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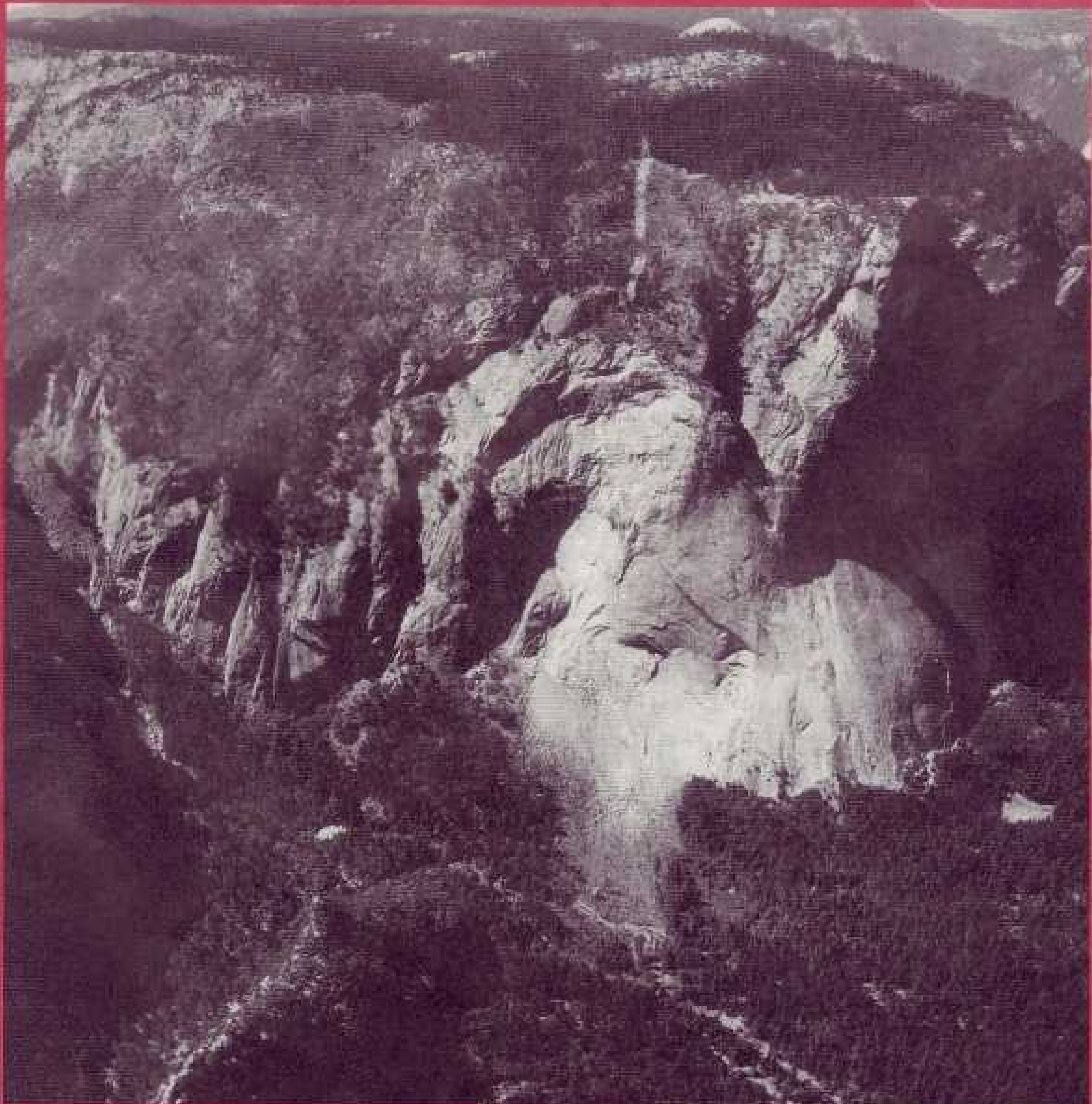
The Ground Shook and the Sky Fell



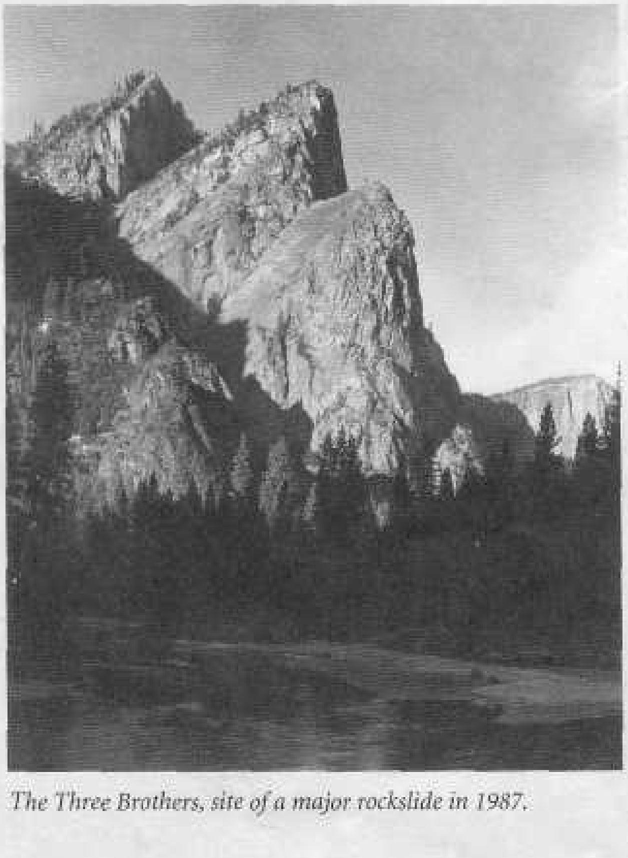
THE GROUND SHOOK AND THE SKY FELL

BY JIM SNYDER

Two rockfalls occurred in Yosemite Valley just seconds apart at 6:52 p.m. on Wednesday, July 10, 1996. The impact killed one young man and injured a number of other people, some seriously. Two lesser rockslides followed early in the morning of July 11 to complete the collapse of a very irregular granite arch on the rim of the valley some 2,000 feet above Happy Isles. Although some people witnessed the first two blocks breaking loose and falling, what most people noticed was the sound and the dust.

There were those who associated the sound with an earthquake. Yosemite's Deputy Superintendent Hal Grovert was out for a run when he thought he heard thunder, although it seemed awfully close. Others likened the sound to low flying jet aircraft. Trail worker Ernie Milan was jogging up the Vernal Falls trail just across from Happy Isles when he became aware of what he took to be the loud engine of a very large jet, close overhead, about to crash. "It felt like an earthquake and sounded like cannon-fire," Florida visitor Bill Leavengood reported. "There were two big booms, then the cloud started forming."[1]

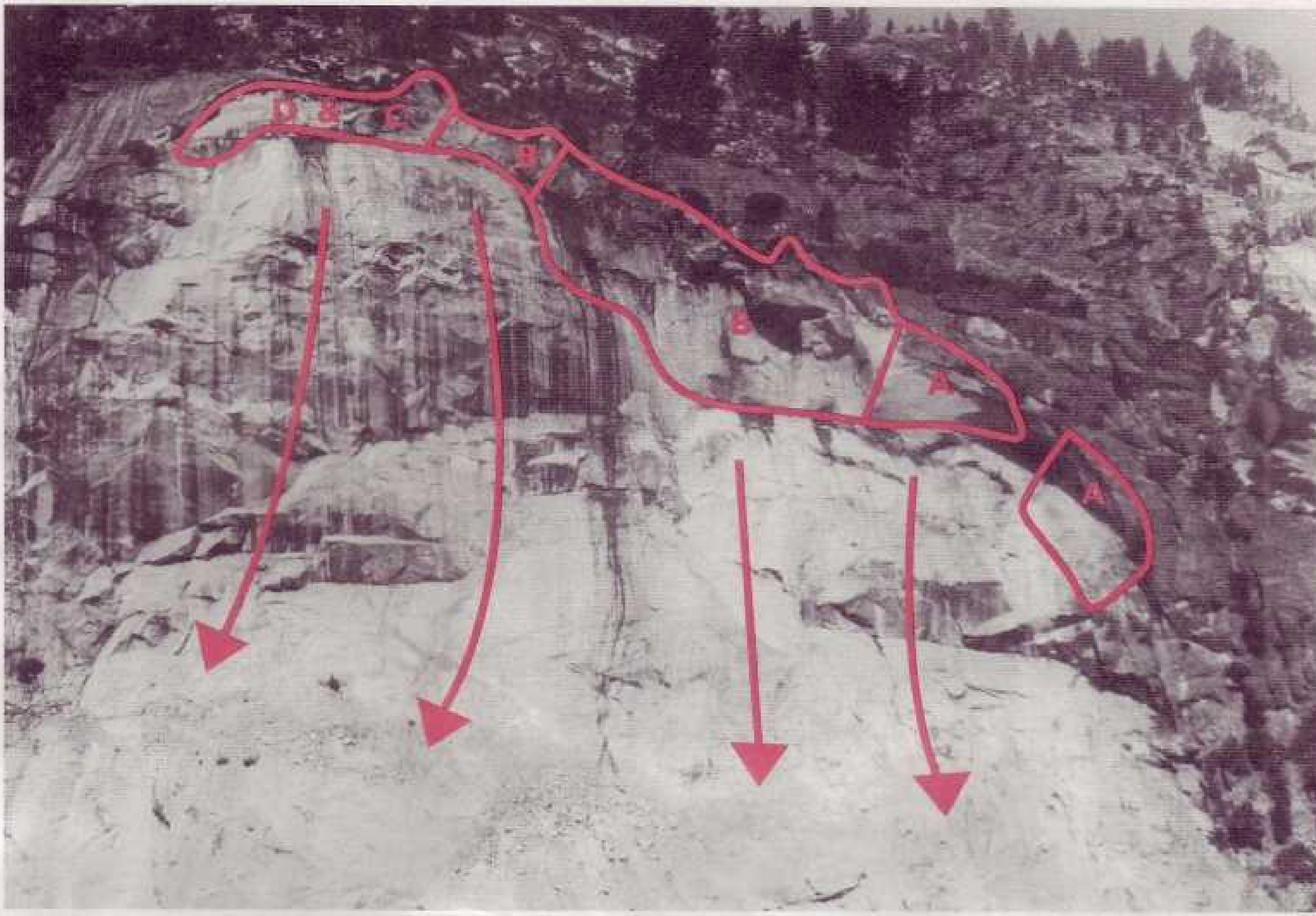
Then came the dust. Ernie checked his watch as he took cover around a cliff and noted, "The lights went out at 6:54 p.m." The dust came quickly, "like a tornado" according to one visitor, enveloping Happy Isles, the nearby trails, and much of Upper Pines Campground. Camper Roger Johnson saw the dust as "a solid wall, a boiling wall of gray." "It turned black, you could not see anything," Gisele Rue recalled. The dust hung in the air around Happy Isles for hours afterwards, limiting visibility and hampering search and rescue efforts. Searcher John Brenner of the Sacramento Fire Department said, "It's like being in a dust storm and searching for a needle in a haystack."[2]



The Three Brothers, site of a major rockslide in 1987.

A typical rockslide in Yosemite Valley has a much different sound. Certainly there can be a kind of thunder in the large ones, but in the process of falling, the rocks quickly break up into a very loud clatter as the initial fall becomes hundreds if not thousands of slides down the walls into the waiting talus. Ranger Phil Hibbs and I happened to be standing almost directly under the largest rockfall in recent memory, one that started on Middle Brother Rock on March 10, 1987. We had been looking for the source of small rocks falling from the wall when a large part of the cliff face collapsed. As it separated from the crag, the block itself broke up into huge, three-dimensional parallelograms formed by the internal jointing of the rock, the cliff unfolding like the stairs of an escalator. These blocks hit the ledges below at different rates, creating many distinct crashes within the roar of the overall slide. The ledges funnelled the descending debris down other rock faces to the talus cone at Rocky Point. The sound of the rock breaking up and bouncing off granite was hardly unified, and quite unlike the sound of a jet. The one slide became many, and the sounds of each were distinct but joined. The Middle Brother slide was characterized by not just one sound, but by many, starting loud and slowly tapering off as the much-broken mass settled.

Likewise, the two dust clouds from the Middle Brother slides (totalling nearly a million and a half tons) were bigger than the cloud from the Happy Isles slide. Hibbs and I watched the granite cascade, dust billowing as rocks were ground and smashed into smaller pieces, especially on impact with the old talus at the cliff's foot. We were able to see the rocks reach the talus, but very soon the dust cloud, turned by the angle of the talus and floor of the valley, moved quickly toward us, enveloping us at our vantage point in Leidig Meadow just beyond the fall line—the line beyond which no large rockfall had passed. There were very small chips shooting by us on a flat tra-



This photograph shows the release point of the rockfall. The lines recreate rock formations as they existed before the fall. The letters A, B, C, D show the sequence and falling direction of each rock section. A fell first, B caused the air blast, C and D followed later in the night.

jectory, fragments resulting from impacts of larger rocks on one another near the foot of the talus. The rockfall gave the dust force, driving it away from the cliff face. The dust did not hit hard, but rather drifted out and then up, creating a cloud that rose to fill the valley. While we could not see very far, perhaps a few feet, the light of day remained. Although this was a bigger fall with a larger cloud, the dust was not as dense or as fast-moving as that of the Happy Isles slide.

What was it about the Happy Isles rockfall that caused these differences in sound and dust levels? In looking at it from the air, we discovered that there was no new rock beyond the historic fall line some 500 feet southwest of the Happy Isles Nature Center. To understand this unusual fact, we decided to look at the slide's release point and the sequence of the collapse.

The area from which the rockfall came lies at the wooded lip of Yosemite Valley's rim. Several photographs of the failed arch-like structure exist.[3] The arch hung on a vertical face with a high elevation of 6,600 feet, some 2,000 feet southeast and 800 feet below Glacier Point. The rock fell from the edge of the valley rim, just below the pine and live oak forest there. The release occurred at or very near the boundary between two plutons, rock intrusions composed one of Granodiorite of Kuna Crest, the other of Half Dome Granodiorite.[4] This juncture may have affected long term erosion processes, helping create the arched structure and contributing to its eventual failure.

The arch, a structure formed by exfoliation and other forces, was about 500 feet long.[5] Erosion along the joints forming the arch had already led to much of its collapse. It once had been a huge plate, 200 or more feet high, but most of its southern two-thirds had already fallen to form the talus cone (on part of which the road to the valley water tank was built) against the cliff south of Happy Isles. A large prehistoric rockslide most likely came from this arch. Another, smaller fall occurred August 2, 1938, adding to the talus cone, creating noise and dust, but causing no damage.[6] This rockslide, noted as a curiosity, occurred because the exfoliated mass had been entirely undercut by long-term erosion. Water flowed in several

The dust cloud was heavy with fresh, sharp material that abraded many of the trees going down in front of it. The bark was stripped from trees facing the impact for nearly 300 feet out from the impact area.

streams underneath the rock mass, as it does today, weathering the joints there.

A solid stand of pine and live oak trees grew along a strong vertical joint defining the back side of the arch, and roots up to eight inches in diameter had been put down into the eroding joint, turning rock into soil and slowly wedging the granite apart. The most eroded part of the arch was its high point, roughly its center, where there was more cross-jointing and an additional weakness caused by a thinly layered intrusion. This was the area of the arch in which there was more soil and more brown, weathered rock than in any other. It seemed the most vulnerable part of the arch perhaps because the small intermittent drainage flowed above and below ground there, supporting the largest trees on the rim's edge.

But it was not the center of the arch that started the collapse. The massive north wing of the arch gave way first. Park Service Interpreter Geoff Green saw two blocks, within several seconds of each other, falling from the rim.


Doug Roe, NPS

This aerial view shows the ramp along which the rocks slid before freefalling.

The seismic record confirms the impact of two blocks. Though not really comparable because rockfall produces different shock waves than do earthquakes, the impact registered roughly 2.1 on the Richter scale. Mathematical refinement of the seismic record at the UC Berkeley Seismographic Station showed two impacts about fourteen seconds apart, the second roughly four times greater than the first.[7]

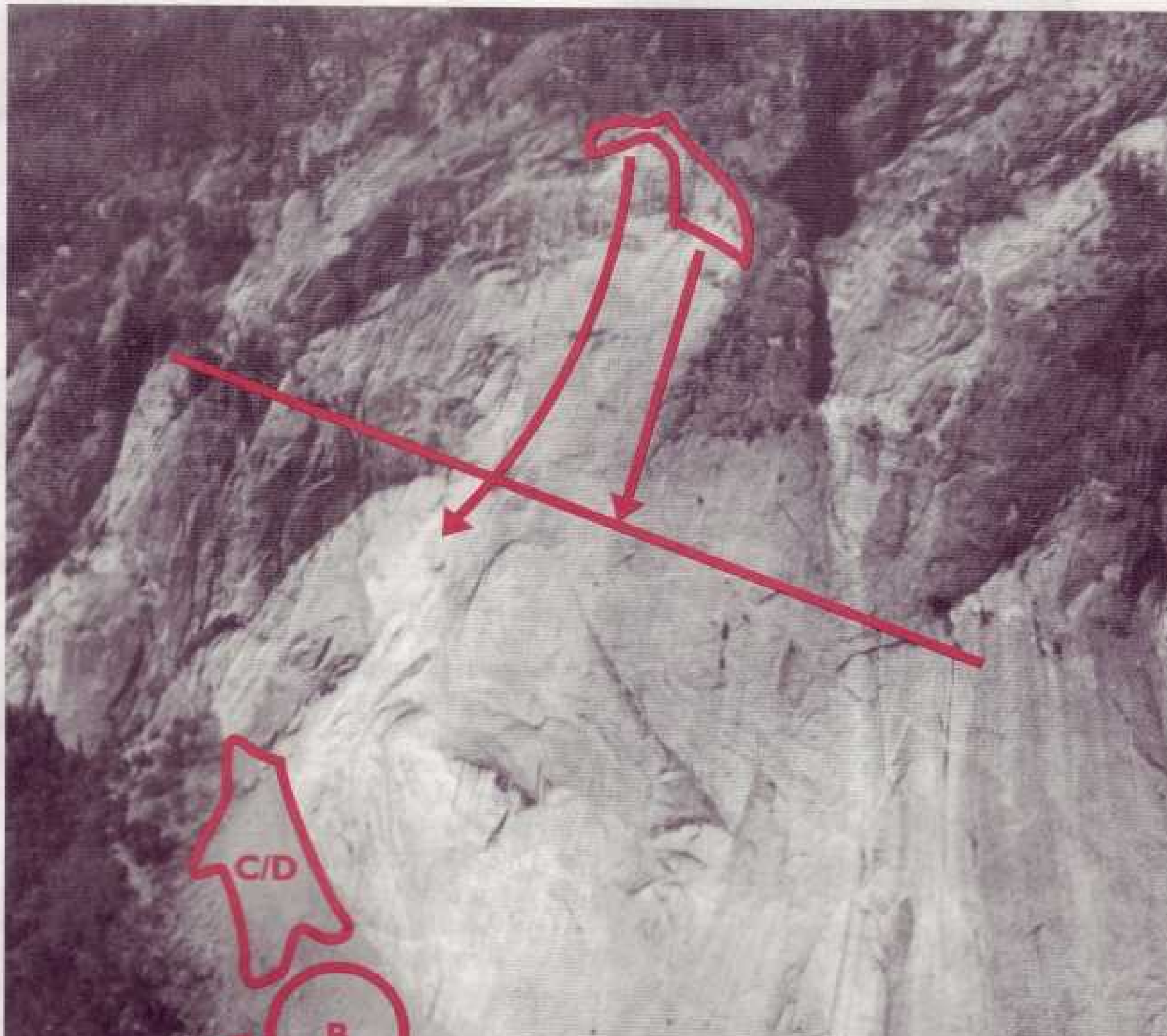
The first block was smaller, consisting of perhaps 15 to 20 percent of the massive north wing of the arch, and caused a separate outlier slab, a 2,000 ton remnant of past exfoliations, to break free. This failure at the north edge of the arch precipitated the almost immediate collapse of the rest. The area up to the arch center—that most weathered, jointed area through which the main drainage ran—fell with the second rockfall. The sequence is registered in the slightly offset impact areas at the foot of the cliff. A low ridge of freshly crushed and broken rock at the northernmost point of the slide intrudes into the existing drainage through talus west of the Happy Isles fen. A much larger hill, representing the second fall, overlaps it.

We saw the release point up close from a helicopter the evening of July 10, and there was a considerable amount of rock hanging out away from the cliff at the arch center. By 4:45 a.m. the next morning it was gone. Our examination that morning showed the collapse of the remainder of the arch to the south and the slippage of material from the drainage at the former arch center where there had been some taller pines and live oaks growing.

Although it can only be a rough estimate because no one was able to measure accurately the size of the failed blocks, approximately 78,000 cubic yards of material weighing about 80,000 tons fell in total. The first two slides on July 10 carried the massive north wing of the arch, accounting for approximately 68,000 of the 80,000 tons of the rockfall sequence, or about 85 percent of the whole. The following morning, the last two brought down the more fragile and graceful south wing of the arch.

A look at the character of the cliff below the release point is also important for an understanding of the unusual impacts on the valley floor. At 6,600 feet, the long arch lay near the top edge of a massive block which itself had been partially separated from the Glacier Point mass by earlier glaciation and long periods of drainage across the Glacier Point apron. From the air that block is distinctive, standing out from the northern cliff face while defining part of the east-facing cliff. The northern end of the block is more weathered than the cliff below it and has considerable vegetation growing in its joints down to a level of about 5,800 feet. At that elevation there is a discrete break in the cliff as well as a distinct change in the character of the granite.

The 5,800-foot line marks the approximate level of the ice at the maximum extent of the Tioga glaciation some 20,000 years ago.[8] Below it, erodable rock was cleared off by the glacial ice, and the much steeper cliff is clean, mas-



Keith Walklet

This aerial view shows the entire rockslide from its release point to its impacts at the base of the cliff. Letters A through D mark the impact areas of each part of the falling arch. Below the impact area, the approximately ten-acre sweep of air blast damage is outlined. The straight diagonal line along the cliff shows the maximum extent of the Tioga glaciation.

David J. Walter

Photographer David Walter captured the expanding dust cloud while climbing the Royal Arches

sive, and without vegetation. Above it, the rock had roughly 750,000 years to wear away through exfoliation, the work of forests, climate change, and the forces of gravity, and was slowly beveled back toward greater stability.

Weathering above and ice cleaning below that line worked to create a fairly long, steeply inclined ramp immediately below the arch. Judging from a topographic map, the ramp is about 500 feet long and drops some 400 vertical feet from the bottom of the release point. At the base of the ramp, the cliff gets much steeper. The effect on the rockfall was this: when the large slabs of the north wing of the arch broke away from their moorings they slid rather than fell down the ramp.

The slabs were so thick (probably about 30 feet) that they did not break up, remaining intact for the most part. The ramp acted as a kind of launch pad, so that when the sliding blocks approached the 5,800 foot level where the cliff became more vertical, they became airborne, falling free about 1,700 feet. Gerald Wieczorek of the U.S. Geological Survey has tentatively estimated that the blocks were travelling well over 160 miles per hour at impact.[9] The compression of air by these great falling slabs combined with the concussion to produce the unusual massive air blast. At the same time, the breakup of the slabs upon impact created the dust cloud and gave it a force the cloud from Middle Brother never had.

The slabs hit the valley floor roughly 100 feet out from the base of the cliff. There is no new talus against the wall in the vicinity of the impact, but there are two new overlapped hillocks marking the impact of the slabs. The rockfall buried and destroyed vegetation over an area of roughly ten acres; fresh rock extended just slightly beyond the fall line defined by previous slides.

The air blast accounted for damage to trees in an additional area of approximately ten acres. Because of the moisture in the ground at the foot of the talus, most trees were simply uprooted there. A few well-rooted specimens were snapped off from twenty to forty feet up their trunks. The falling of trees and the collapse of a footbridge over the Merced caused an instantaneous drop of four inches in the level of the river, which recovered only ten minutes later.[10]

It seems that as they were going down, the trees were hit by the dust cloud which, loaded as it was with debris, moved more slowly than the air blast, yet carried considerable force. While the air blast resulted from compression and concussion of air by rock, the dust cloud formed as the great slab disintegrated on impact, in a kind of implosion, with the force of impact transferred to the dust and shrapnel.

The dust cloud was heavy with fresh, sharp material that abraded many of the trees going down in front of it. The bark was stripped from trees facing the impact for nearly 300 feet out from the impact area. The air blast tore branches, leaves, and bark from trees in the impact area, carrying them about 300 feet, then burying them with sand. Small fragments of rock were embedded in the bark of trees as far out from the impact zone as 550 feet. Samples of the dust show a wide mix of grain size. The heaviest particles were dropped quickly, and only the finest grains remained airborne above Upper Pines Campground. The dust ranged from over two inches in depth near the impact area to about half an inch deep at the nature center.

The air blast and the dust cloud appear to have lost momentum rapidly along their margins and bottom, their greatest forces rising into the tops of trees by the time they reached the nature center. A sequence of photographs of the dust cloud provided by climber/photographer David Walter, shows a swift river of dust stretching from the cliff base to the nature center, where the stream turns into an explosive-like cloud, billowing finally above the trees and then slowly beginning to dissipate.

Near the impact area the air blast and dust cloud acted more like a bulldozer, knocking things over and stripping vegetation directly in its path. The impact area is about eighty feet higher than the Happy Isles Nature Center, which sits beneath a low rocky bluff about as high as its roofline. The building is also situated a little like the prow of a ship into the wave, protecting it further. By the time the blast and cloud reached Happy Isles, they had risen in their main effects and probably acted much like Mono winds have in the area of Camp 6 (the employee tent area in Yosemite Valley), whipping the tops of large trees, taking down those most vulnerable and sitting in the loosest, moistest soils, those trees knocking down others.

While rockfalls are common in Yosemite—they are an integral part of the nature of the beast—the Happy Isles slides were unusual.

Unlike the Mono winds, however, these blasts, though short in duration, were at high speeds with a heavy load. It was the air blast and billowing dirt, not the rockfall, that brought the death and injuries, made the search difficult, complicated clean up, and created so many uncertainties. The dust cloud also created a few moments of terror as people were overtaken and seemingly trapped.

Not all the rock that fell came off the ramp that carried the two large slabs. That ramp is narrow, and the cliff face to which it leads is rounded, bending back into an indentation in the wall likely produced by weathering and glacial plucking. It has been the traditional channel for rockfall from the area of the weathering arch. Bounded on the south by very steep cliffs, the channel feeds directly to the top of the existing talus cone. Prehistoric slides pushed the toe of that cone well out toward Happy Isles and contributed some of the large rocks on the western edge of the Merced River.

The thinner part of the weathering arch did not go down the ramp with the large slabs but instead followed this traditional channel to the talus cone. The rockfall further enlarged the channel by cracking a large block still obstructing the channel just above the cone, hastening its eventual drop to the talus. The rockfall stripped the vegetation from the top of the talus cone and knocked down a good many trees along the south margin of the impact area. Smaller rocks following in the wake of the large slabs fell closer to the cliff and along the north margin of the impact area, mangling and cutting down many oaks and pines there. What had been an oak forest at the foot of the cliff was completely denuded.

The collapse of the south wing of the arch added a foot or two to the size of the talus cone. A back blast caused by the impact of the first rockslides peeled a large but thin sheet of rock off the base of the cliff. Elsewhere, roots and stems of former vegetation are visible, having been cut down by falling smaller material, though not entirely buried. The collapse of the smaller south wing of the arch produced a rockslide more like that reported in August, 1938: dust and noise but no impact to people.

The series of rockslides left a much changed landscape between the Happy Isles Nature Center and the base of the cliffs. Many people liken the scene to the larger landscapes left in the wake of Mount St. Helens. Vegetation has been cleared, landmarks have been lost or obscured by dust and down trees, views are opened that have not existed in human memory, physical features have been rearranged, especially at the base of the cliff.

There had been a spotted owl's nest within the area of firs knocked down by the air blast. Also within the new dustscape had been what I think was Yosemite Valley's last remaining colony of mountain ladyslipper orchid, common enough nearly a century ago to be "often gathered because of its peculiar, showy flowers"[11] but now rather hard to see. Did human gathering of the flower thin the species out, or was it the sharp increases in forest on the valley floor forcing the species to contract in area? Will the rockslides open up possibilities for its recovery?

The peregrines have already returned. They had a nest just below the arch that failed. Fortunately, their young had already fledged this year. The nest was removed by the rockslide, but within a day two peregrines were back flying the cliff. The slides may have created new places on the cliff suitable for nests. Bear and deer also entered the rockfall area very soon after the new landscape developed. Near the impact area were several small holes where

Doug Roe, NPS

A view from the air of the new talus and the trees downed by the air blast. The Happy Isles Nature Center is visible at the upper right.

underground animals had come burrowing out through the new layer of sand. And within two weeks of the rockslide there were new ferns curling out of the dust and fresh shoots leafing out of bare, blasted stalks of big leaf maple.

There is no way to tell just what precipitated this rockfall or why the last support failed when it did, but a number of factors surely contributed. Vegetation worked on rock joints and fractures by extending roots and assisting in soil formation. Earthquakes jarred the cliffs, and rocks adjusted their positions slightly, contributing to eventual failure. Water was a key factor, expanding in cracks as ice, weathering the rocks as chemical agent, and reducing friction as fluid.

Rockfalls occur most frequently during the fall and spring, when there is more precipitation and when there are wider fluctuations of temperatures, causing freezing and thawing. Because it happened in mid-summer, the Happy Isles rockfall did not fit the pattern, and neither did its 1938 predecessor. The best explanation is that a combination of circumstances ultimately precipitated a failure, which then set off a chain reaction around the initial release, causing instability and affecting other weak rock structures on the slides' routes down. Happy Isles reminded us that such natural events can happen at any time. Predictability is necessarily limited.

There is more work to be done to understand the rockslides. The mechanics of the air blast are not fully understood, but may be clarified by USGS studies and aerial photographs of the area. The history of failures along this cliff will help indicate potential rockfall patterns in other areas of the valley.

While rockfalls are common in Yosemite—they are an integral part of the nature of the beast—the Happy Isles slides were unusual. The only other documented rockslide accompanied by a massive air blast was one of a series of slides generated by the earthquake of March 26, 1872. The air blast occurred when a long slab on the west side of Liberty Cap fell. Galen Clark wrote that the impact immediately knocked Albert Snow to the ground and moved Snow's Hotel below Nevada Fall (also known as La Casa Nevada) two inches off its foundations while so severely damaging another building that it had to be taken down and rebuilt. The hotel area also was covered with dust.[12]

No one died in the 1872 rockfall and blast. Although the Happy Isles slides brought the unfortunate death of Emiliano Morales at the ice cream stand, had the rockfall occurred when more people were present, it might have been far worse for Yosemite visitors and employees alike. In human terms, however, the valley remains far safer than the freeways and cities outside it. Rockslides are normal in Yosemite; they are part of ongoing processes, a great work in progress, so to speak, which a renewed Happy Isles should demonstrate.

Study of these slides will tell us more about rates and processes of erosion and about talus formation. Knowing about the very different effects that can result from high elevation releases, we will be better able to see how talus forms, how some of the rocks come to rest far out in the valley, and how effects of rockfall carry well beyond the fall line. We will also learn more about the ongoing effects of glaciation and climate change on erosion patterns and evolution of the valley floor. In the long run, this information will help us better provide for the safety of people and facilities in Yosemite Valley and make us think a little differently about our visits here.

Understanding the processes can make our responses to rockfall more effective, while keeping those responses appropriate, demonstrating that we can live as gracefully as possible with the workings of nature. Air blasts, for example, occur with massive rockfall along steep cliffs where rocks drop with little breakage. Potential locations for such events can be mapped, and air blast potential can be added to maps of valley rockslides and talus. Rockfall hazards can be described; processes can be better anticipated. But ultimately each one of us must take some responsibility for understanding and living within "the cleft or 'gorge' in the granite peak of the Sierra Nevada Mountains," as the 1864 Yosemite Grant neatly put it, that we all admire.

Author's note: *I could never have written this piece without the ongoing assistance of US Geological Survey scientists like Gerald Wieczorek and King Huber. Their contributions to the study of Yosemite geology are the best example of the long, productive relationship between the National Park Service and the Geological Survey. Their publications may be consulted for much more detailed geological explanations of erosion processes in Yosemite rock.*

Jim Snyder is presently the Park Historian for Yosemite. He worked many years for the NPS in the backcountry where rockslides on park trails brought him into contact with US Geological Survey scientists. In this article, he uses this expertise as he looks at the Happy Isles rockslide and compares it to earlier slides in Yosemite's history.

Notes

1. San Francisco *Chronicle*, July 12, 1996, p. A-5; *Mariposa Gazette*, July 18, 1996, p. 14; and *Davis Enterprise*, July 11, 1996, p. A-1.

2. *Davis Enterprise*, July 11, 1996, p. A-4; *San Francisco Examiner*, Afternoon Edition, July 12, 1996, p. A-16; *Mariposa Gazette*, July 18, 1996, p. 1; and *Sacramento Bee*, July 12, 1996, p. A-18.

3. The best photograph of the arch before its collapse appears in Robert Cameron, *Above Yosemite* (San Francisco, CA: Cameron and Co., 1983), lower left hand corner of p. 44.

4. Frank C. Calkins and others, "Bedrock Geologic Map of Yosemite Valley, Yosemite National Park, California," US Geological Survey Miscellaneous Investigations Series Map I-1639 (1985). See also N. King Huber et al, "Geologic Map of Yosemite National Park and Vicinity, California," US Geological Survey Miscellaneous Investigations Series Map I-1874 (1989), and N. King Huber, *The Geologic Story of Yosemite National Park*, US Geological Survey Bulletin 1595 (Washington: GPO, 1987; Yosemite, CA: Yosemite Association, 1989), Plate 2.

5. Huber, *Geologic Story*, pp. 33-35, explains exfoliation with illustrations including a similar but more massive structure, the Royal Arches above the Ahwahnee Hotel.

6. Gerald F. Wieczorek, et al, *Rock Falls in Yosemite Valley, California*, US Geological Survey Open-File Report 92-387 (Reston, VA: USGS, 1992), Appendix 2, p. 54, and Plate 4.

7. Information about the seismic record of the rockfall came in a written communication from Robert Uhrhammer of the UC Berkeley Seismographic Station to Gerald Weiczorek of the USGS. In addition, following the rockfall USGS seismologist Bob Norris installed a small seismograph at the top of the release point to record any movement after the rockfall. In five days the record showed several very small earthquakes in the Mammoth area with no effects on the release point, some small rockfall from the ledges of loose rock below the release point, and signs of a large mammal, probably a bear, walking near the seismograph. There was no sign of further movement in the release point during this period. Nor was there any support for the spurious suggestion that construction at Glacier Point had initiated the rockfall in the first place.

8. See Francois E. Matthes, *Geologic History of the Yosemite Valley*, US Geological Survey Professional Paper 160 (Washington: GPO, 1930), plate 39, "Map of Ancient Glaciers of the Yosemite Region." See also Tau Rho Alpha, Clyde Wahrhaftig, and N. King Huber, "Oblique Map Showing Maximum Extent of 20,000-Year-Old (Tioga) Glaciers, Yosemite National Park, Central Sierra Nevada, California," US Geological Survey Miscellaneous Investigations Series Map I-1885 (USGS, 1987).

9. Written communication from Gerald F. Wieczorek.

10. Written communication from Gerald F. Wieczorek.

11. Harvey Monroe Hall and Carlotta Case Hall, *A Yosemite Flora* (San Francisco, CA: Paul Elder and Co., 1912), p. 62.

12. See Wieczorek, et al, *Rock Falls in Yosemite Valley*, Appendix 2, p. 3.