BY GREG STOCK

INVESTIGATING THE EL CAPITAN ROCK AVALANCHE

At 2:25 on the morning of March 26, 1872, one of the largest earthquakes recorded in California history struck along the Owens Valley fault near the town of Lone Pine just east of the Sierra Nevada. The earthquake leveled most buildings in Lone Pine and surrounding settlements, and killed 23 people. Although seismographs weren't yet available, the earthquake is estimated to have been about a magnitude 7.5. Shock waves from the tembler radiated out across the Sierra Nevada.

On that fateful morning, John Muir was sleeping in a cabin near Black's Hotel on the south side of Yosemite Valley, near present-day Swinging Bridge. The earthquake shook the naturalist out of bed. Realizing what was happening, Muir bolted outside, feeling "both glad and frightened" and shouting "A noble earthquake!" He recalled the experience in his 1912 book *The Yosemite*:

> *I feared that the sheer-fronted Sentinel Rock, towering above my cabin, would be shaken down… The Eagle Rock on the south wall, about half a mile up the Valley, gave way and I saw it falling in thousands of the great boulders I had so long been studying… pouring to the Valley floor… After the ground began to calm I ran across the meadow to the river to see in what direction it was flowing and was glad to find that down the valley was still down.*

The earthquake and rockfall profoundly affected Muir, causing him to view earthquakes as the primary mechanism of rock debris, or talus, formation in Yosemite Valley. Noting the huge volumes of talus in Yosemite Valley, he went on to write:

> *Judging by its effects, this earthquake was gentle as compared with the one that gave rise to the grand talus system of the Range and did so much for the cañon scenery.*

The rockfall witnessed by Muir originated from an area above the present location of the Yosemite Chapel, from a point known as Eagle Rock. The rockfall was about 47,000 cubic yards in size, enough to cover a football field nearly three stories high. The rock itself weighed roughly 108,000 tons, making it one of the larger rockfalls in recorded Yosemite history. However, the debris from the Eagle Rock rockfall actually came to rest upon a pre-existing, and much more extensive, boulder deposit. Located just east of the Chapel near Sentinel Bridge, this deposit is the result of what geologists call a rock avalanche, an especially large rockfall or rockslide that extends far beyond the cliff where it originated. Most Yosemite Valley rockfall debris accumulates at the base of the cliffs, forming a wedge-shaped deposit of talus. Occasionally, however, debris from a rock avalanche will extend out much farther across the valley floor.

Geologist Gerald Wieczorek of the U.S. Geological Survey and colleagues have identified at least five rock avalanche deposits in Yosemite Valley. The largest of these occurred in Tenaya Canyon, at the site of present-day Mirror Lake. Sometime in the past, a rock formation on the north wall of the canyon just east of and probably similar in size to Washington Column collapsed into Tenaya Canyon. The rock debris piled up against the south canyon wall to a depth of over 100 feet. There was so much rubble that it dammed Tenaya Creek, forming a large lake that once extended over a mile upstream of the dam. The lake has since been mostly filled in with sediment carried by Tenaya Creek, but what remains is known today as Mirror Lake. Other rock avalanche deposits in the Valley can be seen near Tenaya Bridge and at the walk-in campground below Royal Arches.

Of them all, perhaps the most interesting and spectacular is the El Capitan rock avalanche deposit, located beneath the southeast face of its namesake. Francois Matthes, a pioneering Yosemite geologist with the U.S. Geological Survey in the early 1900s, described the El Capitan Meadow deposit in 1930:

> *… the most remarkable body of earthquake débris is that which lies in front of El Capitan—not the talus of blocks that slopes steeply from the cliff to the valley floor, but the much vaster hummocky mass, partly obscured by a growth of trees and brush, that sprawls nearly half a mile out into the valley. There can be no doubt that it is the product in the main of one colossal avalanche that came down from the whole height of the cliff face—probably the most spectacular rock avalanche that has fallen in the Yosemite Valley since the glacial epoch… the quantity of débris that fell in this stupendous earthquake avalanche is so great… that its removal doubtless altered appreciably the contour and appearance of El Capitan.*

In 2006, a new digital topographic map of Yosemite Valley was made using a technique called Light Detection and Ranging (LiDAR). In this technique, a laser mounted on a small airplane emits pulses of light, and a sensor on the plane records the reflected light. The time it takes for the light to return indicates the distance from the plane to the ground, and Global Positioning System (GPS) is used to precisely mark the plane's position from above. LiDAR mapping also allows mapmakers to filter vegetation out of the final image, providing a high-resolution image of bare ground surface.

Was the same earthquake that triggered the El Capitan rock avalanche also responsible for the park's other rock avalanches? The answer has important implications for park safety.

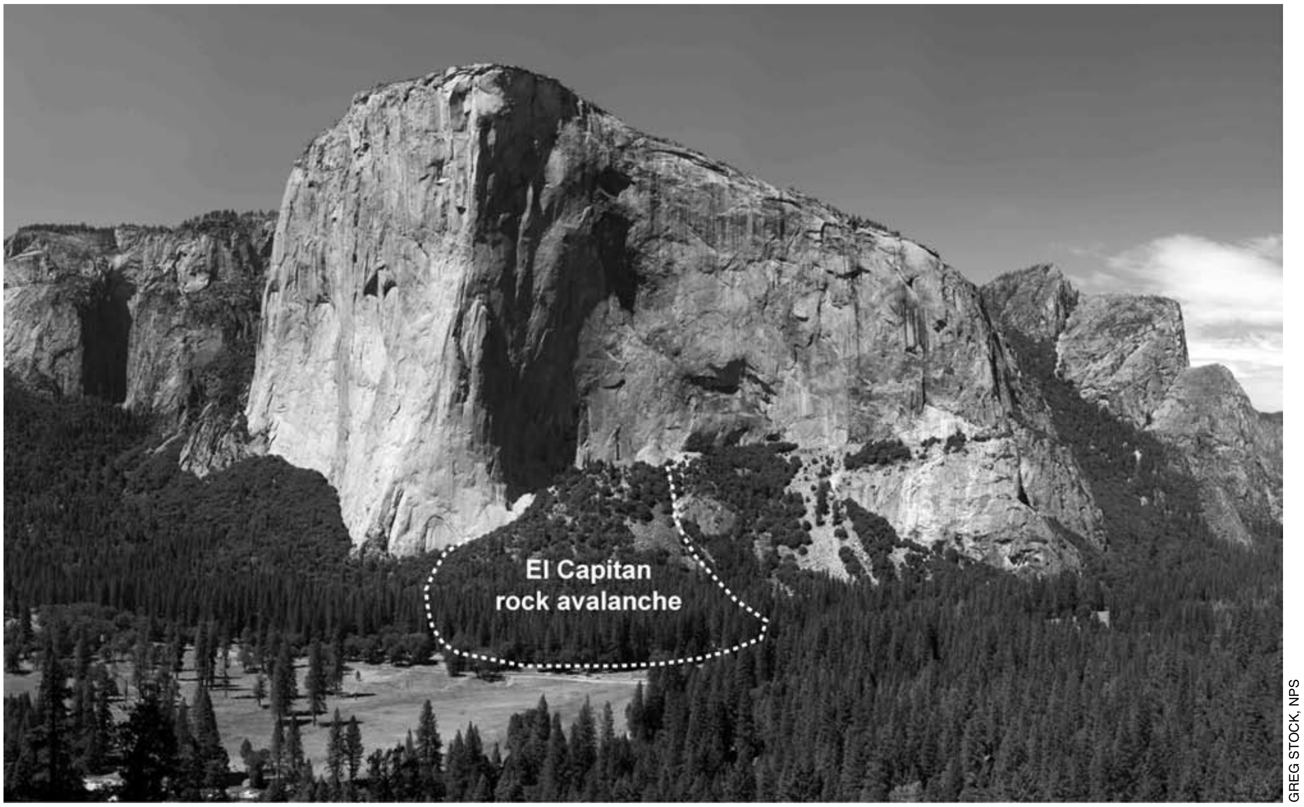
The El Capitan rock avalanche can be seen clearly in the Yosemite Valley LiDAR map, which has a resolution of about one foot. The deposit is shaped roughly like a huge tongue stretching nearly 2,200 feet beyond the base of El Capitan, about twice the length of the adjacent talus slope. It extends so far onto the Valley floor that it forces the Merced River (and now also Northside Drive) to take a sharp detour to the south at a site called Devil's Elbow. The rock deposit is about 1,400 feet wide and at least 60 feet thick in places. The piled rubble slopes downward from the base of El Capitan to the Valley floor, and then climbs upward nearly 20 feet toward the leading edge of the deposit near El Capitan Meadow. This backsloping morphology is common in rock avalanches, which quickly travel outward from the base of the cliff. The El Capitan rock avalanche deposit includes large angular boulders up to about 2,500 cubic yards in size, weighing about 5,700 tons. The entire deposit occupies a volume of about 3.75 million cubic yards, or roughly 8 million tons. For perspective, that is equivalent to a cube of granite about 155 yards on a side, as long as one and a half football fields.

When did the El Capitan rock avalanche occur? It's easy to place a few basic time constraints. We know it must have occurred after the last glacier retreated from Yosemite Valley about 18,000 years ago, but before the "discovery" of Yosemite Valley by white people in 1851. But rock avalanche deposits have traditionally proved challenging to date with standard geological methods. Most techniques provide ages for the rocks themselves, which works well if your intent is to determine when Yosemite's granites cooled from magma, but isn't very helpful if you want to know when a granite boulder came to rest at a particular place. However, a relatively new technique called cosmogenic exposure dating provides a possible solution. The technique is based on the principle that cosmic rays from space are constantly bombarding Earth's surface. Exposure to the rays generates certain chemical isotopes in the rock (isotopes are variants of elements with a different number of neutrons in the nucleus of the atom). The longer a rock has been exposed, the more of these isotopes it will accumulate. Rock avalanche deposits are excellent candidates for this type of dating, for they are composed of rocks that were almost instanteously exposed during the avalanche. Measuring the amount of the isotope beryllium-10 in the El Capitan rockfall boulders should indicate roughly how long these rocks have been lying on the floor of Yosemite Valley.

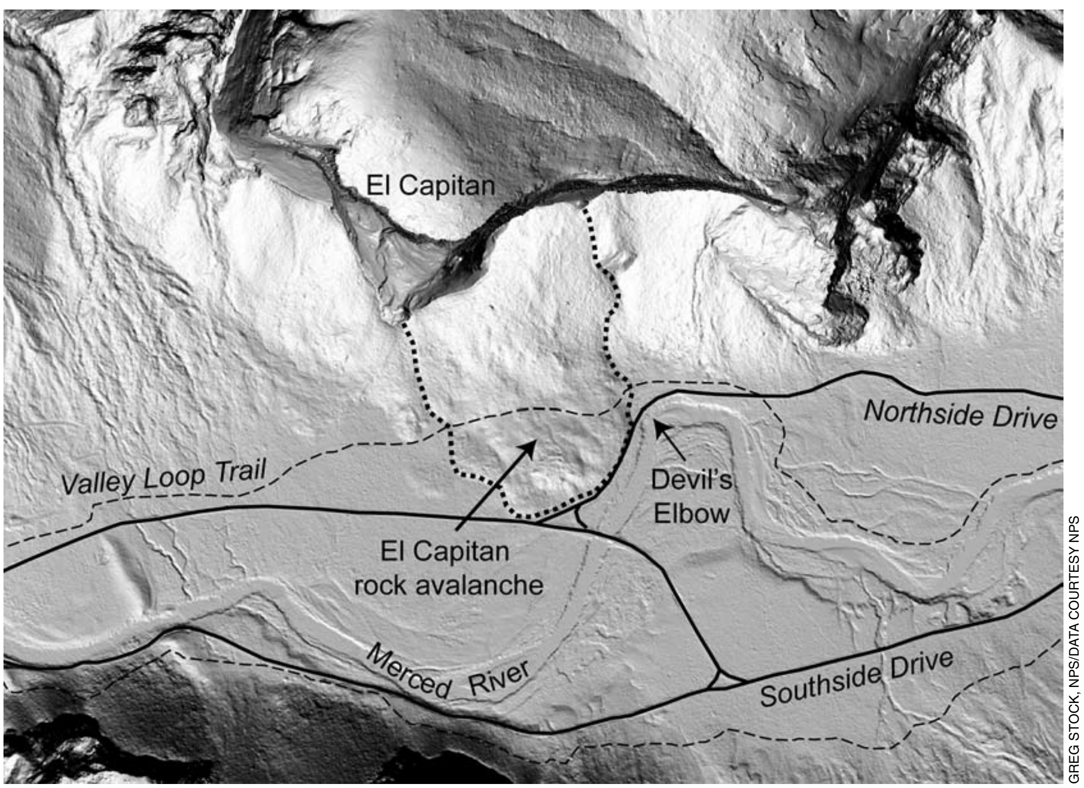
Earlier this year, we chipped small slabs of rock from the tops of five boulders atop the El Capitan rock avalanche and sent them to a laboratory at Purdue University in Indiana that specializes in cosmogenic exposure dating. Four of the five boulder samples returned ages of between 3,400 and 3,700 years, strongly suggesting that the El Capitan Meadow rock avalanche occurred about 3,600 years ago. A fifth boulder returned a much greater age of about 20,000 years. This last sample likely appears older because we sampled rock that was part of the cliff face before the rock avalanche occurred.

We now know fairly precisely when the El Capitan rock avalanche occurred. But what triggered it? Were Muir and Matthes correct in asserting that an earthquake triggered the great rock avalanche deposits in Yosemite Valley? As it happens, the 3,600-year age for the El Capitan rock avalanche coincides nicely with estimates for a pre-1872 rupture of the Owens Valley fault. Jeffrey Lee of Central Washington University and colleagues have dug trenches across the fault to study the subsurface sedimentary layers. Dating the offset sediment layers, they reported in 2001, allowed them to constrain the pre-1872 rupture to between 3,300 and 3,800 years ago—right in the neighborhood of the cosmogenic exposure boulder dates. The dramatic events of March 26, 1872, which made such an impact on John Muir, clearly demonstrated that Owens Valley fault earthquakes are capable of triggering tremendous rockfalls in Yosemite Valley. The most logical conclusion is that an earlier earthquake from the same fault triggered the El Capitan rock avalanche.

But one outstanding question about the El Capitan rock avalanche has not yet been answered: Where exactly on the vast southeast face of El Capitan did the rock avalanche originate? Given that the rockfall dislocated so much of the rock face, it is surprising that the southeast face lacks an obvious scar. The avalanche material could originally have been a broad slab extending over much of the southeast face. However, the vast majority of rocks in the deposit are composed of Taft Granite, which, according to existing geologic maps, appears mainly in the summit area of El Capitan. Diorite, a dark-colored rock that forms the shape of North America on the southeast face,



The southeast face of El Capitan, showing the location of the El Capitan rock avalanche (white dotted line).



Topographic map of El Capitan and vicinity produced with LiDAR (laser scanning) data. The dotted line marks the area of the El Capitan rock avalanche, which extended far into Yosemite Valley and diverted the river at the Devil's Elbow.

is virtually absent from the avalanche rocks. Yet the vast southeast face has never been mapped in detail.

To help answer this question, we are now collaborating with National Park Service Climbing Ranger Jesse McGahey and other climbers to map the rock types along several major climbing routes that go up the southeast face. This data should help us determine more precisely where the massive El Capitan rock avalanche originated.

It is now time to start investigating the other rock avalanches in Yosemite Valley. Was the same earthquake that triggered the El Capitan rock avalanche also responsible for these? The answer has important implications for park safety. And if that isn't reason enough to care about these fascinating deposits, consider Muir's concluding remarks on these immense shards of former mountain cliff faces:

> *If for a moment you are inclined to regard these taluses as mere draggled, chaotic dumps, climb to the top of one of them, and run down without any haggling, puttering hesitation, boldly jumping from boulder to boulder with even speed. You will then find your feet playing a tune, and quickly discover the music and poetry of these magnificent rock piles—a fine lesson.*

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FURTHER READING

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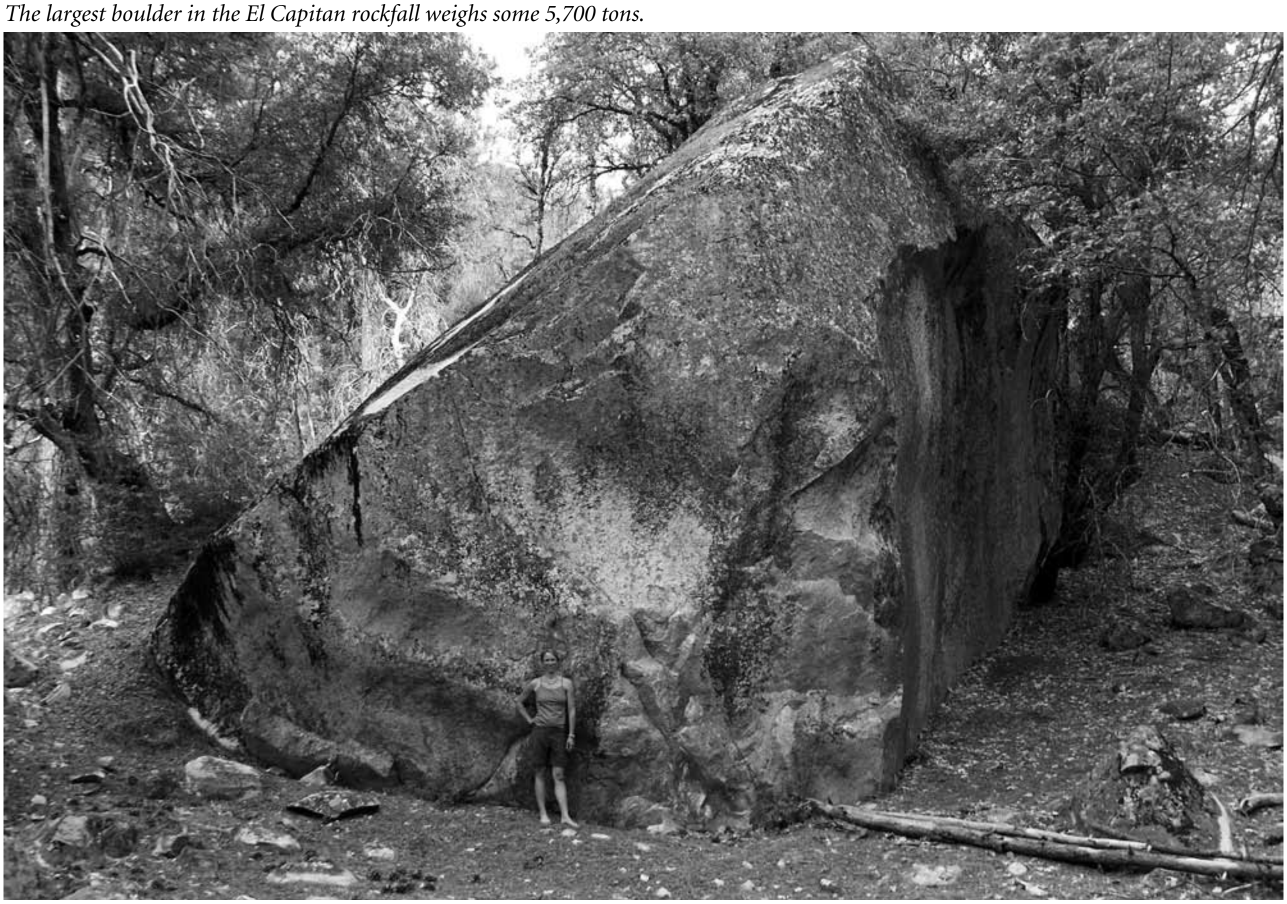
The largest boulder in the El Capitan rockfall weighs some 5,700 tons.



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