# CLEAR LAKE GEOLOGY

## FIELD TRIP GUIDE FOR TEACHERS

MAY 2007

BY

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Prepared under the direction of the

LAKE Science Collaborative

Lake County, California

## Introduction

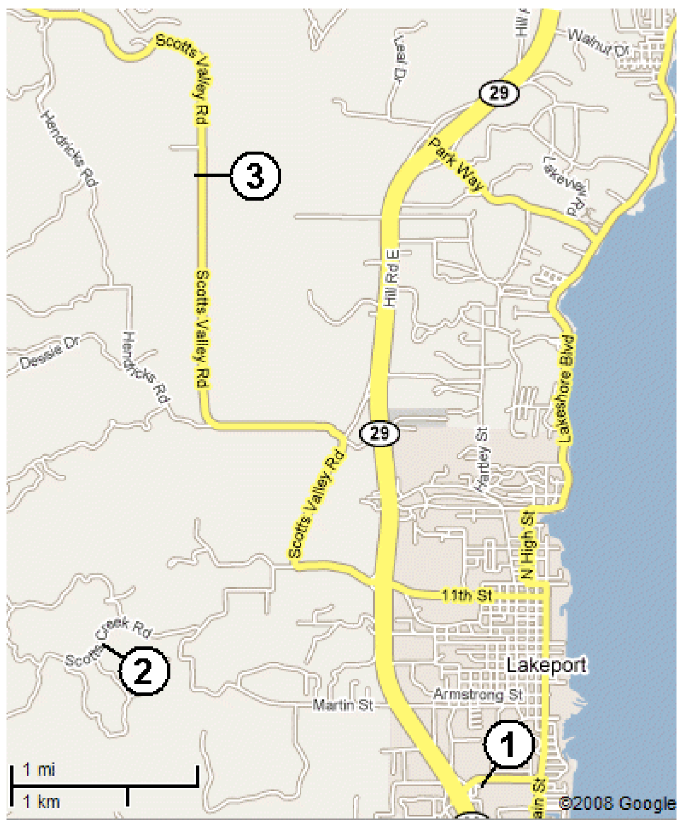
This field trip guide follows the route taken during a field trip on May 5, 2007, sponsored by the LAKE Science Collaborative. It is designed and intended for teachers of grades 4 to 6, with an emphasis on earth science topics. Each stop highlights local geological points of interest that can be integrated into the teaching curriculum for these grades.

We are fortunate to be in a region where the underlying geology is boldly expressed, and where a variety of geological features (many relating the Science Content Standards for California Public Schools) can be visited in a one-day field trip. There are seven stops on this field trip. For convenience, many geological terms appear in **bold** print wherever they first appear in the guide.

The field trip begins at the George Hoberg Visitor Center, located in Lakeport, southeast of the intersection of State Highway 29 and Lakeport Boulevard. For those equipped with GPS equipment, latitude and longitude (NAD-27) are provided for each stop.

## 1) George Hoberg Visitor Center Overlook

Lat.: N 39.03414
Long.: W 122.92062
Trip Odometer: 0.0 miles (reset)
Parking lot at the Visitor Center

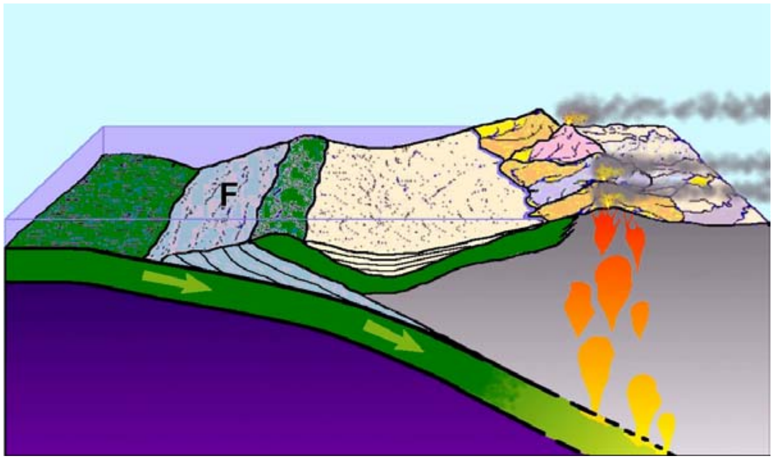



Map showing stops 1, 2 and 3 on the first leg of the field trip.

The Hoberg Visitor Center offers a fine vista from which to see the Clear Lake basin and its surroundings, so it is an excellent launching point for the field trip. It is here that we can review some of the basics of the geology in our area, before moving on to view some specific examples.

Lake County geology can be divided into two assemblages of rocks: 1) The basement rocks, which go back to a time when our area was in the deep ocean; and 2) The overlying rocks, which include volcanic deposits and lake beds, which are much younger than the basement.

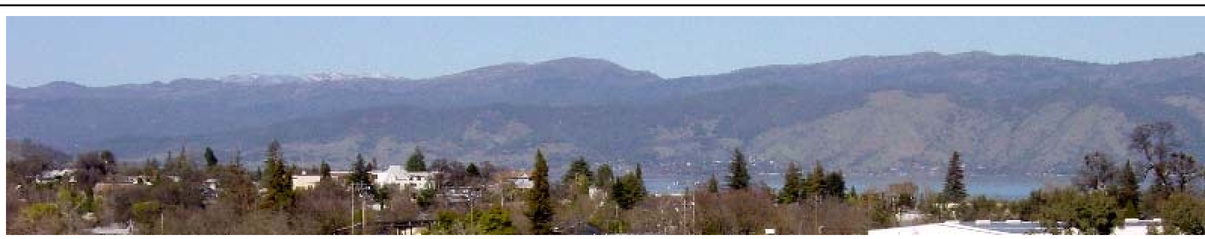
First, let's talk about the basement rocks. **Plate tectonics** played (and continues to play) a key role in the development of our Lake County landscape. The **crust** of the earth is formed by a series of **plates**, which are continually shifting as a consequence of deep convection in the **mantle**. Each earth plate moves differently, depending on what forces are acting on it (and they don't always keep moving in the same direction). Far back in geologic




A diagram of the subduction zone that formed many of the older rock formations in Lake County. The Franciscan Complex is marked by the letter, "F," and it marks the approximate spot where Lake County would be, with respect to the subduction zone. The volcanoes on the right side of the diagram are the ancestral Sierra Nevada, as it might have appeared in the Jurassic and Cretaceous Periods. The downward-pointing arrows indicate the direction of subduction.

time -- in the **Jurassic Period** (about 135 million years ago, during the time of the dinosaurs) -- the west coast of North America was shaped much differently than today. The ocean shoreline was further east, at what are now the foothills of the Sierra Nevada. Lake County was under water, and the sea floor beneath us was the site of colliding earth plates. The ocean floor to the west of us was moving toward us and diving beneath us, in a type of plate collision called **subduction**. The boundary between the **North American Plate** and the earth plates to the west of us (there was more than one), is called the **Coast Range Fault**. It passes through Lake County, but it is not an easy thing to see. To the west of this fault is a group of rock formations we call the **Franciscan Complex**. To the east of the fault are the **Coast Range Ophiolite** and **Great Valley Group**. We'll be visiting several spots that show the Franciscan Complex. The other two formations are best seen in areas east of Clear Lake, which are beyond the range of this field trip.

The Franciscan Complex is aptly named, because for many decades, geologists really didn't understand how it formed (hence, the name "complex"). In many places, the Franciscan Complex is a jumbled up mess of all the rock types one would expect to find in the deep sea floor and deep ocean crust. When it's *really* jumbled, it is often called **mélange** (meaning "mixture"). What perplexed early geologists was the way these rocks are arranged. Rocks that formed at great depths below the sea floor are woven together along faults and folds with rocks that formed at shallow depths. To geologists of the 19th Century, this was not an easy thing to explain. With the modern concept of plate tectonics, it's a bit easier to explain how this complexity can arise. These are bits and pieces of sea floor rock that were lodged on the edge of the North American Plate as the ocean plate dove beneath it. We sometimes use the "pizza topping analogy" to describe how this process takes place: If you try to shove a pizza under a door, some of it will pass underneath, but a lot of the topping will get stuck on the door! The



View looking north, across Clear Lake, from the Visitor Center. The eastern shore of the lake is underlain by rocks of the Franciscan Complex. Snow Mountain, which can be seen on the distant horizon on the left side of the photo, is also underlain by Franciscan Complex rocks.

Franciscan Complex is the equivalent of that pizza topping that didn't pass underneath, and like the pizza, it can get messy!

Mount Konocti and a portion of Clear Lake, viewed looking eastward from the Visitor Center.

Now, let's discuss the younger rock units that are found in Lake County. In the above paragraphs, we reviewed how the basement rocks came to be attached to the North American Plate during the time of the dinosaurs. That sort of movement of earth plates continued in our region until about 3 million years ago. The change was brought about by the passage of the leading edge of the **San Andreas Fault**. The leading edge of this fault today is off the coast of Cape Mendocino. It continues to work its way northward at about the same rate that your fingernail grows (roughly ¾ of an inch per year). To the north of the leading edge of the San Andreas fault, subduction is still occurring.

The San Andreas Fault is the boundary between the **North American Plate** and **Pacific Plate**. Instead of colliding, as plates do in subduction, the plates associated with the San Andreas Fault are moving past each other in a manner called **right lateral transform motion** by geologists. Right lateral means that -- if you stand on one side of the fault and look across at the other side -- objects on that other side are moving to your right. The principle is the same, regardless of which side of the fault you're standing on.

The passage of the leading edge of the San Andreas Fault had a profound effect on the geology of our area. Many things changed as a consequence. First, with the cessation of subduction, the Coast Ranges began to rise. Accompanying the uplift of the mountains was the general spreading and tearing apart of basins in the landscape, just as slits in bread dough widen and deepen as the dough rises. These depressions in the landscape are known as **structural basins**. Clear Lake is an excellent example of a structural basin. As new sediment enters the basin, its weight causes the underlying rocks to shift downward along a fault zone (called the Clover Valley Fault) on the eastern shoreline. The process is much like putting weight on a platform with a spring underneath. The more weight that is added, the more the spring tends to compress. Were it not for this continuing process of **subsidence**, Clear Lake would have filled in with sediment, and transformed into a marshland and meadows long ago.

Along with the changes in the shape of the landscape mentioned above, volcanic activity also commenced in our area following the passage of the leading edge of the San Andreas Fault. There are **volcanic fields** (regions containing related volcanic deposits) extending down the California coast to south-central California. The emergence of each of these volcanic fields is closely tied to the northward progression of the leading edge of the San Andreas Fault. Each volcanic field tends to be active for a time, then go extinct. The **Clear Lake Volcanics** are the northernmost of these fields, and they are still considered active! The field includes The Geysers and Cobb Mountain area, but not Mt. St. Helena. The oldest part of the field (about 2 million years old) is down by Lake Berryessa, and the youngest (less than 40,000 years old) is in the vicinity of Clearlake Oaks and Sulphur Bank. The most striking of these volcanics in our area is Mount Konocti, which is easily seen from the Visitor Center and many other points around Lake

County. We'll be getting a closer look at the Clear Lake Volcanics at some of our other field trip stops.

From the foot of Mount Konocti to Lakeport we can see the broad stretch of relatively flat land called Big Valley. Much of the valley is underlain by **sedimentary** rocks that formed in ancient Clear Lake during the period that Mount Konocti was an active volcano (around 200,000 years ago). These early lake beds were buried and **lithified** over the millennia, but as the Clear Lake Basin continues to change its shape, some of these deposits have been **uplifted**, and are now elevated well above lake level. In the Lakeport and Kelseyville area, these ancient lake beds are called the **Kelseyville Formation**. Further south, by Lower Lake, similar deposits are known as the **Lower Lake Formation**.

Before leaving the Visitor Center, it is worth checking out the rock outcrops on the hill slope on the south side of the hilltop, just below the picnic area. There is a good outcrop of **serpentinite** here. serpentinite (also called **serpentine**) is the official State Rock of California. It is a **metamorphic** rock (one of the three general rock types: **Igneous**, **sedimentary** and **metamorphic**). The serpentinite at this location is probably part of the Franciscan Complex, and it may be as old as 140 million years in age. Before it was transformed (**metamorphosed**) into serpentinite, this rock was a type of igneous rock called **peridotite** (the gemstone, **peridot**, comes from a related rock type). Peridotite forms deep in the sea floor, at or below where the Earth's **crust** and **mantle** meet. When peridotite reacts with sea water, it gradually changes its chemistry by incorporating parts of the water into its crystals. This process (called **hydration**) is how the igneous rock, peridotite, becomes the metamorphic rock, serpentinite.

Serpentinite contains exceptionally high quantities of iron and magnesium, which causes it (as it weathers) to produce soils that are toxic to many plants. Those plants that are specially adapted to live only on serpentinite-derived soils are called **serpentine endemics**. Just below the Visitor Center, and to the south, is an office building that houses the Lake County Air Quality Management District and other county offices. There is a demonstration garden near there, which is worth checking out. It was constructed at the foot of the slope we are standing on, and is designed to showcase the flora that grow well on serpentine soils. We won't be stopping there today, but it's worth a visit!

The Serpentine Landscape Demonstration Garden, near the parking lot of the Lake County Air Quality Management District in Lakeport.

Earth Science Standards to Consider at This Stop:

Grade 4:

- Properties of rocks and minerals (igneous/metamorphic)
- Principles of erosion and deposition.
- Gradual and catastrophic process that shape the earth surface.

<u>Grade 6:</u>

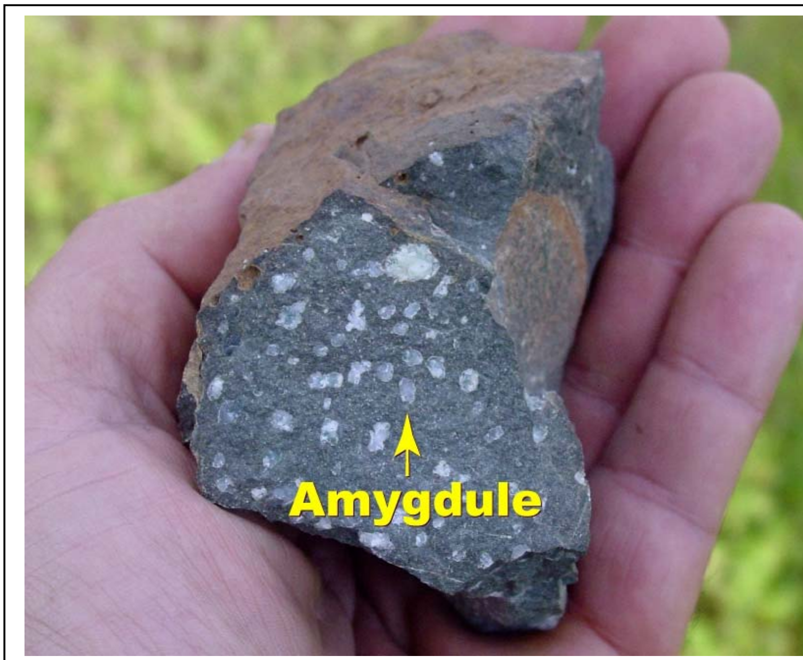
- Plate tectonics (subduction and transform plate motion)
- Mantle and crust (lithosphere)
- Rate of movement of the San Andreas Fault
- Geomorphology (shaping of the surface of Earth by geological processes)

From the Hoberg Visitor Center entrance, turn left onto Lakeport Boulevard, then right onto State Highway 29 <u>north</u>. Exit at the Scotts Valley Road/11th Street offramp (odometer 1.4 mi.). Turn left at stop sign, and continue 0.6 miles on Scotts Valley Road to Riggs Road. Turn left at Riggs Road (odometer 2.0 mi.). Continue 2.7 miles along this winding road to the intersection with Scotts Creek Road. Turn right onto Scotts Creek Road and continue 0.7 miles. Pull onto wide shoulder and good bus turn-around on the left side of road (odometer 3.4 mi.). This is Stop 2.

## <u>2) Scotts Creek Road: Scotts Creek & Franciscan Complex</u>

Lat.: N 39.04538
Long.: W 122.95883
Trip Odometer: 3.4 miles.
Wide bus turn-around on Scotts Creek Road.

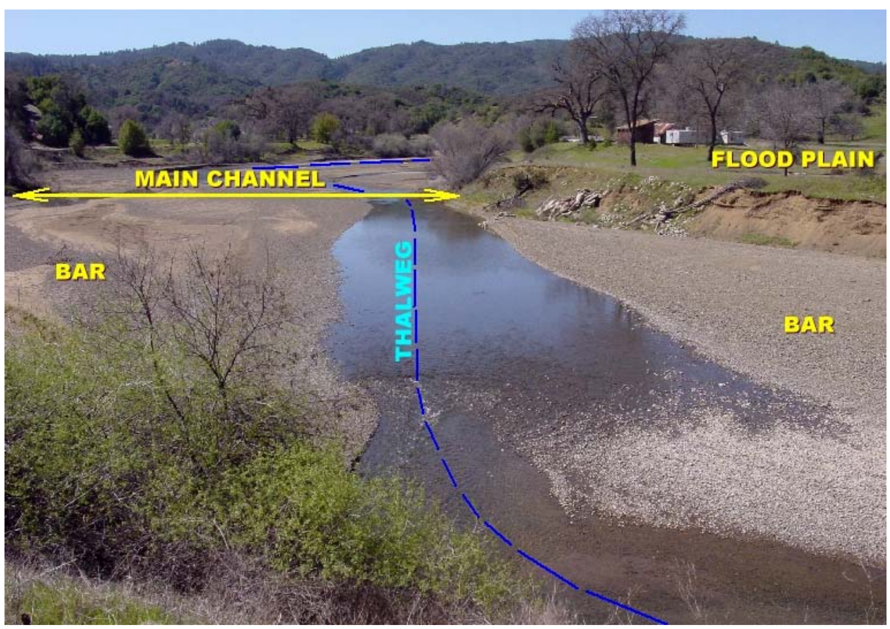
There is a driveway leading over the hill just to the east of our turn-out. On the hillside above this driveway right next to us is a nice roadcut showing examples of one of the rock types found in the Franciscan Complex. This rock is called **greenstone**. The rock began as an **igneous** rock type called **basalt**, but has been chemically transformed to become a **metamorphic** rock. It was probably an ancient lava flow that erupted near a **mid-ocean ridge**. It would have formed deep in the ocean, and it is probably at least 100 million years old. It tends to have a grayish-green color, which is why it is called <u>green</u>stone. The greenish tint is caused by a mineral called **chlorite**. Because it is metamorphic, this rock has new minerals in it that weren't present when it originally formed as a **basaltic lava** on the sea floor. Chlorite is one of these new minerals. If you break open some pieces of the rock, you will see little white or light gray specks (most about 1/8 inch in diameter). Geologists call these **amygdules**. On a freshly broken surface of the



Amygdules in metamorphosed sea floor basalt (greenstone), from the roadcut at Stop 2.

rock, you should be able to perform some physical tests on the white mineral that forms the amygdules. It's important to test only the freshest rock surface you can find, because this rock is **weathered**, and that will change the way some of the minerals will respond when tested. Can the white mineral be scratched by a knife? The answer is yes, it can be scratched to make a fine powder with a knife! You may need to use a hand lens to see the groove and powdery residue left at the scratched area. This tells us it's not **quartz**, which is a common mineral that is harder than steel. **Feldspar** (another common rock-forming mineral) can sometimes be scratched with a knife, but it doesn't scratch as easily as this mineral does. The mineral in these amygdules might be a carbonate mineral (**calcite** or **dolomite**). To check for this, you need to use a dilute acid (hydrochloric acid is usually used). Vinegar will also work to test this (especially if the vinegar has been heated). Place a drop of the acid on a fresh surface of the mineral. Does the acid fizz? If it does, then the mineral is calcite. If it doesn't, try powdering some of the mineral and repeat the process. Does the powder fizz? If it does, then the mineral is dolomite. The samples I tested here appear to be dolomite, but there may be some calcite here, too. The fizzing action is the result of the acid reacting with the carbonate mineral, producing carbon dioxide gas ($CO_2$). It's the same gas that produces the fizz in soda pop.

Changing the topic, let's now walk across Scotts Creek Road to view Scotts Creek. The winter of 2006/2007 was relatively dry, so there wasn't a lot of water flowing in Scotts Creek when the accompanying photo was taken. Notice how the water is flowing along a narrow line (called the **thalweg**), which winds its way back and forth across the **main channel**). In seasonal high flow conditions, there would be water flowing over the entire main channel. Notice also that, on either side of the thalweg are accumulations of gravel, called **bars**. Most of the bars you see here are called **alternate bars**, because they alternate between the opposing sides of the main channel. During the next high water event, the gravel that we see in these bars will move downstream, but it will be replenished by new gravel from the watershed upstream.



View looking upstream on Scotts Creek from Stop 2, showing some of the basic components of the stream channel and flood plain. The photograph was taken in March 2007.

Each stream has its own capacity to handle a certain amount of sediment annually. If the source of the sediment from the upstream watershed is greater than the stream can handle, the surplus gravel will be deposited in a **flood plain**. This is often seen in areas where streams leave mountains and enter valleys. Notice on the opposite side of Scotts Creek that there is a broad flat area with a few buildings on it.

This is the flood plain, where excess gravel is stored by the stream. A good analogy to this is a savings account in a bank. If you earn more money than you can spend, then you store your money in a savings account for later use. In the same way, the stream stores the excess gravel in the flood plain, while only transporting the gravel that it has the capacity to handle. Through time, streams often migrate back and forth (**meander**) across the flood plain. Scotts Creek is no exception. Notice the blocks of concrete and other debris on the opposite bank of the creek? Rock armoring and other techniques are often used to try to keep a main channel from meandering. Containing the course of a stream can be difficult (and sometimes impossible), because the natural tendency is for the stream to meander.

Just as a surplus of gravel will cause a stream to set aside the excess sediment in a flood plain, depletion of gravel from upstream sources will have the opposite effect. If the source of gravel from upstream is reduced too much, the stream will begin to cut a deeper channel and steepen its gradient (called **incising**). This pulls the excess gravel from the surrounding bars into the main channel for transport. Using the banking analogy from above, this would be similar to having to draw from your savings, if your income was suddenly less than your expenses. The stream always tries to achieve **equilibrium**, by maintaining a balance between gravel transported downstream versus gravel coming from upstream.

Earth Science Standards to Consider at This Stop:

Grade 4:

- Diagnostic properties of common rock-forming minerals.
- Moving water and the shaping of landforms.
- Weathering, transport and deposition.
- Igneous and metamorphic rock

Grade 5:

- Moving water and the shaping of landforms.

Grade 6:

- Plate tectonics: Mid-ocean ridges and the formation of ocean basalt (greenstone).
- Stream dynamics and the development of a flood plain.

Return to vehicles, turn around and head back the way we came in, returning to the intersection of Riggs Road and Scotts Valley Road. Turn left onto Scotts Valley Road (odometer 4.1 mi.). Drive approximately 3.6 miles and pull over near the group of houses on the west side of the road (in the vicinity of 3359 Scotts Valley Road). This is Stop 3.

## 3) Scotts Valley Road & Ground Subsidence

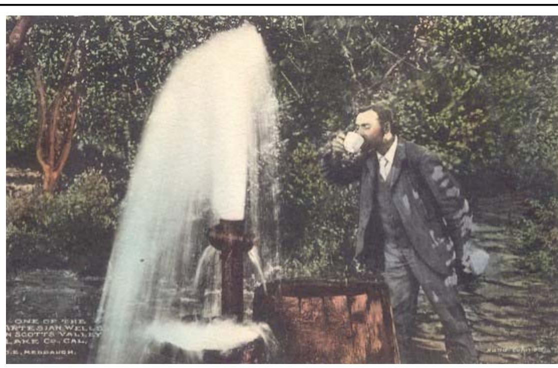
Lat.: N 39.08131
Long.: W 122.94864
Trip Odometer: 7.7 miles
Wide shoulder turnout along straight stretch of Scotts Valley Road. Remain on bus.

Lying beneath the valley floor in this locality is a mixture of ancient Clear Lake sediments, probably ranging in age to as old as 450,000 years. The older sediments have been compacted and **lithified** to become **sedimentary** rock. The oldest formation here is probably the Kelseyville Formation, which we discussed briefly at the Visitor Center overlook.

A groundwater well along Scotts Valley Road, showing subsidence around the well collar.

We're stopping here to discuss groundwater and groundwater usage, which is an important topic in the Grade 5 standards-based curriculum. As many of us know, having lived in this area, groundwater is precious in Lake County. In many places in the county, there is so little groundwater that it can be difficult to provide adequate water to supply a single family home. The amount and availability of groundwater in underlying rock formations is determined by the amount of pore space (**porosity)** and the connectivity between the pores (**permeability**). In order for a rock formation to be a good source of water (called an **aquifer**), it has to have both porosity and permeability. The most important aquifer in the area around Big Valley is the **Kelsey Tuff**. It is a volcanic ash layer that yields plenty of water.

Even the best aquifer has its limits. If pumping from a well exceeds the ability of the aquifer to **recharge** itself, irreversible damage can occur. The damage is most often seen at the surface in the form of subsidence. If a groundwater well is pumped excessively (called **overdraft**), void spaces deep in the ground that normally are filled with water can collapse. The overlying ground will settle, leaving the top of the well sticking out of the ground. Some of the water wells in this area of Scotts Valley show this. Notice the steel pipe (well casing) and pump along the side of the road here. Everything appears to be normal at first glance, but look closely. The top of the concrete "well collar" (poured around the casing after the well was drilled) is protruding about 10 inches out of the ground. The ground surface would have originally been about level with the top of the concrete.


An early photo of an artesian well in Scotts Valley.

This is not a case of blaming anyone. The subsidence is widespread in the valley, and it has taken place over many decades of use. There is still plenty of groundwater available in this area. It is, however, a good visual example of limitations of groundwater as a resource (even in the most productive of aquifers).

Earth Science Standards to Consider at This Stop:

Grade 5:

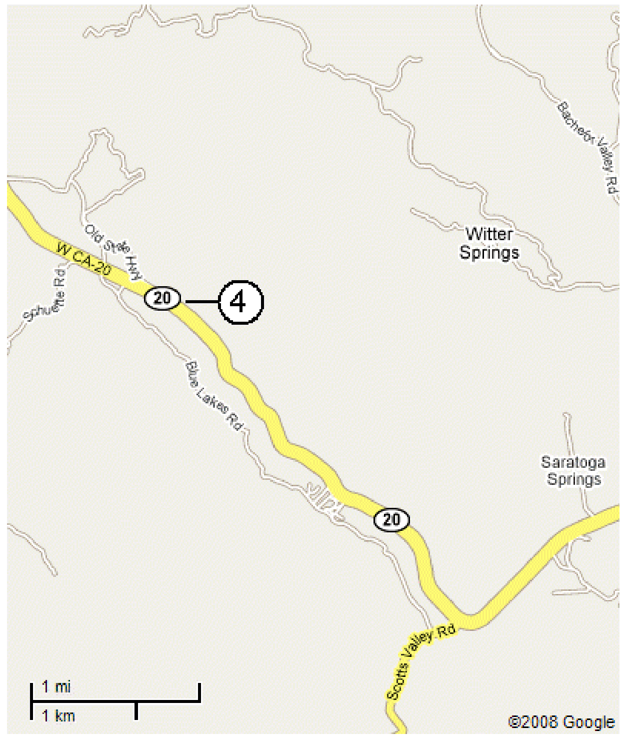
- Groundwater as a limited resource.
- An example of water used in the local community (in this case, for agriculture)

Continue northward on Scotts Valley Road to State Highway 20. Turn left on State Highway 20 and drive past Blue Lakes. At the western end of Blue Lakes, before the northern intersection with Blue Lakes Road, and just before the highway starts up the grade to the Lake/Mendocino County line, pull over on the right shoulder of the highway. The shoulder is wide on both sides of the highway here, making it a good bus turn-around. This is Stop 4.

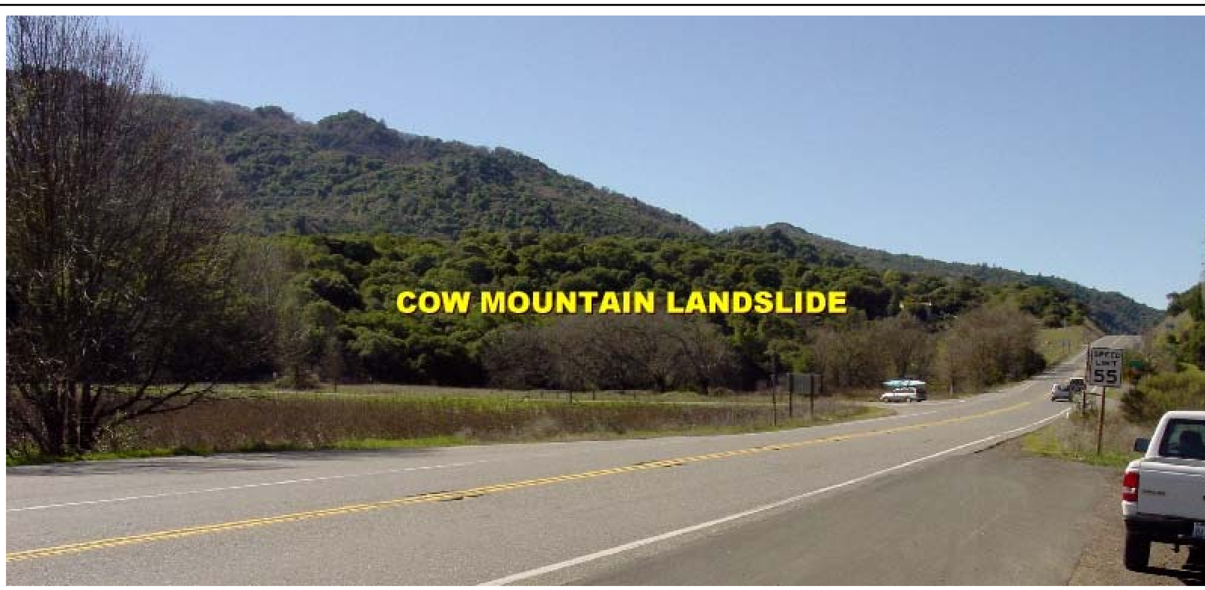
## 4) Blue Lakes & the Cow Mountain Landslide

Lat.: N 39.18647
Long: W 123.02740
Trip Odometer: 17.8 miles.
Wide shoulder turnout on Highway 20 alongside Blue Lakes

The Clear Lake basin has a peculiar geologic history, in that its outflow channel has varied through time. When the lake basin first formed, runoff from Clear Lake flowed eastward into the Sacramento Valley, just as it does today. Sometime during the period that the Clear Lake Volcanics were most active (perhaps around 200,000 years ago), the southern end of the basin became obstructed. There is debate over the exact cause, but it was most likely a combination of uplift of the landscape, combined with natural dams formed by lava flows. The obstruction caused the lake



Map showing stop 4 on the field trip.



The Cow Mountain landslide, view looking west from the turnout on State Highway 20.

level to rise until a new outflow point developed. This point was through Scotts Valley and out through what is now Blue Lakes into Cold Creek. At that point in time, Clear Lake began to drain for the first time into the Russian River watershed. This configuration remained until relatively recent geologic time, when a gigantic landslide catastrophically collapsed into the Cold Creek canyon, blocking flow. Clear Lake rose once again, and eventually carved a new outflow path back to the Sacramento River watershed. That path is the Cache Creek canyon through which Clear Lake outflow passes today.

Blue Lakes, with Clear Lake in the distance.

The age of the Cow Mountain landslide is uncertain, but it is thought that it occurred sometime within the last 10,000 years. Stories of the event have been passed down through generations of Native American oral tradition, suggesting that the landslide may have occurred as recently as just a few thousand years ago.

The Cow Mountain landslide is still visible to this day. From our vantage point, we can see a tree-covered ridge that forms the western end of Blue Lakes. State Highway 20 crosses the toe of the landslide at the Lake/Mendocino County line. Large landslides are not all that unusual for our area. In 1906, shortly after the Great San Francisco Earthquake, a large landslide blocked Cache Creek Canyon on a remote stretch of the creek near Wilson Valley. The landslide formed a natural dam which held back the entire flow of Cache Creek. A lake formed in back of the landslide, and the water level continued to rise until it eventually crested over the top of the natural dam. When it did, the rush of water rapidly carved through the soft landslide debris, creating a torrent of water and mud which caused extensive flood damage to several of the communities in the upper Capay Valley.

**Landslides** and **floods** are examples of **catastrophic** earth processes, unlike many other earth processes (such as uplift), which tend to be **gradual**.

Although the water level in Blue Lakes varies by only a few tens of feet with respect to the water level in Clear Lake, the Blue Lakes will someday be gone. They are **closed basins** (no outlet), and unlike Clear Lake, they are not subsiding as new sediment is fed into them from surrounding streams. The marshlands where Blue Lakes Road meets State Highway 29 near the Cow Mountain landslide show how rapidly this **sedimentation** is occurring. The Narrows in the Blue Lakes and the high ground at Midlake Road are other spots where sediment is filling in the basin. The sediment is coming in from streams on the west side of the lakes. Where the streams meet the lakes, the sediment accumulates in fan-shaped deposits at the water line (called **deltas**). The delta at Midlake has filled completely across the valley, creating a bridge of land that connects both sides of the lakes.

Contrary to rumor, the Blue Lakes aren't "bottomless." They are quite deep, however, because they fill what was once a V-shaped river valley. Fishermen report that the deepest water is around 90 feet deep.

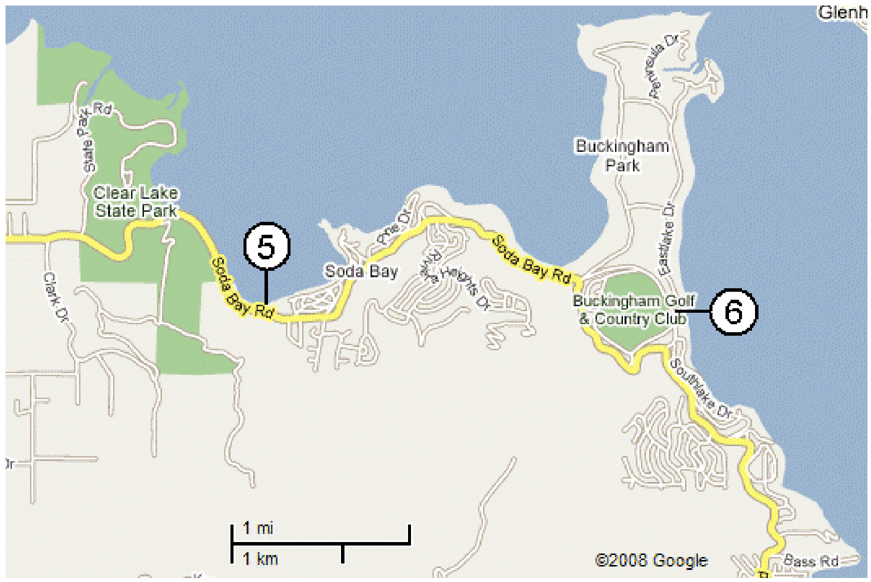
Earth Science Standards to Consider:

Grade 4:

- Gradual and catastrophic earth processes. Here, we view the results of a catastrophic event.

Grade 6:

- Sculpting of the landscape due to flowing water. Cold Creek is an example of a stream whose sediment load and capacity were permanently altered by the landslide event.
- Blue Lakes: An example of deposition in a closed basin. Will ultimately fill in.



Stops 5 and 6, in the vicinity of Soda Bay and Buckingham Peninsula.

Reset trip odometer to zero (0.0 miles). Turn around and drive eastward on State Highway 20 to the junction with State Highway 29. Turn south onto State Highway 29. Continue on State Highway 29 11.1 miles through Lakeport to the stoplight intersection of State Highway's 29 and 175. Turn left at the light. There is a stop sign a short distance from the highway. Turn right onto South Main Street (which becomes Soda Bay Road). Continue on Soda Bay Road 7.8 miles to Ferndale Resort and Marina (6190 Soda Bay Road). Pull off on wide shoulder on the lakeshore side of the highway at the Ferndale entrance. This is Stop 5.

## 5) Maar at Ferndale Resort & Marina

Lat.: N 39.00163
Long.: W 122.79575
Trip Odometer 26.1 miles.
Wide turnout on east side of Soda Bay Road in front of Ferndale Resort and Marina (6190 Soda Bay Road).

Until now, the focus of our field trip has been the older "basement" rocks (Franciscan Complex). In our previous stops, we've had a chance to get a close-up look at serpentinite and greenstone. Those rocks formed in the deep ocean over 100 million years ago. When we passed Clear Lake State Park on the way here, we entered a different (and much younger) group of rocks: The Clear Lake Volcanics. We're at the base of Mount Konocti here, and the layered rocks you see in the roadcut on the west side of the highway are related to the volcanic eruptions from the time that Mount Konocti was an active volcano.

As we first discussed at the Visitor Center, the Clear Lake Volcanics became active after the leading edge of the San Andreas Fault had worked its way past us along the coastline. The

Clear Lake Volcanics are the youngest of a whole series of volcanic fields along the California coast. Fields extending southward from us, starting with the closest, are the Sonoma Volcanics, Tolay Volcanics, Moraga Volcanics, etc., all the way down to The Pinnacles The further south one goes, the older the volcanic rock generally is. The Clear Lake Volcanics range in age from about 2 million years at the southern end (near Lake Berryessa) to only a few tens of thousands of years in the vicinity of Clearlake Oaks and Jago Bay. The field is still considered to be potentially active, and magma (molten rock) is still present beneath us at a depth of about 6 miles.

This roadcut shows a good example of a type of volcanic deposit called a **maar**. Most volcanoes fall into one of three classes: 1) **composite** or **stratovolcano**, 2) **shield volcano**, or 3) **cinder cone**. Mount Konocti is a composite volcano (built up from multiple eruptions over time), but on its flanks at the lake shore are these maars, which are in their own class, as far as volcanoes go. They form when **magma** (molten rock beneath the surface) encounters the water-saturated mud in the lake bottom. Most of the magma that fed the volcanoes in the Clear Lake Volcanics, ascended to the surface via **faults**, which were probably active at the time. Kinks and bends in faults can make excellent pathways for molten rock. You can imagine what happens when molten rock (which is at a temperature of 1,400º F or higher) encounters groundwater! It's going to explode due to the build-up of steam pressure. That's what forms a maar. Geologists call this type of volcanic eruption a **phreato-magmatic** eruption (*phreato* refers to groundwater, while *magmatic* refers to molten rock). These maar craters line up along the shoreline where the Clear Lake Volcanics and Clear Lake meet. Most of the bays on the west shoreline of the lake have a scallop-shaped form, because they are maars. Here, we are on the edge of Soda Bay. Dorn Bay, Horseshoe Bay, and Konocti Bay are formed by the same processes.

Layered volcanic deposits of a maar, viewed from the entrance to Ferndale Resort on Soda Bay Road

The layers of rock you see in the roadcut, are called **base surge** deposits. They consist of a mixture of Clear Lake mud and fragments of volcanic rock that splattered out of the center of the crater during the eruptions. The layers dip at a steep angle toward Clear Lake, because the maar is shaped like a cone with steep sides. When you think about it, the classification of this type of rock can be a bit tricky. It includes pieces of Clear Lake sediment, so it has a **sedimentary** component. This rock would be classified as **igneous**, however, because it was deposited by a volcanic eruption.

<u>Earth Science Standards to Consider:</u>

<u>Grade 4:</u>

- Igneous vs. sedimentary

Grade 6:

- Volcanic eruptions and the shaping of the Earth's surface.
- Faults and their relationship to volcanic vents at Clear Lake.

Continue south on Soda Bay Road 2.2 miles. Turn left onto Little Borax Lake Road at the "Y" intersection. Continue down the grade on Little Borax Lake Road to the junction with East Lake Drive (at the bottom of the hill). Buckingham Golf and Country Club is on the right. Park near the boat trailer parking, at the edge of the golf course. This is Stop 6.

## 6) Buckingham Golf & Country Club – Little Borax Lake

Lat.: N 39.00130
Long.: W 122.75106
Trip Odometer: 29.1 miles.
Alongside boat trailer parking area in front of the Tee Room (2855 East Lake Drive). View of the golf course and Buckingham Peak from the parking lot.

Ponds in golf courses are often constructed for aesthetics, and to increase the level of difficulty of play. In the case of Buckingham, the focal point of the golf course is a circular pond called Little Borax Lake. Its slightly oval shape is not the work of some world-class golf course designer. It is natural! This is another example of a maar, as we saw in the previous stop. The only difference here is that the entire maar crater is above lake level. There are only three known maars around Clear Lake that are fully above lake level. The others are near Clear Lake State Park, and are not nearly as easy to see.

Little Borax Lake got its name from the borax industry, which originated right in Lake County. Borax (hydrated sodium borate) became very popular as a cleanser in the 19th Century, and between 1868 and 1873, the entire nation's supply of it came from Lake County. The first


Aerial photo of Little Borax Lake and Buckingham Peak, showing the location of Stop 6. Notice the nearly circular form of Little Borax Lake, which is situated in the crater of a maar. (Air photo courtesy Lake County GIS).

Little Borax Lake and Buckingham Golf Course, viewed from the parking area near the Tee Room.

discovery in the county was just north of the town of Clear Lake around 1856, at (big) Borax Lake. About four years later, borax was discovered here. The resource was soon depleted, however, and it wasn't long before Lake County's role in the history of the borax industry was eclipsed by the major discoveries in Death Valley in the 1880's.

Borax gets its name from **boron**, which is an **element** often found in elevated concentrations in volcanic soils. At high concentrations, boron is toxic to plants. This is often seen near geothermal springs in our area.

Buckingham Peak, as viewed from Stop 6.

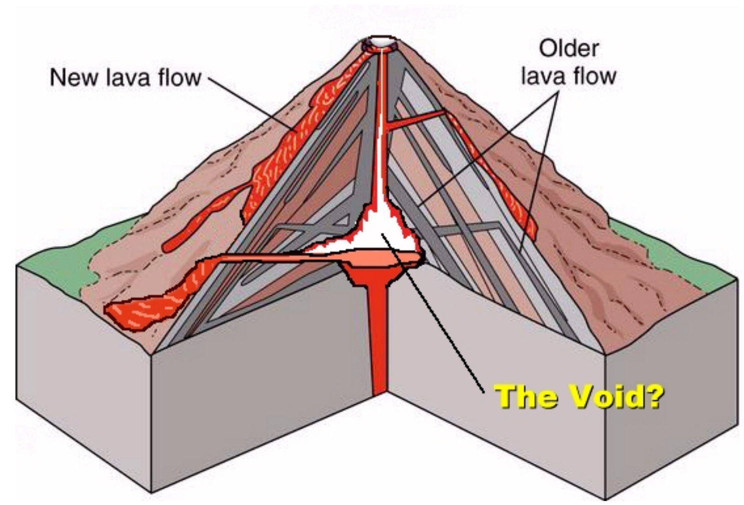
Looking south from Stop 6, we also get a good view of Buckingham Peak (elevation 3,967 ft.). This is one of the five distinctive peaks that are collectively called Mount Konocti. The bluffs near the top of the peak are made up of a type of lava called **dacite**. The volcanic vent from which the flows emanated is concealed, but it is probably near the top of the peak. These flows (called the "Dacite of Buckingham Bluffs") are around 350,000 to 400,000 years old. At the base of the bluffs is a beautiful forested area, known locally as the Black Forest. Intermingled with the trees in the forest are enormous boulders which have fallen from the top of the bluffs. Most of the face of the peak that we can see from this vantage point is actually made up of **landslides** and **rock falls**. Some of them appear to be relatively recent. Landslides of this type are fairly common in our region, and many are quite old (going back to the last ice age). Boulders continue to tumble from the bluffs occasionally, especially after large earthquakes.

Buckingham Peninsula juts out into Clear Lake in a way that makes it appear to be a part of the landslide, but it is not. The peninsula and most of the Clear Lake lakeshore in this area are underlain by a mixture of maar crater deposits and **pyroclastic** rock (bits of volcanic debris that fell from the air during volcanic eruptions). These are some of the youngest volcanic rocks on Mount Konocti. The oldest rocks on the mountain are about 500,000 years old, while these are probably around 200,000 years old.

There is a great deal of lore about Mount Konocti, and some of those stories are worth telling while we're here. It is told in native legends, that an opening exists near the top of the mountain which is the gateway to the underworld. Called the *Zenith Gate*, it is said to be guarded by a den of rattlesnakes who only allowed those who were summoned to pass. According to one legend, Coyote was able to pass through the gate uninvited, with the help of Spider, who spun a web to lower him through.

In the early 20th Century, locals rediscovered this entrance (and one or two others) in the vicinity of Wright Peak. Many folks explored it, and some discovered that the voids ran deep into the mountain. Marked sticks tossed into one particular void were reportedly discovered floating in Clear Lake days or weeks later. This led to the conclusion that there must be a direct connection between the top of the mountain and springs in the lake. It was also known that the mountain "breathes." When a low pressure front passes through our area, a noticeable draft comes out of openings in the mountain. When high pressure prevails, the mountain draws air in. A possible explanation for this is that the mountain contains a large air chamber with constricted openings leading to the surface. The changing drafts may be the mountain's means of adjusting to surrounding air pressure.

The conceptual giant void space in the mountain could well be a shallow **magma chamber** beneath one of Konocti's **volcanic vents**. If, during the course of an eruption from the top of the mountain, a new pathway for the lava broke out low on the mountain's side, it could conceivably drain the magma chamber of molten rock, leaving a large void space in the mountain. Eruptions on the sides of volcanoes (called **flank eruptions**) do occur, so the concept has merit. Proving the concept is difficult, though, because many of the lava flows at the top of the mountain are broken and collapsing. Even the caves that were explored as recently as the 1930's are no longer easily accessible. So, the secrets of Mount Konocti remain to be unlocked (and may never be revealed).



A conceptual model for the void that might exist in Mt. Konocti. Such a void could form where a shallow magma chamber was catastrophically drained during a flank eruption.

Earth Science Standards to Consider:

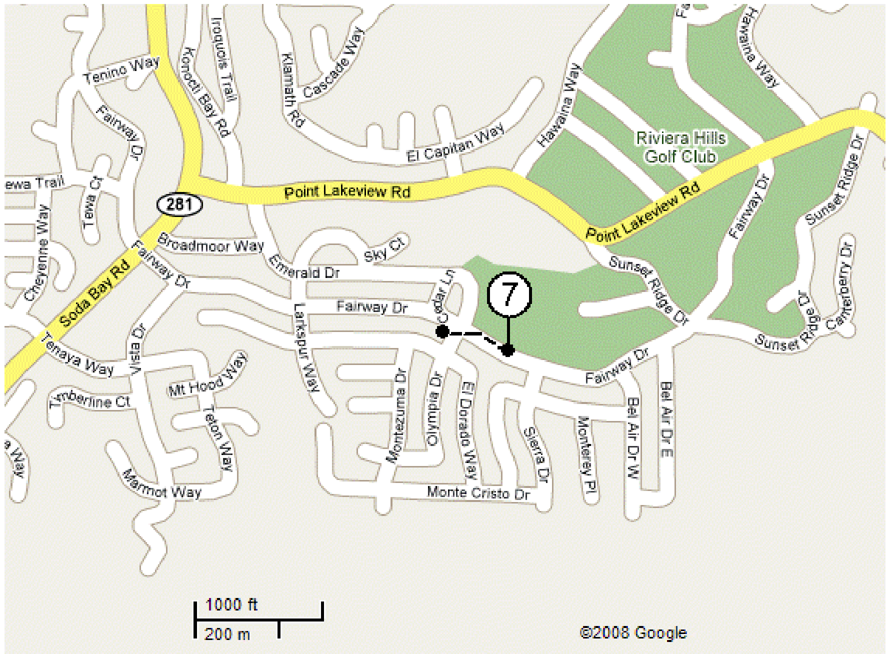
Grade 4:
- Igneous rock.

Grade 6:
- Volcanic eruptions and the shaping of the Earth's surface.
- Natural resources and earth materials for human use.

Continue south on East Lake Drive, and return to Soda Bay Road via Crystal Drive. Turn left onto Soda Bay Road. Drive 4.3 miles south on Soda Bay Road (State Highway 281) to the intersection with Fairway Drive (odometer 33.4 miles). Turn left onto Fairway Drive and drive up the hill 0.5 miles. Park in the paved turnout in front of Riviera Hills Country Club (north side of the road). This is Stop 7.

## 7) Fairway Drive – Konocti Bay Fault Zone

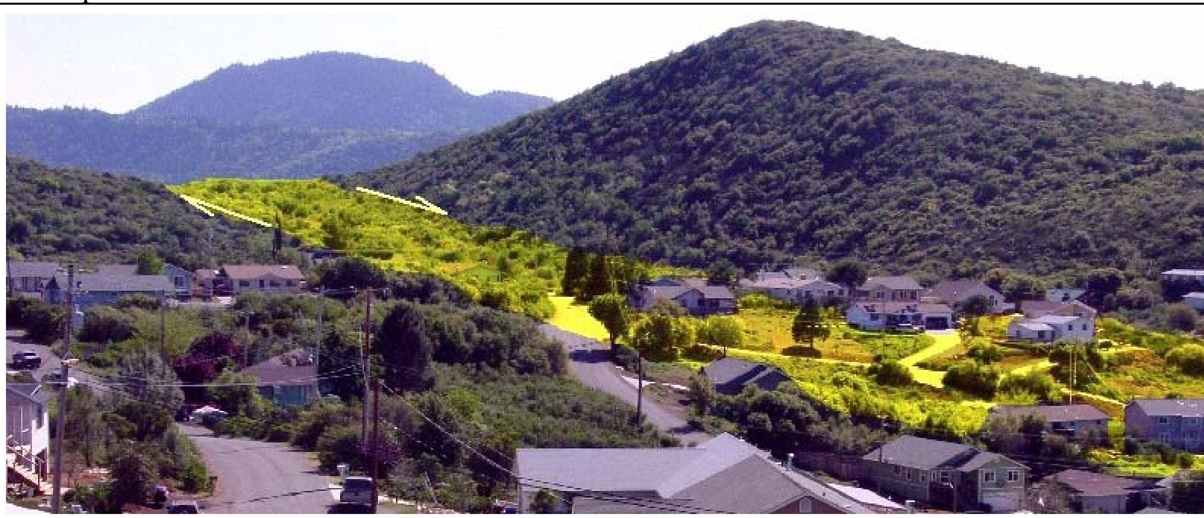
Lat.: N 38.95146
Long.: W 122.71898
Trip Odometer: 33.9 miles



Map of Stop 7 in the Clear Lake Riviera.

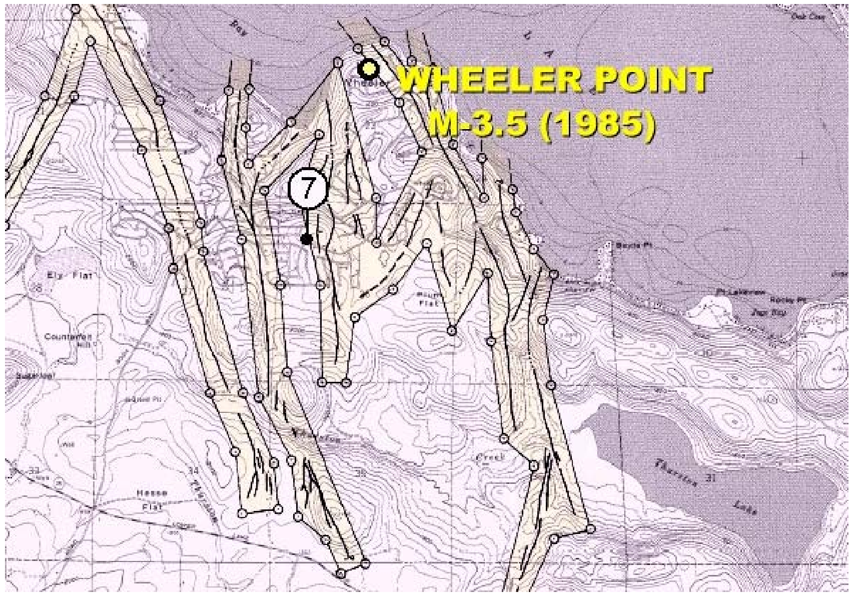
Riviera Hills Country Club (10200 Fairway Drive). Park alongside Fairway Drive in front of the entrance, and walk westward on Fairway Drive to the corner of Fairway and Olympia Drive. This is the final stop for the field trip.

As is generally known, **earthquakes** are a significant hazard in California. We often feel small tremors in Lake County, and we tend to get used to them. In 1985 a **magnitude** 3.5 (M3.5) earthquake occurred just north of here, which caused considerable damage to several homes in the Clear Lake Riviera subdivision. The **epicenter** of the earthquake was near Wheeler Point. For residents here in the Riviera, that event was a reminder that our landscape contains unseen hazards.


A series of splays of the Konocti Bay Fault Zone pass through the residential areas of the Clear Lake Riviera. This one can be view from the intersection of Fairway Drive and Olympia Drive, looking southward. The yellow (lighter colored) area shows the approximate course of the fault splay, and the two arrows indicate the direction of movement of earth on either side of the fault. Mount Hannah can be seen in the distance.

The 1985 earthquake occurred on a **splay** of the Konocti Bay Fault Zone. Faults often don't form just one line (called a **fault trace**) across the landscape. They split into multiple traces that follow the same general direction, each having the same general sense of fault movement. When a fault has multiple traces, it is called a **fault zone**. Below us, looking southwestward, we can see one of the many splays of the Konocti Bay Fault Zone. It comes into sight in the saddle between the two hills just south of the subdivision, and runs north-northwesterly through the Riviera and into Konocti Bay. Mount Hannah (elev. 3,978 feet) can be seen in the distance through the saddle.

The Konocti Bay Fault Zone is an **active** fault zone, meaning that there is a high likelihood of an earthquake along it. **Displacement** (relative movement) along the fault zone can actually be measured, because it slices through the Clear Lake Volcanics. If one stands on one side of the fault and look across it, the rocks on the other side are moving to our right. This is called **right-lateral offset**. We often think of the San Andreas Fault as the big threat in our region, but it is just one of many active faults that pass through our landscape. The smaller faults often share the same (right-lateral) sense of movement as the larger San Andreas. Smaller fault zones like this one, have the potential to produce damaging earthquakes, but not **major** (M7 to M7.9) or **great** (M8 or above) earthquakes. Nevertheless, the small faults have to be considered when planning for building developments, highways, reservoirs, etc. There are several government mapping programs that try to address this. One is called the **Alquist-Priolo Earthquake Fault Zoning Act of 1972**. It is used by California counties to assure that home buyers are aware of active fault zones on or near properties being sold, and it is also used in the planning process for building permits. A portion of the Alquist-Priolo map of Lake County – showing the Clear Lake Riviera – is shown above. Stop 7 is highlighted, so that you can see where we are with respect to the traces of the Konocti Bay Fault Zone.




A portion of the Alquist-Priolo Earthquake Fault Zoning map for Lake County, showing Stop 7 and its relationship to the known splays of the Konocti Bay Fault Zone. The pale yellow colored corridors around each fault splay are used in real estate sales and the county planning process to identify land where special disclosures and building standards apply.

A couple of other interesting sights can be viewed from here. If one were to draw a circle around the limits of the present-day magma chamber (or chambers) that underlies Clear Lake and the Geysers, one would find that Mount Hannah lies directly in the geographic center of that circle. Mount Hannah is a volcanic peak like Mount Konocti, although it is somewhat smaller and older. Mount Hannah is composed of dacite lava flows that range from 900,000 to 1 million years in age.

A short walk across Fairway Drive and up the hill on Olympic Drive will take you to a spectacular view of Mount Konocti and Clear Lake. From here, you get one of the best views of the southeast flank of Mount Konocti and the "lava rings" on Wright Peak. The "rings" are a local term for the crescent-shaped landforms that were created by the last lava that flowed from the top of the peak. This particular lava flow is called the Dacite of Wright Peak. It is about 350,000 years old. As we discussed earlier, Mount Konocti is a **composite** or **stratovolcano**. Volcanoes of this type are formed from many generations of eruptions. That's why there are so many different types of volcanic rock with so many different ages on each of the mountain's peaks.

View of Mount Konocti and Konocti Bay from the top of Olympia Drive

The views of Konocti Bay and parts of the western shoreline of Clear Lake are also great from this spot. Notice the scallop-shaped shoreline, created by the maar eruptions.

Several splays of the Konocti Bay Fault Zone pass into Konocti Bay in the area we see from here. In spots, gas bubbles rise up in the lake water along these fault lines. The most spectacular of these "gas springs" is on the other side of Buckingham Peninsula, out in the lake near Horseshoe Bay. The gas is actually a mixture of a number of volcanic gases and gases that formed from decaying organic matter. Carbon dioxide is the most common component in the springs. It is heavier than air, which is why it has caused safety concerns near some of the springs in Soda Bay.

Earth Science Standards to Consider:

Grade 4:
- Shaping of the landscape due to earthquakes and volcanic eruptions.

Grade 6:
- Earthquakes, epicenters, and plate tectonics.
- Type of building construction in seismically active areas.

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This concludes the main field trip. From Riviera Hills Country Club, an interesting scenic loop can be taken by continuing along the lakeshore via Point Lakeview Road. To do this, continue southward on Fairway Drive 0.6 miles to the intersection with Point Lakeview Road. Turn right onto Point Lakeview Road. Continue 4.3 miles to a wide shoulder turnout overlooking Thurston Lake.

Thurston Lake Overview

Lat.: N 38.92389

Long.: W 122.66067

The road here passes over the Dacite of Wheeler Point (about 400,000 years old) and the Dacite of Thurston Lake (about 440,000 years old). These volcanic deposits form a ridge that


Thurston Lake, as seen from Point Lakeview Road.

isolated the Thurston Lake drainage from the rest of the Clear Lake basin. The bottom of Thurston Lake is considerably higher in elevation than Clear Lake level, so the two aren't directly connected. Seasonal runoff into Thurston Lake does recharge groundwater, however, which eventually enters Clear Lake as springs in the vicinity of Jago Bay. The water in Thurston Lake is remarkably murky (**turbid**), because it is fed by clayey runoff from Manning Flat on the ridge to the southwest. This is a man-made effect. Manning Flat was originally a valley with no natural outlet (called a **closed basin**). Water would have originally accumulated in the basin as seasonal lakes (**vernal pools**). In an effort to drain the valley, land owners attempted (and eventually succeeded) in cutting a channel through the ridge that separates Manning Flat from the Thurston Lake watershed. Since then, the fine-grained sediments in the Manning Flat basin have eroded rapidly, creating a deeply **incised channel** that is actively cutting through the soils in the flat and is threatening State Highway 29. As a prank, the channel was once posted with a sign, reading "Guy's Fault," but the channel has nothing to do with faulting. It is purely erosional, but its path across the flat may have followed portions of old roadways and a race track that was once used there.

Continuing 0.4 miles southward on Point Lakeview Road, we pass Point Lakeview Rock and Redimix. The quarry is on the right side of the road, and has been producing decorative "cinder" rock at this location for many years. This is some of the youngest volcanic rock in the Clear Lake Volcanics. It is probably no more that 40,000 years old. The red rock is **basalt**. Basalt is usually black or dark gray in color. The red pigment is caused when water mixes with the magma as it is erupting. If the conditions are right, the oxygen in the water reacts with iron in the basalt to produce iron oxides, which are red. Most of this rock is full of trapped gas bubbles (called **vesicles**). When basalt is **vesicular** like this, it is also known as **scoria**. During the eruption, the larger chunks of molten basalt would sometimes spin as they flew through the air, giving them a distinctive football-like shape. These are sometimes referred to as volcanic **spindle bombs**. The thick accumulations of these bombs creates a steep-sided cone-shaped volcanic peak, called a **cinder**


Cinder Cone of Roundtop Mountain (Point Lakeview Rock & Redimix quarry).

**cone**. This one is called the Cinder Cone of Roundtop Mountain.

Continue 1.3 miles on Point Lakeview Road to the intersection with State Highway 29. Return via State Highway 29 to the point where the field trip began.

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Suggested Reading:

Adam, D., 1988, Palynology of two Upper Quaternary cores from Clear Lake, Lake County, California: U.S. Geological Survey Professional Paper 1363, 86 p., 5 plates.

Brice, J. C., 1953, Geology of the Lower Lake Quadrangle, California: California Division of Mines Bulletin 166, 72 p., 3 plates

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Hammersley, L. & DePaolo, D. J., 2006, Isotopic and geophysical constraints on the structure and evolution of the Clear Lake volcanic system. Journal of Volcanology and Geothermal Research 153, 331-356.

McLaughlin, R. J., and Donnelly-Nolan, J. M., eds., 1981, Research in the Geysers – Clear Lake geothermal area. U.S. Geological Survey Professional Paper 1141, 259 p.

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McNitt, J. R., 1968, Geology of the Lakeport quadrangle, Lake County, California. California Division of Mines and Geology Map Sheet 10.

Vantine, J., and Spittler, T., 1986, The Geysers field and the McLaughlin mine: Association of Engineering Geologists, 29th Annual Meeting field trip guidebook, October 5-10, 1986, 91 p.