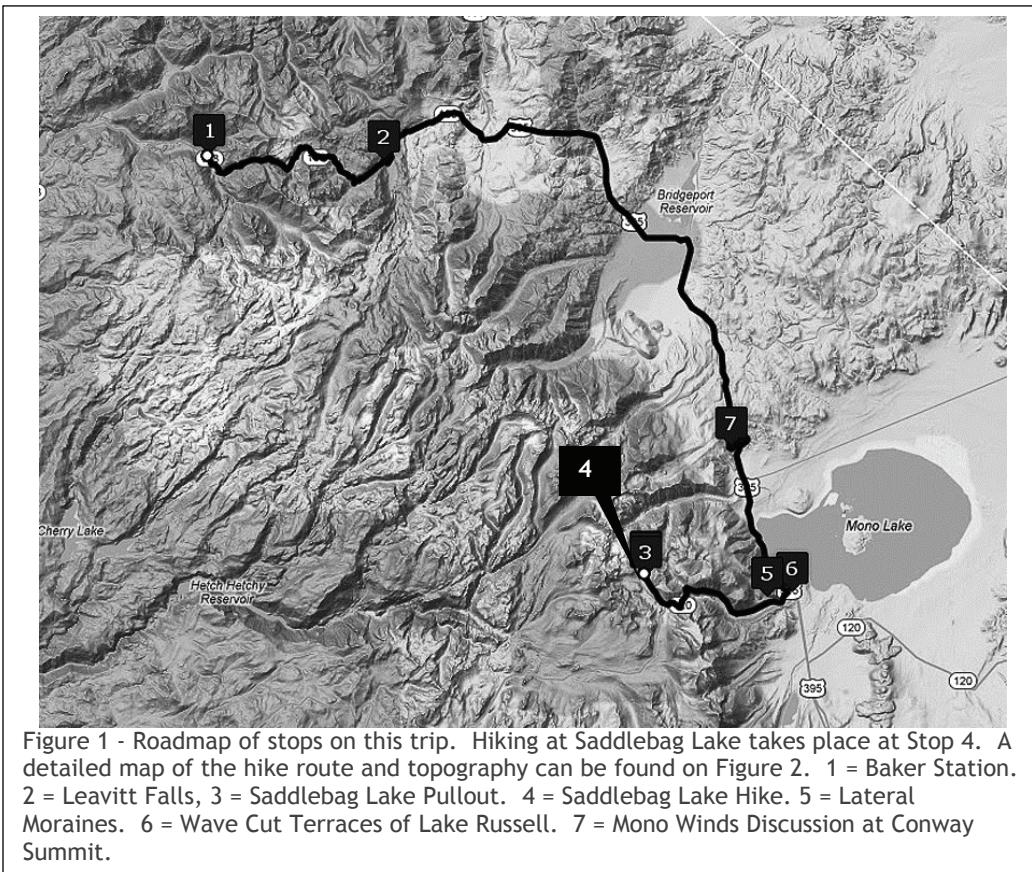


# Geology and Climatology of the Saddlebag Lake Region near Tioga Pass, California.

**Ryan J Hollister - Turlock High School**  
**Laura K Hollister - Pitman High School**

This field trip is designed around a five mile hiking tour into the stunningly beautiful eastern crest of the Sierra Nevada just north of Tioga Pass in the Twenty Lakes Basin of the Hoover Wilderness Area. The tour will explore the glacially-incised boundary zone between the Sierra Nevada Batholith and Saddlebag Lake Pendant which contains rocks from the earliest beginnings of the Sierra Nevada. A good chunk of time will also be given to the exploration of past and present climatology of the area including prehistoric glaciations and historic weather phenomena created by seasonal fluctuations of land and sea temperatures.



Moderate to strenuous hiking at elevations over 10,000' is required. Also, an \$11 dollar water taxi fee across Saddlebag Lake that will eliminate four extra miles of hiking. The roads up to Saddlebag Lake and Log Cabin Mine Road are rough gravel, but most high clearance 2WD vehicles should have no problem navigating them.

Our road log follows a very similar path to that of Garry Hayes' (see *A Teachers Guide to the Eastern Sierra Nevada between Sonora Pass and June Lake, California*) who has done an exceptional job explaining details of roadside attractions all the way south to the June Lake Loop. To eliminate redundancy in this guidebook we have opted to include only the most basic directions to our stops along with Lat/Lon coordinates for GPS users. *All photos taken by Ryan J Hollister unless otherwise noted.*

## Road Log

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### Mileage Btwn Points

#### of Navigation.

#### Total Mileage.

#### Lat/Lon

**0.0 Miles**

**0.0Miles**

**38.328991 / -119.755676**

Stop 1 - Begin at Baker Station and head east up Highway 108. The road gets windy and steep lickity-split.

**15.8 Miles**

**15.8 Miles**

**38.322990 / -119.561180**

Stop 2 - Leavitt Falls turn-out on right. The forest service signage is offset from the road about 100ft making it nearly impossible to find. Look for the pull-out and its 100 yard road that leads into the wooden deck overlook. The 15.8 miles takes over 40 minutes to achieve due to the windy nature of the road. We'll unwind here and take advantage of the pit toilet. Ideally we would like to spend less than 10 minutes here while looking at Leavitt Falls and the Little Walker Caldera across Leavitt Meadows.

**8.8 Miles**

**24.6 Miles**

**38.348461 / -119.452250**

Junction with Highway 395. Turn right and head south on 395. 2012 is the year of road construction for this stretch of road. Hopefully, we'll have smooth sailing.

**41.7 Miles**

**66.3 Miles**

Enter town of Lee Vining. Make sure to slow to the 25mph speed limit. As General Akbar would attest "It's a Trap!"

**1.0 Mile**

**67.3 Miles**

**37.950131 / -119.113054**

Tioga Pass Turn-off. Turn right and ascend HWY 120, taking note of Mobil Gas Station that has the best gourmet fast food in the west: The Whoa Neli Deli. Also be aware that tomorrow there will be over 100 crazy people running from this spot up to Yosemite's entrance in the annual Tioga Pass Run.

**10.0 Mile**

**77.3 Miles**

**37.938303 / -119.248560**

Saddlebag Lake Road junction. Turn right and stay right on gravel road, bypassing campground entrance.

**2.2 Miles**

**79.5 Miles**

Stop #1 for Saddlebag Lake Region (labeled Stop 3 on overview map). Pull-out on left side of road. Stop #3 on overall trip. Description of this stop begins on page following Geologic Setting and is labeled as SB1.

# Hiking Exploration of the Saddlebag Lake Pendant (Road Stops 3-4)

The authors would like to give special thanks to Dr. Richard Schweickert and colleagues for generously sharing their geologic maps and descriptions of the area.

Welcome to one of the most breathtaking areas in the entire nation! If the 10,060' elevation at Saddlebag Lake doesn't purloin your pulmonary response, the vistas most certainly will. The majority of the day will be spent hiking into the amazing Twenty Lakes Basin in the Hoover Wilderness. While we'll try hard not to torture our lungs and legs, we will tax our brains while working to understand the vexing and supremely interesting complexities of the geology. Luckily, a host of great geologists have unraveled a good deal of Saddlebag Lake's geologic story within the past twenty years, making our mission of understanding the rocks just a bit more manageable.



## Stuff to Know and Have

Hike Length: 5.2 miles (or longer/shorter depending on group)

Starting / Max Altitude: 10,060' / 10,580'

Elevation Gain / Loss: +/-1000' due to zig-zag scrambling.

We'll take the water taxi across Saddlebag Lake to shave-off nearly four miles of hiking and get dumped-off into the land where "awesome" was invented. In order to have an exceptionally great time on the hike there are a few things the participant must know. The hike is moderate and requires some physical exertion at altitude. Anyone with experience in the Sierras will be fine. Anyone who hikes or walks or is somewhat fleet of foot will be fine. *Folks who haven't walked more than a mile in the last two months most likely won't be fine.* That being said, your first author's 62 year old mom and 68 year old dad had no trouble with the hike.

*Supplies your first author will be bringing on the adventure:*

- \$11 Water Taxi Fee.
- Camera.
- GPS unit (iPhone) with hike's waypoints.
- Daypack.
- 2 liters of water.
- Sandwich, snacks and gummy bears.
- Light fleece or down poof jacket.
- Light waterproof windbreaker.
- Sun hat and sunglasses.
- First-Aid & CPR Certification along with basic first-aid kit. (Just in case!)
- Positive, cheerful attitude.
- The nagging feeling he's forgotten something.

Bring your camera. We guarantee you will use at least 10 photos from this journey in future lectures and activities. Beyond the camera (if there is such a thing), expect cool temperatures at these high elevations and pack accordingly. Any kind of weather is possible in early September - from snow to thunderstorms to blazing sun. Dehydration and hunger can be crippling at altitude so please also bring food and water. With the obligatory warnings out of the way, let's go have some fun!

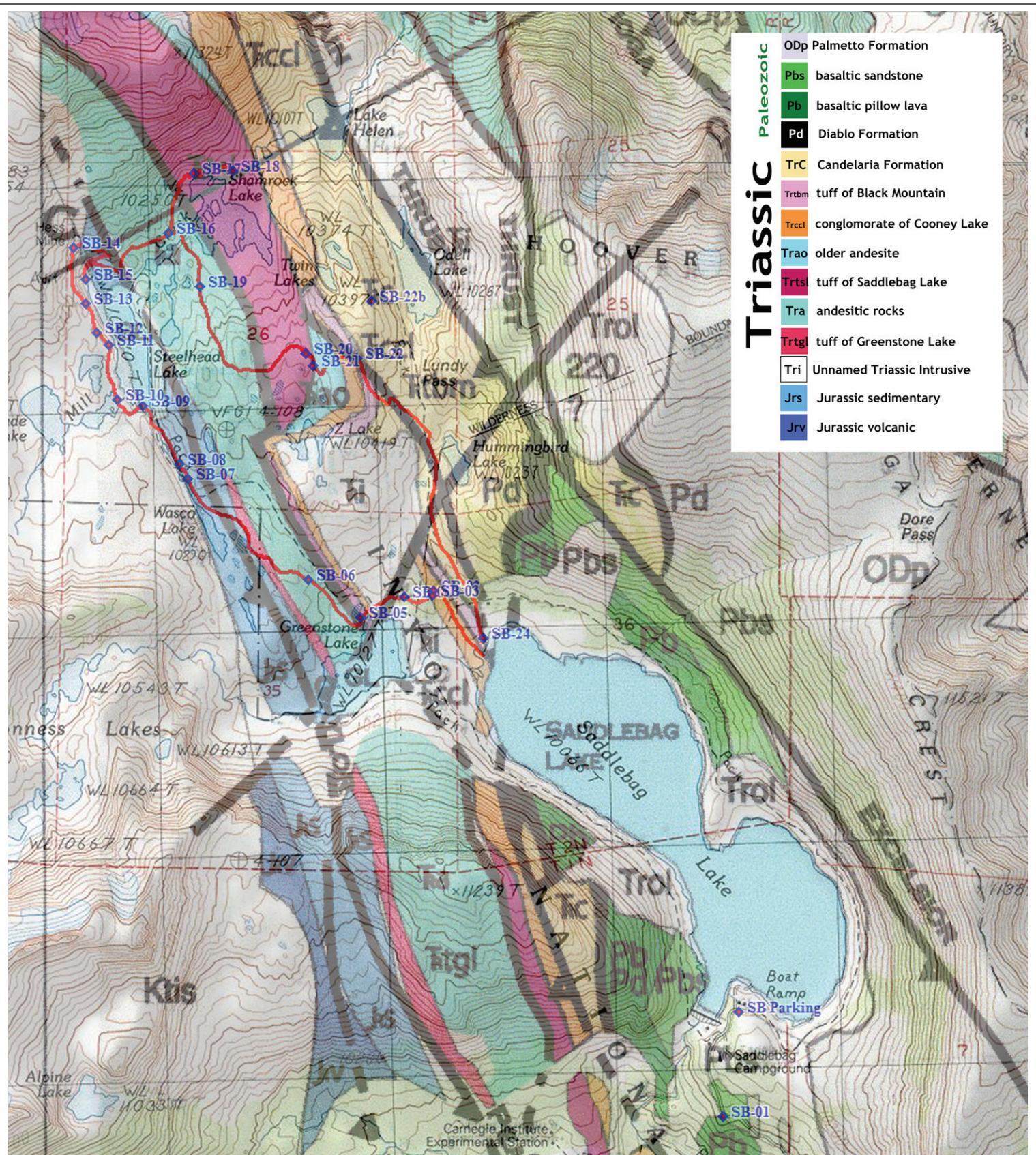


Figure 2- Geologic Map modified from Schweickert & Lahren 2006. Topographic overlay with path of hiking tour shown in red. Hiking waypoints shown as blue diamonds and given ordered numerical designation.

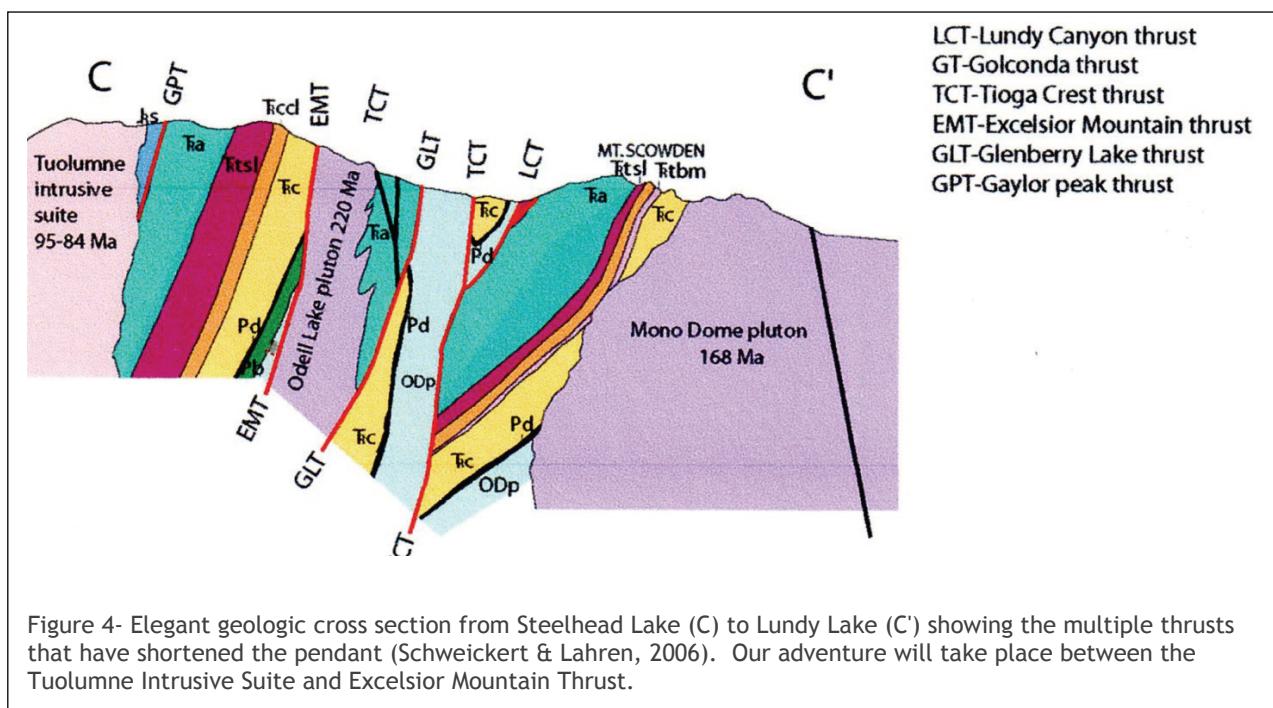
Lithology and Interpreted Paleogeography <b>Saddlebag Lake Pendant</b>	Relative Age **	Rock Formation * Located in area of field trip	
Includes all rocks that stratigraphically overlie the Koip sequence. The sequence contains volcanic sandstone that weathers gray to greenish as well as thinly bedded calc-silicate rock. Thin ash-flow tuff interbeds are present. While the rocks are strongly deformed, grading and cross-bedding can be observed, possibly representing calcareous, volcanoclastic turbidites.	< 211 Early Jurassic	*Sawmill Canyon Sequence	
		Granite of Lee Vining Canyon (Scheelite Intrusive Suite)	
The lower Koip sequence rocks are deposited in a north-northwesterly trending zone which suggests that the region to the northeast was topographic high during their deposition. The Koip sequence rocks were deposited in subaerial and submarine environments and are interpreted to represent a magmatic arc. The Granites of the Sheelite intrusive suite are not formally identified as part of the Koip sequence but Schweickert and Lahren (1999) have stated that the Lee Vining Pluton, part of the Sheelite Intrusive Suite, may represent the sub-surface magma chamber that erupted the rhyolitic ash-flow tuff of Saddlebag Lake from vents along the north wall of the Tioga Pass Caldera.	Rhyodacitic ash-flow tuff with many feldspar phenocrysts and rare quartz. Faint parallel lamination can be discerned.	211	*Rhyodacitic ash-flow tuff of Greenstone Lake
	Include tuff breccia, volcanic conglomerate, lava flows, and interbedded sedimentary rocks.	224 ± 14	*Andesitic rocks
		219	Granites of Mt. Olsen and Odell Lake (Sheelite Intrusive Suite)
	Light colored tuff with abundant broken and embayed quartz phenocrysts as well as 2-3 cm long dark pumice fragments. In the Saddlebag lake region the unit contains lenses of dark gray andesitic ash-flow tuff up to 10 meters long.	222 ± 5	*Rhyolitic ash-flow tuff of Saddlebag Lake
	Shallow water inner fan deposits . Fans likely formed along the southwestern edge of a topographically high region.	Triassic	*Conglomerate of Cooney Lake
	Consists of a medium gray, pumice poor tuff with phenocrysts of plagioclase and occasional phenocrysts of quartz.	Triassic	*Rhyodacitic ash-flow tuff of Black Mountain
Golconda Allochthon Rx – stratigraphic position after Golconda thrust.		(Rocks of the Golconda Allochthon)	
Forms a basin to the northeast and is comprised of sediments derived from the Golconda allochthon that include thinly bedded quartzo-feldspathic siltstone and fine grained sandstone that tend to coarsen upward, suggesting turbidites.	Triassic	*Candelaria Formation	
Composed of conglomerate and lithic chert grained sandstone. The conglomerate contains clasts of chert, quartzite, and marble. Limestone clasts in the conglomerate commonly contain crinoid fragments. A conodont from one clast was dated as permian. The formation most likely shallow marine deposits eroded from high lands in the Roberts Mountains allochthon.	Permian	Diablo Formation	
Rocks assigned to the unit include harzburgite ultramafic tectonite and metagabbro and serpentинized ultramafic rocks, sandstone, quartzite, shale, conglomerate and intermediate siliciclastic volcanic rocks as well as pillow basalts and pillow breccia.	Late Permian	Rocks of the Golconda Allochthon	
Highly iron stained basaltic pillow lavas are exposed in some parts of the pendant. Underlying the pillow basalts is a rust-stained, dark-brown weathered basaltic tuff and tuffaceous sandstone. It is medium grained and parallel lamination occasionally detected indicates deposition in a lacustrine or marine environment.	Permian	Pillow basalts and volcanoclastic sandstone	
Highly deformed, light gray marble. Shows intense mylonitic foliation including several generations of folding. Pennsylvanian conodonts have been found in this unit and the unit has been correlated by Rinehart and Ross (1964) with the Mt. Baldwin marble of the Mt. Morrison pendant to the south.	Pennsylvanian	Limestone of Lundy Canyon	
Underlies entire pendant region except the southeastern part of the Ritter Range pendant and is composed of phosphatic chert, shale, siltstone and argillite with some minor lenses of quartzite, basalt and limestone. Interpreted as a possible continuation of the Antler Orogenic belt.	Ordovician – Devonian (?)	Palmetto Formation	
Figure 3 - Simplified description of rock formations and interpretation of paleogeography represented by each formation. Rock formations are shown in their relative stratigraphic positions. All descriptions, interpretations and dates taken or paraphrased from Schweickert and Lahren, 2006. **Absolute dates in Ma. Dashed lines represent unconformity.			

## Geologic Setting

The Saddlebag Lake pendant, located in the eastern Sierra Nevada Mountains, lies in a northwest orientation from Tioga Pass in Yosemite National Park and extends approximately 35 km northwest to the Twin Lakes region. The pendant is thought to be related to the northern exposure of the Ritter Range pendant (Brook, 1977). Rocks in the eastern exposure of the Saddlebag Lake pendant represent lower Paleozoic metasedimentary rocks interpreted to have originated on the western exposures of the Antler and Sonoma Orogenic belts. The rocks in the western exposure of the pendant represent Triassic-Jurassic metavolcanic and metasedimentary rocks. The Paleozoic and Mesozoic rocks are separated by an angular unconformity (Brook, 1977) and individual formations are separated by unconformities and thrust faults (Schweickert and Lahren, 2006). The pendant is bordered on the east and west by plutonic rocks; the 219 Ma Triassic Mt. Olsen and 168 Ma Jurassic Mono Dome plutons on the east and the 96-84 Ma Tuolumne Intrusive Suite on the west. (Geologic Map of the Saddlebag Lake Pendant, Schweickert and Lahren, 2006).

## Stratigraphy

\*\*\*\*All of the rocks in the Saddlebag pendant have undergone metamorphism, often more than one stage. Lithologic descriptions of formations describe the pre-metamorphic form of the rock following historic convention and as described by Schweickert and Lahren in 2006. \*\*\*\*



### **Stop 1 - Saddlebag Lake Road Pull-Out. (SB-01 - 37.96150,-119.27213)**

This pull-out offers a great view of Sawmill Canyon. Cross the road from the pull-out to view the now steeply dipping, Permian meta-sedimentary sandstone primarily made from basaltic clasts. Cross back over the road and scramble down the hillside below the pullout about fifty feet. You should be able to find a fairly distinct nonconformity where the sandstone ends and large rusty bulbous deposits begin. The large, rusty round rocks are upper Permian pillow basalts that erupted onto an ancient sea floor. The pillows overlie the sandstones making them stratigraphically younger.

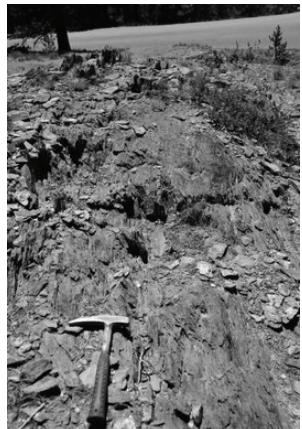


Figure 5 - Upper Paleozoic basaltic sandstone.



Figure 6 - Pillow basalt under hammer with a view looking NW up Sawmill Canyon. Distant snow-capped peaks are part of the 95-84 Ma Tuolumne Intrusive Suite.

**0.4 Miles**

**79.9 Miles**

### **Saddlebag Resort Parking Lot. (SB Parking, 37.96573,-119.27130)**

Saddlebag Lake is the highest drive-to reservoir in California. September, being the off-season, should make parking much easier to find since it is no longer at a premium. Overflow parking is available just 200 meters east of the campground driveway if needed. We'll take a quick look at several downed trees from the December 1<sup>st</sup> Mono Wind event, gather our packs, snacks and water for the day and then head down to the docks to purchase our water taxi tickets. Taxis leave



Figure 7 - Saddlebag Lake "marina".

the dock on :00's and :30's. Take the pontoon taxi across the reservoir to the opposite side of the lake. The reservoir itself has existed since 1919 and is an extension of Southern California Edison's hydroelectric project that we'll discuss further in Tioga canyon near Ellery Lake on our way home – time permitting.

**We'll zero out trail mileage at the north shore drop-off. Due to the drawn-down nature of Saddlebag during this trip it will have an effect on trail distances. In the future it may be necessary to solely rely upon GPS coordinates to successfully find the stops discussed on the excursion.**

Hike Mileage (Start , 37.980034, -119.284279)	Distance from Last Stop 0.0mi	Total Hiking Distance 0.0mi
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#### Stop 2 — Browsing the first exposures of ashflow tuffs

(SB-02, 37.98267,-119.28680)      1193 ft

Immediately, the convoluted & complex geology becomes readily apparent. Here we see our first bit of ashflow tuff which, using Schwieckert & Lahrens geologic map (Figure 2) and descriptions, seems to be part of the Tuff of Black Mountain. There are so many variations of tuff in the area that it sometimes becomes difficult for a geoscientist rusty in field geology to differentiate. The lowest unit of the Koip sequence, the Tuff of Black Mountain lies directly on the Candelaria Formation and is about 40 feet thick in the Saddlebag Lake area. The formation consists of a medium gray, pumice poor tuff with phenocrysts of plagioclase and occasional phenocrysts of quartz.

1193 ft



Figure 8 - Tuff of Black Mountain with hammer for scale.

#### Stop 3 — Foliation and folds.

(SB-03, 37.98248,-119.28690)      51 ft

Just 10 to 15 paces to the southwest of stop #2 is our first example of foliated and folded remnants of what the author interprets to be a higher-grade meta-sandstone of the Conglomerate of Cooney Lake. While the formation displays its characteristic conglomerate much better at stop #18, this rock outcrop is nonetheless an interesting introduction to the contractual forces that have thrust rocks over one another on at least three separate occasions in the area. Let's take a closer look at this rock to indeed confirm that it belongs to the Conglomerate of Cooney Lake .

1244 ft

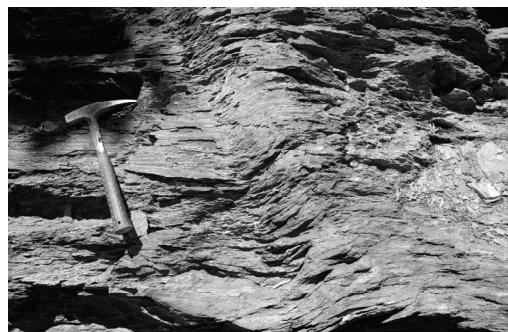


Figure 9 - Folded meta-sandstones.

#### Stop 4 — Strike it Rich at the Exploratory Mine Pit

(SB-04,37.98244,-119.28830)      443 ft

1687 ft

This stop says it all: mining was the pits in this area. This is an exploratory mining pit that surely had its rocks assayed at some point in the 1880's. During the late 1870's -1884 several silver and gold mining towns peppered the Saddlebag Lake pendant region looking to take advantage of the area's tortured geology. The rock layers that had been fractured and weakened by repeated thrusting episodes made perfect conduits for later hydrothermal circulation within the rocks during the emplacement of the Sheelite Intrusive Suite of plutons (and possibly the Tuolumne Intrusive suite as well). Over time, hydrothermal circulation fed by infiltrating surface water altered the rocks surrounding the plutons, turning them a rusty orange and yellow color and depositing trace amounts of silver and gold.

The nearby town of Bennettville thrived on exploratory dreams and positive assays for two years. The Great Sierra Mining company headquartered at Bennettville even went as far as hauling-in expensive machinery in the *winter* of 1882 because dragging steam engines in by sleigh was more efficient than pulling

them up a non-existent Tioga Road. By 1884 the company went bust and Bennettville was abandoned without a single ounce of refined ore ever leaving town. The May – Lundy mine just 10 miles north of here did produce over \$3 million of silver and gold.

The conditions endured by the miners living at elevations in excess of 10,000', *in the winter*, seems almost unimaginable. Working in the cold, dead of winter under feet of snow had to have been nearly impossible, but exploration had to continue year-round to satisfy investors. As described by Douglas Hubbard in *Ghost Mines of Yosemite*, a somewhat terrifying and yet hilarious event occurred at Dana Village on the evening of November 17, 1881 and was recorded in the mining index: “*LUNDY, Nov. 19 — A frightful accident occurred at the Great Sierra Mine, Tioga District, about 11 a.m. on Thursday last, by which three men were seriously, one probably fatally injured. It is the old, old story of thawing frozen nitroglycerine powder on a stove...*”.

Thankfully, the miners actually survived the blast but “*George M. Lee is able to be around as usual, but cannot be induced to sit down, even when engaged with writing. (The fragments of the demolished stove struck George in the rear, below the belt, and numerously.)*”

Let's appreciate the good fortune of visiting here on nice September day as we move to Stop #5 and thank the miners for inspiring the construction of the Tioga Wagon Road – our paved route up Lee Vining Canyon.



Figure 10 - Exploratory mining pit at stop #4. Note hammer for scale in bottom center of photo.



Figure 11 - The remnants of historic Bennettville just a few short miles from Saddlebag Lake. The town was the nerve center of the Great Sierra Mine for two years before going bust in 1883 without producing a dime.

#### **Stop 5 — Look for exposures of Koip Sequence at north end of Greenstone Lake.**

**(SB-05,37.98163,-119.29054)**

**733 ft**

**2420 ft**

Referring to our geologic map we can see that east end of Greenstone Lake marks the beginning of our adventures across the Koip Sequence. The sequence has been tied to volcanic centers originating from the Sheelite Intrusive Suite starting 226-218Ma (Barth et al, 2012). A quick peak at Schweikert & Lahren's stratigraphic section (Figure 3) will help familiarize you with the ordering of the sequence. We'll be starting in the Conglomerate of Cooney Lake (a thin layer here) and working our way through progressively younger rocks until we run into

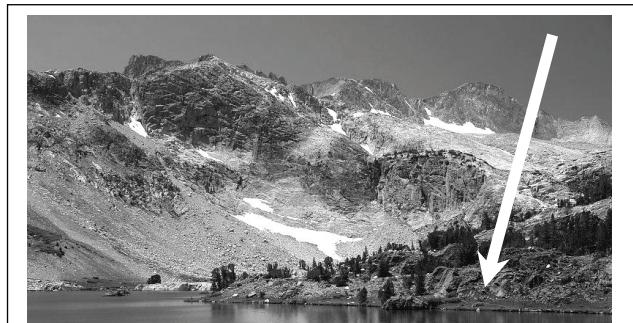


Figure 12 - Greenstone Lake with the Conness ridge in the background. The ridge crest is the eastern boundary of Yosemite National Park. Our path to Stop #5's rocks of interest traverses the area pointed out by the arrow.

the Tuff of Greenstone Lake near Wasco Lake.

**Stop 6 — Polished andesitic rocks with nearby conglomerate.**

(SB-06,37.98313,-119.29319)

.22 mi

.68 mi

Nice exposure of vertically-oriented beddings of andesitic rocks with a nicely glaciated surface that Schweickert and Lahren have called “Triassic Andesitic Rocks”. Let’s take a few moments to study these rocks to use as a reference for our comparison to the other tuffs we’ll later see in the Koip sequence. We’ll be heading off-trail to Wasco Lake for the next half mile or so. Be on the lookout for other weird variations within the Triassic Andesitic Rock as we move. Specifically look for what appears to be a weird little conglomerate or lenses about 200 feet to the northwest of this stop (Figure 14). We’ll also be crossing our first small exposure of the Tuff of Saddlebag Lake and into the Jurassic-aged volcanic sandstones.



Figure 13 - Polished andesitic rocks at Stop #6.



Figure 14 - Rusty spheroidal conglomerates or lenses a few hundred feet northwest of Stop 6. Author's foam finger for scale.

**Stop 7 — Large erratic of Cathedral Peak Granodiorite.**

(SB-07,37.98719,-119.29930)

.48 mi

1.16 mi

We'll be seeing glacial features galore at later stops on the hike, but this massive boulder of Cathedral Peak Granite is too compelling to ignore. The boulder rests atop Jurassic meta-sedimentary rocks. Since the rock didn't originate here and is too far away from any granitic cliffs to have rolled to this spot we can assume it is an erratic. The boulder was transported in (or on) the glacier that once flowed from North Peak and/or Mt Conness, the large granite peaks to our west. The huge feldspar megacrysts make Cathedral Peak Granite one of the easiest to rocks to recognize in the area.



Figure 15 - Cathedral Peak granite glacial erratic from the nearby Tuolumne Intrusive Suite. Be sure to marvel at the phenocrysts of k-feldspar! Note hammer lying at bottom r-center of photo.

### Stop 8 — Gaylor Peak Thrust

(SB-08,37.98775,-119.29970)

.04 mi

1.20 mi

The trail is now following the trace of the Gaylor Peak Thrust Fault through the Jurassic Sandstone. It seems likely that the small linear valley between Wasco and Steelhead Lake was eroded out of softer material ground and weakened by the thrust.



Figure 16 - Trail following Gaylor Peak Thrust.



### Stop 9 — Sawmill Canyon Sequence at south end of Steelhead Lake.

(SB-09,37.99012,-119.30159)

.21 mi

1.41 mi

Upon arriving at the south shore of Steelhead lake, cut-off to the left of the trail to find stunning exposures of vertically dipping Jurassic sandstone. The sandstone is part of the Sawmill Canyon Sequence of rocks. The Sawmill Canyon Sequence includes all rocks that stratigraphically overlie the Koip Sequence and in the Saddlebag Lake area they are about 600 feet thick. The sequence contains volcanic sandstone that weathers gray to greenish and also contains thinly bedded calc-silicate rock. Thin ash-flow tuff interbeds are also present in areas. While the rocks are strongly deformed, grading and cross-bedding can be observed, possibly representing calcareous, volcanoclastic turbidites. Overlying the volcanic sandstone but not present on our adventure are dacitic to rhyolitic ash-flow tuff and andesitic tuff-breccia and lava. No matter one's geologic affinities, all can agree that this is one of the prettiest rocks California has to offer. This exposure has the added benefit of being cross-cut by sills and/or dikes of the Cathedral Peak Granite. From this point we'll be heading cross-country again by scrambling up the south shore of Steelhead Lake and heading over the granite to Cascade Lakes. Things to look for on the way: green to light green thin beds, grading and cross-bedding.

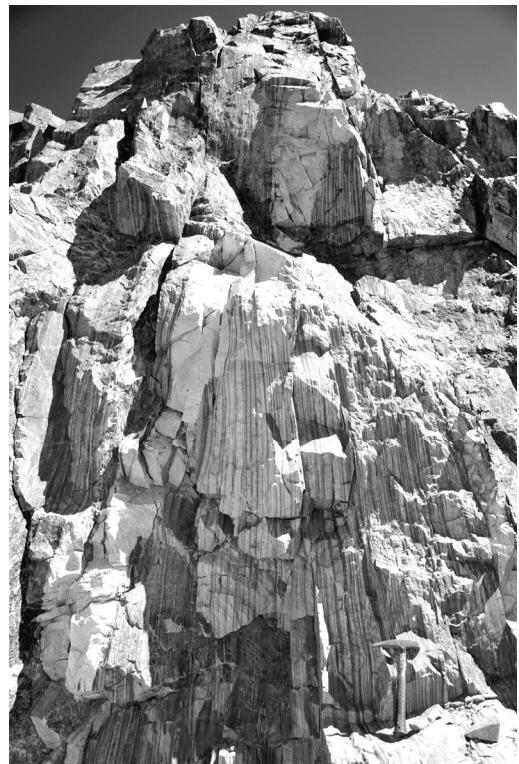


Figure 17 - Jurassic sandstone with cross-cutting feldspar intrusion at south end of Steelhead Lake. B&W doesn't do this beautiful rock justice. Note hammer for scale in bottom right of photo.

### **Stop 10 — Cascade Lakes – Cathedral Peak Granite and Glacial Features.**

**(SB-10,37.99035,-119.30290) .10 mi**

**1.51 mi**

The Cascade Lakes are fair examples of paternoster lakes, a chain of glacially-scoured jewels connected by a single stream. The lake beds were scoured by glaciers during the most recent episodes of glaciation (Figure 37) and their depressions filled with water upon the glaciers retreat. Ample evidence of glaciers can be seen in the glacial polish and striations on the 88Ma Cathedral Peak granite which contains huge megacrysts of potassium feldspar. Looking to the west, we'll be able to appreciate the cirque at the base of massive North Peak.



Figure 18 - Lower Cascade Lake as seen from stop #10. The cirque below North Peak is a fun place to explore with more time.

### **Stop 11 — Photogenic erratic**

**(SB-11,37.99255,-119.30332) .16 mi 1.67 mi**

Continuing our northward tack we'll climb the western shore of Steelhead Lake and quickly come upon this photogenic erratic that found itself perched upon a 100' cliff made of the Jurassic sandstone. We'll now continue north up the contact between Tuolumne Intrusive Suite and Jurassic sandstone.



Figure 19 - Photogenic erratic.

### **Stop 12 — 3,2,1 Contact**

**(SB-12,37.99307,-119.30390) .03 mi 1.70 mi**

It's not often one gets to take a long stroll through time, but the next several hundred meters provide such an opportunity as we walk the nonconformity between the Jurassic sandstone and Cathedral Peak granite. The sandstone predates the intrusion of the granite by nearly 100 Ma! The results are aesthetically arresting and geologically interesting. Many dikes and sills criss-cross the sandstone which appears to have also been contact metamorphosed. Strange green mineral lenses (epidote?) accent rusty yellow and orange sections near the contact, but just several feet away from the contact the characteristics quickly disappear.



Figure 20 - Contact between Jurassic sandstone on right (green, gray & orange) and Cretaceous Cathedral Peak granite on the left. View seen from western cliff of Steelhead Lake. Besides the erratics, look for all the gnarly baked contact metamorphism features.

**Stop 13 — View of Steelhead Lake and Hess Mine Tailings.****(SB-13,37.99420,-119.30448)****.10 mi****1.80 mi**

Continue north on the top of the cliff to reach this overlook of the Hess Tungsten Mine tailings at the northwest of Steelhead Lake. We'll follow a faint trail to the north end of the lake and then pick our way down after stop 14.

**Stop 14 — Pika Party: Symbols of a changing environment.****(SB-14,37.99645,-119.30510)****.18 mi****1.98 mi**

Your trip's author had a five minute-long conversation with a rather brazen Pika in these talus piles on his scouting trip. Hopefully some of its friends will chat with us too. The normally skittish rabbit-relative enjoys rock-star status among climate change mascots because of its overwhelming cuteness. The pika have adapted to life in the talus at very high and cool elevations near timberline. Ecologists are currently studying if and how global warming will affect pika populations. Worst case scenarios project even the highest elevations of their range may become too warm for their habitation in the near future.

Continue down the old mining road to the Hess Mine tailings.



Figure 21 - Pika above Hess Mine. Its ill temper, hideous looks and propensity for attacking unsuspecting victims with a leaping, fang-first attack have helped it become one of the most reviled and feared mammals known to man.

**Stop 15 — Hess Mine Tailings****(SB-15,37.99522,-119.30449)****.20 mi****2.18 mi**

The large tailings piles and indentation dug into the hillside are the remnants of the Hess Tungsten Mine that operated in earnest during the 1940's and sporadically into the 1960's. Tungsten was a strategic mineral used for hardening steel during WWII and many tungsten mines briefly popped-up in the metamorphic roof pendants of the highest Sierra looking to support the war effort. Production information for the mine is sketchy and no official numbers could be found.

To get to stop 16 we'll hike near Steelhead Lake's outlet and follow the trail for a brief steep climb over a small knob and drop down to the pretty Excelsior Lake. Follow the trail to stop 16, traversing a wide exposure of the unnamed andesitic rocks that have conspicuous feldspar phenocrysts.



Figure 22 - Hess Tungsten mine tailings as seen from Stop 16.

**Stop 16 — Andesite Breccia & epidote (?)-rich erratics.****(SB-16,37.99708,-119.30030)****.32 mi****2.50 mi**

This stop has a little of everything. Amazing exposures of what have been interpreted to be slightly metamorphosed andesitic breccias are overlain by erratics of the Cathedral Peak Granite and Jurassic sandstone. The sandstone erratics are covered in an electric green mineral that appears to be epidote or related mineral. The unit named "andesitic rocks" by Schweickert and Lahren (2006) is up to 5,000 feet thick in the Saddlebag area and is a mixture of tuff breccia, volcanic conglomerate, lava flows, and interbedded sedimentary rocks.

These include mafic metavolcanic

flow breccia with angular to rounded clasts of basalt and andesite in a fine grained matrix, massive greenish andesite flows, rhyodacitic tuff, conglomerate, siltstone and graywacke. Pillowed andesites have also been observed in and near Sawmill Canyon.



Figure 23 - Lightly metamorphosed andesitic breccia at Stop 16. Hammer for scale.

For now we'll continue down the trail to Shamrock Lake while traversing our first large and readily recognizable exposures of the Tuff of Saddlebag Lake.

**Stop 17 — Shamrock Lake and easily discernible contacts between three formations in the Koip Sequence.****(SB-17,37.99946,-119.29898)****.19 mi****2.69 mi**

Looking southwest from this spot directly at the hill behind Shamrock Lake, a tri-color Neapolitan rock-unit sandwich should become evident on its slopes. The light gray and orange rock that we stand upon in the center of the sandwich (the vanilla?) is the Tuff of Saddlebag Lake. The unit is 300 feet thick in the



Figure 24 - Neapolitan Rock Sandwich. "Strawberry" orange Conglomerate of Cooney Lake on left, "vanilla" Tuff of Saddlebag Lake in center and darker "chocolate" Triassic andesitic rocks at right. Shamrock Lake in foreground.

Saddlebag area. This tuff weathers white to light gray and contains abundant broken quartz phenocrysts as well as 2-3 cm long dark flattened pumice fragments in a light gray matrix. In the Saddlebag Lake region the unit contains lenses of dark gray andesitic ash-flow tuff up to 10 meters long. It has been dated at  $222 \pm 5$  Ma using U-Pb zircon radiometric dating and has been chemically linked to have been comagmatic with the Sheelite Intrusive suite. The most convincing center of origin for the tuff is the Tioga Pass Caldera (Schweickert & Lahren, 2006) fed by the Lee Vining Canyon granite pluton just several miles to our south!

The “chocolate” of our sandwich are the darker Triassic Andesitic rocks to our right that we passed in Stop 16. To get to stop 18 and the very orange-stained “Strawberry” rock unit of the sandwich, we’ll continue northeast above the shores of Shamrock lake for about 1/10<sup>th</sup> of a mile.

#### Stop 18 — Conglomerate of Cooney Lake

(SB-18,37.99956,-119.29700)

.13 mi

2.82 mi

As promised at Stop 3, we have finally arrived at good exposures of the Conglomerate of Cooney Lake. The conglomerate of Cooney Lake averages 500 feet thick and contains conglomerate and sandstone layers. The conglomerate beds are often flat-bottomed and internally graded indicating they may be turbidites or mass flow sequences on a shallow water fan. The fans likely formed along the southwestern edge of a topographically high region associated with an earlier orogeny. The conglomerate contains rounded to sub-rounded clasts that include quartzite, chert, argillite, and silic volcanic and granitoid rocks. The sandstone layers tend to be massive. Here the conglomerate is also glacially polished and a bit more deformed than elsewhere.



Figure 25 - Conglomerate of Cooney Lake. This portion of the formation has undergone stronger metamorphism as noted by the stretched clasts.

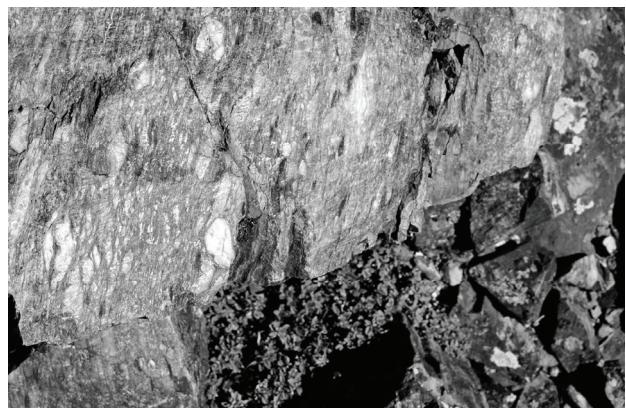


Figure 26 - Fresh surface of the strongly altered conglomerate. Note one rounded clast at the center of the photo that held-up to the changes. Clast is about 1" in diameter.

To get to Stop 19, we must backtrack to Stop 16 and then head due south, off-trail and up the hill behind Shamrock Lake. We'll try to walk the contact between the “vanilla” Tuff of Saddlebag Lake and the unnamed “chocolate” andesitic rocks. The majority of the remaining hike will be cross country. Keep an eye out for amazing cross-cut erratics on our way up the hill.



Figure 27 - Cathedral Peak granite erratic cross-cut by feldspar intrusions.

### **Stop 19 — Stark erratic.**

**(SB-19,37.99489,-119.29865) .57 mi 3.39 mi**

This erratic is a personal favorite of the authors. It lies in such stark contrast to the surrounding oxidized andesite and is so huge and out of place that it is simply breathtaking. It has the added benefit of having its source make a tremendous background for photos. This stop also marks the start of our glacial landform features scavenger hunt. The tuffs and andesite in this area were more prone to carving and polishing and thus have retained some interesting scars from the glaciations. Continue up the hill, cresting at the small saddle and then take a sharp left (west) to Stop 20.



Figure 28 - Giant and stark erratic of Cathedral Peak granite resting upon darker, older and oxidized andesitic rocks.

### **Stop 20 — Crazy-awesome glacial features scavenger hunt.**

**(SB-20,37.99222,-119.29333) .53 mi 3.92 mi**

This is a zig-zagging scavenger hunt to see who can find the most awesome glacial features. The “older andesite” rocks and Tuff of Saddlebag Lake are loaded with glacially created surprises. Within an area of a football field the authors have found deep glacial gouging and polish, what appears to be a pothole formed by subglacial streams (Figure 31) and crescent moon-shaped chatter/ gouging marks where the glacier momentarily skipped atop the bedrock (Figure 30). The power of discovery is strong in this area so we’ll spend a few minutes here to see what we can find. Also, keep an eye out for the structure seen in (Figure 29). The authors are at a loss trying to explain its formation beyond a mafic intrusion and possible subsequent micro faulting. From here hike a mere 200 feet south to Stop 21.



Figure 31 - Pothole carved by probable subglacial stream.



Figure 30 - Glacial striations and chatter marks. 6' fishing rod for scale.



Figure 29 - What is this? Good question. Hopefully we can figure it out. Square black lens cap is a 4" square in center of photo.

### **Stop 21 — “Lightning Rocks”**

**(SB-21,37.99172,-119.29291)**

**.06 mi**

The Older Triassic Andesitic rock at this spot has been hydrothermally altered by cross-cutting long (20m), skinny (20cm), black veins oddly rich in quartz. Some type of chemical reaction obviously happened within the vein and turned the areas directly surrounding the black veins snow white. The result looks like lightning bolts to your authors. Let's put our heads together and try to figure out the mineralogy of the veins. If nothing else, the veins are very photogenic.

To get to stop 22 we'll head west up and over the knob. We'll again briefly cross the Conglomerate of Cooney Lake, a thicker exposure of the Tuff of Black Mountain on our way to Stop 22.

### **Stop 22 — Adios Koip, hello Candelaria!**

**(SB-22,37.99204,-119.29069)**

**.16mi    4.14mi**

At long last we've ditched the Koip Sequence and are now squarely situated on the western-most exposures of the Lower Triassic Candelaria Formation. The Candelaria Formation forms a basin and is comprised of sediments derived from the Golconda allochthon. The formation ranges from 0 to 3,130 feet thick and coarsens upward. It includes thinly bedded quartzo-feldspathic siltstones and fine grained sandstones. The sandstones display well developed Bouma sequences, suggesting turbidites. The formation also contains pebble and cobble conglomerate near the top (our current location) with clasts of chert, granite, and volcanic rocks. The siltstone layers contain fossilized serpulid worm tubes. The Candelaria is dated as Triassic due to its stratigraphic position below Upper Triassic metavolcanic rocks and above Permian Diablo conglomerate. (Schweickert and Lahren, 2006). We'll be looking for thin beds in the sandstone and siltstone, Bouma sequences in the sandstone, and conglomerate.

**3.98 mi**



Figure 32- "Lightning Rocks". Are they the byproduct of hydrothermal alteration in fractures of older andesitic rocks? What made the white stuff? 4x4in square lens cap for scale.



Figure 33 - Thinly bedded sandstone of the Candelaria Formation.

**Stop 22b —OPTIONAL Awesome graded conglomerate of Candelaria.**

**(SB-22b,37.99431,-119.28995)**

**+290 “bonus” yards.**

If time and energy permits, a brief side-track to stop 22-b provides awesome examples of a three-foot thick graded conglomerate laid atop a sandstone. The hike is a bit of a scramble, but worth it if the group can muster it.



Figure 34 - Graded conglomerate resting atop bedded sandstone.  
72mm lens cap for scale.

To get back to the boat docks we'll pick our way down to the trail running alongside Odell and Hummingbird Lakes. It's all Candelaria formation from here on out with fewer exposures, thus the hike back is quick!

**Stop 24 (or 23 if you'd like to be a stickler) — Boat Docks. We survived.**

**(SB-23,37.98079,-119.28428)**

**.96 mi**

**5.1 mi**

Take the taxi back across the lake. Take a potty break. Regroup and then resume our road trip to view evidence of the glaciations in the area. Return down Saddlebag Lake road, pausing at the intersection with HWY 120 to enjoy the view of the Lee Vining Canyon Granite.

## Resume Road Log Mileage at 79.9 miles

---

**2.5 Miles**

**81.4 Miles**

**37.938303 / -119.248560**

**Stop** briefly at widened junction of HWY 120 and Saddlebag Lake road to view Lee Vining Canyon Granite. Then turn left (east) onto HWY 120 and head downhill.



Figure 35 - Lee Vining Canyon Granite as viewed from intersection of HWY 120 and Saddlebag Lake Road. The granite is the likely source of the 222Ma Tioga Pass Caldera.

**1.0 Miles**

**82.4 Miles**

**37.935554 / -119.232315**

Ellery Lake Pullout. If predetermined at last stop, pull out to the left at outlet of Ellery Lake. Lee Vining creek is utilized by Southern California Edison to produce small-scale hydro-power. The energy generated by the long fall of the water from this point down several thousand feet of penstocks has kept the Poole Power Plant at the base of the falls humming since 1923. The damming of Saddlebag, Ellery and Tioga Lake allows for consistent flow throughout the year.

**7.6 Miles**

**90.0 Miles**

**37.940585 / -119.127027**

Exit HWY to Left and onto Log Cabin Mine Road marked by an old wood sign mentioning a Boy Scout Camp. Steeply climb on bumpy dirt road staying LEFT at two different lesser road junctions.

**1.0 Miles**

**91.0 Miles**

**37.942616 / -119.137070**

**STOP 5** – Pull out on the obvious widening of the road that overlooks the canyon.

## Stop 5 - Lee Vining Canyon Moraines: Late Pleistocene Climate Documentarians.

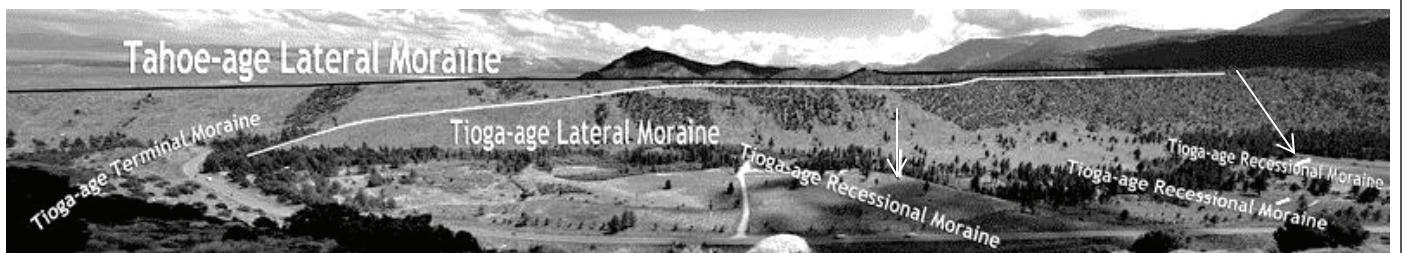


Figure 36 - Tahoe and Tioga age moraine as seen from Log Cabin Mine Road stop.

### Lateral Moraines

This sweeping southerly view across the last third of Lee Vining Canyon was attained by climbing nearly 600 feet along the spines of two sets of glacially-created lateral moraines. Our vantage reveals several prominent glacial features within the canyon that go unnoticed to the untrained eye at highway level. It also provides a sense of the immensity and extent of the glaciations that once occupied the area. The large canyon that accommodates Highway 120 is indeed a large glacial trough, the marginal boundaries of which are marked by the fine examples of lateral moraines across the trough (figure 7). The lateral moraines are composed of jumbled and unconsolidated debris, referred to as till, that was derived from the freeze-thaw erosion of canyon walls upstream in Lee Vining Canyon. The eroded till was deposited atop the margins of the glacier and transported with the flow of the glacier. The till gradually accumulated over time until the glacier melted, leaving behind the large moraines that parallel the valley floor.

A keen eye will be able to differentiate two distinct lateral moraines across the valley; a taller moraine with a rounded ridge and a slightly shorter, sharper-ridged moraine tucked along the inside of the larger moraine. Each moraine represents a distinct period of glaciation, originally distinguished by their relative positions to one another, but more recently given an absolute age using advanced cosmogenic radionuclide dating techniques. The tallest lateral moraine represents the peripheral remnants of Tahoe-age glaciers that occupied the valley sometime between 170 and 80 thousand years ago. Because the shorter lateral moraines are nested within the larger Tahoe-aged moraines, we can deduce that they were created by the smaller, more recent Tioga glaciations. Had the Tioga glaciation been larger, the ice would have wiped-out or re-worked pre-existing moraines of the Tahoe period.

### Terminal & Recessional Moraines

The Tioga glaciation period apparently occurred in three distinct pulses (figure 8) starting around twenty-eight thousand

CHRONOLOGY OF TAHOE & TIOGA GLACIATIONS USING BEST-ESTIMATE UPPER AND LOWER LIMIT AGES FOR MORAINE UNITS SAMPLED IN BISHOP CREEK & VICINITY USING COSMOGENIC DATING.

Production parameterization	Phillips et al. (2001)	Stone et al. (1996)	Swanson and Caffee (2001)
	(ka)	(ka)	(ka)
Tahoe	170–130	140–120	110–80
Tioga 1	28–24	26–22	22–28
Tioga 3	18.5–17.0	17.5–16.0	14.0–12.0
Tioga 4	16.0–14.5	14.0–12.0	11.5–9.5
Recess Peak	13.4–12.0	12.0–10.5	9.5–8.5

Figure 37 - Simplified glaciation timeline of Lee Vining Canyon adapted from Phillips, et all, 2009 .

years ago and ending about nine thousand years ago. More evidence that the Tioga glaciations were smaller and more recent than the Tahoe glaciation can be seen by looking to the southeast from our vantage point. The large pile of till that cuts across Highway 120 just as the road bends out of sight is the Tioga-age terminal moraine, marking the furthest advance of the glacier. The till was transported within the moving glacier and deposited at the glacier's terminus in much the same way a grocery market's conveyer belt dumps groceries at the end of the checkout counter. The Tioga-age terminal moraine rises 100' above the valley floor and a great cross-section of its unsorted and heterogeneous till can be observed in detail at the Highway 120 roadcut which hosts a convenient large pullout near two large water storage tanks.

Three obvious but relatively small recessional moraines can be seen by looking due south and slightly up canyon from our vantage point. Generally speaking, the longer a glacier's terminus (also known as a toe or snout) occupies one spot, the more till will accumulate at the terminal or recessional moraine. The recessional moraines demarcate an area where the receding Tioga glacier paused at several points along its retreat.



Figure 38 - USGS reconstruction of Tioga Glaciation in Yosemite. Available in color at <http://pubs.usgs.gov/imap/i1885/>

#### Cosmogenic Radionuclides and Absolute Age Dating of Moraine Creation

No fewer than fifteen periods of glaciation are recognized to have occurred in the Sierras during the past two million years, but because of erosion and topographic reshaping by subsequent glaciations only two periods of glaciation are recorded in the deposits of Lee Vining Canyon: The Tahoe and Tioga glaciations. As mentioned earlier, prior to the 1980's absolute dating of quaternary moraines was

difficult and limited to radiocarbon dating of organic matter within the youngest glacial moraines. The recent advent of cosmogenic radionuclide dating has entirely changed the once dismal prospects of absolutely dating material younger than several million years but older than the constraints of radiocarbon dating. We felt the basics of this mind-blowing science needed to be briefly described here in the context of dating a moraine to fully appreciate its value. The following bullets are adapted from Cupit (unpublished, 2008).

1. Cosmic rays (ions) generated by supernova shockwaves bombard Earth at constant rate.
2. Cosmic rays collide with the surface atoms of stationary terrestrial rocks exposed to the sky atop moraines.
3. Cosmic rays' interactions with the surface of the rocks blast out subatomic and atomic particles (spallation) whose isotopic rarity makes them identifiable as cosmogenic in origin.
4. The commonly used nuclides  $^{10}\text{Be}$ ,  $^{36}\text{Cl}$ ,  $^{26}\text{Al}$ ,  $^3\text{He}$ ,  $^{21}\text{Ne}$ ,  $^{38}\text{Ar}$ ,  $^{14}\text{C}$  are obtained from various minerals such as calcite, olivine and quartz exposed to the cosmic rays within the surface of the rocks.
5. Collected field samples are subjected to very sensitive, high precision, atomic-grade noble gas spectrometers or accelerator mass spectrometers to determine amounts and ratios of nuclides.
6. After accounting for variables such as altitude, latitude, geomagnetic field and solar winds a precise exposure age calculation can be determined using known production and decay rates of the nuclides.
7. The calculated age reports the duration of time the sample rock sat in its exposed position atop the terminal moraine.
8. Since no new till has been added to the top of the terminal moraine since the retreat of the glaciers, we can assume the age of the exposed rock closely approximates the time at which the glacier started its retreat.

#### **Fosse: A perfect nature preserve.**

The lush valley directly to our north, called a fosse, was created when the Tahoe lateral moraine redirected a small tributary stream. The area is very lush and home to abundant amounts of wildlife that are now preserved as a privately owned sanctuary by the Burger's Sierra Retreat.

After passing the Tioga terminal moraine on Highway 120 on our way back down, try to locate the larger Tahoe terminal moraine before we get to the next stop, just a mile or so beyond the junction of Log Cabin Mine road.

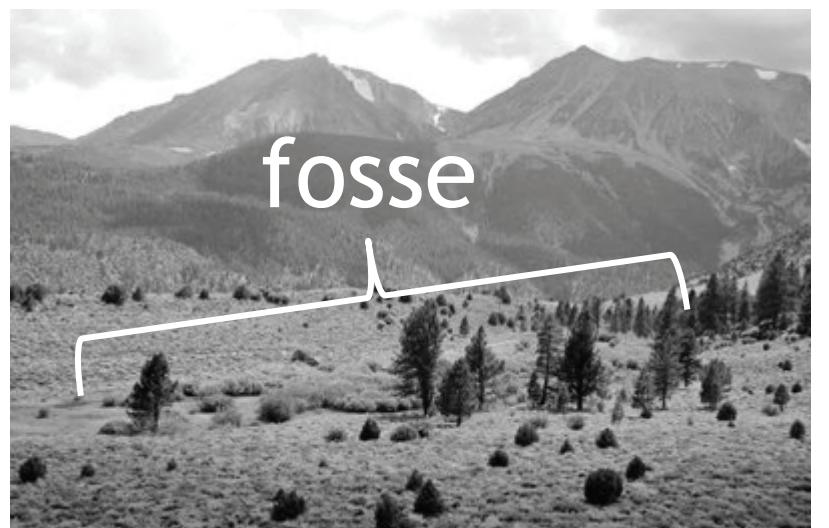


Figure 39 - Fosse alongside Tahoe-aged lateral moraine at Log Cabin Road Stop. The lush valley was created when the lateral moraine diverted the flow of a small creek into the small depression between the moraine and Lee Vining Canyon.

**1.0 Miles                    92.0 Miles**

Back track to the junction of HWY 120. Turn left towards Lee Vining for a short drive to our next turn.

**1.1 Miles                    93.1 Miles                    37.947927 / --119.113879**

Turn Right onto the road leading past the Mobil Gas Station and continue up the road for a quarter mile, keeping left to reach a well-marked overlook with round-about.

**0.2 Miles                    93.3 Miles                    37.947838 / -119.110229**

**Stop # 6 – Park at one of the spaces in the asphalt roundabout. Get out and have a looksee.**

## **Stop 6 - Missing Terminal Moraine and a Flat-Rate Explanation.**

---

Hopefully your hunt for the Tahoe terminal moraine on the drive to this stop was fruitless. No such moraine ever existed! Why? It turns out that this stop is all wet. Strike that. *Was*, all wet. As of this writing in late July of 2012, the Mono Lake surface elevation was at 6382.7' above sea level. However, during the time of the Tahoe glaciation, the lake's surface was much higher, possibly reaching elevations of nearly 7000 feet. Our group would have needed a sturdy boat to be at this exact spot during Tahoe times when Pleistocene Lake Russell (Mono Lake's precursor) consumed most of the view laid before you. The large surface area of Lake Russell provided an extremely long fetch length across which winds could howl, most likely resulting in consistent, if not large, wave action. The wave actions worked their erosive magic near Lee Vining, mowing flat the terraces on which we now stand and etching hundreds of thousands of years of lake level records into the surrounding rocks.



Figure 40 - Bring the scuba gear! View from atop wave-cut terrace just above the Whoa Neli Deli & Mobil Gas Station in Lee Vining. The flat-topped mounds behind the flag are remnants of the Tahoe age lateral moraine that was eroded flat by wave action of a much larger and deeper Pleistocene Lake Russell.

The terraces also provide a vital clue as to why no terminal moraine formed here during the occupation of the very large Tahoe glacier. Quite simply, the glacier ended in the lake and the sediment was rafted "out to sea". Glazner & Stock provide a great visual in their *Geology Underfoot in Yosemite National Park*: "Thus, rather than forming a terminal moraine, the Tahoe glacier instead calved into the lake, sending out floatillas of icebergs. If there had been cruise ships back then, a popular activity would have been watching sediment-laden icebergs calve off the glacier into Lake Russell".

**0.2 Miles                  93.5 Miles**

Backtrack to the Mobil. Take a minute to stretch or tinkle if needed. Turn right onto 120 to meet the junction of HWY 395.

**0.2 Miles                  93.7 Miles**

Turn LEFT on HWY 395 and head north. Pass Mono Lake and climb Conway Grade past the spheroidally-weathered granite.

**11.8 Miles                  105.5 Miles.    38.074135 / -119.176682**

STOP 7. Make a harrowing left turn across traffic into the LARGE paved overlook at Conway Pass. The breezes up here will make a nice backdrop for Stop 7.



Ryan J Hollister

Figure 41- Late springtime view as seen from Conway Pass pullout, home to Stop #7. Mono Lake, Eastern Sierra escarpment and HWY 395 in the distance.

## Stop 7 - Blown-Away: The Monos.

Active geology is not the only exciting and powerful geoscience process in the central Sierras. Regional topographic and climatological factors join forces in the late fall through early spring to periodically create a vicious local katabatic wind known as the Monos. The winds have been known to snap 40" diameter pines at the trunk and are responsible for at least six deaths in Yosemite's history (Ghilgieri & Farabee, 2007). To understand how the Monos are created and why they can wreak such abnormal havoc , a quick primer on atmospheric basics for the Sierras is in order.



Figure 42 - Blown down trees at Mono Pass Trailhead, Yosemite. The trees were felled by the December 1, 2011 Mono wind event. Sustained wind of over 70mph blew through this canyon for nearly 6 hours.

### Atmospheric Basics

The high relief and extensive length of the Sierras act as a staunch barrier between air masses of different pressures on either side of the crest of the range. Air masses, when unimpeded, will travel from areas of high pressure to areas of low pressure across what is known as a pressure gradient. The greater the difference in pressures as well as the proximity of the pressure centers will determine how quickly the air will flow across the gradient. The concept can be imagined in a more visible sense by picturing areas of high pressure as "mountains of air" flowing down into low pressure "valleys of air" (Figure 44). The more extreme the elevation profile between "mountain" and "valley", the faster the air will flow between the centers of pressure. The Coriolis effect also plays a sizable role in the wind direction by deflecting high-to-low flows to the right in the

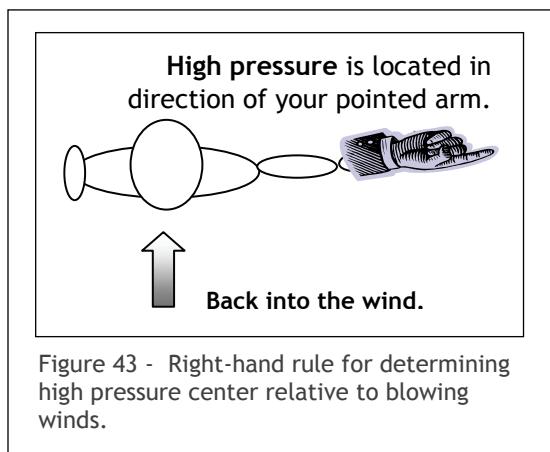


Figure 43 - Right-hand rule for determining high pressure center relative to blowing winds.

northern hemisphere. The force has a much more sizable deflection effect in the higher altitudes where ground friction is minimal. To simply find the direction of the high pressure center, turn your back to the wind and fully extend your right arm to the side (Figure 43). Your arm will now be pointing in the general direction of the high pressure center.

#### **Winter Precipitation and “Normal” pressure gradients.**

The Sierran crest usually separates air masses and impedes their idealized flows over the pressure gradient. This set-up is generally beneficial for water-dependent organisms in California. Moisture-laden storms spun-off the Aleutian Low in the Gulf of Alaska push onshore from the west-northwest in the winter and spring months( Figure 45) following pressure gradients that move the strong polar jet stream (high altitude strong winds) over California . The westward flow forces the moist air up and over the Sierras' west slope in a process known as orographic lifting. The lifted and expanding air mass cools at a generalized dry adiabatic rate of  $10^{\circ}\text{C}/1000\text{m}$  ( $\sim 4^{\circ}\text{F}/1000\text{ft}$ ), quickly causing the air mass to reach its saturation point (Figure 46) The resulting clouds and precipitation from the air in this process provide the water that 65% of the state relies upon for agricultural, domestic and recreational use.

#### **Rain Shadow**

The condensation process within a saturated air mass causes a great deal of latent heat to be released. The added latent heat reduces the cooling rate of saturated, orographically-lifted air masses. Called the “wet adiabatic lapse rate”, the lifted air mass continues to cool at a rate of only  $5.5^{\circ}\text{C}/1000\text{m}$  until the air mass reaches the apex of the Sierran crest. Once the air mass summits (Figure 46) orographic lifting ceases and the now colder, dense air plummets down the

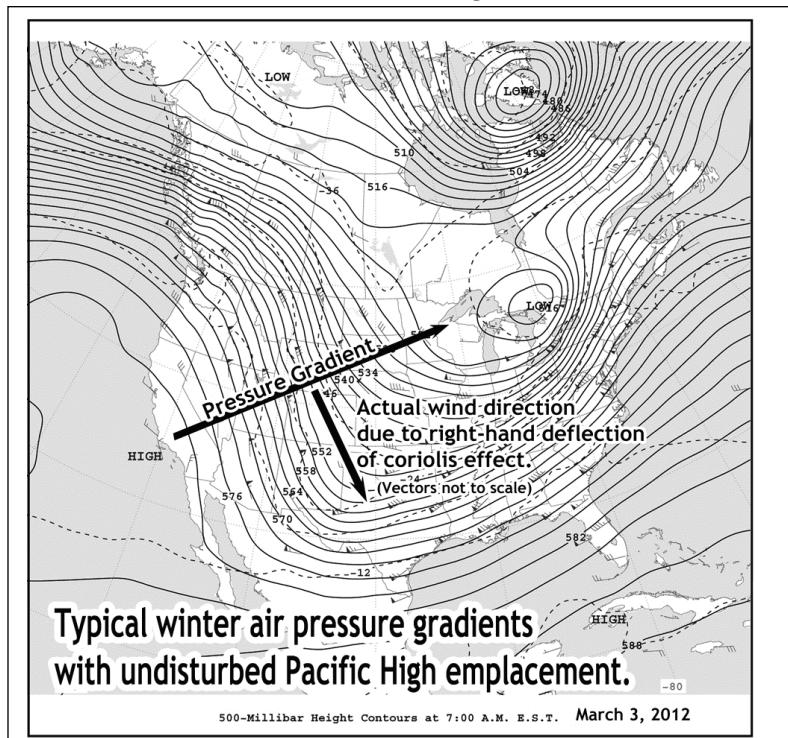


Figure 44 - 500mb air pressure map showing N-NW winds over Midwest . Isobars depict atmospheric height, in dekameters, at which 500mb of pressure occurs. The greater the height of the isobar, the greater the air pressure. Visualizing the isobars in the same fashion as topographic contours helps your authors' students get a handle on the concept of wind flowing across the pressure gradient from high to low. Closer contours = stronger winds. Note light winds over California. (Modified from NOAA archived maps)

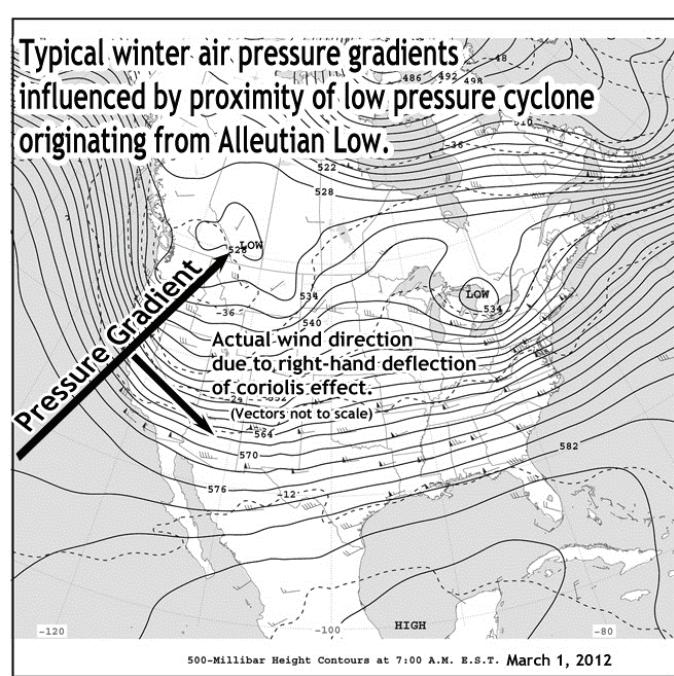


Figure 45 - Typical pressure gradients and NW winds created by interaction of low pressure storms and high pressure off the Pacific during the California's winter. Note strong pressure gradient (tight contours) above California. (Modified from NOAA archived maps)

eastern slope, compressing and warming as it goes. In a cruel twist of thermodynamic fate for the Eastern Sierra, the adiabatic warming due to the sinking and compressing air mass happens at the dry adiabatic rate of  $10^{\circ}/1000\text{m}$ . The adiabatic warming rapidly desaturates the air, stealing precipitation that was abundant just several miles to the west. The resulting rain shadow leaves lower lands to the east of the Sierra high and very dry (Figure 46).

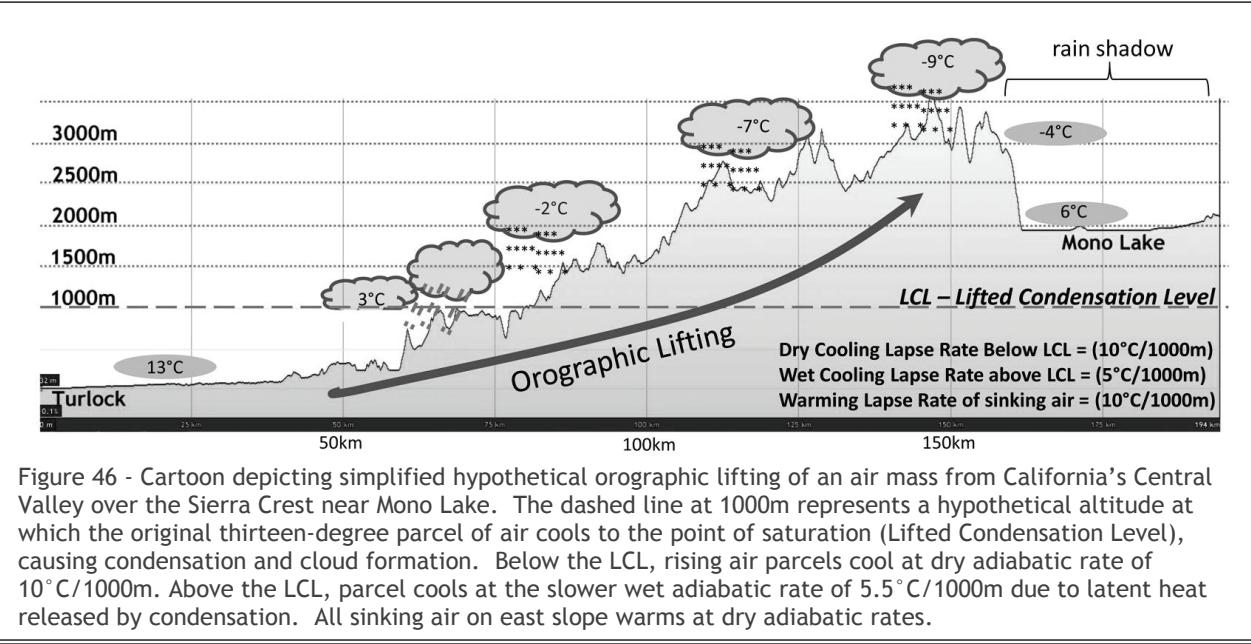


Figure 46 - Cartoon depicting simplified hypothetical lifting of an air mass from California's Central Valley over the Sierra Crest near Mono Lake. The dashed line at 1000m represents a hypothetical altitude at which the original thirteen-degree parcel of air cools to the point of saturation (Lifted Condensation Level), causing condensation and cloud formation. Below the LCL, rising air parcels cool at dry adiabatic rate of  $10^{\circ}\text{C}/1000\text{m}$ . Above the LCL, parcel cools at the slower wet adiabatic rate of  $5.5^{\circ}\text{C}/1000\text{m}$  due to latent heat released by condensation. All sinking air on east slope warms at dry adiabatic rates.

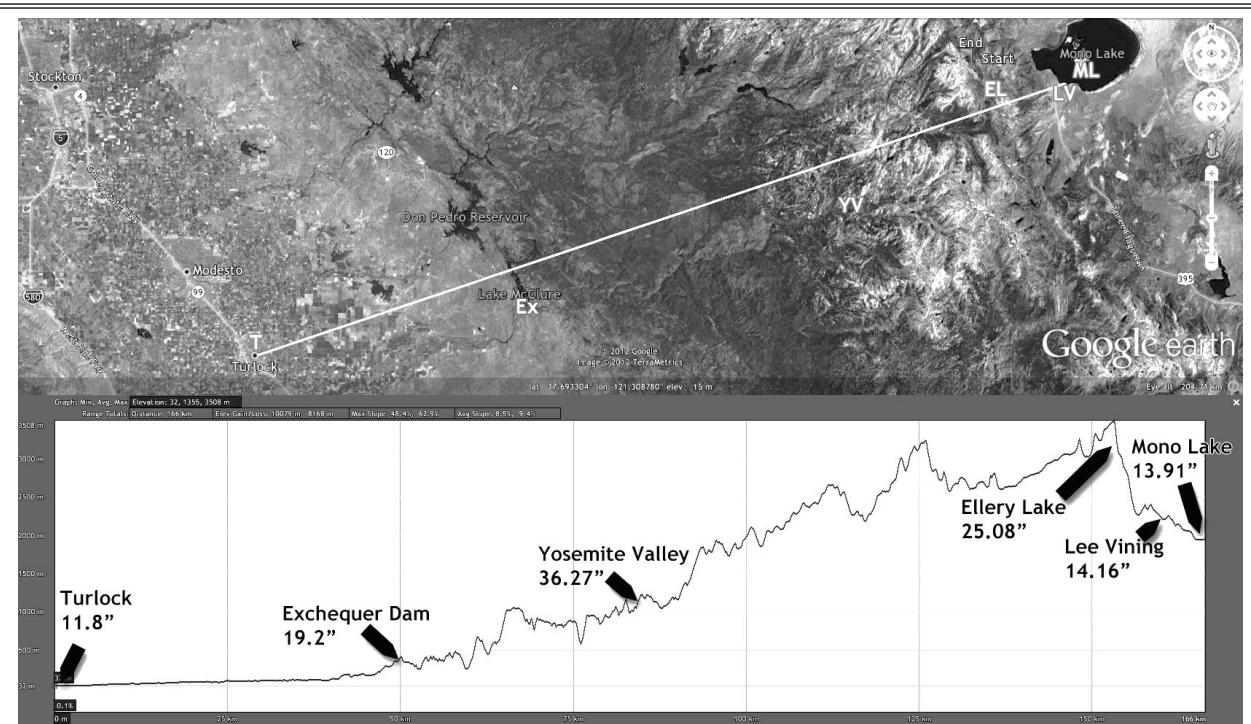


Figure 47 - Topographic profile from Turlock, CA to Mono Lake, CA showing discrepancies in average annual precipitation totals due to the effects of a rain shadow. Turlock lies in the rain shadow of the Coast Ranges. Western sierra slope totals increase due to orographic uplift and rapidly decrease after "summiting and plummeting". (Modified Google Earth screen capture using data from Western Regional Climate Center website: <http://www.wrcc.dri.edu/coopmap/>)

## Mono a Mono

Now that the long-winded (ha!) basics are covered ,we can tackle the creation of the Monos. The Monos are a northeasterly downslope wind that originates near Mono Lake in the cold , winter season when the typical pressure gradient that creates westerly winds are reversed. The seeds of the Monos are sewn when strong high pressure centers from Canada consisting of cold, dry air squeeze into the Great Basin between the Sierras and Rockies. In order for the Monos to form, the high pressure center in the Great basin needs to interact with a strong low pressure center west or south of the Sierra crest.

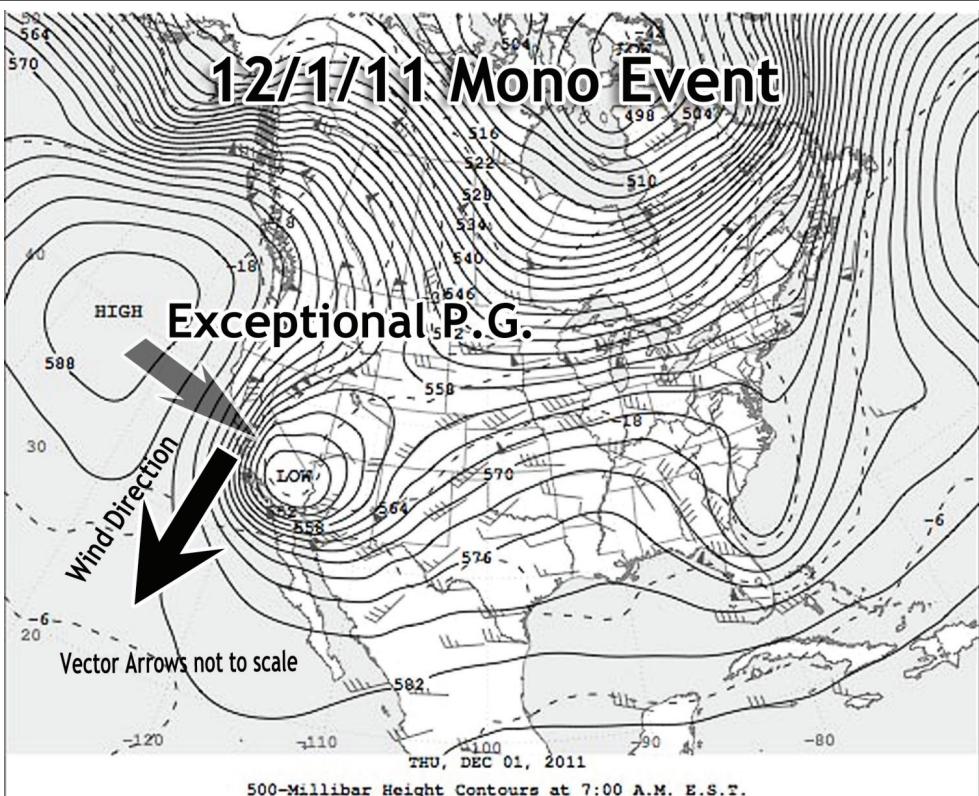


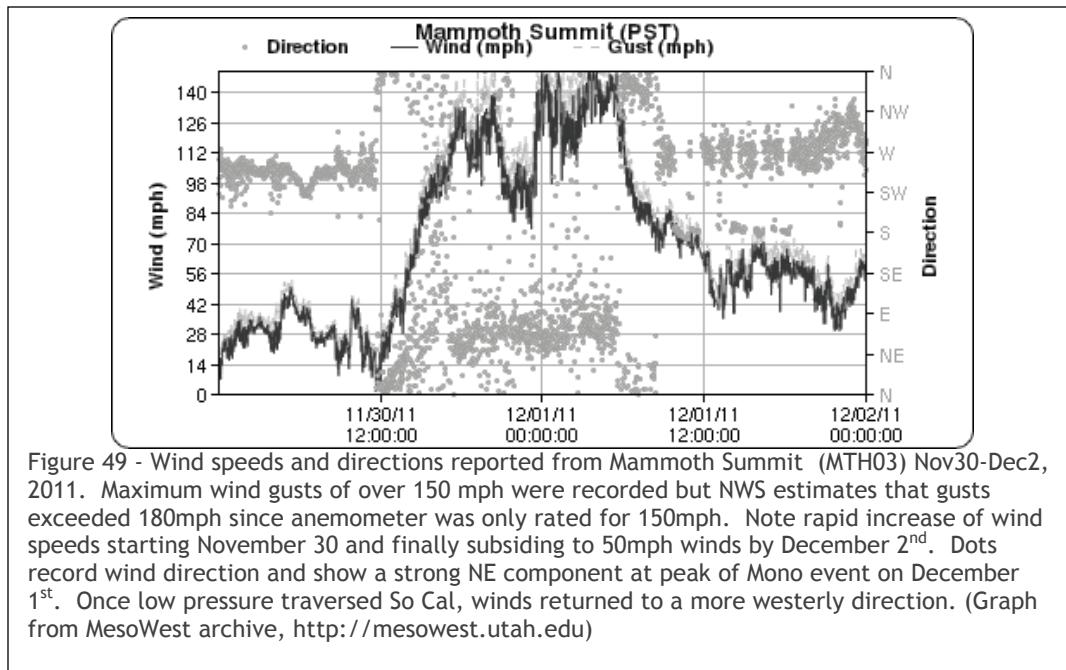
Figure 48 - 500mb map of December 1st, 2011 Mono Event. The exceptionally tight isobars created the very strong pressure gradient needed to create the strong Mono winds. Note that the wind direction is from the NE instead of more common W-NW. Not depicted on this map is a surface high pressure in northern Nevada that added to surface wind speeds. (Modified from NOAA archived map)

The resulting pressure gradient spawns winds from the east-northeast that are funneled through similarly oriented Sierra passes (Figure 48). Following the laws of fluid dynamics, the winds must increase in velocity to squeeze through the restricted canyon openings. The resultant winds are commonly above 60mph for several hours at a time down the western drainage basins. In rare cases the Monos can accelerate to mind-boggling speeds of over 120mph wreaking havoc on both natural and developed lands alike.

The most recent Mono event (and possibly most destructive) occurred between November 30<sup>th</sup> and December 2<sup>nd</sup>, 2011 (Figure 49). The winds' impetus came from the interaction of a record-breaking high pressure center dominating the northwest and Great Basin while a very strong low pressure

system moved over southern California. The resulting pressure gradient was one of the greatest observed in many years and the Monos took full advantage of the situation.

The weather station atop Mammoth Peak, 20 miles south of here, recorded nearly 24 hours of sustained winds greater than 80mph. Peaking in the evening hours of December 1<sup>st</sup>, sustained winds topped 140mph for nearly six hours and gusts maxed-out the anemometer rated for 150mph! The National Weather Service estimated gusts reached at least 180mph. Speeding down the western slope the winds also warmed and dried the atmosphere.



When the dust finally settled on December 2<sup>nd</sup>, the extent of the damage caused by the Monos became clear in communities across the Sierras. Hardest hit was the area of Devils Postpile National Monument in which more than 3,000 trees with diameters of over two feet were uprooted and deposited across park facilities. Removal of the mass treefall delayed the park's opening by nearly two months until June 29<sup>th</sup>. As of this writing an estimated 50 miles of heavily used backcountry wilderness trails near the park still need to be cleared by hand tools.

Mono Pass, just a few miles south of here in Yosemite also suffered a massive tree fall that is evidenced by the trees at Mono Pass trailhead on HWY 120 (Figure 42). There, the crowns of the victimized trees are synchronously pointed to the west, a testament to the easterly direction from which their killer emerged.

Among the many communities affected by the gales was Twain Harte, just east of Sonora on HWY 108. Two cabins and a dental office complex in the hamlet were each bifurcated by pines greater than 30" in diameter. One of the affected cabin owners was home at the time of the storm and had fallen asleep on her living room couch. She had the misfortune of being awoken by a large crash and subsequently found her legs pinned between the large tree and couch with a clear view through her roof to the sky. Luckily the victim survived with only a broken wrist and fractured skull. Her legs were merely bruised from the nearly two tons of tree that had fallen on her lap!



Figure 50 - Authors' cabin neighbors' unexpected renovation at the hands of the December 1<sup>st</sup> Mono wind event. No one was injured in this house. (Photo by Nancy Hollister)

In a nutshell, just remember the Monos are created when high pressure settles-in over the Mono Lake region.

**That concludes the academic tour! We hope you enjoyed yourself.**

Continue north on HWY 395 past Bridgeport until you come to the junction of Sonora Pass HWY 108.

**31.0 Miles                    136.5 Miles.**

Junction of 395/108. Turn left onto Sonora Pass HWY 108 and follow it back all the way to Baker Station.

**24.3 Miles                    160.8 Miles**

**Return to Baker Station and prepare for some yummy food and evening presentations.**

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