FINAL TECHNICAL REPORT

PALEOSEISMIC INVESTIGATION OF THE BLOSSOM HILL FAULT

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INTRODUCTION

Faulting in the northeastern foothills of the Santa Cruz Mountains and southwest Santa Clara Valley has been the subject of recent interest in seismic hazard research and engineering communities (e.g., Hitchcock et al., 1994; Bürgmann et al., 1997; Hitchcock and Kelson, 1999; McLaughlin et al., 1999; Fenton and Hitchcock, 2001; Rubin et al., 2005). The faults, generally referred to as part of the "range-front fault system" or "Foothills thrust system", are of interest because of their proximity and tectonic relationship to the nearby San Andreas fault zone, and because they occupy an area with increasingly dense residential development (Figure 1). Regional studies have concluded the faults are at least late Pleistocene active based on geomorphology and subsurface exposures of faults within soils. Portions of the range-front faults in Los Gatos, CA experienced coseismic deformation in the 1989 M 6.9 Loma Prieta Earthquake in the Santa Cruz Mountains. Many site investigations have documented the presence of the faults within the shallow subsurface, yet the recency of activity has not been conclusively defined.

The present study consists of a paleoseismic trench at a site along a mapped fault within the Shannon fault zone at Heintz Open Space, Los Gatos (Figure 2); however, the Heintz site is an alternate to the originally proposed study site. The following discussion provides background on the circumstances and rationale for selection of the Heintz study site. Previously, the fault was exposed approximately 400 m northwest within excavations during residential construction on Greenridge Terrace, also in Los Gatos. At that site, faulting was expressed within shallow subsurface soils during a subsequent consulting investigation of the fault (summarized in Rubin et al., 2005). The faulted soils were generally comprised of shallow colluvium, which suggested Holocene rupture; however, a radiocarbon age of the faulted horizons was not obtained. The fault was informally referred to as the Blossom Hill fault to distinguish it from several other traces of the Shannon fault.

The adjacent residential property along the fault appeared to be an adequate site to better constrain rupture events based on the site conditions and data on the fault from the consulting study, so I submitted a proposal for the present study to NEHRP. Between the time the proposal was submitted and ultimately accepted, the Town of Los Gatos issued a stop work order on the residential construction based on identification of the fault and the consultants' recommendations. That property owner then entered into litigation in an attempt to recover financial losses. Neighboring property owners were aware of the controversy and feared becoming associated based on their understanding of the legal approach being utilized, and presumably lacked appreciation for the benefits of further local fault characterization. Amidst this tension, access was not granted to the accepted NEHRP study site on Greenridge Terrace. Though the property owner was informed that the fault mapped across his property was already considered active by the Town, he ultimately ceased to respond to further attempts at correspondence.

Subsequently, other residential sites along the fault were considered for possible study; however, given the climate of apprehension amongst local property owners I concluded Heintz Open Space represented the most feasible alternative study site. NEHRP Program Officer Elizabeth Lemersal and then Regional Coordinator David Schwartz agreed this was the most reasonable path forward, despite greater uncertainties regarding fault location and adequacy of subsurface stratigraphy at the Heintz site. Handaugers completed at the site prior to trenching indicated deepened, massive colluvial stratigraphy.

The trench location was selected based on Town approval of a specific site, and a location presumed most likely to intersect the fault in the shallow subsurface within that area. Exploration was limited to a relatively small area, and the Town indicated work should minimize disturbance to surrounding trees, shrubs, and overall undeveloped setting. A large excavation would likely not have been approved by the Town, and was not feasible within the awarded budget. Exploration at the Heintz site experienced logistical challenges and expenditures of time and funds not anticipated in the proposal such as: limited area approved for trenching, limited accessibility for equipment, sensitive access road, rental and installation of chain-link security fencing around entire work area, and accommodation of other requirements by the Town.

GEOLOGIC SETTING

The range-front fault system trends sub-parallel to the San Andreas and includes southwest-dipping thrust, reverse, and oblique right-lateral faults. From west to east, the system is comprised of the Sargent, Berrocal, Monta Vista, Shannon, and Cascade faults as well as others that may exist further east beneath Santa Clara Valley. Geomorphic expression of the faults is mapped regionally, including the site area, by Hitchcock et al. (1994). The expression is variable, and generally better in upland areas underlain by Pliocene and older bedrock where saddles, linear fronts, and linear depressions are common. Within the valley floor, vegetation lineaments are most common.

Surface deformation associated with the 1989 Loma Prieta Earthquake was coincident with some mapped traces of the range-front fault system (e.g., Haugerud and Ellen, 1990; Schmidt et al., 1995). Recent seismic data from the region, including those from the 1989 Loma Prieta Earthquake, have thrust-sense mechanisms that project toward surface traces of range-front faults and downward toward the San Andreas, possibly intersecting and crossing it at about 8-10 km (e.g., Bürgmann et al., 1994; Langenheim et al., 1997; Zoback et al., 1999). Accumulation of postseismic strain following the Loma Prieta Earthquake is consistent with aseismic slip at depth below surface traces of the range-front fault system (Bürgmann et al., 1997). Tuttle and Sykes (1992) suggest that a M 6.5 earthquake in 1865 may have been centered within the range-front fault system.

Despite this evidence for possible Holocene fault activity, paleoseismic investigations have thus far not conclusively demonstrated Holocene activity on range-front faults in the southwest Santa Clara Valley. In the foothills on the San Francisco peninsula to the north, Hengesh et al. (1996) identified evidence of Holocene activity on the Serra fault east of the San Andreas.

To date, slip rates on the range-front system have been based on relatively long term geologic, geochronologic, and geomorphic data. The average geologic uplift and shortening rate since ~5 Ma is approximately 0.5-0.6 mm/yr (McLaughlin et al., 1999). Fission-track data for the same time period suggest approximately 0.8 mm/yr (Bürgmann et al., 1994). Based on various types of data Hitchcock and Kelson (1999) estimated an average long-term deformation rate along the range front of 0.25-0.4 mm/yr due to aseismic processes, and a slip rate of approximately 0.2 mm/yr for the Monta Vista fault itself.

The fault trace studied here is referred to as the Blossom Hill fault, and is one of four traces of the Shannon fault zone mapped at a regional scale by McLaughlin et al. (2001) and incorporated into the Quaternary Fault and Fold Database (USGS and CGS, 2011; Figure 2). Its southeast extent lies within bedrock uplands in the Blossom Hill area, and to the northwest it extends into the valley floor in Los Gatos. Hitchcock et al. (1994) map a series of distinct co-linear saddles across north-trending ridgelines as local geomorphic evidence of the fault. The northwest extent in the valley was a locus of surficial deformation during the Loma Prieta Earthquake (Schmidt et al., 1995).

Herd (in Bedrossian, 1980) maps a trace to the northeast at what was presumably interpreted as the local geomorphic boundary between bedrock uplands and valley floor. This trace appears to have been incorporated into the Quaternary Fault and Fold Database (Figure 2); although it is referenced therein to Hitchcock and Kelson (1999). The Herd trace is approximately coincident with a prominent escarpment visible as it crosses Regent Drive.

Previous investigation along the fault (Rubin et al., 2005) indicated the fault had up to 1.5 m of Holocene displacement during at least three events. Ages were estimated based on soil profile development; radiocarbon ages were not obtained.

TRENCH SITE GEOLOGY AND GEOMORPHOLOGY

The Heintz Open Space study site is located along the southeast extent of the Blossom Hill fault, within a north-northeast trending drainage swale between two generally north-trending spur ridgelines. The region is chiefly underlain by mapped Monterey Formation bedrock, with localized Temblor Sandstone in the hanging wall of the fault (e.g., McLaughlin et al., 2001). Plio-Pleistocene Santa Clara Formation is mapped in very limited bodies occupying the ridgeline saddles along the fault. The drainage is underlain by deepened Holocene colluvium and has no noticeable active channel.

Hitchcock et al. (1994) maps saddles coincident with the fault within the adjacent ridges. The saddles are visible in stereo aerial photographs and LiDAR-based topographic contours provided by Santa Clara County Geologist James Baker. Sidewalls of the drainage are greater than 20 m high to the west and 50 m high to the east. Fault-parallel hillside swales within the drainage sidewalls are visible in the contours, and appear to be approximately 30 m wide. The drainage swale widens significantly where it intersects the hillside swales.

Local observations of stereo aerial photographs (Table 1) indicate the fault is not well-expressed at the surface in the form of scarps, either along the ridgeline or in Holocene colluvium within the drainage swale. Scarps are not apparent in colluvial swales along the fault to the northwest. The ridgeline saddles mapped by Hitchcock et al. (1994) appear to capture the extent of local fault expression. Attempts at developing a bare-earth model from the available LiDAR point cloud data were not successful when utilizing typical processing methods, and a significant effort to analyze the data is beyond the scope of this project.

Though fault scarps are not mapable at the surface, the trench location was selected to cross the transition between a northeast-facing, steeply-inclined bedrock slope and colluvial swale in the approximate location of the mapped fault (Figure 3). The steepest portion of the bedrock slope appears to be greater than 50 m in height, beyond which it becomes indistinguishable from the overall spur ridge. Regionally, faults within the range-front system have been relatively well-expressed in the subsurface where bedrock can be identified in the hanging-wall. Heavy brush at the north end of the trench precluded further excavation.

Subsurface conditions and age estimates

Soil is logged within the full extent of the trench; bedrock was not exposed (Figure 4). The trench ranged from approximately 2.5 to 3 m deep and was 23.8 m long. Two primary soil units are logged, with a third limited to a small area at the south end. Unit 10 represents the active colluvial surface. It is primarily massive clay with approximately 10% angular gravel, has abundant roots and krotovina, and has only weakly developed granular soil structure. Unit 20 is also a massive clay colluvial deposit; although, in contrast is lighter in color, has increased consistency, contains more gravel, has fewer roots and orgaincs, krotovina are generally confined to the top of the unit, and soil structure is not evident. A third colluvial unit (Unit 30) is found only in the deepest part of the uphill end of the trench. It is distinct in its yellowish brown color, silty texture, and lack of an oxidized gravel component. A hand auger boring advanced from the trench bottom at the south end indicates Unit 30 extends 1.6 m from the bottom of trench to the top of bedrock, at a total depth of approximately 4.7 m. Bedrock is laminated Monterey Formation siltstone.

The contact between Units 10 and 20 is wavy and gradational over 20 to 30 cm. The contact between Units 20 and 30 is wavy and varies locally from clear to gradational. Due to the distinct color contrast between Units 20 and 30, mixing of soil fragments up to 0.5 m in diameter is clearly evident. The mixing did not appear to follow any preferred structural fabric. Shearing, planar discontinuities, and through-going structures were not identified. Lacking structure, colluvial processes appear to be the most likely origin of the mixing.

Local concentrations of gravel are observed in the northern half of the trench, and an accumulation of gleyed, highly plastic clay (Unit 25) appears to be contained within Unit 20. The singular appearance of evidence for bedding is a gravel lens, which has no apparent dip over a distance of approximately 2 m.

Maximum ages of Units 10 and 20 are estimated to be mid to late Holocene based on the near complete lack of soil structure, color variation, or other evidence for pedogenic development. Presumably, clayey subsurface soils with significant antiquity would display evidence of a blocky structure and contrasting color development. Several charcoal samples were collected; however, without evidence of fault displacement radiocarbon ages were not ordered.

DISCUSSION

The lack of evidence for faulting in the trench could be explained by the following: 1) faulting does not extend through the young soils due to a combination of low slip rate and/or high sedimentation/soil development rate; 2) the fault is not Holocene active at this location; 3) the trench did not cross the fault; or 4) the fault does not exist.

The existence of mapped traces of the Shannon fault is confirmed by published geologic maps and local site investigations where the fault is encountered in the subsurface (4 does not apply). Locally poor surficial expression of the fault and lack of constraints on the fault location at the trench site leaves a moderate amount of uncertainty in locating the fault (3 applies). As mapped, the existence of multiple strands of the Shannon fault are permissible of partitioning slip north toward a possible fault trace closer to the current local range front (ie., Herd, in Bedrossian, 1980) at the latitude of the trench site (2 applies). Data yielded by this investigation do not constrain that possibility because of uncertainty in the actual fault location at the study site (3 applies), and the possibility that Holocene activity is recorded at depths greater than the limits of completed trenching (1 applies).

Given the dramatic break-in-slope at the Heintz Open Space trench site, it is likely that the trench crossed the fault. The lack of fault expression in the trench soils is most likely related to low fault slip rate (1), or lack of Holocene activity at this site (2). Exposures at the Greenridge Terrace site along the fault to the northwest suggests the trace has experienced slip during Holocene time, yet may not have a rate of activity sufficient to rupture a thickened young soil profile. Possible fault-related escarpment along the Herd trace to the northeast nearer the range front, may suggest Holocene slip transfers from the Blossom Hill fault somewhere between the Heintz Open Space site, and the Greenridge Terrace site; or that the Blossom Hill fault accommodates less slip than other traces of the Shannon fault.

FUTURE WORK

Going forward, I am continuing attempts to develop a useful bare-earth LiDAR model to evaluate the location and nature of the range-front faults, including the Blossom Hill fault. If the LiDAR data are high quality they may facilitate improved mapping and selection of possible future trench sites. Areas where the range front faults cross Holocene alluvium are of particular interest. If the faults appear to displace Holocene materials, CGS may consider future zonation under the Alquist-Priolo Earthquake Fault Zone Act.

ACKNOWLEDGEMENTS

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Table 1

List of Stereo Aerial Photographs

Photo number	Date	Scale	Color
GS-HR 1-58, 59	9/26/48	1:24k	B&W
CIV-6DD-23, 24	9/28/63	1:24k	B&W
SCL 104-105, 106	5/16/65	1:12k	B&W

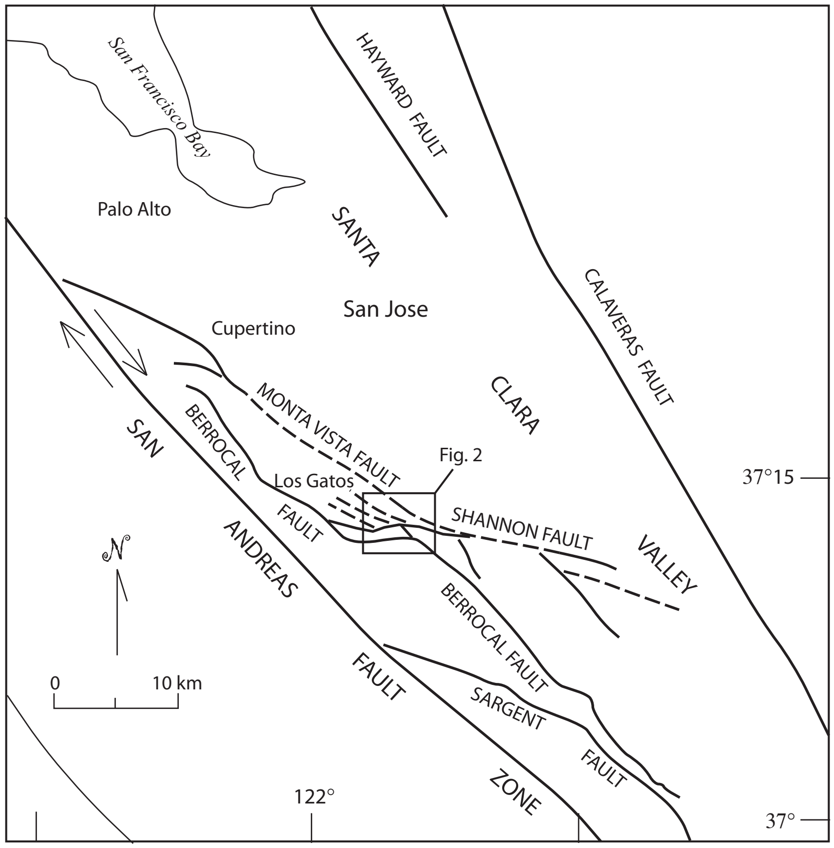

Figure 1. Generalized fault map showing site location regional faults along the southwest margin of Santa Clara Valley. Approximate area of Figure 2 shown.

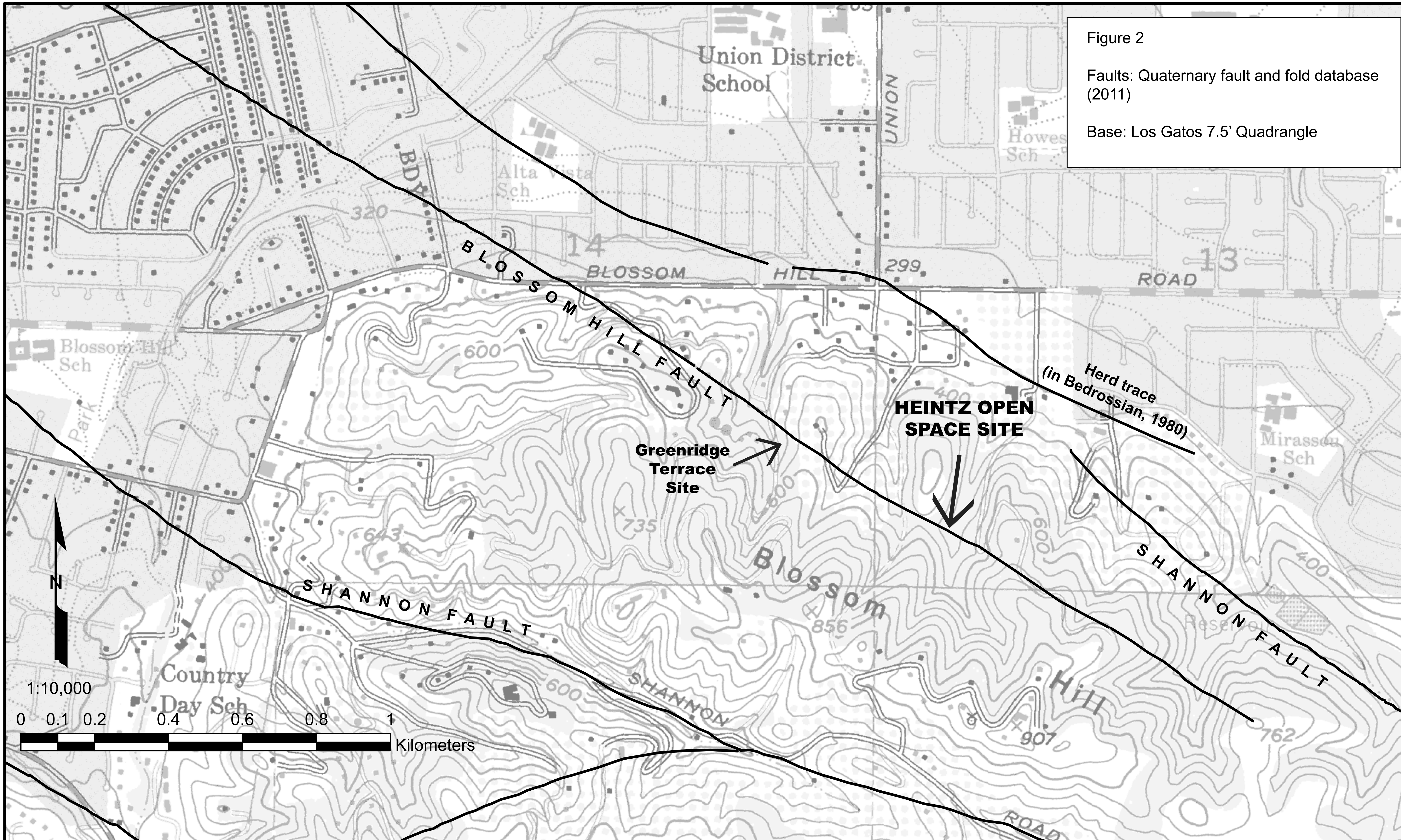

Figure 2
Faults: Quaternary fault and fold database (2011)
Base: Los Gatos 7.5' Quadrangle
Union District School
UNION
Alta Vista Sch
Howes Sch
Blossom Hill Sch
Park
BLOSSOM HILL ROAD
BLOSSOM HILL FAULT
Herd trace (in Bedrossian, 1980)
HEINTZ OPEN SPACE SITE
Greenridge Terrace Site
Mirassou Sch
SHANNON FAULT
SHANNON FAULT
Blossom Hill
Country Day Sch
SHANNON ROAD
Reservoir
320
299
600
400
643
735
856
907
762
14
13
N
1:10,000
0 0.1 0.2 0.4 0.6 0.8 1
Kilometers

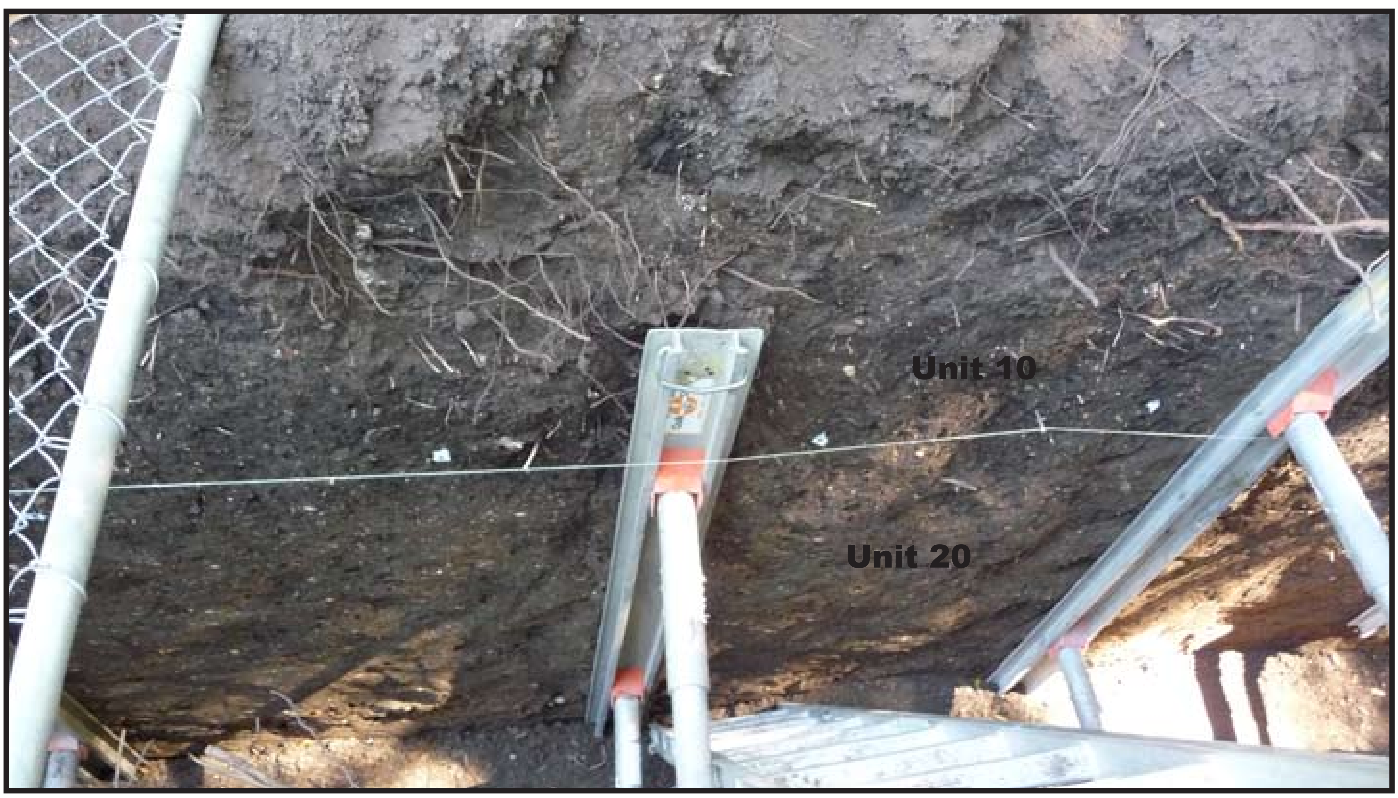

Figure 3. Field photographs. Upper photo looking east across trench site; red line approximates trench location. Lower photo of eastern trench wall. White flags approximate pedogenic contact between Units 10 and 20.

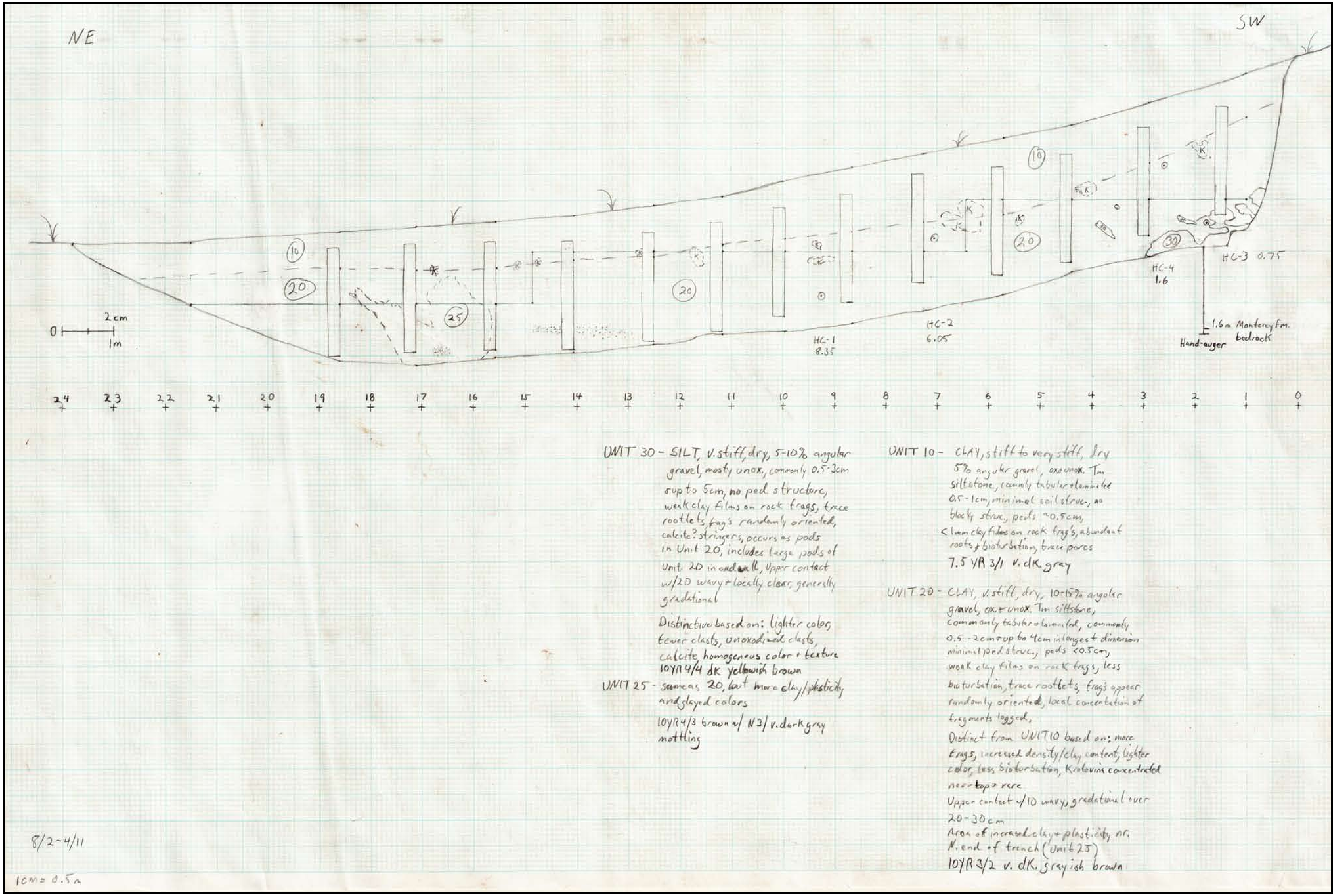

Figure 4. Log of Heintz open space trench.