InfraTerra, Inc.

FINAL REPORT

Desktop Fault Evaluation Study

Fremont BART Station Parking Lots (TOD)
Fremont, California

Prepared for:
Bay Area Rapid Transit (BART)

June 4, 2025

Infra•Terra, Inc.
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Consulting Services for the earth and built environment

June 4, 2025

Pawan Kumar, PE
Associate
Arup
560 Mission Street, Suite 700
San Francisco, CA 94105

Subject: Fault Evaluation Study, Fremont BART Station TOD, Fremont, California

Dear Mr. Kumar:

InfraTerra, Inc. is pleased to submit this Fault Evaluation Study presenting the results of our desktop fault study in support of potential development for the Fremont BART Station in Fremont, California. We appreciate the opportunity to be of service to ARUP and BART by performing this study. Please contact us if you have any questions or if we can be of further assistance.

Sincerely,

INFRATERRA, INC.

Christopher Hitchcock

PROFESSIONAL GEOLOGIST
CHRISTOPHER S. HITCHCOCK
No. 2017
CERTIFIED ENGINEERING GEOLOGIST
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Christopher Hitchcock, C.E.G. 2017
Principal Engineering Geologist

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1.0 INTRODUCTION

This report summarizes results of activities performed, and observations, conclusions and recommendations made by InfraTerra, Inc., as part of a desktop surface fault rupture evaluation of existing parking lots adjacent to the Fremont BART station in Fremont, California. The purpose of this study is to document the presence of earthquake-related surface fault rupture hazard as part of evaluation of the feasibility of BART's Transit-Oriented Development (TOD) program.

1.1 PROJECT LOCATION AND DESCRIPTION

Parking lots A through E are located southwest of the Fremont BART station and lots F through I, including I-R, are located northwest of the station, as shown in Figure 1.

1.2 SCOPE OF SERVICES

The desktop review conducted for this study consisted of evaluation of possible surface fault rupture hazards within the vicinity of the parking lots at the Fremont BART station. The scope of work performed for our investigation included:

- Compilation and review of available geotechnical and geologic data pertinent to the project;
- Review of historic aerial photographs and available Light Detection and Ranging (LiDAR) data;
- Site reconnaissance; and,
- Preparation of this desktop report.

Our approach to assessment of surface fault rupture hazard was to document the likely locations of active faults and associated fault-related deformation within the footprint of the parking lot parcels of interest based on review of relevant compiled geologic data from published fault maps, previous fault evaluation studies including fault trenches, and interpretation of historic aerial imagery and LiDAR terrain data. Results of this study include this fault evaluation report, signed and stamped by Christopher Hitchcock (Certified Engineering Geologist #2017).

1.3 LIMITATIONS

The conclusions and recommendations contained in this report are professional opinions derived in accordance with current standards of professional practice. This report may only be used and relied on by BART which is responsible to ensure that all relevant parties to the project, including designers, contractors, subcontractors, etc., are made aware of this report in its entirety.

2.0 REGULATORY BACKGROUND

2.1 ALQUIST-PRIOLO EARTHQUAKE FAULT ZONING ACT

The purpose of the Alquist-Priolo Earthquake Fault Zoning Act (hereafter referred to as the “A-P Act”) is to address the hazard of surface fault rupture by preventing the construction of structures for human occupancy across traces of active faults (California Public Resources Code (CPRC), Division 2, Chapter 7, Section 2621.5). The AP Act defines an active fault as that which has ruptured the ground surface approximately within the last 11,000 years ago (the Holocene Epoch).

Earthquake Fault Zones (EFZ) are regulatory zones (also known as A-P Zones) that encompass traces of Holocene-active faults to address hazards associated with surface fault rupture (CGS, 2018). EFZ zones are delineated by the State Geologist and implemented by lead agencies through permitting, inspection and land-use planning activities. Because there is uncertainty in the exact location and width of active faults, and because active secondary faults may be located close to a main active fault, the EFZ boundaries are conservatively drawn with a buffer several hundred feet wide surrounding well defined active fault traces.

Site-specific investigations are required for developments with human occupancy within the EFZ boundaries depicted on these maps and, if the potential for fault rupture is identified, plans to mitigate the hazard must be provided prior to a lead agency issuing a permit for construction (CGS, 2018). Because the A-P Act explicitly prohibits the construction of structures for human occupancy across traces of Holocene-active faults, the only mitigation the A-P Act allows for is avoidance (CGS, 2018). Avoidance of surface fault rupture hazard based on identification of fault-related features beneath a site, or lack of direct evidence that conclusively demonstrates absence of faulting, typically consists of a set-back distance from the features within which building construction is not permitted.

Both the western (main) trace of the Hayward fault and the eastern trace in the vicinity of the Fremont BART station are identified by the State as active faults and are bounded by EFZ boundaries. These boundaries encompass all or portions of Lots A through C and F through I, including Lot I-R (Figure 1). Under the AP Act, a geologic investigation and report are required to ensure that proposed buildings will not be sited upon an active fault. Because there is the potential for active secondary traces within the Hayward fault zone, subsurface investigation will be required to directly evaluate the absence or presence, activity and characteristics of secondary faults or discontinuous shears that cross the proposed development. The subsurface investigation and reporting should follow guidance provided by the California Geological Survey (CGS) Note 49, “Guidelines for Evaluating the Hazard of Surface Fault Rupture”, and CGS Special Publication 117 “Guidelines for Evaluation and Mitigating Seismic Hazards in California,” which recommend methodologies for assessing seismic hazards in California.

2.2 A-P FAULT INVESTIGATION PROCEDURE

The owner/developer (or their agent) typically works with the local lead agency in order to determine what portions of the proposed project are subject to the A-P Act and what studies are required to comply with the law (CGS, 2018). It is the owner/developer who must hire a project geologist to conduct the fault investigation and submit a fault investigation report to the lead agency for review.

Trenching is the most common type of subsurface fault investigation (CGS, 2018). Trenches excavated for the purpose of determining recency of fault activity should be excavated as orthogonal to the trend of a mapped fault as feasible and consider possible projections of potential unmapped splay faults, to ensure that areas within, and close to, the building footprint(s) are not affected by Holocene-active faults. If a Holocene-active fault is found during a fault investigation, a structure for human occupancy will not be allowed to be built across that fault. However, it is insufficient for the fault investigation to conclude the absence of faulting as the fault rupture exploration must expose unfaulted native soils of sufficient age to demonstrate absence of active faulting.

Based on the results of the fault investigation, the project geologist commonly will designate areas where structures can be located, as well as recommending setbacks from faults with the potential for surface fault rupture. These setbacks will help determine how much area within a parcel is available for construction of structures with human occupancy.

3.0 GEOLOGIC AND TECTONIC SETTING

The San Francisco Bay Area is one of the most seismically active regions in the USA. Dominated by the San Andreas fault system, the Bay Area is comprised of mostly northwest-trending strike-slip faults driven by the interaction of the Pacific and North American Plates.

3.1 REGIONAL SETTING

The San Francisco Bay Area lies along an active system of faults forming the boundary between the North American and Pacific plates, and consisting of the San Andreas, Hayward-Rodgers Creek, and Calaveras fault, as well as other lesser structures. The Hayward Fault borders the eastern margin of the East Bay hills in the eastern San Francisco Bay area and is a major component of the 195-mi-long (314-km-long) Rodgers Creek-Hayward-Calaveras fault system.

3.2 HAYWARD FAULT

The 66.5-mi-long (107 km) Hayward fault is mapped along the western margin of the Diablo Range through the many urbanized communities of the San Francisco Bay Area (WGCEP 2003; Lienkaemper et al., 2014). The Uniform California Earthquake Rupture Forecast Version 3.0 (UCERF 3.0) (Field et al., 2015) assigns a probability of 32% that the Hayward-Rodgers Creek fault (HRCF) will produce an earthquake of M≥6.7 in the next 30 years, the highest probability for any San Francisco Bay Area fault other than the San Andreas fault. To the north, the fault extends northwest and offshore into San Pablo Bay, where the Hayward fault makes a 2.5-mi-wide (4-km-wide) right step (or bend) to join the Rodgers Creek fault (Dawson, 2013; Watt et al., 2016). The southern end of the Hayward fault transfers slip to the central Calaveras fault across a left restraining bend via a series of closely spaced, northwest-striking oblique slip faults (Chaussard et al., 2015).

The Hayward fault is subdivided into two fault sections, based on a variety of geomorphic, geologic, geophysical, and slip rate changes, and includes:

- Hayward fault south (HFS) (length of approximately 33.5 mi [54 km]), mapped from Fremont to Oakland, California

- Hayward fault north (HFN) (length of approximately 32.9 mi [53 km]), mapped from the Oakland to San Pablo Bay.

The section boundaries between the northern and southern fault sections are based primarily on the extent of previous historic earthquakes, such as the 1868 earthquake (Lettis, 2001; WGCEP 2003, 2008 Dawson, 2013).

The Fremont BART Station site is located along the southern Hayward fault section. Directly east of the Fremont BART station, extending north and south of Walnut Avenue, the Hayward fault bounds the topographic depression known locally as "Tule Pond" (Figure 1). Tule Pond is a fault-bounded, pull-apart basin located between two primary strands of the fault.

At Walnut Avenue, these two primary strands are parallel and about 350 ft (107 m) apart and have an average orientation of about N32˚W (Figure 1). About 1,750 ft (530 m) north of Walnut Avenue, the two primary fault strands merge into a single fault trace and form the northern end of Tule Pond. South of Walnut Avenue, the eastern fault strand dies out, and the Tule Pond depression rises gradually to a linear hill directly southeast of Stevenson Boulevard. The former Fremont Civic Center occupies the crest of this fault-bounded "pressure ridge".

The locations and characteristics of major strands of the Hayward Fault near Walnut Avenue are reasonably well known on the basis of documented creep-related deformation of cultural features, numerous recent trenches, and original site topography (Figure 1). These primary fault strands are defined based on local evidence of fault creep (e.g., deformed curbs, sidewalks, and pavement; Lienkaemper, 1992), and within fault trench exposures.

3.3 SITE GEOLOGY

The Fremont Bart station is located on the broad alluvial fan of Alameda Creek. West of the main fault trace are older sand and gravel alluvial deposits of the Niles alluvial cone (California Department of Water Resources, 1967). Surface Holocene deposits consist of loose to moderately consolidated silty clays, clayey silts, and occasional lenticular fine sand.

Geologic deposits within the Tule Pond depression located east of the station generally consist of fine-grained deposits, with varying amounts of silt and clay, and some sand, particularly near the main fault trace. Localized deposition of marsh deposits consisting of soft to firm clay, organic clay, and peat has occurred in Tule Pond. Due to poor consolidation and high organic content, these deposits are highly compressible. Previous subsurface investigations for the Fremont BART Station indicate that the marsh deposits extend to depths of 20 to 30 feet (6 to 9 m) beneath the pond. These materials have a relatively high susceptibility to groundshaking. Although these fine-grained materials are considered to have a low liquefaction potential, localized conditions that are conducive to liquefaction including sand layers and high groundwater levels may be present within some marsh deposits. As summarized in the Geotechnical Impact Report for the BART Warm Springs Extension by Parikh Consultants, Inc. (2003), the Holocene Alluvial Fan Deposits in the vicinity of Tule Pond are considered to have a high susceptibility to liquefaction. Evidence of previous occurrences of liquefaction has been identified in United States Geological Survey (USGS) fault trenches south of Walnut Avenue and within the marsh deposits located north of Tule Pond.

Cone Penetration Test (CPT) soundings collected along the southern margin of Walnut Avenue by Fugro (2002) documented the presence of relatively loose to moderately dense interbedded fine-grained sediments, interpreted as fill and Holocene deposits, overlying massive, dense sand and gravel. The CPT soundings showed an abrupt increase in sand content and density at depths of about 7 to 10 ft, west of the western fault strand. The dense, sandy sediments are interpreted as late Pleistocene to early Holocene deposits and are similar to deposits at similar depths within nearby USGS trenches (Trench USGS-00A; USGS, 2002). These denser sediments overlain by fill and fine-grained Holocene deposits likely are present at shallow depths beneath the parking lots (Lots A through G) located west of the western fault strand of the Hayward fault.

Prior to development, Lots I and I-R, and the eastern portion of Lot G, were at a somewhat lower elevation adjacent to Tule Pond than the rest of the Fremont BART station and other parking lots based on review of historical aerial imagery. As a result, fill placed to level the lots may be thicker than that present at the other parking lots. In addition, the portions of these lots located east of the western fault strand, in the area between the two fault strands that form Tule Pond, likely are underlain by softer, fine-grained pond deposits that may be less desirable for construction. Given their position within the fault zone and shallow groundwater levels, these deposits may also be more prone to liquefaction and secondary fault deformation.

4.0 FAULT LOCATION AND ASSOCIATED DEFORMATION

For this study, we reviewed existing geologic information from published geologic maps, scientific papers, and unpublished fault investigations conducted in the site vicinity. We have interpreted this information to provide an evaluation of the location of the Hayward fault in the vicinity of the Fremont BART station parking lots (Figure 1).

4.1 FAULT MAPPING

As initially mapped by Radbruch-Hall (1974), the Hayward Fault zone in the vicinity of Tule Pond consisted of two potentially active traces that bounded the pond. The locations of active strands of the Hayward Fault in the vicinity of the Fremont BART station are primarily based on more recent mapping by the California Geological Survey (e.g. Hart, 1979), conducted as part of the official fault zoning process, and by the USGS based on locations of active fault creep and results of fault trenching (Lienkaemper, 1992).

4.2 PREVIOUS FAULT STUDIES

Previous trenching investigations conducted for A-P fault and USGS research studies provide excellent information on the location, width, and characteristics of active strands of the Hayward Fault in the vicinity of the Fremont BART station north of Walnut Avenue (Figure 1). The general location of the Hayward Fault zone in the vicinity of the station has been investigated and mapped by various entities including Cooper-Clark and Associates (1968), Woodward-Clyde and Associates (1970), Purcell, Rhoades and Associates (1989), and the US Geological Survey (1998, 2000, 2002).

In general, multiple trenches in close proximity to the proposed alignment suggest that the fault zone includes two primary strands bordering the margins of Tule Pond northwest of Walnut Avenue (Figure 1). The western fault strand exhibits evidence of fault creep and continues southeast of Walnut Avenue to the former Fremont City Center, whereas the eastern fault strand south of Walnut Avenue dies out into a southwest-facing flexure (Woodward-Clyde Associates, 1970). The total width of the fault zone containing both fault strands in the vicinity of Walnut Avenue is about 350 ft (107 m).

As noted above, the Tule Pond depression is a fault-bounded, pull-apart basin located between the western and eastern strands of the fault. The location of the western fault strand is well constrained by a prominent northeast-facing scarp developed on Holocene alluvium, and by numerous exploratory trenches. These include, in the area between Walnut Avenue and Stevenson Boulevard, six trenches by the USGS (1998, 2000, 2002) and five trenches by Woodward-Clyde & Associates (1970) (WC-A, WC-D, WC-G, WC-I, and WC-K; Figure 1). These show clear geologic evidence of fault displacement within a zone that is as much as about 25 ft (8 m) wide at or near the base of the fault scarp. The fault in these trenches commonly is associated with a 15- to 25-ft-wide (5- to 8-m-wide) graben and shows a net down-on-the-northeast vertical separation.

Similarly, the western fault strand in the area between Walnut Avenue and the northern end of Tule Pond was exposed in multiple trenches (Figure 1). These include six trenches by Cooper-Clark (1968) completed prior to construction of the BART parking lots and two trenches by Purcell, Rhoades and Associates (1989). Cooper-Clark and Associates (1968) located the western trace of the Hayward Fault in trenches along the western side of Tyson's Lagoon. The fault trace was roughly coincident with an east-facing scarp identified on historical aerial photographs, now covered by parking lots H, I-R, and I. These trenches also show a substantial zone of shearing and warping that is as much as about 30 ft (9 m) wide.

The character and intensity of shearing of the near-surface sediments in these trenches is substantial and similar to that exposed in the trenches located southeast of Walnut Avenue. Collectively, the trench exposures of the western fault strand along the margin of Tule Pond show that this is a continuous, major zone of displacement. There is no geologic information from which to evaluate the true sense or amount of fault slip. However, the presence of lateral fault creep and regional relations suggest that the majority of movement along the fault is right lateral, with a component of northeast-down vertical displacement.

The eastern margin of the Tule Pond is associated with a southwest-facing linear scarp along the eastern strand of the Hayward Fault (Figure 1). At the northern end of the pond, two trenches by Purcell, Rhoades & Associates (1989), two trenches by Earth Systems Consultants (1983), and five trenches by Williams (1992) all show a major zone of active faulting. Williams (1992), in particular, provides detailed logs of the fault deformation and shows that the fault is as much as 13 ft (4 m) wide. The fault is also associated with some southwesterly tilting of sediments, within a 33 to 50 ft (10 to 15 m) wide zone including the primary fault strand (Williams, 1992). The topographic scarp associated with this deformation at the northern end of Tule Pond continues southeastward to Walnut Avenue.

Directly southeast of Walnut Avenue, the fault was exposed in two trenches by Woodward-Clyde & Associates (1970; WC-B, WC-C), in two trenches by P. Williams (unpublished; PW T-1 and PW T-2), in trench ESC89 T-2 by ESC (1989), and in one recent trench by the USGS (2002). These trenches demonstrate that the eastern fault strand is about 30 ft (9 m) wide near Walnut Avenue but is progressively narrower and less prominent in a southeasterly direction (Woodward-Clyde, 1970; Williams, 1992). Trenches WC-E and WC-F show that the eastern fault dies out as a distinct, young strand and merges into a broad flexure. At the location of trench WC-H, the deformation consists of a broad, 41-ft-wide (12-m-wide) flexure in the young sediments. Trenches south of WC-H along the projection of the eastern fault strand (trenches WC-L, WC-M, ESC89 T-3, ESC86 T-2) show an absence of young faulting. Thus, previous studies interpret that the eastern fault strand progressively becomes a broad flexure southeastward of Walnut Avenue and eventually dies out directly south of the BART alignment (Woodward-Clyde, 1970; Williams, 1992; ESC, 1989; USGS, 2000; Figure 4).

In 2000, the USGS (2002) excavated three trenches, Trenches 00A, 00B, and 00C, in Tule Pond south of Walnut Avenue. In 2002, the USGS excavated and logged five additional trenches in an east-west transect across Tule Pond, several hundred feet south of Walnut Avenue. These trenches help constrain the locations and style of deformation for both the western and eastern fault strands.

4.3 FAULT CREEP

Fault creep is slow movement that occurs on some active faults without an earthquake. This movement consists of aseismic fault slip that occurs in the uppermost part of the earth's crust between large stress-releasing earthquakes on a fault or as afterslip in the days to years following an earthquake. It is commonly assumed that the primary surface rupture during a large earthquake will coincide with the active creeping fault trace, although fault rupture may also occur on non-creeping fault strands.

The Hayward Fault is creeping at the surface along its entire length (Lienkaemper and others, 1991; Lienkaemper and Galehouse, 1997, 1998), although the rate of creep varies along the fault trace. Measurements of surface creep (Lienkaemper and others, 1991; Lienkaemper and Galehouse, 1997) show that the Hayward Fault has an average creep rate of about 3.5 to 6.5 mm/yr, and a high of 9 mm/yr locally near Fremont. About 1 km north of the Tule Pond, the fault creeps at 5.3 ± 0.3 mm/yr (at the USG Warehouse site, Lienkaemper et al., 1991). About 1 km south of Tule Pond, the fault creeps at a rate of 5.2 ± 0.3 mm/yr (at the Senior Center site, Lienkaemper et al., 1991).

Evidence of fault creep provides excellent information on the location of active fault strands. Fault creep in the vicinity of Tule Pond was first noted and mapped by Bonilla (1966) based on deformation of railroad tracks. As mapped by Lienkaemper (1992), there are several localities near Walnut Avenue where fault creep is documented or suspected. Presently, the most prominent evidence of fault creep near the Fremont BART Station is present across the Walnut Avenue pavement, where a series of en echelon cracks extends across the roadway and coincides with the western fault strand. We observed no similar prominent cracks across Walnut Avenue where it is traversed by the eastern fault strand, nor in the area between the two strands.

Northwest of Walnut Avenue, Lienkaemper (1992) notes the presence of en echelon cracks and an offset curb in the present-day BART parking lot. Additional evidence of creep along a single fault strand is present at multiple locations northwest of Tule Pond (as summarized by Lienkaemper, 1992).

4.4 SURFACE FAULT DEFORMATION

Based on past fault trenching, deformation along the western fault strand is substantial, and includes faulting and folding within a zone as much as about 30 ft (9 m) wide. Deformation along the eastern margin of Tule Pond at Walnut Avenue consists of a broad 40-ft-wide (12-m-wide), west-facing flexure and likely less surface deformation compared to that along the western fault strand. Figure 2 shows possible setback distances that incorporate the likely width of fault deformation and uncertainty in the fault location. These possible setback distances shown in yellow are for general guidance only and must be confirmed by subsurface exploration.

5.0 RESULTS OF FAULT RUPTURE EVALUATION

For this study, we reviewed existing geologic information from published geologic maps, scientific papers, and consulting reports. Previous observations of fault creep and trench exposures provide reasonably well-constrained information on the location, orientation, and width of active faulting along the Hayward fault within the project area. We also reviewed the primary data used to originally map the fault including historical aerial imagery from 1939 through the present (2025) along with more recent LiDAR datasets that provide information on modern topography.

5.1 INTERPRETATION OF AVAILABLE AERIAL PHOTOGRAPHY AND TERRAIN DATA

As part of this task, we reviewed multiple sets of historical aerial photography, including aerial photographs from UC Berkeley and UC Santa Barbara libraries (Table 1). The aerial photographs were reviewed in order to: (1) evaluate the pre-development terrain and land use at the site prior to construction of Fremont BART station, and (2) interpret topographic and photo-lineaments suggestive of fault-related deformation. The aerial photographs consist of matching sets of stereo-paired, black-and-white and color aerial photographs reviewed at scales of 1:10,800 to 1:30,000, and are included for reference in Appendix A.

Table 1. List of Aerial Photographs Reviewed for This Study

Date	Type	Source	Flight Line / Frames	Scale
7/26/1939	Black and White	UCSB (USDA)	C-5750 281-72 through 281-74	1:20,000
3/13/1958	Black and White	USGS	BUT-1958 5V-182 and 5V183	1:20,000
5/1/1965	Black and White	USGS	CAS-65-130 9-83 through 9-84	1:12,000
6/22/2000	Color	UCSB (Altaphoto)	HM-2000-US 1115-276 through -277	1:10,800

We also downloaded and interpreted publicly available USGS LiDAR terrain data collected in 2007 as part of the EarthScope Northern California LiDAR Project and collected in 2021 as part of the USGS 3D Elevation Program (3DEP). Raw points clouds from these high-density (ranging from 5.17 to 37.53 pts/m^2) LiDAR datasets, available on-line via opentopography.org, were downloaded and processed for this study. Derivative products, including hillshade, slope-shade, slope-aspect and topographic-contour maps were used to identify subtle potentially fault-related geomorphic features.

Based on review of the historic aerial imagery, the site of the parking lots was originally level with the eastern portion of the lots gently sloping toward Tule Pond. The land was used for agricultural purposes and consisted of open fields with some nearby apricot and walnut orchards. The main fault strands of the Hayward fault show relatively clearly as disturbed or discolored soil lineaments and scarps. Review of the aerial photographs show additional faint lineaments which may represent secondary or cross faults.

5.2 SITE RECONNAISSANCE

InfraTerra performed geologic reconnaissance of the site and vicinity to examine potential fault-related geomorphic features associated with the Hayward fault. The reconnaissance conducted by Christopher Hitchcock (CEG) on April 25, 2025, included identification of likely underground utilities and other constraints that may impact fault trenching. Underground electrical conduits connecting free-standing lights within the parking area, storm drains, and limited landscaping irrigation pipes were identified within the limits of the parking lots.

Evidence of active fault creep included right-laterally offset concrete curb and en echelon pavement cracking within parking lot H (Photos 1 and 2; see Figure 1 for location).

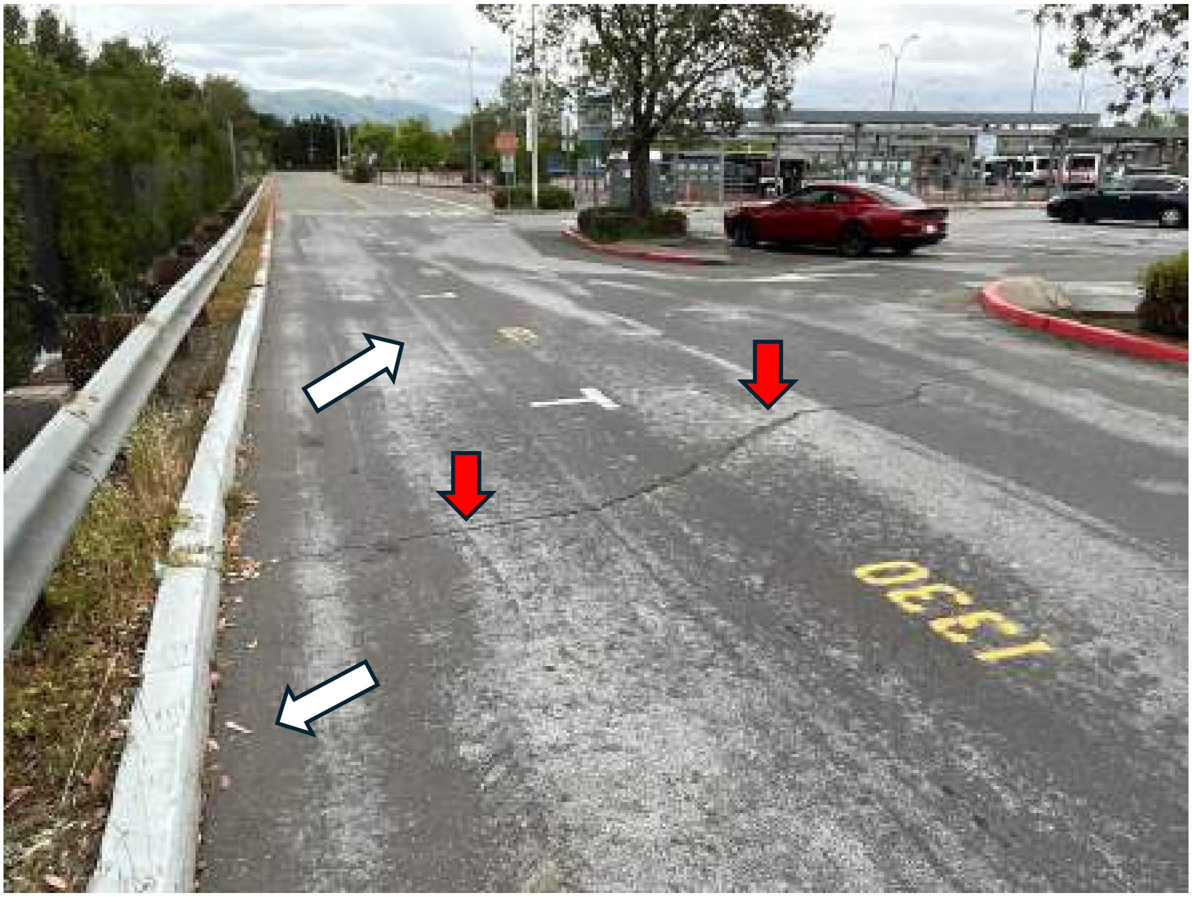

Photo 1: View to south along eastern access road within Parking Lot H. Note offset curb (white arrows) and cracking in pavement (red arrows).

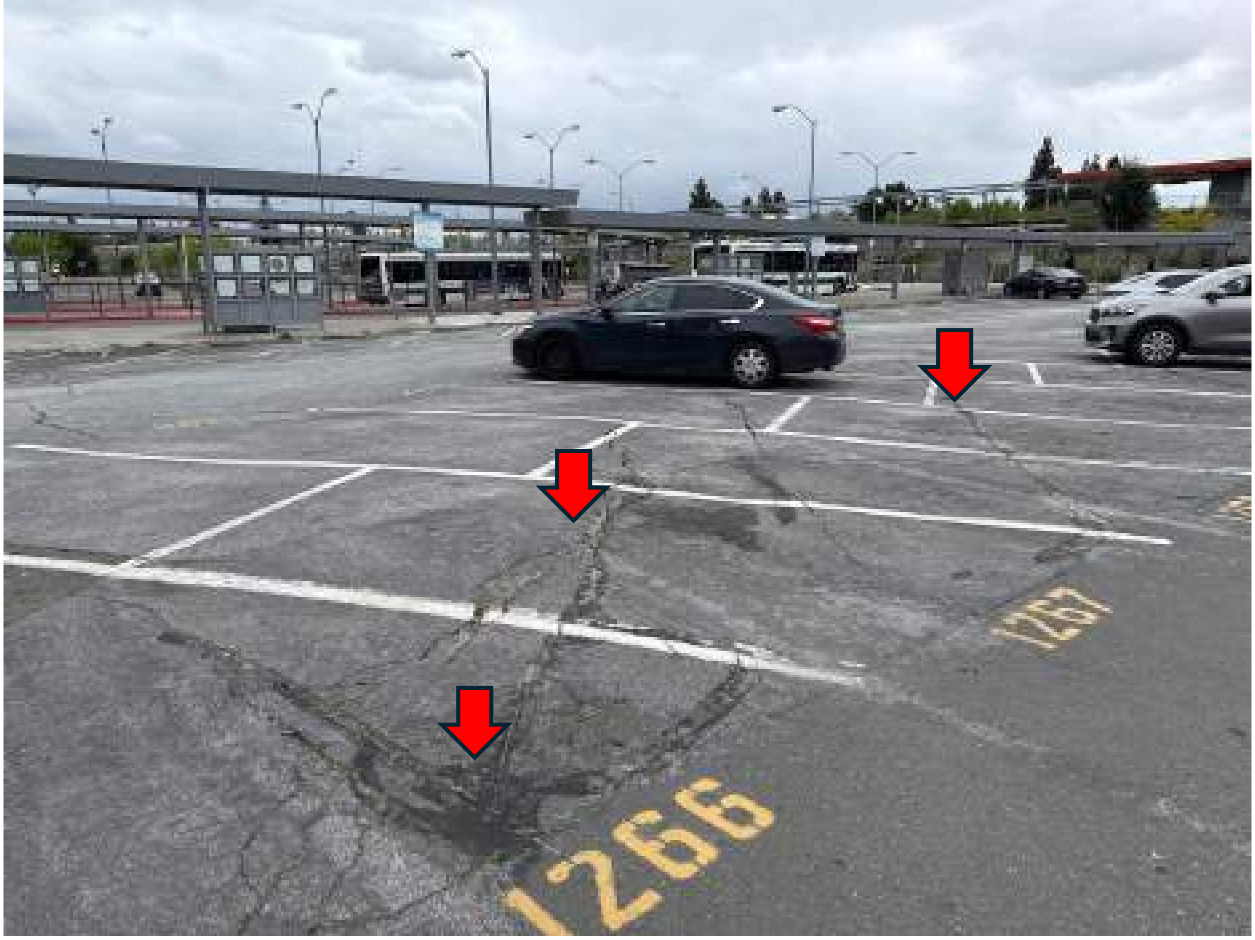

Photo 2: View to southwest of pavement cracking (red arrows) within Parking Lot H coincident with mapped creeping trace of the Hayward fault (Lienkaemper, 1992).

6.0 POTENTIAL DEVELOPMENT CONSTRAINTS

Based on results of our investigation, we conclude that development within two of the subject parking lots (D and E) is not constrained by the A-P Act with only a small portion of lot C within the zone of required investigation (EFZ). The footprint of any proposed building complex within lot C likely is outside the EFZ given the location immediately adjacent to the BART station. As described below, and shown in Figures 1 and 2, lots A, H, I, and I-R are entirely within the EFZ and significant portions of lots B, F, and G are within the zone of required investigation. Of these lots, H, I, and I-R are crossed by mapped active strands of the Hayward fault (Figure 1).

6.1 SECONDARY FAULT DEFORMATION

Field and laboratory models show that pull-apart basins developed along strike-slip faults commonly contain short, basin-crossing faults that link the primary fault zones along the basin margins (McClay and Dooley, 1995; Sylvester, 1988). Surface deformation between major strike-slip fault strands can take various additional forms, including development of secondary structures like Riedel shears and synthetic shears. Riedel shears are secondary fault structures that develop at an angle to the main fault and are commonly associated with strike-slip faults. Synthetic shears are secondary, discontinuous faults that can form between Riedel shears.

Woodward-Clyde (1978) concluded that there is a high potential for the development of cross faults, shears, and lurch cracking in the area between the two main traces of the Hayward fault. This potential should be considered as part of evaluation of the viability for development of lots I and I-R as both lots are located between the two main mapped fault traces (Figure 2). As noted above, aerial photographs show faint lineaments which may represent such secondary faulting. If found during fault trenching, these secondary fault features may preclude building on lots I and I-R.

Probabilistic models developed by Rodriguez Padilla and Oskin (2023) for strike-slip faults indicate an approximately 2% probability of distributed fault rupture displacement of 4 inches or greater for an earthquake of magnitude (M_W) 7 at a distance of 50 feet away from the primary fault rupture, consistent with site-specific conclusions by Woodward-Clyde (1970). Expected displacements along secondary faults could cause minor repairable damage to rigid structures. Assuming a 30-ft wide fault zone with 50-ft fault setback (e.g. Figure 2), adding up to roughly 40,500 square ft of non-buildable space, up to 114,000 square ft of lot H (or approximately 74% of the western lot area) may be available for residential development.

6.2 POTENTIAL SUBSURFACE EXPLORATION ISSUES

Site conditions that may directly impact the ability to characterize fault rupture hazards for development by trenching include the potential presence of shallow groundwater, thick emplaced fill overlying native deposit, and the presence of soft or loose marsh deposits. Shallow groundwater and loose or soft soils can make trenching unstable and unsafe. Additional cost may be incurred to pump the water out of trenches and unstable trench walls may preclude the ability to trench deep enough to expose unfaulted native soils of sufficient age to demonstrate absence of active faulting. Similarly, the presence of thick fill can result in unstable trench walls or burial of native soils at depths that can't be safely reached by trenching.

Alternatives to fault trenching include high-resolution geophysics and transects of closely spaced CPTs. CPTs are geotechnical field tests used to determine the characteristics of soil beneath the ground surface that involves pushing an instrumented cone into the soil at a controlled rate, measuring resistance to penetration (tip resistance and sleeve friction). Typically these exploration techniques need to be combined to be effective and therefore typically more expensive than trenching. These techniques for identifying fault rupture hazard generally are less conclusive in terms of both identifying fault features and documenting absence of fault rupture hazard for strike-slip faults than trenching and, therefore, less likely to be accepted by regulatory agencies. The risk of using non-trenching techniques is that the results may not conclusively document the absence of fault-related ground deformation under areas of proposed development, resulting in more conservative fault setbacks with less area approved for construction.

6.3 FAULT RUPTURE EXPLORATION COSTS

Estimated approximate costs of fault trench investigations for each parking lot are presented in Table 2, with the suggested trenching program shown in Figure 2. Excavation costs for trenching typically are 2/3s of the total overall cost. Fault trenches typically need to be deep enough to expose continuously unfaulted native soils. Trench dimensions are generally 8 to 14 ft deep and 3 ft wide. Pavement and concrete curbs would need to be cut prior to trenching. Trenching typically is performed using a rubber-tire backhoe with a 3-ft bucket. A 500 ft trench generally takes three to four days to excavate and up to five days to backfill to compaction. As required by law, the site needs to be to marked and Underground Service Alert (USA) notified. A private underground utility locator typically is engaged to identify and/or clear the planned trench locations of any utility conflicts prior to digging.

Trench spoils are stockpiled onsite, adjacent the trench. The stockpiled material is used to backfill the trenches when finished, typically to 90% compaction. Field testing would be required to confirm this level of compaction. Our trenching estimates do not include the cost of importing soil, if needed to complete the backfilling to grade or removal of excess remaining soil if not all the soil can be placed as part of the backfill process.

Once open, the trenches are made safe by emplacement of hydraulic shoring (typically consisting of 7-ft aluminum speed shores) as required by OSHA regulations. These shores are typically spaced at 4 to 5 ft intervals, depending on soil type and trench stability, with double, overlapping shores installed for trench depths greater than 8 ft. Fault trenches typically are covered by plywood when not being logged and the trench perimeters fenced to prevent entry.

Labor costs to document and interpret the fault trenches to develop recommendations for development typically are about 1/3 of the total A-P trenching exploration costs presented in Table 2. Trench walls need to be scrapped clean to expose and flag geologic units that are typically documented by a team of at least two engineering geologists with specialized expertise in paleoseismology. Within the proposed fault trenches, geologic units along with any fractures, shears, and faults will be documented and measured. The trenches will be logged at an appropriate scale to show lithology, lithologic contacts between units, and geologic structure. Trenches typically are open for one to two weeks to allow for logging by the project geologists and review by representatives of regulatory agencies.

In summary, the cost estimates presented in Table 2 were developed based on the following components work:

- Pavement/concrete trenching
- Trench excavation (backhoe)
- Hydraulic shoring rental
- Labor for shoring installation
- Fence rental
- Plywood
- Trench backfilling (Backhoe)
- Labor for shoring removal
- Trench fill compaction (testing)
- Engineering geologist time for field presence, mapping, interpretation and reporting

The results of the trenching investigation would be incorporated in a formal report for review by the regulators and to provide BART with clearly defined information that can be used for future planning and development purposes. This information will include:

- Locations of “No-build” zones if active faults are identified (and from which CGS will mandate a 50-foot setback); and
- “Cleared” zones where new structures may be built, per California law.

Table 2. Estimated Costs for Parking Lot Fault Rupture Hazard Evaluation

Parking Lot	Within A-P Zone	Crossed by Mapped Fault	Potential for Secondary Faulting	Exploration Required	Estimated Trenching Footage	Estimated Cost
A	Yes, entirely within zone	No	Moderate	Yes	Two trenches, 300 ft	$74,000
B	Yes, eastern portion	No	Low	Yes	One trench, 200 ft	$49,225
C	Yes, eastern boundary	No	Very Low	No, screened by trenching for Lot B	No trenches	-
D	No	No	Very Low	No	No trenches	-
E	No	No	Very Low	No	No trenches	-
F	Yes, eastern boundary	No	Low	Yes	One trench, 85 ft	$21,000
G	Yes	No	Moderate to Low	Yes	One trench, 530 ft	$130,500
H	Yes, entirely within zone	Yes	High	Yes	Two trenches, 530 ft	$130,500
I-R	Yes, entirely within zone	Yes	Very High	Yes	Two trenches, 400 ft	$98,500
I	Yes, entirely within zone	Yes	Very High	Yes	One trench, 375 ft	$92,500

6.4 STRUCTURAL/FOUNDATION CONSIDERATIONS

Proposed development with sufficient setback distance from estimated fault locations derived from the subsurface explorations suggested herein are expected to mitigate the risk of large fault rupture displacements. However, as summarized in Section 6.1, secondary fault deformation on the order of a few inches is still possible up to 200 feet away from a principal fault rupture. The structural and foundation design for planned structures should consider the residual risk of secondary fault rupture displacements, informed by a detailed fault rupture displacement hazard analysis.

In addition to fault rupture considerations, other seismic hazards of relevance to the project site include strong ground shaking, near-fault effects such as rupture directivity and fling-step ground motion, and liquefaction potential.

Specific recommendations on structural and foundation design will depend on the nature of planned development and are outside the scope of this report. Some general considerations are summarized below:

- Foundation design needs to strike a balance between mitigating surface fault rupture hazard (from distributed ruptures) and the impacts of strong ground shaking, near-fault effects and liquefaction. A continuous stiff foundation (such as a rigid mat foundation) is anticipated to perform better than other foundation solutions when subjected to fault rupture displacements, which is also the recommendation provided in the most recent draft of the Eurocode (FprEN 1998-5, 2024). However, the potential for liquefaction may also warrant consideration of deep foundations and/or ground improvement.

- The structural seismic force-resisting system should be designed to accommodate the anticipated strong shaking in close proximity to the Hayward Fault. If structural response at long structural periods (low frequencies) are of relevance (as may be the case for tall buildings or base-isolated structures), the potential impacts of near-fault effects such as rupture directivity and fling-step ground motion should be explicitly incorporated into the structural design and analysis.

- If planned utility lines cross any of the mapped traces of the Hayward fault, automatic cutoff valves should be considered on the gas, electric and water lines where in conformance with utility company practice.

7.0 CONCLUSIONS AND RECOMMENDATIONS

Based on results of our desktop investigation, we conclude that several parking lots under consideration for future development at the Fremont BART station are crossed by recently active (Holocene) traces of the Hayward fault including lots H, I, and I-R. These lots require subsurface exploration to determine the extent of active fault deformation crossing each lot. It is considered likely that substantial setbacks will be required from the main mapped traces of the Hayward fault, specifically the western fault strand mapped by CGS, USGS, and others.

We conclude that active strands of the Hayward fault extend beneath lots H, I-R, and I. In addition, the soils underlying lots I and I-R likely are younger and less stable than those underlying the lots located west of the fault zone. Finally, it is also considered strongly likely that secondary faults and/or shears may be encountered beneath these lots during trenching that would preclude use of much or all of the lots for construction of structures with human occupancy. Given the likely fault-related constraints identified for this desktop study, lots I and I-R are not recommended for future study, and therefore potential development. In contrast, although the eastern corner of lot H likely is crossed by the creeping western strand of the fault, most of the western portion lot should be located west of any estimated setback (‘no occupied building area’) from the fault and therefore likely available for development (e.g. Figure 2). Finally, underground utilities that extend across these lots may experience ongoing fault creep and more significant deformation during future large ground-rupturing earthquakes on the Hayward fault.

Although partially within the official A-P zone of required fault investigation, Lots A, B, C, F, and G are unlikely to be crossed by active fault rupture. However, portions of these lots will require subsurface investigation to confirm the absence of faulting for regulatory agencies. Lots D and E are not within the A-P zone and therefore should not require additional subsurface investigation for surface fault rupture.

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APPENDIX A

Historical Aerial Photographs


7-26-39
BUT-281-72


7-26-39
BUT-281-73


7-26-39
BUT-281-74


8-13-58
BUT-5V-182


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BUT-5V-183


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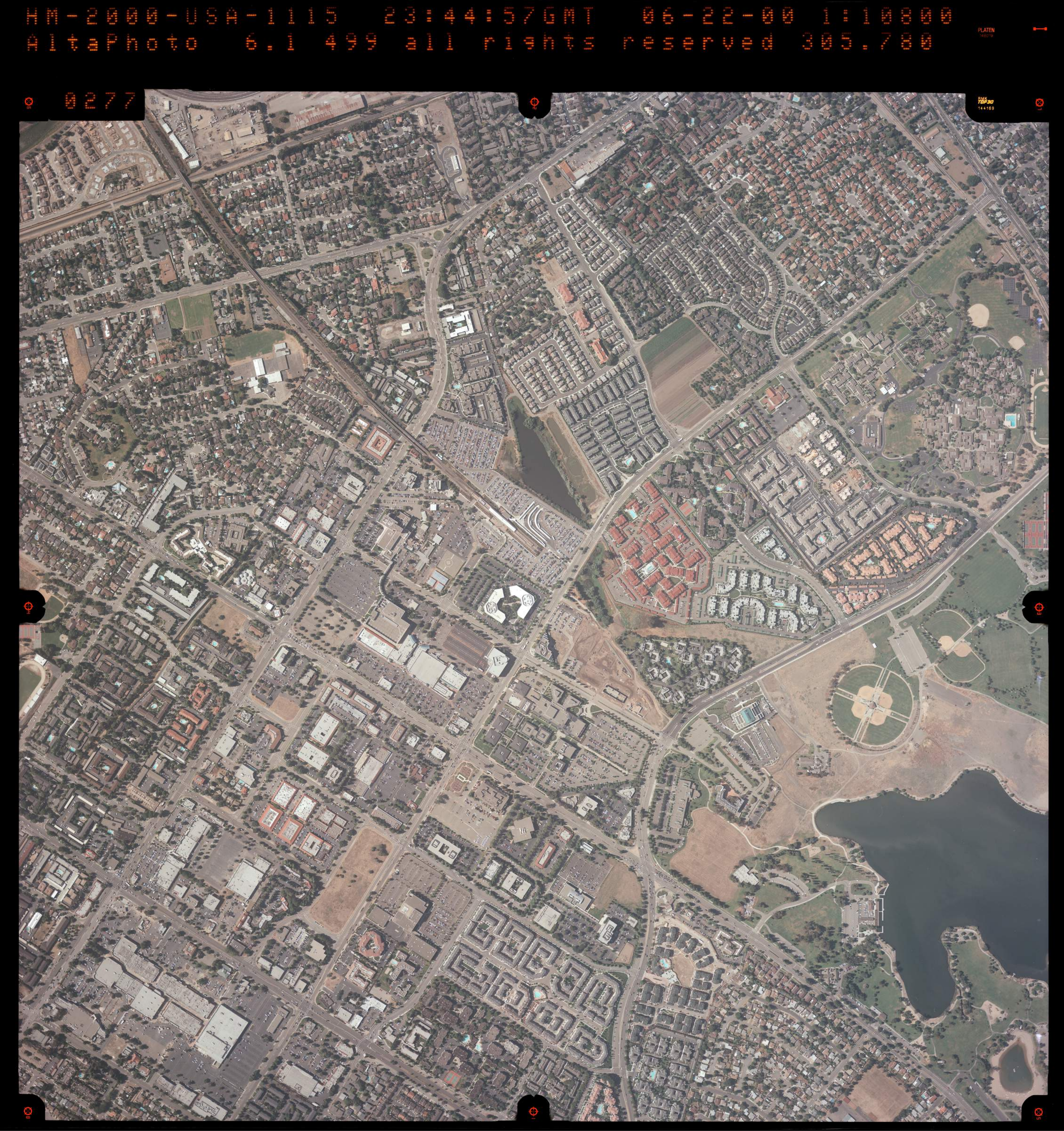
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