10% sand; medium dry strength; no to slow dilatancy; medium toughness; medium plasticity; weak irregular angular pedogenic structure; clay films on pedogenic surfaces and clasts, few 0.5 cm wide CaCO3 nodules, common vertical CaCO3 filaments; few angular coarse sand clasts, nodules effervesce strongly with HCl, matrix has weak to no reaction to HCl; basal contact is diffuse over <6 inches and planar [BEDROCK, siltstone member of the mixed alluvial bedrock deposited at post/coincident Moraga time, Btk soil overprint, pedogenic subunit of Unit 45].

Unit Descriptions (continued)

35 — SILT with sand (ML); Reddish brown (2.5YR 4/4); dry to slightly damp; soft; ~60% silt, ~40% sand, trace clay; no dry strength; slow dilatancy; low toughness; low plasticity; very weak angular blocky pedogenic structure, weak clay films on pedogenic fracture surfaces and clasts; sand is fine to coarse grained, subangular; CaCO3 filaments coating/infilling some pedogenic fractures, filaments have strong reaction to HCl, matrix has weak to no reaction to HCl; Unit 35 has no residual bedrock fabric, Unit 30 has blocky siltstone fabric, siltstone is well cemented and crumbles in angular irregular <1 inch siltstone clasts [BEDROCK, siltstone member of the mixed alluvial bedrock deposited at post/coincident Moraga time, Bt soil overprint].

30

25 — SAND, silty, clayey (SC-SM); Dark reddish gray (5YR 4/2); damp soft to medium stiff; ~80% very fine sand, ~10% silt, ~10% clay, trace gravel; massive with occasional gravel interbeds; well sorted; slight to strong reaction to HCl; basal contact is gradational over 1" [BEDROCK, fine-grained facies of conglomerate member of the mixed alluvial bedrock deposited at post/coincident Moraga time; Bt overprint].

20 — GRAVEL with silt and sand (GW-GM); Reddish brown (2.5YR 4/4); dry; loose; ~55% gravel, ~35% sand, ~10% silt; conglomerate with subrounded Orinda and Moraga gravels; poorly sorted; highly friable; many CaCO3 nodules and filaments (stringers) up to 3" long; indistinguishable pedogenic structure, upper 2 feet of conglomerate is highly weathered, clasts of Orinda Formation are weathering in place; conglomerate is well cemented in places and weakly weathered where more than 2 feet of the conglomerate profile is exposed [BEDROCK, conglomerate member of the mixed alluvial bedrock deposited at post/coincident Moraga time; Bt overprint].

15 — BRECCIATED ANDESITE; crushed and breciated andesite with anastomosing calcium carbonate seams and coated blocks. Fault zone material.

10 — ANDESITE; gray agglomerate volcanic rock, angular blocks of weathered andesite

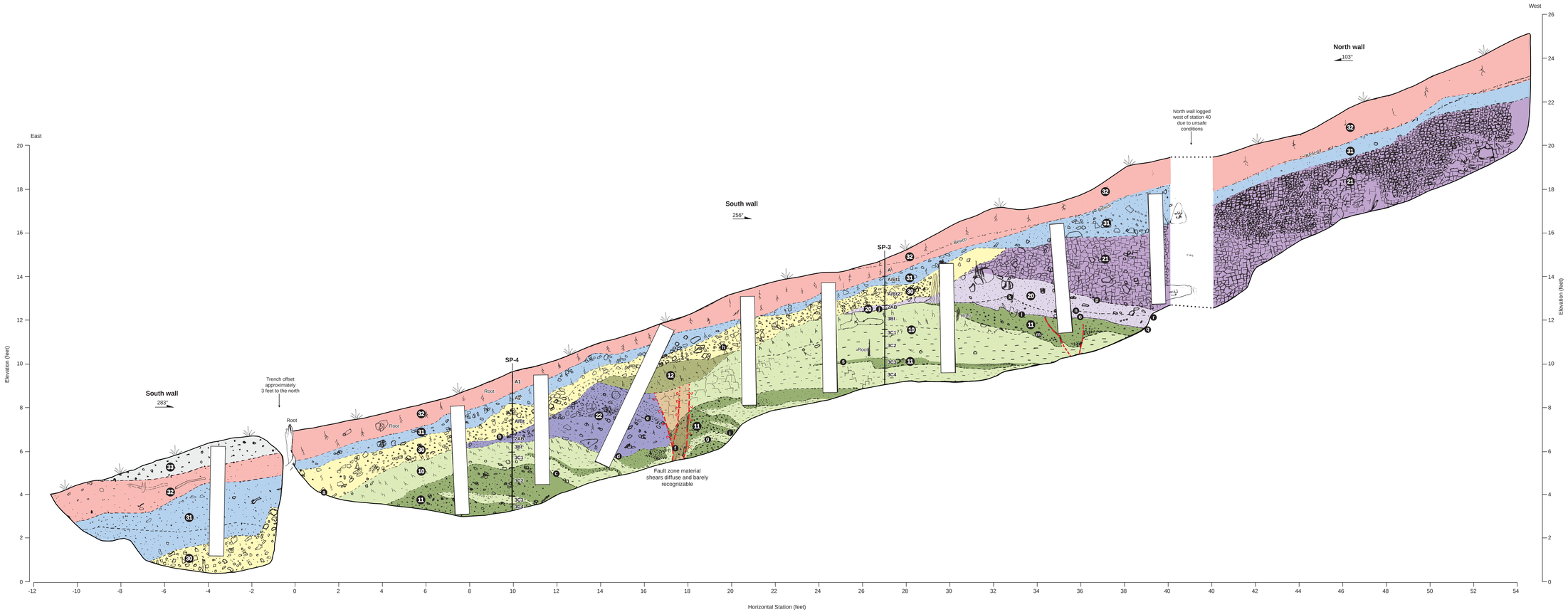
Notes

- **a** Fault orientation, 33°, 21°NW
- **b** Fault orientation, 321°, 8°NE
- **b'** Fault plane, opposite (north) wall, 267°, 30°N
- **c** Fault orientation, 314°, 30°N. Locally, between Stations 38 and 41 the fault plane is wavy and undulates with 3-6 inches relief. A 1-2 mm thick rind of CaCO3 coats the fault plane, the CaCO3 is moderately hard, and picks clean as resistant shelf, no striations or movement indicators.
- **d** Fault orientation, 302°, 28°NE. A 1-2 mm thick rind of CaCO3 coats the fault plane, the CaCO3 is moderately hard, and picks clean as resistant shelf, no striations or movement indicators.
- **e** Bedding orientation, 283°, 25°N
- **f** Fault orientation, 290°, 35°NE
- **g** Bedding orientation, 354°, 19°E
- **h** East-dipping shear places coarse sand in fault contact with siltstone
- **i** East-dipping shear not present on North wall, east-dipping shear is discontinuous near the base of the trench where it is truncated by a west-dipping shear. West-dipping shear is the dominant feature.
- **j** Fault orientation, 326°, 56°SW. Across trench strike and dip measured from the base of fine sand overlying gravel.
- **k** Soil bedding orientation, 324°, ≤10°SW (Soil ABt3)
- **l** Clay gouge ~1.5" thick at bottom of trench thins to single strand of clay, ≤1 inch thick, where it crosses Station 38.
- **m** Primary fault zone highly sheared, completely altered bedrock, very weak, no remaining bedrock fabric.
- **n** Shear zone several inches wide defined by thin seams of clay gouge CaCO3-lined shears, fractures and aligned and stretched weathered Tm pebbles.
- **o** CaCO3-lined fractures predominantly subhorizontal through gravel to sub vertical, thick vertically orientated CaCO3-lined fracture near Station 13.

PALEOLANDSLIDE INVESTIGATION
LOG OF TRENCH T-1

PLATE 2

Graphics, Active Projects, 2072.001, Modified:08.31.09



Explanation

Symbols

- Soil pattern
- Pedogenic fractures
- Contact, solid where certain, dashed where approximate, dotted where inferred
- Fault, dashed where approximate, queried where uncertain, dotted where concealed
- **SP-4** — A1, A2, A/Bt: Soil profile (see Appendix A)

Unit Descriptions

33 — SILT with sand and gravel (ML); very dark grayish brown (10YR 3/2); dry; medium stiff to soft; ~55% silt, ~25% sand, ~20% gravel; poorly sorted subangular to subrounded gravels up to 0.8' diameter or andesite and siltstone; medium dry strength, slow dilatancy, low toughness, no plasticity; many grass roots, organics, and foreign material (nails and glass); no reaction to HCl; lower contact diffuse over 0.2' (FILL)

32 — SILT with sand (ML); very dark gray (10YR 3/1); dry; medium stiff; ~60% silt, ~35% sand, ~5% gravel, trace clay; moderately sorted; massive; sand is fine to coarse grained andesite and tuff; gravel increasing in abundancy near lower contact; medium to low dry strength, slow to no dilatancy, low toughness, no plasticity; several large roots, many rootlets; no reaction to HCl; lower contact diffuse over 0.2' (A Horizon in Colluvium)

31 — SILT with gravel (ML); black (5Y 2.5/1); dry; medium stiff to soft; ~50% silt, ~30% gravel, ~20% sand; low dry strength, slow dilatancy, low toughness, no plasticity; poorly sorted; gravels are andesite and welded tuff clasts, subangular, 0.05' to 0.4' diameter; many roots and rootlets; no reaction to HCl; lower contact gradational over 0.3' (A/Bt horizon in Colluvium)

30 — COLLUVIUM (gravel/silt/clay conglomerate); light brownish gray (10YR 6/2) clasts with very dark gray (10YR 3/1) matrix; dry; medium dense; poorly sorted; clayey matrix towards the east; clasts are subangular weathered andesite and some welded tuff ignimbrite 0.05' to 0.5' diameter; ~60% gravels, ~40% matrix, matrix grading to more silty and sandy upslope to the west; few roots and rootlets; no reaction to HCl (Colluvium derived from Moraga Fm.)

22 — ANDESITE siltstone with sand and gravel; dark grayish brown (10YR 4/2) to very dark grayish brown (10YR 3/2); moderately sorted; sand is fine to coarse grained; gravel is subangular andesite, <0.4' diameter, random orientation with no fabric; few roots and krotovina; no reaction to HCl, well defined lower contact (Moraga Fm.)

Unit Descriptions (continued)

21 — ANDESITE; dark brown (10YR 3/5) with fresh, gray (10YR 5/1) exposed; moderately to slightly weathered; very weak to hard; ~80% gravel to boulders, ~20% sandy matrix between fractured clasts; boulders <2' diameter; andesite vesicles are filled with a black secondary mineral; blocky planar fractures with random orientation; weathering rinds on all surfaces; no reaction to HCl (Moraga Fm.)

20 — SILT (lapilli TUFF) with sand and clay (ML); very dark grayish brown (10YR 3/2); dry; medium stiff; ~55% silt, ~30% sand, ~15% clay, several subangular andesite gravels intermixed; medium dry strength, slow to no dilatancy, medium toughness, low plasticity; sand grains are subrounded volcanic lapilli; no reaction to HCl; no pedogenic structure; lower contact diffuse over 0.1'; less silt and clay with ~25% gravel towards the west (Moraga Fm.)

12 — SILTSTONE; brown (10YR 4/3) with some dark reddish brown (2.5YR 3/3); moderately weathered; very weak; moderately sorted; slightly mottled; siltstone is ~60% silt, ~25% sand, ~15% clay; coarse sand and trace gravel is subrounded to subangular sandstone; few roots; no reaction to HCl; faint angular blocky pedogenic structure; lower contact diffuse over 0.3' (Orinda Fm. or very old Orinda-derived colluvium)

11 — CONGLOMERATE; dark yellowish brown (10YR 3/4); moderately weathered; very to extremely weak; clast supported; fine gravel to coarse sand clasts; subrounded to subangular <0.1' diameter clasts of sandstone with siltstone, tuff, andesite and trace shale, quartzite, and serpentinite; iron oxide and manganese weathering rind on surfaces of clasts; interfingering layers of siltstone 0.3' to 1.0' thick; siltstone equally intermixed towards west; few roots and rootlets; no reaction to HCl; lower contact diffuse over 0.5' (Orinda Fm.)

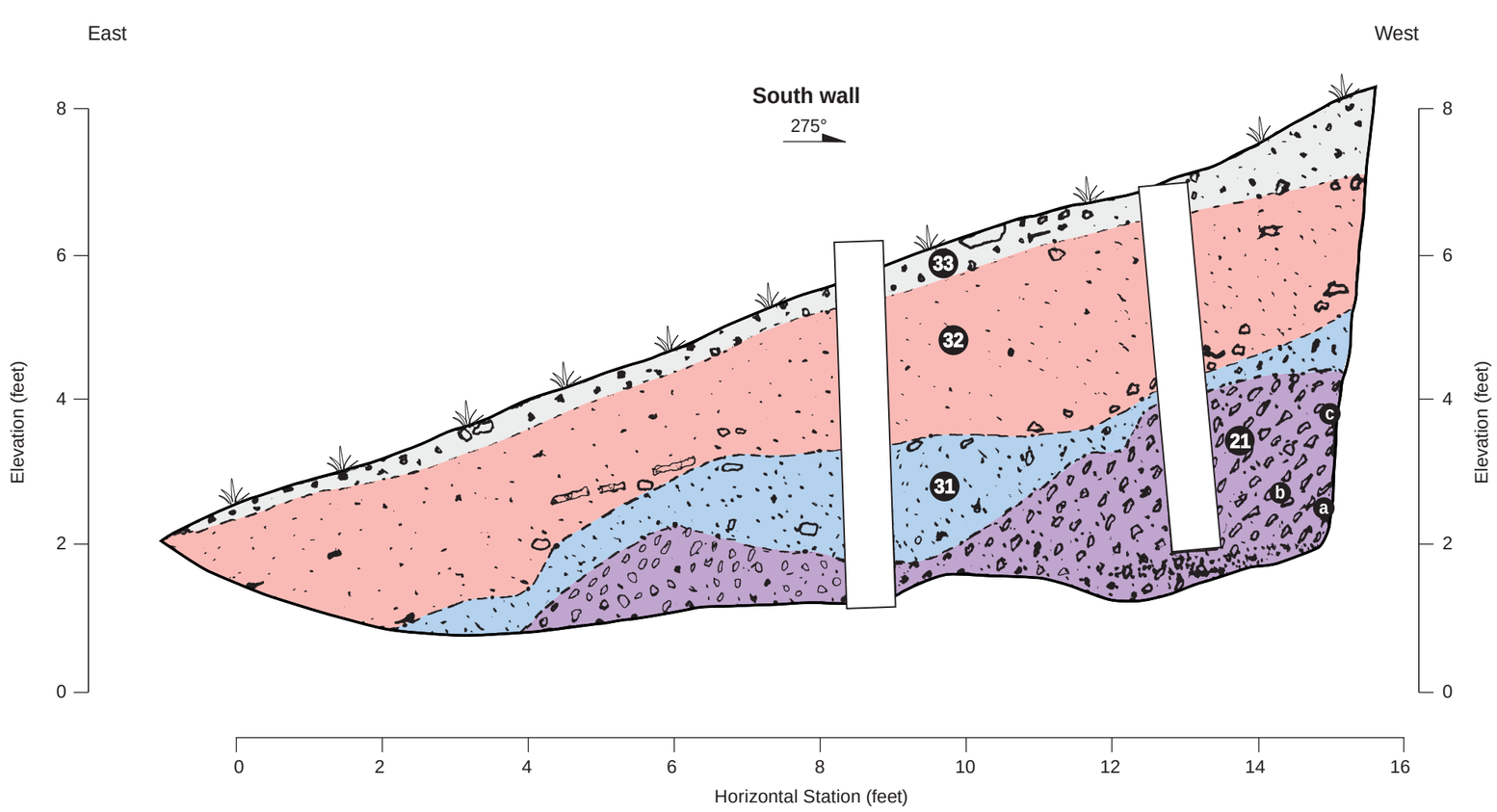
10 — SILTSTONE; dark gray (5YR 4/1), dark reddish brown (2.5YR 3/4), and dark grayish brown (10YR 4/2); very to extremely weak; moderately to slightly weathered; massive with some mottling, medium plasticity; well sorted grading up to poorly sorted; slightly sandy with trace to 15% subrounded to subangular sandstone and siltstone gravels; interfingers with conglomerate unit; some volcanics intermixed towards upper and lower contacts; angular blocky pedogenic structure; contacts diffuse over 0.3'; no reaction to HCl; (Orinda Fm.)

Bedding and Orientations

- **a** — Ignimbrite tuff dips steeply north to paleoswale on north wall. Top of rock is under hole. Total thickness of ignimbrite is unknown.
- **b** — 330, 40NE
- **c** — 022, 27NW
- **d** — 040, 25NW
- **e** — 050, 27NW
- **f** — 019, 76SE
- **g** — Sharp 65°-70° contact 020, 15NW
- **h** — 257, 26E
- **i** — Mixed zone of units to east; 025, 15NW
- **j** — 005, 20E
- **k** — 015, 16SE
- **l** — 330, 10SW
- **m** — 335, 19SW
- **n** — 325, 13SW
- **o** — 330, 8-12SW
- **p** — 357 - 350, 11SW
- **q** — Thin (0.8-1.3 cm.) clay lens at lapilli tuff (Tm) (above unit) and competent gray siltstone (Tsr) (below unit). Low to moderate plasticity, no kinematic indicators observed. 337 along seam in floor.
- **r** — Unit contains welded tuff volcanic bombs.
- **s** — 302, <10°SW

Graphics, Active Projects, 2072.001, Modified 08.11.09

PALEOLANDSLIDE INVESTIGATION
LOG OF TRENCH T-2



Explanation

Unit Descriptions

33 — SILT with sand and gravel (ML); very dark grayish brown (10YR 3/2); dry; medium stiff to soft; ~55% silt, ~25% sand, ~20% gravel; poorly sorted subangular to subrounded gravels up to 0.8' diameter or andesite and siltstone; medium dry strength, slow dilatancy, low toughness, no plasticity; many grass roots, organics, and foreign material (nails and glass); no reaction to HCl; lower contact diffuse over 0.2' (FILL)

32 — SILT with sand (ML); very dark gray (10YR 3/1); dry; medium stiff; ~60% silt, ~35% sand, ~5% gravel, trace clay; moderately sorted; massive; sand is fine to coarse grained; gravel increasing in abundancy near lower contact; medium to low dry strength, slow to no dilatancy, low toughness, no plasticity; several large roots, many rootlets; no reaction to HCl; lower contact diffuse over 0.2' (A Horizon developed with colluvium))

31 — SILT with gravel (ML); black (5Y 2.5/1); dry; medium stiff to soft; ~50% silt, ~30% gravel, ~20% sand; low dry strength, slow dilatancy, low toughness, no plasticity; poorly sorted; gravels are andesite and welded tuff clasts, subangular, 0.05' to 0.4' wide; many roots and rootlets; no reaction to HCl; no pedogenic development; lower contact gradational over 0.3' (Colluvium)

21 — ANDESITE; dark brown (10YR 3/5) with fresh, gray (10YR 5/1) exposed; moderately to slightly weathered; very weak to hard; ~80% gravel to boulders, ~20% sandy matrix between fractured clasts; boulders <2' wide; andesite vesicles are filled with a black secondary mineral; blocky planar fractures with random orientation; weathering rinds on all surfaces; no reaction to HCl (Moraga Fm.)

Bedding and Orientations

a — Fracture; 350, 27°W; wavy to planar; several similar fractures subparallel spaced 0.5 to 1 inch apart.

b — Joint; 006, 40°SE; wavy to planar; tight; no infill but weathered surface; many similar subparallel joints spaced 0.02 to 0.1 inch apart

c — Joint; 045, 47°S; wavy to planar; no infill but weathered surface; many similar subparallel joints spaced 0.02 to 0.1 inch apart

Graphics, Active Projects, 2072.001, Modified 08.31.09

PALEOLANDSLIDE STUDY
TEST PIT TP-1

PHOTOGRAPHS

Photograph 1. View to the northwest showing the trench T-1 location in a narrow lawn area sloping southwest toward Building 42 (not shown).

Photograph 2. View to the east showing the location of trench T-1.

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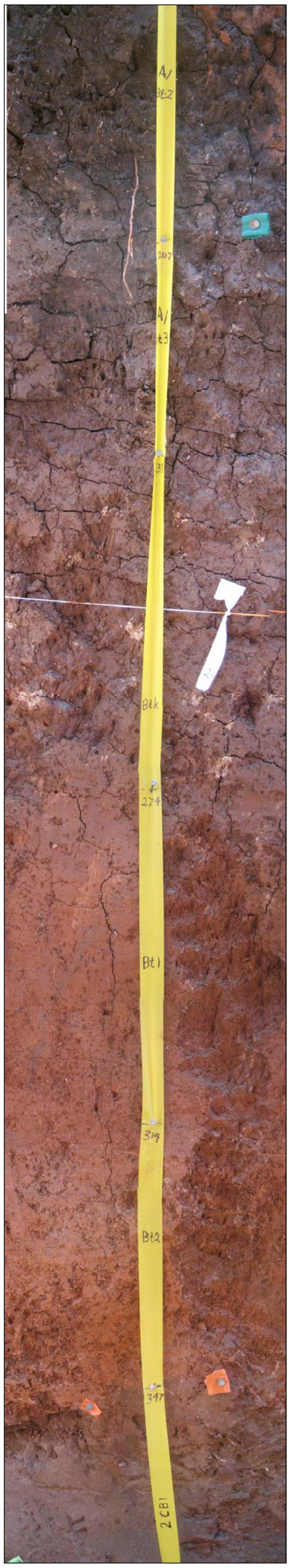
Photograph 3. View of the southwall of trench T-1 near Station 16 feet. Photograph shows the coarse-grained and partially bedded and fractured character of the Tertiary sediments. Overlying the coarse-grained deposit is a reddish brown fine-grained silt also part of the Tertiary sediments.

Photograph 4. View of the zone of folding and faulting in Tertiary sediments near Station 22 feet.

Graphics, Active Projects, 2072.001, Modified 08.31.09



Photograph 5. Photomosaic of a portion of soil profile SP-1 evaluated at Station 24 feet. See Appendix A for the description of the profile and explanation of the soil horizon abbreviations.

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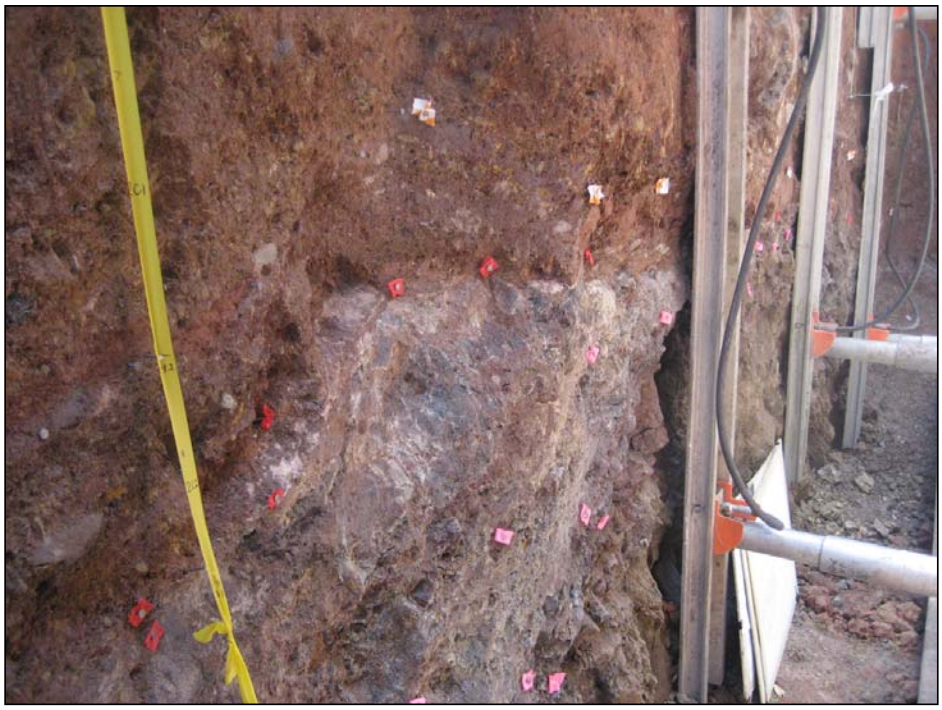
Photograph 6. View of the geologic contact between the Tertiary sediments (reddish brown in color) and sheared Moraga Formation (grayish in color) near Station 38 feet in trench T-1. Yellow tape is the location of soil profile SP-2 (see Appendix A).

Graphics, Active Projects, 2072.001, Modified 08.31.09



Photograph 7. View looking west of the abrupt and sheared contact (red flags) between the Tertiary sediments (reddish brown in color) and the Moraga Formation (grayish in color) near Station 38 feet in trench T-1.

Photograph 8. A close-up of calcium carbonate lining the shear zone between the Tertiary sediments and Moraga Formation at Station 42 feet near note b (see log of trench T-1).

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Photograph 9. View looking west and upslope toward the southern Building 25 parking lot showing the location of trench T-2. The geologist standing in the trench is within the Moraga Formation located at the west end of trench T-2.

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Photograph 10. View of the geologic contact between Moraga-derived colluvium (orange/white stripe flags) and Moraga Formation (Lapilli tuff) (yellow flags) and the underlying Orinda Formation (from yellow flags to bottom of trench) near Station 38 feet. Yellow tape is the location of soil profile SP-3 (see Appendix A).

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Photograph 11. View of the south wall of trench T-2 showing the geologic contact (yellow flags) between the Moraga Formation (brownish blocky material) and the Orinda Formation (gray and red siltstone) near Station 34 feet.

Photograph 12. Close-up of the geologic contact (yellow flags) between the Moraga and Orinda Formations at Station 34 feet showing the absence of shearing.

Graphics, Active Projects, 2072.001, Modified 08.31.09

APPENDIX A

Soil Profile Data Sheets

SOIL PROFILE DESCRIPTION

William Lettis & Associates, Inc.

Profile: SP-1 Site: LBL Building 25, T-1

Elevation: Slope: Job #: 2072

Site description: Sloping lawn area surrounded by trees, in between buildings 25 and 4
Trees = dawn redwood, sequoia, live oak

Date: 7-16-09
Time: 11:00 am
By: JM Sowers

Depth (cm)	Horizon	Boundary	Color dominant	Color mottles	Structure	Gravel size rnd %	Consistence wet moist dry	Texture	Clay films	Salts & silica	Notes: (pores, roots, HCl test samples, pH, etc.)
85	Fill	a s; c w; g i; d b	(d) / (m)	(d) / (m)	m vf gr; sg f pl; 1 m p r; 2 c cpr; 3 vc abk; sbk	f r 0; m sr 10; sa 25; c a 50; 75; 100	so po lo; ss ps vfr lo; s p fr so; vs vp fi sh; vfi h; efi vh; eh	C; SC SiC; SCL CL SiCL; LS SL L SiL; S Si	v1 f pf; 1 d po; 2 br; 3 p co; cobr	k I; y II; z III; q IV; V; V+	Fill Abundant fin-co roots Ang. ss gravel in sandy matrix
115	A	a s; c w; g i; d b	(d) / 7.5YR 3/2 (m)	(d) / 7.5YR 4/4-5/6 (<5%) (m)	m vf gr; sg f pl; 1 m p r; 2 c cpr; 3 vc abk; sbk	f r 0; m sr 10; sa 25; c a 50; 75; 100	so po lo; ss ps vfr lo; s p fr so; vs vp fi sh; vfi h; efi vh; eh	C; SC SiC; SCL CL SiCL; LS SL L SiL; S Si; clay ~ 60%	v1 f pf; 1 d po; 2 br; 3 p co; cobr	k I; y II; z III; q IV; V; V+	Dark brown silty clay w/ strong brown lining pores and coating ped faces v. few clay films coat clasts
179	A/Bt1	a s; c w; g i; d b	(d) / 7.5YR 3/2 (m)	(d) / 2.5YR 4/4 5YR 5/6 (m)	m vf gr; sg f pl; 1 m p r; 2 c cpr; 3 vc abk; sbk	f r 0; m sr 10; sa 25; c a 50; 75; 100	so po lo; ss ps vfr lo; s p fr so; vs vp fi sh; vfi h; efi vh; eh	Tri co. ang sand; C; SC SiC; SCL CL SiCL; LS SL L SiL; S Si	v1 f pf; 1 d po; 2 br; 3 p co; cobr	k I; y II; z III; q IV; V; V+	Dark brown clay with distinct reddish (dusky red, yellowish red) stains on prominent vertical fractures and lining pores. Coarse roots.
207	A/Bt2	a s; c w; g i; d b	(d) / 7.5YR 3/2 (m)	(d) / (m)	m vf gr; sg f pl; 1 m p r; 2 c cpr; 3 vc abk; sbk	f r 0; m sr 10; sa 25; c a 50; 75; 100	so po lo; ss ps vfr lo; s p fr so; vs vp fi sh; vfi h; efi vh; eh	C; SC SiC; SCL CL SiCL; LS SL L SiL; S Si; clay ~ 70%	v1 f pf; 1 d po; 2 br; 3 p co; cobr	k I; y II; z III; q IV; V; V+	Dark brown clay
233	A/Bt3	a s; c w; g i; d b	(d) / 7.5YR 3/3 to 2.5Y 4/3 (m)	(d) / (m)	m vf gr; sg f pl; 1 m p r; 2 c cpr; 3 vc abk; sbk	f r 0; m sr 10; sa 25; c a 50; 75; 100	so po lo; ss ps vfr lo; s p fr so; vs vp fi sh; vfi h; efi vh; eh	C; SC SiC; SCL CL SiCL; LS SL L SiL; S Si; clay ~ 50%	v1 f pf; 1 d po; 2 br; 3 p co; cobr	mn <I; k II; y III; z IV; q V; V+	Dark reddish-brown clay w/ rectangular blocky structure Color reddens with depth Tri mn coatings Scattered $CaCO_3$ nodules ≤ 0.5 cm
274	Btk	a s; c w; g i; d b	(d) / 2.5YR 3/4 (m)	(d) / 7.5YR 8/3 ($CaCO_3$) (m)	m vf gr; sg f pl; 1 m p r; 2 c cpr; 3 vc abk; sbk	rectangular; f r 0; m sr 10; sa 25; c a 50; 75; 100	so po lo; ss ps vfr lo; s p fr so; vs vp fi sh; vfi h; efi vh; eh	C; SC SiC; SCL CL SiCL; LS SL L SiL; S Si; clay ~ 50%	v1 f pf; 1 d po; 2 br; 3 p co; cobr	k I; y II; z III; q IV; V; V+	Red-brown clay $CaCO_3$ nodules, up to 1.5 cm - soft, punky exterior ~10-20 cm apart. Most have hard interiors May be degraded

Notes:

SOIL PROFILE DESCRIPTION

William Lettis & Associates, Inc.

Profile: SP-1 Site: LB2 Building 25 T-1

Elevation: Slope: Job #: 2072

Site description:

Date: 7-16-09
Time:
By: JM Sowers

Depth (cm)	Horizon	Boundary	Color dominant	Color mottles	Structure	Gravel size rnd %	Consistence wet moist dry	Texture	Clay films	Salts & silica	Notes: (pores, roots, HCl test samples, pH, etc.)
274 314	Bt1	a s c w g i d b	(d) 2.5YR 4/6 (m)	(d) (m)	m vf gr sg f pl 1 m p r 2 c cpr abk 3 vc sbk	f r 0 10 m sr 25 sa 50 c a 75 100	so po lo vfr lo ss ps vfr so s p fr sh vs vp fi h fi vh efi eh	C SC SiC SCL CL SiCL LS SL L SiL S Si clay ~30%	v1 f pf 1 po 2 d br 3 p co cobr	k < I y II z III q IV V V+	Dark red clayey silt v. few stringers & pore fillings of $CaCO_3$ silt grains = red 6
347	Bt2	a s c w g i d b	(d) 2.5YR 4/4-4/6 (m)	(d) (m)	m vf gr sg f pl 1 m p r 2 c cpr 3 vc abk sbk	f r 0 10 m sr 25 sa 50 c a 75 100	so po lo vfr lo ss ps fr so s p fi sh vs vp vfi h efi vh eh	C SC SiC SCL CL SiCL LS SL L SiL S Si	v1 f pf 1 po 2 d br 3 p co cobr	k < I y II z III q IV V V+	Dark red as above, with stronger structure v. few stringers & pore fillings of $CaCO_3$ 7
375	2CBt1	a s c w g i d b	(d) 2.5YR 3/3-4/2 (m)	(d) (m)	m vf gr sg f pl 1 m p r 2 c cpr abk 3 vc sbk	f r 0 10 m sr 25 sa 50 c a 75 100	so po lo vfr lo ss ps fr so s p fi sh vs vp vfi h efi vh eh	C SC SiC SCL CL SiCL LS SL L SiL S Si clay <5%	v1 f pf 1 po 2 d br 3 p co cobr	k < I y II z III q IV V V+	Sand with primary bedding Clay films on bedding partings $CaCO_3$ filaments, v. few Sand incl. volcanic grains 8
396	2CBt2	a s c w g i d b	(d) 2.5YR 3/3 (m)	(d) (m)	m vf gr sg f pl 1 m p r 2 c cpr abk 3 vc sbk	f r 0 10 m sr 25 sa 50 c a 75 100	so po lo vfr lo ss ps fr so s p fi sh vs vp vfi h efi vh eh	C SC SiC SCL CL SiCL LS SL L SiL S Si	v1 f pf 1 po 2 d br 3 p co cobr	mn < I k II y III z IV q V V+	Sandy gravel, w/ primary bedding. Rounded ss and volcanic clasts, many can be cut w/ knife. Coated w/ clay films 9
B.T		a s c w g i d b	(d) (m)	(d) (m)	m vf gr sg f pl 1 m p r 2 c cpr abk 3 vc sbk	f r 0 10 m sr 25 sa 50 c a 75 100	so po lo vfr lo ss ps fr so s p fi sh vs vp vfi h efi vh eh	C SC SiC SCL CL SiCL LS SL L SiL S Si	v1 f pf 1 po 2 d br 3 p co cobr	k I y II z III q IV V V+	
		a s c w g i d b	(d) (m)	(d) (m)	m vf gr sg f pl 1 m p r 2 c cpr abk 3 vc sbk	f r 0 10 m sr 25 sa 50 c a 75 100	so po lo vfr lo ss ps fr so s p fi sh vs vp vfi h efi vh eh	C SC SiC SCL CL SiCL LS SL L SiL S Si	v1 f pf 1 po 2 d br 3 p co cobr	k I y II z III q IV V V+	

Notes:

FIELD SKETCH

Soil SP-1

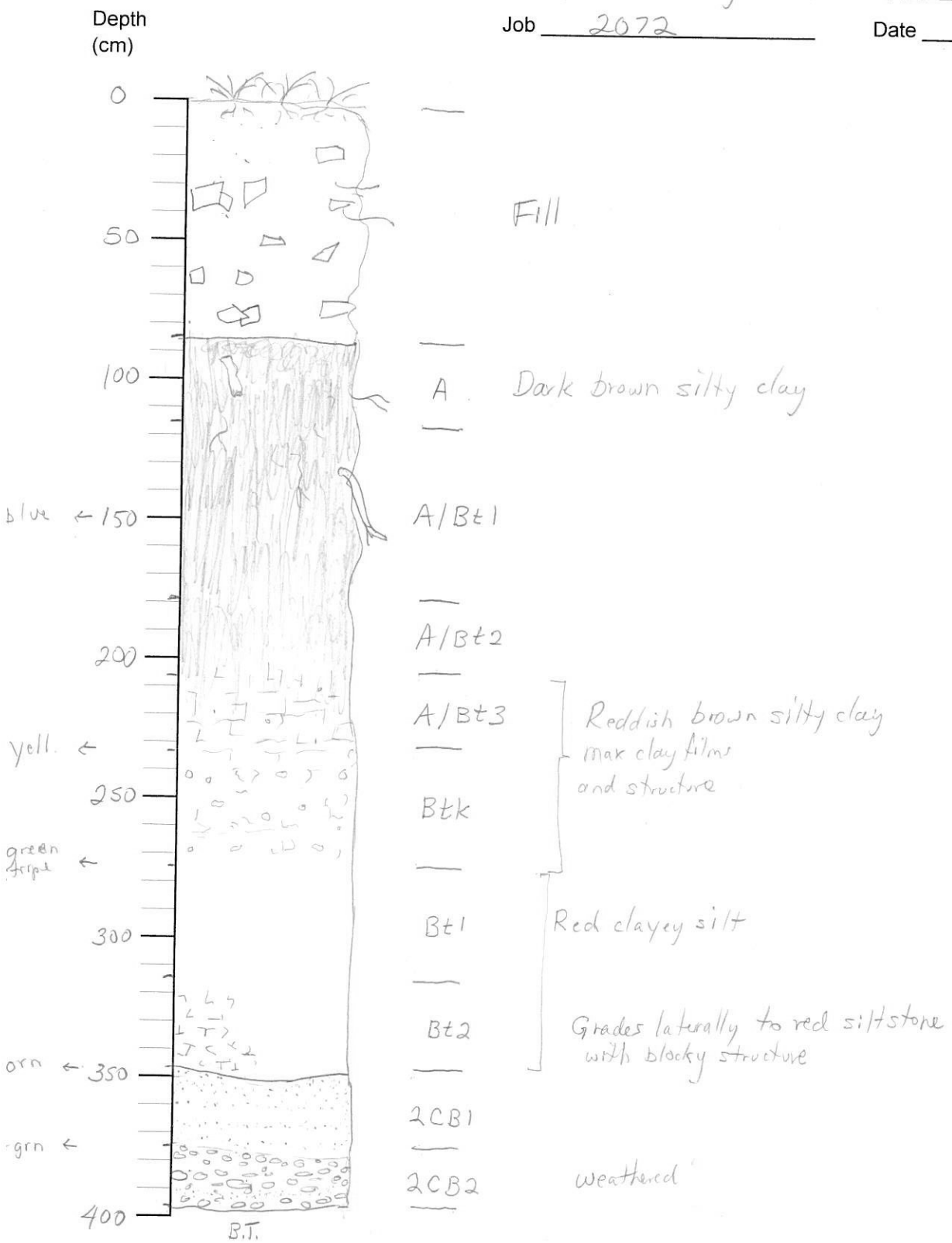
Site LBL Building 25

Job 2072

Page 3 of 3

By JM Sowers

Date



SOIL PROFILE DESCRIPTION

William Lettis & Associates, Inc.

Profile: SP-2 Site: LBL Building 25 T-1

Elevation: Slope: Job #: 2072

Site description:

Date: 7-17-09
Time:
By: JM Sowers

Depth (cm)	Horizon	Boundary	Color dominant	Color mottles	Structure	Gravel size rnd %	Consistence wet moist dry	Texture	Clay films	Salts & silica	Notes: (pores, roots, HCl test samples, pH, etc.)
76		a s c w g i d b	(d) (m)	(d) (m)	m vf gr sg f pl 1 m p r 2 c cpr 3 vc abk sbk	f r 0 10 m sr 25 sa 50 c a 75 100	so po lo lo ss ps vfr so s p fr sh vs vp fi h vfi vh efi eh	C SC SiC SCL CL SiCL LS SL L SiL S Si	v1 f pf 1 po 2 d br 3 p co cobr	k I y II z III q IV V V+	FILL
99		a s c w g i d b	(d) (m)	(d) (m)	m vf gr sg f pl 1 m p r 2 c cpr 3 vc abk sbk	f r 0 10 m sr 25 sa 50 c a 75 100	so po lo lo ss ps vfr so s p fr sh vs vp fi h vfi vh efi eh	C SC SiC SCL CL SiCL LS SL L SiL S Si	v1 f pf 1 po 2 d br 3 p co cobr	k I y II z III q IV V V+	1
129		a s c w g i d b	(d) (m)	(d) (m)	m vf gr sg f pl 1 m p r 2 c cpr 3 vc abk sbk	f r 0 10 m sr 25 sa 50 c a 75 100	so po lo lo ss ps vfr so s p fr sh vs vp fi h vfi vh efi eh	C SC SiC SCL CL SiCL LS SL L SiL S Si	v1 f pf 1 po 2 d br 3 p co cobr	k I y II z III q IV V V+	2
160		a s c w g i d b	(d) (m)	(d) (m)	m vf gr sg f pl 1 m p r 2 c cpr 3 vc abk sbk	f r 0 10 m sr 25 sa 50 c a 75 100	so po lo lo ss ps vfr so s p fr sh vs vp fi h vfi vh efi eh	C SC SiC SCL CL SiCL LS SL L SiL S Si	v1 f pf 1 po 2 d br 3 p co cobr	k I y II z III q IV V V+	~blue 3
197		a s c w g i d b	(d) (m)	(d) (m)	m vf gr sg f pl 1 m p r 2 c cpr 3 vc abk sbk	f r 0 10 m sr 25 sa 50 c a 75 100	so po lo lo ss ps vfr so s p fr sh vs vp fi h vfi vh efi eh	C SC SiC SCL CL SiCL LS SL L SiL S Si	v1 f pf 1 po 2 d br 3 p co cobr	k I y II z III q IV V V+	Dark brown w/ $CaCO_3$ nodules, 2-10mm, scattered — green 4
219		a s c w g i d b	(d) (m)	(d) (m)	m vf gr sg f pl 1 m p r 2 c cpr 3 vc abk sbk	f r 0 10 m sr 25 sa 50 c a 75 100	so po lo lo ss ps vfr so s p fr sh vs vp fi h vfi vh efi eh	C SC SiC SCL CL SiCL LS SL L SiL S Si	v1 f pf 1 po 2 d br 3 p co cobr	k I y II z III q IV V V+	Red brown clayey silt with rectangular blocky structure. Lower 10 cm has $CaCO_3$ nodules 10-20 mm. — yell 5 green

Notes:

SOIL PROFILE DESCRIPTION

William Lettis & Associates, Inc.

Profile: SP-2 Site: LBL Building 25, T-1

Elevation: Slope: Job #: 2072

Site description:

Date: 7-17-09

Time:

By: JM Sowers

Depth (cm)	Horizon	Boundary	Color dominant	Color mottles	Structure	Gravel size rnd %	Consistence wet moist dry	Texture	Clay films	Salts & silica	Notes: (pores, roots, HCl test samples, pH, etc.)
244		a s c w g i d b	(d) (m)	(d) (m)	m vf gr sg f pl 1 m pr 2 c cpr 3 vc abk sbk	f r 0 10 m sr 25 sa 50 c a 75 100	so po ss ps s p vs vp / lo vfr fr fi vfi efi / lo so sh h vh eh	C SC SiC SCL CL SiCL LS SL L SiL S Si	v1 f pf 1 po 2 d br 3 p co cobr	k I y II z III q IV V V+	Red clayey silt. Grades into unit below. 6
292		a s c w g i d b	(d) (m)	(d) (m)	m vf gr sg f pl 1 m pr 2 c cpr 3 vc abk sbk	f r 0 10 m sr 25 sa 50 c a 75 100	so po ss ps s p vs vp / lo vfr fr fi vfi efi / lo so sh h vh eh	C SC SiC SCL CL SiCL LS SL L SiL S Si	v1 f pf 1 po 2 d br 3 p co cobr	k I y II z III q IV V V+	Sandy gravel w/ red silt at base. Drn weathered. 80 % of clasts can be cut w/ knife. 7
319		a s c w g i d b	(d) (m)	(d) (m)	m vf gr sg f pl 1 m pr 2 c cpr 3 vc abk sbk	f r 0 10 m sr 25 sa 50 c a 75 100	so po ss ps s p vs vp / lo vfr fr fi vfi efi / lo so sh h vh eh	C SC SiC SCL CL SiCL LS SL L SiL S Si	v1 f pf 1 po 2 d br 3 p co cobr	k I y II z III q IV V V+	Sandy gravel, also w/ red silt at base. 60-70% of clasts can be cut w/ knife. Abrupt, sloping lower contact 8
390		a s c w g i d b	(d) (m)	(d) (m)	m vf gr sg f pl 1 m pr 2 c cpr 3 vc abk sbk	f r 0 10 m sr 25 sa 50 c a 75 100	so po ss ps s p vs vp / lo vfr fr fi vfi efi / lo so sh h vh eh	C SC SiC SCL CL SiCL LS SL L SiL S Si	v1 f pf 1 po 2 d br 3 p co cobr	k I y II z III q IV V V+	Sheared, weathered volcanic 9
	B.T	a s c w g i d b	(d) (m)	(d) (m)	m vf gr sg f pl 1 m pr 2 c cpr 3 vc abk sbk	f r 0 10 m sr 25 sa 50 c a 75 100	so po ss ps s p vs vp / lo vfr fr fi vfi efi / lo so sh h vh eh	C SC SiC SCL CL SiCL LS SL L SiL S Si	v1 f pf 1 po 2 d br 3 p co cobr	k I y II z III q IV V V+	
		a s c w g i d b	(d) (m)	(d) (m)	m vf gr sg f pl 1 m pr 2 c cpr 3 vc abk sbk	f r 0 10 m sr 25 sa 50 c a 75 100	so po ss ps s p vs vp / lo vfr fr fi vfi efi / lo so sh h vh eh	C SC SiC SCL CL SiCL LS SL L SiL S Si	v1 f pf 1 po 2 d br 3 p co cobr	k I y II z III q IV V V+	

Notes:

FIELD SKETCH

Soil SP-2

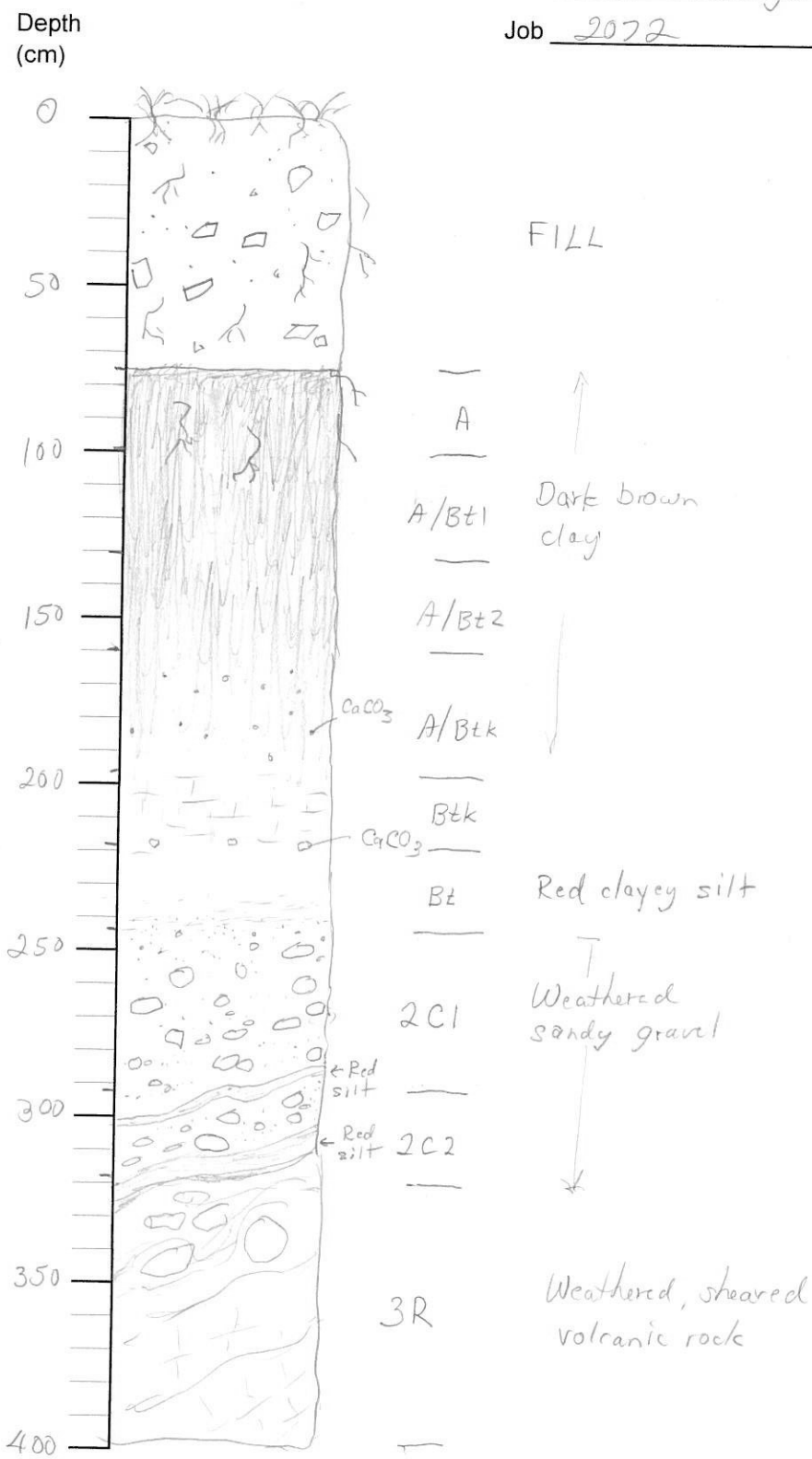
Site LBL Building 25, T-1

Job 2072

Page 3 of 3

By JMSowers

Date 7-17-09



SOIL PROFILE DESCRIPTION

William Lettis & Associates, Inc.

Profile: SP-3 Site: LBL Building 25, T-2

Elevation: Slope: Job #: 2072

Site description: East-facing grassy slope below Building 25
In trench T-2, North wall at 29 ft. Large pines 20-50 ft to north

Date: July 29, '09
Time: 9:30 am
By: JM Sowers

Depth (cm)	Horizon	Boundary	Color dominant	Color mottles	Structure	Gravel size rnd %	Consistence wet moist dry	Texture	Clay films	Salts & silica	Notes: (pores, roots, HCl test samples, pH, etc.)	
23	A1	a s / c w / g i / d b	10YR 2/2 (d) / (m)	(d) / (m)	m vf gr / sg f pl / 1 m pr / 2 c cpr / 3 vc abk / sbk	f r 0 / m sr 10 / sa 25 / c a 50 / 75 / 100	so po / ss ps / s p / vs vp / lo vfr / fr / fi / vfi / efi / lo so / sh / h / vh / eh	C / SC SiC / SCL CL SiCL / LS SL L SiL / S Si; clay 30%	v1 f pf / 1 d po / 2 br / 3 p co / cobr	k I / y II / z III / q IV / V / V+	Colluvium Common fine to co. roots Rodent burrows	1
36	A/Bt	a s / c w / g i / d b	10YR 2/2 (d) / (m)	(d) / (m)	m vf gr / sg f pl / 1 m pr / 2 c cpr / 3 vc abk / sbk	f r 0 / m sr 10 / sa 25 / c a 50 / 75 / 100	so po / ss ps / s p / vs vp / lo vfr / fr / fi / vfi / efi / lo so / sh / h / vh / eh	C / SC SiC / SCL CL SiCL / LS SL L SiL / S Si; clay ~20%	v1 f pf / 1 d po / 2 br / 3 p co / cobr	k I / y II / z III / q IV / V / V+	Colluvium Common fine to co. roots Clay films coat clasts, and some ped faces, incr. w/ depth. Stained 10YR 2/2	2
63	A/Bt 2	a s / c w / g i / d b	matrix 7.5YR 3/3 (d) / (m)	clast surfaces 7.5YR 4/4 to 5/4 (d) / (m)	m vf gr / sg f pl / 1 m pr / 2 c cpr / 3 vc abk / sbk	f r 0 / m sr 10 / sa 25 / c a 50 / 75 / 100	so po / ss ps / s p / vs vp / lo vfr / fr / fi / vfi / efi / lo so / sh / h / vh / eh	C / SC SiC / SCL CL SiCL / LS SL L SiL / S Si; clay ~30%	v1 f pf / 1 d po / 2 br / 3 p co / cobr	k I / y II / z III / q IV / V / V+	Colluvium, gravelly. Common fine to co roots Clay films coat clasts and some ped faces. Color lighter than above. Bioturbation	3
68	2A/Bt	a s / c w / g i / d b	10YR 6/4, 6/6 (50%) 7.5YR 3/2 (d) / (m)	7.33 (50%) (d) / (m)	m vf gr / sg f pl / 1 m pr / 2 c cpr / 3 vc abk / sbk	f r 0 / m sr 10 / sa 25 / c a 50 / 75 / 100	so po / ss ps / s p / vs vp / lo vfr / fr / fi / vfi / efi / lo so / sh / h / vh / eh	C / SC SiC / SCL CL SiCL / LS SL L SiL / S Si; clay 5-10%	v1 f pf / 1 d po / 2 br / 3 p co / cobr	k I / y II / z III / q IV / V / V+	Yellowish ash? Stained from above Few med roots	4
96	3Bt	a s / c w / g i / d b	10YR 5/1 (70%) 2.5YR 4/6, 3/3 (d) / (m)	(30%) (d) / (m) Colors grade into each other	m vf gr / sg f pl / 1 m pr / 2 c cpr / 3 vc abk / sbk	f r 0 / m sr 10 / sa 25 / c a 50 / 75 / 100	so po / ss ps / s p / vs vp / lo vfr / fr / fi / vfi / efi / lo so / sh / h / vh / eh	C / SC SiC / SCL CL SiCL / LS SL L SiL / S Si; clay 5-10%	v1 f pf / 1 d po / 2 br / 3 p co / cobr	k I / y II / z III / q IV / V / V+	Gray siltstone mottled with red, vertical fractures. Few med roots along vertical ped faces.	5
106		a s / c w / g i / d b	2.5YR 4/3 (d) / (m)	(d) / (m)	m vf gr / sg f pl / 1 m pr / 2 c cpr / 3 vc abk / sbk	f r 0 / m sr 10 / sa 25 / c a 50 / 75 / 100	so po / ss ps / s p / vs vp / lo vfr / fr / fi / vfi / efi / lo so / sh / h / vh / eh	C / SC SiC / SCL CL SiCL / LS SL L SiL / S Si; clay 5-10%	v1 f pf / 1 d po / 2 br / 3 p co / cobr	k I / y II / z III / q IV / V / V+	Red siltstone v. few med roots	6

Notes:

SOIL PROFILE DESCRIPTION

William Lettis & Associates, Inc.

Profile: SP-3 Site: LBL Building 25, T-2

Elevation: Slope: Job #: 2072

Site description:

Date: July 29, 09
Time:
By: JM Sowers

Depth (cm)	Horizon	Boundary	Color dominant	Color mottles	Structure	Gravel size rnd %	Consistence wet moist dry	Texture	Clay films	Salts & silica	Notes: (pores, roots, HCl test samples, pH, etc.)
135		a s c w g i d b	2.5YR 4/3 10YR 5/1 (d) 2.5Y 5/2 (m)	6/1 (d) Color boundary sharp. (m)	m vf gr sg f pl 1 m p r 2 c cpr 3 vc abk sbk	f r sr m sa c a 0 2.5% 10 25 50 75 100	so po ss ps s p vs vp / lo vfr fr fi vfi efi / lo so sh h vh eh	C SC SiC SCL CL SiCL LS SL L SiL S Si	v1 1 2 3 f d p / pf po br co cobr	~0~ I k II y III z IV q V V+	Red siltstone, mottled with gray. Few fi-med roots along ped faces 7
158		a s c w g i d b	7.5YR 6/2, 6/1, 2.5Y 6/2 (70%) 2.5YR 3/3, 4/4 (30%) (d)	(d)	m vf gr sg f pl 1 m p r 2 c cpr 3 vc abk sbk	f r sr m sa c a 0 10 25 50 75 100	so po ss ps s p vs vp / lo vfr fr fi vfi efi / lo so sh h vh eh	C SC SiC SCL CL SiCL LS SL L SiL S Si clay 5-10%	v1 1 2 3 f d p / pf po br co cobr	~0~ I k II y III z IV q V V+	Gray sand with stringers of red siltstone and line of gravel clasts at top. [rounded] mixed lithology 8 line
171		a s c w g i d b	2.5YR 4/4 (d)	(d)	m vf gr sg f pl 1 m p r 2 c cpr 3 vc abk sbk	f r sr m sa c a 0 10 25 50 75 100	so po ss ps s p vs vp / lo vfr fr fi vfi efi / lo so sh h vh eh	C SC SiC SCL CL SiCL LS SL L SiL S Si clay <5%	v1 1 2 3 f d p / pf po br co cobr	~0~ I k II y III z IV q V V+	Red siltstone 9 v. few fi-med roots
B.T.	—	a s c w g i d b	(d)	(d)	m vf gr sg f pl 1 m p r 2 c abk 3 vc sbk	f r sr m sa c a 0 10 25 50 75 100	so po ss ps s p vs vp / lo vfr fr fi vfi efi / lo so sh h vh eh	C SC SiC SCL CL SiCL LS SL L SiL S Si	v1 1 2 3 f d p / pf po br co cobr	I k II y III z IV q V V+	
		a s c w g i d b	(d)	(d)	m vf gr sg f pl 1 m p r 2 c abk 3 vc sbk	f r sr m sa c a 0 10 25 50 75 100	so po ss ps s p vs vp / lo vfr fr fi vfi efi / lo so sh h vh eh	C SC SiC SCL CL SiCL LS SL L SiL S Si	v1 1 2 3 f d p / pf po br co cobr	I k II y III z IV q V V+	weathered ignimbrite breccia @ ~40' in T-2
		a s c w g i d b	(d)	(d)	m vf gr sg f pl 1 m p r 2 c abk 3 vc sbk	f r sr m sa c a 0 10 25 50 75 100	so po ss ps s p vs vp / lo vfr fr fi vfi efi / lo so sh h vh eh	C SC SiC SCL CL SiCL LS SL L SiL S Si	v1 1 2 3 f d p / pf po br co cobr	I k II y III z IV q V V+	

Notes:

SOIL FIELD SKETCH

Soil SP-3

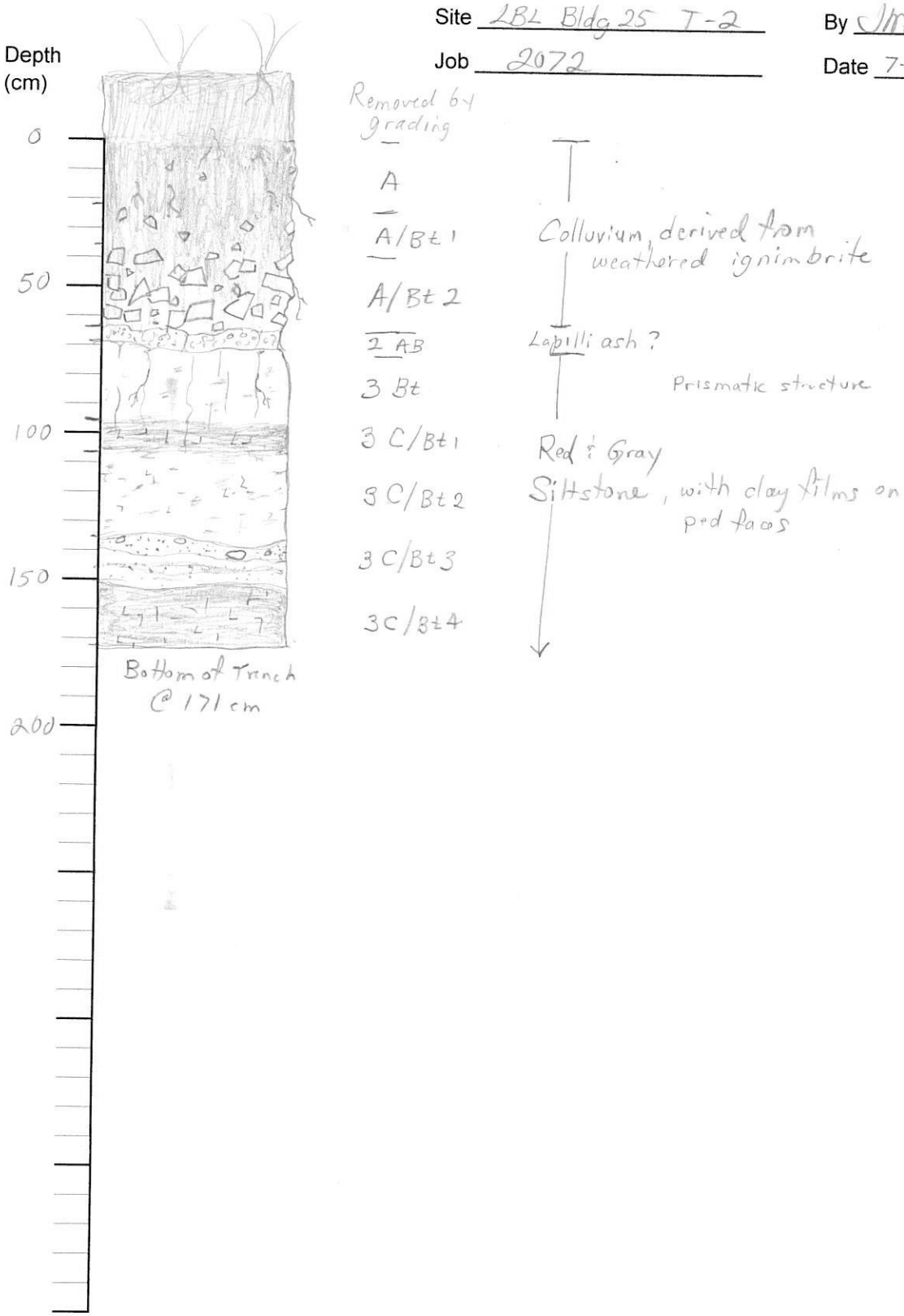
Site LBL Bldg 25 T-2

Job 2072

Page 2 of 3

By JMSowers

Date 7-29-09



SOIL PROFILE DESCRIPTION

William Lettis & Associates, Inc.

Profile: SP-4 Site: LBL Building 25 T-2

Elevation: Slope: Job #: 2072

Site description: Trench T-2 @ 10 ft

Date: July 29, 09
Time:
By: JM Sowers

Depth (cm)	Horizon	Boundary	Color dominant	Color mottles	Structure	Gravel size rnd %	Consistence wet moist dry	Texture	Clay films	Salts & silica	Notes: (pores, roots, HCl test samples, pH, etc.)
25	A	a s / c w / g i / d b	(d) / (m)	(d) / (m)	m vf gr / sg f pl / 1 m p r / 2 c cpr / 3 vc abk / sbk	f r 0 / m sr 10 / sa 25 / c a 50 / 75 / 100	so po / ss ps / s p / vs vp; lo vfr fr fi vfi efi / lo so sh h vh eh	C / SC SiC / SCL CL SiCL / LS SL L SiL / S Si	v1 1 2 3 / f d p / pf po br co cobr	k y z q / I II III IV V V+	Colluvium
43	A/Bt1	a s / c w / g i / d b	(d) / (m)	(d) / (m)	m vf gr / sg f pl / 1 m p r / 2 c cpr / 3 vc abk / sbk	f r 0 / m sr 10 / sa 25 / c a 50 / 75 / 100	so po / ss ps / s p / vs vp; lo vfr fr fi vfi efi / lo so sh h vh eh	C / SC SiC / SCL CL SiCL / LS SL L SiL / S Si	v1 1 2 3 / f d p / pf po br co cobr	k y z q / I II III IV V V+	Colluvium w/ ang. yell-gray ignimbrite clasts
84	ABt2	a s / c w / g i / d b	(d) / (m)	(d) / (m)	m vf gr / sg f pl / 1 m p r / 2 c cpr / 3 vc abk / sbk	f r 0 / m sr 10 / sa 25 / c a 50 / 75 / 100	so po / ss ps / s p / vs vp; lo vfr fr fi vfi efi / lo so sh h vh eh	C / SC SiC / SCL CL SiCL / LS SL L SiL / S Si	v1 1 2 3 / f d p / pf po br co cobr	k y z q / I II III IV V V+	Colluvium w/ ang. yell-gray ignimbrite clasts
96	2	a s / c w / g i / d b	(d) / (m)	(d) / (m)	m vf gr / sg f pl / 1 m p r / 2 c cpr / 3 vc abk / sbk	f r 0 / m sr 10 / sa 25 / c a 50 / 75 / 100	so po / ss ps / s p / vs vp; lo vfr fr fi vfi efi / lo so sh h vh eh	C / SC SiC / SCL CL SiCL / LS SL L SiL / S Si	v1 1 2 3 / f d p / pf po br co cobr	k y z q / I II III IV V V+	? Lapilli Tuff ?
109	3Bt1	a s / c w / g i / d b	(d) / (m)	(d) / (m)	m vf gr / sg f pl / 1 m p r / 2 c cpr / 3 vc abk / sbk	f r 0 / m sr 10 / sa 25 / c a 50 / 75 / 100	so po / ss ps / s p / vs vp; lo vfr fr fi vfi efi / lo so sh h vh eh	C / SC SiC / SCL CL SiCL / LS SL L SiL / S Si	v1 1 2 3 / f d p / pf po br co cobr	k y z q / I II III IV V V+	Red siltstone
130	3Bt2/C	a s / c w / g i / d b	(d) / (m)	(d) / (m)	m vf gr / sg f pl / 1 m p r / 2 c cpr / 3 vc abk / sbk	f r 0 / m sr 10 / sa 25 / c a 50 / 75 / 100	so po / ss ps / s p / vs vp; lo vfr fr fi vfi efi / lo so sh h vh eh	C / SC SiC / SCL CL SiCL / LS SL L SiL / S Si	v1 1 2 3 / f d p / pf po br co cobr	k y z q / I II III IV V V+	Reddish gray w/ ltgy. rounded mottles siltstone Few floating clasts of rounded gravel, wt'd.

Notes:

SOIL PROFILE DESCRIPTION

William Lettis & Associates, Inc.

Profile: SP-4 Site: LBL Building 25 T-2

Elevation: Slope: Job #: 2072

Site description:

Date: 7-29-09
Time:
By: JM Sowers

Depth (cm)	Horizon	Boundary	Color dominant	Color mottles	Structure	Gravel size rnd %	Consistence wet moist dry	Texture	Clay films	Salts & silica	Notes: (pores, roots, HCl test samples, pH, etc.)
169	3C2	a s / c w / g i / d b	(d) / (m)	(d) / (m)	m vf gr / sg f pl / 1 m p r / 2 c cpr / 3 vc abk / sbk	f r 0 / m sr 10 / c sa 25 / a 50 / 75 / 100	so po lo / ss ps vfr so / s p fr sh / vs vp fi h / vfi vh / efi eh	C / SC SiC / SCL CL SiCL / LS SL L SiL / S Si	v1 f pf / 1 po / d 2 br / 3 p co / cobr	k I / y II / z III / q IV / V / V+	Weathered conglomerate, mixed lithology. most clasts can be cut w/ knife
181	3C3	a s / c w / g i / d b	(d) / (m)	(d) / (m)	m vf gr / sg f pl / 1 m p r / 2 c cpr / 3 vc abk / sbk	f r 0 / m sr 10 / c sa 25 / a 50 / 75 / 100	so po lo / ss ps vfr so / s p fr sh / vs vp fi h / vfi vh / efi eh	C / SC SiC / SCL CL SiCL / LS SL L SiL / S Si	v1 f pf / 1 po / d 2 br / 3 p co / cobr	k I / y II / z III / q IV / V / V+	Gray siltstone
191	3C4	a s / c w / g i / d b	(d) / (m)	(d) / (m)	m vf gr / sg f pl / 1 m p r / 2 c cpr / 3 vc abk / sbk	f r 0 / m sr 10 / c sa 25 / a 50 / 75 / 100	so po lo / ss ps vfr so / s p fr sh / vs vp fi h / vfi vh / efi eh	C / SC SiC / SCL CL SiCL / LS SL L SiL / S Si	v1 f pf / 1 po / d 2 br / 3 p co / cobr	k I / y II / z III / q IV / V / V+	Weathered sandy conglomerate
		a s / c w / g i / d b	(d) / (m)	(d) / (m)	m vf gr / sg f pl / 1 m p r / 2 c cpr / 3 vc abk / sbk	f r 0 / m sr 10 / c sa 25 / a 50 / 75 / 100	so po lo / ss ps vfr so / s p fr sh / vs vp fi h / vfi vh / efi eh	C / SC SiC / SCL CL SiCL / LS SL L SiL / S Si	v1 f pf / 1 po / d 2 br / 3 p co / cobr	k I / y II / z III / q IV / V / V+	
		a s / c w / g i / d b	(d) / (m)	(d) / (m)	m vf gr / sg f pl / 1 m p r / 2 c cpr / 3 vc abk / sbk	f r 0 / m sr 10 / c sa 25 / a 50 / 75 / 100	so po lo / ss ps vfr so / s p fr sh / vs vp fi h / vfi vh / efi eh	C / SC SiC / SCL CL SiCL / LS SL L SiL / S Si	v1 f pf / 1 po / d 2 br / 3 p co / cobr	k I / y II / z III / q IV / V / V+	
		a s / c w / g i / d b	(d) / (m)	(d) / (m)	m vf gr / sg f pl / 1 m p r / 2 c cpr / 3 vc abk / sbk	f r 0 / m sr 10 / c sa 25 / a 50 / 75 / 100	so po lo / ss ps vfr so / s p fr sh / vs vp fi h / vfi vh / efi eh	C / SC SiC / SCL CL SiCL / LS SL L SiL / S Si	v1 f pf / 1 po / d 2 br / 3 p co / cobr	k I / y II / z III / q IV / V / V+	

Notes:

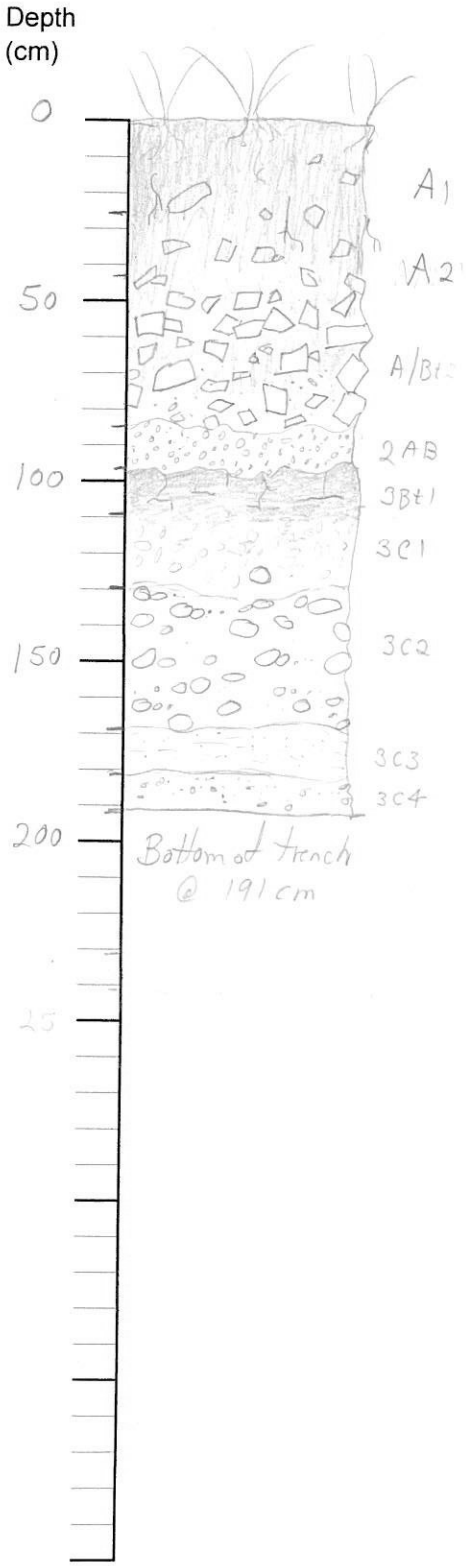
SOIL FIELD SKETCH

Soil SP-4

Site LBL Building 25

Job 2072

Page 3 of 3

By JMSawyers

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