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Historical Rock Falls in Yosemite National Park, California

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Introduction

This report contains an inventory of historical rock falls reported in Yosemite National Park, with data on the location, date, type of slope movement, trigger, size-volume, types of damage, narrative description and reference(s) for 519 rock falls that occurred between 1857 and early 2004. About 330 of these events occurred within Yosemite Valley and most others were in the near proximity, for example, along El Portal Road in the Merced Gorge. This information was collected from review of published and unpublished historical accounts and field studies of recent rock falls. Many more than 500 rock falls undoubtedly occurred during this historical period, but many went unnoticed or unreported because of the small size of individual rock falls or the lack of impact on trails, roads, structures or utilities. This report is an update of a previous rock-fall inventory of Yosemite National Park (Wieczorek et al., 1992).

Following the modern discovery of Yosemite Valley (1851), larger rock falls were mentioned in the writing of many visitors, including Josiah Whitney, State Geologist of California; John Muir, noted naturalist; and Joseph LeConte, Professor of Geology at the University of California. More systematic recording of both small and large rock falls affecting facilities began after 1916 with the monthly National Park Service (NPS) Superintendent's Reports, because repairs were necessary to maintain damaged trails and roads. Although the bedrock and glacial geology of Yosemite have been studied extensively (Matthes, 1930; Calkins, 1985; Huber, 1987; and Peck, 2002), slope movement processes, such as rock falls and other forms of slope movement, have not been examined systematically.

Rock falls, rock slides, and other forms of slope movement are a serious natural hazard in Yosemite National Park and, especially in Yosemite Valley. In this report, the term "rock fall" in the title is used as a generic, collective term for all slope-movement processes in Yosemite, including rock fall, rock slide, debris slide, debris flow, debris slump, and earth slump, individual types of slope movement according to the classification system of Varnes (1978).

In addition to damaging roads, trails, and other facilities, rock falls endanger some of the more than 3 million visitors that annually visit Yosemite National Park. Between 1857 and 2003, 12 people have been killed and at least 62 injured by rock falls in Yosemite Valley. The U.S. Geological Survey (USGS) and the National Park Service

(NPS) have cooperated to document rock-fall hazards in Yosemite National Park from archival records, aerial photographic interpretation, and field investigations. An initial collection of historical rock-fall information compiled by Snyder (NPS, unpub. data, January 1990) became the basis of the rock-fall inventory (Wieczorek et al., 1992 and this updated report). Additional investigations and mapping of prehistoric, historical and recent rock falls have been conducted in Yosemite (Rempel, 1983; Snyder, 1981, 1986a, 1986b, 1996; Wieczorek et al., 1995; 1998, 1999, 2000; Wieczorek and Jäger, 1996; Wieczorek and Snyder, 1999; Wieczorek, 2002).

Data Files

The rock-fall inventory data in this report are contained in three separate sheets within an Excel file. These sheets contain columns with information including a chronological number assigned to each event (ID #), type of slope movement, time and date of the event, location, volume and relative size of event, trigger, damage, reference of informational published or unpublished source(s), and narrative description. Subsequent to the preparation of the first inventory in Yosemite (Wieczorek et al., 1992), historical records of a few additional rock falls were discovered; consequently, the new numbering system does not coincide with the previous inventory. Therefore, in this inventory we have listed both the new number and the previous number adjacent to each other in the first two columns of each spreadsheet.

Types of slope movement were classified using the system of Varnes (1978) based on the type of material involved in movement—soil, rock, or debris—and the dominant type of movement—sliding, flowing, falling, toppling, or a combination thereof. Most accounts either identified the type of slope movement or were sufficiently descriptive so that the type of slope movement could be interpreted based on examination of the form and character of source or deposits. Rock slides and rock falls were the most numerous kinds of slope movement recorded in Yosemite National Park; debris flows, debris slides, and earth or debris slumps were recorded but were much less common.

Some rock-fall descriptions in historical accounts had sufficient detail to determine the exact locations where the rock falls occurred. However, in other historical accounts, the locations were not given or referred vaguely to segments of trails or roads and general regions of the park. Many informal place names, particularly climbing routes, are used locally in Yosemite and are not on USGS published topographic maps. These names, such as the “Cookie,” are put in quotation marks in the inventory.

The dates and times of occurrence of historical rock falls are known with varying degrees of accuracy. The larger and more damaging events attracted more attention and were noted more commonly with precision as to the day and hour. However, some events, such as those observed after the winter or spring seasons, could be associated only with the several months of a particular season. As Yosemite Valley visitation increased and as park employees became more aware of rock falls, the time of rock falls has been more regularly noted and reported, specifically to the hour or minute.

Examination of historical photographs revealed that some rock falls occurred which had never been reported. For example, historic photos have documented the occurrence of unreported rock falls in the 1860’s, around 1900, and around 1950 on the eastern part of Glacier Point above Happy Isles (James Snyder, written commun., 10/18/1999). Unreported rock-fall events, such as these, that were only identifiable from examination of photographs were not included in this inventory because although the locations are known, the times of the events were only widely bracketed by the irregular time interval (years or decades) between photographs and the limited areas covered by these photos.

The volume or weight of a rock fall is sometimes mentioned in historical reports, but more frequently, only relative size terms such as small or large, were given. Several factors complicated the determination of accuracy of the size of rock-fall descriptions. An historical estimate of rock-fall volume blocking a road may represent only a fraction of the total deposit because other portions of the rock fall may have stopped uphill or have been transported downhill beyond the road. In such cases, the reported volume is a minimum estimate. Momentum transfer also can complicate estimates of the size of rock falls. The volume of an empty rock-fall scar is at most an accurate measure of the initial minimum volume at the release point; upon impact, a transfer of momentum can mobilize additional talus on a steep slope and increase the volume significantly. Thus, in some events, the initial and final volumes may differ substantially; historical records generally refer to final volumes of deposition. If tonnage was reported, volume was calculated assuming an average unit weight of 175 lb/ft^3 (2803 kg/m^3). Inaccuracy in estimating volume can also result from differences in average unit weight between intact bedrock and rock-fall deposits. Considering the qualifications regarding volume estimates, the volumes reported in this inventory are order-of-magnitude estimates, unless the volume or weight were reported, or dimensions of the release point or entire deposit were more accurately measured.

Descriptions of some rock falls include incomplete estimates of size, such as the length of distance that a rock fall blocked a trail; such descriptions require additional assumptions to estimate volume. In some cases, older historical rock falls have been measured in the field. Other descriptions lack any information relative to size. In addition to quantitative estimates of volume, we have also characterized the range of sizes in relative terms, ranging from extremely small to extremely large (see Table 1). A correlation between these relative size terms and the range of volume and assigned median volume was developed based on detailed examination of specific rock falls and the overall distribution of rock-fall volume. The assignment of volumes based on qualitative size terms provides a method for volume estimates for examining the entire inventory of rock falls.

RELATIVE SIZE	VOLUME RANGE (m^3)	MEDIAN VOLUME (m^3)
Extremely small	0-0.5	0.2
Very small	0.5-5	2
Small	5-50	20
Medium	50-500	200
Large	500-5,000	2,000
Very large	5,000-50,000	20,000
Extremely large	50,000-500,000	200,000

Table 1. Relative-size categories of rock falls in Yosemite National Park.

A few slope movements were observed directly by eyewitnesses to be closely associated with rain storms or earthquakes; however, in many accounts, although the slope movement was not observed as it occurred, the triggering event was reported to be an associated coincident event, such as an earthquake, rain storm, period of rapid snowmelt, wind, or period of extreme freeze-thaw conditions. The capability that earthquakes of a certain magnitude with epicenters located a certain distance from Yosemite could trigger rock falls was examined with historical earthquake-landslide information (Keefer, 1984; Keefer, 2002). Rain and snow events were referred to collectively as a precipitation trigger, in part, because during a winter storm, both rain and snow may occur during a single storm and may vary greatly depending upon elevation. In many accounts no triggering event was reported. In some cases, the slope movement was closely observed, but no trigger was recognized. Events with an unrecognized trigger indicate that additional triggers may exist that are not easily recognized. Infiltration of rainfall may take days or weeks following storm events, or snowmelt may occur even more gradually over months during seasonal warming to increase pore-water pressure and cause rock falls. Other gradual processes that contribute to weakening slopes, such as exfoliation, weathering of rock, and root penetration are mentioned in some descriptions of the conditions at sources of slope movements where no obvious trigger was apparent. Rock falls that occur without an apparent trigger are not unusual in areas worldwide where post-glacial stress unloading or rebound occurs. In cases where an apparent trigger is unreported or indefinite, the trigger is listed as “?” in the inventory. In cases where the event was closely observed, but the trigger is unrecognized, it is listed as “UNR”. Several reasons may account for the abundance of unreported (and unrecognized) triggering events. The delayed effect of earthquake shaking in weakening rock masses and accelerating the rate of slope movements in the months, years, or decades following an earthquake could not be evaluated. Geologic processes including chemical weathering and exfoliation can gradually weaken a rock mass to the point of failure. High pore water pressure, resulting from infiltration of rainfall or snowmelt, can cause rock falls, but cannot be easily measured and is only rarely observed as water flowing from a rock-fall release area. For example, examination of the release area shortly after the March 1, 2000, rock fall at Middle Brother (ID #454), revealed water emerging from joints, although the cold temperature had frozen moisture on the rock surfaces and valley floor. Removal of lateral support following retreat of glacial ice could cause redistribution of internal stresses in the valley walls with consequent strain. Unloading of a rock mass can open joints or fractures weakening the rock mass.

The damage associated with particular rock falls (Sheet #2) is categorized in three different ways: number of deaths, number of injuries, and effects on trails, roads, structures, or utilities. In some descriptions, the estimated cost of damage or repairs was included, but we did not attempt to characterize these with respect to the magnitude of damage. Likewise, we did not distinguish severe from minimal damage caused by rock falls. For example, severe damage from a rock fall may have torn apart or covered a large portion of a road, requiring days for repairs; whereas in some cases, only a few relatively small rocks falling onto a road, resulted in the road being closed for several days until the site was judged safe to reopen. The degree of seriousness of injuries was not characterized separately in most historical accounts; thus the number of injuries includes both minor and major injuries. For a more comprehensive evaluation of the hazards or risks posed by these rock falls, the damage described in the narrative descriptions should prove useful.

The descriptions of rock falls (Sheet #3) vary greatly in length and detail. The descriptions of large rock falls that occurred within a short time period from the same release point are listed as separate events. For example, on March 10, 1987, a large rock fall from the face of Middle Brother spread rapidly across the talus cone, covered Northside Drive, and sent a few boulders across the Merced River (ID #381). Another large rock fall occurred later that day from the same release (ID #382). The combined volume of these two rock falls listed as a single event (ID# 381) is an estimated 600,000 m^3, the largest reported historical event. The volume of ID #382 is listed Sheet #1 as “above” indicating that the value is a summation of the two rock falls.

A few or many small rock falls may occur following a large rock fall for periods of days, weeks and sometimes months. For example, numerous small rock falls continued at Middle Brother for at least one month following the two large rock falls on March 10, 1987 (Wieczorek et al., 1995). Although the number and timing of rock falls were noted by monitors after those large failures, it was not possible to distinguish other details, such as size and release point, necessary for inclusion in this inventory. Information on small rock falls is particularly difficult to collect from night events or events only heard without being observed, because reports of location and size can vary widely and because, in winter, distinctions between ice fall and rock fall are problematic. Therefore, this inventory was generally compiled listing rock falls for which sufficient descriptive information or physical evidence was available.

In some cases, rock falls from the same release point occur at observed separate times, even only several seconds apart, are listed as separate events (ID #418, ID #419), but the description of the several events may be combined for continuity, e.g. (ID #494, #495, and #496). In some cases, e.g. ID #236, ID #237, and ID #260, a single listed event may include a number of actual events from different release points, but with a common trigger, because a trigger was clear but specific releases were not. In some cases, photographs or maps are referenced in the descriptions of the rock falls from the cited sources; however, these are not shown in this inventory, but may be included in later publications.

Descriptions of rock falls were compiled using both published and unpublished information. The sources of published information are listed on Sheet #1 in the references column and are included in the list of references below. Published and unpublished sources are cited on Sheet #3 in the column of narratives. The many sources of unpublished information included newspaper articles, field notes, reports, memorandums, emails and oral communications. The first collection of rock-fall information that we used was an unpublished rock-fall inventory prepared by Snyder (NPS, unpub. data, January 1990). Other subsequent investigations included studying the unpublished notes, journals, and letters of John Muir from the Holt-Atherton Collections, University of Pacific Libraries, Stockton, California. The Guardians' Reports, cavalry administration reports, and the Superintendent's Monthly Reports of Yosemite National Park were examined at the Yosemite Research Library and at the National Archives in Washington, D.C. The field notes and draft maps of Francois Matthes were consulted at the USGS Photo Library and Field Records in Denver, Colorado, while Matthes' personal diaries are in the Bancroft Library, University of California, Berkeley. The other sources of unpublished sources are available for examination at the Yosemite Research Library.

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