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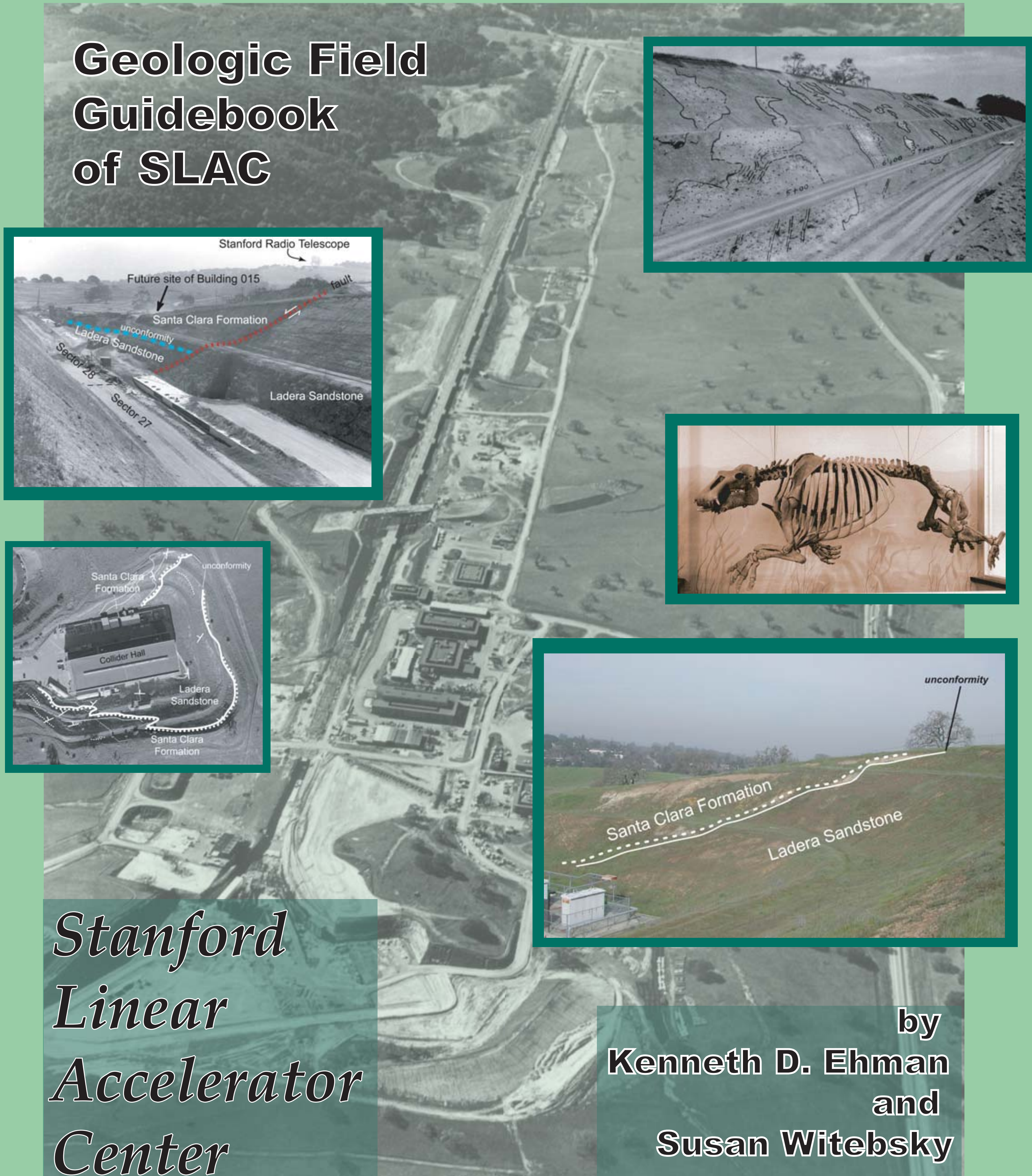
SLAC-I-750-2A32H-015

Geologic Field Guidebook of SLAC



Stanford Linear Accelerator Center

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Geologic Field Guidebook of Stanford Linear Accelerator Center

By Kenneth D. Ehman[1] and Susan Witebsky[2]

TABLE OF CONTENTS

1.0 Introduction to SLAC 1
2.0 Geology of SLAC 2
2.1 Introduction....................2
2.2 Regional Geologic Setting 3
2.2.1 Introduction....................3
2.2.2 Stratigraphy Overview 3
2.2.3 Regional Structural Features....................4
2.3 Overview of Field Stops 4
3.0 Field Stops 12
3.1 Sectors 26 – 27 (North Side), Whiskey Hill Formation – Ladera Sandstone 12
3.1.1 Stop Overview 12
3.1.2 Geology of Sectors 26 – 27 Area....................12
3.1.3 Groundwater Flow at SLAC 14
3.2 Sectors 18 – 20, Service Road, Miocene-aged Claystone (Monterey Formation) 21
3.2.1 Stop Overview 21
3.2.2 Geology of the Sector 18 – 20 Area 21
3.2.3 Biostratigraphic Analysis and Results 22
3.2.4 Native Fill 23
3.2.5 Regional Mineralization and Alteration 24
3.2.6 Acidic Groundwater....................25
3.3 Sectors 0 – 11, Whiskey Hill Formation....................33
3.3.1 Overview....................33
3.3.2 Age of the Whiskey Hill Formation....................33
3.3.3 Whiskey Hill Formation Stops....................33
3.4 Sector 28 (South Side) Santa Clara Formation – Ladera Sandstone 39
3.4.1 Stop Overview 39
3.4.2 Geology of the Sector 28 Area 39
3.4.3 Test Lab Fault 40
3.5 Research Yard – Ladera Sandstone 45

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3.5.1 Stop Overview 45
3.5.2 Geology of the Research Yard Area 45
3.6 Eastern SLAC: Santa Clara Formation – Ladera Sandstone – Page Mill Basalt....51
3.6.1 Stop Overview 51
3.6.2 Geology of the Eastern SLAC Area....51
4.0 References Cited....59

LIST OF FIGURES

Figure 1	Location map of SLAC
Figure 2a	Generalized geologic map of SLAC area showing field stops
Figure 2b	Regional east – west geologic cross section of SLAC Area
Figure 3	Oblique aerial photograph of SLAC excavation, 1965
Figure 4	Photo of SLAC excavation, 1963
Figure 5	Portion of the geologic map of ABA (1965), Sectors 26 and 27
Figure 6	Conceptual geologic block diagram, SLAC area
Figure 7	Geologic map of the FSUST and Sectors 26 – 27 area
Figure 8	Photograph of outcrops of Ladera Sandstone, Sector 27, north side
Figure 9	Cross section B-B’, FSUST area
Figure 10	Regional groundwater elevation map for SLAC
Figure 11	Effects on groundwater caused by subdrainage system
Figure 12	Geologic map of the Clean Landfill Area
Figure 13	Oblique photo of Clean Landfill Area
Figure 14a	Outcrop of Miocene-aged claystone, Sector 18 Service Road
Figure 14b	Groundwater seep in Miocene-aged claystone
Figure 15	Estimated thickness of Clean Landfill native fill material
Figure 16	Groundwater elevation and pH map of the Clean Landfill Area
Figure 17	Geologic cross sections of the Clean Landfill Area
Figure 18	Photographs of Whiskey Hill Formation “chaotic facies” from Page and Taber (1967)
Figure 19	Geologic map of Sectors 11 – 12 from ABA (1965).
Figure 20	Geologic map of Sectors 0 – 4 from ABA (1965)
Figure 21	Photograph of Rattlesnake Rock, Jasper Ridge
Figure 22	Geologic map of the FHWSA
Figure 23	Geologic cross sections of the FHWSA
Figure 24	Photograph of Sector 28 outcrop showing fault
Figure 25a	Photograph of SLAC excavation from 1964 showing Test Lab Fault
Figure 25b	Geologic cross section from Page and Tabor (1967)

Figure 26	Photograph of Research Yard excavation from 1963
Figure 27	Photograph of *Paleoparadoxia*
Figure 28	Photograph of Ladera Sandstone beds in the Research Yard excavation
Figure 29a	Photograph of trough cross bedded sandstone, Ladera Sandstone
Figure 29b	Photograph of wavy storm beds of Ladera Sandstone
Figure 29c	Photograph of *Ophiomorpha* trace fossils, Ladera Sandstone
Figure 30	Photograph of core from Ladera Sandstone
Figure 31	Photograph of Collider Hall excavation, 1985
Figure 32	Aerial photo showing geology of the Collider Hall area
Figure 33	Photograph of north side of Collider Hall excavation
Figure 34a	Photo of chert pebble gravel if Santa Clara Formation
Figure 34b	Photograph of cobbles Santa Clara Formation
Figure 35	Lithologic log from MW-57
Figure 36a	Photograph of interbedded Ladera Sandstone and Page Mill Basalt, Alpine Road
Figure 36b	Photograph of Page Mill Basalt, Page Mill quarry off old Page Mill Road

Geologic Field Guidebook of Stanford Linear Accelerator Center

1.0 Introduction to SLAC

Stanford Linear Accelerator Center (SLAC) is a national research facility whose mission is the study of the basic properties of matter. It is owned and operated by Stanford University for the U.S. Department of Energy. The facility is located in San Mateo County on 426 acres of low, rolling foothills between the alluvial plain to the east and the Santa Cruz Mountains to the west (Figure 1).

This field guidebook has been designed to provide an overview of the geology of the SLAC area. Figure 2a is a generalized geologic map of the SLAC area showing the field stops. Figure 2b is a generalized east – west geologic cross section and illustrates the stratigraphic and structural relationships exposed at SLAC.

The authors would like to thank the many people who have contributed to the understanding of the geology of SLAC. Helen Nuckolls, Micki DeCamara, Dellilah Sabba, and Dwight Harbaugh of the Environmental Protection Department of the Environmental Health and Safety Division of SLAC have provided much of the information presented in this report. Discussions with Rick Stanley, Earl Brabb, Bob McLaughlin of the U. S. Geological Survey, and Ben Page and Bob Coleman of Stanford University, and Léo Laporte of U. C. Santa Cruz provided much insight into the regional geologic setting of SLAC. Carey Peabody and her colleagues at Erler and Kalinowski, Inc. have provided expertise to help solve many of the environmental problems at SLAC and made significant contributions to the understanding of the geology of SLAC. Will Neal of Geochem Applications provided insights into the origin of acidic groundwater at Sectors 18 – 20. Special thanks to Ray Cowan of SLAC for showing us the Page Mill Basalt at the old Page Mill Quarries. We finally would like to thank Fred Conwell, one of the authors of ABA (1965), for providing us with historical documents and photographs of SLAC during construction during the early 1960s.

2.0 Geology of SLAC

2.1 Introduction

Figure 2a is a generalized geologic map showing the field stops for this guidebook. The understanding of the geology and hydrogeology of SLAC is based on over forty years of geotechnical investigations related to constructing SLAC facilities and over ten years of environmental restoration investigations. Pre-construction geological investigations for siting of the two-mile long linear accelerator (as known as the Linac) began in 1959, and continued into the mid-1960's (Blume and Associates, 1960; Tabor, 1961; 1962). These early investigations focused on how the subsurface environment would affect siting, construction, and operation of the linear accelerator. A two-mile trench was excavated during the construction of SLAC in the early 1960's (Figures 3 and 4). This excavation was logged in detail and a geologic map was constructed as part of ABA (1965) (Figure 5). This geologic map is still considered state-of-the-art and is used extensively in projects today.

Geological and hydrological investigations of the eastern portion of the SLAC site were performed in 1975 and 1982 to gather data for the siting and construction of two additional underground experimental facilities, the Positron Electron Project (PEP) and the Stanford Linear Collider (SLC) (Dames and Moore, 1977; 1981; ESA, 1975; 1982; 1983).

Construction of the underground portions of the experimental facilities at SLAC required extensive information on the geology underlying the site. Numerous studies were performed with the goal of determining how the geologic environment would affect construction and the integrity of the underground tunnels. Information on the subsurface environment was obtained through the drilling of almost two hundred boreholes. A small percentage of the boreholes were converted into groundwater monitoring wells to determine the groundwater elevation and its impact on tunneling operations. These monitoring wells were subsequently destroyed.

Since the early 1990’s, over 100 groundwater monitoring and extraction wells have been installed at SLAC as part of the environmental restoration program. In addition to the wells, hundreds of samples from soil borings have been collected and thousands of chemical analyses have been performed on soil, rock, and groundwater samples. A background metals study was completed for soil at SLAC (EKI, 2003). Four major site investigations have been completed as of 2006: 1) the Former Solvent Underground Storage Tank Area (FSUST) (SLAC, 2002a), 2) the Test Lab/Central Lab Area (SLAC, 2002b), 3) the Plating Shop Area (SLAC, 2003), and 4) the Former Hazardous Waste Storage Area (FHWSA) (SLAC, 2004a). All the data from these site investigations, as well as other investigations, have been integrated into our understanding of the geology and hydrogeology of SLAC. The geology of the eastern part of SLAC is summarized in SLAC (2006).

2.2 Regional Geologic Setting

2.2.1 Introduction

SLAC is located in the foothills of the Santa Cruz Mountains on the San Francisco Peninsula of California. The peninsula is part of the California Coast Ranges, a tectonic province characterized by active strike-slip and compressional tectonics. The foothills are separated from the main mass of the mountains by the San Andreas fault that is located west of SLAC (Figure 2a).

SLAC is underlain by marine sedimentary rocks, consisting mainly of sandstones, siltstones, and shales that exceed 1.9 miles in thickness west of the San Andreas fault, and are up to 1.2 miles thick east of the San Andreas Fault (Dibblee, 1966; Brabb and Pampeyan, 1983, Brabb and others, 2000). These marine rocks generally range in age from Eocene to Miocene (55 to 5 million years old). Unconformably overlying the above marine units are non-marine silts, sands, and gravels of the Santa Clara Formation of late Pliocene to Pleistocene age (about 2 million to 100,000 years old; Brabb and Pampeyan, 1983; Pampeyan, 1993) which has limited exposure at SLAC. Alluvial deposits and landslides are also present in the region. A conceptual geologic block diagram of the SLAC area is shown on Figure 6.

Franciscan Complex rocks, present to the south and west of the site, are Jurassic to Cretaceous in age (165 to 65 million years old) and consist mainly of metabasalt, serpentinite, shale, and sandstone (Coleman, 2004).

Other stratigraphic units present at SLAC include the Page Mill Basalt which separates the Ladera Sandstone and Whiskey Hill Formation on the far eastern portion of the SLAC property.

2.2.2 Stratigraphy Overview

The Whiskey Hill Formation is exposed in the western part of SLAC. An angular unconformity between the Miocene and Eocene rock units suggests the Eocene rocks were folded prior to the deposition of the overlying Miocene rocks. The Whiskey Hill Formation is characterized by normal bedded sandstone and mudstone sequences and "chaotic" zones of mixed lithology. Chaotic zones are composed of a mudstone matrix with blocks consisting mainly of sandstone. A few exotic blocks that have no resemblance to any of the Eocene rocks are present within the chaotic zone and consist of metabasalt, quartzite, and granitic rocks. The Whiskey Hill Formation was probably deposited in a deep-marine slope and basin.

Exposures of Page Mill Basalt are restricted to the easternmost part of the SLAC property along Alpine Road. The Page Mill Basalt is best exposed east of SLAC along Radio Telescope Hill and in the old quarries off Old Page Mill Road. Here the unit consists of a series of alternating breccias and olive-green to deep blue-gray massive basalt flows with occasional vesicular beds of a maximum thickness of approximately 600 feet. The Page

Mill Basalt separates the underlying Whiskey Hill Formation from the overlying Ladera Sandstone, however a thin Ladera-like sandstone is locally present under the basalt.

The Miocene-aged Ladera Sandstone occupies a broad syncline in contact with the Eocene rocks to the west and the Page Mill Basalt on the east. The Ladera rests unconformably on the Page Mill Basalt east of SLAC, however on the main SLAC campus, the Page Mill Basalt is absent and the Ladera Sandstone rests unconformably on the Whiskey Hill Formation. The Ladera Sandstone consists of marine silty sandstone to sandy siltstone. Paleoenvironmental indicators suggest that the Ladera Sandstone was deposited in a nearshore to open shelf marine environment.

The Pliocene to Pleistocene Santa Clara Formation unconformably overlies the Ladera Sandstone at scattered localities at SLAC. The largest exposure of Santa Clara Formation is on the eastern end of SLAC. Based on logged borings and outcrops, the unit can be described as generally uncemented, reddish brown gravel, sand, silt, and clay in lenticular beds. Gravels are typically composed of chert, sandstone, volcanic, and mudstone clasts. Siltstone and claystone beds occur locally.

2.2.3 Regional Structural Features

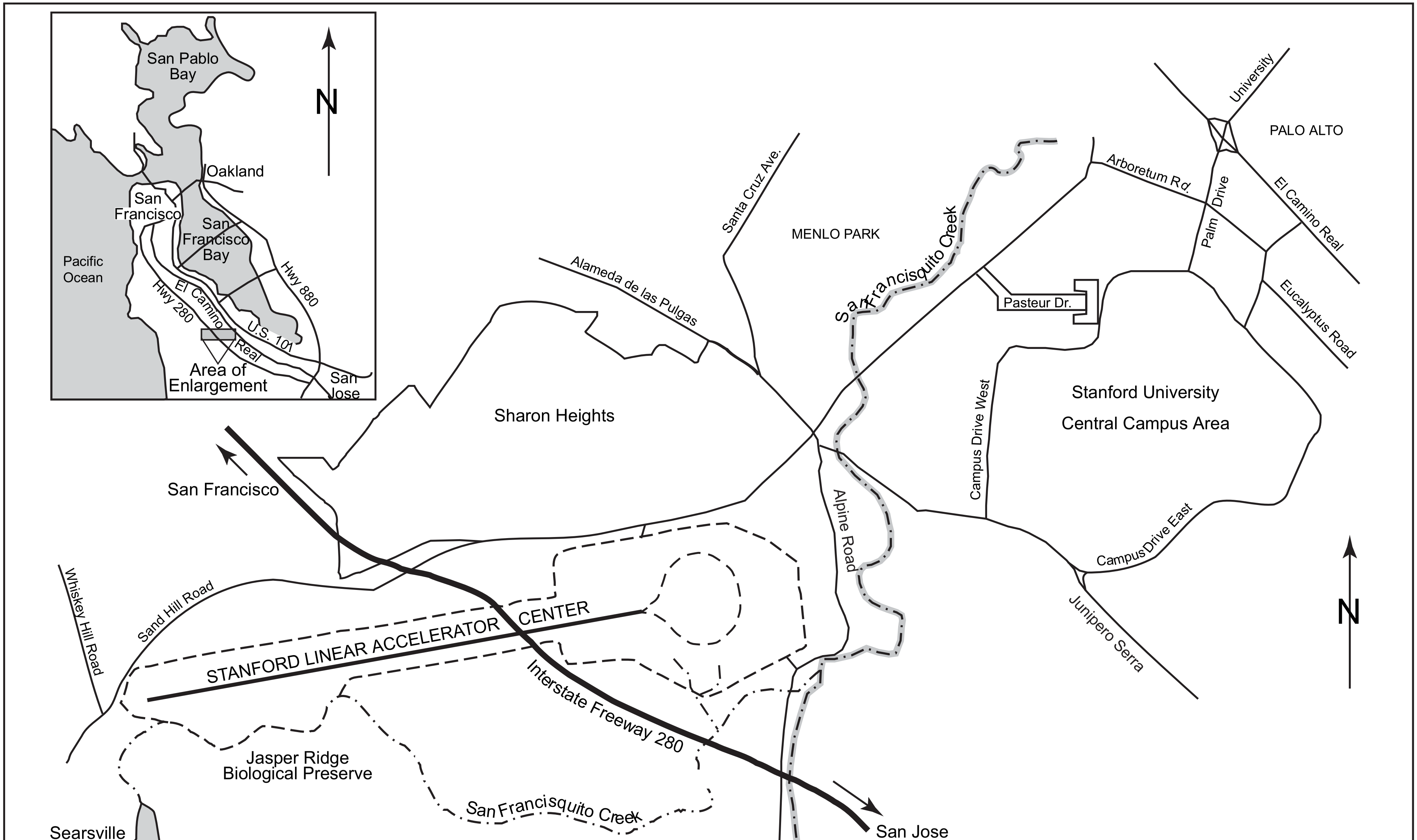
The Eocene and Miocene rocks exposed at SLAC are part of an active, east-vergent fold and thrust belt associated with the San Andreas fault system that underlies the foothills of the Santa Cruz Mountains (Brabb and Olsen, 1986, Kovach and Beroza, 1991). As a result, these rocks are folded and cut by numerous faults. Rocks of the foothills have been compressed into northwest-trending folds, which have been overridden by Mesozoic-age rocks along southwest-dipping low-angle faults (Figure 2a). Overlying the Eocene and Miocene sedimentary rocks are relatively undeformed upper Pleistocene and Holocene alluvial and estuarine deposits of the alluvial plain (Pampeyan, 1993; Helley and LaJoie, 1979).

The prevalent Quaternary folds and reverse faults, aligned sub parallel with the San Andreas Fault imply the existence of compressive stress normal to the plate, superimposed on the dominant northwest-southeast horizontal dextral shear that characterizes the transform plate boundary (Kovach and Page, 1995).

2.3 Overview of Field Stops

Field stops are shown on Figures 2a and 2b. Each stop is discussed in Section 3.0.

- Sectors 26 – 27 (North Side), Whiskey Hill Formation – Ladera Sandstone
- Sectors 18 – 20, Service Road, Miocene-aged Claystone (Monterey Formation)
- Sectors 0 – 11, Whiskey Hill Formation
- Sector 28 (South Side) Santa Clara Formation – Ladera Sandstone
- Research Yard – Ladera Sandstone
- Eastern SLAC: Santa Clara Formation – Ladera Sandstone – Page Mill Basalt
  Collider Hall



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Location map of SLAC

Date	Document Number	Figure No.
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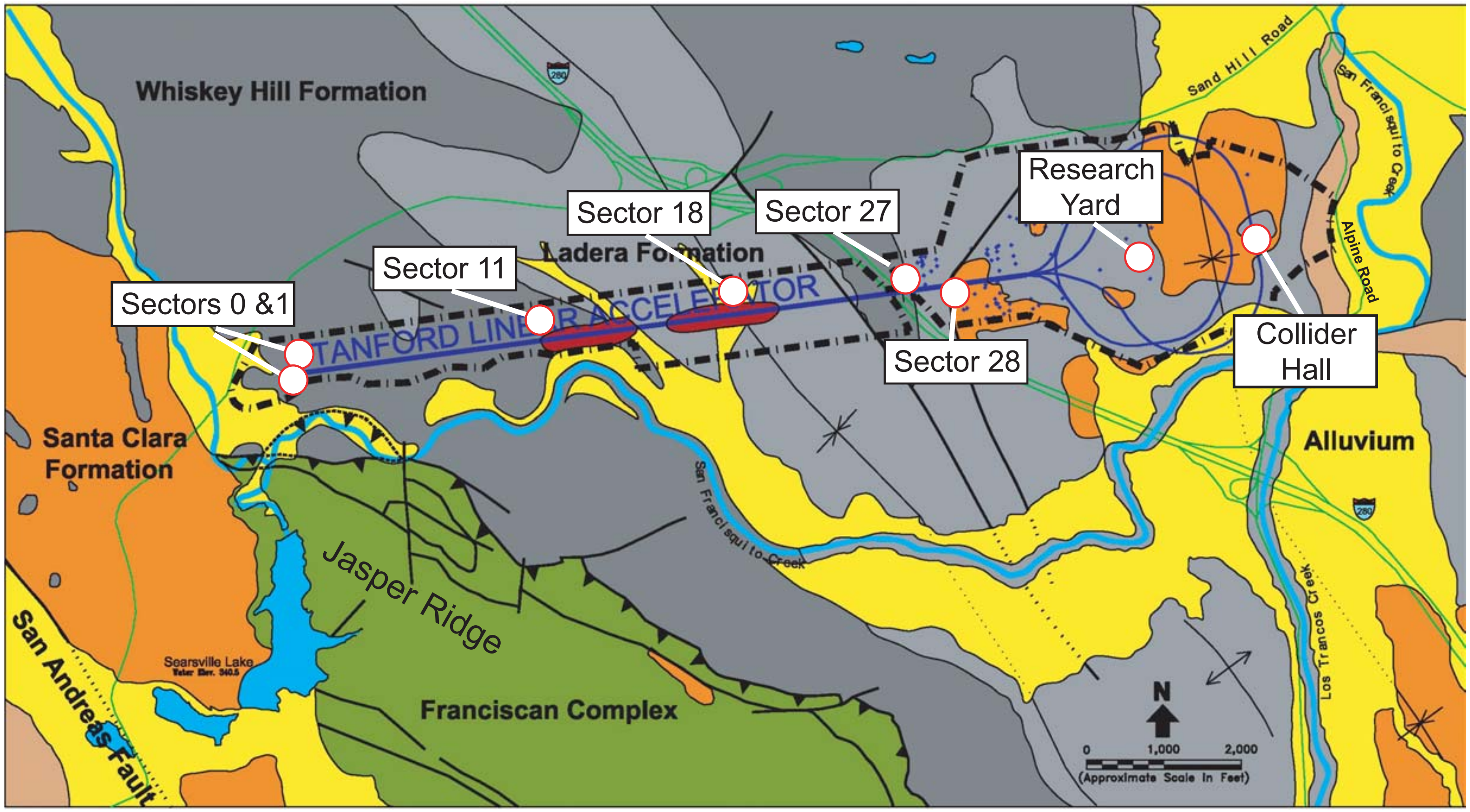

Explanation

Ladera Sandstone
(Miocene, 11 - 14 million years)

Page Mill Basalt
(Miocene, 14 million years)

Whiskey Hill Formation
(Eocene, 36 - 58 million years)

Franciscan Complex
(Jurassic - Cretaceous, 65 - 165 million years)

Native Fill*

Alluvium
(Recent)

Santa Clara Formation
(Pliocene - Pleistocene, 100,000 - 2 million years)

Fault
dashed where covered

Thrust fault
dashed where covered
(barbs on upper plate)

Stratigraphic contact
dashed where covered

Anticline
dashed where covered

Syncline
dashed where covered

*only shown along Linac, not shown on eastern SLAC

modified after Page (1993); Pampeyan (1993); SLAC (1994)

Field Stops

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Regional geologic map of the SLAC area		
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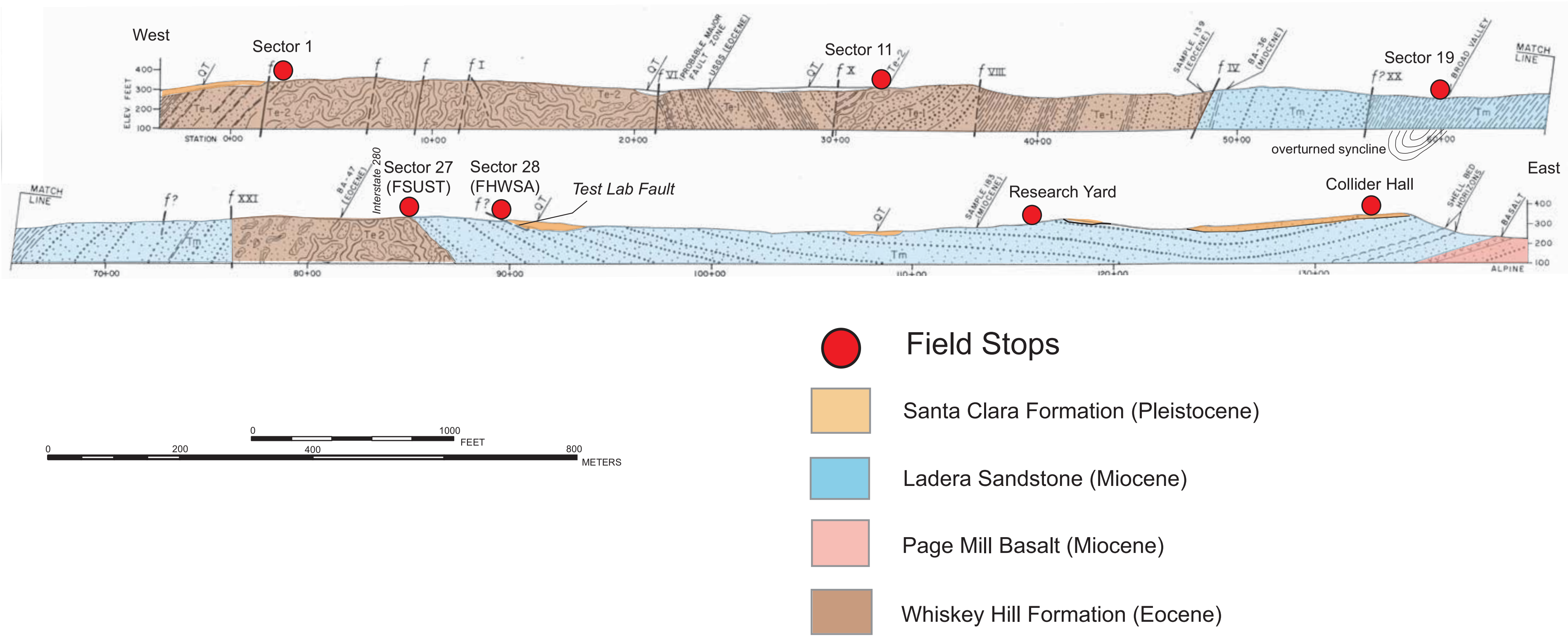

Modified from ABA (1965)

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Regional east - west geologic cross section of SLAC area

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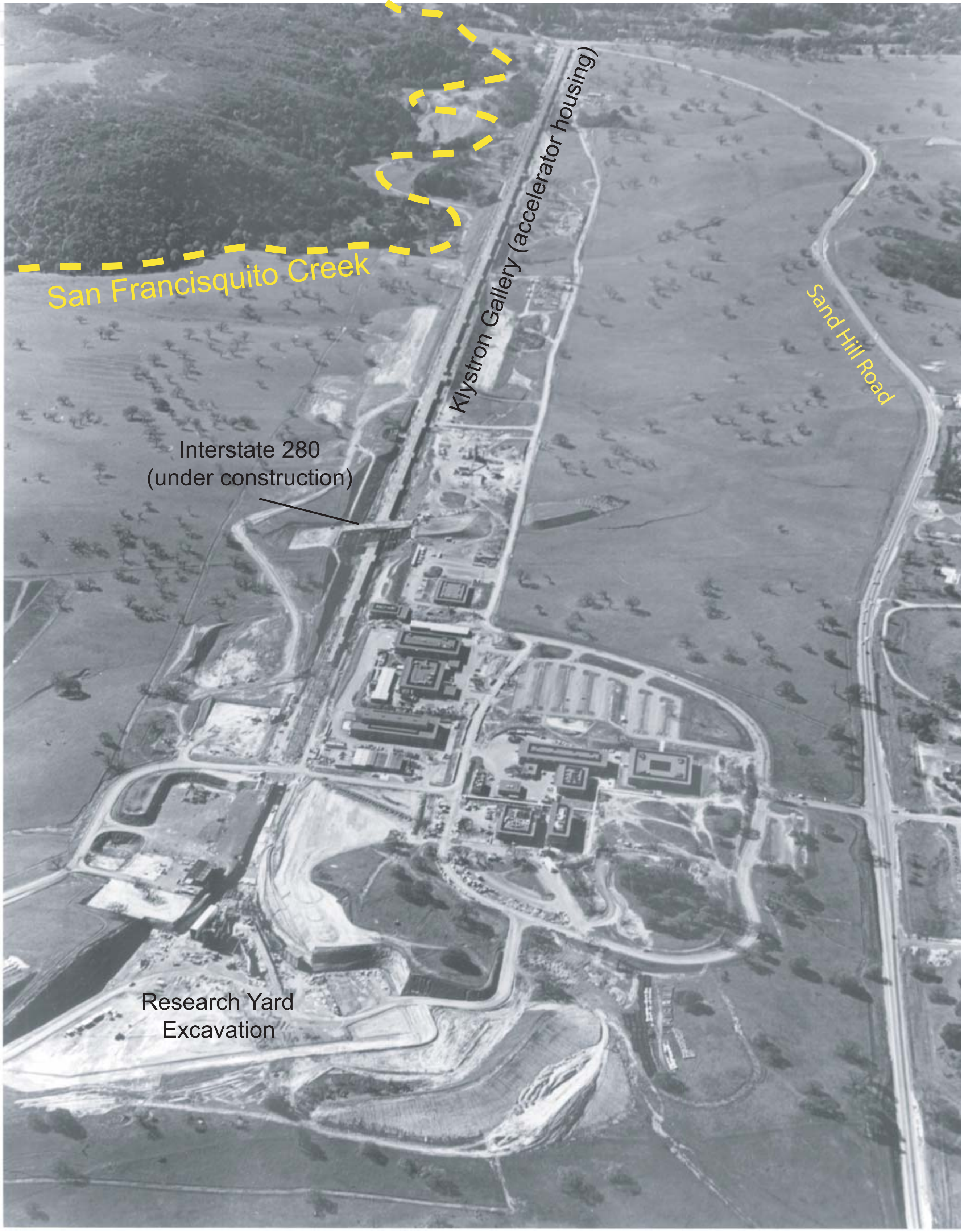


Photo: M1277
Date: 2-14-1965
Source: SLAC ER Photo Archive

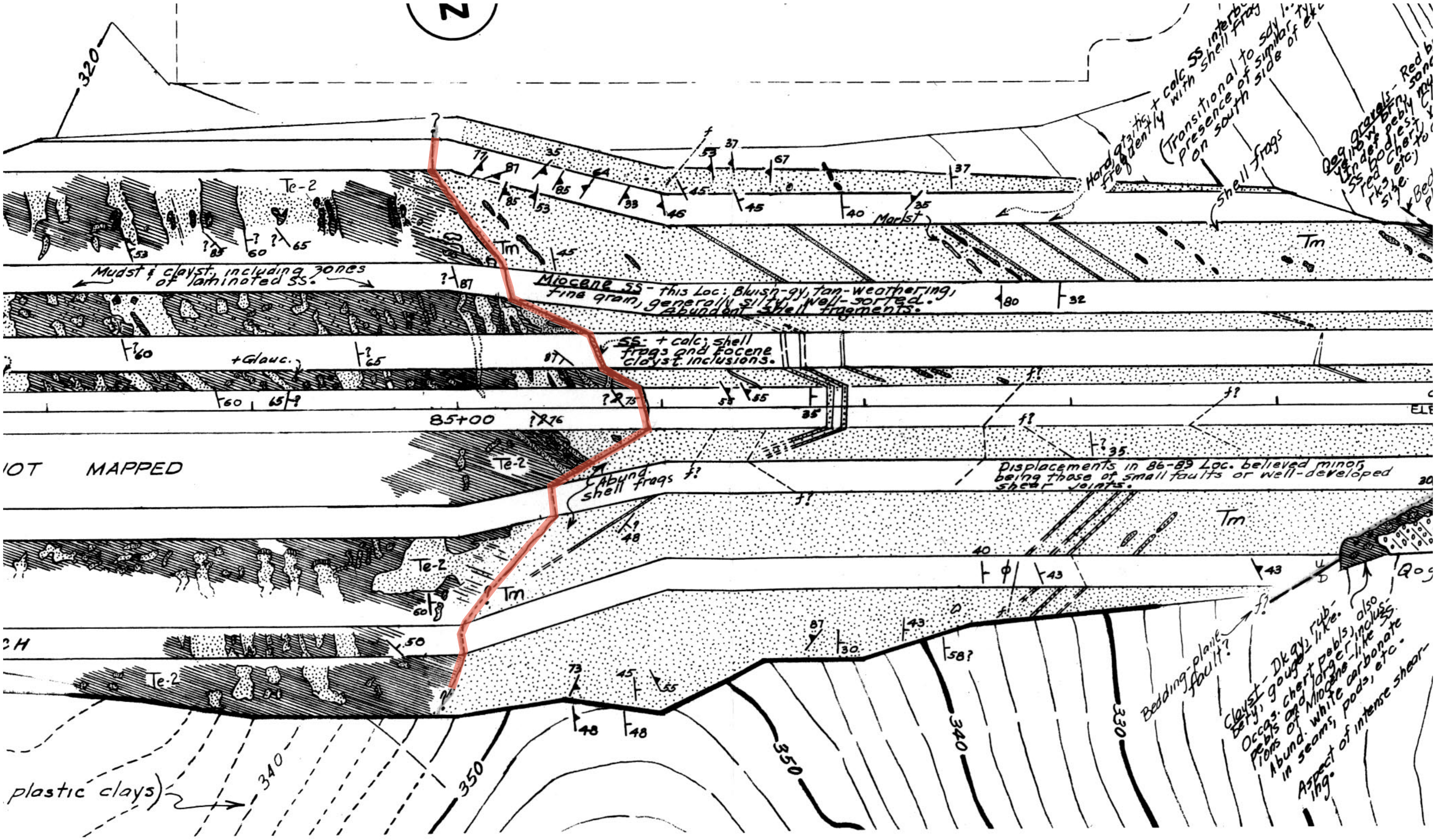
Oblique view of SLAC looking west during final stages of initial construction. Note the overpass for future Interstate 280.

Stanford Linear Accelerator Center Oblique aerial photo of SLAC excavation, 1965		
Date November 2006	Document Number SLAC-I-750-2A32H-015	Figure No. 3

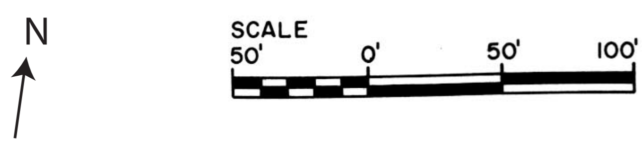
Photo: 51 M35-4
Date: 7-26-1963
Source: SLAC ER Photo Archive

View of excavation for accelerator housing, looking east from Sector 0. Completed section of housing sub-slab is shown. Eocene-aged Whiskey Hill Formation exposed in excavation.

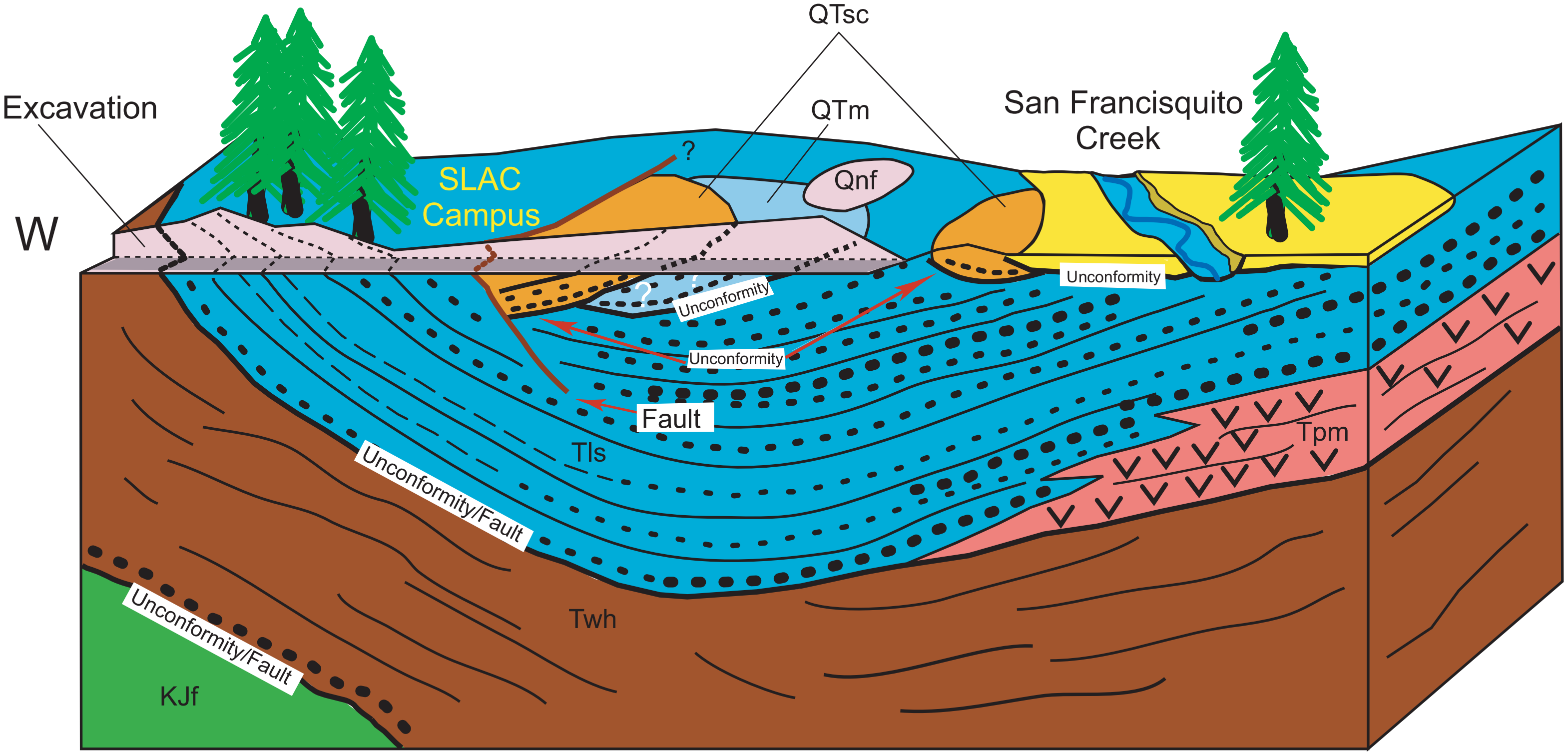
Stanford Linear Accelerator Center Photo of SLAC excavation, 1963		
Date November 2006	Document Number SLAC-I-750-2A32H-015	Figure No. 4



ABA (1965) geologic map showing Whiskey Hill Formation (Chaotic Facies - Te-2) overlain by Ladera Sandstone (Tm) along unconformity (?) shown in red.



Stanford Linear Accelerator Center Portion of the geologic map of ABA (1965), Sectors 26 and 27		
Date November 2006	Document Number SLAC-I-750-2A32H-015	Figure No. 5



not to scale

QTsc	Santa Clara Formation (Pleistocene)
QTm	Merced (?) Formation* (Pliocene)
Tls	Ladera Sandstone (Miocene)
Tpm	Page Mill Basalt (Miocene)
Twh	Whiskey Hill Formation (Eocene)
KJf	Franciscan Complex (Jurassic - Cretaceous)
Qnf	Native Fill
Qal	Alluvium (Recent)

* presence of Merced (?) Formation at SLAC uncertain.

Conceptual block diagram illustrating major stratigraphic - structural relationships between rock units in eastern SLAC area. Diagram not to scale. LINAC excavation contains Native Fill (Qnf) that has been removed to illustrate geology. Page Mill Basalt (Tpm) actually crops out on both east and west side of San Francisquito Creek. Franciscan Complex (KJf) does not crop out on SLAC property but is present at Jasper Ridge, southwest of SLAC (see Figure 2a).

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Conceptual geologic block diagram, SLAC area

Date	Document Number	Figure No.
November 2006	SLAC-I-750-2A32H-015	6

3.0 Field Stops

3.1 Sectors 26 – 27 (North Side), Whiskey Hill Formation – Ladera Sandstone

3.1.1 Stop Overview

The first stop is located on the north side of the linear accelerator at Sector 27 (Figure 2a and 2b). In the Sectors 26 – 27 area, the contact between the Eocene-aged Whiskey Hill Formation and overlying Miocene-aged Ladera Sandstone mapped by ABA (1965), dips between 35˚ to 45˚ to the east (Figure 7). This contact has been interpreted as both a fault (Page and Tabor, 1967) and an angular unconformity (ABA, 1965; Pampeyan, 1993). Today, this contact is covered by vegetation, but can be inferred by the subtle change in the slope of the excavation trench. Poorly-exposed, eastward dipping calcite cemented sandstone beds of the Ladera Sandstone are present at this location (Figure 8). These dipping beds are fine-grained and heavily fractured with calcite fracture fillings. Bedding is poorly defined with no definitive sedimentary structures.

3.1.2 Geology of Sectors 26 – 27 Area

Cross section B-B' extends across the FSUST Area and integrates all available subsurface data into a structural and stratigraphic model that is consistent with the geology exposed along the adjacent linear accelerator trench walls (Figures 7 and 9). Well data (both lithology and gamma ray log data) were projected into the line of cross section along the inferred strike of bedding. The well data can be correlated by incorporating the structural framework from the geologic mapping of the trench (ABA, 1965) with the borehole data of the site. The horizontal line at approximately 290 feet MSL on Figure 9 represents the elevation of the bench along the side of the accelerator that is now a service road. The underlying horizontal line at approximately 252 feet MSL represents the elevation of the subdrain beneath the linear accelerator (see section 3.1.3).

The Whiskey Hill Formation is penetrated by only one boring in the FSUST Area, MW-3, located in the parking lot south of Building 81 (Figure 7 and Figure 9). The absolute depth of the Ladera-Whiskey Hill Formation contact is uncertain; however the lithologic log and gamma ray log suggest the contact is at approximately 27 to 31 feet below ground surface (bgs). The Whiskey Hill Formation (below 31 feet) is described as dry tight gray clay, dry fine dark green sandy silt, and dark brown damp clay.

Within the Eocene formation, blocks of chaotic sandstone within sheared mudstone matrix ("Chaotic Facies") were observed and described in the linear accelerator trench adjacent to the FSUST Area by both ABA (1965) and Page and Tabor (1967) and are represented diagrammatically on Figure 9.

The contact between the Eocene Whiskey Hill Formation and Miocene Ladera Sandstone dips from 35˚ to 45˚ to the east. This contact has been interpreted both as a fault (Page and Tabor, 1967) and as an angular unconformity (Pampeyan, 1993). The contact is poorly exposed at present (possibly due to weathering since the accelerator trench was cut). Cross section B-B' (Figure 9) shows this contact as an unconformity. The contact is discordant and the Page Mill Basalt that separates the two formations along Alpine Road is missing.

The whole of the FSUST Area is underlain by the Ladera Sandstone, and all the monitoring wells and borings in the FSUST Area penetrate the Ladera Sandstone. In the FSUST Area, the Ladera Sandstone rests on the Whiskey Hill Formation (Figures 7 and 9), and mainly consists of fine-grained sandy siltstones to silty sandstones. The bedding dips approximately 45˚ east on the west side of the FSUST Area. The dip progressively shallows to approximately 32˚ east on the east side of Building 35.

The Ladera Sandstone is exposed along the accelerator trench walls to the south of the FSUST Area and was described in detail by ABA (1965) and Page and Tabor (1967). When the trench was excavated during the construction of the accelerator, the lithology of the Ladera Sandstone south of the FSUST Area was described as massive, light-colored, fine- to medium-grained sandstone that was well sorted and sparsely fossiliferous (ABA, 1965). ABA (1965) described thin, generally one to three feet thick, discontinuous concretionary beds of hard, calcite-cemented sandstone, as shown on Figure 9. Currently, the majority of the accelerator trench wall south of the FSUST Area is grass-covered with very sparse outcrop, except for cemented sandstones that crop out along the excavation walls.

Although lithologic descriptions exist for most of the borings and monitoring wells in the FSUST Area, the most complete lithologic data are from the continuous cores collected from MW-11 and MW-12 in 1997 (see Figure 7 for location). The unweathered Ladera Sandstone is composed of dark greenish gray to light olive gray, mottled sandy siltstone and silty sandstone that is soft and friable. Most of the samples collected for geotechnical analysis from the FSUST Area are classified as sandy siltstones (SLAC, 2002a).

The typical Ladera Sandstone observed in core is composed of intensely burrowed and homogenized sandy siltstone and silty sandstone. Well-defined bedding is rare because of the extensive bioturbation. If preserved, parallel laminations are the most common sedimentary structure, and rare fine ripple laminations are observed in the core from MW-11 and MW-12. Small pieces of thin shelled fossils are present throughout the core.

Less common are beds of cemented silty sandstone and sandstone that are preserved only as rubble zones in certain intervals of cores from MW-11 and MW-12. Hard, calcite or dolomite-cemented sandstones are also described from other boreholes (e.g. MW-9 at 60 feet bgs; SB-3 at 45 feet bgs). These well cemented sandstone beds probably represent the discontinuous, concretionary beds observed along the accelerator trench walls south of the FSUST Area (Figure 8).

There is a distinct color change in the Ladera Sandstone between the unweathered rock below approximately 30 feet bgs and the weathered rock above. The contact between the unweathered and weathered rock is gradational, with notable interstratified weathered and unweathered zones near the contact that appear to be in part controlled by lithology.

3.1.3 Groundwater Flow at SLAC

The regional groundwater elevation contours shown in Figure 10 indicate that groundwater generally flows to the southeast across the SLAC facility and towards San Francisquito Creek which is located to the south and east of SLAC. On the local scale, groundwater flow is strongly affected by the linear accelerator subdrainage system (Figure 11).

This system was installed during construction of the linear accelerator and consists of a 6-inch diameter perforated pipe at the base of a gravel wall on either side of the accelerator housing for its entire two mile length (Figure 11). The subdrainage system was designed to intercept groundwater along the accelerator housing in order to prevent water from "damming" up along the accelerator.

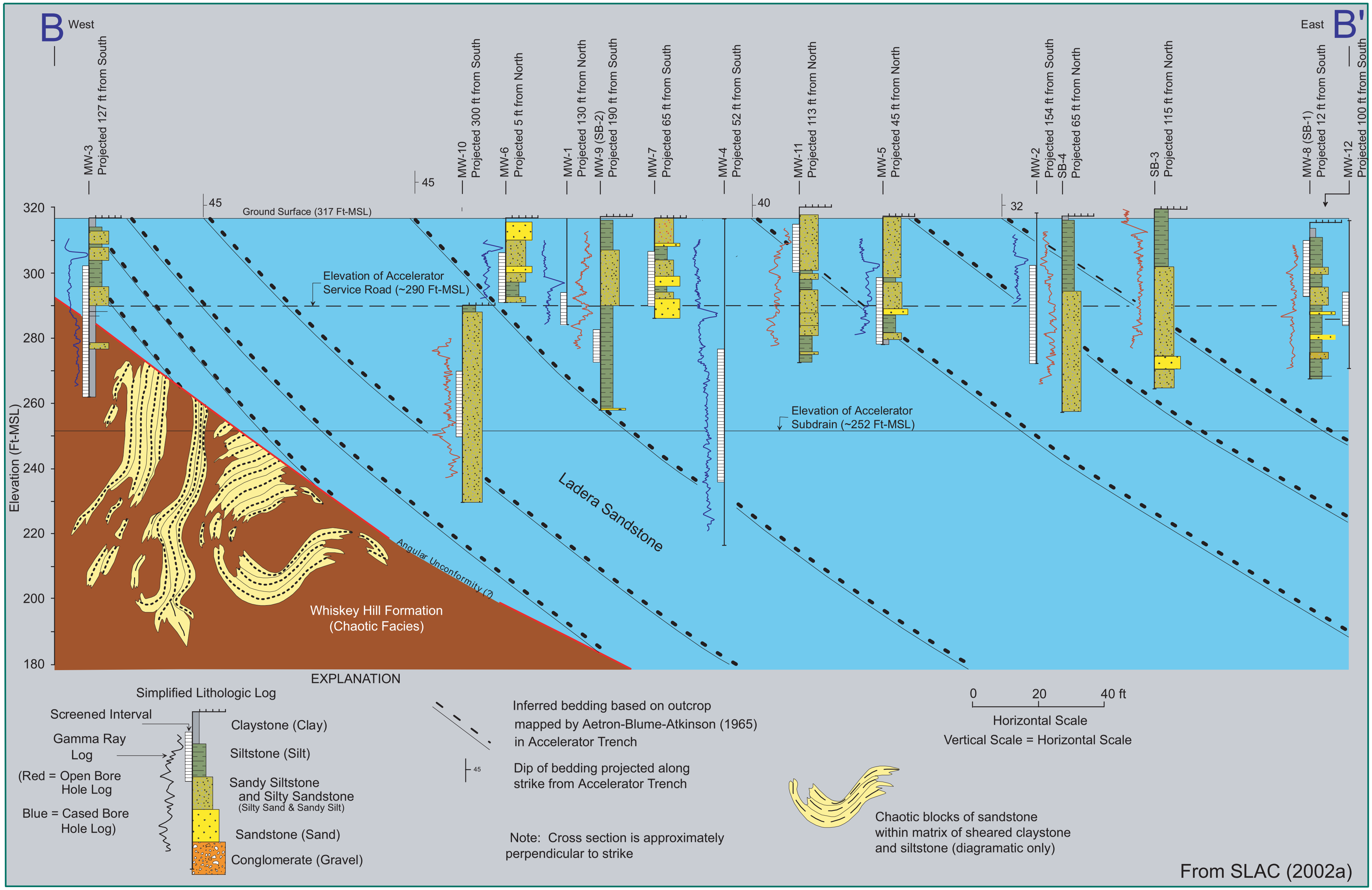
Groundwater does appear to be captured by the subdrainage system based on the observed groundwater gradient in the area of the linear accelerator. On the western side of Figure 10, immediately north of the accelerator, the groundwater flow direction changes from southeast (the regional flow direction) to south, toward the accelerator. Similarly, in the area south of the accelerator, the southeastern groundwater flow is deflected to the north, towards the accelerator (Figure 10).

Groundwater recharge into the Tertiary bedrock primarily occurs from surface infiltration, which is geographically limited to the undeveloped areas at SLAC and neighboring properties. In addition to groundwater discharging to the accelerator subdrainage system, groundwater in the Tertiary bedrock may also provide recharge to San Francisquito Creek.

Figure 7 (11x17)

Back of Figure 7

Stanford Linear Accelerator Center Photograph of outcrops of Ladera Sandstone, Sector 27, north side		
Date November 2006	Document Number SLAC-I-750-2A32H-015	Figure No. 8



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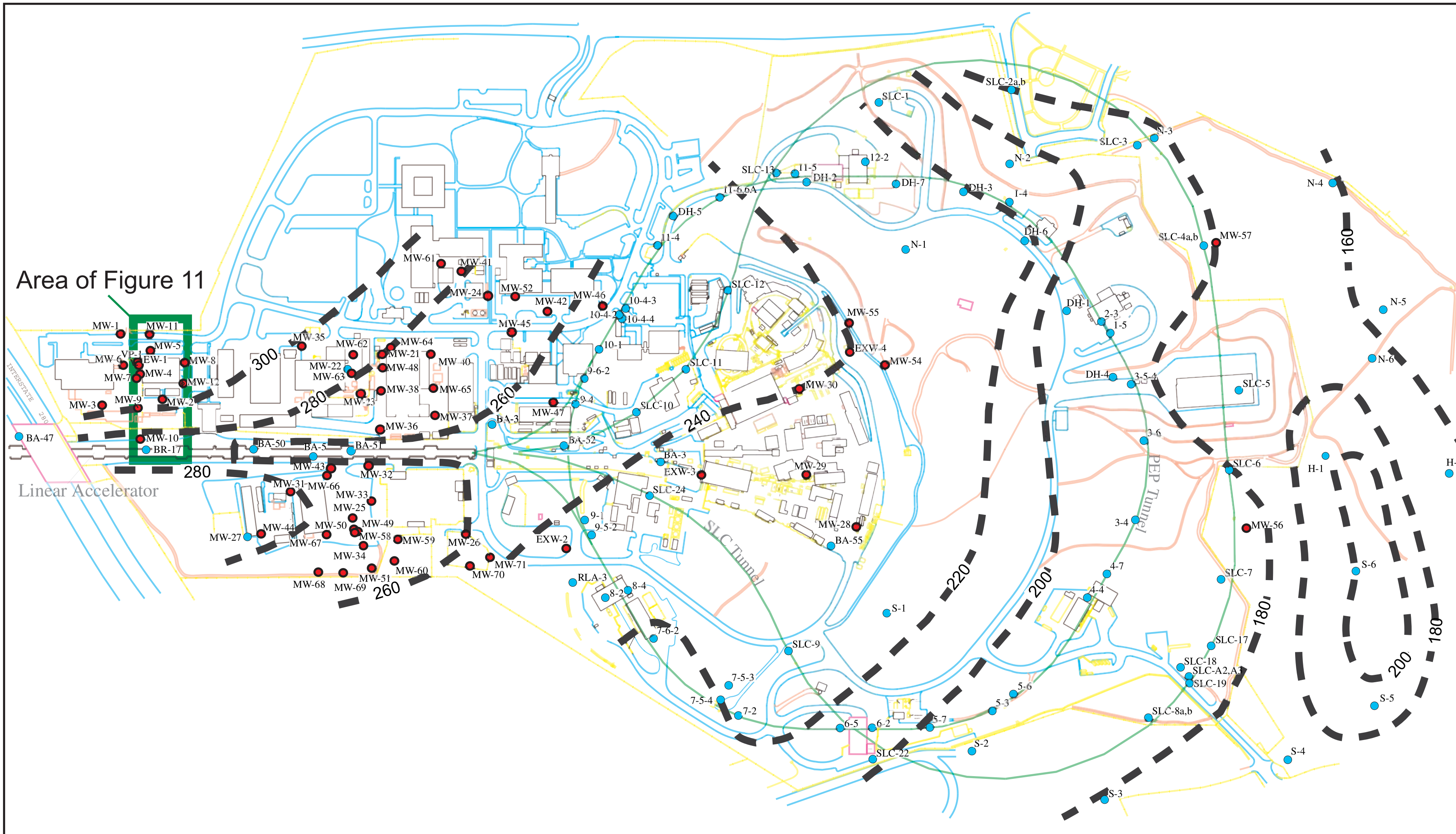
Cross section B-B', FSUST Area

Date	Document Number	Figure No.
November 2006	SLAC-I-750-2A32H-015	9



EXPLANATION

MW-11 Existing Monitoring Well

9-6-2 Historic (Destroyed) Monitoring Well

260 Groundwater Elevation Contour (feet, Mean Sea Level)

N

0 200 400 600 ft

SCALE

From SLAC (2002a)

STANFORD LINEAR ACCELERATOR CENTER		
Regional groundwater elevation contour map		
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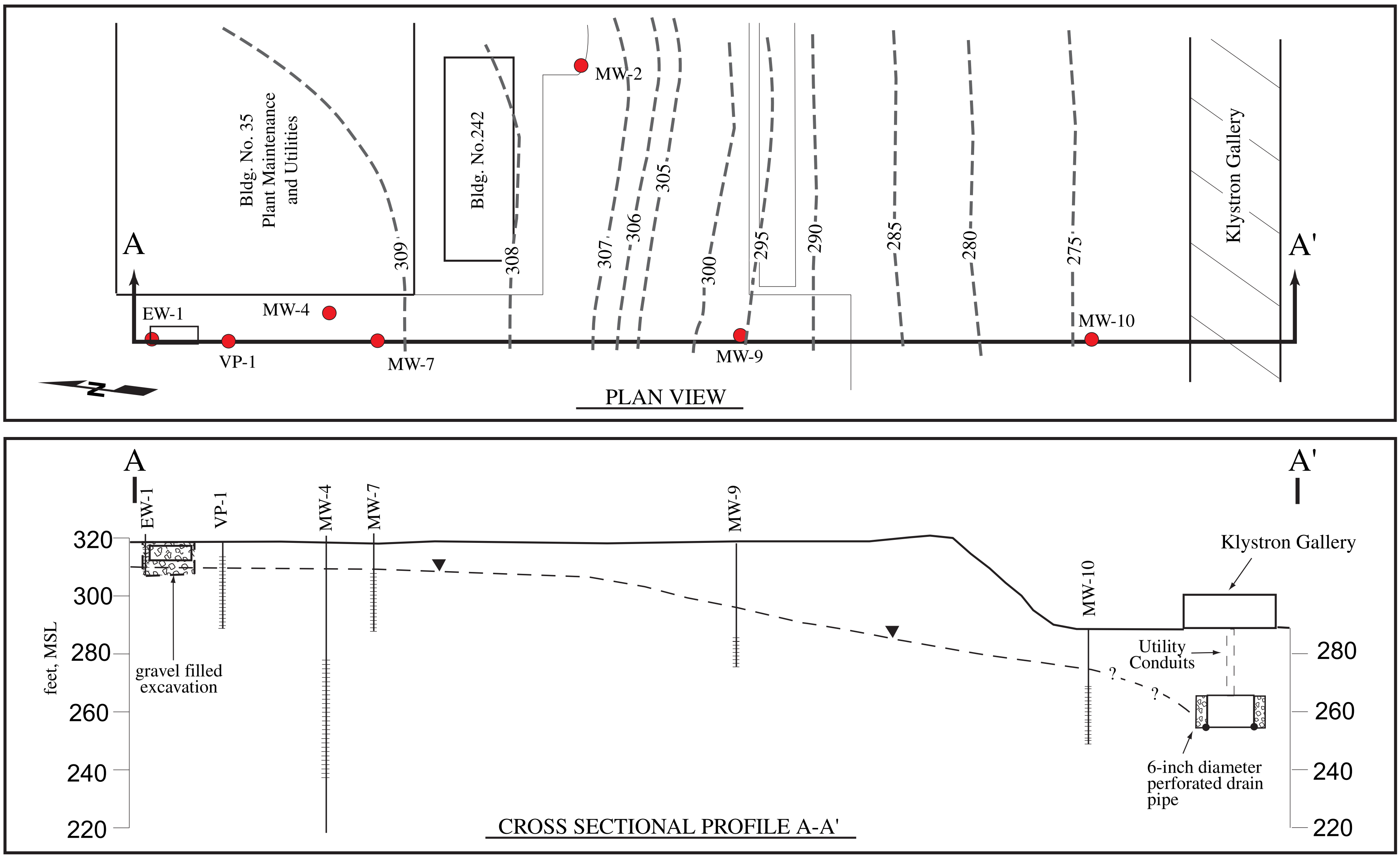

EXPLANATION

MW-1 Monitoring well (Plan view)

well screen Monitoring well (Cross section)

Groundwater elevation

280 Groundwater elevation contour (ft, MSL, based on August 1997 well data)

0 50 ft

Scale

Vertical to Horizontal = 1:1

From SLAC (2002a)

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Effects on groundwater caused by subdrainage system

Date	Document No.	Figure No.
November 2006	SLAC-I-750-2A32H-015	11

3.2 Sectors 18 – 20, Service Road, Miocene-aged Claystone (Monterey Formation)

3.2.1 Stop Overview

Presently, the Miocene-aged claystone, probably equivalent to the Monterey Formation, can be observed along a road cut at the service road north of Sector 19 and within the drainage channel on the south side of the Clean Landfill near the SLAC property boundary (Figure 2a and 2b). The presence of this claystone is critical in the understanding of anomalous acidic groundwater observed in this area. During the excavation of the SLAC trench, a swath of claystone was exposed. These exposures were subsequently covered with native fill over the "broad valley," the topographic low that is observed to the south of the stop. The broad valley is one of the largest areas of native fill at SLAC.

3.2.2 Geology of Sector 18 – 20 Area

The geology of the Sector 18 - 20 area was first described by Tabor (1961; 1962) and updated in ABA (1965). The detailed geologic map of ABA (1965) shows the exposures of rock units along the linear accelerator excavation as well as road cuts and borehole locations. Two rock units were defined by ABA (1965) in this area: Miocene-aged sandstone and Miocene-aged claystone. Both of these units were subsequently grouped within the Ladera Sandstone by Pampeyan (1993) after Beaulieu (1970). During the construction of SLAC, native fill was used to grade the area over the broad valley and this fill covers all the excavated exposures of the Miocene-aged claystone along the linear accelerator. Figure 12 shows the current geologic map of the area modified after ABA (1965) and Pampeyan (1993) and shows the borehole locations used to modify the map (SLAC, 2004).

ABA (1965) mapped two areas of Miocene-aged sandstone in the study area, one on the west at Sector 18 and one on the east at Sector 21 with the Miocene-aged claystone separating the two exposures (Figure 12). These exposures are now covered by native fill. The sandstone is interpreted to be on the limbs of a syncline, with the claystone in the axis of the syncline. The sandstone unit is described as containing thick- to massive-bedded, light-colored, generally fine-to-medium grained sandstones with minor thin interbeds of claystone or siltstone. The contact with the underlying Eocene Whiskey Hill Formation (to the west of Figure 12) was mapped as a fault, though the contact relationship is not clear.

Fresh claystones are dark gray to dull black but weather to light gray, olive brown and olive green near to surface. From the boreholes, the claystone unit is described as an assemblage of olive gray to black, hard, silty claystones, claystones, siltstones, and clayey siltstones that are intensely fractured (ABA, 1965). Disseminated pyrite and fracture filling pyrite crusts were described in a number of the boreholes. For example, in BA-44, (see Figure 12 for location) a zone of selenite-coated fractures was described at 15 to 20 feet depth (relative to pre-SLAC topography, approximately 242 - 248 feet mean sea level (msl). Below 20 feet, (242 feet msl) the fractures have a "pyrite crust." BA-44 is located within the low-pH groundwater area, approximately 70 feet southeast of MW-53, a well with consistently low pH groundwater. A yellow fracture-filling mineral was observed in a number of the samples collected by SLAC (2004b), and X-ray diffraction analysis indicates that this mineral is jarosite, a weathering by-product of pyrite. Disseminated and fracture-filled gypsum was also observed in many of the soil samples (SLAC, 2004b).

Bedding is steeply dipping to the southwest between 60 and 70 degrees, and BA-44 is more or less on strike with MW-53. MW-53 is screened from approximately 250 to 260 feet msl, almost at the same depth as the "pyrite crust" described in BA-44. Other boreholes contained fractures filled with jarosite.

Presently, the claystone unit is observed in outcrop in two areas (Figures 12 and 13). An outcrop of yellow-brown weathered claystone is observed at this stop (Figure 14a) (along the service road immediately north of CLF-B-1). This outcrop is heavily fractured and ABA (1965) measured a strike and dip from this location as shown on Figure 12 (note that the strike and dip is uncertain because of the difficulty of differentiating bedding and fractures in this area). The other outcrop is observed on the south side of the Clean Landfill Area within a channel that runs along the south boundary of the fill near the property line at Sector 19.5 (Figure 14b). Here stagnant pools of acidic water collect above exposed bedrock of yellow-brown weathered claystone along seeps. No bedding is observed, but the claystone appears fractured.

3.2.3 Biostratigraphic Analysis and Results

ABA (1965) reported a Miocene age based on foraminifera collected from BA-6, BA-44, TB-13, and TB-14 (see Figure 13 for location). ABA (1965) considered the claystone unit younger than the Ladera Sandstone, correlative with the Monterey Shale exposed in the vicinity of Page Mill Road and Interstate 280. Earl Brabb (U. S. Geological Survey – retired) did much of the early biostratigraphic work as reported in ABA (1965). Regarding these Miocene age calls, Brabb recalls:

> *"I was able to locate 2 reports at my home one of them ABA-88 with Unocal foram ages from my collections. I was not, unfortunately, able to find the original Unocal paleo determinations. My notes indicate the lower Miocene call was for boring 13 at a depth of 35 ft with a sample number EB 581 collected probably in 1961. My original notes were lost and I am reading from a poor copy. The Unocal paleontologist who did the work was an excellent man but some of his calls were based on pyritized radiolaria ("gold balls") and forams that have a limited range locally but are not limited when the whole state is concerned. I think the discussion in Pampeyan's geologic map (I-2371) is an excellent analysis that tells us essentially that we do not know the age of the Miocene rocks at SLAC either with Kleinpell's 1938 zones or with more modern standards. That they are Miocene is*

> *clear but where in the Miocene is not known*." (Earl Brabb, written communication, June 11, 2004)

Four samples of claystone core material were collected and sent to Micropaleo Consultants of Encinitas, California for environment of deposition and age analysis in 2004. The following table summarizes the results of the analysis. Details of the results are found in SLAC (2004b).

Summary of results of biostratigraphic analysis.

Sample Number	Foram Age	Foram Environment	Diatom Age
CLF-B-1 25'	Middle to Upper Miocene (Upper Relizian to Upper Mohnian)	Bathyal	Possible latest early to early late Miocene
CLF-B-7 30'	Indeterminate	Bathyal	Indeterminate
CLF-B-8 30'	Miocene (Probable Zemorrian to Mohnian; "Pseudosaucesian")	Lower Bathyal	Indeterminate
CLF-B-9 30'	Miocene (Probable Zemorrian to Mohnian; "Pseudosaucesian")	Lower Bathyal	Indeterminate

The results confirm a Miocene age for the claystone unit. In addition, the claystone appears to have been deposited in a very deep marine environment, lower bathyal to bathyal depths. After discussions with a number of U. S. Geological Survey geologists familiar with the regional geology of the SLAC area (Earl Brabb, Robert McLaughlin, and Richard Stanley), it seems likely that the claystone unit may indeed be equivalent to the Monterey Shale exposed further south in the Los Altos Hills as suggested by Pampeyan (1993) and ABA (1965). The Monterey Shale in the Los Altos Hills area is considered to be generally younger than (but in part equivalent to) the Ladera Sandstone.

3.2.4 Native Fill

The native fill was derived largely from the excavation of Miocene and Eocene sandstones, siltstones and claystones and consists of a crushed mixture of siltstone, claystone, and sandstone. In core, the material is a heterogeneous assemblage of clay, silt and sandstone that has a mottled and disrupted appearance. Typically the sand and clay appear as pebble-sized clasts within a clayey silt matrix. Lesser amounts of asphalt concrete debris and locally Portland cement concrete debris are present on the south side of the accelerator. The native fill occupies the area on both the north and south sides of the linear accelerator between Sectors 18 and 20, and extends up to 400 feet from the linear accelerator. Figure 15 shows the estimated distribution and thickness of native fill material in the study area. The thickness was calculated taking the present day topography and subtracting the pre-SLAC topography. It should be noted that significant changes in the topography occurred on the northwest side of the study area with the addition of material after 1999.

The thickest area of fill is approximately 50 feet along the trace of the accelerator where it crosses the axis of the broad valley. South of the accelerator, the fill reaches up to 30 feet in thickness, while north of the accelerator, the fill is generally thinner and only reaches 20 feet in thickness.

3.2.5 Regional Mineralization and Alteration

Evidence of hydrothermal alteration and sulfide mineralization is reported at several locations in the vicinity of SLAC by Pampeyan (1993), in particular within the Whiskey Hill Formation in the Sharon Heights area, just north of SLAC. At these localities, sedimentary rocks have been altered by the substitution of ammonium for potassium or other alkali cations in feldspars, micas, smectites, and jarosite with the most common conversion being feldspar to the mineral buddingtonite.

McLaughlin and others (1985) reported the epithermal occurrence of silver, lead and zinc in the “Hermit prospect” on Jasper Ridge, southwest of the Sector 18 – 20 area. Unpublished lead isotope data from this prospect provide a young (probably Miocene) age for mineralization (Robert McLaughlin, written communication, June 2004). Robert McLaughlin of the U. S. Geological Survey further states:

> *“…there seems to be evidence for an elevated geothermal gradient in the Jasper Ridge/SLAC area in the mid-Miocene (i.e. Page Mill basalt time), that was not merely confined to local extrusion of the Page Mill basalt. I would argue that magma was shallow enough regionally to produce a more extensive geothermal overprint in the shallow crust, evidenced by the epithermal mineralization and also by Hg mineralization in Franciscan terrane east of the San Andreas fault in the Emerald Lake area (Redwood City)…*” (Robert McLaughlin, written communication, July 2, 2004)

Exposures of the Page Mill Basalt are restricted to the easternmost part of SLAC along Alpine Road (Figure 2). Exposures along Alpine Road are poor, and the Page Mill Basalt is relatively thin at this location. The Page Mill Basalt has been encountered in several geotechnical borings on the far eastern side of SLAC. To the west, the Page Mill Basalt is absent. The unit is not present in the Sector 18 – 20 Area.

Pampeyan (1993) reported a potassium-argon age of 14.0 Ma (middle Miocene) for the Page Mill Basalt. He also reported that the unit appeared to be hydrothermally altered with pyrite and marcasite disseminated throughout the lower fresh-appearing flows, but showed no evidence of metallic mineralization.

3.2.6 Acidic Groundwater

SLAC (2004b) concluded that the acidic groundwater in the vicinity of the Miocene-aged claystone is naturally occurring. The acidic groundwater is limited in extent, occurring in soil zones where the oxidation of sulfide minerals and the secondary formation of jarosite has occurred within the Miocene-aged claystone bedrock exposed in the area.

Groundwater elevation and the distribution of acidic groundwater in the Sector 18 – 20 area are shown on Figure 16. Cross sections A-A' and B-B' are shown on Figure 17.

Evidence for the natural occurrence of acidic groundwater includes:

- The areal relationship between the bedrock geology and the distribution of acidic groundwater.

- Laboratory experiments that mixed soils and deionized water and generated acidic water for many locations and depths.

- The presence of pyrite and jarosite within fractures in the Miocene-aged bedrock. The presence of jarosite in fractures is an indicator of acidic groundwater. Jarosite is stable at a pH of 5 and lower and can act as a strong "acid buffer" that can keep pH values in groundwater as low as 3 until it is dissolved.

- Acidic soil and groundwater present in areas that are unaffected by the linear accelerator or Positron Vault. For example, MW-95 was installed in Miocene-aged claystone and is north of the limit of native fill. Acidic groundwater is present at MW-95, 400 feet north of the linear accelerator and 700 feet northwest of the Positron Vault and MW-53.

- Groundwater and soil from native fill material are typically neutral when compared to Miocene-aged claystone.

- Geochemical parallels to the acidic, sulfate-rich waters commonly generated in areas of sulfide-mineral oxidation.

The Miocene-aged claystone mapped as Ladera Sandstone is restricted to the Sector 17 – 20 area in the western part of SLAC, and this is the only area of known acidic groundwater. In this area, the groundwater pH appears to be controlled by geochemical reactions with various acid-forming and acid-buffering minerals such as pyrite and jarosite. These minerals are present in fractures and disseminated through the Miocene-aged claystone bedrock. The original pyrite and/or other sulfide-bearing minerals may be the result of regional hydrothermal activity in the Miocene Epoch, evidence of which is observed in areas immediately surrounding SLAC. Neutral buffering of soil and groundwater pH by ubiquitous carbonate minerals to varying degrees causes large variations in observed groundwater pH and geochemical signatures, both laterally and vertically within the study area.

Though not observed to date, it is possible that acidic groundwater exists at other areas of SLAC, since jarosite has been observed in subsurface soils elsewhere at SLAC and the presence of sulfides in sediments may be more widespread due to regional hydrothermal alteration. This suggests that neutralization reactions are more effective in areas of SLAC outside of Sector 18 – 20 area which may, in turn, reflect a combination of higher hydraulic conductivity and greater carbonate mineral content. The hydraulic conductivity of the claystone matrix in Sectors 18 – 20 is probably lower when compared to the sandstones and siltstones more typical of the main SLAC campus (where the vast majority of groundwater monitoring wells is located). This low hydraulic conductivity likely results in groundwater flow limited to a network of fine fractures within the claystone. These fractures, which may be lined to varying degrees by secondary minerals such as gypsum, limit the neutral buffering of acidic groundwater by minimizing the participation of carbonates in potential neutralization reactions. Elsewhere at SLAC, in more typical lithologies such as sandstones and siltstones, groundwater flow occurs both within the matrix as well as the fractures, allowing more participation of ubiquitous carbonates within the soil-groundwater system.

Within the study area of Sectors 18 – 20, actual discharge of acidic groundwater to the surface appears quite minimal. Acidic groundwater discharge to the surface has been discovered at only one location, occurring as an imperceptible flow along the soil-bedrock contact in the intermittent stream south of the linear accelerator that results in small pools of acidic ponded surface water.

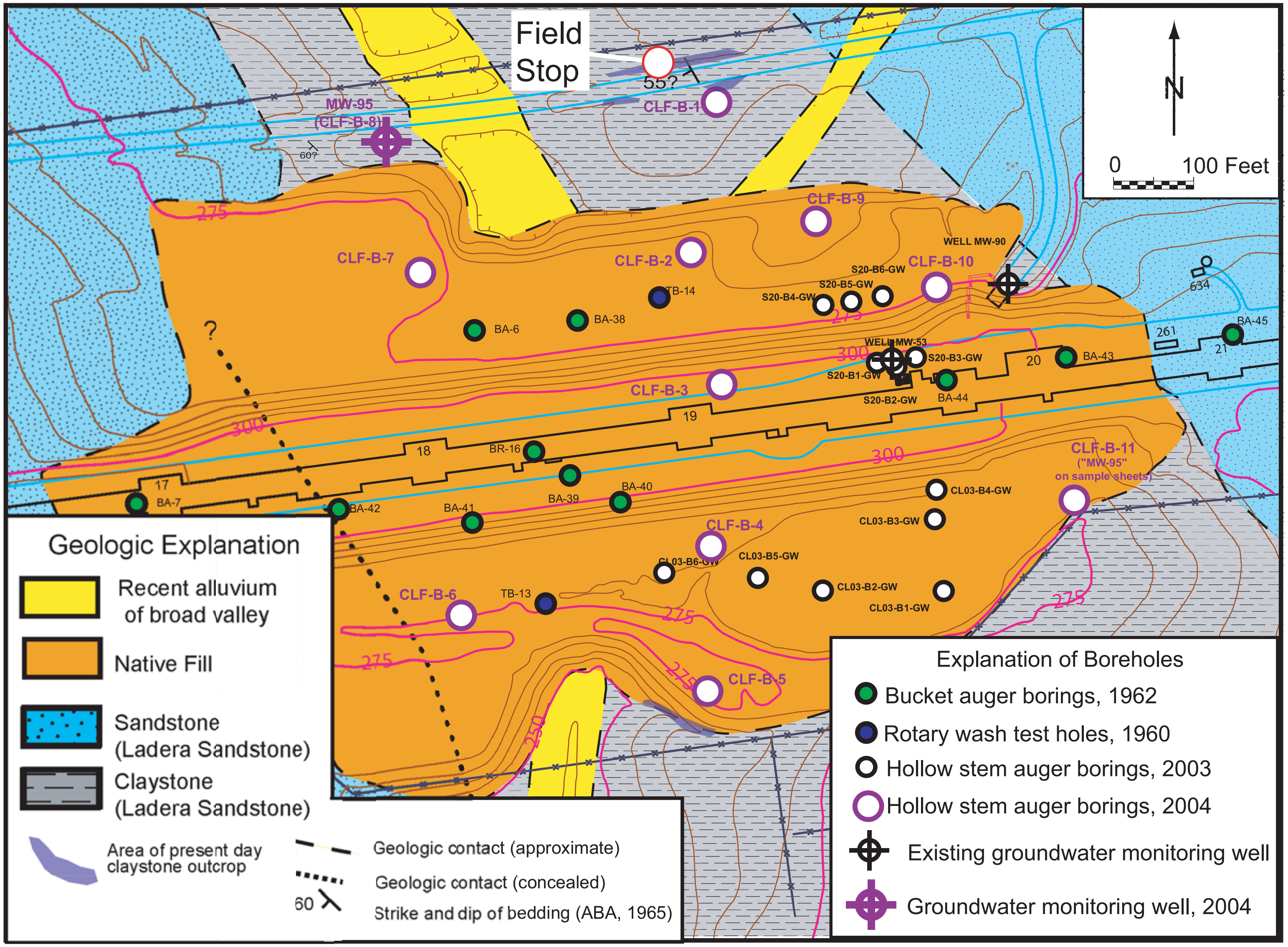

Figure from SLAC (2004b); geology modified from ABA (1965)

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Geologic map of the Clean Landfill Area

Date	Document No.	Figure No.
November 2006	SLAC-I-750-2A32H-015	12

View looking north. Scale variable.

from SLAC (2004b)

Photo: FC610-4/5
Date: 9-30-1992
Source: SLAC ER Photo Archive

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Oblique photo of Clean Landfill Area, 1992.

Date	Document Number	Figure No.
November 2006	SLAC-I-750-2A32H-015	13

Figure 14a. Outcrop of Miocene-aged claystone, Sector 18 Service Road

Figure 14b. Groundwater seep in Miocene-aged fractured claystone, south side of Clean Landfill

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Miocene-aged claystone, Clean Landfill

Date	Document Number	Figure No.
November 2006	SLAC-I-750-2A32H-015	14

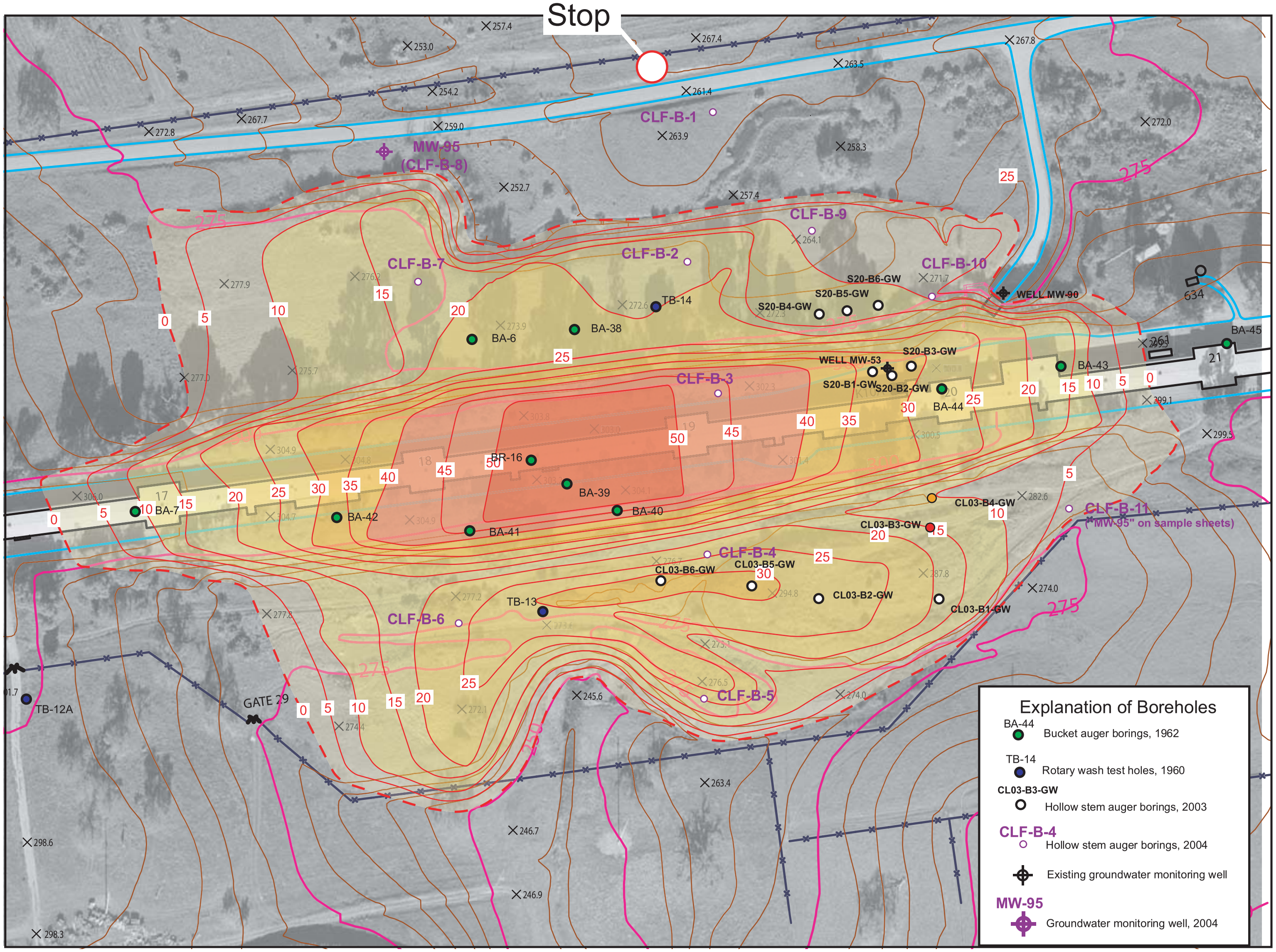


Photo: Aerotopica STDT073
Date: 12-15-1999
Source: SLAC ER Photo Archive

Topography in feet above mean sea level.
Contour interval = 5 feet

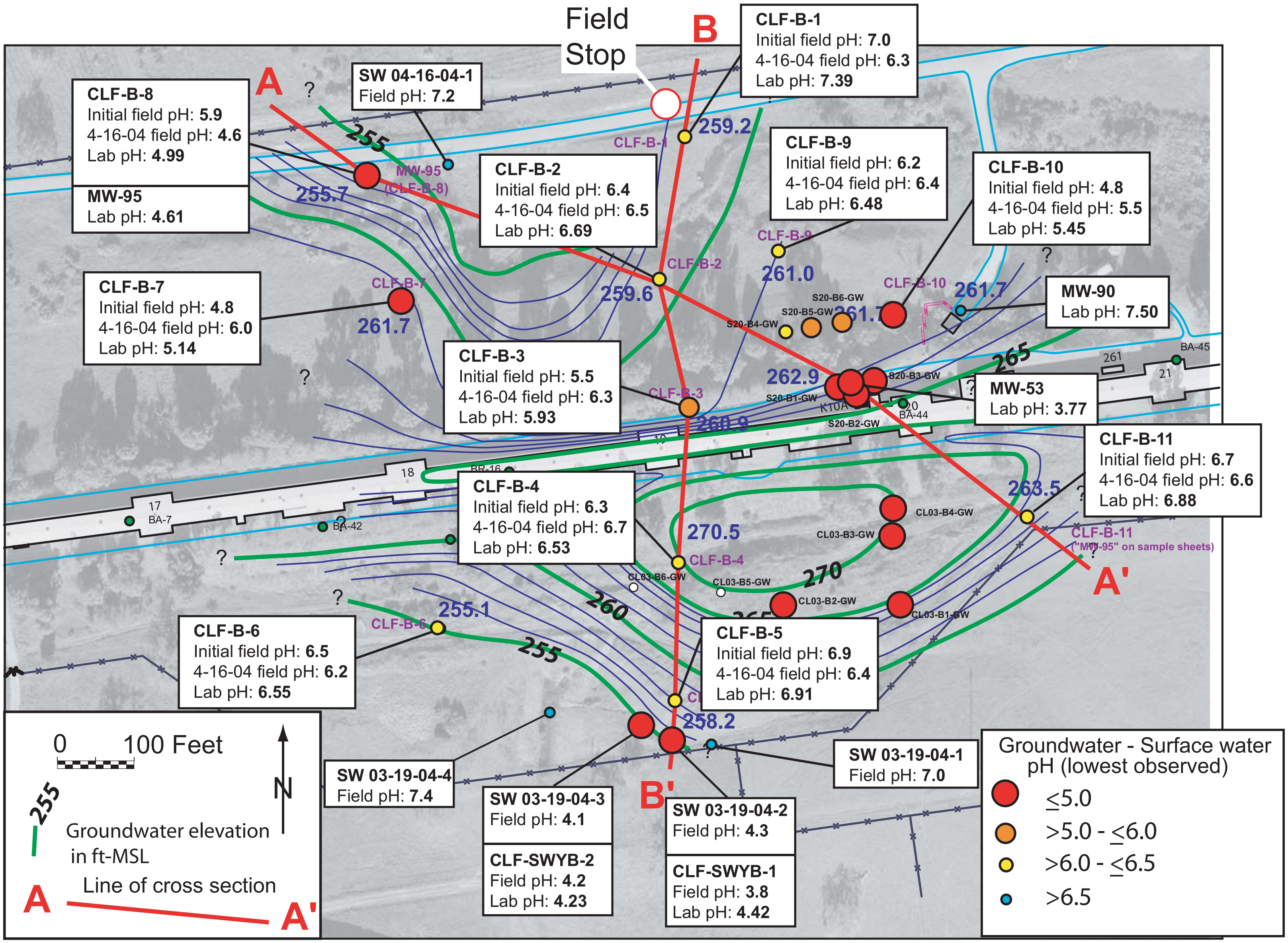
Thickness of fill shown in red (feet).
Thickness calculated from taking difference in present day and pre-SLAC topography.

N

0 100 Feet

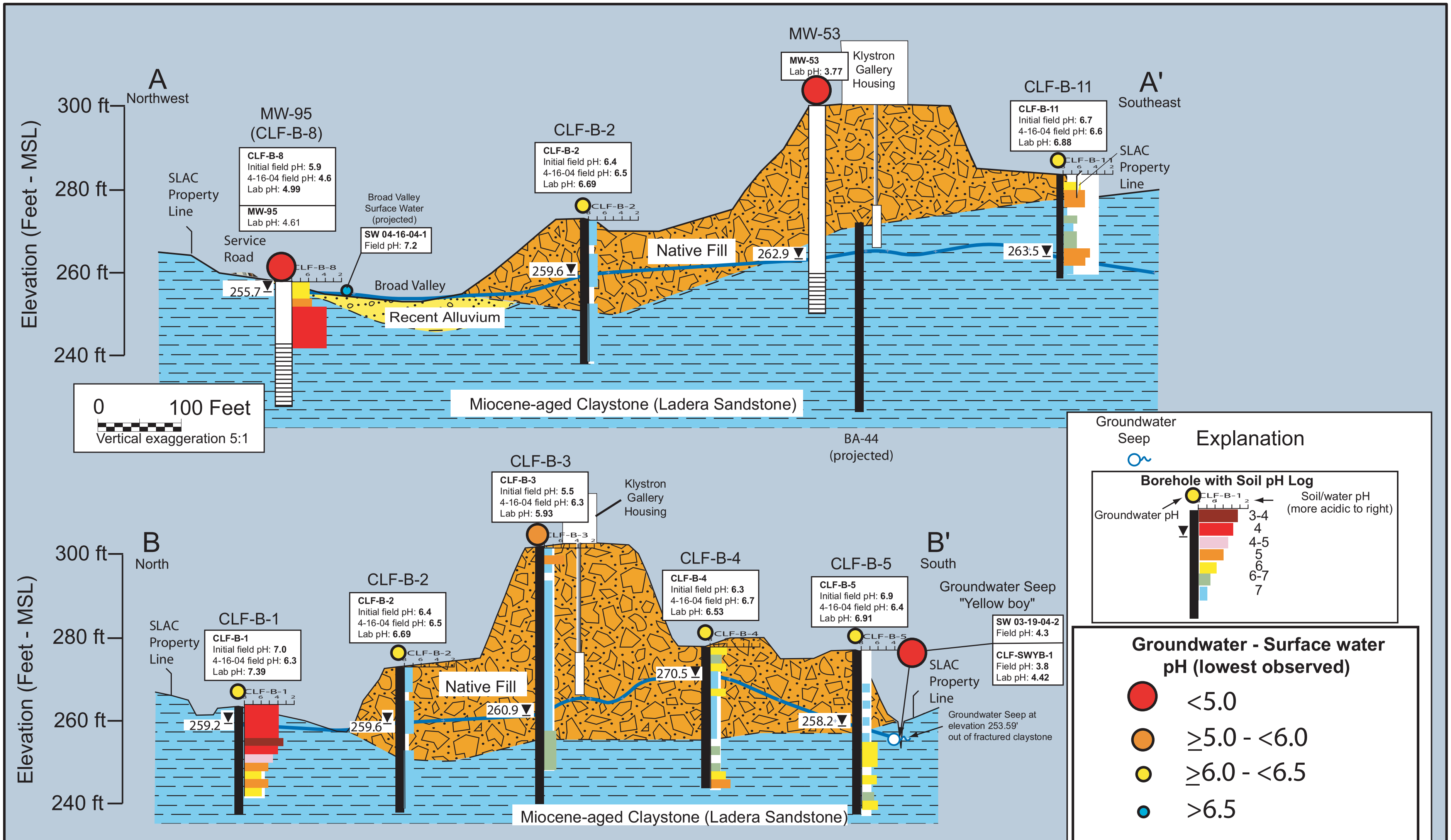
from SLAC (2004b)

Stanford Linear Accelerator Center Estimated thickness of Clean Landfill native fill materal		
Date November 2006	Document Number SLAC-I-750-2A32H-015	Figure No. 15



from SLAC (2004b)

Stanford Linear Accelerator Center Groundwater elevation and pH map of Clean Landfill Area		
Date November 2006	Document Number SLAC-I-750-2A32H-015	Figure No. 16



Geologic Cross Sections of Clean Landfill Area from SLAC (2004b)

Stanford Linear Accelerator Center Geologic cross sections of the Clean Landfill Area		
Date November 2006	Document Number SLAC-I-750-2A32H-015	Figure No. 17

3.3 Sectors 0 – 11, Whiskey Hill Formation

3.3.1 Overview

Steeply-dipping sedimentary rocks of Eocene age are present on the western half of SLAC (Figure 2). Pampeyan (1993) designated these Eocene rocks as the "Whiskey Hill Formation" after Beaulieu's (1970) type section along Whiskey Hill Road. Descriptions of the Eocene rocks that underlie SLAC are available in Page and Tabor (1967) and ABA (1965) as a result of mapping of the substantial cuts made through the local topographic highs during construction of the linear accelerator in the mid-1960's. The "orderly" Eocene sandstone and mudstone sequences contain many features that clearly represent the effects of tectonic deformation and are interrupted by so-called "chaotic zones" (Page and Tabor, 1967; Pampeyan, 1993).

An angular unconformity between the Miocene and Eocene rock units suggests the Eocene rocks were folded prior to the deposition of the overlying Miocene rocks (ABA, 1965). The strike of Eocene bedding is northwesterly, with dips ranging from about 30° to the southwest or northeast to vertical (ABA, 1965). Total stratigraphic thickness of the Eocene rocks in the vicinity of SLAC is about 3,000 to 4,000 feet (Page and Tabor, 1967; Pampeyan, 1993). Sandier lithologies are typically calcite-cemented, moderately hard to hard and closely fractured to massive when fresh. Rock in the weathered zone is generally weak to friable and the weathered zone extends down to as much as 30 feet below ground surface (bgs) (ABA, 1965). Finer grained rocks are less hard and more fractured. Locally, the sandstone is concretionary, cemented with calcite (ABA, 1965).

The Eocene rocks include zones exhibiting chaotic structure (ABA, 1965; Page and Tabor, 1967). These chaotic zones are composed of a mudstone matrix with blocks consisting mainly of sandstone (Figure 18). A few exotic blocks that have no resemblance to any of the Eocene rocks are present within the chaotic zone and consist of metabasalt, quartzite, and granitic rocks (ABA, 1965). Figure 18 shows photographs of exposures of the chaotic facies of the Whiskey Hill Formation exposed along the accelerator excavation near the western end of SLAC. These photos were taken in the mid 1960's and come from Page and Tabor (1967). These exposures are now covered by native fill and vegetation.

3.3.2 Age of the Whiskey Hill Formation

Pampeyan (1993) summarized the age control data for the Whiskey Hill Formation. Coccolith biostratigraphy of Whiskey Hill claystones from the far western end of the accelerator give a range from early middle to middle middle Eocene age.

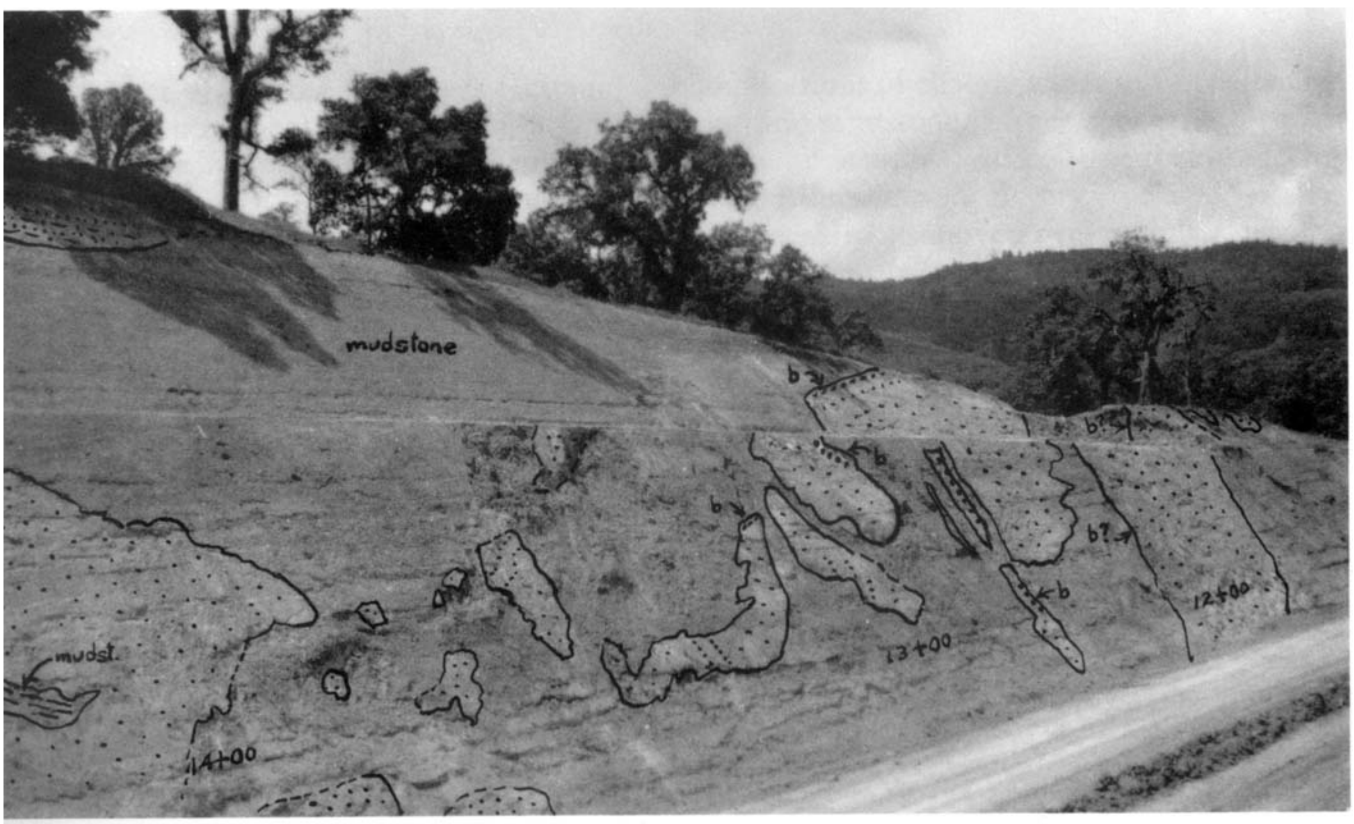
3.3.3 Whiskey Hill Formation Stops

Most all exposures of Whiskey Hill Formation at SLAC are now covered in vegetation or buried by fill. Along the linear accelerator, under the Interstate 280 overpass, exposures of Whiskey Hill Formation are still visible, but not accessible. There are three accessible locations that are the best sites for examining the Whiskey Hill Formation at SLAC.

Whiskey Hill Formation Stop 1. Sectors 11 – 12 Service Road (north side). Figure 19 is the geologic map of ABA (1965) showing the location of this stop. Pods of sandstone are still exposed here, surrounded by claystone that is covered in vegetation. This is the chaotic facies of the Whiskey Hill Formation. The white mineral on the surface of the outcrop is halite and is precipitating out of groundwater.

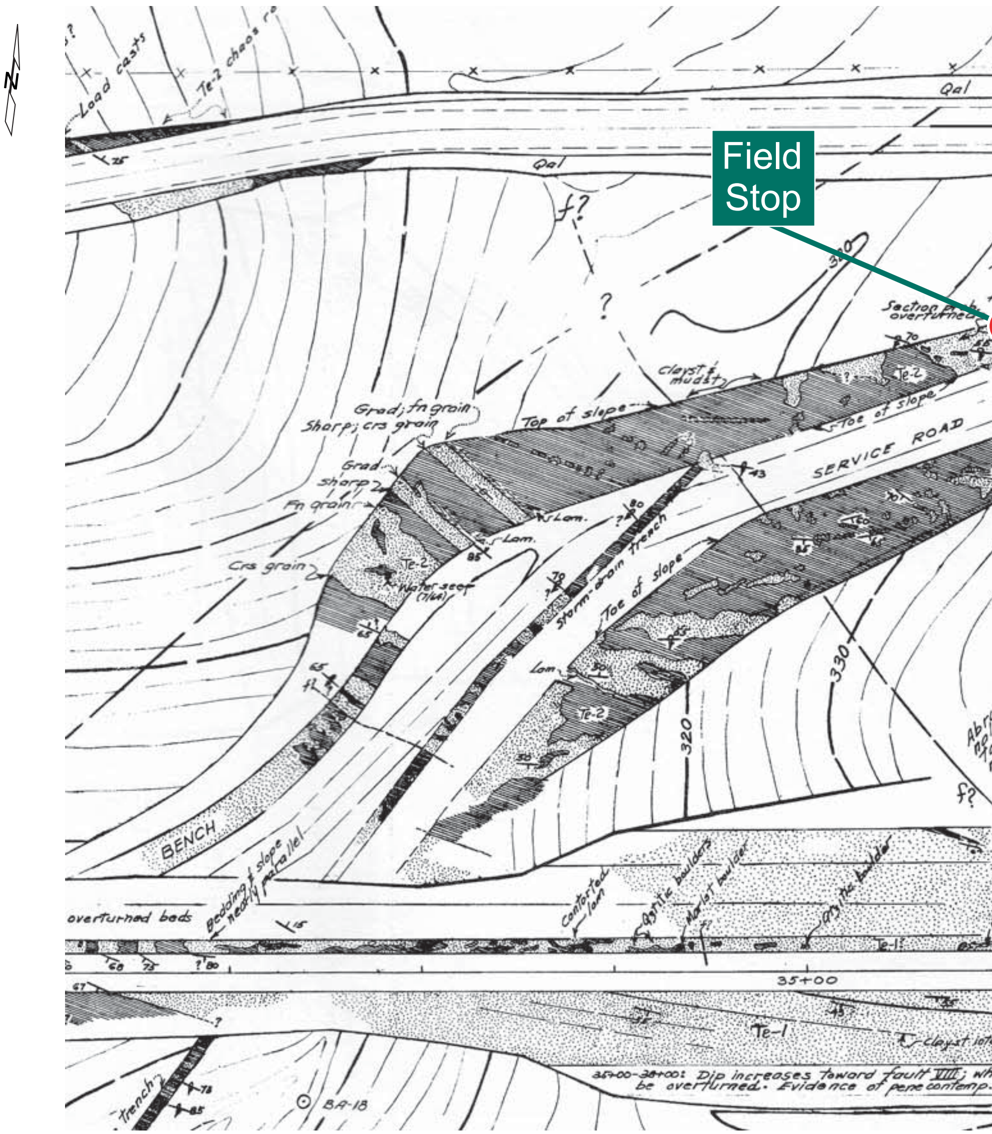
Whiskey Hill Formation Stop 2. Sectors 0 – 4, behind Bldg. 012 (north side). Here at the end of the accelerator, there is a large block of coarse sandstone that appears to be dipping to the southwest (Figure 20). Possible dish structures suggest this unit is overturned. This is the chaotic facies of the Whiskey Hill Formation.

Whiskey Hill Formation Stop 3. Sector 0 (south side). Jasper Ridge Overview. Outcrops of the Whiskey Hill sandstone are observed to the south at Rattlesnake Rock along Jasper Ridge (Figure 21). The Whiskey Hill sandstone is overthrust by serpentinite of the Franciscan Formation along the crest of Jasper Ridge. This outcrop is mapped as a structural wedge of sandstone between two thrust faults, and is considered "coherent facies" of the Whiskey Hill Formation (Coleman, 2004).



Photos from Page and Tabor (1967) of SLAC excavation showing irregular pods of sandstone within matrix of mudstone, Whiskey Hill Formation "Chaotic Facies."

Stanford Linear Accelerator Center Photographs of exposures of "chaotic" Whiskey Hill Formation		
Date November 2006	Document Number SLAC-I-750-2A32H-015	Figure No. 18



0 100 feet

Whiskey Hill Chaotic Facies in Sector 11 area

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Geologic map of Sectors 11 - 12 from ABA (1965)

Date	Document Number	Figure No.
November 2006	SLAC-I-750-2A32H-015	19

Whiskey Hill Formation sandstone with dish structures (?) indicating overturned bedding. Sector 1.

Aerial Photo from 1999 and Geologic Map of ABA (1965) showing geology of western end of SLAC excavation

Stanford Linear Accelerator Center Geologic map of Sectors 0 - 4 from ABA (1965)		
Date November 2006	Document Number SLAC-I-750-2A32H-015	Figure No. 20

Rattlesnake Rock is mapped as Whiskey Hill Formation, coherent facies. View to south from Sector 0.

Stanford Linear Accelerator Center Photograph of Rattlesnake Rock, Jasper Ridge		
Date November 2006	Document Number SLAC-I-750-2A32H-015	Figure No. 21

3.4 Sector 28 (South Side) Santa Clara Formation – Ladera Sandstone

3.4.1 Stop Overview

The Pliocene to Pleistocene aged Santa Clara Formation unconformably or disconformably overlies the Ladera Sandstone at scattered localities at SLAC, including the FHWSA site (Figure 2a, 22, and 23) (ABA, 1965; Page and Tabor, 1967; Page, 1978; Dames and Moore, 1977; 1981, SLAC, 2004a). On the south side of the linear accelerator at Sector 28, near the FHWSA, the Santa Clara Formation rests above the Ladera Sandstone along an easterly dipping fault (Figures 22, 24, and 25) referred to as the "Test Lab Fault" by SLAC (1989).

3.4.2 Geology of Sector 28 Area

All the monitoring wells in the FHWSA penetrate the Ladera Sandstone and/or the Santa Clara Formation. In the FHWSA, the Ladera Sandstone mainly consists of fine-grained sandy siltstones and silty sandstones. The bedding dips very shallowly to the southeast. The Santa Clara Formation overlies the Ladera Sandstone in portions of the FHWSA (Figures 22 and 23). The borehole lithology of the Santa Clara Formation is generally described as poorly consolidated to loose, uncemented, yellowish brown gravels with interbedded gravelly sands, silts, and clays. The gravels are fine- to coarse grained (up to two inches) with chert and sandstone clasts. Because of extensive grading of this area, most of the FHWSA has at least several feet of native fill material capping the native soil. The artificial ridge on the southern boundary of the FHWSA has up to 28 feet of native fill material. The fill material is a combination of native material from the vicinity of the site, and material stockpiled from the original excavation of the linear accelerator trench in the early 1960's (see section 3.2.4).

The Ladera Sandstone and Santa Clara Formation are exposed along the accelerator trench walls less than 100 feet to the north of the FHWSA and was described in detail by ABA (1965) and Page and Tabor (1967) (Figure 22). In particular the lithology of the Ladera Sandstone north of the FHWSA was described as massive, light-colored (bluish gray), fine- to medium-grained sandstone that was well sorted and sparsely fossiliferous (ABA, 1965). ABA (1965) also described the presence of thin, interbeds of hard, darker-colored, calcite-cemented sandstone, and calcareous concretions. Gravels, sands, sandy clays, and clays of the Santa Clara Formation crop out northwest of the FHWSA in the walls of the accelerator trench. The contact with the Ladera Sandstone is a north-northeasterly striking fault and was described by Page and Taber (1967) (Figures 22, 24, and 25).

The Santa Clara Formation as mapped at SLAC remains undated by either radiometric or biostratigraphic methods and was mapped on the basis of regional correlation and superposition. Sediments of the Santa Clara Formation can be distinguished from younger alluvium by the local occurrence of red chert pebbles and cobbles of Franciscan provenance.

The "Merced (?) Formation", as discussed by Pampeyan (1993), may be present in the FHWSA region. Pampeyan (1993) described the "Merced (?) Formation" in the Arastadero Road – Felt Lake area approximately 2.5 miles southeast of SLAC. The shallow marine sands of the Merced rest stratigraphically above the Ladera Sandstone (and Monterey Shale) but below the continental Santa Clara Formation. Pampeyan (1993) described the “Merced (?) Formation” as:

> *...Dusky yellow to dark yellowish orange friable, fine-grained sandstone, pebbly sandstone and silty sandstone.....contains pebbles of sub- to well-rounded white semi-siliceous shale and white and brown banded porcelaneous shale derived from the Monterey Shale...*

The unit contains a variety of marine macro fossils. Pampeyan (1993) believed that the “Merced (?) Formation” (marine unit) and the Santa Clara Formation (continental unit) interfingered and were age-equivalent rock units. Although never mapped at SLAC, evidence from core suggests that the “Merced (?) Formation” may be present (although extremely limited), and mapped as Santa Clara Formation in the FHWSA. Porcelaneous shale clasts and sharks teeth are present in several cores from the FHWSA, suggesting the presence of the Merced (?) Formation at SLAC.

3.4.3 Test Lab Fault

A photo of the exposure of the excavation from August of 1964 (Figure 25a) shows the Santa Clara Formation resting along an eastward dipping fault contact. This fault, referred to as the Test Lab Fault (SLAC, 1989), dips 28° to the east and places gravels of the Santa Clara Formation over Ladera Sandstone. Figure 25a shows the Santa Clara Formation resting above the Ladera Sandstone along an angular unconformity in the hanging wall of the fault. Figure 25b shows a cross section looking south taken from Page and Tabor (1967) showing the geologic relationships between the Santa Clara Formation and the Ladera Sandstone (the cross section is shown as a mirror image of the section presented in Page and Tabor, 1967). The authors suggested that the fault may either be a décollement or a landslide, but were perplexed by the complex structural – stratigraphic relationships exposed in the excavation. Currently, the majority of the exposed accelerator trench wall north of the FHWSA has been filled with native fill, and any exposures left are grass-covered with very sparse outcrop, however Santa Clara gravels can still be observed and dip ~55° to the east.

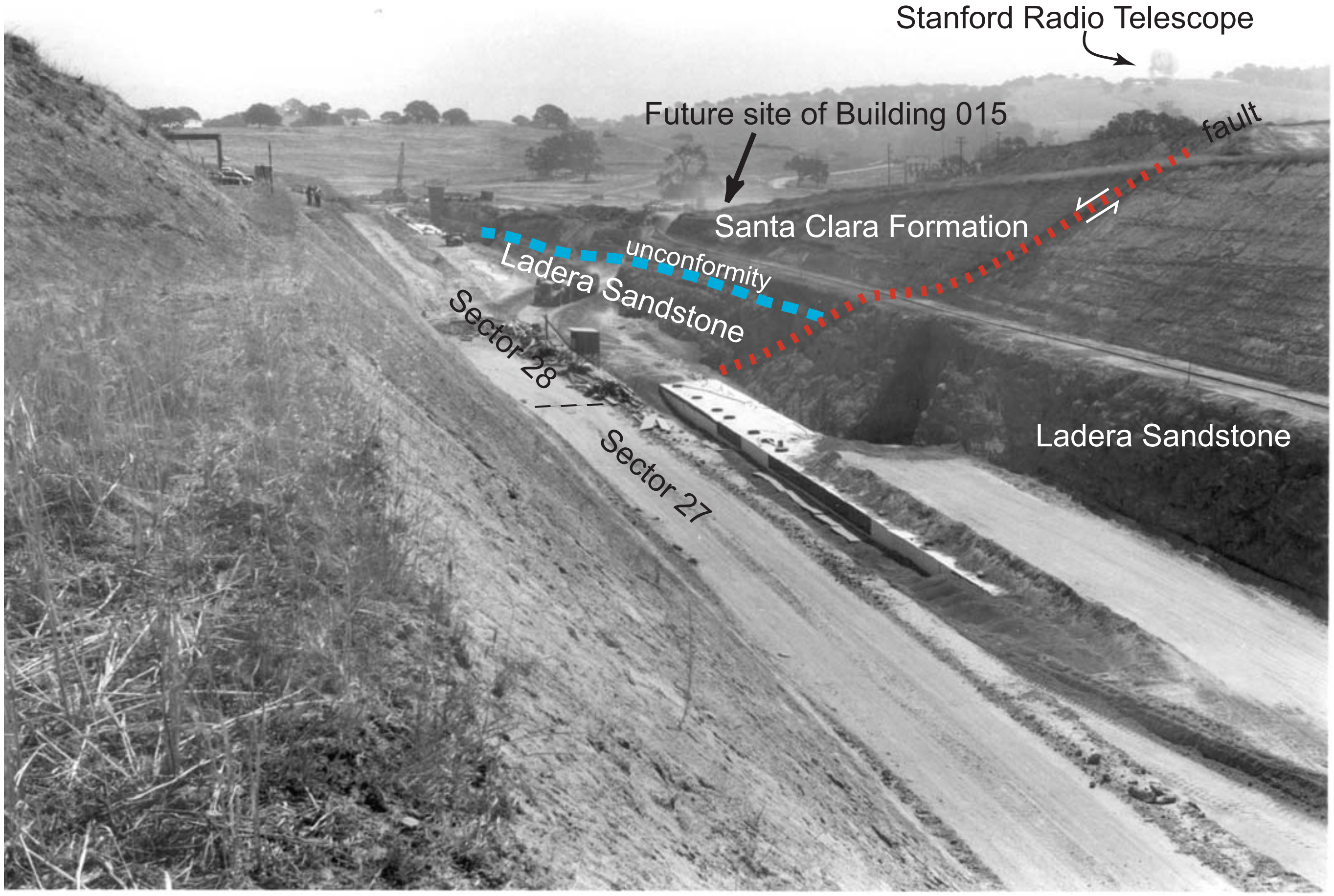
No evidence of recent movement on the Test Lab Fault was reported by Page and Tabor (1967), and there was no definitive effect on the accelerator alignment until the Loma Prieta earthquake of 1989. Co-seismic movement of the fault was documented by Fischer (1989) with cracked accelerator housing over a broad area. In addition, there was cracking of the Test Lab (Building 044) concrete floor and the patio between the southeast corner of the A&E Building (Building 041) along the mapped trace of the fault. The cracks in the floor of the Test Lab and the outside patio are still present today.

Figure 22 (11x17)

Figure 23 (11x17)

View to the south

Stanford Linear Accelerator Center Photo of Sector 28 outcrop		
Date July 2006	Document Number SLAC-I-750-2A32H-015	Figure No. 24



Source: SLAC archives, photo no. 92M35-8, 8-6-1964

Figure 25a. Photo of SLAC excavation with LINAC under construction, August, 1964. Sector 27 and 28 area, view southeast.

Photo shows exposure of Santa Clara Formation in fault and stratigraphic contact with the Ladera Sandstone in the area of the future site of Building 015.

Exposures Ladera Sandstone and Santa Clara Formation are still present today, but largely covered with vegetation.

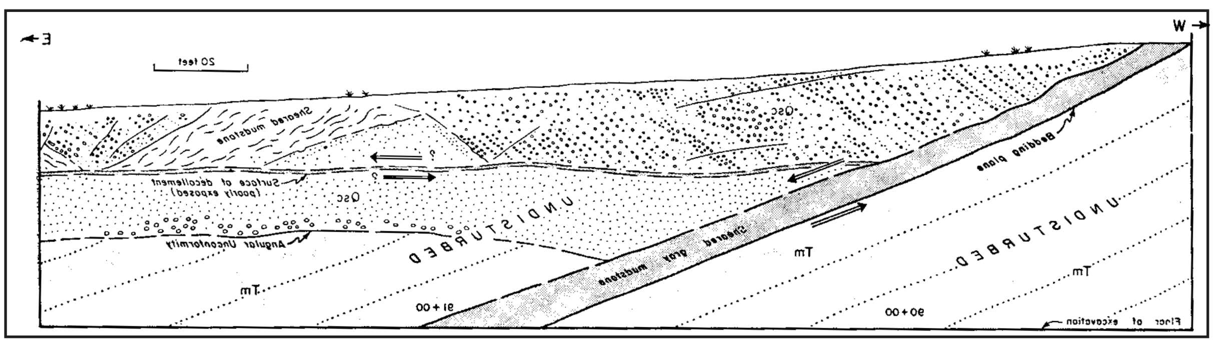


Figure 25b. Figure 5 from Page and Tabor (1967) shown in reverse to the same view point as above photo. Cross section shows the stratigraphic and structural relationships between the Santa Clara Formation and Ladera Sandstone as mapped by ABA (1965).

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Photograph of SLAC excavation from 1964 showing Test Lab Fault		
Date November 2006	Document Number SLAC-I-750-2A32H-015	Figure No. 25

3.5 Research Yard – Ladera Sandstone

3.5.1 Stop Overview

The Research Yard provides some of the best exposures of the Ladera Sandstone at SLAC (Figure 2a). The Research Yard was the largest excavation done as part of the construction of SLAC in the early 1960's. Figure 26 shows the excavation of the Research Yard in 1963. A nearly complete skeleton of the fossil *Paleoparadoxia*, a Miocene-aged marine mammal, was found in the Research Yard, and was reconstructed by Adele Panofsky, the wife of SLAC's first director Pief Panosfky (SLAC, 1998). A cast of the reconstructed fossil is on display at the SLAC visitor's center (Figure 27). In addition the *Paleoparadoxia* skeleton, an assortment of marine mammal bones, shark's teeth, snails, clams, and other fossils have been recovered from the Ladera Sandstone.

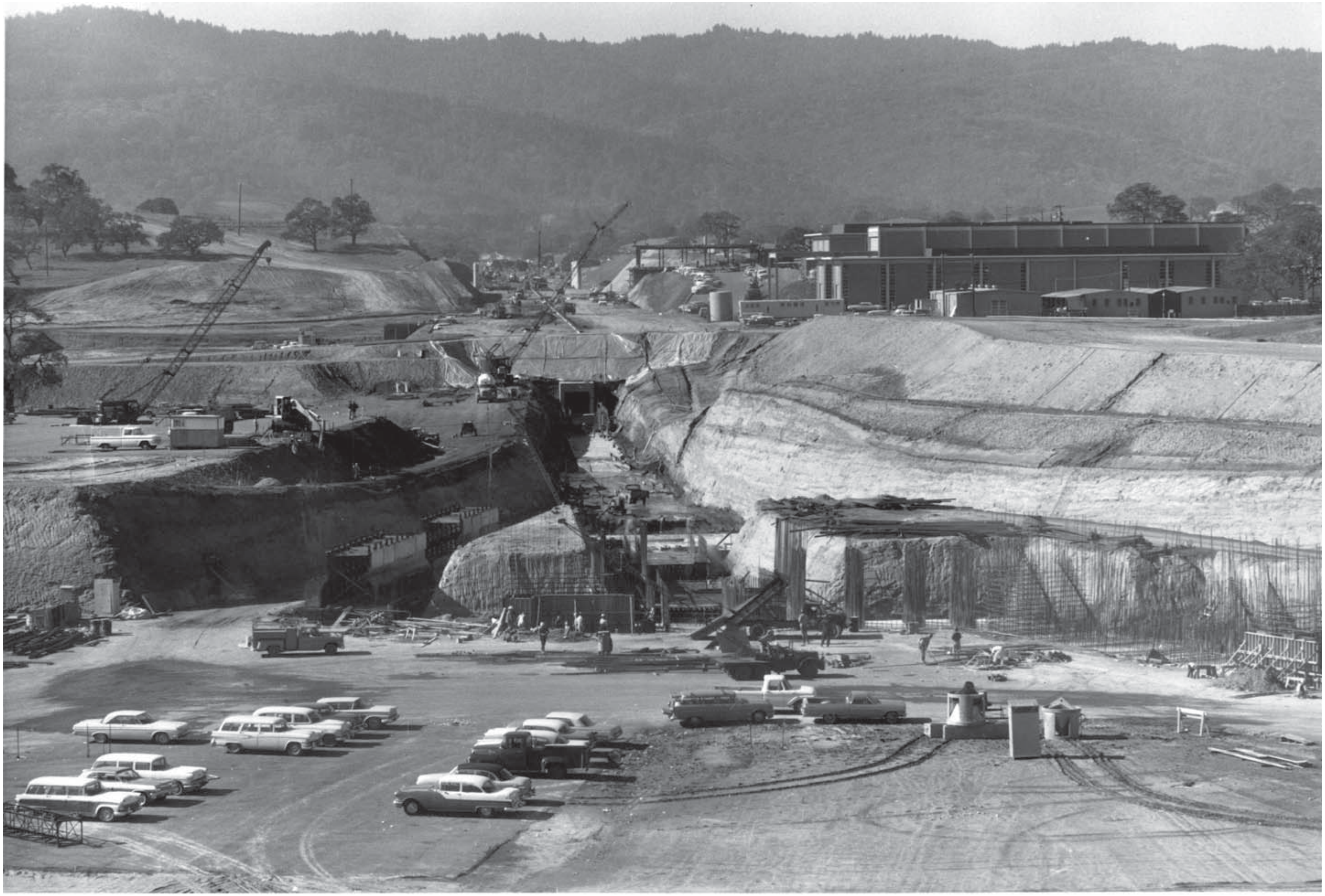
3.5.2 Geology of the Research Yard Area

The best exposures of Ladera Sandstone are present on the eastern wall of the Research Yard excavation (Figure 28). Prominent calcite-cemented beds of medium- to coarse-grained sandstone dip gently to the east. The coarsest-grained beds are trough cross bedded, bioclastic sandstones, made up of barnacle hash (Figure 29a). Beds have a wavy appearance (Figure 29b), and contain the trace fossil *ophiomorpha* and other burrows (Figure 29c), suggesting deposition in a shallow, high-energy marine environment, and is consistent with the interpretation that *Paleoparadoxia* lived in a shallow, open shoreface environment. These beds are similar to beds observed in cores from boreholes on the eastern side of SLAC (Figure 30).

The Ladera Sandstone observed at the Research Yard is significantly different than the Ladera Sandstone observed at Sector 28 (Section 3.1). The lithology at the Research Yard is much coarser, shows shallow-water sedimentary structures and trace fossils. At Sector 28, the Ladera Sandstone is dominated by silty sandstone and sandy siltstone with only a few thin calcite-cemented sandstone beds. Ladera Sandstone observed in core from Sector 28 area is extensively bioturbated, and contains thin-shelled clams preserved in life position and was probably deposited below normal wave base. The few calcite cemented beds may represent thin storm beds that have been homogenized by post-storm bioturbation. In the Research Yard, the presence of *ophiomorpha* suggests that sands were deposited above normal wave base, and thus is a shallower water facies than the lithology observed at Sector 28.

Pampeyan (1993) summarized the biostratigraphic age control for the Ladera Sandstone. Foraminifera and fossil fish scales suggest a probable middle Miocene age. Vertebrate fossils, including seal and whale bones, shark teeth, and the marine mammal *Paleoparadoxia* skeleton are equivalent in age to the middle to late Miocene molluscan fauna from nearby localities.

A thin veneer of Santa Clara Formation is present along the northeastern edge of the Research Yard excavation. Cobbles and pebbles from the Santa Clara gravel veneer have come down the slope and are present on in the Research Yard floor.



View to the west

Stanford Linear Accelerator Center Photograph of Research Yard excavation from 1963		
Date November 2006	Document Number SLAC-I-750-2A32H-015	Figure No. 26

The marine mammal ***Paleoparadoxia*** was recovered from the walls of the excavation in the Research Yard. This fossil was found within the Miocene Ladera Sandstone (approximately 10 to 14 million years old).

A cast of the fossil was reconstructed by Adele Panofsky and is on display at the SLAC Visitor Center.

Stanford Linear Accelerator Center Photograph of *Paleoparadoxia*		
Date November 2006	Document Number SLAC-I-750-2A32H-015	Figure No. 27

Stanford Linear Accelerator Center		
Photograph of Ladera Sandstone beds in Research Yard		
Date November 2006	Document Number SLAC-I-750-2A32H-015	Figure No. 28

Figure 29a.
Wavy storm beds of
Ladera Sandstone

Figure 29b.
Trough crossbedded,
bioclastic - barnacle
sandstone of the
Ladera Sandstone.

Figure 29c.
Ophiomorpha burrows in Ladera Sandstone

Stanford Linear Accelerator Center Photographs of Ladera Sandstone		
Date November 2006	Document Number SLAC-I-750-2A32H-015	Figure No. 29

3-inch diameter core from MW-57
Bioclastic, barnacle sandstone
Ladera Sandstone

Stanford Linear Accelerator Center Photograph of core from Ladera Sandstone		
Date November 2006	Document Number SLAC-I-750-2A32H-015	Figure No. 30

3.6 Eastern SLAC: Santa Clara Formation – Ladera Sandstone – Page Mill Basalt

3.6.1 Stop Overview

The Collider Hall was constructed in 1985 and required a major excavation (Figure 2a and Figure 31). Material was removed from the excavation and transported to a large mound immediately east of the Research Yard (Figure 31). The excavation exposed the unconformity between the Santa Clara Formation and underlying Ladera Sandstone (Figure 32). Southeast of the excavation, near Alpine Road, the Page Mill Basalt is exposed beneath (and interbedded with) the Ladera Sandstone (Figure 32).

A new construction project, the Linac Coherent Light Source (LCLS), located immediately to the south of the Collider Hall, will involve both cut and fill excavation and tunneling (Rutherford and Chekene, 2003). This project is due to begin in the summer of 2006.

3.5.2 Geology of the Eastern SLAC Area

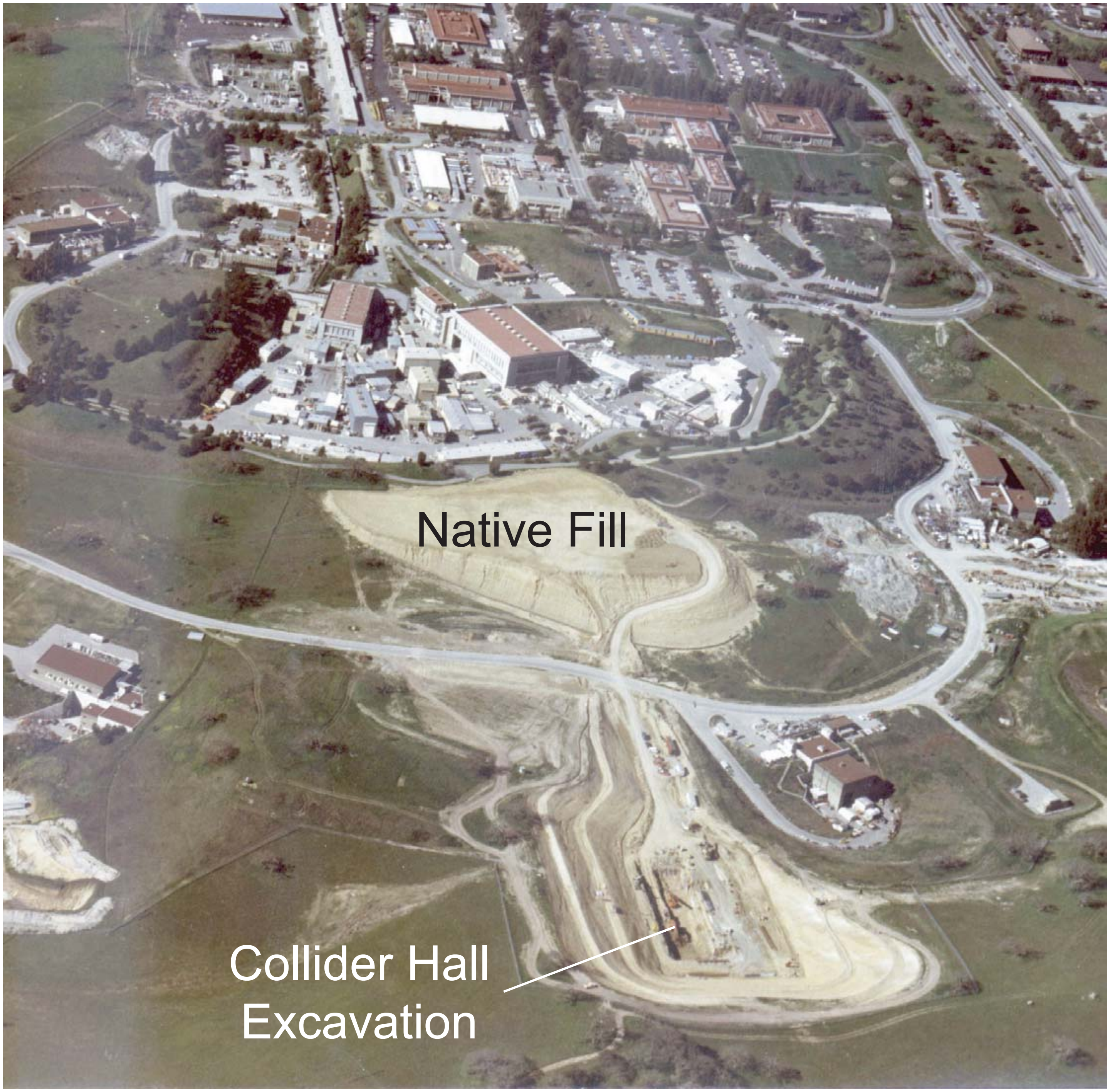
The unconformity between the Santa Clara Formation and the underlying Ladera Sandstone can be traced around the walls of the Collider Hall excavation (Figure 32). The contact is subtle but is best observed on the north side of the Collider Hall (Figure 33). Chert pebble gravel rests on the Ladera Sandstone (Figure 34a). Cobbles of various other Franciscan lithologies are also observed within the Santa Clara Formation at this location (Figure 34b).

The largest exposure of Santa Clara Formation at SLAC is here on the eastern end of the property. Although the Santa Clara Formation covers a large area in this region, the unit is typically thin, and in some places, only is a very thin remnant soil horizon with chert pebbles and cobbles resting above the Ladera Sandstone. The groundwater monitoring well MW-57, located north east of the Collider Hall (Figure 2a) contains approximately 14 feet of Santa Clara Formation above the Ladera Sandstone (Figure 35). Bioclastic sandstones, similar to those observed at the Research Yard are present below a depth of 125 feet in MW-57.

Exposures of the Page Mill Basalt are restricted to the easternmost part of the map area along Alpine Road (Figure 2a and 32). Exposures along Alpine Road show the Page Mill Basalt interbedded with the overlying Ladera Sandstone (Figure 36a). The Page Mill Basalt has been encountered in several geotechnical borings on the far eastern side of the map area. To the west, the Page Mill Basalt is absent.

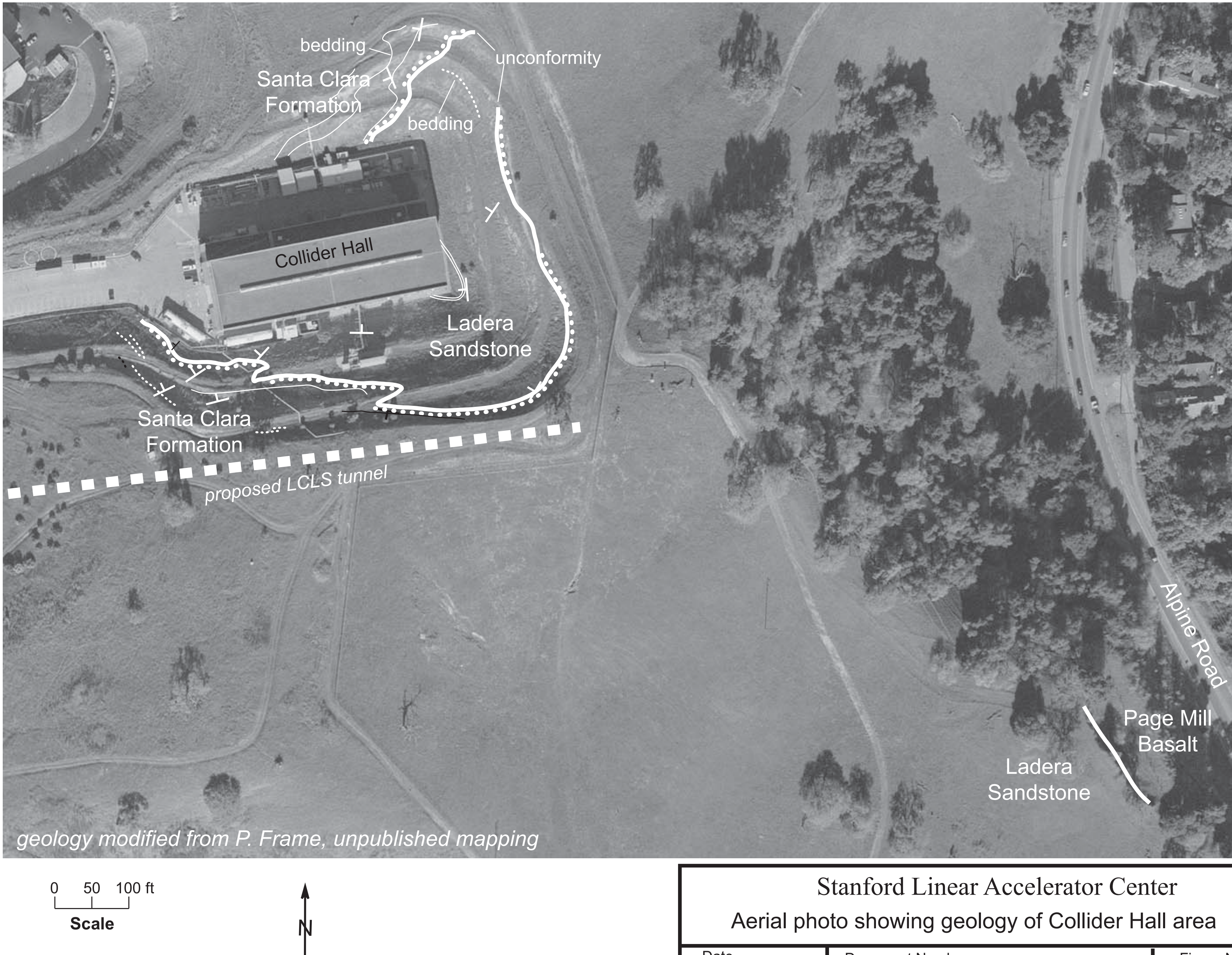
The Page Mill Basalt is best exposed east of the map area along Radio Telescope Hill and in old quarries off Old Page Mill Road (Figure 36b). Here the unit consists of a series of alternating breccias and olive-green to deep blue-gray massive basalt flows with occasional vesicular beds of a maximum aggregate thickness of approximately 600 feet. The Page Mill Basalt essentially separates the underlying Whiskey Hill Formation from the overlying Ladera Sandstone; however a thin Ladera-like sandstone is locally present under the basalt. In the main part of SLAC, the Page Mill Basalt is not present, with the Ladera Sandstone resting directly on the Whiskey Hill Formation.

Pampeyan (1993) reported a potassium-argon age of 14.0 Ma (middle Miocene) for the Page Mill Basalt.



Photograph of collider hall excavation, 1985, view looking west.
Material from excavation was moved west, across PEP Ring Road.
Excavation revealed unconformity separating Santa Clara
Formation from underlying Ladera Sandstone.

Stanford Linear Accelerator Center Photograph of Collider Hall excavation		
Date November 2006	Document Number SLAC-I-750-2A32H-015	Figure No. 31



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Aerial photo showing geology of Collider Hall area

Date	Document Number	Figure No.
November 2006	SLAC-I-750-2A32H-015	32

view to north

Stanford Linear Accelerator Center Photograph of north side of Collider Hall excavation		
Date November 2006	Document Number SLAC-I-750-2A32H-015	Figure No. 33

Figure 34a. Photo of chert pebble gravel from the Santa Clara Formation above Ladera Sandstone

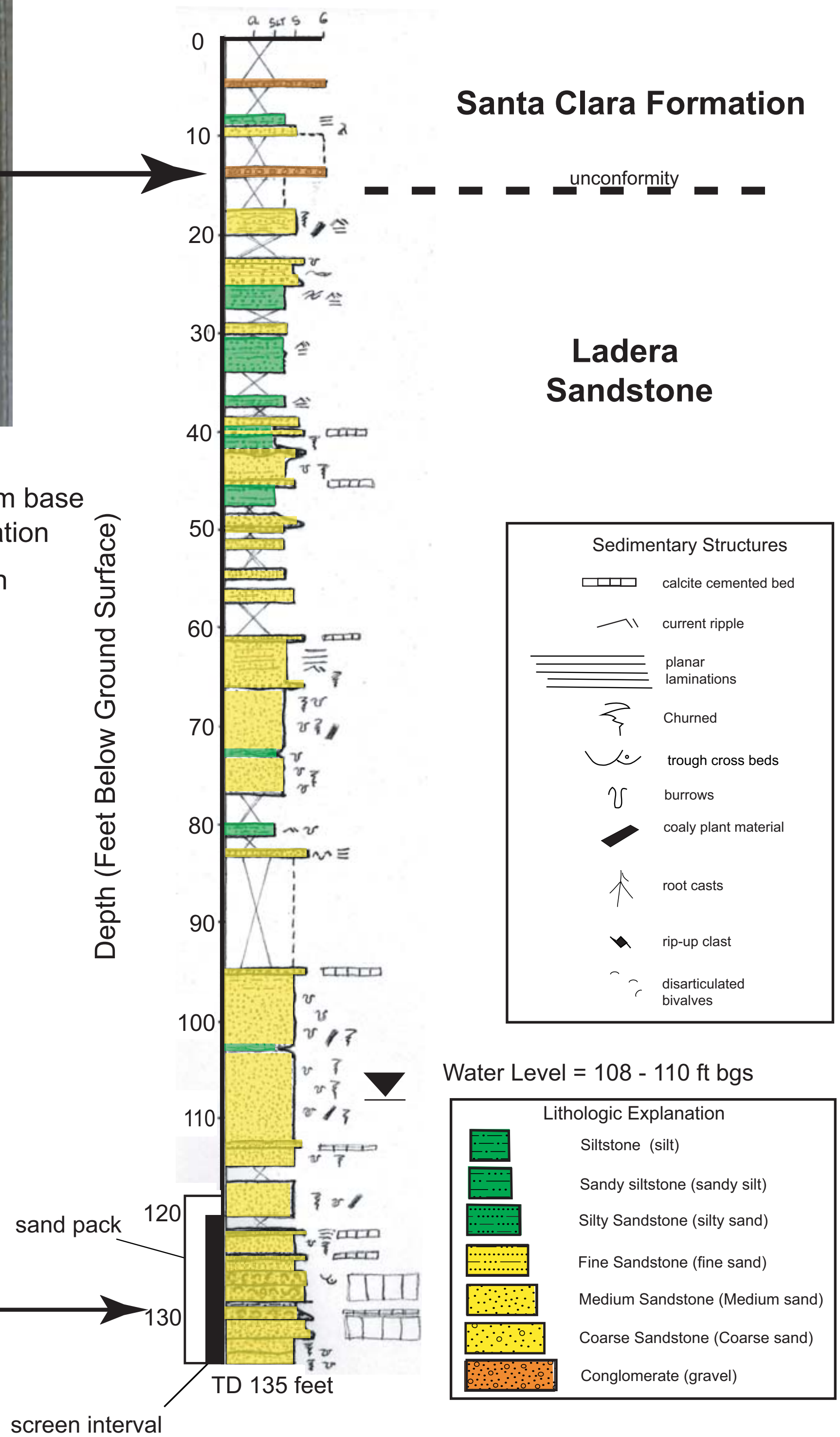
Figure 34b.
Photo of cobbles from the Santa Clara Formation

Stanford Linear Accelerator Center Photographs of Santa Clara Formation		
Date November 2006	Document Number SLAC-I-750-2A32H-015	Figure No. 34

Core photograph
Cobbles of red chert from base of Santa Clara Formation

Core piece of Barnacle hash in Ladera Sandstone

core photograph
MW-57
125 - 135 ft bgs



Stanford Linear Accelerator Center Lithologic log from MW-57		
Date November 2006	Document Number SLAC-I-750-2A32H-015	Figure No. 35

Figure 36a. Ladera Sandstone resting unconformably on darker colored Page Mill Basalt, west side of Alpine Road.

Figure 36b. Basalt flows in Page Mill Basalt, in quarry off Old Page Mill Road.

Stanford Linear Accelerator Center Photos of Page Mill Basalt		
Date November 2006	Document Number SLAC-I-750-2A32H-015	Figure No. 36

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