THE INCREDIBLE CENOZOIC GEOLOGIC HISTORY OF SOUTHERN CALIFORNIA

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TO THE EDGE OF A PLATE - FIELD GUIDE TO THE GEOLOGY BETWEEN THE SAN FERNANDO VALLEY AND PALMDALE, CALIFORNIA

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INTRODUCTION

The drive from the San Fernando Valley to Palmdale on the I-405, I-5, and Hwy 14 (Antelope Valley) freeways (Fig. 1) exposes travelers to a wide variety of geological features. Rock types range from marine and terrestrial sedimentary to extrusive and intrusive igneous, and rock ages range from Precambrian to Pleistocene; geologic resources extracted from these rocks include oil, gold, water, and sand & gravel; geologic structures include normal, thrust, and strike-slip faults, anticlines, and synclines; and to top it off, of course, is the world's most famous fault, the San Andreas, separating the Pacific and North American tectonic plates. We're truly fortunate to be within a short drive of this plate boundary. We're also fortunate that the route traverses an area with virtually complete coverage on 1:24,000 geological maps published by the Dibblee Geological Foundation. Road guides from several previous field trips that cover all or portions of this trip are available and have been liberally borrowed from, including Livingston (1949), Hester and Hallinger (1987), Baldwin et al. (1989), Silvester and Crowell (1989), and Sharp (1994). Material has also been gleaned from Oakshott (1958, 1975), Winterer and Durham (1962), Buckley and Larson (1990), Woods and Seiple (1995), and Tsutsumi and Yeates (1999).

Unlike many geology field trip guides, this one is not primarily aimed at professionals, but rather at students, middle and high school teachers, and community college instructors. Thus, more background material is presented, more definitions are provided, and more photographs are included. The combination of a variety of rock types and structures, the dramatic Vasquez Rocks, and the incomparable San Andreas fault, added to the accessability and short distances involved, make this trip one that should appeal to all students of earth science.

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GEOLOGIC BACKGROUND

Rocks

The igneous and sedimentary rocks seen on this trip vary widely in age and environment of formation. The rock units are listed below in order of decreasing geologic age, that is, from oldest to youngest, and with one exception are limited to the units actually observed.

San Gabriel anorthosite-syenite intrusion

This igneous body is Precambrian in age (1.125 Ga - billion years ago) and forms a large, layered intrusion exposed over about 250 km^2 (90 mi^2) and is composed primarily of the rock types anorthosite, gabbro, and syenite. Anorthosite is a rock containing more than 90% plagioclase feldspar, and gabbro contains plagioclase and a significant amount of pyroxene (augite and/ or hypersthene). Syenite is similar to gabbro except that the feldspar is a mixture of plagioclase and potassium-bearing feldspars. Primary Mg-bearing minerals in these three units mostly have been altered to amphibole. Anorthosite is the rock type that makes up the highlands of the Moon. In the rest of this guide, these units are collectively referred to as the San Gabriel anorthosite.

Mount Lowe intrusion

This igneous body is Late Triassic in age (220 to 208 Ma - million years ago) and forms a mineralogically zoned, composite batholith exposed over about 300 km^2 (100 mi^2). The rocks seen on this trip represent the marginal zone, which is composed of foliated hornblende quartz monzodiorite. Monzodiorite is part of the gabbro-granite series and contain mostly feldspar (in which the amount of plagioclase feldspar exceeds that of alkali feldspar), 5% to 20% quartz, and >10% mafic mineral. In these rocks, the mafic mineral is hornblende that has been partly altered to epidote. The hornblende crystals are roughly aligned and form a foliated texture. Inner zones of this body, not seen on this trip, are characterized by the presence of orthoclase phenocrysts or the presence of garnet or biotite.

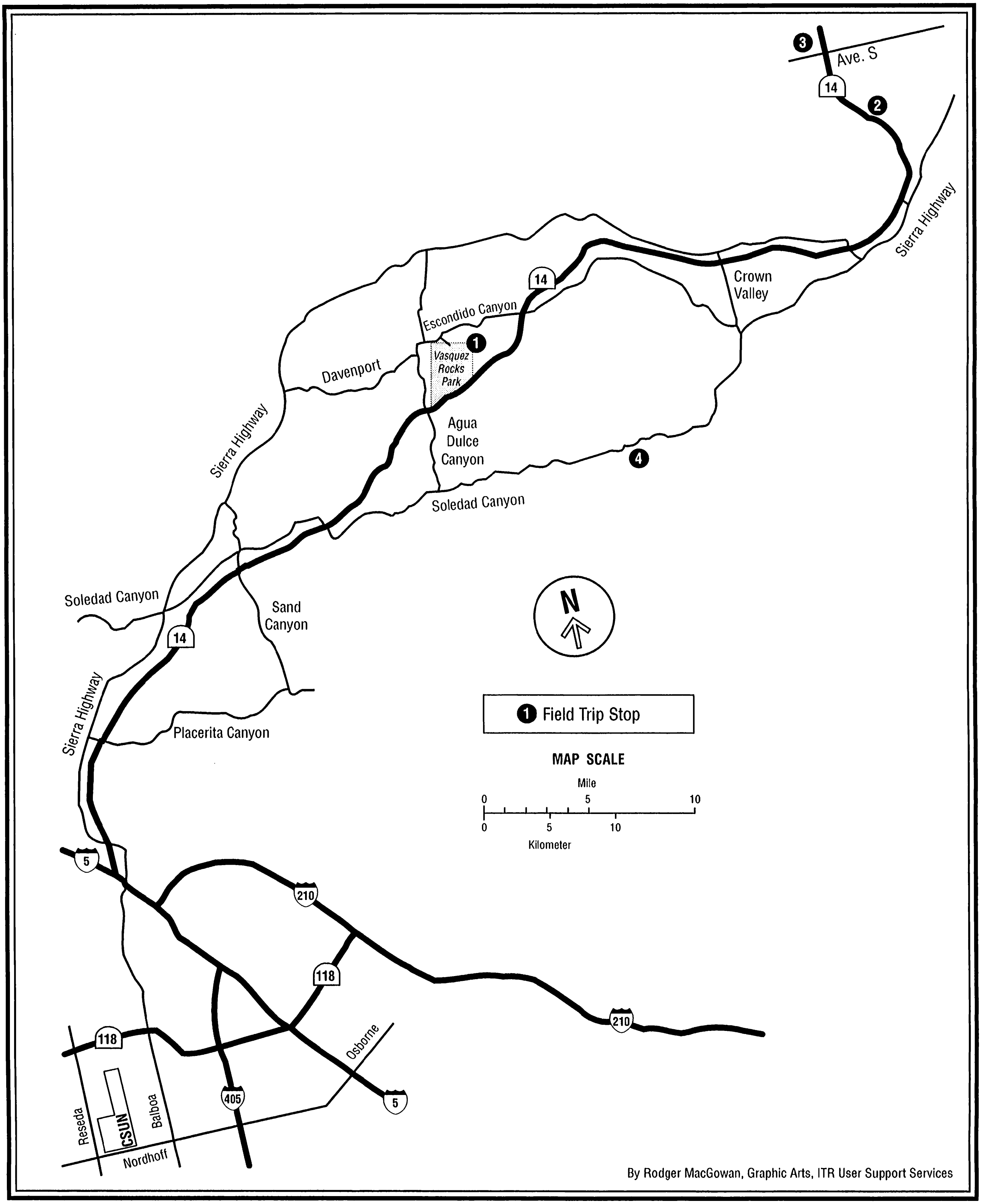

Figure 1. Sketch map showing the major roads between the CSUN campus and the San Andreas fault in Palmdale.

Vasquez Formation

This formation is uppermost Oligocene to lower Miocene in age (26 to 22 Ma) and consists of a maximum of 5,800 m (18,150 ft) of claystone, sandstone, and minor conglomerate. These nonmarine sediments accumulated as fluvial, lacustrine, and minor debris-flow deposits in a series of river valleys, lakes, and alluvial fans along a rising source to the south. Both the San Gabriel anorthosite and the Mount Lowe intrusion were exposed in these highlands at this time and contributed sediment to this and younger formations. Near the base of this formation are about 1,300 m (4,300 ft) of andesitic lava. The lake deposits in the Tick Canyon area were mined for the boron mineral colemanite between 1908 and 1922. Ages determined by the potassium-argon method suggest these lavas erupted between about 25.6 and about 23.6 million years ago.

Tick Canyon Formation

This formation is middle Miocene in age (21 to 19 Ma) and consists of about 200 m (660 ft) of nonmarine conglomerate and sandstone deposited in streams and alluvial fans coming off the slopes of the ancestral San Gabriel Mountains to the south. Vertebrate fossils recovered from this formation include ancestral three-toed horses, oreodonts (sheep-like animals), ancestral camels, pocket mice, rabbits, and hawks.

Mint Canyon Formation

This formation is middle to upper Miocene in age (16 to 10 Ma) and consists of about 800 m (2,600 ft) of nonmarine conglomerate, sandstone, and claystone. The base of the formation was deposited in a wide floodplain that contained a meandering river system. Higher in the formation, the environment consisted of a braided river system in the east that flowed into a relativly large lake to the west. Vertebrate fossils recovered from this formation include mastodons, rhinoceroses, three genera of horses, peccaries, camels, pronghorn antelope, dogs, and rabbits.

Monterey Formation

This formation is middle to upper Miocene in age (12 to 8 Ma) and consists of deep-marine siliceous shale and sandstone that were deposited in basin plain and submarine fan environments. The top part of the Monterey Formation interfingers with the bottom portion of the younger Towsley Formation. Although an extremely widespread formation in coastal California, we observe the Monterey Formation only briefly on this trip.

Towsley Formation

This formation is latest Miocene to earliest Pliocene in age (8 to 4 Ma) and consists of up to 1,200 m (4,000 ft) of marine conglomerate, sandstone, and claystone that were deposited in a submarine fan environment. The fan sloped westward and had its head near the San Gabriel fault. Conglomerate clasts in the formation came from east of the fault in the San Gabriel Mountains. The top of the Towsley Formation interfingers with the base of the younger Pico Formation.

Pico Formation

This formation is Pliocene in age (4 to 2.5 Ma) and consists of up to 1,500 m (5,000 ft) of shallow-marine sandstone and minor conglomerate. These rocks were deposited above wave base in a shoreface environment that gradually prograded westward and covered the Towsley submarine fan. The top of the Pico Formation interfingers with the basal parts of the younger Saugus Formation.

Saugus Formation

This formation is latest Pliocene to Pleistocene in age (2.5 to 0.5 Ma) and consists of up to 2,120 m (7,000 ft) of shallow-marine and nonmarine conglomerate, sandstone, and claystone that were deposited in alluvial fan and coastal plain environments. The fans were headed in and skirted around the San Gabriel Mountains and merged into a coastal plain that was bounded on the west by a shoreline. The interfingering contact between the Towsley and Saugus Formations represents the shoreline that slowly migrated westward through time as the eastern Ventura basin filled with sediment..

Geologic Provinces

San Fernando Valley

The San Fernando Valley is an elongated synclinal depression that is bounded on the north by north-dipping reverse faults and on the south by the anticlinal Santa Monica Mountains. There is no evidence for a fault on the south edge, therefore the valley is not a graben, which by definition is bounded by faults on both sides.

San Gabriel Mountains

The San Gabriel Mountains make up part of the Transverse Ranges provinces, a complex, east-trending region of mountain ranges and valleys, about 500 km (300 mi) long, that averages about 50 km (30 mi) in width. The province forms a relatively youthful physiographic feature; uplift began in the late Oligocene (~26 Ma) and accelerated in Pleistocene and

Recent times (2 Ma to present) in response to concentrated north-south crustal shortening in a region where the plate boundary trends obliquely to the overall motion directions of the North American and Pacific plates. Thus the San Andreas fault exhibits a more westerly orientation as it passes between the San Bernardino and San Gabriel Mountain ranges, compared to its more northwesterly orientation both north and south of this area. The western San Gabriel Mountains have been partly above sea level since at least the late Oligocene (26 Ma) as indicated by distinctive plutonic rock fragments found in late Oligocene to Recent sedimentary strata. However, the mountains probably did not attain their present great height until the late Pleistocene. The San Gabriel Mountains have gained their dramatic height [over 1,500 m (5,000 ft) at their western end] by displacements on a set of north-dipping reverse faults, such as the San Fernando and Sierra Madre fault zones, that have caused the mountains to be pushed southward up and over the San Fernando Valley. An exploratory oil well drilled south of the San Fernando fault near Sylmar bottomed at about 3,600 m (12,000 ft) in Pliocene sedimentary rocks, implying that the total sedimentary section adjacent to the mountain front may be on the order of 6,000 m (20,000 ft) in thickness. This further implies a structural relief here of at least 7,500 m (25,000 ft).

Santa Susana Mountains

The Santa Susana Mountains are composed of Miocene to Pliocene sedimentary rocks that have been uplifted by the north-dipping Santa Susana thrust fault. Based on the presence of anorthosite fragments in Saugus beds older than ~760,000 yrs and their absence in younger beds, Jerry Treimen and Richard Saul theorize that the uplift of these hills has occurred very recently, within the past ~1 million years. The highest elevation in the Santa Susanas is 1,135 m (3,747 ft).

Soledad Basin

The Soledad basin is a small, northeast-trending basin within the Transverse Ranges that began to open in the late Oligocene and accumulated a sequence, now west-dipping, of about 8,000 m (26,000 ft) thick of proximal, nonmarine detritus, most of which was shed from the ancestral San Gabriel Mountains to the east.

Faults

Northridge Hills fault

This blind, north-dipping reverse fault extends in the subsurface for 15 km (9 mi) from Chatsworth through Northridge to Pacoima. It crosses beneath the I-405 Freeway about at Plummer Street. Convergence has created a set of small hills that represents the top of the actively growing Northridge Hills anticline, topographically expressed by the slopes encountered on Reseda Blvd., Balboa Blvd., Hayvenhurst Ave., and Woodley Ave. These small hills are being thrust southward above the fault. Because of this tectonic morphology, the Northridge Hills fault is considered potentially active.

Mission Hills fault

This east-west trending reverse fault dips to the north and extends for 9 km (5.5 mi) along the southern margin of the Santa Susana Mountains and Mission Hills. It crosses the I-405 Freeway at Rinaldi Street. Convergence has created the actively growing Mission Hills anticline that has created the Mission Hills, which are being thrust southward above the fault. The Mission Hills fault has been active in the Quaternary.

San Fernando fault

The western portion of the Sierra Madre fault system, a frontal fault system that borders the San Gabriel Mountains on their southern edge, produced surface ruptures during the 1971 San Fernando earthquake forming the San Fernando fault. This reverse fault dips to the northeast beneath the San Gabriel Mountains at an angle of about 40°. It may have experienced as much as 25,000 ft of vertical displacement.

Santa Susana fault

The Santa Susana fault is part of a reverse fault system that is located in the southern foothills of the Santa Susana Mountains. It dips 50° to 55° to the northeast, although near the surface it flattens to near horizontal. This fault extends from the I-5 Freeway in Mission Hills northwestward nearly to the town of Piru.

San Gabriel fault

The San Gabriel fault is a high-angle, right-lateral, strike-slip fault that extends about 140 km (46 mi) northwestward across Los Angeles County. The western half consists of a single fault zone which is truncated by the San Andreas fault at Frazier Park. The eastern half consists of two branches that split near Big Tujunga Ranger Station. This strike slip fault has about 62 km (37 mi) of right-lateral displacement, partly based on exposures of sedimentary rocks of the Plush Ranch Formation, a correlative of the Vasquez Formation, which are located northwest of Frazier Park. The principal phase of activity on the San Gabriel fault was from about 12 Ma to about 5 Ma. Today, it is considered by most to be inactive, although some offsets of young strata have been noted in a few trenches across its trace.

San Andreas fault

The San Andreas transform fault came into existence about 29 Ma as a result of the rearrangement of interactions between the Farallon, Pacific, and North American plates when the East Pacific rise (the spreading center between the Farallon plate in the east and the Pacific plate in the west) came into contact with the subduction zone that had characterized the western edge of the North American plate since at least the Late Triassic (~220 Ma). Sinc e middle Miocene time, 330 km (180 mi) of right slip has occurred along the fault, the evidence for which is based primarily on correlations of offset portions of several rock units which range greatly in composition, origin, and age. Perhaps the best documented correlation is between the lower Miocene Neenach Volcanics, which are exposed between Palmdale and Gorman northeast of the San Andreas, and the Pinnacles Volcanics located southwest of the fault, 315 km (180 mi) to the northwest in Pinnacles National Monument in the Gabilan Range near the town of San Juan Bautista. Additionally, the Precambrian San Gabriel anorthosite and the lower Miocene Vasquez Formation, which will be seen on this trip, have equivalents across the fault on the west side of the Salton Sea in the Orocopia Mountains 240 km (144 mi) to the southeast. The historic slip rate of the San Andreas fault is 35 mm/yr (1.4 in/yr), more that half of the geologic rate of slip of 55 mm/yr (2.3 in/yr) between the Pacific and North American plates. The rest of the slip is accommodated by other faults, such as the Elsinore and San Jacinto faults in southern California, and by deformation east of the San Andreas. The great geographical extent of the fault was fully appreciated only after the 1906 San Francisco earthquake; the great displacement wasn't recognized until the 1950s. This fault is now known to stretch about 1,100 km (660 mi) between the Sea of Cortez (Gulf of California) on the southeast to Cape Mendocino in northern California on the northwest.

Kerry Sieh at Cal Tech has determined the recent earthquake history of the Mojave segment of the San Andreas fault from the paleoseismic record at Pallett Creek, the closest paleoseismic site to Palmdale. Evidence shows that the last 10 major earthquakes on this segment occurred on 9 January 1857 and 8 December 1812 and in ~1480 AD, ~1345 AD, ~1100 AD, ~1050 AD, ~1000 AD, ~800 AD, ~735 AD, and ~670 AD. These earthquakes suggest a clustering of two to three events every 300 to 400 years or so, rather than a regular repeat interval. The record at Wrightwood is slightly different in detail, but also shows 10 major earthquakes during the last 1,300 years or so.

Earthquakes

Fort Tejon earthquake

The 9 January 1857 Fort Tejon earthquake is estimated to have had a magnitude of about 8. Its surface rupture extended 400 km (240 mi) from Parkfield southeastward to the Cajon Pass near San Bernardino. Right-lateral ground displacement ranged from 2 to 5 m (6.6 to 16.5 ft). Although Fort Tejon, located to the northwest of here near where the San Andreas fault crosses I-5, gave its name to this great earthquake, the epicenter was probably centered near the present town of Parkfield in Monterey County. See the description of this temblor in Doug Yule's trip guide (this guidebook).

San Fernando earthquake

The San Fernando (or Sylmar) earthquake (M=6.7) occurred at 6:01 AM on 9 February 1971. The epicenter was located about 11 km (6.5 mi) north-northeast of San Fernando on the north side of the San Gabriel Mountains 8 km (5 mi) east of Canyon Country, and the focus was about 13.3 km (8 mi) deep. Surface rupture occurred over a distance of about 15 km (9 mi) from Mission Hills eastward to Big Tujunga Canyon. Movement took place on the San Fernando fault, a reverse fault that dips 40° to the northeast beneath the San Gabriel Mountains. The maximum vertical and horizontal displacements were both about 1 m (3.3 ft). Monetary loss was estimated at $511 million, 67 people lost their lives, and over 1,500 houses and apartment buildings were damaged or destroyed.

Northridge earthquake

The Northridge earthquake (M=6.7) hit at 4:31 AM on 18 January 1994, a Monday holiday celebrating Martin Luther King's birthday. The focus was about 19.1 km (11 mi) beneath the surface, approximately beneath the intersection of Reseda Boulevard and Saticoy Street in Reseda. Movement took place on a reverse fault that dips 40° to the south-southwest. No surface rupture along the fault plane was found, making this a "blind" thrust fault. The maximum underground slip on the rupture surface has been calculated to be 3 m (10 ft); ground GPS stations were uplifted up to 4.2 m (14 ft) and displaced horizontally by up to 2.2 m (7 ft). Monetary loss approached $40 billion and about 72 people died. Of the 57 buildings on the CSUN campus, 52 sustained significant damage. A repair and rebuilding program is still in progress (Spring 2000), aided by about $350 million from the Federal Emergency Management Agency.

Resources

Gold

Gold was undoubtedly used and traded by Native Americans. It was first re-discovered in California in the 1830s near the community of Castaic, located on I-5 north of Magic Mountain. Gold in the area of Hwy 14 was discovered in Placerita Canyon on 9 March 1842. (*Placerita* = "small sand bank" in reference to the presence of gold in stream sediments.) The story goes that cattle rancher Francisco Lopez was relaxing for lunch under a large oak tree. Waking from a snooze and a wild dream, he pulled up a wild onion to take home for the evening meal and discovered a small gold nugget. This still-standing oak was named the Oak of the Golden Dreams. This find several years before the big California gold rush of 1849 prompted a small gold rush which was restricted to Mexicans from Sonorra, who kept the discovery a secret.

Oil

The Placerita oil field, discovered in 1920, is located just west of Hwy 14 in Canyon Country. The field was discovered by drilling after oil was found in road cuts during construction of the old highway. Oil and gas are produced from the Plio-Pleistocene Saugus Formation (2.5 to 0.5 Ma) and the older Pliocene Pico Formation (4 to 2.5 Ma) from depths of 180 to 515 m (600 to 1,700 ft). The oil field is a south-dipping monocline; oil accumulation is controlled to the north by the San Gabriel fault and on the east by the N-S Whitney fault. The most likely source rocks are fine-grained organic clastic rocks of the Miocene Monterey (Modelo) Formation. A period of minor development from 1920 to 1930 was followed by a major period after the field was rediscovered in 1948. When the State Well Spacing Act was declared unconstitutional in 1949, exploration mushroomed, and at one point in 1949, 140 wells were located on only 60 acres; this area sprouted so many wells that it was nicknamed "Confusion Hill" (Fig. 2). Production of both oil and gas

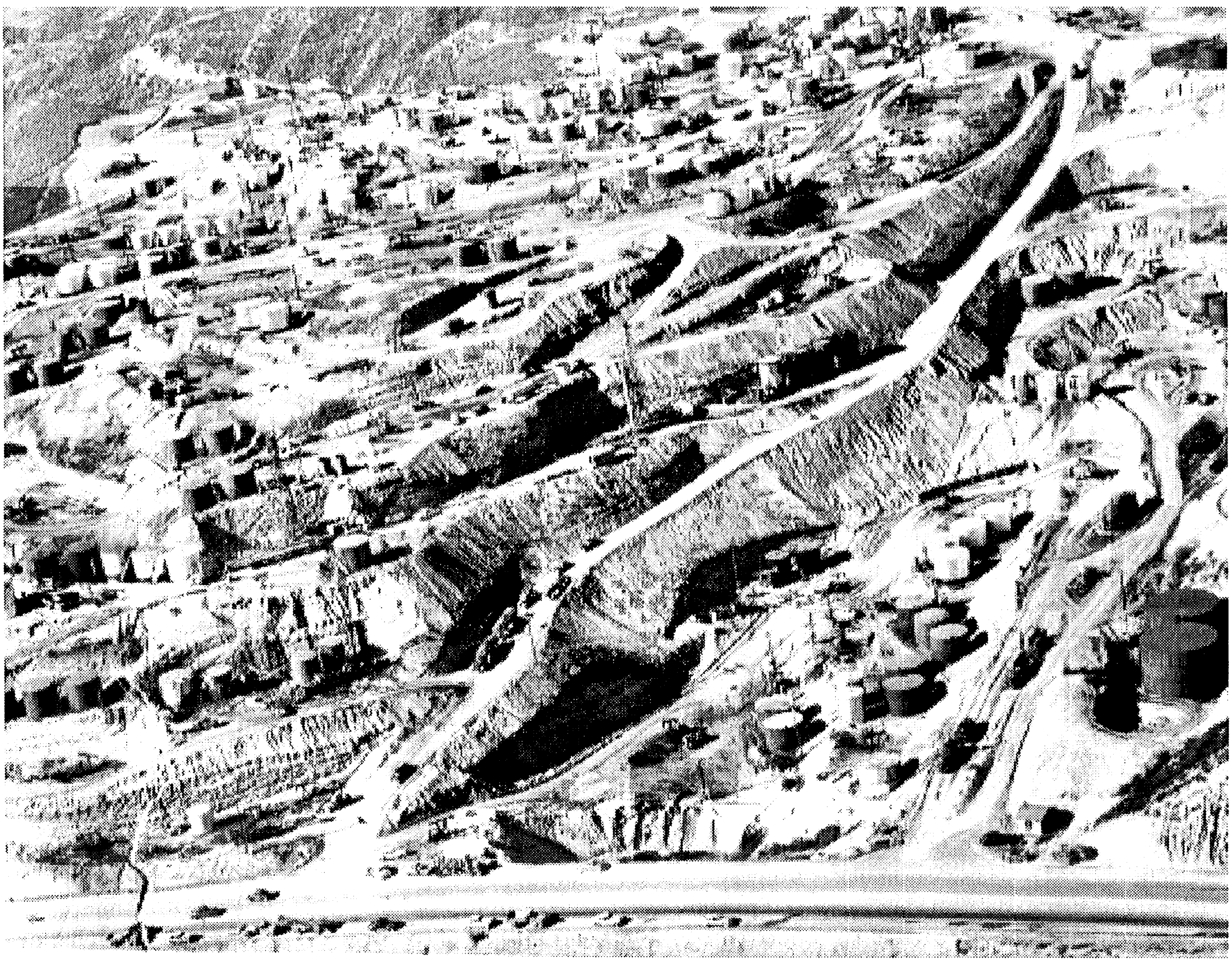

Figure 2. Historical photograph of oil wells in the Placerita oil field at "Confusion Hill" taken about 1952. Sierra Highway in the foreground. Photo courtesy of Santa Clarita Valley Historical Society via P. Scorza and A. Erickson.

peaked in 1950 after a short period of unregulated drilling and exploitation and overproduction quickly depleted the field. In 1998, 172 wells operated by four different companies produced 1.2 million barrels of oil. This field may have as much as 46 million barrels of recoverable reserves. These days, enhanced oil recovery utilizes injected steam to heat the remaining oil in order to lower its viscosity so that it more easily flows to the wells. The AES Placerita steam plant is easily visible just north of Placerita Canyon Road west of the Hwy 14 Freeway, and the Berry Petroleum Oil Company plant can be seen at the top of the hill to the north.

The Placerita oil field is one of dozens of fields associated with the Ventura basin, a depositional basin that extends from Newhall on the east to far into the ocean west of Ventura. The southeastern portion of this basin in the Castaic-Newhall area is host to more than a dozen oil-producing areas.

The Newhall area has a rich history with petroleum. For instance, Newhall was the location of California's first commercially successful refinery, begun in 1876. California's second truly commercial oil well, located in Pico Canyon a few miles to the west of Newhall, operated from 1875 to 1990, longer than any other well in the U. S. Both Union Oil Company and Chevron Oil Company had their origins in Newhall.

Sand and Gravel

Several companies recover material from the Santa Clara River bed and also from the San Gabriel anorthosite just past the Soledad Canyon exit on Hwy 14. Sand and gravel, the foundation of the construction industry, was an $800 million business in California in 1998, second only to oil and gas as a natural-resource product of the state. The largest company in the Soledad Canyon exit area, Triangle Rock Products, sold over 700,000 tons of material in 1999 worth several million dollars. Products included boulders (called rip rap), railroad ballast, dry crushed aggregate for asphalt and road base, and washed and sized sand for concrete. Ilmenite from the anorthosite body used to be separated and sold for Ti ore and for roofing granules.

Utilities

The northern San Fernando Valley near the intersections of four freeways - I-5, Hwy 14, I-210, and I-405 - is the point of entry of several utilities that are distributed to other parts of Los Angeles and southern California - water, electricity, natural gas, and petroleum (Fig. 3). The most visible signs of the infrastructure associated with these utilities include the Los Angeles Reservoir just north of the intersection of the I-405 and I-5 Freeways, the Sylmar (electrical) Converter Station a little farther north on I-5, and the two water cascades still a little farther to the north.

Water

There's a saying, "Water in California doesn't necessarily flow downhill, it flows where it's sent!" We'll see several pieces of evidence for this Law of Economics in the north part of the San Fernando Valley where water from northern parts of California is filtered and treated before being distributed.

Water for the City of Los Angeles comes from several sources (Table 1). San Fernando Valley's water mostly comes from Owens Valley via the two Los Angeles Aqueducts which end in the northern San Fernando Valley at what the Los Angeles Department of Water and Power calls Terminal Hill. This represents the end of the 370-km-long (230-mi-long) aqueduct which brings up an average of 260 million (!) gallons of water a day to Los Angeles from the eastern Sierra Nevada Mountains via Owens Valley. (*Sierra* = "mountain range", *Nevada* = "snowy") At Terminal Hill, each aqueduct splits into a pipe and an open channel - these are the two cascades. The southern, higher, and smaller open waterway coming down the hill north of the golf course represents the last segment of the 2nd Los Angeles Aqueduct, completed in 1970. The northern, lower, and larger water course represents the 1st Los Angeles Aqueduct; water first flowed down the Cascades on 5 November 1913 (Fig. 4). This event was witnessed by about 40,000 people, the largest crowd to ever gather in the U. S. at that time, and was dramatized in the movie "Chinatown" with Jack Nicholson and Faye Dunaway. At this dedication, William Mulholland uttered his famous quote, "There it is, take it." Water in the adjacent pipes, called penstocks, is under pressure and runs electrical generators in the Foothill and San Fernando power plants. When either generator is not running, or when water flow exceeds the capacity of the power plants, water is released to run down the Cascades.

Table 1. Sources of Los Angeles Water

Source	Per cent
Owens Valley	75
Groundwater	15
MWD	10

After the power plants, the water flows into the Los Angeles Aqueduct Filtration Plant where it is disinfected with ozone, filtered of fine particles, chlorinated, and then delivered to the Los Angeles Reservoir, where it is temporarily stored before distribution.

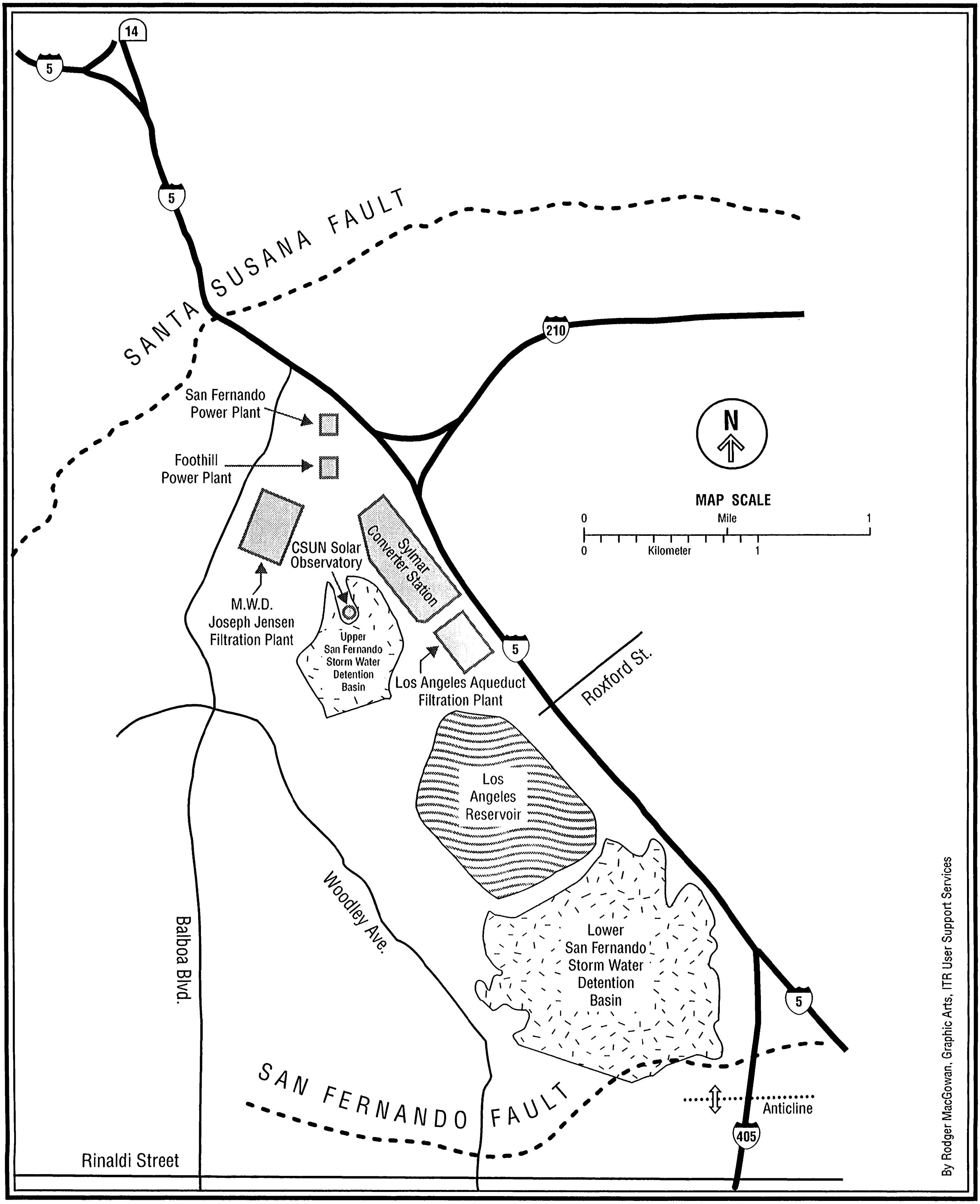

Figure 3. Sketch map of the confluence of electrical and water facilities in Granada Hills.

Figure 4. Historical photograph of water flowing down the Cascades on Nov. 5, 1913. Photo courtesy of the Los Angeles Department of Water and Power via L. A. Jackson, and C. Plumb.

Water also comes into the north Valley from the Feather River in northern California via the California State Water Project's California Aqueduct and the Metropolitan Water District's distribution system. The aqueduct divides in the Antelope Valley. The West Branch flows into Quail, Pyramid, and Castaic Lakes before it is piped into the north San Fernando Valley. Pipes of this part of the system are not visible on our trip. This water is treated at the Jensen Filtration Plant, located between the I-5 Freeway and Balboa Blvd. west of the electrical station before it is distributed to Ventura County, West Los Angeles, Santa Monica, and the Palos Verdes Peninsula. The East Branch crosses the Hwy 14 Freeway in Palmdale. This aqueduct delivers an average of 540 million gallons of water per day which is pumped into Lake Silverwood high in the San Bernardino Mountains. Los Angeles and southern California also receive water from the Colorado River.

Electricity also is delivered into the north Valley. Table 2 lists the sources of the City's electricity. Some of this electricity is generated by Owens Valley water as it descends over 1,000 m (3,300 ft) from its source. (The final power plants were mentioned just above.) Other electricity comes from the Pacific High Voltage Direct Current Intertie Transmission Line all the way from the Columbia River. The destination for this electricity is the Sylmar DC-AC Converter Station, easily visible from the I-5 Freeway just north of the Los Angeles Reservoir. A second converter station, Sylmar East, is located just east of the I-5 Freeway. Los Angeles also receives electricity from local and out-of-state power plants (coal, oil, gas, and nuclear) and from Hoover Dam on the Colorado River.

Table 2. Sources of Los Angeles Electricity

Source	Per cent
Coal	45
Oil and gas	20
Hydroelectric	12
Nuclear	9
Purchased	14

County Parks

Two county parks are situated just a few miles from the freeway route between the San Fernando Valley and Palmdale. Placerita Canyon Park and Nature Center on Placerita Canyon Road in Newhall has a Nature Center with biology and geology exhibits, self-guiding Ecology and Heritage trails, and picnic grounds. Numerous activities for families and school groups are offered and can be seen at the Park's Web site <www.placerita.org>. The current supervisor is Darrell R. Wanner.

Vasquez Rocks Natural Area County Park on West Escondido Road in Agua Dulce has Geology and Nature-Heritage trails and many miles of hiking and horse trails. Its scenery includes the famous Vasquez Rocks sandstone hogbacks which have provided the backdrop for countless movies and television shows. Family and school activities are available and can be arranged by telephone - 805-268-0840. The current supervisor is Michael Sharp.

ROAD GUIDE

The route of the field trip is shown in Figure 1. In the following road guide, turns are designated by *italics*. In addition, Dibblee Geological Foundation maps which cover each portion of the trip are indicated by bold italics and DF numbers. These maps can be ordered for $12 each from Mr. E. R. Blakley, Sales Contractor, Dibblee Geological Foundation, 958 Isleta Ave., Santa Barbara, CA 93109. Note that roadway distances are only given in miles. Numbers along the left side of the column in the road log are cumulative mileages from indicated starting points. Numbers in parentheses are individual mileages from the previous location.

DF-33 - San Fernando and Van Nuys (north 1/2) quadrangles

0.0(0.0) Mileage for this leg of the field trip begins in Northridge at the beginning of the northbound onramp at Nordhoff Street to the San Diego Freeway (I-405) or at the bridge where the northbound I-405 crosses over Nordhoff Street.

The San Fernando Valley is bounded on the north by an impressive set of hills and mountains. Up ahead on the left are the relatively young Santa Susana Mountains, composed of Miocene to Pleistocene sedimentary rocks. On the right are the San Gabriel Mountains, largely composed of ancient resistant igneous and metamorphic rocks. The San Gabriel Mountains have gained their dramatic height by displacements on a set of north-dipping reverse faults that have caused the mountains to be pushed southward, up and over the San Fernando Valley.

1.2(1.2) Offramp for Devonshire Street.

1.6(0.4) Offramp for the 118 Freeway. This interchange escaped largely undamaged from the M=6.7 Northridge earthquake on 18 January 1994. Portions of the 118 Freeway were damaged a few miles west of here where it crosses Bull Creek.

2.2(0.6) Offramp for San Fernando Mission Boulevard.

2.8(0.6) Offramp for Rinaldi Street. The Mission Hills community of Los Angeles is named after the hills ahead which form an anticline which may be actively "growing" (that is, the sedimentary rocks are continuing to be folded during present (Holocene) geologic time) as they are being thrust southward above the north-dipping Mission Hills fault.

3.2(0.4) Just past the northbound onramp from Rinaldi Street on the right can be seen the axis of the Mission Hills anticline in the deep-marine Monterey Formation of Miocene age (12 to 8 Ma). Because of faulting, past the anticline axis, the rocks become younger to the north, although individual formations are difficult to pick out in the rest of the roadcut. For the record, after the Monterey comes the marine Towsley Formation of latest Miocene to earliest Pliocene age (8 to 4 Ma) and finally the shallow-marine Sunshine Member of the Saugus Formation of late Pliocene-Pleistocene age (2.5 to 0.5 Ma).

3.5(0.3) In the middle of these hills, just before the intersection of I-405 and I-5, the Reservoir segment of the San Fernando fault (also called the Mission Wells fault) crosses the freeway. This reverse fault broke the surface here during the 1971 San Fernando earthquake, north side up about 20 cm (8 in).

4.2(0.7) I-405 merges into I-5 and ends. To the west of the freeway (left) is what used to be called the Lower van Norman Reservoir, now empty and renamed the Lower San Fernando Storm Water Detention Basin. The earthen dam of this reservoir nearly failed in the 1971 San Fernando earthquake. The Los Angeles Department of Water and Power, in a cautionary move, now uses the emptied reservoir as an emergency catchment in case of catastrophic failure of the Los Angeles Reservoir, filled with water from the Owens Valley.

4.7(0.5) Offramp for Roxford Street. On the left is the filled Los Angeles Reservoir.

5.5(0.8) The Sylmar [electrical] Converter Station on the left (west) was severely damaged in the 1971 San Fernando quake.

5.6(0.1) Offramp for I-210.

5.7(0.1) Those with a quick eye will see the white dome just behind the converter station. This is the San Fernando Solar Observatory, run by CSUN's Department of Physics and Astronomy.

DF-36 - Oat Mountain and Canoga Park (north 1/2) quadrangles

5.9(0.2) Offramp for truck traffic. These truck lanes have been constructed so that large trucks can stay in the right-hand lanes in this large intersection.

6.2(0.3) To the right (east), under construction at the time of this writing (4/2000), is the new Cascades Golf Course and Cascades Business Park. The southern, higher, and smaller open waterway coming down the hill north of the golf course represents the last segment of the 2nd Los Angeles Aqueduct, completed in 1970 (Fig. 5). The northern, lower, and larger water course (difficult to see from the freeway) represents the 1st Los Angeles Aqueduct; water first started flowing down the Cascades on 5 November 1913. Water in the adjacent penstocks is under pressure and runs electrical generators in the Foothill and San Fernando power plants. When water flow exceeds the capacity of the power plants, water is released to run down the Cascades. There was ground rupture associated with the 1971 San Fernando earthquake in this area along the Santa Susana fault zone.

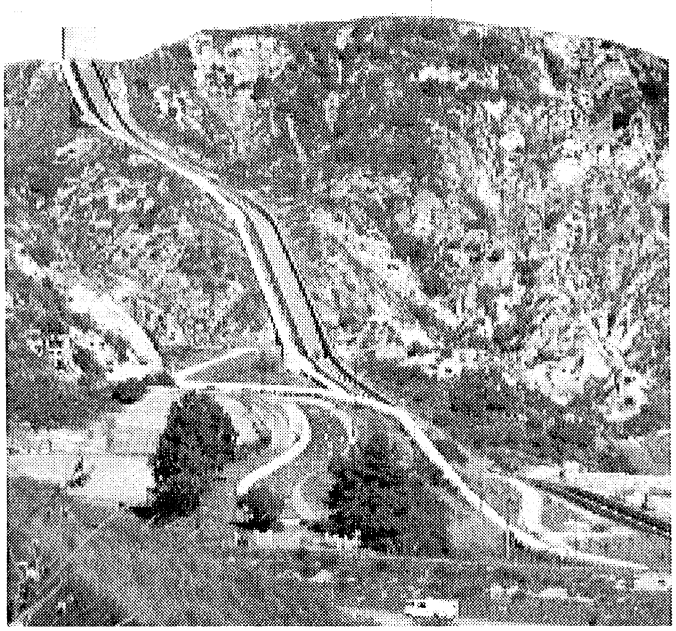

Figure 5. Photograph in northern Granada Hills showing the two sets of channels and penstocks representing the terminations of Los Angeles Aqueducts 1 (left) and 2 (right).

6.8(0.6) Farther to the north, on the west (left) side of the freeway, is the Sunshine Canyon Landfill, which recently gained approval from the L. A. City Council to expand into Granada Hills and begin accepting most of the city's trash. Operated by BFI Industries, this 215-acre landfill operated from 1958 to 1991. The 194-acre expansion will allow BFI to accept 55 million tons of trash during the next 26 years.

7.0(0.2) On the west side of the freeway is a nicely exposed anticline in the latest Miocene-earliest Pliocene Towsley Formation (8 to 4 Ma) (Fig. 6).

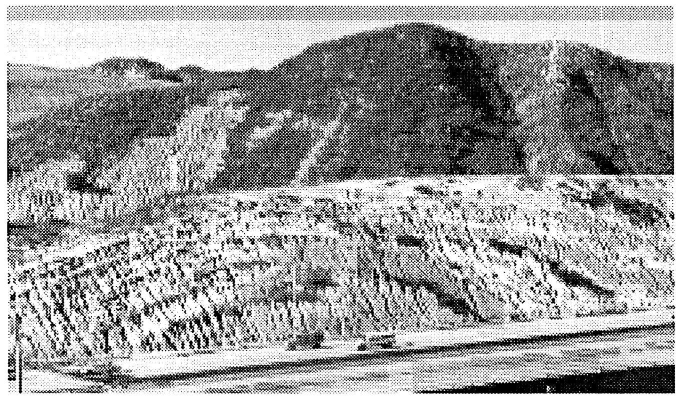

Figure 6. Anticline exposed in the latest Miocene-earliest Pliocene Towsley Formation on the west side of I-5.

7.3(0.3) *Take the exit for California Highway 14 (Antelope Valley Freeway).* This interchange (Fig. 7), while still under construction, suffered some collapse in the 1971 San Fernando earthquake and then again in the 1994 Northridge earthquake. It has been commemorated as the Clarence Wayne Dean Memorial Interchange after a motorcycle policeman, rushing to work after being awakened by the Northridge temblor, plunged to his death off a collapsed span. At the time of the earthquake, Cal Trans was in the process of retrofitting bridges in southern California. No retrofitted bridges failed; those that did fail were scheduled for

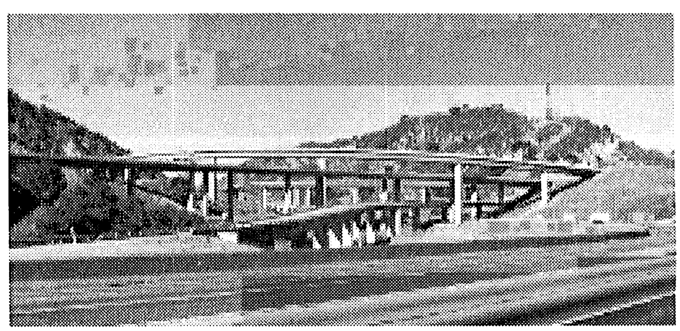

Figure 7. Photograph of the Clarence Wayne Dean Memorial Interchange between the I-5 and Hwy 14 Freeways.

retrofitting, but hadn't been completed due to lack of funds.

7.8(0.5) Note on the west (left) the nicely exposed syncline (Fig. 8) in the Plio-Pleistocene Saugus Formation (2.5 to 0.5 Ma).

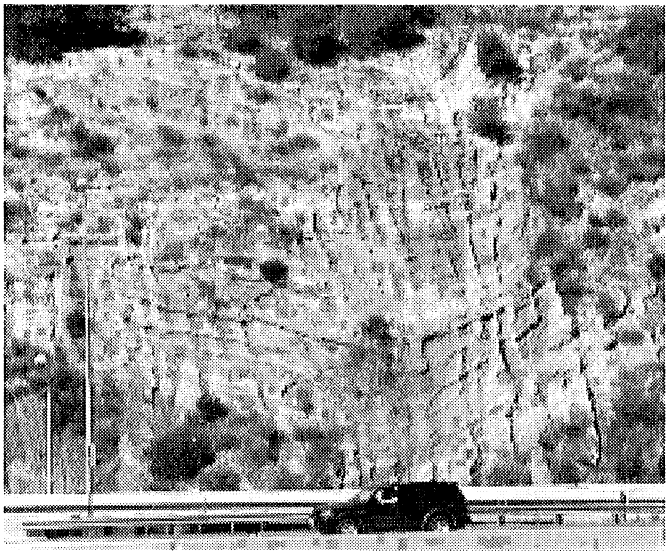

Figure 8. Syncline exposed in the Plio-Pleistocene Saugus Formation on the west side of Hwy 14 Freeway.

8.1(0.3) The next large freeway cut on the left displays south-dipping, Pliocene to Pleistocene (4 to 0.5 Ma) marine and nonmarine shale, sandstone, and conglomerate of the Pico and Saugus Formations. These strata display large erosional channels (Fig. 9) that are cut by many small faults. The edges of the larger channels can easily be mistaken for faults.

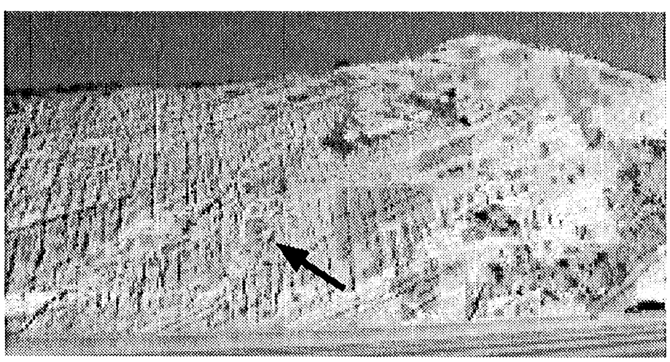

Figure 9. Stream-cut channels (arrow) exposed on the west side of the freeway in the Pico/Saugus Formations.

8.3(0.2) At the far end of this large cut, a large fault in the sedimentary rocks is visible on the left.

8.6(0.3) In the canyon on the left was the small Newhall Oil Refinery, built in the mid 1930s and dismantled in the early 1990s.

DF-33 - San Fernando and Van Nuys (north 1/2) quadrangles

9.6(1.0) Offramp for San Fernando Road.

9.8(0.2) Visible over the next 1.5 mi are oil wells (Fig. 10) and storage tanks associated with the Placerita oil field, discovered in 1920. Oil and gas are produced from the Plio-Pleistocene Saugus Formation (2.5 to 0.5 Ma) and the older Pliocene Pico Formation (4 to 2.5 Ma). The oil field is a south-dipping monocline; oil accumulation is controlled to the north by the San Gabriel fault and on the east by the N-S Whitney fault.

DF-57 - Mint Canyon quadrangle

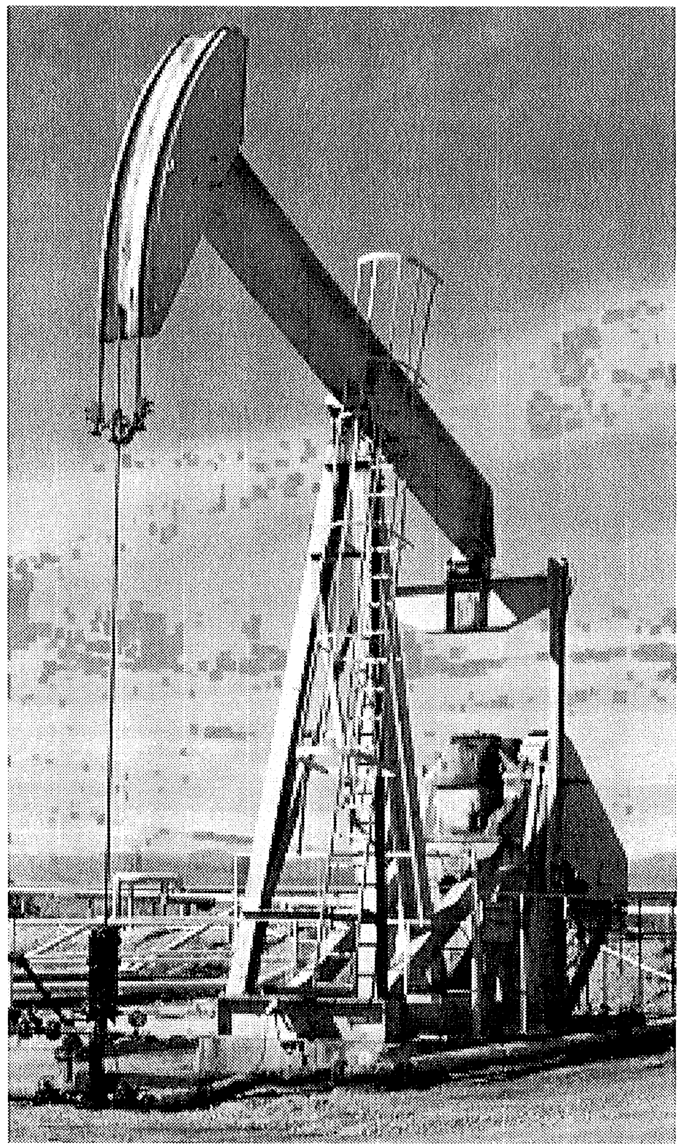

Figure 10. Oil well in the Placerita oil field. This particular well is #9-31 on the Wickham Ferrier lease operated by Berry Oil Company

10.7(0.9) Offramp for Placerita Canyon Road. A few miles east of here is the Placerita Canyon Nature Center which has interesting exhibits, nature trails, picnic grounds, and numerous nature programs for school kids. Gold in this area was discovered by cattle rancher Francisco Lopez on 9 March 1842. *(Placerita* = "small sand bank" in reference to the presence of gold in stream sediments.) The industrial complex on the left at the bottom of the hill (difficult to see from the northbound freeway) and another at the top of the hill produce steam used to increase oil production. The hills above the lower plant were the site of unregulated oil drilling in 1949 and 1950; it sprouted so many wells that it was nicknamed "Confusion Hill".

12.1(1.4) The right-lateral San Gabriel fault comes through here at the crest of the hill.

12.3(0.2) Offramp for Golden Valley Road.
On the right, just past the northbound onramp, is a large, bowl-shaped depression with uneven (hummocky) topography. This represents the Freeway Earthflow, a slide that occurred in the claystone portion of the Mint Canyon Formation. Freeway construction activities in 1970 caused this slide to reactivate.

12.7(0.4) Although not visible from the freeway, the unconformable contact between the Saugus Formation (2.5 to 0.5 Ma) and the older Mint Canyon Formation of Miocene age (16 to 10 Ma) is located here. The Santa Clara River Valley stretches out in front of us.

13.2(0.5) Offramp for Sierra Highway.

13.5(0.3) Offramp for Via Princessa.

14.7(1.2) Bridge over the current channel of the Santa Clara River. Construction on this floodplain has increased dramatically in recent years. As a stream channel migrates over the floor of a valley, it creates a floodplain - a flat area about level with the top of the channel that lies on either side of the channel. This is the part of the valley that is inundated when a stream or river spills over its banks. Small floods occur every 2 to 3 years on average; larger floods occur less frequently, every 10, 50, or 100 years. Floodplains are attractive because of the fertility of the fine-grained sediment deposited by floods and because they provide flat topography for building. The primary drawback of building or living on a floodplain, of course, is ....

A river's flow is referred to as its discharge, which is the volume of water that flows past a point in a given unit of time, expressed either as cubic feet per second (cfs) or cubic meters per second (m^3/s). The long term average discharge of the Santa Clara River is a paltry 20 cfs; however during the devastating floods of 1938, it reached 24,000 cfs! So return in 50 years to observe how many of these houses are still here.

15.1(0.4) Rocks on the left represent the Mint Canyon Formation, a middle to upper Miocene unit (16 to 10 Ma) composed of terrestrial sediments coming down the river from across the San Andreas fault and also being shed from the San Gabriel Mountains. Fossils of horses, camels, and elephants have been recovered in this formation.

15.9(0.8) Offramp for Sand Canyon Road. Approaching the Sand Canyon Road bridge, note on the left horizontal stream gravels of the ancestral Santa Clara River of Pleistocene age (0.5 Ma) overlying the west-dipping Mint Canyon Formation (16 to 10 Ma), thereby forming an angular unconformity. The presence of an angular unconformity in the geologic record implies a period of deformation followed by erosion of the older, tilted strata before the younger sediment was deposited. This angular uncomformity represents a time gap in the rock record of perhaps 9.5 million years.

18.3(2.4) *Exit at Soledad Canyon Road, cross Soledad Canyon Road, take the onramp back onto the freeway, and proceed slowly and cautiously.* Just before the onramp merges with the freeway, note on the left the especially good exposures of the same angular unconformity seen previously (Fig. 11). Note that because the older sedimentary beds are dipping to the west and we're driving to the east, we're driving toward older and older rocks.

DF-58 - Agua Dulce quadrangle

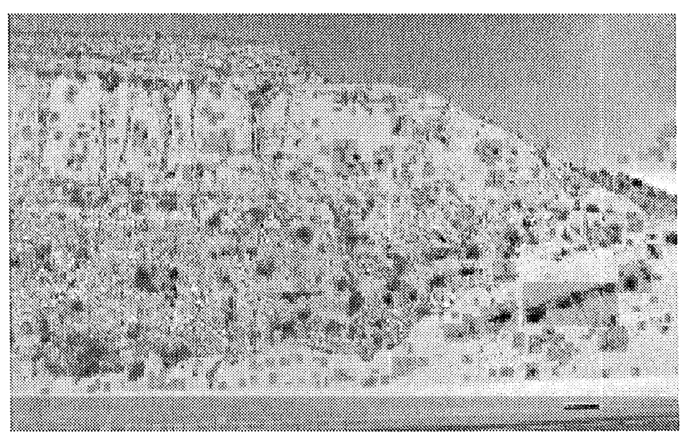

Figure 11. Angular unconformity exposed on the west side of Hwy 14 Freeway at the Sand Canyon exit. Horizontal stream gravels of the ancestral Pleistocene Santa Clara River overlying west-dipping Mint Canyon Formation.

19.0(0.7) Note the large sand and gravel operations on the right. These companies recover material from the river bed and also from the San Gabriel anorthosite.

19.8(0.8) We're now in the middle Miocene (21 to 19 Ma) Tick Canyon Formation, a unit of terrestrial conglomerate and sandstone deposited by streams in alluvial fans coming off slopes of the ancestral San Gabriel Mountains draining older rocks to the south and east.

22.5(2.7) *Take the exit for Agua Dulce Canyon Road.* (*Agua dulce* = "sweet water".) As we approach the Agua Dulce Canyon bridge, note in the roadcut on the far left a boulder conglomerate of lower Tick Canyon Formation (21 to 19 Ma) consisting of anorthosite and gabbro boulders. This is an alluvial fan deposit made of a mixture of stream and debris-flow deposits coming from the San Gabriel Mountains.

22.6(0.1) *Cross Agua Dulce Canyon Road and take the onramp back onto the freeway - proceed slowly and carefully.*

22.8(0.2) Near the end of the onramp is the contact (Fig. 12) between the younger Tick Canyon Formation (above; 21 to 19 Ma) and pink sedimentary rocks of the late Oligocene to early Miocene (26 to 22 Ma) Vasquez Formation composed of terrestrial claystone and sandstone and minor conglomerate. Because the underlying Vasquez beds are more steeply dipping than the younger Tick Canyon strata, this contact represents another angular unconformity. This unconformity represents a time gap of at least 1 million years. A few kilometers to the northwest in Tick Canyon are the remains of an old borax mine that recovered ore from an evaporite lake deposit in the Vasquez Formation.

23.5(0.7) Note on the right the thick boulder conglomerate; this was deposited as a debris flow (debris flows are masses of sand and gravel plus water that move downslope under the influence of gravity). Exposures of Vasquez sandstone and

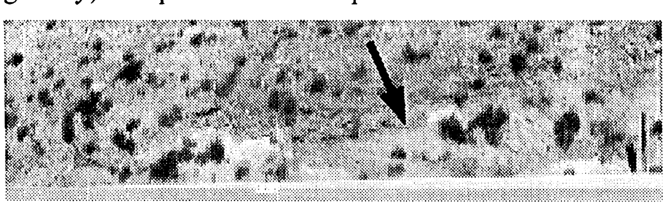

Figure 12. Contact (arrow) between the younger Tick Canyon Formation (above) and the older Vasquez Formation (below) on the north side of the Hwy 14 Freeway just east of Agua Dulce Cnyn. Road.

conglomerate on the right over the next 1/2 mi are spectacular.

24.2(0.7) On the left are the well known rock formations of Vasquez Rocks (Fig. 13). These eroded hills of steeply inclined strata are called "hogbacks" or "flatirons".

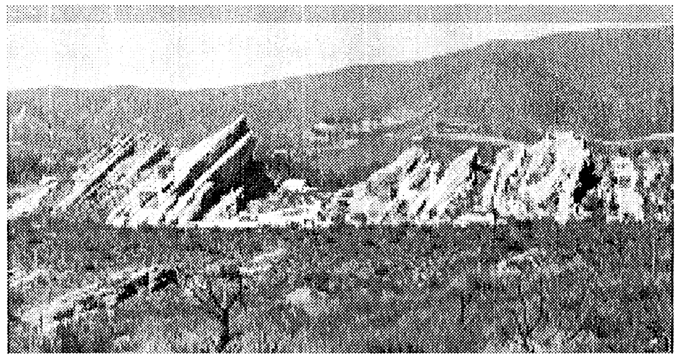

Figure 13. Hogbacks of sandstone and conglomeratic strata of the Vasquez Formation exposed in Vasquez Rocks Natural Area.

24.9(0.7) The dark hills on the left are underlain by andesite lavas of the Vasquez Formation (26 to 22 Ma). Exposures of these lavas, forming a pile about 1,360 m (4,500 ft) in thickness, continue for about the next 4 mi. They have been dated at about 24.5 Ma.

25.9(0.8) *Take the exit for Escondido Canyon Road.* Vasquez andesite is well exposed in the freeway cut on the left. (*Escondido* = "hidden".)

26.1(0.2) *Turn left on Escondido Canyon Road*

26.4(0.3) Over the next 0.7 mi are 4 roadcuts on the right. In the first half of the first roadcut are sandstone and conglomerate of the lower Vasquez Formation. Some of these conglomerate beds represent debris-flow deposits and contain large fragments of anorthosite. In the second half of the cut, the sedimentary rocks are in fault contact with massive, dark-red-weathering syenite of Precambrian age (about 1.2 Ga). Syenite is an intrusive igneous rock composed of more K-feldspar than plagioclase with variable amounts of mafic minerals and little quartz. This unit is part of the San Gabriel anorthosite-syenite intrusion. The fault shows left-lateral offset and is a minor one between the left-lateral Elkhorn and Agua Dulce faults.

26.7(0.3) Roadcut #2 is composed of anorthosite boulder conglomerate of the lower Vasquez Formation.

26.8(0.1) Roadcut #3 is composed of more Vasquez conglomerate.

26.8(0.0) Roadcut #4 is similar to #1 - lower Vasquez conglomerate with angular blocks of anorthosite in fault contact with massive, dark red syenite.

27.1(0.3) Vasquez lavas over the next 0.3 mi occur on both sides of the road.

27.4(0.3) This area is called Sierra Pelona Valley.

28.5(1.1) *Turn left into poorly marked entrance to Vasquez Natural Area County Park.*

28.6(0.1) *Take the left fork and park in the dirt area on the right across the trailhead to the Geology Trail.*

STOP 1 - VASQUEZ ROCKS NATURAL AREA COUNTY PARK

Vasquez Rocks Natural Area may be the only park in the United States, if not the world, named for a notorious outlaw who was hanged. In the mid-1800s, a bandito named Tiburcio Vasquez used the caves and rocks in the area as his hideaway from sheriffs' posses and vigilantes who were constantly on his trail. Vasquez and his band of desperados ranged up and down southern California, rustling cattle, robbing stagecoaches, and stealing horses. He often gave his stolen money to needy Mexican families, like another legendary outlaw of the era, Joaquin Murietta. As a result, Vasquez was regarded by many of the Mexicans as a Robin Hood battling the "gringos". However, Vasquez' weakness for women finally did him in. One night he had an affair with the wife of one of his lieutenants. The irate husband shot and wounded Vasquez and betrayed the hideaway to the sheriff. Two posses moved in on the hideout, one from the north and one from the south. Finally, near the tallest rock formation, they surrounded the gang and fought it out. When the shooting stopped, the lawmen searched for Vasquez among the dead and wounded, but he had escaped. Vasquez, wounded and unable to use his old hideout, couldn't evade the persistent lawmen for long. He was captured in a shack in the Cahuenga Pass (in present North Hollywood) and taken to San Jose, where in March of 1875 he stood trial and was convicted and executed.

The distinctive rock formations in Vasquez Rocks Natural Area are the result of the uplifting, tilting, and differential erosion of resistant beds of sandstone and conglomerate called the Vasquez Formation. These beds were originally deposited as accumulations of sand and gravel in the latest Oligocene to early Miocene Epochs (between about 26 to 22 million years ago) and have subsequently been exposed by selective erosion. Rock formations like these that are tilted at a steep angle are sometimes called "hog's back", "hogback" ridges, or "flatirons". Some sedimentary layers erode more easily than others, depending partly on how strongly the sedimentary particles are cemented together. These sedimentary layers were deposited by streams and rivers that originated in highlands that now lie to the east and flowed into a large lowland called the Soledad basin. Some of the layers contain particles of sand and silt that accumulated in stream channels and on flanking flood plains during relatively quiet geologic times. Other layers contain, besides sand grains, larger pebbles and cobbles (which together are called gravel) that were deposited in debris flows during floods (debris flows are masses of sand and gravel plus water that move downslope under the influence of gravity - they commonly produce a sedimentary deposit with no internal layering or bedding). The highlands, which now make up the impressive San Gabriel Mountains - the high skyline to the south - produced great amounts of sediment over the course of many millions of years. Prior to the deposition of these alluvial layers, a thick pile of lavas accumulated from many volcanic eruptions in this area between about 25.5 and 23.5 million years ago. These lavas can be seen today just east of here on the Antelope Valley Freeway (California Hwy 14) at the Escondido Canyon Road exit.

Stop #1-1 Sandstone and Conglomerate

Directly behind the marker is a sandstone layer (Fig. 14) composed of solidified (lithified) sand-size particles. These sedimentary layers were originally laid down in horizontal, or nearly horizontal, beds, and earth movements have tilted them to the orientation we see today. Geologists describe the orientation of tilted strata by their *attitude*, a combination of strike (the compass direction of a horizontal line on the bed) and dip (the angle that the bed makes with a horizontal plane). These beds have a strike of about N70°W and a dip of about 50°SW.

To the right, behind the "Geology Trail" sign, is a conglomerate layer, about 0.5 m (1.5 ft) in thickness, composed of sand-size particles as well as pebbles. Note the large fragment of metamorphic rock that was incorporated into a debris flow. Look for a small fault about 3 m (10 ft) off the ground in the conglomerate layer. This fault has about 15 cm (6 in) of offset and extends toward marker #2.

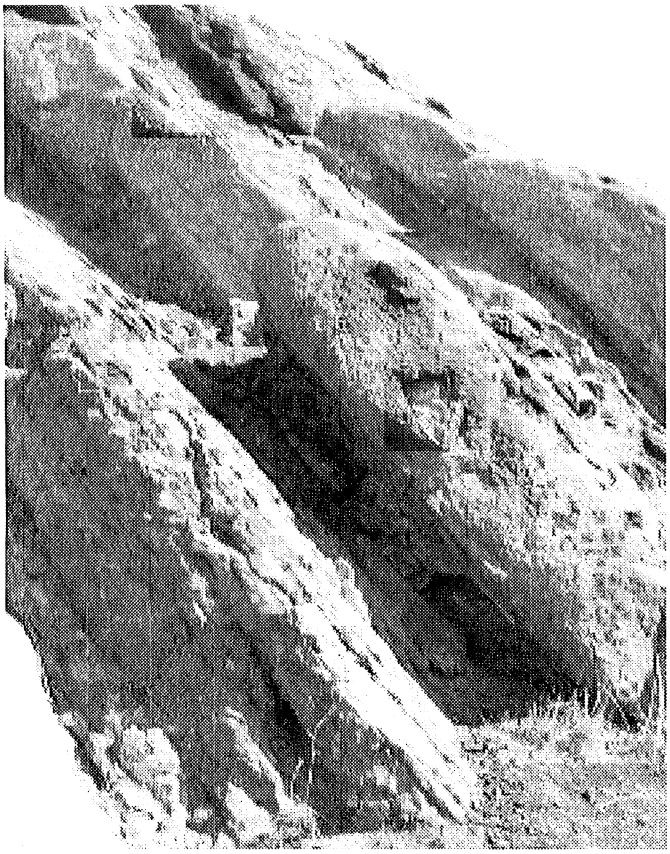

Figure 14. Inclined sandstone of the Vasquez Formation at Stop #1 on the Geology Trail.

Stop #1-2 Rock Varnish and Solution Holes

Surfaces on this rock outcrop are partly covered by black deposits called "rock varnish" because of its shiny appearance. These deposits consist of a thin layer of bacteria, clay minerals, and manganese and iron oxides - it's the Mn oxide that makes the black color. The bacteria trap clay particles from blowing dust and excrete the Mn and Fe oxides, which in turn help cement the clay to the rock surface.

The holes and cavities in these rocks at this outcrop are called "solution holes", "cavernous weathering", or "honeycomb weathering". This common type of irregular weathering has been explained as being the result of local wind turbulence on wet rocks. Wind causes the water to evaporate, which causes the growth of tiny salt crystals at and slightly beneath the rock surface, which in turn puts pressure on the sand grains. Some of these loosened grains pop out and form small cavities, which then localize the wind, promoting further evaporative crystallization, thus enlarging the hole. Eventually, solution holes develop, as seen here.

As at Stop #1-1, note the different layers of sandstone and conglomerate. About 3 m (10 ft) past the marker on the right side of the trail is a layer of large boulders at the top of a conglomerate bed which was deposited as a debris flow.

Stop #1-3 Debris flow - Conglomerate

Here is a large exposure of conglomerate (Fig. 15) composed of numerous large rock fragments distributed throughout a matrix of sand-size particles. Many of the larger fragments have sharp corners, indicating that they weren't tumbled in a stream bed for a very long distance. The larger fragments are composed of a granite-like rock consisting of light-colored feldspar and dark hornblende. The hornblende crystals are commonly aligned within the fragments. These fragments are identical to a distinctive rock body exposed to the east in the San Gabriel Mountains called the Mount Lowe intrusion. Geologists conclude from this sort of evidence that about 23 million years ago, streams flowed across the Mount Lowe intrusion, eroded and carried chunks of it along in the stream bed, and deposited these chunks in the Soledad basin in stream, flood plain, and alluvial fan deposits (alluvial fans are broad aprons of sediment deposited by streams as they flow out of mountains). The conglomerate layer here might represent a gravel bed that was deposited by a single debris flow. Can you identify pebbles in this outcrop composed of rocks besides the Mount Lowe intrusion?

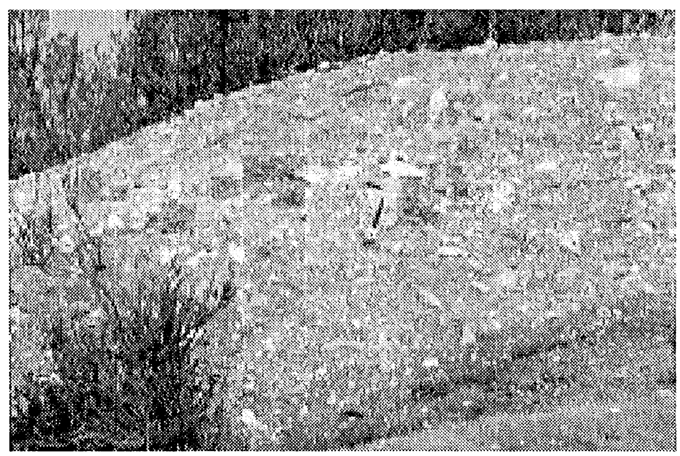

Figure 15. Conglomerate of the Vasquez Formation at Stop #3 on the Geology Trail.

Stop #1-4 Do Plants Grow on Rocks?

Plants usually require soil to grow in and ordinarily don't grow directly on rocks. Some primitive forms are able to "pioneer" this sparse environment. First bacteria, then lichens (combinations of algae and fungi growing together), attach to the rock, obtaining nourishment directly from the rock surface, the air, and any available water. They slowly break away tiny pieces of rock and minerals (clay and sand), which drop onto ledges and into cracks. Dead bacteria and lichens add organic matter to the sand, forming the beginnings of a sparse soil. Plants such as grass, wild flowers, or small shrubs may become rooted in these tiny pockets of soil. These plants in turn continue to weather the rock and add organic matter to the accumulating soil. Eventually, as seen here, even bushes may take root. So, although it appears that the juniper bush is growing directly out of the rock, it is actually rooted in soil that may have taken thousands of years to accumulate within the small depression in the rock outcrop. Its roots have grown into cracks and minute fractures between sand grains. Pressure from the growing roots can expand these cracks and fractures and contribute to the weathering of the rock.

Note that sedimentary strata in the large boulder behind the marker have a different orientation (attitude - strike and dip) compared to the other outcrops in the area - can you guess why? How many differently colored varieties of lichen can you count?

About 20 m (60 feet) farther up the Geology Trail is a marker for the Pacific Coast Trail, which extends from Mexico to Canada.

Stop #1-5 Bedding Planes

Here you see strata of sandstone overlain by conglomerate. What criteria distinguish one bed from another? Some of these are grain size, color, resistance to weathering, and grain composition. The reddish color you see in some of the layers is iron oxide, formed by the natural rusting of iron-bearing minerals. This sort of oxidation can only occur when sediment is deposited on land and are exposed to the atmosphere. That's one reason that we know that this sediment was not deposited in an ocean.

Stop #1-6 Displacement

Sedimentary strata usually form continuous layers. In this outcrop you can see sedimentary layers that show small offsets (Fig. 16), on the order of a few centimeters (an inch or two). These small offsets are most easily seen here near the ground. Cracks along which there's been displacement are called faults, and the offsets are usually produced during an earthquake. How many tiny faults can you count? The irregular areas of red paint on the conglomerate about 3 m (10 ft) off the ground resulted from a film company many years ago trying to make this area look like Red Rock Canyon.

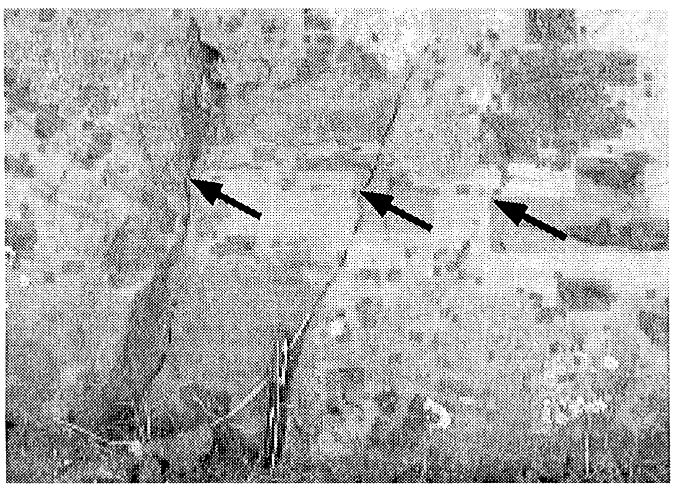

Figure 16. Small displacements (arrows) shown by sandstone strata of the Vasquez Formation at Stop #6 on the Geology Trail.

Stop #1-7 From Solid Rock to Sand

Note the many cracks in the outcrops in this area - cracks in rocks along which there has been no displacement are called "joints" and are caused by shrinkage, tension, folding, faulting, or unloading (by erosion of overlying rocks). Joints (and faults) are important because they can create places where water and air can seep into rocks allowing chemical weathering to attack the rock surfaces. Roots from plants can also extend into the joints and mechanically disturb the rock. Loosened rock and mineral fragments then are removed from the joint by gravity or running water creating larger cracks. Eventually, these joints and faults can become eroded into spaces several meters wide, such as the one along the fault on the north side of the trail.

Notice that the trail is covered with sand. This sand has been derived from the chemical and mechanical weathering of the solid Vasquez sandstone and conglomerate and is a good reminder that the rock cycle continues.

Stop #1-8 Overview

To the southeast (left), the crest of the San Gabriel Mountains forms the high skyline. In the foreground on the left are the famous "hogback" ridges of Vasquez Rocks, inclined and eroded sandstone and conglomerate strata of the Vasquez Formation. To the west (right) are ridges of Vasquez lavas that have been eroded into a distinctive shape called a "saddlebag ridge". In the valley below the ridge lies the rural community of Agua Dulce.

28.7(0.1) *Drive farther into the Park and park beyond the main distinctive outcrop in the large sandy parking area near the portable toilets.*

Return to Escondido Canyon Road

RESET YOUR ODOMETER TO 0.0 AT THE INTERSECTION OF THE PARK ROAD WITH ESCONDIDO CANYON ROAD.

0.0(0.0) *Turn right onto Escondido Canyon Road.*

0.1(0.1) The relatively high ridge forming the skyline to the left is Sierra Pelona, consisting of the Pelona

Schist. (*Pelona* = "bald".) This chlorite-actinolite schist is interpreted to be composed of rocks from subducted oceanic crust that were emplaced beneath the western North American plate in the early Tertiary period (60 Ma) and subsequently uplifted and exposed by erosion.

1.6(1.5) The fault separating the Vasquez sedimentary rocks from the Precambrian syenite is easily seen from this direction.

2.3(2.3) *Turn left toward Palmdale onto the Hwy 14 Freeway onramp.*

DF-66 - Sleepy Valley and Ritter Ridge quadrangles

DF-59 - Acton quadrangle

3.8(1.5) Escondido Summit, with an elevation of 987 m (3,258 ft). (*Escondido* = "hidden".) The Santa Clara River has its beginning here. With a length of merely 117 km (70 mi), the river has an average gradient of 8.4 m/km (46.5 ft/mi), 90 times greater than that of the Mississippi River!

The relatively high ridge forming the distant skyline to the left is Sierra Pelona, consisting of the Pelona Schist.

5.8(2.0) Offramp for Red Rover Mine Road and Sierra Highway. The Red Rover gold mine operated on and off between the 1870s and 1940. Along with the nearby Governor (New York) mine and scores of smaller mines, it belonged to the Cedar mining district. The Governor mine has accounted for about half of the approximately 170,000 ounces of gold produced in Los Angeles County. In both of these mines, gold occurred with pyrite in quartz veins.

7.1(1.3) Exposures of Vasquez lavas over the next 2 miles.

7.4(0.3) Offramp for Crown Valley Road.

9.4(2.0) Offramp for Santiago Road.

11.2(1.8) Offramp for Soledad Canyon Road.

11.7(0.5) Exposures of brownish Mount Lowe intrusion of Triassic age (220 to 210 Ma), which is intruded by younger irregular masses of light pink and white granite. These old plutonic rocks represent the basement onto which the Vasquez sediment was deposited.

Pacifico Mountain quadrangle (not yet published by the Dibblee Foundation).

Palmdale quadrangle (not yet published by the Dibblee Foundation).

13.2(1.5) Offramp for Pearblossom Highway

13.6(0.4) First views of the high portion of the Mojave Desert.

14.1(0.5) Over the next mile, we'll be driving through five roadcuts, mostly in volcanic and sedimentary rocks of the Vasquez Formation. Roadcut #1 - lava (massive, purple and greenish-brown) and volcanic conglomerate.

14.4(0.3) Roadcut #2 - sedimentary and volcanic conglomerate.

14.7(0.4) Roadcut #3 - lava and volcanic conglomerate.

15.0(0.3) Roadcut #4 - lava and volcanic conglomerate.

15.2(0.2) Roadcut #5 - fractured, dark-red-weathering syenite of Precambrian age (about 1.2 Ga). Syenite is an intrusive igneous rock composed of more K-feldspar than plagioclase, with variable amounts of mafic minerals and little quartz. This unit is part of the San Gabriel anorthosite-syenite intrusion. Again, these old plutonic rocks represent basement onto which the Vasquez sediment was deposited.

15.7(0.5) *Pull into the Lamont M. Odett Vista Point.*

STOP 2 - LAMONT M. ODETT VISTA POINT

This overlook is dedicated to a local leader who worked for years promoting the construction of this freeway. The bronze plaque commemorating this dedication refers to the "1957" earthquake. It should of course be 1857, the date of the last big earthquake on the San Andreas fault in this area.

The broad valley extending from the southeast beneath the lake off to the northwest (Leona Valley) represents the San Andreas fault zone, here about 2 km (1.2 mi) wide. The trace of the San Andreas fault lies along the far side of the lake, whereas the trace of the Nadeau fault (another member of the San Andreas fault "family") lies along the near side. The world's most famous fault is a transform plate boundary which separates the Pacific plate beneath your feet from the North American plate on the other side of the low ridge to the north. Reflect for a moment on the fact that land that *used to* lie a mile to the north of you 20 million years ago is now located some 240 km (150 mi) to the southeast. Similarly, land that *now* lies a mile north of you used to be located 315 km (180 mi) to the northwest 20 million years ago! Why is there a discrepancy between these two amounts of offset? It's because some of the motion between the two plates south of here is taken up by other faults like the San Jacinto and Elsinore faults.

Look north at the wedge-shaped western end of the high portion of the Mojave Desert, which stretches from the San Andreas fault in the foreground to the distant Tehachapi Mountains rising above the left-lateral Garlock fault. The cities of Palmdale and Lancaster here in the Antelope Valley are among the fastest growing in California. Palmdale Lake below us is a modified sag pond (enlarged by a dam) filled with water from Little Rock Creek via the Palmdale ditch. A sag pond is defined as a small body of water occupying an enclosed depression (or sag) formed where active fault movement has impounded drainage. The East Branch of the California Aqueduct, filled with water from the Feather River in northern California, crosses the Hwy 14 Freeway in front of us. This aqueduct delivers an average of 540 million gallons of water per day which is pumped east of here into Lake Silverwood high in the San Bernardino Mountains. See the description of this stop in the trip by Doug Yule (this guidebook).

Pull back onto the 14 Freeway.

DF-66 - Sleepy Valley and Ritter Ridge quadrangles

16.2(0.5) California Aqueduct. Just beyond this point, the freeway crosses the Nadeau fault, here buried by alluvium.

17.0(0.8) *Take the exit for Avenue S. Turn left onto Avenue S.*

17.4(0.4) *Turn left on Guyon Road and park.*

STOP 3 - THE FAMOUS PALMDALE ROADCUT

One of the best, most readily accessible exposures of the geology within the San Andreas fault zone is provided by the roadcut where the Antelope Valley Freeway (Hwy 14) crosses the fault zone (Figs. 17 and 18). The freeway is a limited-access, divided highway and stopping along the shoulder to view the geology is not permitted. The best way to view the roadcut is to climb the hill on the west side of the freeway, being careful to stay west of the fence.

The San Andreas fault is generally defined as the trace of the most recent surface rupture, which last

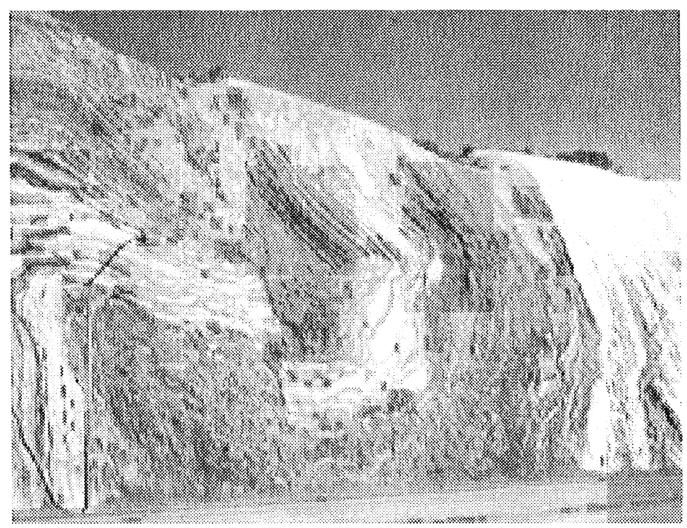

Figure 18. Historical photograph of the Avenue S roadcut. Photo taken by R. E. Wallace courtesy of the US Geological Survey and Michael Moore.

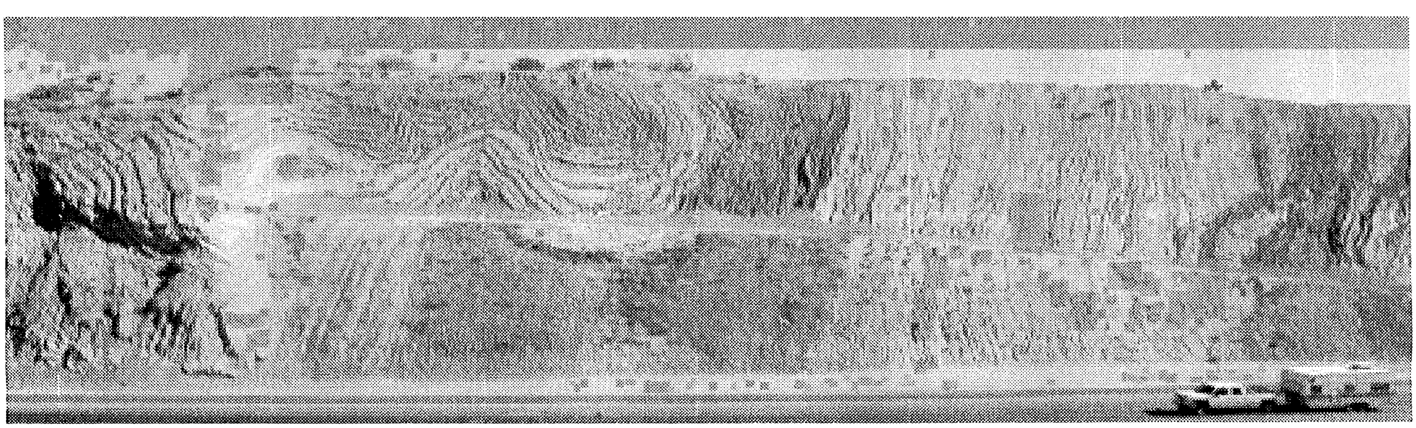

Figure 17. Panorama of deformed strata of the Anaverde Formation on the east side of Hwy 14 Freeway just north of Avenue S. Photo by Charles Nussrallah.

occurred in this area during the great 1857 Fort Tejon earthquake. At the roadcut, the trace of this rupture passes along the northern edge of the Palmdale Reservoir and beneath the freeway exactly at the southern end of the roadcut.

Cross Avenue S with great care and begin to hike to the top of the ridge. The traces of the 1857 Fort Tejon rupture angle across the freeway and pass beneath the freeway onramp and offramp north of Ave. S. You will officially walk from the Pacific plate to the North American plate as you begin climbing the first small hill.

The nonmarine Anaverde Formation, lower middle Pliocene in age, is spectacularly exposed in this roadcut for a distance of 730 m (2,400 ft) between the San Andreas fault on the south and a major splay on the north called the Little Rock fault. Located about 75 m (250 ft) north of the northern end of the cut, the Little Rock fault is considered a possible ancestral trace of the San Andreas fault and records more than 20 km (13 mi) of right-lateral displacement since the deposition of the Anaverde Formation. Bedrock immediately north of the Little Rock fault consists of Mesozoic plutonic rocks.

The roadcut consists of interbedded, buff, arkosic sandstone and dark brown, gypsiferous shale. Locally, the shale contains 80% to 90% gypsum, and gypsum crystals up to many centimeters long occur in some beds. This hill was one of California's earliest known sources of gypsum. This mineral was mined here from 1892 to 1915; from 1900 to 1908, this locality was the state's most productive source of gypsum. The intricate folds and faults in the sedimentary rocks graphically demonstrate the plastic deformation within this block of Anaverde Formation caught up between the San Andreas and the crystalline basement rock north of the Little Rock fault. Although the San Andreas undergoes predominantly strike slip motion, small irregularities in its trace produce minor compression resulting in pressure ridges of folded strata such as seen here.

Note the expensive houses on the hill to the south. The 1972 Alquist-Priolo Act requires geologists to map traces of potentially active faults. County ordinances then prohibit building a new house within 50 feet of the known active fault trace. The upscale houses to the south are clearly located more than 50 feet from the 1857 rupture. Do you think that they are therefore safe if the epicenter of the upcoming San Andreas earthquake is in this vicinity?

Return to the vehicles. RESET YOUR ODOMETER.

0.0(0.0) *Turn right (east) onto Avenue S towards the freeway.*

0.1(0.1) *Turn right (south) onto the Hwy 14 Freeway towards Los Angeles.*

3.7(3.6) Offramp for Pearblossom Highway.

DF-59 - Acton quadrangle

6.2(2.5) *Take the exit for Soledad Canyon.*

6.4(0.2) *Turn right onto Sierra Highway.*

6.8(0.4) *Turn right onto Soledad Canyon Road.*

8.7(1.9) Intersection with Santiago Road.

9.1(0.4) Intersection with Aliso Canyon Road. (*Aliso* = "alder tree".)

9.3(0.2) Triassic Mount Lowe intrusion.

9.4(0.1) Light-colored granite.

10.0(0.6) The prominent ridge ahead is called Parker Mountain and is underlain by Mount Lowe intrusion.

10.8(0.8) Intersection with Crown Valley Road.

11.3(0.5) Roadcuts over the next 1.5 miles are in the Mount Lowe intrusion. If you drive through these roadcuts slowly, you might be able to pick out the distinctive texture of the Lowe: partly aligned hornblende crystals (now partly altered to epidote and chlorite) in a matrix of light feldspar. Here, the Lowe is cut by several mafic dikes and by irregular masses of light-colored granite. The second large outcrop of the Mount Lowe intrusion is also cut by irregular intrusions of granite.

13.5(2.2) Outcrop of gneiss composed mostly of feldspar with varying amounts of hornblende.

13.6(0.1) Small outcrop of strikingly white San Gabriel anorthosite of Precambrian age. Over the next 1.5 miles are exposed white anorthosite and dark brown lavas of the Vasquez Formation in contact along the Soledad fault. Note the Vasquez sedimentary rocks on the hills to the right.

15.0(1.4) Bridge over the Santa Clara River.

15.1(0.1) *Pull off on the right into the parking area immediately past the bridge.*

Cross the road with extreme care!!

STOP 4 - FAULT CONTACT BETWEEN ANORTHOSITE AND VASQUEZ LAVAS

This is an opportunity to examine a rare rock type - anorthosite. It's composed almost entirely of plagioclase feldspar crystals which have been bleached white. It commonly has no dark-colored minerals, as here. In this outcrop, it's in contact with Vasquez lavas along the Soledad fault (Fig. 19).

Figure 19. Soledad fault with lavas of the Vasquez Formation in contact with San Gabriel anorthosite exposed on Soledad Canyon Road.

Typical of many massive outcrops of lava, few features, like individual flows or visible phenocrysts, are evident here. Under the microscope, you can see tiny crystals of plagioclase feldspar and the pyroxene augite in a fine-grained groundmass with some volcanic glass. Consider for a moment the huge difference in geologic age and the difference in emplacement locations between these two rock types - the 1.2-Ga anorthosite represents an igneous intrusion that crystallized within the middle crust [maybe 25 km (15 mi) below the surface], whereas the Vasquez rocks represent 24.5-Ma extrusive andesite lava flows. About 15 m (50 ft) past the major fault is some anorthosite with a splotchy appearance. This texture, informally called "leopard rock", was formed during the crystallization of the anorthosite magma as pyroxene grains grew to large size, enclosing numerous small plagioclase feldspar crystals. The pyroxene has since altered to an amphibole mineral. Can you find in this roadcut a mafic dike, a granite intrusion, and slickensides associated with a small fault?

Return to the vehicles and *continue driving west on Soledad Canyon Road.*

DF-58 - Agua Dulce quadrangle

15.3(0.3) Another sliver of Vasquez lavas in contact with anorthosite along the Soledad fault. Outcrops on the left for the next 5 mi are anorthosite.

20.4(5.1) Bridge over the Santa Clara River.

20.6(0.2) Intersection with Agua Dulce Canyon Road.

20.8(0.2) Conglomerate of the upper Vasquez Formation composed of anorthosite fragments.

21.1(0.3) More anorthosite.

21.2(0.1) This quarry road is another good place to look at anorthosite. Note the contorted mafic dike, the fault, and the granite intrusion.

21.6(0.4) Tunnel; the Pole Canyon fault extends vertically through the tunnel.

22.5(0.9) We're back in the Tick Canyon Formation. The epicenter of the 1971 San Fernando earthquake is about 8 km (5 mi) south of here.

23.1(0.6) Now we're back in the Mint Canyon Formation. There's a good view of the sand and gravel operation from this area.

24.1(1.0) *Turn left onto the onramp back onto the Hwy 14 Freeway headed south towards Los Angeles.*

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