A Geologic Excursion to the East San Francisco Bay Area

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Fieldtrip Overview

This fieldtrip serves two purposes. First, we will take a look at some of the interesting geology that characterizes the San Francisco Bay region. This will be a “hands-on” look that I think offers a better feel for the role of geology in the shaping of the landscape, and the impact of geology on society, than can be obtained in a purely classroom environment. Second, and probably more important, we will have a chance to practice the technique of observational science, following the fundamental principles of the scientific method (observe, hypothesize, test). Geology, perhaps more than any other science, is based on deductive reasoning, because many of the geologic features we work with probably formed over thousands or millions of years. We see only the end product, and we have to deduce how it got that way. Understanding how those features developed and evolved requires looking at the normally very slow (though occasionally catastrophic) processes that are going on today, and extending those processes by thousands or millions of times. However, just a few basics will allow the careful observer to start to understand how the world around us took on the shape it now has and how ongoing geologic forces can impact our lives.

Each of our three stops has three sections in this fieldtrip guide—a short introductory section, an exercise for you to do in the field, and a longer section of material related to the geology seen at that stop. We will be discussing most of what is covered while we are in the field, so the longer section will be mostly useful for you after the trip is over. There is also a road log that lists mileage between the stops and indicates various geologic features along the way.

The point of each exercise is to put you into the field boots of a geologist. Remember that all science starts with an observation, and this is never more true than in geology. Be prepared to take a look at the world in a new way. Any observation may hold the key to understanding the geology at each stop.

If you think that geology is just about looking at rocks and minerals, this fieldtrip may be a bit of a shock. We will not talk much about different kinds of rocks until the third stop, and will hardly mention minerals at all. Geology is about understanding the Earth and how it works. Rocks and minerals can provide a lot of information about the geology (as we will see at the third stop), but they are only a part of the story.

I hope that the information and figures contained in this guide will also be useful to you in your classroom. If you want to know more, the U.S. Geological Survey and the National Park Service maintain web-pages where additional information is available. An excellent introductory page is available at: http://www.nature.nps.gov/grd/usgsnps/project/interp.html. Information about the San Francisco Bay region is available from http://sfbay.wr.usgs.gov, with field geology being emphasized at http://sfgeo.wr.usgs.gov.

I hope you enjoy the trip, and that you come away with an expanded idea of what geology is all about.

Road Log

Mileage/Notes

0.0 **Trip start—U.S. Geological Survey, Menlo Park.**

South on Middlefield Rd., LEFT onto Willow, RIGHT onto Bayfront Expressway (Highway 84), cross Dumbarton Bridge.

7.5 The freeway cuts through the south end of Coyote Hills. This ridge of Franciscan mélange was probably lifted up by a fault thought to be long inactive that runs under the flat area on the west edge of the hills. The hills are now in the process of being buried by young sediments as the Bay Block sinks down. (A block is a large crustal rock mass bounded by faults that moves or behaves as a single unit within a greater tectonically active region.)

EXIT onto I-880 South, EXIT at Mission Blvd., proceed northeast on Mission Blvd.

20.2 You just crossed the most active strand of the Hayward Fault. Did you notice it? Much more about the Hayward Fault and how to recognize faults as we go along.

Right on Stanford Ave., drive to the end of the street and park.

21.3 STOP 1—Mission Peak Landslide, Fremont

Return on Stanford Ave., LEFT on Mission Blvd., RIGHT onto I-680 North.

24.5 Notice the ridge on the right. The highland is underlain by early Pleistocene (about 0.5 to 1.5 million years old) Irvington Gravel (this is where the mammal fossils indicative of early Pleistocene age were first described in North America). The ridge has a very straight west side (see fig. 2.1) cut by the Hayward Fault. Just judging by this ridge, which way would you say the fault was moving?

EXIT at Mission Blvd., LEFT onto Mission Blvd.

27.5 The ridge to the right was formed by motion on the Mission Fault similar to that on the Hayward Fault, but the Mission Fault is thought to be inactive. Why do you think the ridge is still there?

30.1 To your right is Niles Canyon (see fig. 2.2). On the map you can see that Niles Canyon meanders back and forth in large curves. Normally a deep canyon like this is pretty straight, but this one has retained curves from a time before the hills were here. The hills have lifted up over the past million years or so, and Alameda Creek, curves and all, has just eroded its channel through the rocks to form the canyon as the hills were going up.

33.4 To your right the Hayward Fault has formed benches in the sides of the hills. Did you notice there is more than one level of benches? Faults like the Hayward Fault often form zones of deformation with multiple breaks at the surface.

Stay on Mission Blvd. to downtown Hayward, park at B Street.

39.3 STOP 2—Hayward Fault Zone, Hayward

RIGHT onto A Street, LEFT onto Foothill Blvd., merge onto I-580 West.

43.2 Notice the dropoff to the left. This scarp is formed by a strand of the Hayward Fault Zone that was until recently thought to be inactive. Recent studies have documented that it is active, though. The Hayward Fault Zone through here is made up of at least three active strands in a zone almost a kilometer (0.6 miles) wide!

48.8 Notice the white rock in the quarry to the right of the freeway. The rock exposed is a Jurassic (about 160 million years old) volcanic rock called the Leona Rhyolite. Today it is used for construction, but earlier in the 20th century it was mined for pyrite (iron sulphide, also called fool's gold). The sulphur was used to make chemicals. This area was listed as a potential copper mining area because of the high percentage of copper in the pyrite (many minerals are impure, with one element replacing a percentage of another element, like copper for iron in pyrite. Sometimes the impurity is what you're really after!). However, the copper potential never worked out. Imagine a big open-pit copper mine in the Oakland hills!

EXIT onto Highway 13.

52.7 This long, narrow valley was formed when rocks ground up by the motion of the Hayward Fault were more easily eroded than the surrounding rocks. Linear valleys like this can be a good indicator of a fault.

54.3 On the left is Lake Temescal (now a regional park). This long, narrow reservoir takes advantage of the long, narrow valley carved along the Hayward Fault Zone. Unfortunately, the Hayward Fault is still here, and still very active. This reservoir probably would never be built today.

EXIT onto Highway 24 East, go through the tunnel, just past the tunnel exit at Fish Ranch Road, turn RIGHT back over the freeway, turn RIGHT again onto the frontage road, and park in the large open area just before the freeway entrance

56.7 STOP 3—Caldecott Tunnel between Oakland and Orinda

Information on Stops

Stop 1—Mission Peak Landslide, Fremont

Introduction

In March 1998, after two consecutive years of heavy rainfall, a large portion of the northwest flank of Mission Peak detached from the mountain and began to slide down towards the newly constructed neighborhoods of luxury homes below (fig. 2.3). The huge body of displaced material moved slowly, only a few centimeters each day, but when motion finally ceased months later, a mass more than one mile long and a quarter mile wide had moved several hundred feet down the mountainside. Fortunately, only one home was affected by the slide, because its path took it along the side of one neighborhood and stopped just short of another.

Exercise

Geology is an observational science; our conclusions are based on features we see in the landscape, the soil, and the underlying rocks. Look at the 1998 slide (fig. 2.4*A*). How would you describe the shape of the land inside the slide? How would that show on a topographic map? Look at the map (fig. 2.4*B*) to see if there are other areas nearby with similar topography. What does that suggest?

More About It

Normally, the gravitational force that is continually trying to pull material downhill is countered by cohesion and friction in and among the rocks that make up the hillside. However, when conditions are created where the cohesion and friction are reduced enough, material will move downhill. The constant breaking down of rock to form soil by weather, plants, and animals is one way cohesion and friction are reduced, and some material is constantly moving downslope at a very slow rate, much less than a millimeter per day. This slow process is called hillside creep. At times, however, conditions exist when masses of rock can move relatively quickly (for rocks), a process called landsliding.

Several things can lead to landsliding—earthquake shaking, poorly engineered construction, natural erosion, and rainfall. Although landsliding is caused by any of these, and by combinations of them as well, rainfall is by far the most important factor. Heavy rainfall can increase the tendency for landsliding in several ways: by increasing the weight of a body of rock, by providing lubrication between and within the rocks of a hillside, and by raising water pressure sufficiently to lift bodies of rock away from the hillside (this is discussed below).

The Mission Peak Landslide is a very large example of a bedrock, or deep-seated, slide (the technical term is slump earthflow), one of several different kinds of landslides. Bedrock landslides happen where a weak zone below the surface of a hillside allows a large mass of rock to slide downslope all at once. After one or more years of heavy rain, the groundwater in the rock under the hillside is fully charged (all the space within the rocks that can contain water is filled up), and additional incoming water from rainfall creates increased water pressure. The water pressure can begin to lift the rocks near the surface up and away from the hillside, reducing the friction. If water pressure reduces the friction enough, and a weak zone exists in the rocks, a mass of rock will become detached and slide downward. Usually the pace of the slide, while fast for rocks, is slow in human terms, centimeters per day, so bedrock landslides seldom pose a threat to human life. The size and mass of these landslides, however, make them a substantial threat to buildings, roads, and other construction. In 1998, more than $140 million of landslide damage occurred in the San Francisco Bay region, most of it caused by bedrock slides.

Bedrock slides create a collection of unique landscape features (shown and described in fig. 2.5). The place the material is moved from (the zone of depletion) is characterized by features related to extension, whereas the place the material is moved to (the zone of accumulation) is characterized by features related to compression. The main scarp of the Mission Peak landslide is very prominent because of the light-colored rocks exposed there (fig. 2.6).

Over geologic time, the landscape features formed during a landslide are worn down by the effects of weather and hillside creep, leaving progressively more subtle, but still visible signs of older landslides (see fig. 2.7). The 1998 Mission Peak landslide was a reactivation of part of a much larger, older landslide (see fig. 2.8) that was still visible in the landscape prior to 1998.

Almost all hillsides in the San Francisco Bay region show some trace of old landslides (some 90,000 landslides have been mapped in the Bay area!), but some areas are more prone to new landsliding than others (geologists call the greater or lesser tendency to slide "landslide susceptibility"). Three main factors contribute to a hillside's susceptibility to bedrock landslides—the kind of rock that underlies the hillslope, the steepness of the hillside, and the presence or absence of previous landslides. Weak rock, steep slopes, and the presence of previous landslides all make the area of the Mission Peak landslide very susceptible to bedrock landslides. Research is being conducted right now to quantify the susceptibility to bedrock landslides in the San Francisco Bay region. We are working to provide a tool that can be used for informed land-use planning, so that regions of very high susceptibility can be identified and rejected for development. The community on the flank of Mission Peak was lucky in 1998, the area affected by the slide was for the most part undeveloped. Informed planning can, hopefully, insure that new developments are kept out of harm's way.

In addition to bedrock landslides, another common type of landslide deserves mention, the debris flow (more commonly called a mudslide, but this name is misleading because the mass is made of rocks, trees, and other debris, as well as mud, and because the mass does not move by sliding!). Debris flows occur during very intense rain storms, when the layer of soil that covers the hillslope is saturated. A small slump occurs in the soil, causing the saturated material to liquefy, and flow quickly down slope, carrying rocks, trees, and other debris with it (see fig. 2.9). This type of landslide is small, but very fast-moving, up to 50 km/hour. The speed of these "slides" makes them very dangerous to human life. In 1998, three people were killed by a comparatively few debris flows in the San Francisco Bay region, but in 1982 an intense storm throughout the region caused 18,000 debris flows that killed 25 people.

Stop 2—Hayward Fault Zone, Hayward

Introduction

In 1868, a length of the Hayward Fault Zone stretching from Oakland to Fremont broke, and the rocks west of the fault suddenly jumped several feet to the northwest with respect to those east of the fault. The energy released by this sudden motion produced a large earthquake, causing destruction throughout the San Francisco Bay region (fig. 2.10). Until the earthquake of 1906, the Hayward Fault Zone quake was known as the Great San Francisco Earthquake. Although the effects of this earthquake were well studied at the time, the work was for the most part lost, thought to have been suppressed by local government officials concerned that scientific studies of earthquakes could dampen growth and development in the region!

Since 1868, however, the Hayward Fault Zone has been relatively quiet, and has not generated a large earthquake. The forces that lead to earthquakes have not stopped, though. The rocks underlying San Francisco Bay continue to move northwest with respect to those east of the Hayward Fault Zone, but most of the fault zone itself is stuck, and pressure is slowly building up in the rocks near the fault zone. Eventually the pressure will overcome the friction and other forces that are causing the fault zone to stick, and the accumulated energy will be released in another big earthquake.

While almost all of the fault zone is stuck, in some places conditions within the rock allow the portion of the fault at the surface to slowly slide along in response to the pressure building up on the stuck fault. This slow sliding is called fault creep. Although the motion of creep is very slow (on the Hayward Fault Zone, the maximum creep rate is 9 mm/yr, or about 1/1000 mm/hr!), over the years the effects of the offset can be seen, especially in man-made structures. It is important to note that while creep does allow that part of the fault near the surface to slide along without pressure building up, most of the fault at depth is still stuck, so creep doesn't do much to help reduce the next big earthquake. However, creep does help us find some of the parts of the fault zone where pressure is building up.

Exercise

Look for evidence of creep in the manmade structures (curbs, streets, parking lots, and buildings) in the area. Remember that the rocks west of the fault are moving north with respect to those east of the fault. Mark the position of the fault creep on the detailed map (fig. 2.11*A*)**.** Use your observations of fault creep to make a map of the surface trace of the creeping fault. Transfer your fault trace to the map of the larger area (fig. 2.11*B*). Do you see any other features in the map that look like they might be related to the motion of the fault?

More About It

Major fault zones, like the Hayward Fault Zone, are fractures in the upper crust, formed when very large blocks of the Earth's lithosphere slide along, over, or under other blocks (the lithosphere is the rigid outer part of the Earth composed of the crust and the upper mantle). The force that drives the motion of these blocks is provided by the continual formation, motion, and destruction of huge pieces of lithosphere called plates. The collective motion of the plates (fig. 2.12), called plate tectonics, is the driving force for most of the earthquakes, volcanoes, and mountain uplifts in the world. Where plates interact by sliding past one another, like they do in California, the upper crust near the plate boundary is broken into large blocks that are separated from each other by fault zones, like the Hayward Fault Zone. Driven by the northwest motion of the Pacific Plate with respect to the North American Plate, the blocks in the San Francisco Bay region are in motion. Each block moves northwest with respect to the one east of it.

Although most people, including many geologists, tend to think of a fault as a single crack in the Earth's crust, the major fault zones are actually very complex systems composed of many faults (fig. 2.13), not all of which are moving at the same time or in the same way. Through the long history of a fault zone (the Hayward Fault Zone is probably about 12 million years old), the sliding motion between the moving blocks is sometimes focused in one area, later in another area. The creeping part of the Hayward Fault Zone has probably moved only about 5 km, roughly 1/20 of the total offset of the Hayward Fault Zone as a whole.

Just as the long history of the fault zone is complex, the active part of the fault zone also involves more than a single crack. In the area near our stop, at least three different faults have evidence of recent activity (perhaps you spotted one in the exercise). Geologists look for evidence of recent fault motion because we believe those parts of a fault zone that have moved most recently are most likely to move again. Remember that although the moving parts of the fault zone have changed, those changes took place over millions of years.

Recent fault activity, like landsliding, produces unique landscape features (fig. 2.14) that can be used to locate active parts of a fault zone. In the Hayward area, linear ridges, linear valleys, fault scarps, and offset streams all mark the active parts of the Hayward Fault Zone (fig. 2.15). It is important to note that not all active parts of the fault zone are creeping, although creeping parts are all active.

It is important to know which parts of the fault zone are currently active because one of the hazards during an earthquake is fault rupture (fig. 2.16). Any structure built across a fault that suddenly moves with offsets up to several feet will suffer extreme damage. In California, the U.S. Geological Survey (USGS) cooperates with the California Division of Mines and Geology (CDMG) to make special maps showing all faults known to be active, and special geologic studies are required before any structure can be built within 50 feet of one of the active faults. Because of the regulatory nature of the maps, though, only those faults known to be active are shown. In Hayward, only the creeping part of the Hayward Fault is shown. The other two faults that have features related to recent movement are not shown because their activity is not proven (though proof for one has recently been discovered, so it will probably be added to the next version of the maps).

Even more important than the fault-rupture hazard is the hazard from earthquake shaking and related effects (the 1989 Loma Prieta earthquake occurred deep in the crust, there was no fault-rupture damage, all the damage was caused by shaking and related effects). Shaking occurs in response to waves of energy that are released by and move away from the rupturing fault. In general, the intensity of the energy waves decreases as they move away from the fault, so the farther from the fault rupture, the less shaking is felt. However, shaking can be magnified by the geologic or man-made material under the surface. Loose materials like artificial fill, bay mud, and sand dunes tend to amplify shaking the most, whereas bedrock tends not to amplify shaking at all. In addition, loose materials saturated with water can be converted to "quicksand" by shaking, a process called liquefaction. Shaking can also trigger landslides, especially if there has also been heavy rainfall. Although these hazards have long been recognized (the danger of artificial fill was noted after the 1868 earthquake!), maps of these hazards have only recently begun to be produced. USGS is currently cooperating with the CDMG to produce maps showing areas of liquefaction and earthquake induced landslide hazard. Regional maps showing predicted shaking intensity for large earthquakes on several faults in the San Francisco Bay region are available from the Association of Bay Area Governments: their informative earthquake website is http://www.abag.ca.gov/bayarea/eqmaps/eqmaps.html.

The Holy Grail of earthquake study is, of course, earthquake prediction. Accurate prediction of earthquakes is at present impossible, because irregularities in the fault surface, differences in properties of the rocks cut by the fault, and the interplay of pressure buildup and release on every fault in the region, all affect the exact amount of pressure that needs to build up to overcome the resisting friction on any given part of a fault. Perhaps one day geologists will be able to measure tiny changes in some property of the fault zone, such as electrical, magnetic, acoustic, production of various gasses, to give an early warning of an earthquake. For now, scientists at USGS and elsewhere are using more general techniques to try to determine where and when an earthquake is likely to occur. Information about when the last major earthquake was, how fast pressure is building up, and how large an earthquake to expect are combined to give a probability of an earthquake on active faults over a 30-year time period. At the same time, engineers are using seismic data to design earthquake resistant structures.

It may be interesting to note that the idea of plate tectonics that all our understanding of earthquakes and major faults is now based on is a relatively new concept. The first observations that ultimately led to the modern ideas of plate tectonics were made mostly after World War II, and the theory was only fully accepted by the scientific community in the late 1960's.

Stop 3—Caldecott Tunnel Between Oakland and Orinda

Introduction

In the San Francisco Bay region, vegetation and soil obscure much of the detail about the underlying rocks. Geologists make the most of those few areas where the rocks are well exposed, either by natural processes like canyon erosion, or by man, such as in the roadcut at this stop (figs. 2.17 and 2.18). When Caldecott Tunnel was expanded, the steep and deep cuts here exposed a body of rock that otherwise would have been for the most part obscured. The complete exposure allows us to make important observations that can tell us what the environment was when the rock formed, where material that was deposited here came from, how old the rocks are, and what has happened to the rocks since they were formed.

Exercise

The work of the geologist in the field is much like the work of a detective, making careful observations and trying to put all the information together to make a coherent story that explains what we observe. Use the map (fig. 2.19) to record your observations about the rocks at this stop (Are they all the same color? Texture? Are they made up of the same things? Are they layered?). Try to think of a story that explains what you see.

More About It

The first thing to look at here is the big picture. As we look north, we see that there are two very different kinds of rock bodies (fig. 2.18). On the left, the rocks are green, light gray, and in some places red: they are distinctly layered, and some layers are harder than others. This body of rocks is called the Orinda Formation. On the right, the rocks are dark brown, hard, with thicker layers that are less distinct. This body of rocks is called the Moraga Volcanics. Geologists name rock bodies after the place where they were first discovered or described, or where they are best exposed. Naming rock formations helps geologists communicate with each other our observations about various rock bodies, although misuse of names sometimes leads to confusion.

A closer look at the Orinda Formation reveals that it is made up of layers of broken up pieces of other kinds of rock (fig. 2.20). Rocks made up of pieces of other rocks are called sedimentary. Some layers are made of large pebbles and cobbles (geologists call rocks like these conglomerate), other layers are made of tiny grains too small to see (geologists call that mudrock), others are in between, made up of sand (sandstone). A very close look at the pieces reveals that there are many different kinds of rocks among the pieces, all mixed together here. The pieces were broken off a variety of rock bodies somewhere else, mixed together during their transport here, and then dropped off to form the layers you see. But how?

There are several different forces on the Earth's surface that can move rock fragments, such as glaciers, wind, landslides, ocean currents, and rivers. Because the pieces in the layers here are sorted out into different sizes in different layers, we can eliminate glaciers and landslides. Why? Because observations by geologists have shown that glaciers and landslides deposit all different sizes of fragments mixed together. And wind does not have enough force to move the large cobbles we see in some of the layers here. So, that leaves ocean currents and rivers, which can form very similar-looking layers. We need a little help here, but the fossils of land mammals discovered here and elsewhere in the Berkeley Hills (fig. 2.21) reveal that the layers were deposited by rivers. The conglomerate layers formed in stream beds, where fast moving water could bring the large pieces, and floods formed the sandstone and mudrock as the river overflowed its banks and dropped out sediments in the floodplain as the moving water slowed down.

The Moraga Volcanics, as the name suggests, are an entirely different kind of rock body, not made up of broken pieces of other rocks brought here. A closer look at the rock body reveals that it is fairly uniform, dark and heavy. A very close look shows that it is not made of pieces, but is, instead, a solid mass. In some places, though, we can find parts of the rock body that are full of holes, and in others the solid mass is punctuated by well-formed crystals of a white mineral called plagioclase. Geologists know that a solid mass like this can only form when molten rock cools and crystallizes, forming an igneous rock. Igneous rocks can form deep within the earth, slowly cooling and crystallizing, producing rocks made of large crystals like granite (fig. 2.22), or can form when molten rock flows or erupts out onto the surface of the earth, cooling quickly with no time to form large crystals. The lack of large, interlocking crystals here shows us that this rock formed from molten rock on the surface (lava), which flowed out of volcanoes to make volcanic rocks (hence the name Moraga Volcanics). The holes we see in some places (fig. 2.23) are actually the remnants of bubbles, produced by gas released from the lava, and trapped when the lava hardened. The plagioclase crystals are large crystals that formed slowly deep below the volcano, and were brought to the surface with the lava during eruptions. The dark color of the volcanic rock reveals that it is rich in iron and magnesium, a kind of rock called basalt. The volcanoes that produced the lava were long ago eroded away, although you can still see the remnants of one at Sibley Volcanic Regional Park nearby.

The place where the two bodies meet is called a contact (fig. 2.24). There are two ways a contact between different rock bodies can form. One is by sliding two rock bodies next to each other along a fault, which would form a fault contact. Fault contacts are usually recognizable by the grinding and stretching in the rocks on either side. The absence of grinding and stretching here says that this is not a fault contact. The other way a contact can form is when a younger rock body is formed next to an older body, a depositional contact. A closer look at the contact here reveals a thin, bright red layer of mudrock. The brick-red color is the result of baking, the hot lava cooking the layer of mud that it flowed onto. So, here, we can tell that this is a depositional contact, the lava flowed onto the sedimentary layers, and the volcanic rocks formed there. Geologists are very interested in contacts, because they tell us a lot about the history of the formation of the rocks. We make geologic maps that show where the contacts between different rock bodies are. However, in the San Francisco Bay region, it is very unusual to be able to see a contact as well as this.

Another thing you notice right away about this roadcut is that all the layers are steeply tilted (figs. 2.17 and 2.18). One of the earliest observations by geologists was that sedimentary and volcanic layers are almost always formed close to horizontal. This is called the Law of Original Horizontality, a fancy name for a simple idea—rock layers start out flat. The Grand Canyon is a perfect example of a place where the layers are still flat, but not so here. The plate tectonic forces that are driving the Hayward Fault Zone have also tilted and folded the layers of the Orinda Formation and the Moraga Volcanics. The roadcut has exposed the tilted layers of part of one side of a U-shaped structure called a syncline (fig. 2.25). As we leave this stop, we will drive east on the freeway to see the other side of the syncline, where the layers are tilted the other way. The tilting makes it hard to visualize the place these layers originally formed, everything is now standing on its edge. Even if the volcanoes that produced the lava flows were preserved, they too would be tipped entirely onto their sides!

Nevertheless, we can start to put together the history of these rocks. We start with a river system that over thousands of years of geologic time builds up a thick pile of sedimentary layers. At some point volcanoes erupt nearby, filling the river valleys with lava, flow after flow to build up a thick pile. Later, the originally flat sedimentary and volcanic layers are tilted and folded. This kind of story reveals the sequence, or relative age of events associated with these rocks. The idea of relative age is another of the earliest ideas of geology. All of the geologic periods that you may have heard of (like Jurassic, as in "Jurassic Park") were divided up using the ideas of relative age, including those involving fossils. Over the last few decades, though, we have been able to deduce the numeric age of certain kinds of rocks by measuring the decay of certain radioactive elements in the minerals within the rock (radiometric dating). Sedimentary rocks are not very good for this technique, but volcanic rocks are much better. The Moraga Volcanics here are about 10 million years old. You can see how numeric age and relative age can be combined. Clearly the Orinda Formation is older that 10 million years, the folding of the layers is younger than 10 million years.

And there's more! The way the cobbles in the conglomerate stack on one another tell us that the sediments in the Orinda Formation came from the west, the large size of the cobbles tells us the rivers were energetic and flowed down a steep slope, and the rounding-off of the edges and corners of the cobbles and pebbles tells us the sediments were only brought a moderate distance. It is hard to imagine now, but the hills we are in here were once a low river valley, and where San Francisco Bay is now were once pretty high hills and mountains!

So what happened? One clue is that the Hayward Fault Zone is between us and the Bay, so the mountains and hills that provided the sediment have been moved northwest by the fault motion, but how far? The answer is only now being unraveled, and the Moraga Volcanics play a big part. That is because the Moraga Volcanics are only half of the lava flows that were produced by volcanoes 10 million years ago. The other half is now found about 45 kilometers to the northwest (fig. 2.26), moved there by offset on the Hayward Fault Zone, so the mountains and hills must also have been moved that far (actually, there is another part of the Hayward Fault system that branches west of the volcanics, the total offset on the Hayward Fault Zone is about 90 kilometers). In addition to sliding northwest, the rocks of the San Francisco Bay block have also been pushed down by the same plate tectonic forces that folded and tilted the layers and lifted up the hills.

A geologist is trained to understand all the complexities of the story that the rocks can tell us and can draw on the observations and experiments of many geologists working before him or her, but we all start with careful observations of the rocks. Knowing just a few of the basics will allow anyone to begin to unravel the history of the landscape around us and the rocks under our feet. We can look at the world with a new point of view. Did any of us think about where the flat layers of the Grand Canyon came from before now? Have they been exposed to the same kind of plate tectonic forces that the rocks here have?

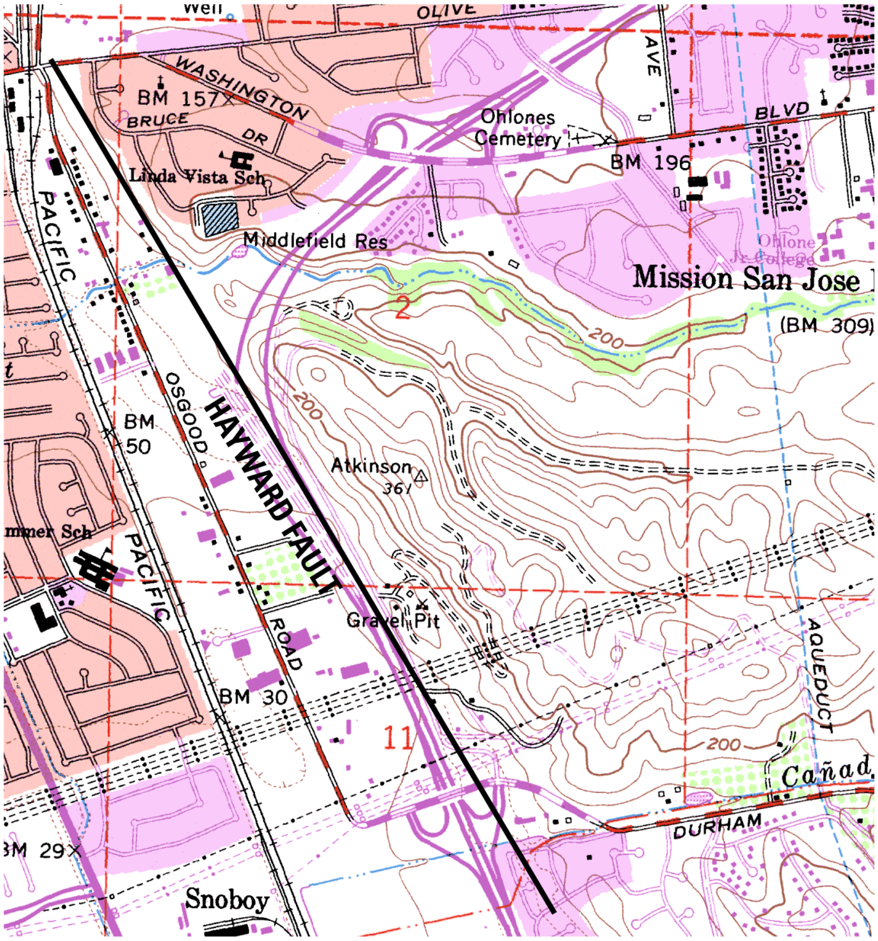
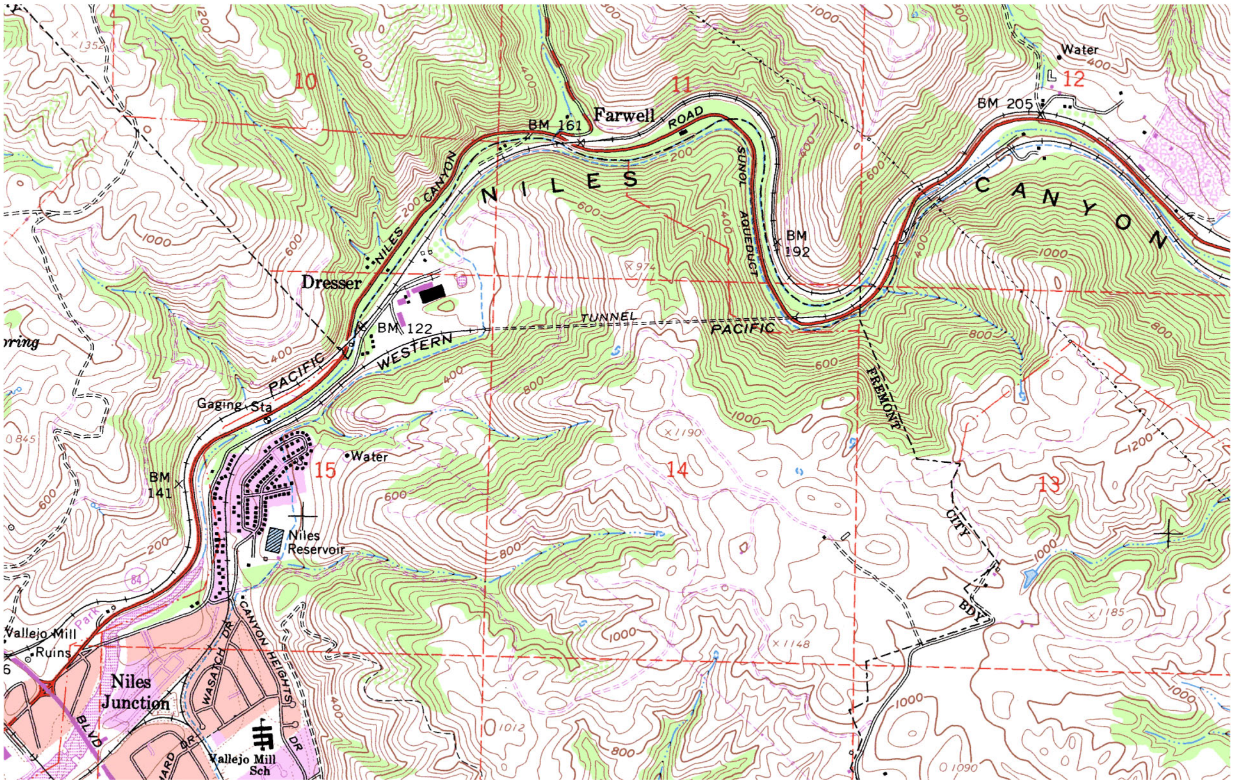


Figure 2.1. The ridge to the east of the freeway in the Irvington District of Fremont has a straight west face carved by the Hayward Fault (marked by the thick black line). This kind of face is called a scarp. (The map from the a portion of the Niles 7.5-minute quadrangle USGS topographic map.)

▼**Figure 2.2.** Notice the meandering path of Alameda Creek in Niles Canyon. These meanders were probably formed before the hills, and were trapped in the shape of the canyon which formed as the stream eroded through the hills being lifted up. (The map from the a portion of the USGS Niles 7.5-minute quadrangle topographic map.)



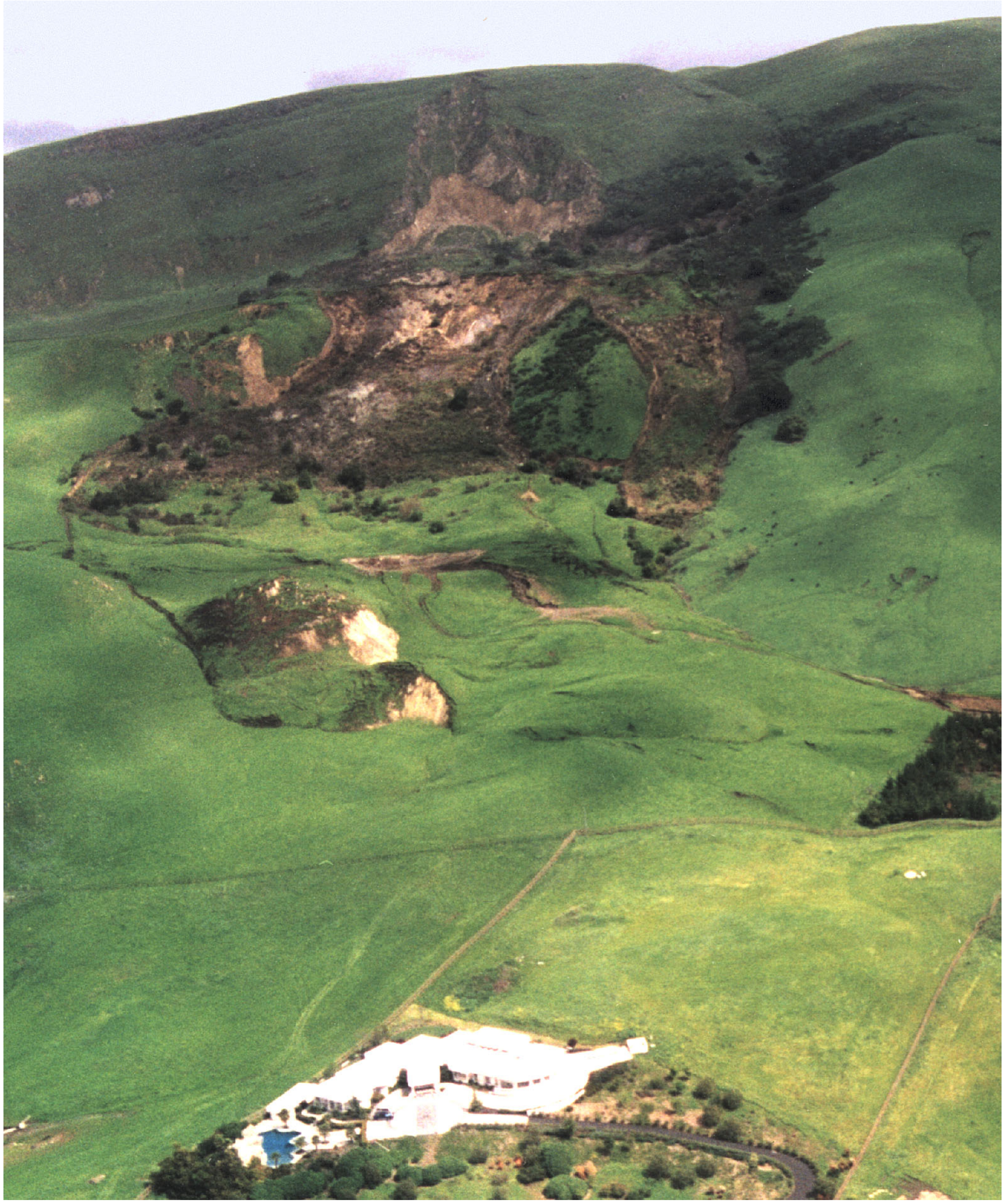


Figure 2.3. An aerial view of the Mission Peak Landslide (photo by Jeff Coe, U.S. Geological Survey).

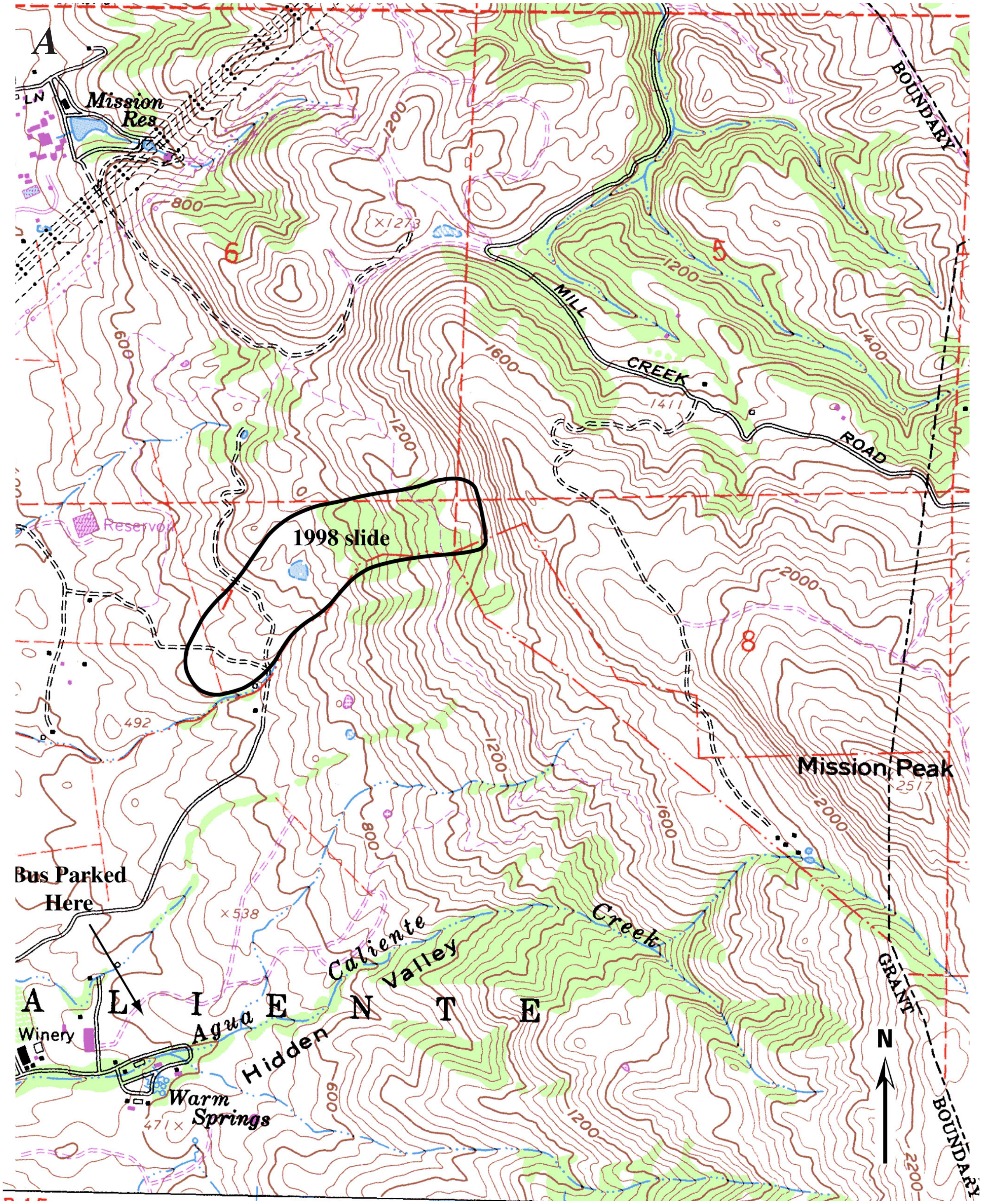


Figure 2.4*A* and *B*. Exercise maps for Stop 1 (portions of the USGS Niles 7.5-minute quadrangle topographic map).

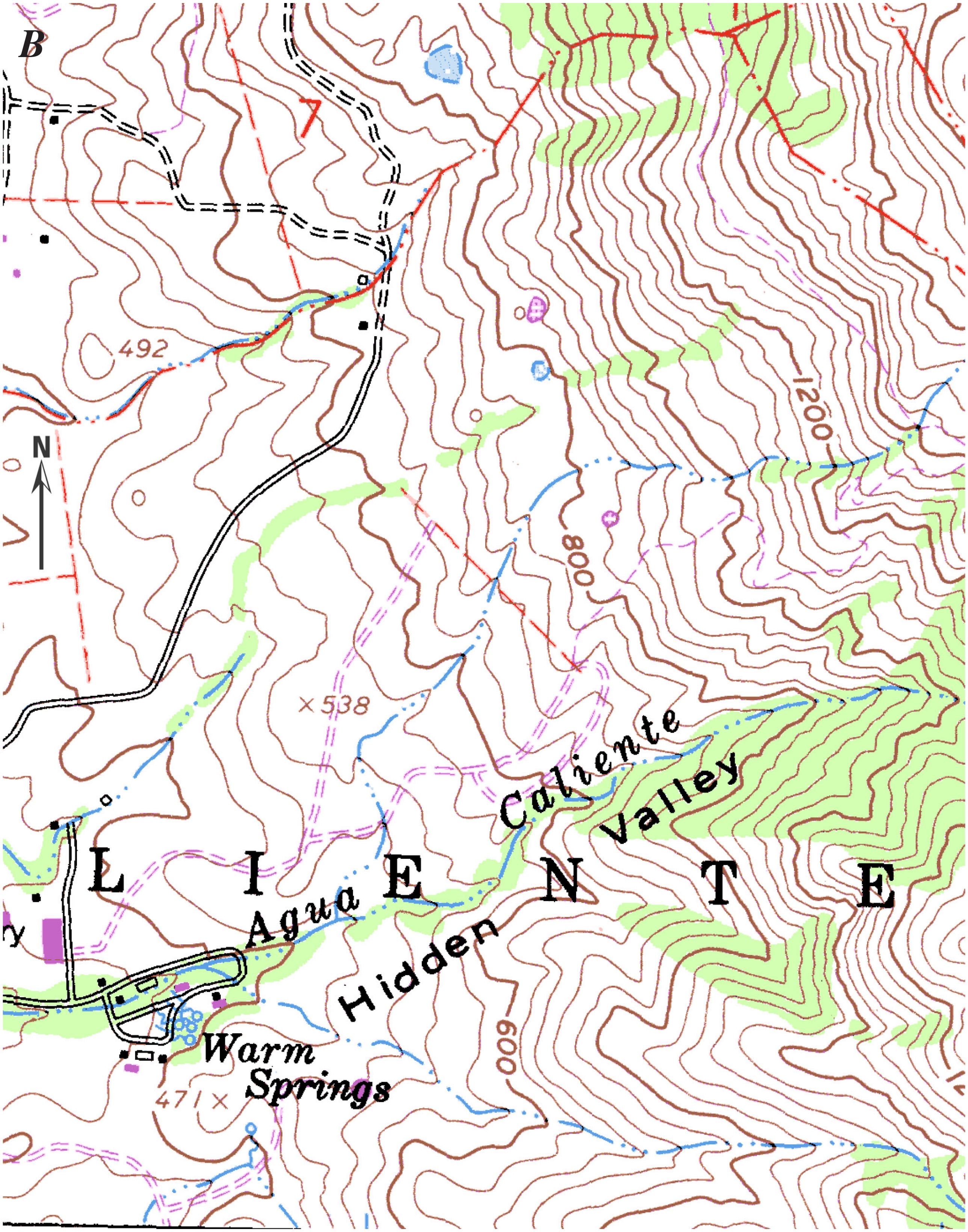


Figure 2.4*A* and *B*—Continued. Exercise maps for Stop 1 (portions of the USGS Niles 7.5-minute quadrangle topographic map).

MAIN SCARP—A steep surface on the undisturbed ground around the periphery of the slide, caused by the movement of slide material away from undisturbed ground. The projection of the scarp surface under the displaced material becomes the surface of rupture.
MINOR SCARP—A steep surface on the displaced material produced by differential movements within the sliding mass.
HEAD—The upper parts of the slide material along the contact between the displaced material and the main scarp.
TOP—The highest point of contact between the displaced material and the main scarp.
TOE OF SURFACE OF RUPTURE—The intersection (sometimes buried) between the lower part of the surface of rupture and the original ground surface.
TOE—The margin of displaced material most distant from the main scarp.
TIP—The point on the toe most distant from the top of the slide.
FOOT—That portion of the displaced material that lies downslope from the toe of the surface of rupture.
MAIN BODY—That part of the displaced material that overlies the surface of rupture between the main scarp and toe of the surface of rupture.
FLANK—The side of the landside.
CROWN—The material that is still in place, practically undisplaced and adjacent to the highest parts of the main scarp.
ORIGINAL GROUND SURFACE—The slope that existed before the movement of interest occurred. If this is the surface of an older landslide, that fact should be stated.
LEFT AND RIGHT—Compass directions are preferable in describing a slide, but if left and right are used they refer to the slide as viewed from the crown.
SURFACE OF SEPARATION—The surface separating displaced material from stable material, but not known to be a surface of failure.
DISPLACED MATERIAL—The material that has been moved from its original position on the slope. It may be in a deformed or undeformed state.
ZONE OF DEPLETION—The area within which the displaced material lies below the original ground surface.
ZONE OF ACCUMULATION—The area within which the displaced material lies above the original ground surface.
VC—Vertical component of slump.
HC—Horizontal component of slump.
L— Length of displaced zone along the slope.
LC—Length of slump along the slope.
D—Depth to rupture surface.

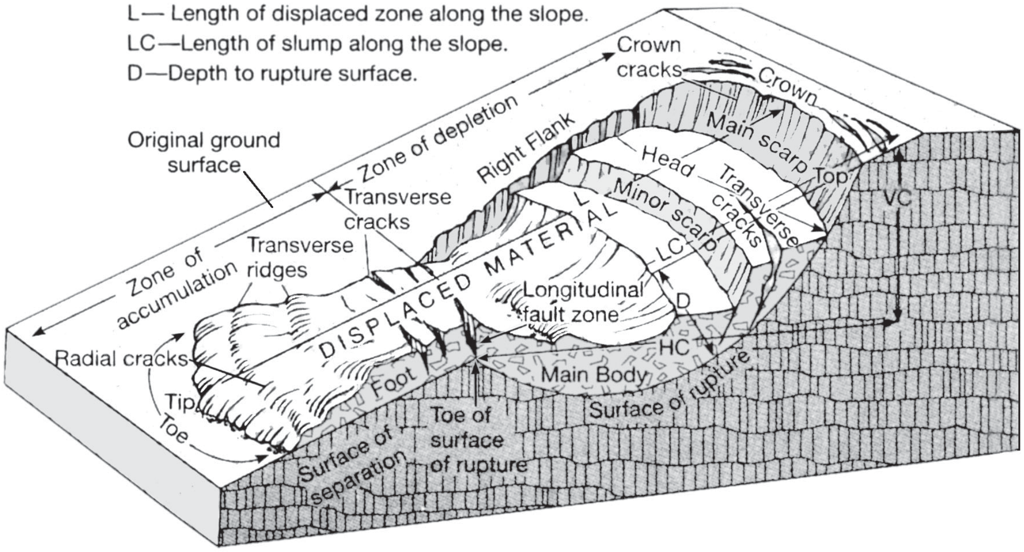


Figure 2.5. Anatomy of a landslide, showing landscape features produced by a bedrock landslide. Notice especially the different kinds of features at the top and the bottom of the landslide. This difference reflects the different forces at work in the area where rock is being piled up (the bottom, or zone of accumulation) and where the rock is being moved away (the top, or zone of depletion). Can you see some of these features in the Mission Peak slide? See fig. 2.3. (Diagram modified from West, T.R., 1995, Geology applied to engineering: Englewood Cliffs, New Jersey, Prentice-Hall, p. 294)

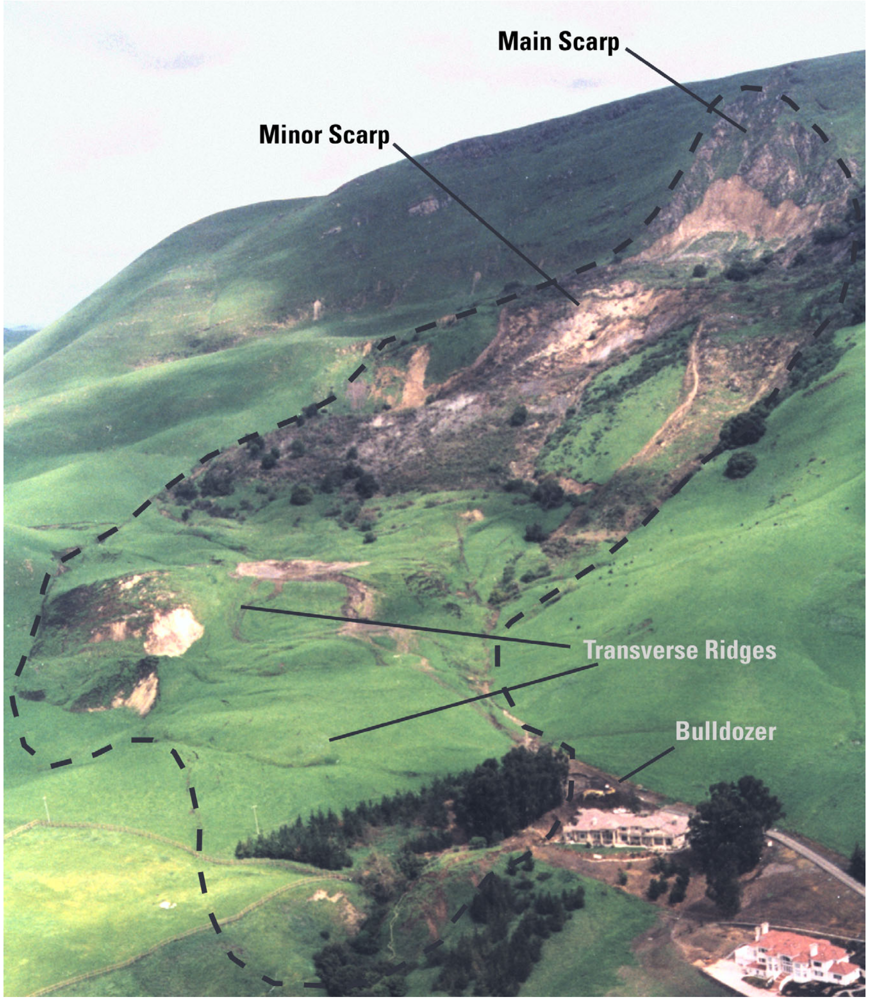


Figure 2.6. The outline of the slide is shown by the dashed line. The house nearest the slide experienced some damage during the slide, despite strenuous efforts to divert sliding material (note the large bulldozer beside the house!). Several of the landscape features formed during the slide are also marked (see fig. 2.5 for more about landscape features formed by bedrock landslides) (photo by Jeff Coe, U.S. Geological Survey).

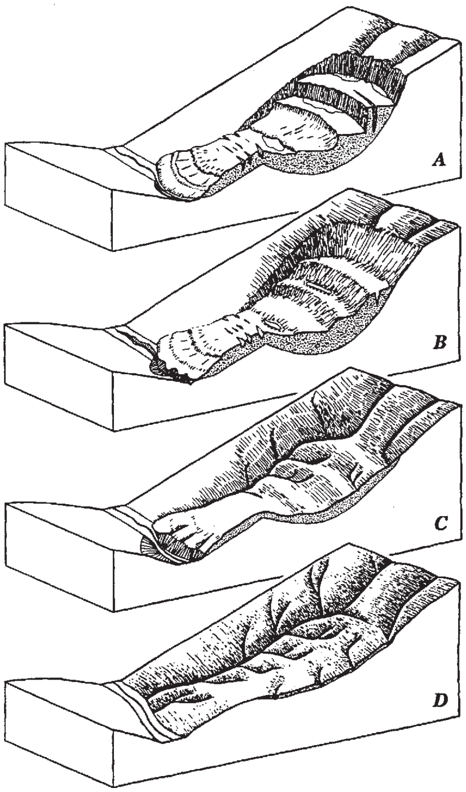


Figure 2.7. The effects of erosion on landscape features formed by landslides, from ***A***: a very recent slide, to ***D***: a very old slide.

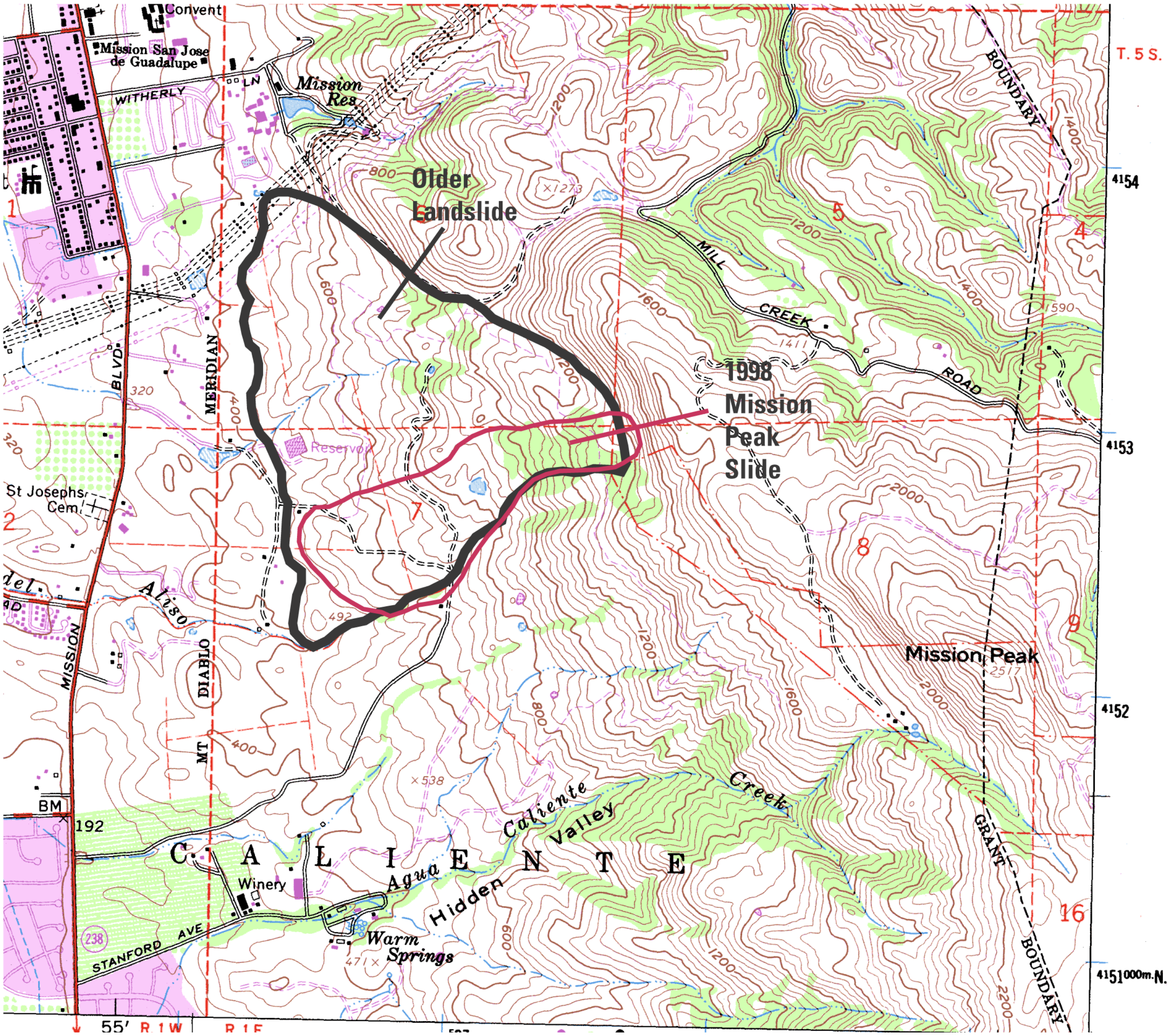
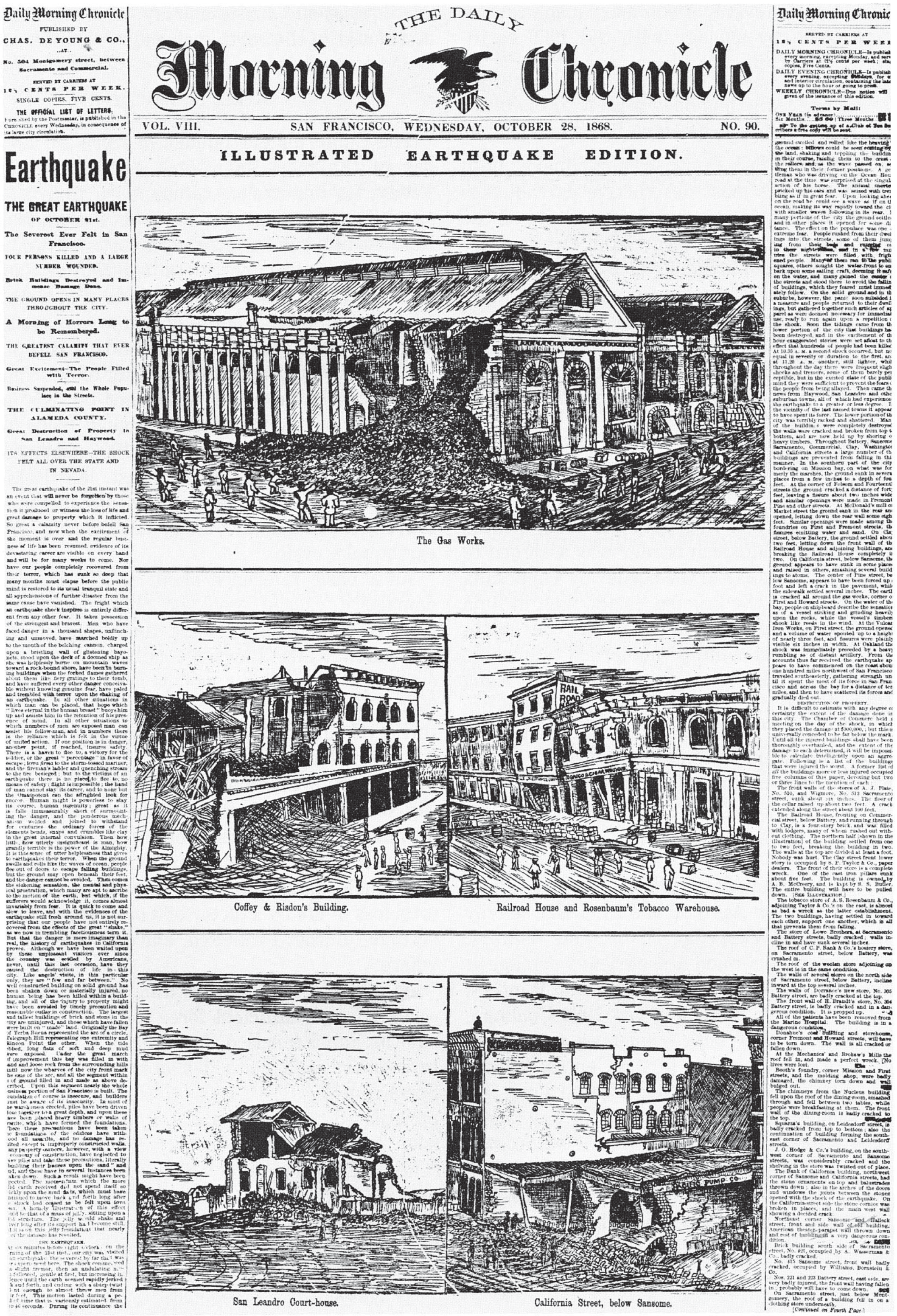


Figure 2.8. Map showing the approximate outline of both the 1998 Mission Peak landslide and the much larger, older landslide that contains it. Note the irregular appearance of the contour lines within the older landslide. Do you see other areas on the map that could be older landslides?

Figure 2.9. Debris flows: small, shallow, fast-moving landslides that commonly occur during very heavy rainstorms. Photo ***A*** shows a natural hillside scarred by many debris flows in 1998. Photo ***B*** shows the impact of a single debris flow on a home in Marin County in 1998.



Daily Morning Chronicle

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ILLUSTRATED EARTHQUAKE EDITION.

Earthquake

THE GREAT EARTHQUAKE

OF OCTOBER 21st.

The Severest Ever Felt in San Francisco.

FOUR PERSONS KILLED AND A LARGE NUMBER WOUNDED.

Brick Buildings Destroyed and Immense Damage Done.

THE GROUND OPENS IN MANY PLACES THROUGHOUT THE CITY.

A Morning of Horrors Long to be Remembered.

THE GREATEST CALAMITY THAT EVER BEFELL SAN FRANCISCO.

Great Excitement—The People Filled with Terror.

Business Suspended, and the Whole Populace in the Streets.

THE CULMINATING POINT IN ALAMEDA COUNTY.

Great Destruction of Property in San Leandro and Haywood.

ITS EFFECTS ELSEWHERE—THE SHOCK FELT ALL OVER THE STATE AND IN NEVADA.

The great earthquake of the 21st instant was an event that will never be forgotten by those who were compelled to experience the sensation it produced or witness the loss of life and great damage to property which it inflicted. So great a calamity never before befell San Francisco, and now when the excitement of the moment is over and the regular business of life has been resumed, evidence of its devastating career are visible on every hand and will be for many weeks to come. Nor have our people completely recovered from their terror, which has sunk so deep that many months must elapse before the public mind is restored to its usual tranquil state and all apprehensions of further disaster from the same cause have vanished. The fright which an earthquake shock inspires is entirely different from any other fear. It takes possession of the strongest and bravest. Men who have faced danger in a thousand shapes, unflinching and unmoved, have marched boldly up to the mouth of the belching cannon, charged upon a bristling wall of glistening bayonets, stood upon the deck of a doomed ship as she was helplessly borne on mountain waves toward a rock-bound shore, have been in burning buildings when the forked flames gathered about them like fiery gratings to their tomb, and have suffered every other danger conceivable without knowing genuine fear, have paled and trembled with terror upon the shaking of an earthquake. In all other situations in which man can be placed, that hope which "lives eternal in the human breast" buoys him up and assists him in the retention of his presence of mind. In all other situations to which numbers of men are exposed man can assist his fellow-man, and in numbers there is the reliance which is felt in the virtue of united action. If one position is in danger, another point, if reached, insures safety. There is a haven to flee to, a victory for the soldier, or the great "percentage" in favor of escape; *terra firma* to the storm-tossed mariner, and the fireman's ladder and quenching stream to the fire besieged; but to the victims of an earthquake there is no place to flee to, no means of safety; flight is impossible; the hand of man cannot stay its career, and to none but the Omnipotent can the affrighted look for succor. Human might is powerless to stay its course, human ingenuity; great as it is falls immeasurably short of surmounting the danger, and the ponderous mechanism welded and joined to withstand for centuries the ordinary forces of the elements bends, snaps and crumbles like clay in the great internal convulsion. Then how little, how utterly insignificant is man, how grandly terrible is the power of the Almighty. It is this sense of utter helplessness that gives to earthquakes their terror. When the ground swells and rolls like the waves of ocean, people flee out of doors to escape falling buildings, but the ground may open beneath their feet, and the danger cannot be avoided. Then comes the sickening sensation, the mental and physical prostration, which many are apt to ascribe to the motion of the earth, but which, if the sufferers would acknowledge it, comes almost invariably from fear. It is quick to come and slow to leave, and with the evidences of the earthquake still fresh around us, it is not surprising that our people have not entirely recovered from the effects of the great "shake," as we now in trembling facetiousness term it. But that the danger is more imaginary than real, the history of earthquakes in California proves. Although we have been waited upon by these unpleasant visitors ever since the country was settled by Americans, never, until this last occasion, have they caused the destruction of life in this city. Like angels' visits, in this particular only, they are "few and far between." No well constructed building on solid ground has been shaken down or materially injured, no human being has been killed within a building, and all of the injury to property might have been avoided by timely precaution and reasonable outlay in construction. The largest and tallest buildings of brick and stone in the city are uninjured, and those which have fallen were built on "made" land. Originally the Bay of Yerba Buena represented the arc of a circle, Telegraph Hill representing one extremity and Rincon Point the other. When the tide bbed, long flats of soft and deep mud were exposed. Under the great march f improvement this bay was filled in with and and loose rock from the surrounding hills until now the wharves of the city front mark he [illegible] of the arc, and all the segment within s of ground filled in and made as above described. Upon this segment nearly the whole usiness portion of San Francisco is built. The oundation of course is insecure, and builders ust be aware of its insecurity. In most of he warehouses erected, piles have been driven lose together to a great depth, and upon these ave been placed heavy timbers or walls of ranite, which have formed the foundations. here these precautions have been taken he foundations of the edifices have withtood all assaults, and no damage has resulted except to improperly constructed walls. any property owners, however, with a view economy of construction, have neglected to ive piles and take these precautions, literally building their houses upon the sand" and ud, and these have in several instances been aken down. Such a result might have been pected. The momentum which the more lid earth received did not spend itself so ickly upon the mud flats, which must have ntinued to move back and forth long after e shock had ceased to be felt upon terra ma. A homely illustration of this effect uld be that of a mass of jelly, sitting upon a lid structure. The jelly would shake and iver long after its support had become still. d it is on this jelly foundation that nearly of the damage has resulted.

THE EARTHQUAKE.

At six minutes before eight o'clock on the rning of the 21st inst., our city was visited an earthquake the severest by far that was r experienced here. The shock commenced a slight tremor, then an undulating mo n followed, gentle at first, but increasing in lence until the earth seemed rapidly jerked k and forth, and ending with a sharp twist ient enough to almost throw men from ir feet. This motion lasted during a pe d of time that is variously estimated from to 40 seconds. During its continuance the

The Gas Works.

Coffey & Risdon's Building.

Railroad House and Rosenbaum's Tobacco Warehouse.

San Leandro Court-house.

California Street, below Sansome.

ground swelled and rolled like the heaving the ocean; billows could be seen coming o the land, shaking and toppling the buildin in their course, raising them to the crest the rollers and, as the wave passed on, se tling them in their former positions. A ge tleman who was driving on the Ocean Hou road at the time was surprised at the singul action of his horse. The animal snorte pricked up his ears and was seized with tre bling as if in great fear. Upon looking ahe on the road he could see a wave as if on t ocean, making its way rapidly toward the c with smaller waves following in its rear. many portions of the city the ground settle and in other places it opened for some di tance. The effect on the populace was one extreme fear. People rushed from their dwel ings into the streets, some of them jum ing from their beds and running o in their nightclothes, and in a few mi utes the streets were filled with frigh ened people. Many of them ran to the publ squares, others sought the water-front to em bark upon some sailing craft, deeming it saf on the water, and many gained the center the streets and stood there to avoid the fallin of buildings, which they feared must immed ately follow. On the solid ground and in th suburbs, however, the panic soon subsided a measure and people returned to their dwel ings, but gathered together such articles of a parel as were deemed necessary for immedia use, ready to run again upon a repetition the shock. Soon the tidings came from th lower portion of the city that buildings ha been destroyed, and in the excitement of th hour exaggerated stories were set afloat to th effect that hundreds of people had been kille At 10.35 A. M. a second shock occurred, but n equal in severity or duration to the first, an at 11.20 A. M. another, still lighter, whil throughout the day there were frequent sligh shocks and tremors, some of them barely pe ceptible, but in the excited state of the publ mind they were sufficient to prevent the fears the people from being allayed. Then came th news from Haywood, San Leandro and othe suburban towns, all of which had experience the earthquake to a greater or less degree. the vicinity of the last named towns it appear to have spent its force. The lower portion of th city was terribly racked and shattered. Man of the buildings were completely destroye the walls were cracked and broken from top t bottom, and are now held up by shoring o heavy timbers. Throughout Battery, Sansome Sacramento, Commercial, Clay, Washingto and California streets a large number of th buildings are prevented from falling in thi manner. In the southern part of the city bordering on Mission bay, on what was formerly the marshes, the ground sunk in severa places from a few inches to a depth of fou feet. At the corner of Folsom and Fourteent streets the ground cracked a distance of fort feet, leaving a fissure about two inches wide and similar openings were made in Fremont Pine and other streets. At McDonald's mill o Market street the ground sank in the rear an opened, letting down the rear wall some eigh feet. Similar openings were made among th foundries on First and Fremont streets, th fissures emitting water and sand. On Cla street, below Battery, the ground settled abou two feet, letting down the front wall of th Railroad House and adjoining buildings, an breaking the Railroad House completely i two. On California street, below Sansome, th ground appears to have sunk in some place and raised in others, smashing several buildings to atoms. The center of Pine street, below Sansome, appears to have been forced up foot and left a crack in the pavement, whil the sidewalk settled several inches. The eart is cracked all around the gas works, corner o First and Howard streets. On the water of th bay, people on shipboard describe the sensatio as of a vessel striking and grinding heavil upon the rocks, while the vessel's timber shook like reeds in the wind. At the Vulca Iron Works, on First street, the ground opene and a volume of water spouted up to a heigh of nearly three feet, and fissures were plain visible six inches in width. At Oakland th shock was immediately preceded by a heav rumbling as of distant artillery. From th accounts thus far received the earthquake appears to have commenced on the coast abou one hundred miles northwest of San Francisco traveled southeasterly, gathering strength until it spent the most of its force in San Francisco and across the bay for a distance of te miles, and then to have scattered its forces and gradually died out.

DESTRUCTION OF PROPERTY.

It is difficult to estimate with any degree o certainty the extent of the damage done i this city. The Chamber of Commerce held meeting on the day of the shock, in which they placed the damage at $300,000,; but this universally conceded to be far below the mark. Until all the injured buildings shall have been thoroughly overhauled, and the extent of the damage to each determined, it will be impossible to calculate intelligently upon an aggregate. Following is a list of the buildings that were injured the worst. A former list of *all* the buildings more or less injured occupied five columns of this paper, devoting but two or three lines to the mention of each:

The front walls of the stores of A. J. Plate, No. 510, and Wigmore, No. 512 Sacramento street, sunk about six inches. The floor of the cellar raised up about two feet. A crack extended along the street about 100 feet.

The Railroad House, fronting on Commercial street, below Battery, and running through to Clay, is a four-story brick, and was filled with lodgers, many of whom rushed out without clothing. The northern half [shown in the illustration] of the building settled from one to two feet, breaking the building in two. The walls at the top are divided at least a foot. Nobody was hurt. The Clay street front lower story is occupied by S. P. Taylor & Co., paper dealers. The front of their store is a complete wreck. One of the cast iron pillars sunk about five feet. The building is owned by A. B. McCreery, and is kept by S. S. Butler. The entire building will have to be pulled down. [SEE ILLUSTRATION.]

The tobacco store of A. S. Rosenbaum & Co., adjoining Taylor & Co.'s on the east, is almost as bad a wreck as the latter establishment. The two buildings, having settled in toward each other, support one another, which is all that prevents them from falling.

The store of Lowe Brothers, at Sacramento and Battery streets, badly cracked; walls incline in and have sunk several inches.

The roof of C. P. Rank & Co.'s hosiery store, on Sacramento street, below Battery, was crushed in.

The roof of the woolen store adjoining on the west is in the same condition.

The walls of several stores on the north side of Sacramento street, below Battery, incline inward at the top several inches.

The walls of Dorrance's new store, No. 305 Battery street, are badly cracked at the top.

The front wall of H. Brandt's store, No. 304 Battery street, is badly cracked and in a dangerous condition. It is propped up.

All of the patients have been removed from the Marine Hospital. The building is in a dangerous condition.

Donahue's coal building and storehouse, corner Fremont and Howard streets, will have to be torn down. The wall is all cracked or fallen down.

At the Mechanics' and Brokaw's Mills the roof fell in, and made a perfect wreck. [No lives were lost.

Booth's foundry, corner Mission and First streets, and the molding shop, were badly damaged, the chimney torn down and wall bulged out.

The chimneys from the Nucleus building fell upon the roof of the dining-room, smashed through and fell between two tables, while people were breakfasting at them. The front wall of the dining-room is badly cracked to the top.

Squarza's building, on Leidesdorff street, is badly cracked from top to bottom; also the continuation of building forming the southeast corner of Sacramento and Leidesdorff streets.

J. O. Hodge & Co.'s building, on the southwest corner of Sacramento and Sansome streets, was considerably cracked and the shelving in the store was twisted out of place.

The Bank of California building, northwest corner of Sansome and California streets, had the stone ornaments on top and balustrades thrown down; also in the arches of the doors and windows the joints between the stones opened with the shock of the earthquake. On the California-street side the stone cornice was broken in places, and the main west wall showing a decided crack.

Northeast corner Sansome and Halleck street, front and side wall of old building. American theater, parapet wall thrown down and rest of building in a very dangerous condition.

Brick building south side of Sacramento street, No. 425, occupied by A. Wasserman & Co., badly cracked.

No. 415 Sansome street, front wall badly cracked, occupied by Williams, Bornstein & Co.

Nos. 221 and 223 Battery street, east side, are very badly injured, the front wall having fallen in; probably will have to come down.

On Sacramento street, just below Montgomery, the roof of a building fell in on a clothing store underneath.

[Continued on Fourth Page.]

Figure 2.10. The front page of the San Francisco Chronicle following the 1868 earthquake on the Hayward Fault Zone.

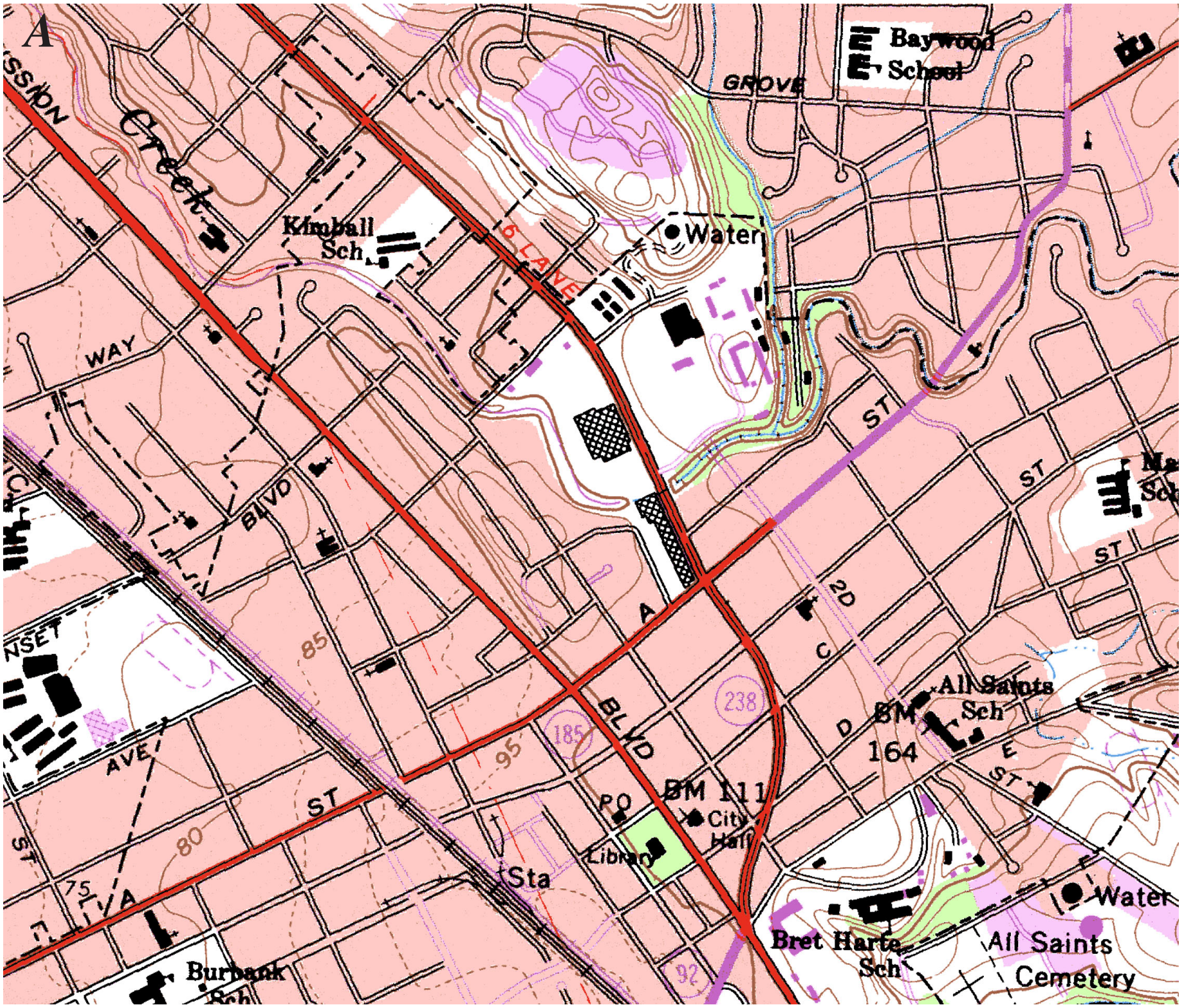

Figure 2.11*A* and *B*. Exercise maps for Stop 2 (portions of the USGS Hayward 7.5-minute quadrangle topographic map).

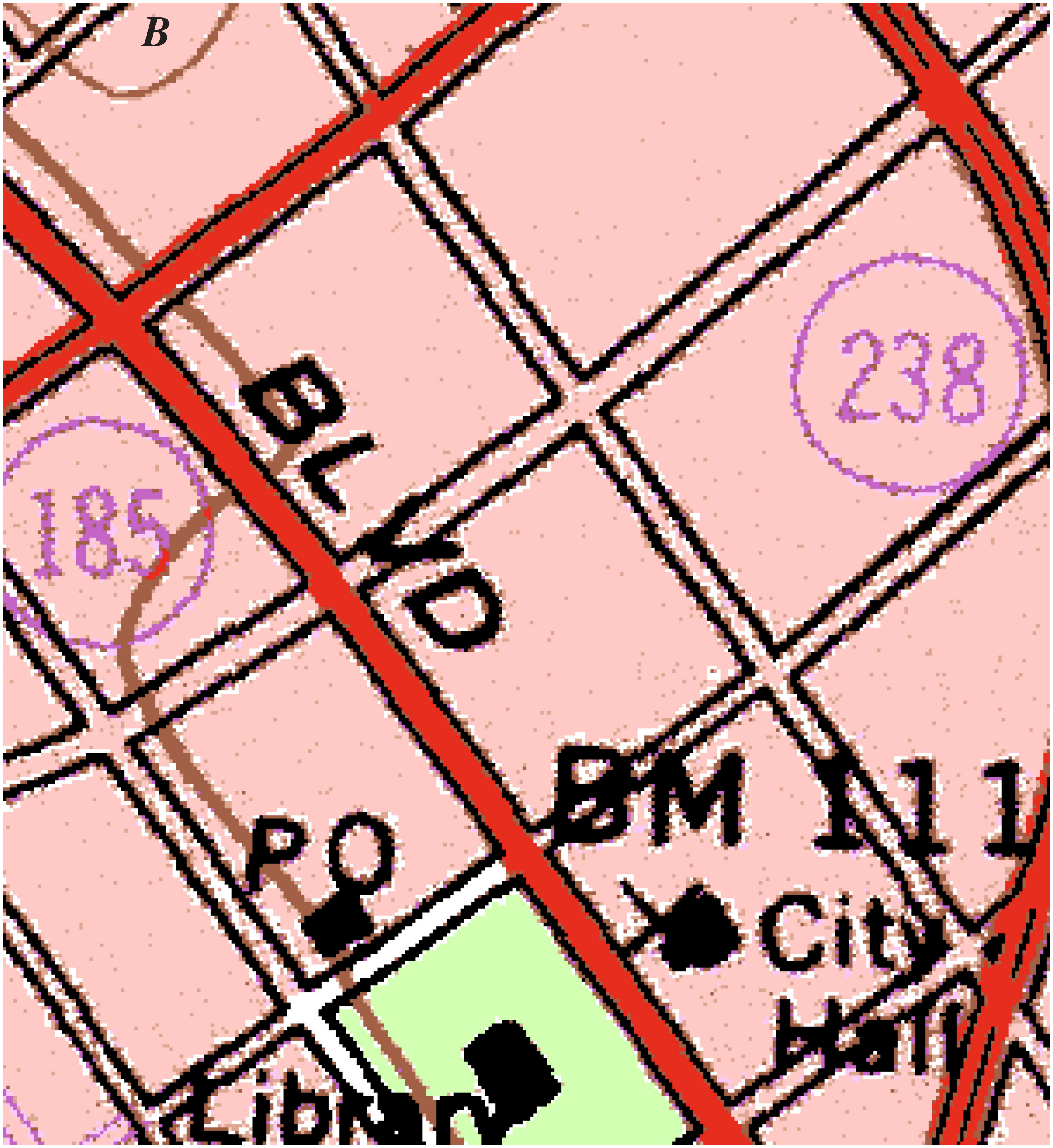

Figure 2.11*A* and *B*—Continued. Exercise maps for Stop 2 (portions of the USGS Hayward 7.5-minute quadrangle topographic map).

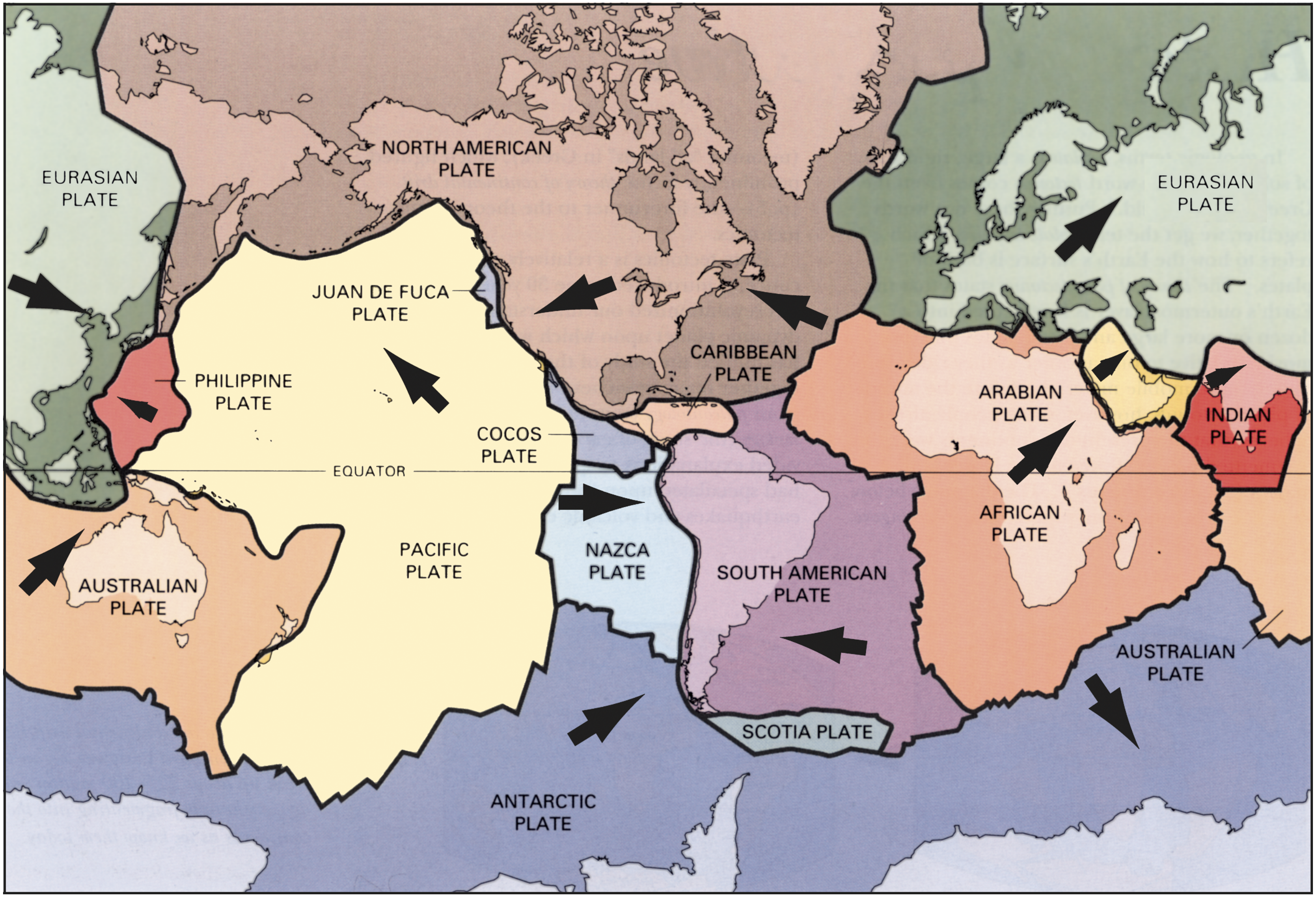

Figure 2.12. Map of the Earth's lithospheric plates, showing the direction of the relative motion of some of the largest. The motion of the Pacific and North American Plates is the driving force for the faults in California, like the Hayward fault. The U.S. Geological Survey and the National Park Service have excellent web-pages with more information about plate tectonics and links to detailed descriptions at http://pubs.usgs.gov/publications/text/dynamic.html and http://www2.nature.nps.gov/grd/usgsnps/pltec/pltec1.html.

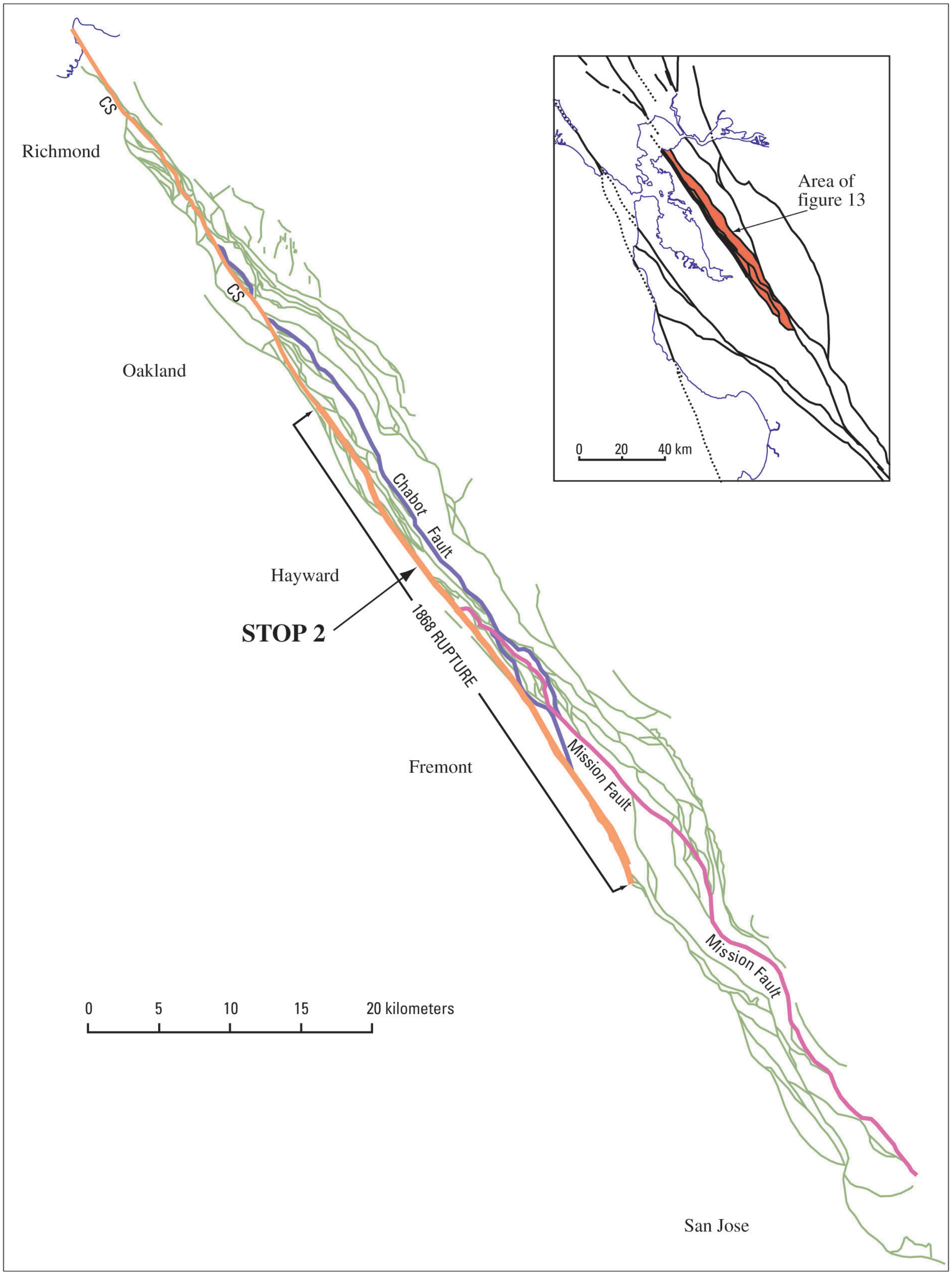

Figure 2.13. Generalized map showing all the known faults in the Hayward Fault Zone. Note that most of the faults are not presently active, but all have played a part in the 12-million-year history of the fault zone. The creeping part of the fault zone is shown by the thick line marked CS, and other named faults in the fault zone are labeled. The length of the fault rupture in 1868 is also shown.

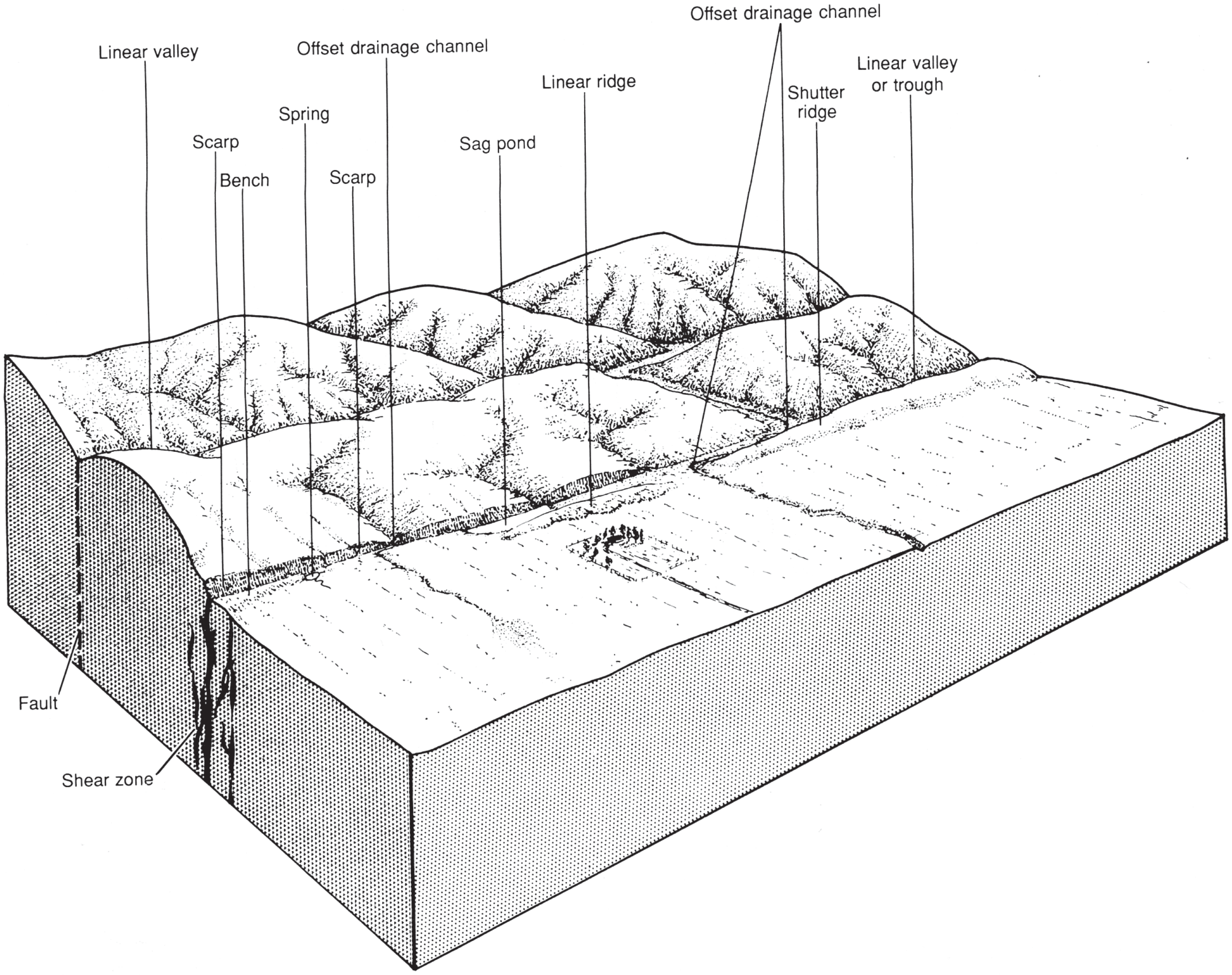

Figure 2.14. A block diagram of part of the upper part of the crust showing the landscape features associated with fault offset. Recognizing the presence of these features can help geologists locate faults that might be active even if they are not creeping. (Diagram from Wallace, R.E., ed., 1990, The San Andreas Fault System, California: U.S. Geological Survey Professional Paper 1515, p. 17.)

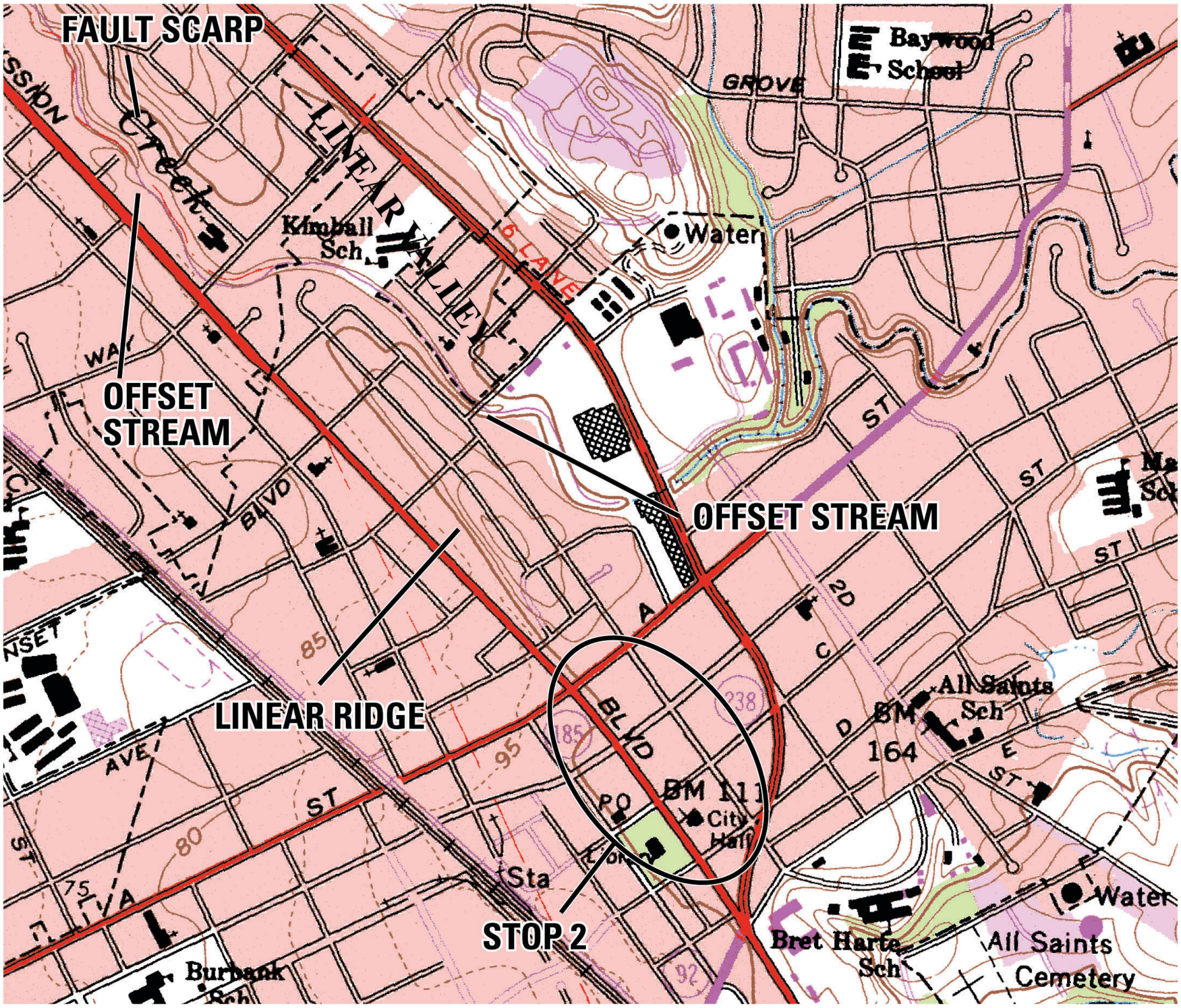

Figure 2.15. Topographic map of northern Hayward showing the landscape features associated with the Hayward Fault in the area of Stop 2.

Figure 2.16. Two photos showing the effects of fault rupture. During an earthquake, the Earth's surface along a fault can be suddenly and permanently offset by many meters. Photo ***A*** shows the result of 6 meters of offset that occurred during the 1940 Imperial Valley earthquake in southern California. Photo ***B*** shows the crack left by 6 meters of offset that occurred near Point Reyes during the 1906 San Francisco earthquake. Imagine what would happen to anything built across the fault. (Photos from Wallace, R.E., ed., 1990, The San Andreas Fault System, California: U.S. Geological Survey Professional Paper 1515, p. 163.)

Figure 2.17. Photo looking west from the parking area at the deep roadcut east of Caldecott Tunnel. Exposure like this is very rare in the San Francisco Bay region.

Figure 2.18. Another view of the roadcut east of Caldecott Tunnel. Notice the two very different kinds of rocks—the lighter rocks on the lower-left are the Orinda Formation, the darker rocks on the upper-right are the Moraga Volcanics.

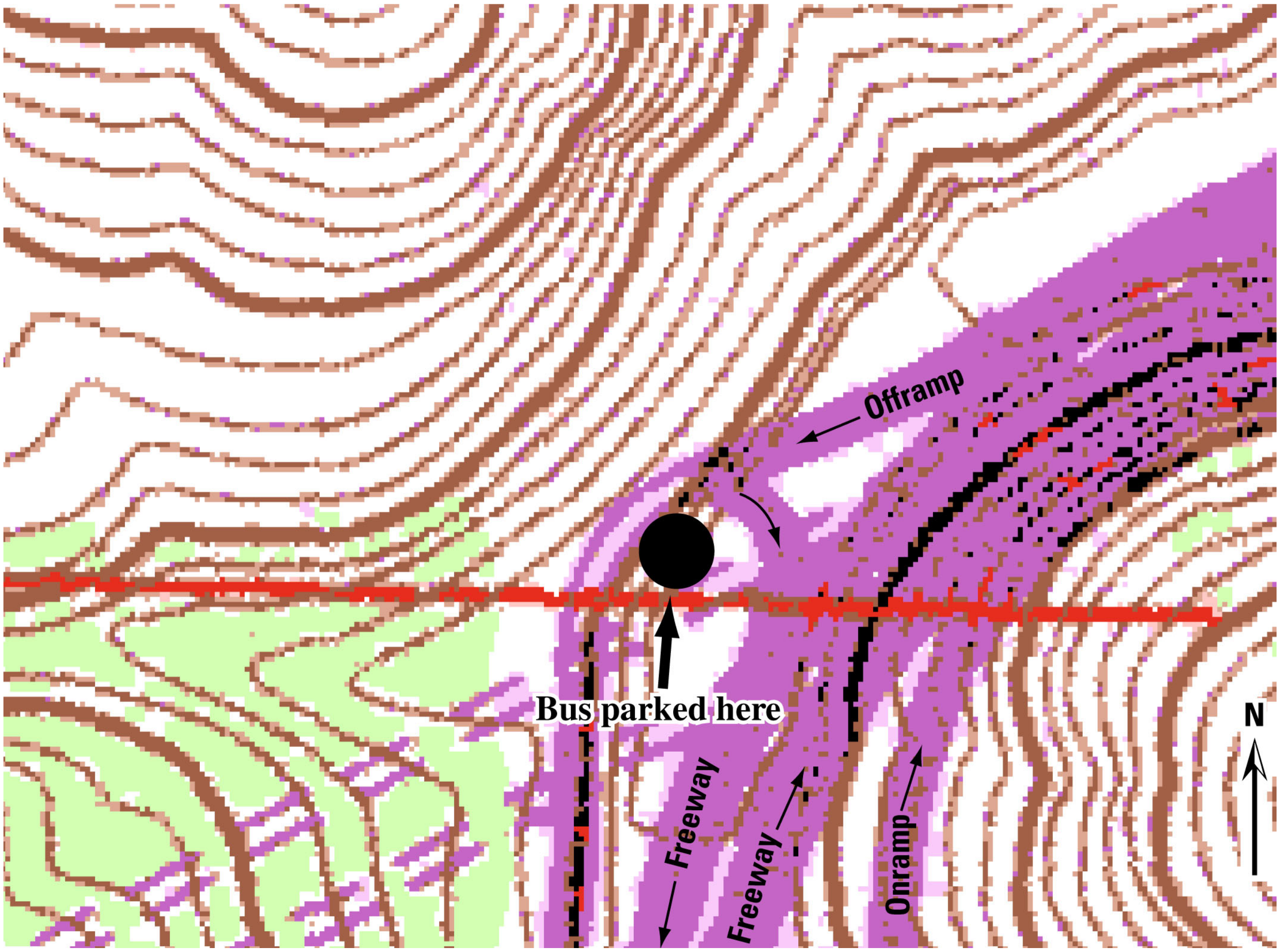

Figure 2.19. Exercise map for Stop 3 (a portion of the USGS Oakland East 7.5-minute quadrangle topographic map).

Figure 2.20. Two close-up views of the Orinda Formation. In the upper photo, notice how the rock is made up of fragments of many other kinds of rocks mixed together. In the lower photo, notice the layers, and how the different sized pieces are sorted into separate layers, cobbles and pebbles in the layer on the left, sand in the layer on the right, and mud in the red and green layers in the middle. Geologists use information like this to deduce how rocks were formed, in this case by deposition of eroded material by a river.

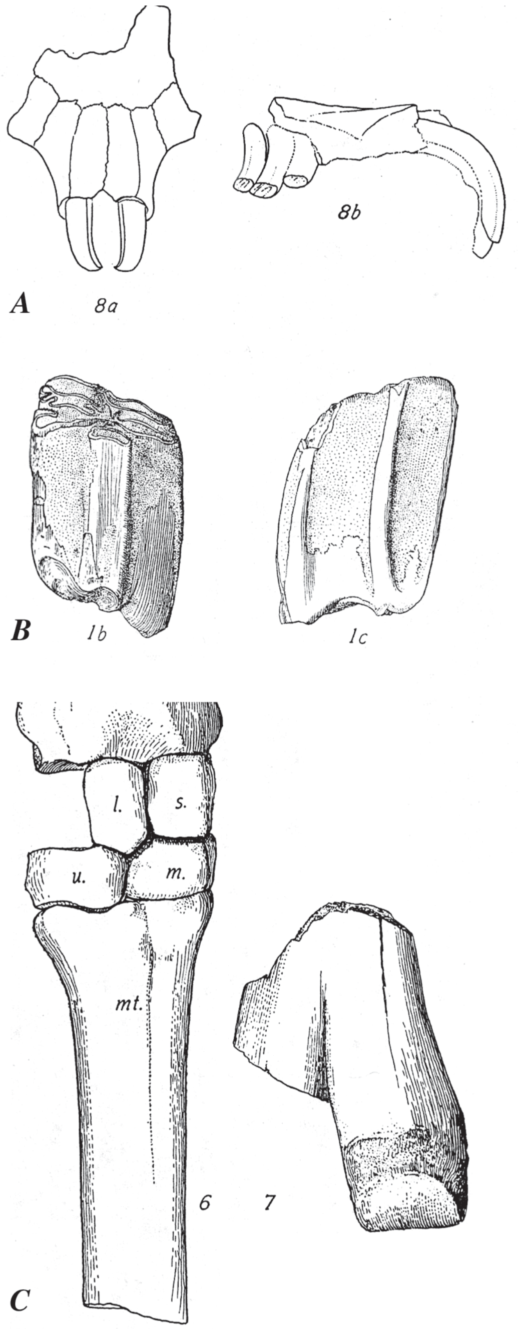

Figure 2.21. Sketches of fossils found in the Berkeley Hills. ***A*** is part of a beaver skull, ***B*** shows two horse teeth, and ***C*** shows two parts of a camel leg. Fossils from rabbits, hippos, and various plants have also been found. Notice the difference between the teeth of a beaver more than 10 million years ago and the teeth of a beaver today! These fossils show that the sedimentary rocks here formed in rivers, not in the ocean. What sort of fossils would you expect from rocks formed in the ocean? (Sketches reproduced from Merriam, J.C., 1913, Vertebrate fauna of the Orindan and Siestan beds in Middle California: University of California, Bulletin of the Department of Geology, v. 7, no. 19, p. 373-385.)

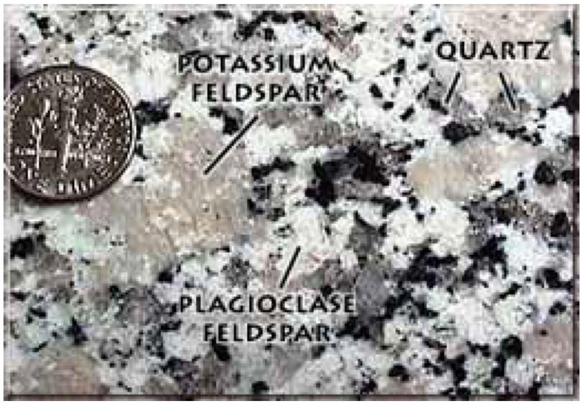

Figure 2.22. A close-up photo of granite. Notice that it is made up of interlocking large crystals. The large crystals form when molten rock is allowed to cool slowly deep within the earth. When molten rock is erupted onto the surface by volcanoes, it cools quickly, so volcanic rocks mostly lack large crystals. The labels show the names of some of the minerals in granite.

Figure 2.23. A close-up view of part of the Moraga Volcanics. Notice the many holes in the rock. These are vesicles, bubbles of gas released from the lava as it erupted (like carbonation is released when a bottle of soda is opened) and trapped when the lava hardened into rock.

Figure 2.24. The south face of the roadcut east of Caldecott Tunnel. The depositional contact between the Orinda Formation on the right and the Moraga Volcanics on the left is marked.

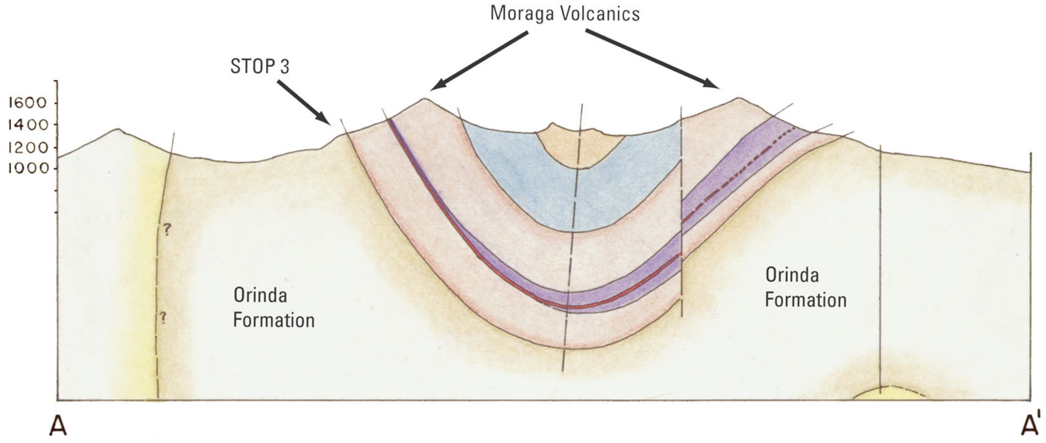

Figure 2.25. A hand-drawn diagram of the tilted and folded geologic units in the Berkeley Hills. The diagram looks at the layers in the Earth's crust from the side, as if you could slice the crust like a layer cake (geologists call that a cross section). The Orinda Formation and Moraga Volcanics are labeled, as well as the general location of Stop 3. The numbers on the left side mark feet above sea-level. This U-shaped fold in the layers of rock is called a syncline. Remember that all the layers were originally flat. The same plate tectonic forces that are driving the Hayward and San Andreas Faults today have bent and warped the layers in the rocks here, and have also pushed up rocks that were formed in a river valley to make the hills we see now. (Diagram drawn by A. Sarna-Wojcicki, U.S. Geological Survey.)

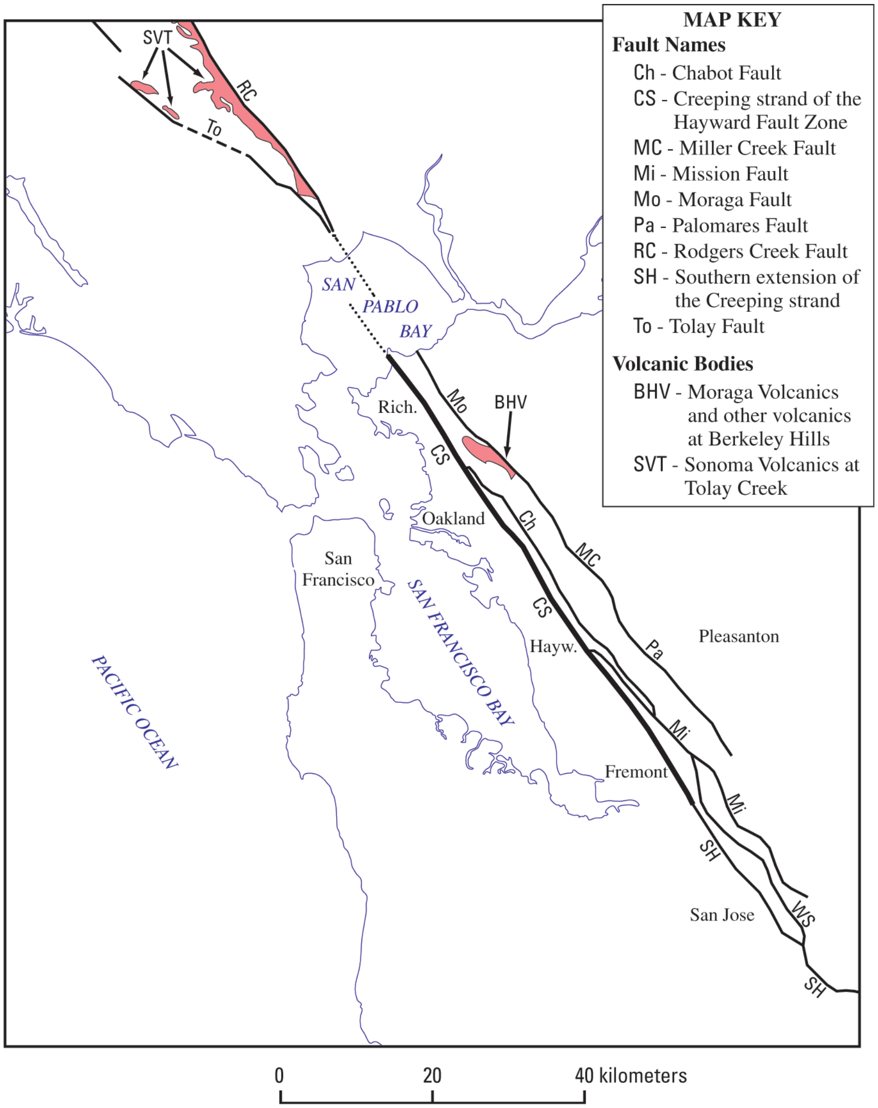

Figure 2.26. Map showing the area of the Moraga Volcanics and other volcanics at the Berkeley Hills and their offset equivalent north of San Pablo Bay, as well as the faults of the Hayward Fault Zone and the next fault zone to the east. Note that the Tolay Fault passes west of the northern volcanics. 45 more kilometers of offset have taken place on that part of the Hayward Fault Zone. Note also that the volcanics at the Berkeley Hills are bounded on the east by a fault zone. Do you think the Berkeley Hills Volcanics could have been moved northwest by those faults too?