EASTERN SIERRA GEOLOGY

Everywhere there is evidence of the work of fire and ice. Glacier-excavated canyons open onto basins and valleys that cradle lava domes, craters, volcanoes, and hot springs – reminders of the Eastern Sierra's dynamic geology.

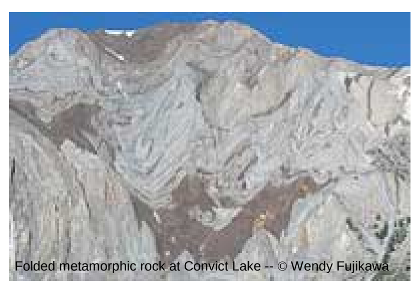
– Irwin 2002

The Sierra Nevada Mountain Range is about 400 miles (640 km) long, extending from Tehachapi Pass in the south to Mount Lassen in the north, and 50 to 80 miles (64 to 130 km) wide. Nestled along the eastern escarpment from Mount Whitney to Tioga Pass lies the heart of the Eastern Sierra, a land shaped by ice, wind, and fire. Here the Eastern Sierra crest averages 12,000 feet in elevation, has the highest peak in the continental United States (Mount Whitney at 14,494 feet), one of the youngest volcanic chains in the country (Inyo-Mono Craters), the southernmost active glacier in the U.S. (Palisade Glacier), and one of the oldest bodies of water in North America (Mono Lake). Following is a brief geologic history of this unique landscape. For more information, see *references* at the end of this section.

Formation of the Sierra Nevada Mountain Range

The geologic story of the Mammoth Lakes area begins with the formation of the Sierra Nevada Mountain Range. Approximately 500 million years ago, a vast, shallow sea that was part of the Pacific Ocean covered the area now known as western California. Mud, silt, and sand were deposited on the ocean floor to a thickness of 12,000 feet. The weight of overlying material caused the deeper sediments to solidify into sedimentary rock. About 400 million years ago, underground forces pushed the land higher than the sea and the rock layers were subjected to enormous stresses that folded and tilted them westward. The sea reclaimed the land again around 300 million years ago and additional sediments were deposited on top of the oldest sedimentary rocks. When the land rose above the ancient sea again about 225 million years ago, streams eroded some of the younger, overlying sedimentary rock creating an uneven landscape.

About 190 million years ago, the land sank below the sea for the third time, accompanied by widespread volcanic eruptions that spewed layers of volcanic material into the water. When the land rose above the sea for the last time about 100 million years ago, the volcanic rock and underlying older sedimentary rock was folded and again tilted steeply westward.


Folded metamorphic rock at Convict Lake -- © Wendy Fujikawa

The modern Sierra Nevada batholith, or rock masses that form the core of the mountain range, was formed about 225 to 65 million years ago as molten granitic material invaded the folded sedimentary rocks tens of thousands of feet below the surface of the earth. The magma either pushed aside or melted existing rock, partially or wholly assimilating it, and depositing precious veins of gold. The immense heat of the molten granitic material caused new minerals to crystallize in the overlying volcanic and sedimentary rock, converting them into metamorphic rock.

The molten material, buried deep under sedimentary, volcanic, and metamorphic rock, cooled over several million years and solidified into the bodies of granite (or plutons) that now form the batholith of the modern Sierra Nevada Mountain Range. During this time, streams and rivers were eroding the overlying rock to expose the batholith until the region finally became an area of low, gently rolling granitic hills. About 20 million years ago, widespread volcanic eruptions again blanketed the area with lava flows and volcanic material. As the eruptions increased in frequency, the eastern edge of the modern Sierra Nevada Mountain Range began to rise along fractures, or faults, and tilted an approximately 400-mile long, 70-mile wide block of the earth's crust westward – the modern Sierra Nevada Mountain Range. Uplift of the eastern escarpment continues today, even as erosional processes wear down the mountains.

The Power of Ice

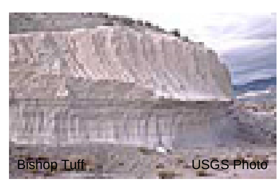
About two million years ago, the earth's climate became cooler and moister. Snow continuously accumulated on mountain slopes year-round, eventually compacting into ice that crept or "flowed" down canyons as glaciers. Over the past one million years, cycles of cooling and warming have brought at least six episodes of glacial advance and retreat. The last ice age in the Sierra Nevada Range ended about 15,000 years ago during the Pleistocene era, with glaciers receding from the main canyons. A minor episode of climatic cooling caused the Little Ice Age from about 800 to 150 years ago, when most of today's glaciers were formed.

Glaciers formed bodies of ice hundreds of feet thick that ground over the landscape, creating cirques at the heads of valleys, scooping out U-shaped valleys, and polishing bedrock as they passed over. Two glaciers on either side of a crest left a knife-edged ridge, and three glaciers left a sharp peak, or "matterhorn." As glacial ice flowed down the valleys, large boulders were carried and deposited miles from their source, leaving glacial *erratics*. The ice flows pushed earth and rock in front and to the side of the glacier, forming glacial moraines, which remained when the ice melted away. The Town of Mammoth Lakes is located on a glacial moraine, while the oldest recognizable glacial deposit is McGee Till, located on the south rim of the Long Valley Caldera below McGee Mountain.

Many of the tallest peaks in the Sierra were never sculpted into smooth, rounded domes by overriding glaciers, but instead stood well above the ice where freezing and thawing cycles splintered off layers of rock, a process continuing today. Rainwater or snowmelt seeps into cracks and expands as it freezes, widening cracks and eventually causing loosened rock to succumb to gravity. Thus, jagged peaks and spires are left standing in striking contrast to the rounded, glacier-carved domes and ridges below them.

The Age of Volcanoes

Although the Eastern Sierra has been volcanically active for the past three million years, formation of the current volcanic landscape began about 760,000 years ago with the cataclysmic eruption of the Long Valley Caldera. Over 150 cubic miles of molten rock and ash blasted out of Long Valley, about 2,500 times the amount blown out in the 1980 eruption of Mount St. Helens. Enough volcanic material was released to pave a 12-lane highway to the moon, and ash has been found as far away as Nebraska and Kansas. The rosy tan, soft pumice ash, known as Bishop tuff, covered 600 square miles between Bishop and Mono Lake to a depth of 580 feet. The eruption partially emptied the magma chamber in Long Valley, causing the roof to collapse and the chamber to sink in on itself and form a caldera 10 miles long (north to south) by 20 miles wide. Today, the caldera depression is rimmed by Crowley Lake, the Sherwins, Mammoth Mountain, San Joaquin Ridge, White Wing, Bald Mountain, Glass Creek Dome, and the Glass Mountains (see geologic map on p. 5).


Bishop Tuff USGS Photo

About 100,000 years ago, volcanic eruptions began building Mammoth Mountain. Known as a *cumulo-volcano,* at least 12 domes and associated lava flows constructed the cone-shaped mountain out of eruptive lava, ash, and tephra (airborne ash and dust). Last erupting about 50,000 years ago, Mammoth


Mammoth Mountain -- ©Brad Peatross

Mountain is part of the Inyo-Mono volcanic chain, which extends about 28 miles northwest to Mono Lake. Eruptions in this chain began as early as 300,000 years ago, but most activity has occurred within the past 40,000 to 20,000 years. Volcanic activity began forming the Mono Craters around 35,000 years ago, with the most recent eruption forming Paoha Island in Mono Lake approximately 250 years ago. This volcanic chain has been relatively active over the last 2,000 years with an estimated 20 eruptions, forming many of the domes and craters that are described in *Prominent Landforms*.

Geology Today

Mammoth is currently a dormant, or sleeping, volcano. Fumaroles, or steam vents, attest to continuing volcanic activity and can be seen and smelled (a distinct sulfur or rotten egg odor) at the bottom of China Bowl off Chair 3 (Face Lift Express) and occasionally along the ridge of Mammoth Mountain. Evidence such as the "resurgent dome" in the center of the caldera, which has risen 28 inches since 1980, indicates that at least one hot magma body still lies beneath the Long Valley Caldera. Heat from the magma is harnessed locally by a geothermal plant, producing 40 megawatts of electricity per hour.

Minor earthquakes are common in the Mammoth Lakes area and typically occur on a daily basis, testament to still active volcanic and geologic forces. Most earthquakes are too small to be felt but are detected by sensitive instruments monitored by the United States Geological Survey. Recent activity is noted at http://quake.wr.usgs.gov/recenteqs/Maps/Long_Valley.html.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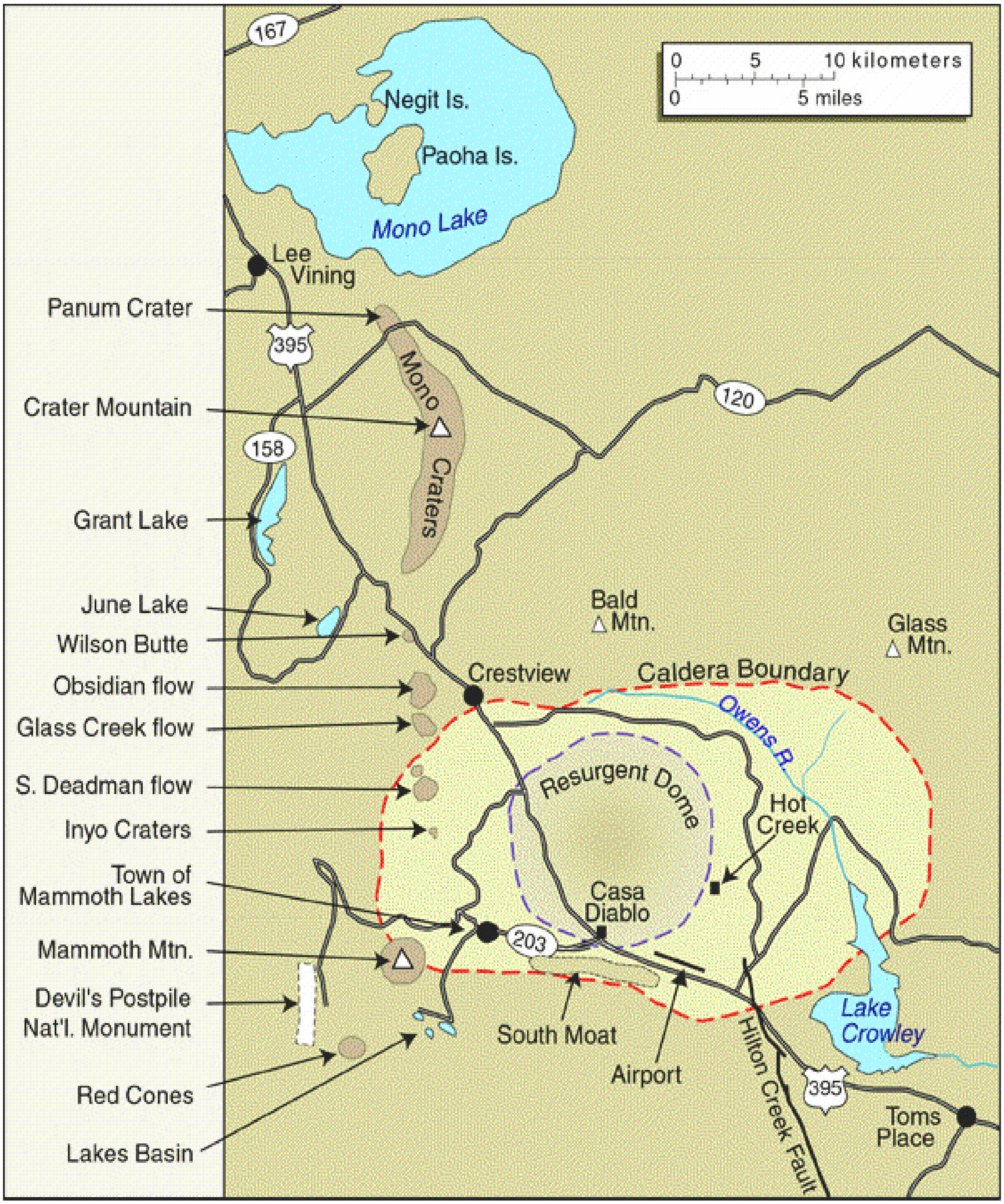
After several earthquakes in 1989, many trees began to die around Horseshoe Lake in the Lakes Basin area due to an increase in carbon dioxide (CO_2) concentrations in the soil. Scientists theorized that the 1989 earthquakes caused fissures or cracks to form in the earth's surface, allowing CO_2 produced by underground magma to rise and displace oxygen in the soil. Deprived of necessary oxygen, tree roots die and eventually the trees suffocate. The main tree-kill area is along Horseshoe Lake, but smaller, less significant areas can be found on Mammoth Mountain by Chair 12. In these locations, CO_2 accumulates in depressions or holes, under snow banks, and in other low-lying, poorly ventilated areas where it is potentially dangerous to humans and animals.

General Geologic Map of the Long Valley Area

Source: United States Geologic Survey, Department of the Interior [Internet], Menlo Park, California: "General map of the Long Valley area, California;" 1999 [cited 15 February 2003]. Available from: http://lvo.wr.usgs.gov/gallery/MapGallery.html



Mammoth's Top 10 Geologic Questions

(Answers provided by USGS seismologist, Dr. David Hill)

1. **Where is the volcano?**
   There is no single volcano. The area of most recent activity (in the last 40,000 years) is along the Inyo-Mono volcanic chain, which runs from just north of Mono Lake to the Red Cones, south of Mammoth Mountain.

2. **What is the possibility of a major eruption?**
   Small to moderate eruptions have occurred every few hundred years within the above-mentioned region. It is possible that geological unrest could escalate into an eruption, however geologists think the chance of any major activity in the area is small.

3. **If we had an eruption similar to the most recent one in Mono Lake (about 250 years ago), what would the damage be to the Town of Mammoth Lakes?**
   The eruption at Mono Lake was small and had little to no impact on the Mammoth Lakes area. An eruption of its size today might leave a few inches of ash and pumice to clean up in the Town of Mammoth Lakes.

4. **What would be the likely size of an eruption?**
   In the last 4,000 years, eruptions have been small to moderate in size. Given this history, future eruptions will likely be the same size.

5. **Would a local eruption be similar to the Mount St. Helens eruption?**
   It is very unlikely. Most of the damage caused by the Mount St. Helens was due to a lateral eruption that blew the entire north side of the mountain away. Eruptions in the Long Valley area in the last 4,000 years have been vertical eruptions from isolated vents.

6. **Is Mammoth an active volcano?**
   No. It is a dormant ("sleeping") volcano.

7. **Is there a higher risk of damage from geological activity in this area than elsewhere in California?**
   No. In fact, other areas of California face a somewhat higher risk because of many active faults and the relative high frequency of moderate to large earthquakes.

8. **Are small earthquakes considered normal activity for this region?**
   Small earthquakes are common in this area and do not present an immediate threat.

9. **What is the largest recorded earthquake in the Mammoth area?**
   In May of 1980 there were four magnitude 6 earthquakes.

10. **Is the area monitored for geologic activity?**
    The area surrounding the Long Valley Caldera is one of the closest monitored regions in the world. The onset of any volcanic activity can be predicted with fair reliability, and in the unlikely event of an eruption, the community would be warned of the potential danger.

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