Excerpt from

Geologic Trips, Sierra Nevada

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ISBN 0-9661316-5-7
GeoPress

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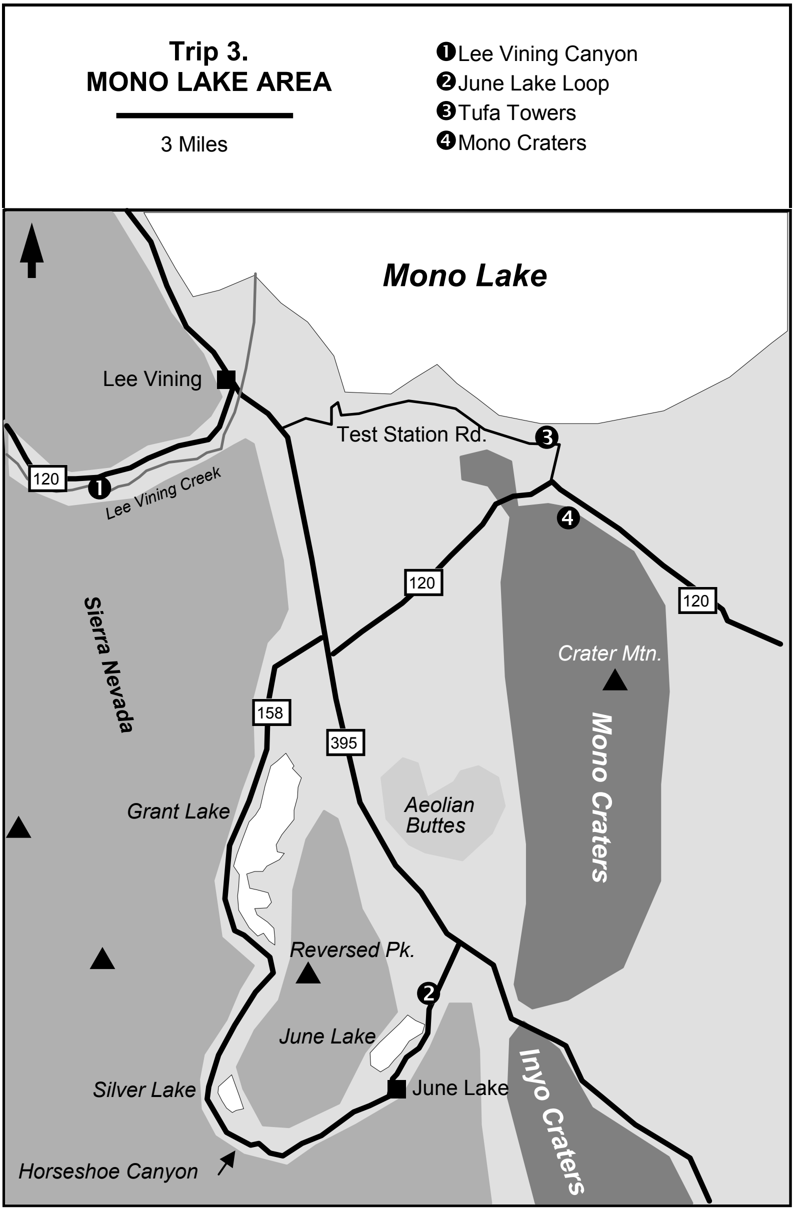


The Mono Basin Scenic Area Visitor Center, located on Highway 395 just north of Lee Vining, has interactive exhibits on Mono Lake and guided walking tours along the shoreline (760-647-3044).

Trip 3

MONO LAKE AREA

Glaciers on the Eastern Slope

Mono Lake occupies a low spot in the Mono Basin, one of the many basins in the Basin and Range Province. The Mono Basin was formed when a large block of the earth's crust subsided along a major fault that goes through Lee Vining. The Sierra block was uplifted along this fault as the Mono Basin subsided. Most of this faulting occurred over the last five million years. As the Sierra Nevada was uplifted, the mountains were eroded and the erosion products were conveniently deposited in the subsiding Mono Basin. From time to time, volcanic rocks were added to the sediments as the basin subsided. To date, an estimated 10,000 feet of sediments and volcanic rocks have been dumped into Mono Basin from the Sierra Nevada.

Mono Lake is an enclosed saline lake. The lake gets most of its water from the Sierra, but has no outlet. Since the Mono Basin is arid, evaporation of the lake water has increased the salinity of the lake and the lake is now more saline than seawater. This saline water supports a large population of brine shrimp, which attract birds and other wildlife. The lake is also noted for its unusual tufa pinnacles that are found locally along the shoreline.

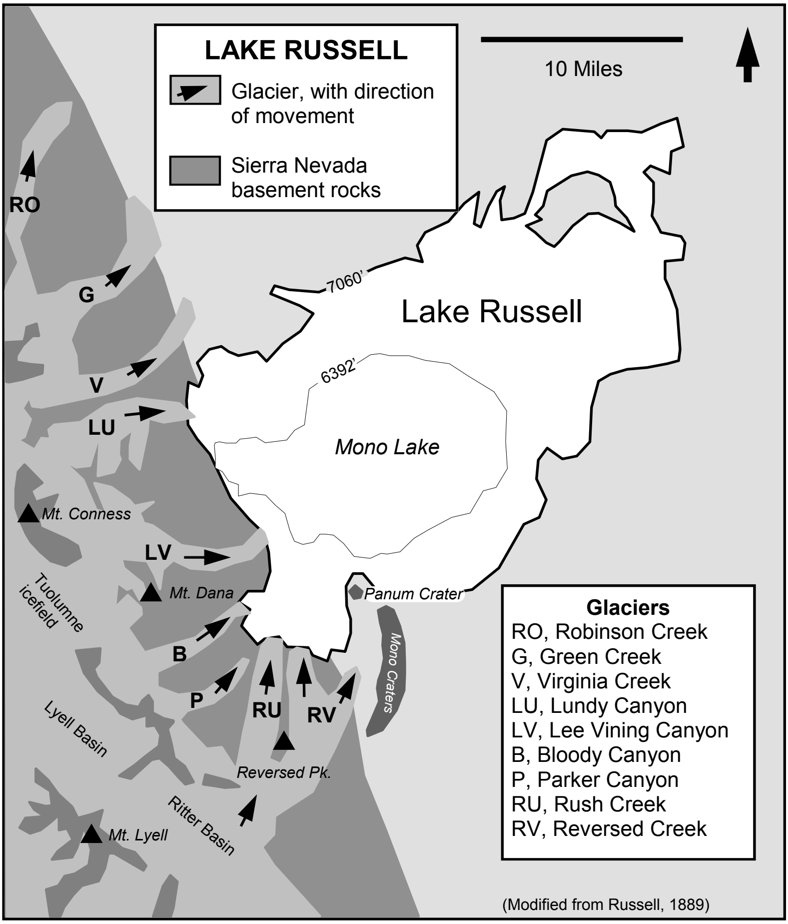
Until 1941, Mono Lake had been supplied with fresh water that flowed into the lake along Rush, Parker, Walker and Lee Vining Creeks. In 1941, the Los Angeles Department of Water and Power began to divert this water to Los Angeles through a newly completed tunnel and aqueduct system. Since these creeks had been the main water supply for Mono Lake, the water level of the lake began to drop at a rate of over one foot per year. By 1982, the water level had dropped 45 feet and the existence of the lake and the associated wildlife began to be seriously threatened. Concerned groups sounded the alarm and started a major movement for restoration of the lake. As a result of this movement, in 1985 the lake was declared a natural preserve and in 1994 the Department of Water and Power agreed to maintain the elevation of the lake at 6,392 feet. This elevation is 20 feet above the 1982 low-point and 25 feet below the pre-diversion level. The lake is not expected to reach its mandated level until 2014.

Lake Russell

Although the Mono Lake area is now arid, Mono Lake looked quite different during the Pleistocene glacial episodes. The glacial-age lake, referred to as Lake Russell, was much larger than the present lake and over 600 feet higher. Glaciers, fed mainly by the large Tuolumne icefield in the High Sierra, came down Lundy Canyon, Lee Vining Canyon, Bloody Canyon, Rush Creek and Reversed Creek and pushed their glacial ice and debris into the western shore of Lake Russell. In route, the glaciers carved and widened their valleys, scooped out bedrock that would later be filled by lakes, and carried a large load of rock debris. When the glaciers melted at the end of the glacial episodes, they left a number of large lateral, terminal, and recessional moraines along the eastern slope of the Sierra Nevada, from Robinson Creek in the north to Reversed Creek in the south. Some of this glacial debris was pushed over a mile beyond the mountain front.

Prior to eruption of the Long Valley Caldera, Lake Russell drained south into the Owens River, and from there into Owens Lake. However, this outlet was plugged by the eruption of the Long Valley volcano. From that time to present, the lake has had no outlet and the lake level has risen and fallen, depending on the supply of water, the rate of evaporation, and the thirst of Los Angeles. The lake level was high

The horizontal lines along the lower part of the Sierra mountain front, as seen from the Mono Basin Visitor Center, define several old shorelines of Pleistocene Lake Russell.



during the glacial episodes and low during interglacial times. Many of the shorelines of these earlier lakes can be seen as faint lines encircling the lake.

During the trip to the Mono Lake area, you will see the lateral, terminal and recessional moraines and some of the other glacial features formed by the Pleistocene glaciers in Lee Vining Canyon and in the June Lake area. You will also walk along the shoreline of Mono Lake, see the famed tufa towers, and learn how these unusual features were formed. Finally, you will visit the Mono Craters, see how the craters were formed, and get a close look at the volcanic rocks that make up the Mono Craters.

➊ *Lee Vining Canyon*

During the Pleistocene glacial episodes, Lee Vining Canyon was filled with the large Lee Vining glacier, which abruptly terminated in Lake Russell. The glacier started in the Tuolumne icefield, which spilled over Tioga Pass, and was then joined by glaciers from several side canyons as it moved down Lee Vining Canyon. When the Lee Vining glacier melted, it deposited its load of rocks as lateral and recessional moraines. There were at least four major glacial episodes during the Pleistocene. Each episode brought new glaciers that bulldozed through the earlier moraines and left their own moraines. Thus, many of the early moraines were destroyed, and most of the moraines that we see today are from the latest glacial episodes, the Tahoe and Tioga.

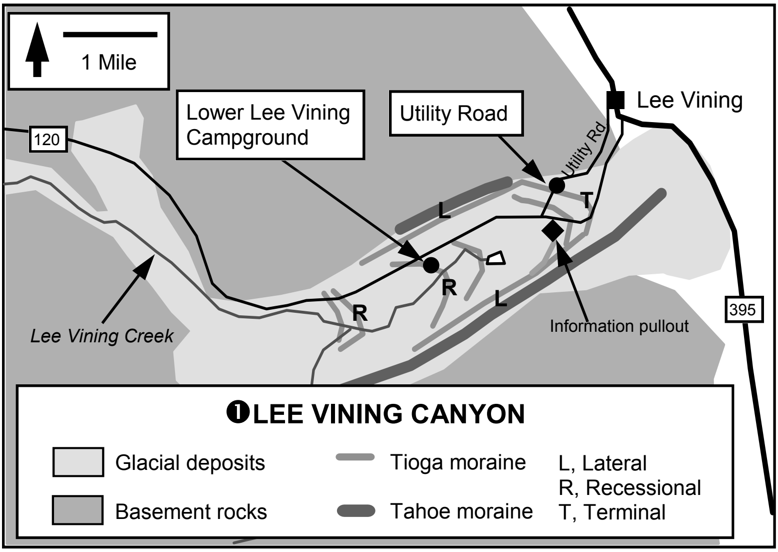
The most prominent moraines are the lateral moraines that form the high linear ridges along the sides of lower Lee Vining Canyon. These ridges are as much as 700 feet high and have two crests on each side of the valley. The outer crest was formed during Tahoe glaciation and the inner crest during the younger Tioga glaciation. There is also a large terminal moraine at the end of Lee Vining Canyon, just east of the information pullout on Highway 120. In addition a number of smaller recessional moraines appear as a series of low ridges that cross the lower part of Lee Vining Canyon west of the information pullout.

Utility Road - *From Lee Vining, go W on Hwy. 120 1 mi.; turn N on Utility Rd. and park in the first pullout.*

Utility Road cuts through the terminal moraine at the end of Lee Vining Canyon and you can see the rocks that make up this moraine in the roadcuts along Utility Road. These rocks are unsorted, and include clay, gravel, and huge boulders. Most of the boulders and smaller stones are rounded or subangular. A few have grooves and striations that were formed when the rock was ground against resistant bedrock. The moraine is 500 feet high at Utility Road.

Lower Lee Vining Campground – *From Lee Vining go W 2.5 mi. on Hwy. 120; park at the entrance to Lower Lee Vining Campground.*

Lower Lee Vining Campground lies immediately east of one of the recessional moraines in the lower part of Lee Vining Canyon. The moraine forms a 20-foot high ridge that extends across the valley between the two large lateral moraines on the sides of the valley. This recessional moraine briefly served as a dam for Lee Vining Creek, but the creek now cuts through the moraine. Further up the valley over the next two miles there are many other recessional moraines. Cattleguard and Moraine campgrounds are both built on recessional moraines.



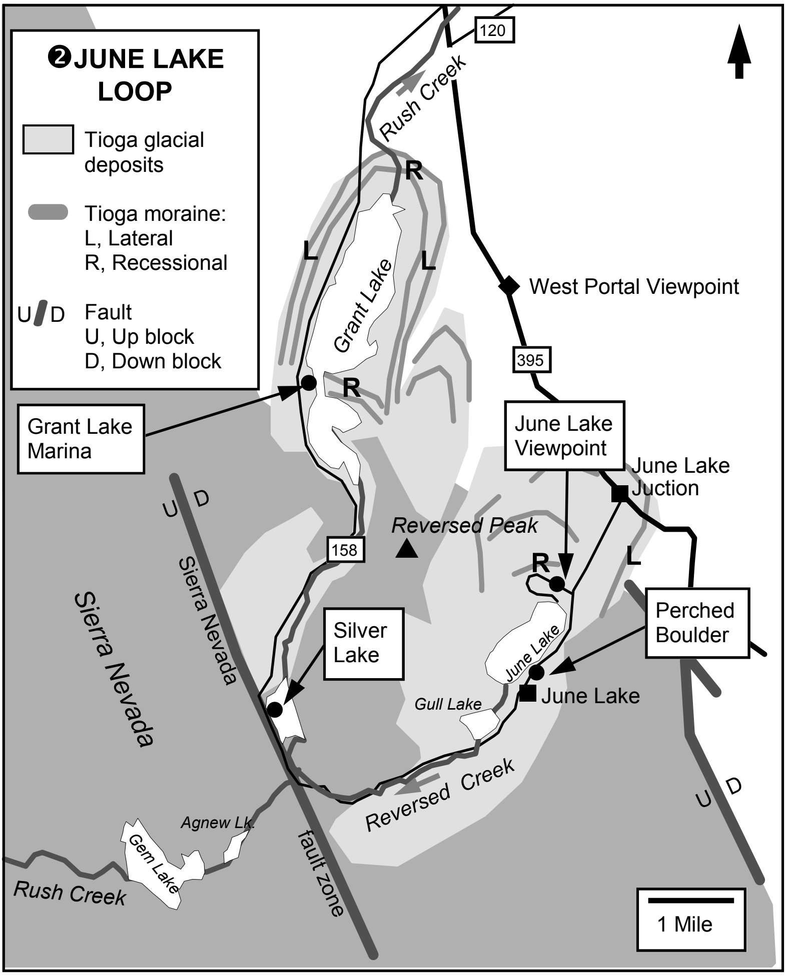
This photo is at the entrance to the Lower Lee Vining Campground. The ridge at the right with the patch of snow is a recessional moraine (RM) that was deposited during retreat of the Lee Vining glacier at the end of the last glacial episode. The valley wall in the background is the large lateral moraine (LM) that was deposited on the south side of the Lee Vining glacier.

❷ *June Lake Loop*

When going from Lee Vining to Mammoth Lakes, make a detour along the June Lake Loop. It only takes a few extra minutes, but you'll see some great scenery and geology. The loop begins four miles south of Lee Vining and follows Highway 158 for twelve miles through a large horseshoe-shaped valley that cuts into the eastern front of the Sierra Nevada. Reversed Peak lies in the center of the horseshoe. Highway 158 bends around the west side of the peak as it loops to the south.

This horseshoe-shaped valley was formed by the Rush Creek and Reversed Creek glaciers. These are actually two lobes of the same glacier that were split by Reversed Peak. These glaciers gave the horseshoe valley its unique shape. The Rush Creek glacier had its origin in the icefields of the High Sierra, where large quantities of ice crossed the crest of the Sierra and followed Rush Creek down the eastern slope. On this part of its journey, the Rush Creek glacier gouged out the basins for the Marie Lakes, Waugh Lake, Gem Lake and Agnew Lake. Immediately east of Agnew Lake, the Rush Creek glacier tumbled down a steep fault scarp along the Frontal fault system, and then encountered the weak fractured rocks in the fault zone at the base of the scarp. On the east side of the fault zone, the glacier bumped into the hard rocks of Reversed Peak. Since the glacier could not go over Reversed Peak, it split and sent one lobe north and the other lobe south. The main part of the Rush Creek glacier took the northern route. For the first mile, this lobe followed the fractured rocks in the fault zone and carved out the basin for Silver Lake from the weak rocks in the fault zone. The Rush Creek lobe then turned northeast, flowed along the northwest side of Reversed Peak and entered Pleistocene Lake Russell about six miles north of the peak. The southern fork of the Rush Creek glacier followed the fault zone south from Silver Lake for about a mile, then turned northeast, carved out the basins for Gull Lake and June Lake, and entered Lake Russell on the southeast side of Reversed Peak. The Rush Creek and Reversed Creek glaciers reached a maximum thickness of 1,600 feet, but never covered Reversed Peak, which stands 2,000 feet above the lakes.

The Rush Creek glacier picked up a large amount of rock and debris from the Sierra Nevada as it worked its way across the Sierra crest, down the eastern slope, and along the Frontal fault zone. When the Rush Creek and Reversed Creek glaciers melted, this debris was deposited as moraines and till in and along both valleys. This till covers much of the area on the east side of Reversed Peak between June Lake and Grant Lake and as far east as Highway 395.



Grant Lake Marina - *From Lee Vining drive S 4 mi. on Hwy. 395; turn W on Hwy. 158 and park at the Grant Lake Marina.*

Grant Lake is used as the collecting reservoir for most of the Mono Basin water that is being diverted to Los Angeles. From here the water goes under Highway 395, around Aeolian Buttes, through a tunnel under the Mono Craters, into the Owens River, and then travels south 400 miles to Los Angeles. Grant Lake rests almost entirely in sediments deposited from the Rush Creek glacier. The sides of the lake are formed from the large lateral moraines of the glacier, and the dam at the north end is a large recessional moraine, enhanced by a man-made dam. The marina is on another recessional moraine that nearly bisects the lake.

Silver Lake **-** *From the Grant Lake Marina drive 3 mi. S on Hwy. 158; park in the parking lot on the SW side of Silver Lake.*

Silver Lake was carved out of the fractured rocks along a major fault zone in the Sierra Nevada fault zone. The Sierra block was uplifted several thousand feet along this fault. The steep slope from Agnew Lake to Silver Lake is a fault scarp formed by the fault and cleaned off by the Rush Creek glacier. At Silver Lake, the road follows the fault. Just south of the lake, the fault can be seen cutting across the granitic rocks at the base of the escarpment. This fault zone is responsible for putting the bottom of the "U" in the horseshoe. Without the fault zone, there would be no Silver Lake.

Perched Boulder **-** *From Silver Lake, continue 4 mi. S on Hwy. 158 to the fire station at the N end of the community of June Lake.*

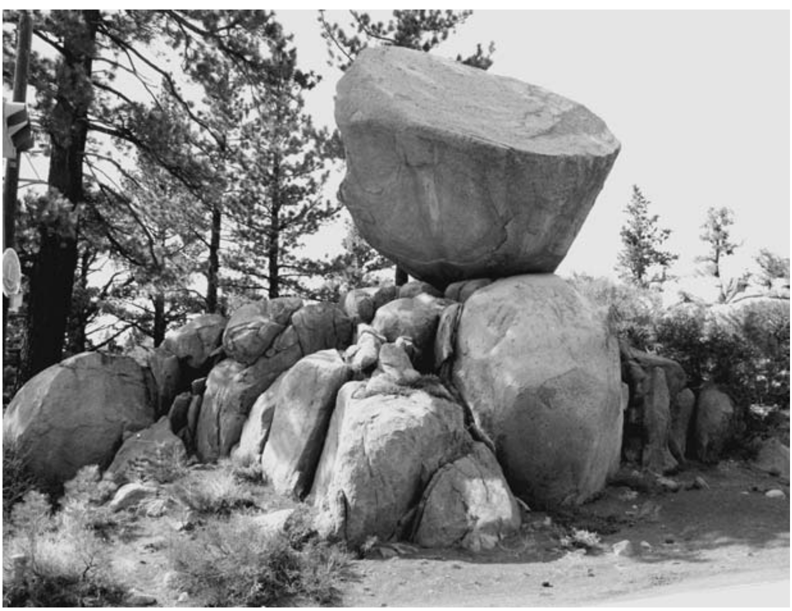
Adjacent to the June Lake Fire Station there is a large boulder perched on an outcrop on the north side of the road. The boulder is a glacial erratic that is 18 feet high and weighs 150 tons. This boulder was picked by the Rush Creek glacier from somewhere in the Sierra and carried to this locality. When the glacier melted, the boulder was stranded on top of a small roche moutonnée.

June Lake Viewpoint **-** *From June Lake go N 1 mi. on Hwy. 158 to the Oh! Ridge viewpoint.*

This viewpoint is on a large recessional moraine that lies at the eastern end of June Lake. From the viewpoint, you can look southwest across June Lake down the Reversed Creek valley toward the Sierra escarpment. Reversed Creek begins at June Lake, flows through Gull Lake, and joins Rush Creek just south of Silver Lake. From there, Rush Creek flows through Silver Lake to Grant Lake. Prior to diversion of the Mono Basin water to Los Angeles, Rush Creek flowed from Grant Lake into Mono Lake, and was the main water supply for Mono Lake.

Reversed Creek is unique. It is the only creek along the entire eastern Sierra that flows west toward the mountain front rather than away from the mountains. The reversed drainage was formed when the Reversed Creek glacier encountered hard rock in the valley floor after it left the fault zone at the base of the Sierra escarpment. The glacier rode up and over these hard rocks as it continued northeast toward Mono Lake. The direction of movement of a glacier depends on the slope of ice surface, not on the slope of the valley floor. As a glacier flows down a canyon, the bottom of the glacier can scoop out low spots and benches. Thus, the ice at the bottom of the glacier can travel upslope for some distance.

The long sloping ridge on the northwest side of Grant Lake, as seen in the center of this photo, is a large lateral moraine (LM) that was deposited by the Rush Creek glacier.



This large perched boulder near the June Lake Fire Station is a glacial erratic that was left here when the Reversed Creek glacier melted. The boulder sits on a small roche moutonnée that is being broken apart by jointing.

❸ *Tufa Towers*

At several places along the shoreline of Mono Lake there are clusters of spectacular white towers that form spires and rounded knobs up to ten feet high. These towers are formed from tufa. Tufa is one of many forms of calcium carbonate, and is of the same composition as the stalactites and stalagmites that occur in limestone caves. In Mono Lake, these towers form where fresh water springs feed into the bottom waters of the lake. The fresh spring water contains calcium in solution, and the lake water contains sodium and potassium carbonate in solution. When the fresh water wells up into the lake water, it is lighter and begins to rise through the lake water. As the fresh water rises, the calcium in the fresh water and the carbonate in the lake water combine to form tufa. The tufa in the towers is porous, so the fresh water flows through this porous structure until it finds a surface where it comes into contact with the lake water. The intricate spires and knobs of the towers are formed by this process. Although tufa is found in other alkaline bodies of water, the quantity, size, and variety of the tufa towers at Mono Lake is unique.

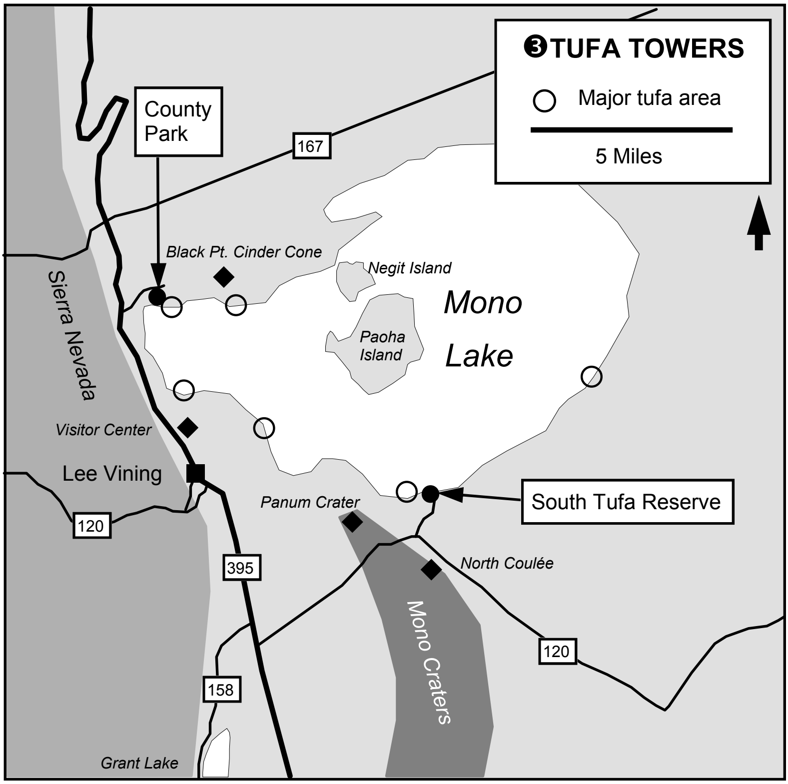
In many places, tufa towers can be found along higher shorelines of Mono Lake. Since tufa towers can only be formed in lake water, we know that these towers were formed when the lake was at a higher level and covered these areas. Some of the towers along the older shorelines of the lake formed as much as 13,000 years ago.

South Tufa Reserve **-** *From Lee Vining go S 4 mi. on Hwy. 395; turn E on Hwy. 120 and drive 5 mi. to the turnoff to the South Tufa Reserve; drive 1 mi. and park at the reserve. Seasonal tours at 1 PM Saturday and Sunday.*

The South Tufa Reserve has many groups of tufa towers and is the largest and best developed of the tufa areas. These towers were formed mostly between 200 to 900 years ago. The towers were exposed when the level of the lake dropped following diversion of the water to Los Angeles. The lake level is rising again. When it reaches the planned level in 2014, the shoreline of the lake will be near the parking lot and many of these towers will again be covered.

County Park **-** *From Lee Vining drive 4 mi. N on Hwy. 395; turn R on Cemetery Rd.; drive 0.5 mi. to the Mono Lake County Park.*

There is an elevated wood walkway at Mono Lake County Park that makes it easy to investigate the shoreline of the lake and the tufa towers along the shoreline. This site is well worth a visit, even if time is short.



Tufa towers in Mono Lake at the South Tufa Reserve.

❹ *Mono Craters*

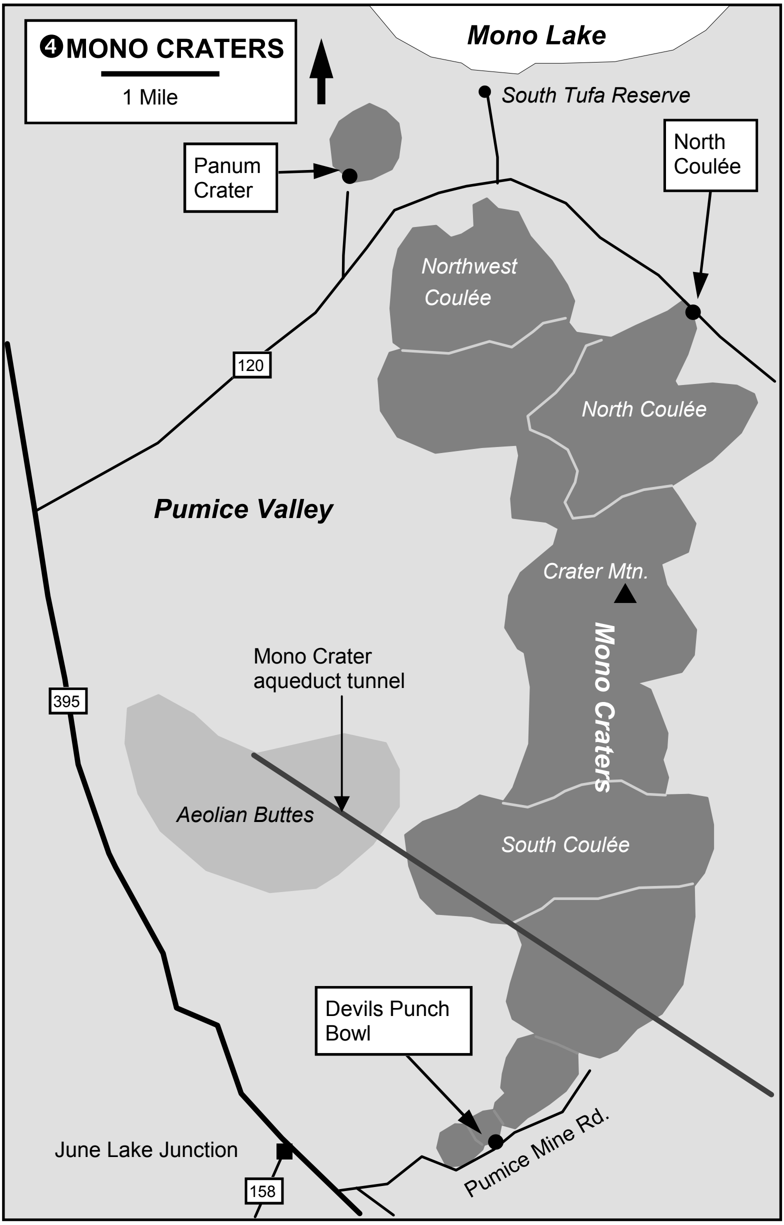
As you drive south from Lee Vining on Highway 395, you will see a low range of light-gray mountains to the east. These are the Mono Craters. They extend from Panum Crater on the south shore of Mono Lake southward for about ten miles to Devils Punch Bowl. The highest peaks rise 2,000 feet above Mono Lake and many of the peaks have steep slopes with craters at the top.

The Mono Craters were formed by volcanic activity that started about 40,000 years ago and has continued up to the present time. Paoha and Negit islands in Mono Lake are on a northern extension of this volcanic chain. Negit Island formed during volcanic eruptions 1,700 years ago. Paoha Island formed 325 years ago when lake-bottom sediments were pushed up by volcanic activity. The Black Point cinder cone at the northwest shore of the lake erupted during the last high stand of Mono Lake. Panum Crater also erupted about the same time.

Older volcanic rocks are also present in this area. The Aeolian Buttes, just west of the Mono Craters, are formed from the Bishop Tuff, which was deposited during the eruption of the Long Valley volcano. A layer of Bishop Tuff was also encountered at a depth of 1,400 feet under Paoha Island when an oil exploration well was drilled in 1908.

There are about 30 volcanic centers along the Mono Craters. Most eruptions followed a general sequence of events. The eruption would begin when stiff rhyolite magma forced its way to the surface along a crack in the earth's crust. Ash and coarse pumice were then thrown from the vent. After this, the vent would clear its throat with a large explosion that created a crater with a rim of pumice, rock debris, and fragments of bedrock. Stiff rhyolite magma would then ooze from the vent like toothpaste, leaving a small rhyolite plug in the center of the crater.

An eruption could stop at any of the above phases. If the eruption continued, the rhyolite magma would slowly ooze out of the vent until the crater was filled and formed a circular steep-sided dome. Following this, the rhyolite magma might either push through the older overlying volcanic material or squeeze out beneath the older material. On some domes, the rhyolite magma flowed over the crater wall and enveloped the original crater. In some places, after spilling over the wall of the crater, the flow continued as a stream of stiff molten glass that extended for up to two miles from the crater. These glass flows are known as coulées. Some domes have small secondary craters formed when gas built up behind a plug and was released in an explosion. The trips to



Panum Crater, North Coulée, and Devils Punch Bowl illustrate several different types of eruptions that have occurred along this trend.

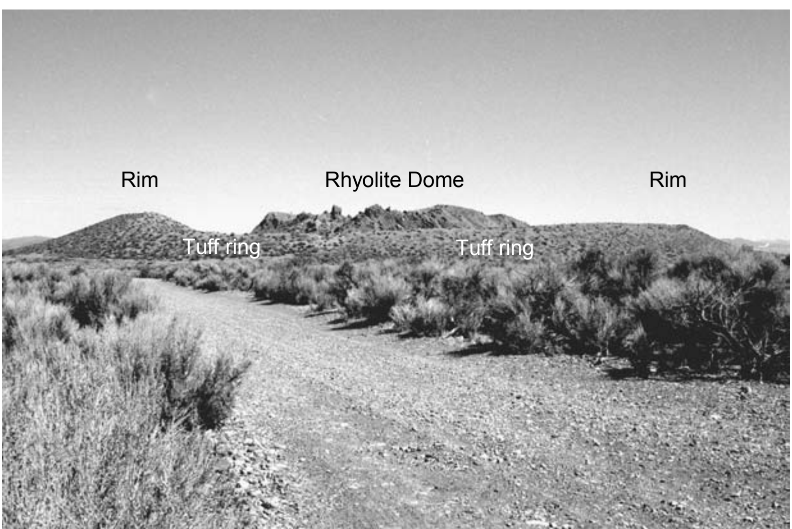
This photo shows two of the larger eruptive centers along the Mono Craters. There are about 30 eruptive centers along this ten-mile trend of rhyolitic domes and craters.

The North Coulée obsidian flow is formed from rhyolitic magma that flowed from a vent at the north end of the Mono Craters about 630 years ago.

Panum Crater - *From the junction of Hwy. 395 and 120, drive 3 mi. E on Hwy. 120; turn N at the sign for Panum Crater; drive 1 mi. on the gravel road to the parking area.*

Panum Crater erupted in about 1320, and has changed little since then. From the parking area, take the short trail to the rim of the crater. From the rim, you will see that the crater is about 2,000 feet across and has a prominent rhyolite dome in the center. Follow the trail around the rim. Note that the rocks that make up the rim are mainly tuff and pumice. If you look hard, you will also find a few smooth rounded pebbles mixed in with the tuff and pumice. The material that makes up the rim was ejected from the vent at the beginning of the eruption. The rounded pebbles came from the layer of gravel upon which Panum Crater was built. This gravel was part of a delta formed by Rush Creek during the last glacial episode.

Next, take the short trail across the moat to the rhyolite dome in the center of the crater. Note that the rhyolite is splintered. This happened when the dome was shattered by an explosion during formation of the dome. The explosion blew a gap in the tuff ring and threw glass blocks through the gap into Mono Lake. The gap in the tuff ring was partly filled by pumice from later eruptions.



The jagged rocks in the middle of the photo are part of the rhyolite dome that lies in the center of Panum Crater. The low brush-covered slope that extends across the center of the photo is the tuff ring that forms the rim of the crater.

North Coulée – *From Hwy. 120 and the Panum Dome turnoff drive 3.5 mi. E on Hwy. 120 to milepost 20.00; park in the pullout where the coulée is near the road.*

Along the trend of the Mono Craters, there are three large coulées, South Coulée, North Coulée and Northwest Coulée. These coulées are made up of thick obsidian flows that extend for one to two miles from their vents. Obsidian flows of this length are unusual. Most rhyolite magma forms domes and plugs because it is too viscous to flow for any significant distance. All three of these coulées are young. The flows that formed the North Coulée occurred about 630 years ago, and the flows that formed the South Coulée occurred about 700 years ago.

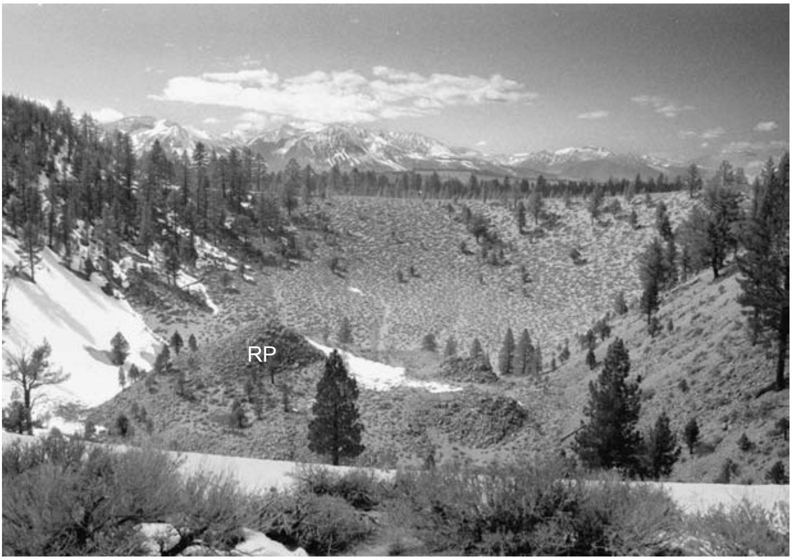
North Coulée has two lobes. This geologic site is at the northern lobe. You can see the southern lobe about half a mile to the south. Each lobe represents a different flow. The flows began from vents about one mile to the west. The flow is 200 to 300 feet thick, the sides are steep, and there is talus at the base of the flow. The rocks at the surface of the flow chilled rapidly, forming glassy blocks that were broken during movement of the flow. As the flow progressed, the front of the flow carried debris that was eventually overridden and incorporated into the flow. This jumble of broken sharp glass makes quite a mess – not good for climbing without lots of bandages.

The steep front of the North Coulée obsidian flow consists of a jumble of obsidian blocks and other volcanic debris.

Devils Punch Bowl - *From June Lake Junction drive S on Hwy. 395 for 0.4 mi.; turn E on Pumice Mine Rd. (gravel) and drive 1.5 mi. to the "Punch Bowl" sign; follow the dirt road 0.1 mi. to the rim of Devils Punch Bowl.*

The Devils Punch Bowl is a small crater, about 1,200 feet in diameter and 140 feet deep, at the south end of the Mono Craters. This crater was formed by an explosion at the beginning of the eruption, and differs from Panum Crater in that there is no significant tuff ring around the crater. The small rhyolite dome in the center of Devils Punch Bowl was formed about 700 years ago and is younger than the nearby domes.

Devils Punch Bowl illustrates an early stage in the development of the craters and domes along the Mono Craters trend. This eruption simply quit early, and it is unlikely that Devils Punch Bowl will later develop into a large dome or coulée.



The crater that forms Devils Punch Bowl was blasted out of the preexisting volcanic rocks about 700 years ago. Note the small rhyolite plug (RP) in the center of the crater.