

Excerpt from  
Geologic Trips, Sierra Nevada

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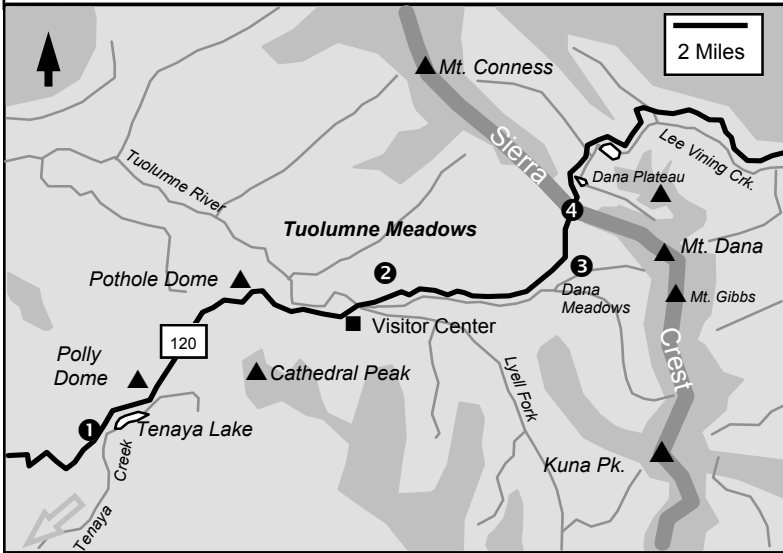
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### Trip 8. TUOLUMNE MEADOWS

Basement      Icefield

- ① Tenaya Lake
- ② Tuolumne Meadows
- ③ Dana Meadows
- ④ Tioga Pass



In this view from Pothole Dome, Tuolumne Meadows is the low grassy area in the middle ground. The boulders in the foreground are glacial erratics, stranded on Pothole Dome when the Tuolumne icefield melted.

## Trip 8

# TUOLUMNE MEADOWS

### *The Tuolumne Icefield*

During the Pleistocene glacial episodes, the Tuolumne Meadows area was covered by a huge icefield. Only the tops of the highest mountains rose above the ice. From this icefield, glaciers extended down many valleys on the eastern and western slopes of the Sierra. Among these, the Lee Vining glacier flowed down Lee Vining Canyon to Lake Russell, the Merced glacier flowed through Yosemite to El Portal, and the Tenaya glacier followed Tenaya Creek where it joined the Merced glacier at the head of Yosemite Valley. As the ice moved from the icefield down the glacial valleys, the ice was continually replenished by new snowfall over the icefield.

The Tuolumne icefield was about 2,000 feet thick, and the thick ice exerted a tremendous pressure on the underlying rocks. As the ice moved across Tuolumne Meadows and into the glacial valleys, it removed the soil and weathered rocks that had covered the High Sierra surface in pre-glacial times. The ice also gouged out the underlying granitic rocks where they were jointed and weak. Where the underlying rocks were hard, the glacial ice smoothed and polished the bedrock with rocks that were carried in the ice, as if the icefield were a huge sheet of sandpaper.

When the icefield melted, about 15,000 years ago, it left a blanket of sand, silt, clay, and boulders littering the surface of the ground. Much of this glacial debris collected in the lower parts of Tuolumne Meadows, where it formed a flat land surface with poor drainage that was covered by marshes, ponds, and shallow lakes. Over time, many of the bodies of water on that land surface were filled in to form meadows. The meadows have remained largely open, because trees find it difficult to grow in the shallow water table with poor drainage. Although Tuolumne Meadows is the largest of these alpine meadows, Dana Meadows and a number of other smaller meadows were formed the same way.

On the geologic trip to the Tuolumne Meadows, you'll see examples of the handiwork of the icefield: polished granite, scoured-out lakes, roche moutonnée, nunataks, exotic rocks, alpine meadows, and glacial till left behind when the icefield melted.

### **The Tuolumne Intrusive Suite**

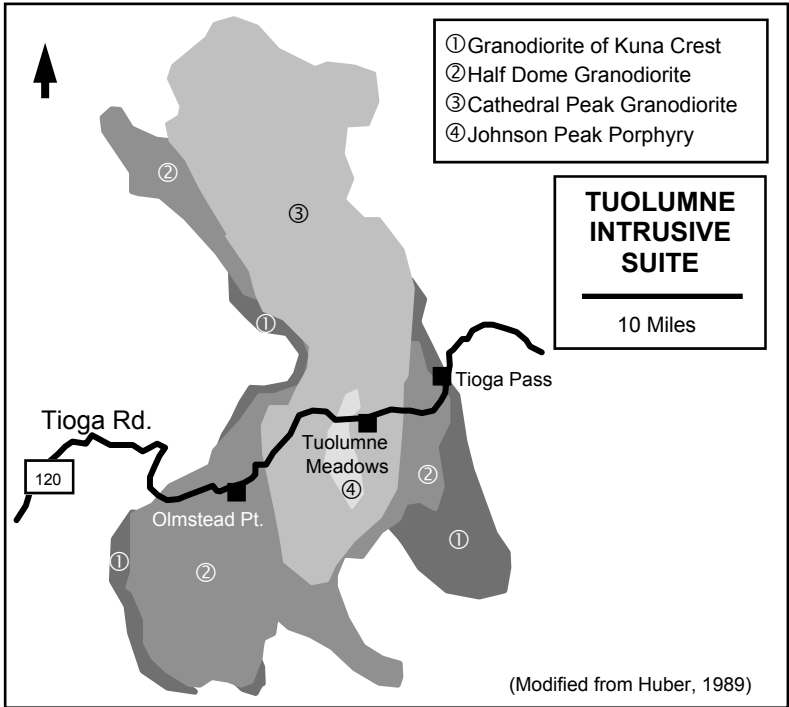
One of the great benefits of glaciation – for a geologist – is that the glaciers scrape away all of the soil and decomposed rock and leave the underlying bedrock clean and well-exposed. For this reason, the Tuolumne Meadows area is an excellent place to study the granitic rocks of the Sierra Nevada batholith. Detailed studies have shown that most of the granitic rocks in this area are related and are part of the same pluton. The rocks in different parts of the pluton appear different because they crystallized at different times and the composition of the magma changed as the rocks crystallized.

These related granitic rocks, referred to as the Tuolumne Intrusive Suite, were intruded into the Sierra Nevada batholith during Cretaceous time, about 86 to 91 million years ago. The oldest member of the suite, the Granodiorite of Kuna Crest, forms the outer edges of the pluton and is rich in biotite and hornblende. Biotite and hornblende crystallize at high temperatures and are among the first minerals to crystallize from magma. The Granodiorite of Kuna Crest is exposed at Glacier Point on the west side of the pluton and near Tioga Pass on the east side of the pluton.

The next rock to crystallize was the Half Dome Granodiorite, which contains more quartz and potassium feldspar than the earlier rocks. Quartz and feldspar crystallize at lower temperatures than biotite and hornblende and thus crystallize later in the sequence. The Half Dome Granodiorite is exposed from Half Dome to Olmstead Point.

The next rock to crystallize was the Cathedral Peak Granodiorite. This rock is readily identified by its large phenocrysts of potassium feldspar, and forms most of the core of the pluton. The Cathedral Peak Granodiorite is very widespread in Tuolumne Meadows and there are excellent exposures of these rocks at Lembert Dome and Pothole Dome.

The last rock to crystallize was the Johnson Granite Porphyry. This rock occurs in the central part of the pluton and can be seen in a small outcrop near the Tuolumne Meadows store. The Johnson Granite Porphyry has large phenocrysts of potassium feldspar, like the Cathedral Peak Granodiorite, but the matrix is fine-grained. The fine matrix probably formed when the rock chilled quickly, perhaps from release of pressure during volcanism. This rock may represent the roots of a volcano that erupted on the surface above the Tuolumne Intrusive Suite while the granitic rocks were crystallizing at depth.



TUOLUMNE INTRUSIVE SUITE			
Name	Age	Description	Location
Johnson Granite Porphyry	Cret.	Porphyry; light colored, few large phenocrysts in fine grained matrix.	Tuolumne River, across from store
Cathedral Peak Granodiorite	Cret. 86 MYA	Potassium feldspar phenocrysts 2 to 3" long, medium grained background.	Pothole Dome Lembert Dome
Half Dome Granodiorite	Cret. 87 MYA	Medium to coarse grained, well-formed plates of biotite and rods of hornblende.	Olmstead Point Half Dome Royal Arches North Dome Nevada Fall Vernal Fall
Granodiorite of Kuna Crest	Cret. 91 MYA	Darker than Sentinel Granodiorite, streaky appearance, parallel flakes of biotite and hornblende; disc-shaped inclusions.	Glacier Point Washburn Point Tioga Pass

### ① **Tenaya Lake**

Part of the ice from the large Tuolumne icefield flowed south down the Tenaya Creek drainage between Mt. Hoffman on the west and Tresidder Peak on the east. In route, the glacier scooped out a 114-foot deep depression from fractured Half Dome Granodiorite west of Tresidder Peak. This depression is now filled by Tenaya Lake. Glacial polish and erratic boulders found along the walls of the valley indicate that the ice was 2,460 feet deep in this area and covered Polly Dome and Pwiack Dome. These domes are *roche moutonnée*, similar to Lember Dome.

**Tenaya Lake** - *From the Tuolumne Meadows Visitor Center go W on Tioga Rd. 8 mi.; park at the picnic area.*

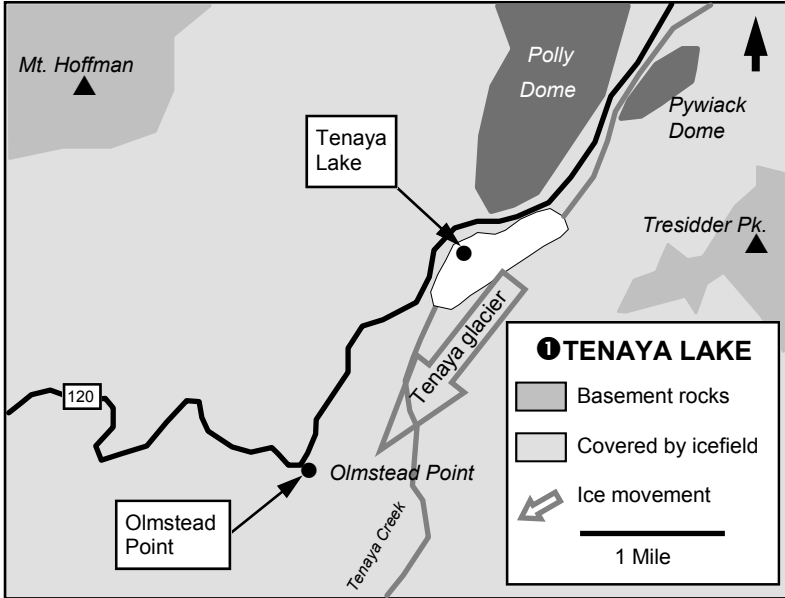
Tenaya Lake (8,149') is partly dammed by glacial till left at the southwest end of the lake by the Tenaya glacier as it melted and retreated toward the icefield in Tuolumne Meadows. The lake is slowly being filled by sediments that are accumulating where Tenaya Creek enters the east end of the lake. In time, the lake will become a meadow, as is the fate of most mountain lakes.

The contact between the Half Dome Granodiorite and the Cathedral Peak Granodiorite lies immediately west of Tenaya Lake. The rocks at Tenaya Lake appear to be a mixture of these two rock units in that the Half Dome Granodiorite contains potassium feldspar phenocrysts like those in the Cathedral Peak Granodiorite.

The granodiorite in the roadcuts near the lake is broken into large exfoliation slabs a foot or so thick that are parallel to the wall of the valley. Exfoliation slabs are formed when massive unjointed granite expands as it is exposed at the surface. Thus, exfoliation slabs on steep slopes and valley walls, like these at Tenaya Lake, are usually parallel to the valley wall.

**Olmstead Point** - *From the Tenaya Lake picnic area drive W on Tioga Rd. 2 mi. to the parking area for Olmstead Point.*

The bedrock at Olmstead Point consists of the Half Dome Granodiorite. These rocks stood in the path of the Tenaya glacier and were smoothed and polished by the glacier as it rode over the rocks. When the glacier melted, it left numerous glacial erratics lying on the surface of the granite. You can see good examples of glacial polish and erratics by taking the 1/4-mile nature trail from the parking area to Olmstead Point.



At Olmstead Point, glacial erratics rest on granite that was polished by glaciers moving down Tenaya valley.

## ② Tuolumne Meadows

During the last glacial episode, Tuolumne Meadows was covered by the 2,000-foot thick Tuolumne icefield. Much of this ice moved slowly westward down the Tenaya and Tuolumne River drainages. When the ice encountered a low hill of resistant granite, it overrode the hill and ground the hill into a rounded, streamlined shape, called a *roche moutonnée*. There are many *roche moutonnée* in the Tuolumne Meadows area. Two of the best examples are Lembert Dome and Pothole Dome.

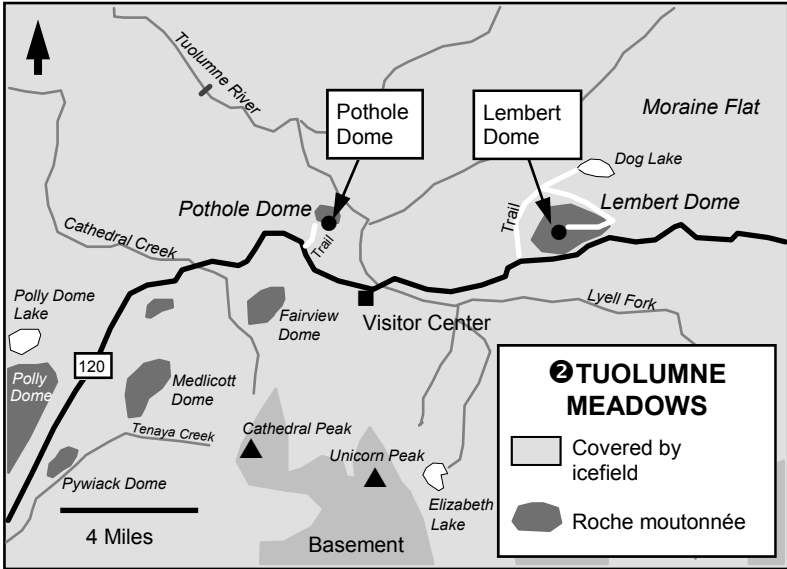
**Lembert Dome** - From the Tuolumne Meadows Visitor Center take Tioga Rd. 1.2 mi. E to the Dog Lake parking area; take the Dog Lake trail for 0.9 mi. then follow the primitive trail to the top of Lembert Dome; 2.8 mi. RT; moderate.

Lembert Dome is a 500-foot high elongated granite dome with a gentle east side and steep rugged west side. Fortunately, the hike to the summit goes up the gentle side. During the Pleistocene glacial episodes, Lembert Dome was covered by about 1,500 feet of glacial ice that was moving west, following the Tuolumne River drainage. The eastward upstream side of the dome was pushed and scraped by this glacial ice. The force of the glacier on this flank was roughly equal to dragging a block of granite the height of Lembert Dome over the dome. When the ice reached the west side of the dome, it was no longer pushing, scraping, and polishing the granite. Instead, it pulled, broke, and quarried the granite, and then removed the quarried blocks, leaving the granite on the west side of the dome steep and jagged.

The dome is formed from the Cathedral Peak Granodiorite, which is easily identified by its large feldspar phenocrysts. These crystals of feldspar are about two inches long, have a pinkish tinge, and break along flat cleavage surfaces. Each phenocryst is twinned, and consists of two halves that have cleavage at opposing angles. The Cathedral Peak Granodiorite is cut by a number of white aplite dikes that are a few inches thick. These dikes intruded the granodiorite at a very late stage of crystallization when no dark minerals remained in the magma.

On the hike to the summit, look for patches of granite that have been polished by the glacier. In places, the aplite dikes retain the polish and the adjacent granodiorite has no polish. This occurs because aplite is more resistant to weathering than the granodiorite. Also, note the many exotic blocks left on the dome when the glacier melted. Some of these blocks are composed of Cathedral Peak Granodiorite and some are composed of other intrusives.





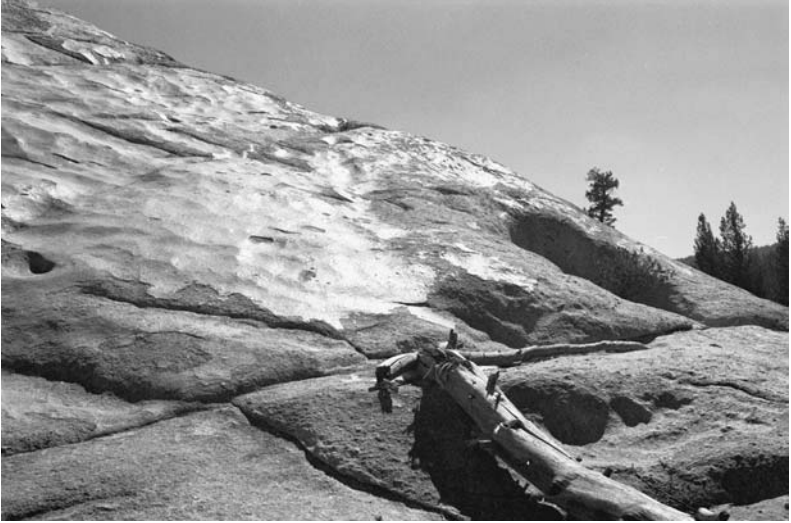
Lembert Dome is a classic roche moutonnée, formed when the Tuolumne icefield covered the dome. The ice, which was moving west, rode up the smooth east flank of the dome and plucked the jointed granite from the steep west flank.

**Pothole Dome** - From the Tuolumne Meadows Visitor Center take Tioga Rd. 1 mi. W to the parking lot for Pothole Dome; take the short trail to the dome.

It is a nice easy hike to the summit of the Pothole Dome. On the hike you'll see that the dome is a *roche moutonnée* formed from the Cathedral Peak Granodiorite and that the dome has good examples of the same geologic and glacial features described at Lembert Dome. However, Pothole Dome also has potholes and flutes, features that are common in rivers but rarely found on *roche moutonnée*.

The potholes, which occur on the south side of the dome, are circular steep-sided holes several feet in diameter. Potholes are formed by cobbles or boulders being spun around continuously by a circular turbulent eddy of water. The spinning rocks, called grinders, drill holes into the rock by abrasion. Potholes mostly occur in the beds of turbulent mountain rivers or streams. However, at Pothole Dome the potholes were formed by meltwater from the Tuolumne icefield. The meltwater collected on the surface of the icefield and then flowed into vertical shafts in the ice, called *moulins*. The moulins were scoured out by the swirling meltwater as it poured down from the surface. At the base of the glacier, the water from the moulins collected into rivers that flowed beneath the glacier. The turbulent water in these rivers formed the potholes. The grinders for the potholes were conveniently supplied by rocks carried in the glacier. The force and grinding action of the turbulent water pouring down a shaft in a glacier that is 1,000 to 2,000 feet thick must have been enormous. Some of the granite near the potholes has been shaped into a wavy, fluted surface by the water flowing beneath the glacier. Where fresh, the fluted surfaces are polished. The polish appears similar to glacial polish, but glacial polish forms flat surfaces.





This fluted granite surface on Pothole Dome was polished by meltwater that was running below the Tuolumne icefield.



↑ This pothole on Pothole Dome was formed when turbulent meltwater flowing below the ice formed an eddy. Rocks taken from the glacier and caught in the eddy were used as grinders.

← Pothole Dome is similar to Lembert Dome, but also has flutes and potholes formed by water flowing under the icefield.

### ③ **Dana Meadows**

The ice in the Tuolumne icefield picked up a large amount of rock debris as it moved across the granitic basement rocks of the Tuolumne landscape during the glacial episodes. This debris consisted of boulders plucked from the mountains and hills that were encountered by the ice, as well as sand, silt, clay, and smaller rocks ground up by the glacier. When the icefield melted at the end of the Tioga glacial episode, about 15,000 years ago, large quantities of glacial till were left behind in many of the low-lying areas of Tuolumne Meadows and Dana Meadows. East of Lambert Dome, Highway 120 travels across thick deposits of this glacial till as it follows the Dana Fork of the Tuolumne River to Tioga Pass.

**Glacial Till** – *From the Tuolumne Meadows Visitor Center go 3 mi. E on Tioga Rd.; park in the pullout at marker T33.*

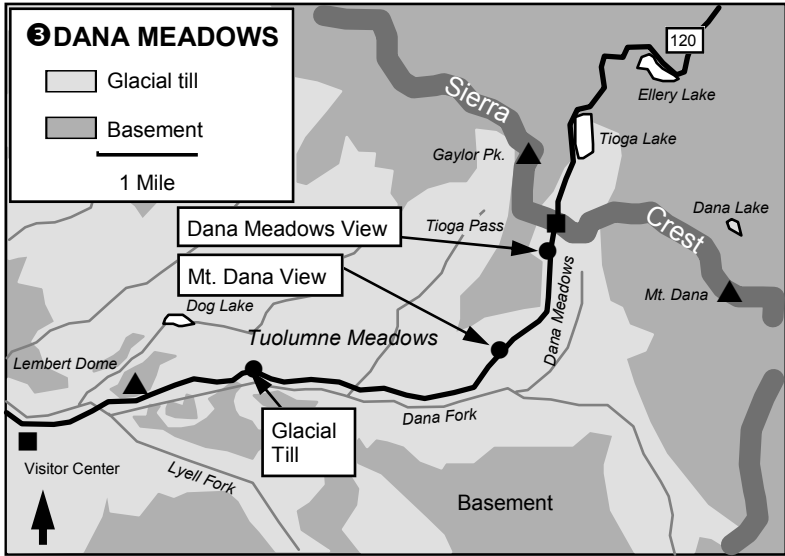
This roadcut is one of the best places in Tuolumne Meadows to see the glacial till that was left behind at the end of the last glacial episode. The till consists of piles of unsorted and unstratified boulders, sand, silt and clay.

**Mt. Dana View** – *From marker T33 go E on Tioga Rd. 3.5 mi. to marker T36.*

This viewpoint lies at the south end of Dana Meadows. From here, the Sierra crest and the west side of Mt. Dana (13,053') appear as a subdued rolling landscape tilted to the west. This land surface is probably a remnant of the Miocene landscape that existed prior to the Plio-Pleistocene uplift of the Sierra. When the Sierra block was uplifted, erosion of the western slope began in the foothills to the west, and is slowly working its way eastward toward the crest of the Sierra. This erosion has not yet reached the western side of Mt. Dana, so the gentle Miocene landscape is still preserved.

**Dana Meadows View:** *From marker T36 go E on Tioga Rd. 1.5 mi. to marker T38.*

This viewpoint is just west of Tioga Pass and is a good place to see Dana Meadows. The meadows lie in the low, poorly-drained area west of Mt. Dana and are dotted with many small ponds and lakes. This was one of the last areas where the Tuolumne icefield lingered at the end of the last glacial episode. The small ponds and lakes in Dana Meadows are referred to as *kettles* and were formed where large blocks of ice were deposited in the till. When the ice melted, the depressions were filled with water in the poorly drained till.



The west slope of Mt. Dana, seen in the far center, is relatively gentle. This surface is a relic of the old Miocene pre-uplift land surface.

#### ④ **Tioga Pass**

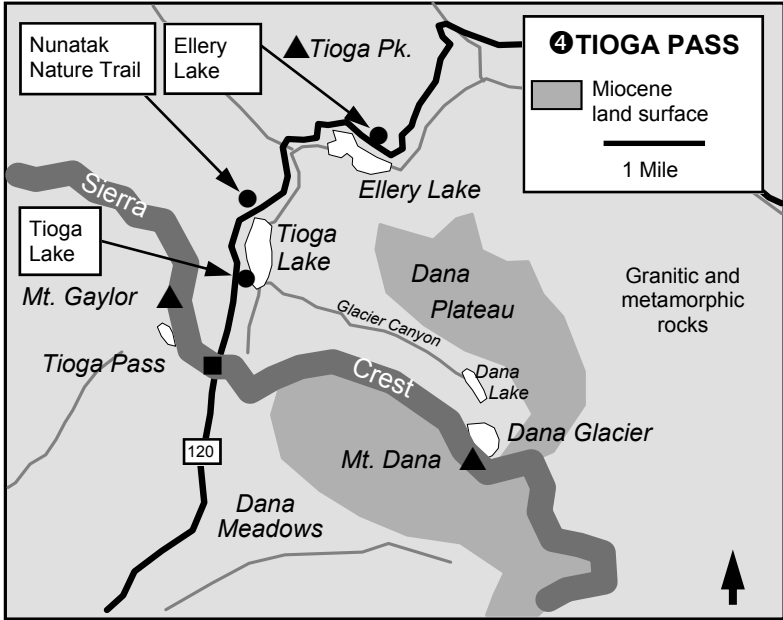
At Tioga Pass, Highway 120 abruptly leaves Tuolumne Meadows and begins its descent down the steep eastern escarpment of the Sierra Nevada as it follows Lee Vining Creek to the town of Lee Vining. Large glaciers flowed down this canyon during the Pleistocene glacial episodes and the results of this glaciation can be seen in many places. At Tioga Pass, Highway 120 also begins to cut through two large roof pendants that lie within the Sierra Nevada batholith. The first of these roof pendants consists of Mesozoic volcanic rocks. These rocks are exposed in the vicinity of Tioga Lake. The next roof pendant consists of Paleozoic metasedimentary rocks, and these rocks are exposed at Ellery Lake.

**Tioga Lake** - *From the Tioga Pass Entrance Station drive E on Hwy. 120 1 mi. to the Tioga Lake overlook at the W end of the lake.*

From here, you can look southeast across Tioga Lake and up Glacier Canyon. Mt. Dana lies on the crest of the Sierra to the right, and Dana Plateau is on the left. During the Pleistocene glacial episodes, Glacier Canyon was filled by a large glacier that had its origin along the east flank of Mt. Dana. This canyon cuts deeply into the old Miocene land surface that existed prior the Plio-Pleistocene uplift of the Sierra. Part of the old Miocene land surface is preserved as the flat top of Dana Plateau and another part is preserved on the west flank of Mt. Dana. Prior to the erosion of Glacier Canyon, the Miocene land surface extended from the Dana Plateau to Mt. Dana. Although you cannot see it from here, the small Dana Glacier lies in a cirque on the steep north face of Mt. Dana near the head of Glacier Canyon. This is one of about 100 active glaciers in the Sierra Nevada. Most of these glaciers have been decreasing in size over the last several decades. All of these glaciers completely melted during several warm spells over the last 15,000 years. The present glaciers are not small remnants of Pleistocene glaciers, but have formed during cool periods since the end of the Pleistocene.

**Nunatak Nature Trail** - *The trailhead for the Nunatak Nature Trail is just E of Tioga Lake, on the N side of Hwy. 120.*

During the Pleistocene glacial episodes, the Tuolumne icefield covered everything in the high country, except for the tops of the highest peaks. These *nunataks* served as refuges for plants and wildlife, and speeded reclamation of barren areas after the ice melted. This quarter-mile nature trail has a number of descriptive plaques about the nunataks and other natural features of this area.



In this view looking southeast across Tioga Lake, Glacier Canyon separates Dana Plateau on the left from the Sierra Crest on the right. The flat top of Dana Plateau and the gentle west flank of the Sierra Crest are remnants of the low-relief surface of the Sierra Nevada that existed prior to the Plio-Pleistocene uplift of the range. Glacier Canyon was cut into this gentle land surface mainly by glaciers during the Pleistocene glacial episodes.

**Ellery Lake** – *From Tioga Lake go E 2 mi. on Hwy 120; park in the large parking area immediately west of the Ellery Lake dam.*

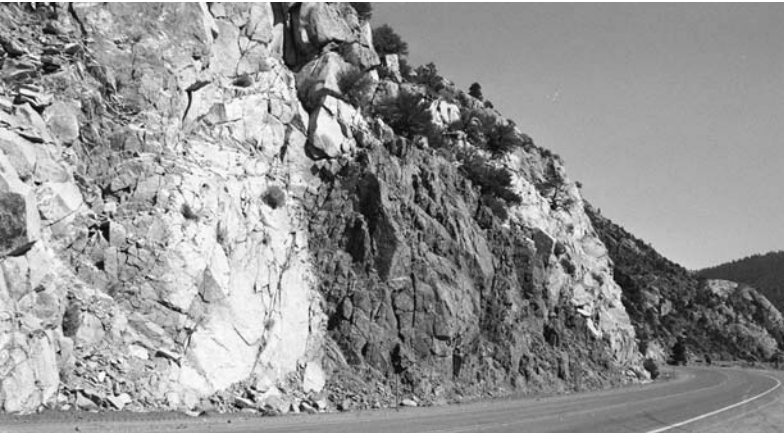
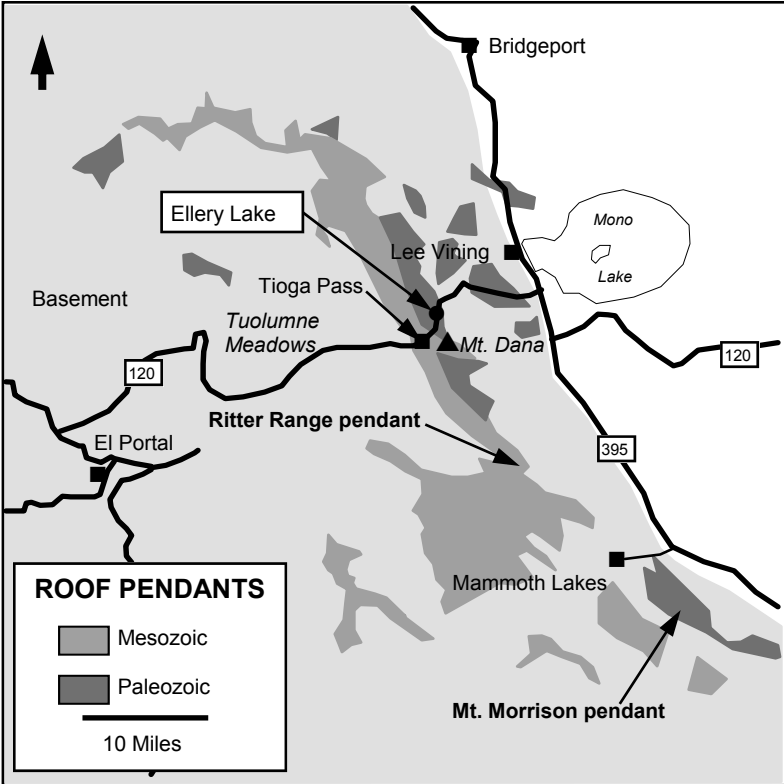
Most of the rocks in Tuolumne Meadows are granitic and are part of the Sierra Nevada batholith. However, along the eastern border of Yosemite National Park there are large areas of metamorphic rocks. These metamorphic rocks occur as roof pendants and are surrounded and underlain by the granitic rocks of the Sierra Nevada batholith. The roof pendants represent older rocks that were part of the roof of the batholith, and were intruded, heated, and metamorphosed during intrusion of the batholith.

There are two main types of roof pendants in this area—metamorphosed Paleozoic sedimentary rocks, and metamorphosed Mesozoic volcanic rocks. Most of the Mesozoic roof pendants occur along the crest of the Sierra from near Bridgeport to south of Mammoth Lakes. Mt. Dana, Tioga Lake, and the Ritter Range are on this trend. Many of these rocks are reddish, and provide a lively landscape. You saw some of these rocks at Tioga Lake. Most of the Paleozoic roof pendants lie in a trend immediately east of the Mesozoic roof pendants. The Paleozoic rocks are mostly dark and somber. Ellery Lake and the Mt. Morrison Roof Pendant are on this trend. The Mt. Morrison Roof Pendant is of special interest because it has a nearly complete sequence of Paleozoic rocks, from Cambrian to Permian.

In the roadcuts across from the Ellery Lake parking area, there are good exposures of the dark metasedimentary rocks of the Paleozoic roof pendant. Most of these rocks are hornfels, a fine-grained rock composed of a mosaic of equidimensional grains. Hornfels is formed when sedimentary and volcanic rocks of various compositions have been heated by nearby granite intrusions. The heat from the intrusion encourages recrystallization of the intruded rock. Other metamorphic rocks found here include quartzite, metaconglomerate, and marble. Prior to metamorphism, these rocks were sandstone, conglomerate and limestone.

Just east of Ellery Lake, Highway 120 leaves the Paleozoic roof pendant and again enters into the granitic rocks of the Sierra Nevada batholith. However, for several miles east of Ellery Lake you can see small roof pendants in many places on the walls of Lee Vining Canyon. The roof pendants appear as dark-colored rocks surrounded by the light-colored granitic rocks of the Sierra batholith.





Four miles east of Ellery Lake, this roadcut on Highway 120 exposes a small roof pendant of dark metamorphic rocks surrounded by light-colored granitic rocks. This is one of many roof pendants of metamorphic rocks exposed along the walls of Lee Vining Canyon.