INVESTIGATION OF THE AUGUST 24, 2019, CABLE MOUNTAIN ROCK AVALANCHE, ZION NATIONAL PARK, UTAH

by Jessica J. Castleton and Ben A. Erickson

REPORT OF INVESTIGATION 281
UTAH GEOLOGICAL SURVEY
a division of
UTAH DEPARTMENT OF NATURAL RESOURCES
2019

INVESTIGATION OF THE AUGUST 24, 2019, CABLE MOUNTAIN ROCK AVALANCHE, ZION NATIONAL PARK, UTAH

by Jessica J. Castleton and Ben A. Erickson

Cover photo: *Cable Mountain rock avalanche scar, photo date September 25, 2019.*

Suggested citation:

Castleton, J.J., and Erickson, B.A., 2019, Investigation of the August 24, 2019, Cable Mountain rock avalanche, Zion National Park, Utah: Utah Geological Survey Report of Investigation 281, 11 p., https://doi.org/10.34191/RI-281.

REPORT OF INVESTIGATION 281
UTAH GEOLOGICAL SURVEY
a division of
UTAH DEPARTMENT OF NATURAL RESOURCES
2019

Blank pages are intentional for printing purposes.

STATE OF UTAH
Gary R. Herbert, Governor

DEPARTMENT OF NATURAL RESOURCES
Brian Steed, Executive Director

UTAH GEOLOGICAL SURVEY
R. William Keach II, Director

PUBLICATIONS
contact
Natural Resources Map & Bookstore
1594 W. North Temple
Salt Lake City, UT 84116
telephone: 801-537-3320
toll-free: 1-888-UTAH MAP
website: utahmapstore.com
email: geostore@utah.gov

UTAH GEOLOGICAL SURVEY
contact
1594 W. North Temple, Suite 3110
Salt Lake City, UT 84116
telephone: 801-537-3300
website: geology.utah.gov

CONTENTS

FIGURES

TABLES

INVESTIGATION OF THE AUGUST 24, 2019, CABLE MOUNTAIN ROCK AVALANCHE, ZION NATIONAL PARK, UTAH

by Jessica J. Castleton and Ben A. Erickson

ABSTRACT

On August 24, 2019, at approximately 5:30 p.m., a large slab of Navajo Sandstone detached from a vertical cliff face of Cable Mountain above the Weeping Rock area, in Zion National Park, Utah. The slab of rock detached approximately 2000 vertical feet (610 meters) above the parking lot at the Weeping Rock trailhead. Utah Geological Survey (UGS) geologists conducted a site reconnaissance on August 26, 2019. An additional investigation including high-resolution photographs and video collected using a small unmanned aircraft system (sUAS), was conducted October 24–25, 2019. Data were also collected to help assess the stability of a prolific rockfall area that has repeatedly damaged the nearby Hidden Canyon trail. The sUAS data collected were used to create a digital elevation model (DEM), structure from motion (SfM) model, and an orthomosaic image of a large part of the western Cable Mountain, Weeping Rock, and Hidden Canyon areas. The estimated volume of the rock avalanche was calculated to be 435,712 cubic feet (12,338 m^3). The rock mass was approximately 31,000 tons. The calculated volume and flow-like qualities of the event classify it as a very small rock avalanche. No specific triggering event could be identified for the rock avalanche event; however, it appears thermal cycling is a likely contributing factor. The recommended solution in this situation is (1) avoidance of the rockfall hazard, such as not building structures and limiting access in areas with frequent rockfall and/or (2) acceptance of the hazard and the risk associated with it, knowing that the consequences of this option could result in loss of life and damage to property. All images, video, and model data collected and created from the sUAS flight will be provided to Zion National Park.

INTRODUCTION

On August 24, 2019, a large slab of Navajo Sandstone detached from a vertical cliff face of Cable Mountain above the Weeping Rock area (figure 1) of Zion National Park, Utah. The slab of rock detached approximately 2000 vertical feet (610 meters) above the parking lot at the Weeping Rock trailhead. The large piece of rock fell with such force that it broke apart and continued to flow downslope as sand particles. Based on volume estimates, the disintegration of the sandstone, and the resulting rapid flow of sand particles, the event can be classified as a very small rock avalanche. A rock avalanche is defined as the transformation of a rock slide (in itself characterized by limited disintegration) into a deeply disintegrated, rapid, and catastrophic flow of rock (De Blasio, 2011). The particles had a flow-like quality (figure 2) and the force of this event uprooted and entrained trees and damaged heavy-duty excavation equipment. The East Rim trail was severely damaged, but fortunately, was closed due to previous rockfall that occurred in January 2019. Three hikers on the Weeping Rock trail sustained non-life-threatening injuries. At the request of the National Park Service, Utah Geological Survey (UGS) geologists conducted a site reconnaissance on August 26, 2019. An additional investigation, including high-resolution photographs and video collected with a small unmanned aircraft system (sUAS), was conducted October 24–25, 2019. Data were also collected to help assess the stability of a prolific rockfall area that has repeatedly damaged the nearby Hidden Canyon trail.

Zion National Park is known for its towering cliffs and tranquil valley floor. The canyon is geologically active with frequent rockfalls ranging from individual blocks of rock detaching from a cliff to catastrophic rock avalanches. With annual visitation exceeding 4.3 million in 2018, the likelihood of geologic hazards affecting park visitors and infrastructure continues to rise.

PURPOSE AND SCOPE

The purpose of this investigation was to document the characteristics of the August 24, 2019, rock avalanche event, obtain flight authorization and process sUAS imagery of the source area and the deposit, estimate the volume of the event, assess risk associated with the rockfall event, and document the damage to existing trails. The UGS visited the site on August 26, 2019, to conduct a preliminary assessment of the rock avalanche and determined that a more detailed investigation could help National Park Service officials document the nature and extent of the hazard and help determine the risk and the short- and long-term rockfall recurrence for the Cable Mountain area. The UGS was authorized by the National Park Service to fly a sUAS in Zion National Park and conducted a geologic-hazard sUAS reconnaissance of the Weeping Rock and Hidden Canyon trail area on September 24 and 25, 2019. The UGS also visited the top of Cable Mountain, directly above the source

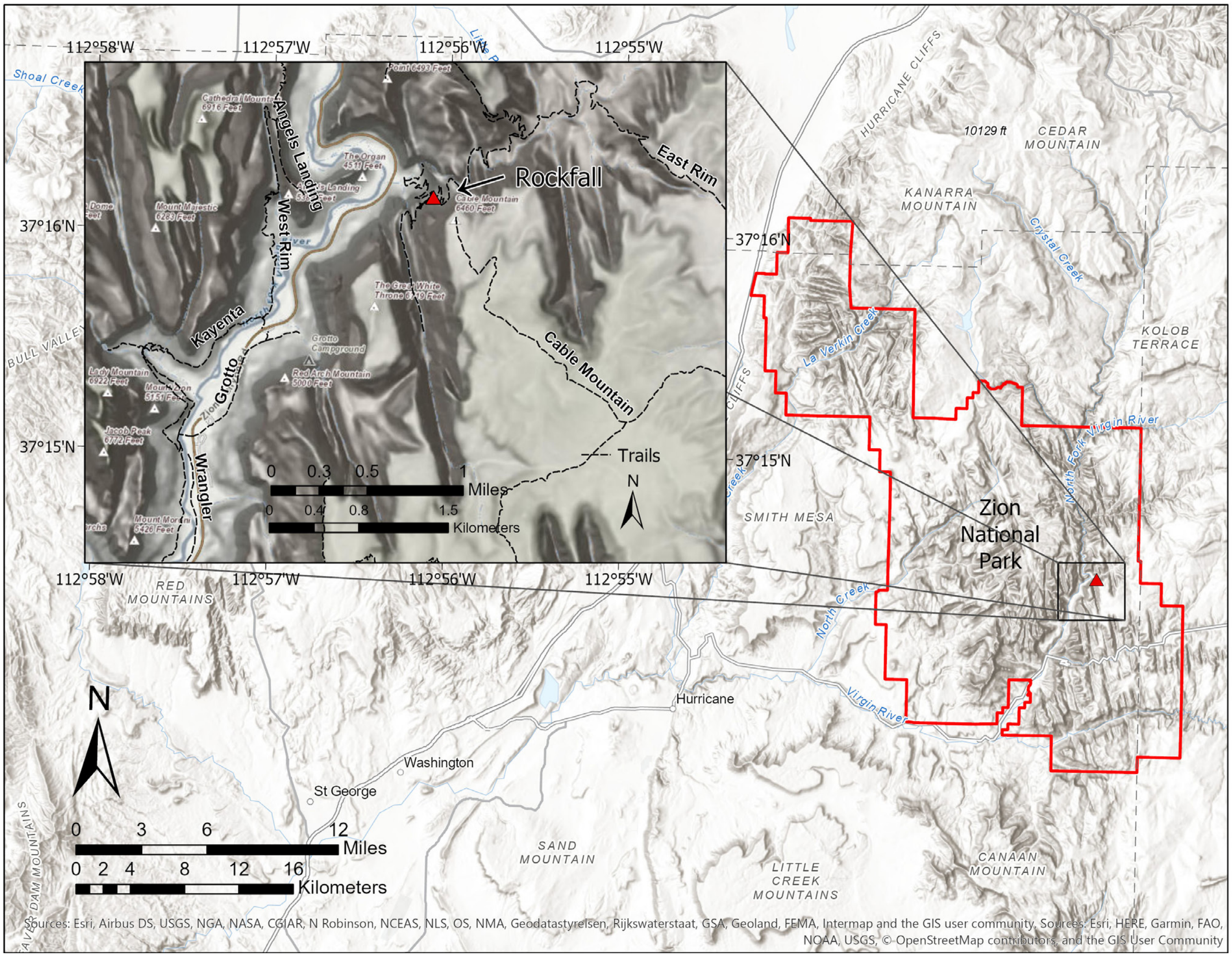


Figure 1. *Location of Zion National Park and the Cable Mountain rock avalanche.*

Figure 2. *sUAS photograph showing the flow direction (indicated by the vegetation and arrow) and broken and entrained trees in the Cable Mountain rock avalanche debris deposit. Photo date: October 24, 2019.*

area, for additional photographs and observations. The collected sUAS imagery data were used to create a digital elevation model (DEM), structure from motion (SfM) model, and an orthomosaic image of a large portion of the western Cable Mountain, Weeping Rock, and Hidden Canyon areas.

CABLE MOUNTAIN ROCK AVALANCHE DESCRIPTION AND SIZE ESTIMATES

Rock Avalanche Description

On August 24, 2019, at approximately 5:30 p.m., a large slab of Navajo Sandstone detached from the vertical northwestern face of Cable Mountain and broke apart, sending debris flowing downslope toward the Weeping Rock trailhead parking lot. The granular debris damaged the East Rim and Weeping Rock trails, deposited sediment on the Hidden Canyon trail, and flowed across Zion Canyon Scenic Drive to the Virgin River. The flow knocked down and entrained multiple trees. The source area (figure 3) appears to have been a semi-detached arch of Navajo Sandstone with vegetation growing in a crack where the rock was attached to the main cliff face. The granular debris consisted of sand, gravel, and up to boulder-size rocks and created a large cloud of fine dust.

Rock Avalanche Volume and Mass Estimates

Our estimates of rock avalanche volume and mass of the rockfall source are based on modelling using the DEM and orthomosaic created from sUAS imagery data. The average thickness of the rock slab that fell was approximately 16 feet (5 m), which is a conservative estimate based on measurements of the source area, where thickness is easily determined The actual thickness likely varied and is difficult to determine without pre-event high-resolution DEM data. Lidar elevation data collected in 2015 for the area is not accurate enough on vertical cliff faces like the source area location. The rock slab that fell measured approximately 197 feet (60 m) horizontally and 243 feet (74 m) vertically, as measured on the longest axes. The rock avalanche volume was calculated to be 435,712 cubic feet (12,338 m^3), which classifies the event as a very small rock avalanche (De Blasio, 2011). The rock mass was approximately 31,292 tons, based on the approximate specific gravity of Navajo Sandstone. The range of specific gravity values reported for sandstone in the American Geological Institute (AGI) Geoscience Handbook (AGI, 2006) is 2.28–2.37. The average is 2.33, which we round to 2.3 to reflect the fact that the value used is an estimate and was not determined specifically for rock at this site. Given the above assumptions regarding the shapes of the rock mass and boulders and their specific gravity, we consider our volume and mass estimates accurate to ± 15% (after Lund and others, 2014).

Rock Avalanche Triggering

No specific triggering event could be identified for the rock avalanche event. Typically, rockfall events are triggered by frost weathering, precipitation or snow melt, and/or seismic events. The August 24, 2019, rock avalanche does not appear to have initiated from any of these triggers; however, thermal cycling is likely a contributing factor. The precipi-

Figure 3. *Cable Mountain rock avalanche source area outlined in yellow, the scar measures approximately 133 feet at the red line based on the orthomosaic image. The volume of the rock avalanche was calculated to be 435,712 cubic feet (12,338 m^3), with a corresponding mass of approximately 31,292 tons. Photo date: October 24, 2019.*

tation for August 2019, as reported at the weather station located at the Zion Human History Museum, was 0.19 inches (4.8 mm; Utah Climate Center, 2019; these data indicate that measurements for one to nine days in August may be missing). The overall precipitation average for August is 1.54 inches (39.2 mm). The mean temperature for August 2019 was 85.10°F (29.5°C; Utah Climate Center, 2019), and the average August temperature since record keeping began in 1904 is 81.60°F (27.5°C). Rock slabs on cliff faces, such as the slab that failed above Weeping Rock, bulge and move with daily heating and cooling cycles. Rockfall events can be triggered on the warmest times of day and year (Collins and Stock, 2016). The rock slab was partially detached from the main cliff face by multiple vegetation-filled cracks around the edges of the slab.

ROCKFALL HAZARD

Another large rock slab having void space behind it, like the slab that fell, is located to the northeast on the Cable Mountain cliff face. This slab was investigated due to its proximity to the failed slab's scar; however, fractured rock slabs that pose a rockfall hazard are located all along the cliff face. The acquired sUAS imagery data show these large rock slabs are highly fractured and semi-detached, bulging away from the cliff face. Vegetation commonly fills fractures (figure 4). The cliff face is highly jointed, fractured, and has many areas of alcoves, arches, and slabs (figure 5). These slabs are unstable and may fall at any time. The area near the August 24, 2019, rockfall scar, especially on the lower left side, is highly fractured and possibly unstable, posing a high rockfall hazard. Potential rockfall triggering events occur more frequently in areas that have highly variable daily temperatures, where frost weathering can occur, and during intense precipitation, seismicity, and high temperature events; however, slabs can detach from cliffs with no warning or identifiable trigger mechanism.

EAST RIM AND HIDDEN CANYON TRAIL ASSESSMENT

sUAS imagery was obtained to assess the conditions of the East Rim and Hidden Canyon trails after multiple recent rockfall events have impacted them. The East Rim trail above the Weeping Rock trailhead consists of a series of switchbacks that ascend the steep slope at the base of Cable Mountain. The trail was significantly impacted by the latest rock avalanche. The East Rim trail has 12 switchbacks over 1.07 trail miles (1.72 km) of which approximately 0.7 trail miles (1.12 km) were covered in debris (figures 6 and 7). Approximately 0.06 trail mile (0.09 km) of the Weeping Rock trail was covered in debris. The debris is sand- to boulder-size material (with larger boulders measuring approximately 9 feet [2.7 m] by 8 feet [2.8 m] [boulder measured on the orthomosaic model just upslope of trail segment 11, figure 8]) with entrained vegetation, including large trees. The switchbacks were assigned numbers for each segment for the purpose of estimating the debris thickness as shown on figure 8. Thickness of the debris deposited on the trail for each profile location is listed in table 1.

Zion National Park and the U.S. Geological Survey acquired 1-meter lidar elevation data (AGRC, 2015) for the park in 2015. A slope shade created from this data shows the East Rim trail before the rock avalanche (figure 9). A 0.3-meter-resolution slope shade created using the acquired sUAS data shows the areas where the trail is covered by debris (figure 9).

Using differencing between the 2015 lidar elevation data (AGRC, 2015) digital terrain model (DTM) and the sUAS model, we were able to estimate deposition depths (figure 10). Much of the area shows no depositional change, as shown in green. Areas where depostion depths exceed 1 foot (0.3 m) are shown in yellow and orange. Areas of high deposition, shown in red, are scattered throughout the area; however, many of the high-deposition areas are the result of trees or

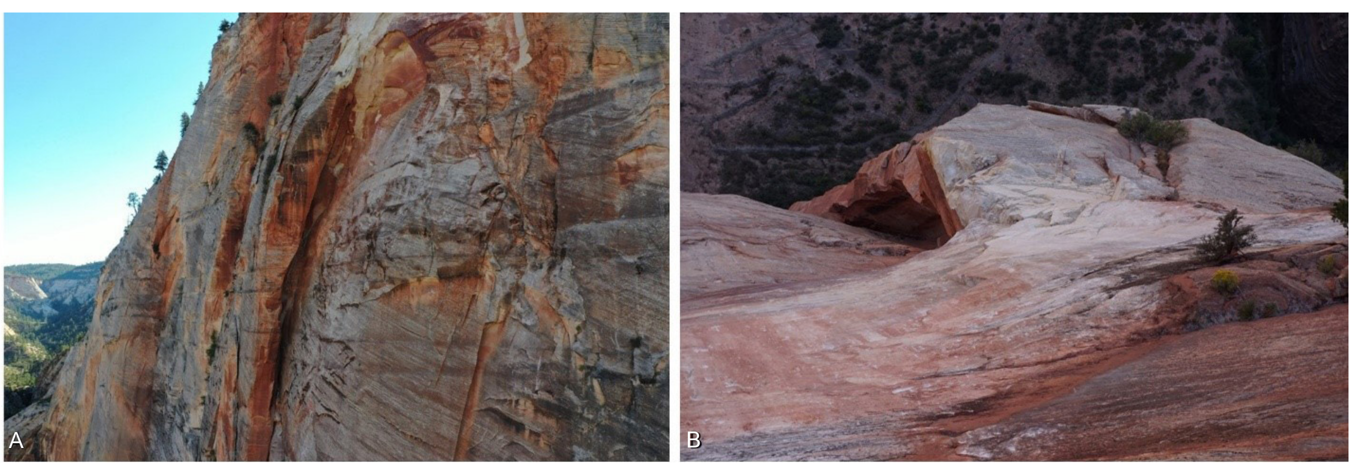


Figure 4. A. *sUAS photo showing the void space between the rock bulge and the main cliff face of Cable Mountain.* ***B.*** *Photo from the top of Cable Mountain showing significant rock bulging and fractures filled with vegetation. (photo credit: Tyler Knudsen) Date of photos: October 24, 2019.*

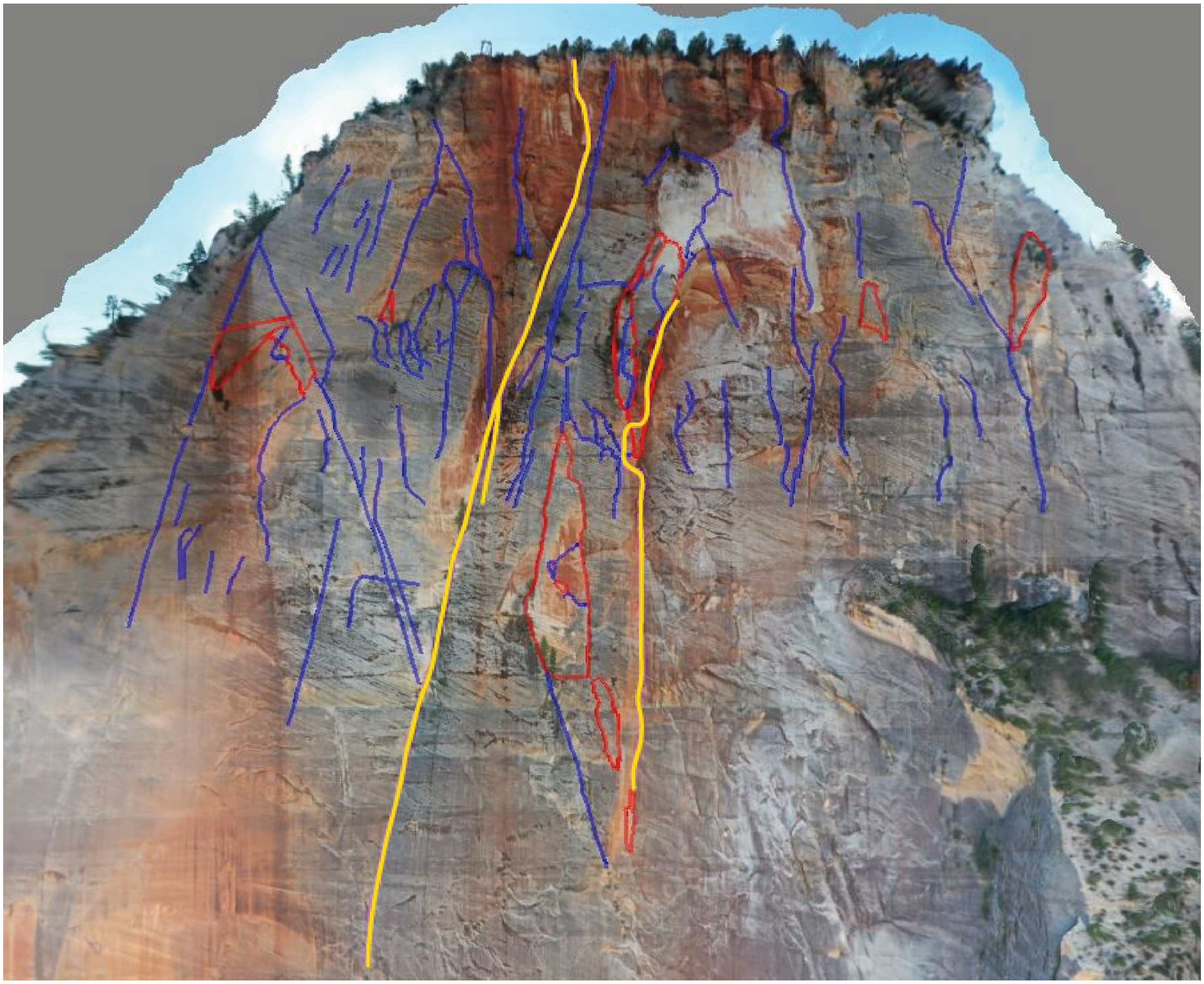


Figure 5. *Orthomosaic image of Cable Mountain created from sUAS imagery using Agisoft Metashape software. The red polygons indicate sandstone blocks that are highly fractured. The blue lines indicate prominent fractures on the cliff face. The yellow line indicates a large fracture on the cliff face, the longest of which measures approximately 968 feet, based on the orthomosaic image.*

cliff faces that distort the data. The area of high deposition north of the first switchback in a drainage that extends down slope to the Weeping Rock trail is considered to be an actual estimate of depositional accumulation. According to the model made from sUAS data, the deposition in the channel exceeds 20 feet (6 m) of material.

The Hidden Canyon trail (figure 11) appears to be mildly affected by the Cable Mountain rock avalanche with settlement of sand and dust. Part of this project was to collect imagery of the Hidden Canyon rockfall scar (figure 12). The scar appears to show evidence of an event similar to the recent Cable Mountain rock avalanche at a smaller scale. The rock located to the north of the scar is extremely fractured and has a very high future rockfall hazard. At least five rockfalls occurred in Hidden Canyon from July to November 2018 (personal communication, Zion National Park).

CONCLUSIONS AND RECOMMENDATIONS

The August 24, 2019, Cable Mountain rock avalanche sent approximately 435,712 ft^3 (12,338 m^3) (± 15%) of rock debris downslope towards the Weeping Rock parking lot and trailhead. The rock mass, approximately 31,292 tons (± 15%), disintegrated into boulders, cobbles, sand, and dust, entraining large trees and other vegetation. No trigger could be clearly identified for this event, but thermal cycling appears to have substantially contributed because average daily temperatures in August were higher than 85°F (29°C). The Utah Climate Center (2019) reports only nine years since record keeping began in 1904 that had average daily temperatures above 85°F (29.4°C) in the month of August. Rockfall is the most frequent mass wasting process in Zion National Park. The rockfall hazard map prepared for Zion National Park (Lund and others, 2010) indicates that the Weeping Rock area is within a high rockfall hazard zone. The East Rim and Hidden

Figure 6. *Sandy debris containing rock fragments and vegetation covers the East Rim trail. A rockfall that occurred on January 19, 2019, is also visible in the right center of the photo (circled reddish scar above switchback). This rockfall measures approximately 41 feet wide and 54 high, based on the orthomosaic image. Photo date: October 24, 2019.*

Figure 7. *Rock avalanche debris on the East Rim trail, showing rocks and trees entrained in the sandy deposit. Photo date: October 24, 2019.*

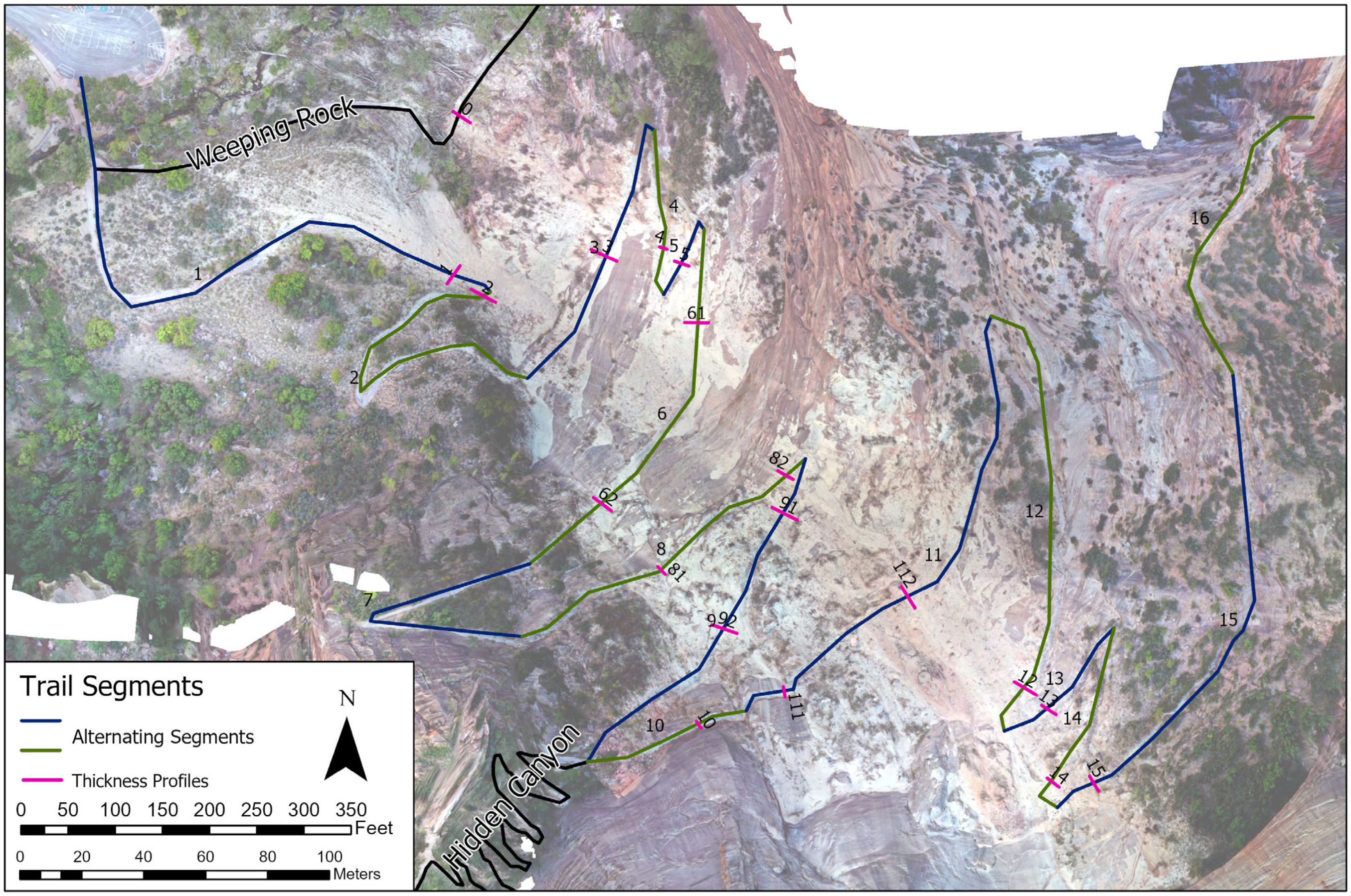
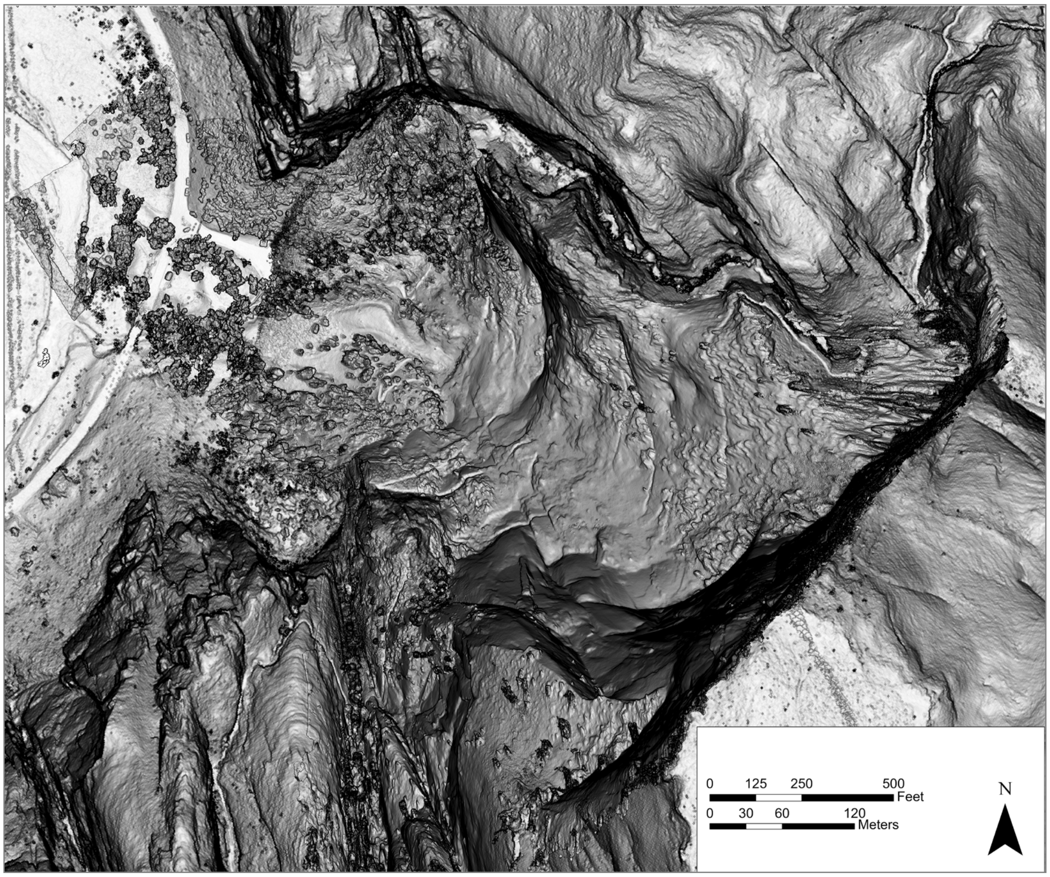


Figure 8. *East Rim trail broken into segments shown as alternating blue and green lines. Selected locations for thickness profiles are shown in dark red. Shown on orthomosaic created from sUAS imagery.*

Table 1. *Estimated thickness of debris deposited on the East Rim trail at profile locations shown on figure 8.*

Profile number	Estimated thickness of debris
0	3.28 feet (1 m)
1	8.2 feet (2.5 m)
2	3.28 feet (1 m)
3	3.28 feet (1 m)
4	1.6 feet (0.5 m)
5	3.28 feet (1 m)
6	3.28 feet (1 m)
62	3.28 feet (1 m)
81	1.6 feet (0.5 meter)
82	4.9 feet (1.5 m)
91	3.28 feet (1 m)
92	3.28 feet (1 m)
111	1.6 feet (0.5 m)
112	3.28 feet (1 m)
12	trail scoured and is 1.6 feet (0.5 m) lower than original grade, unable to determine thickness
13	1.6 feet (0.5 m)
14	0.82 feet (0.25 m)
15	trail possibly scoured and is 0.82 feet (0.25 m) lower than original grade, unable to determine thickness

A.



B.

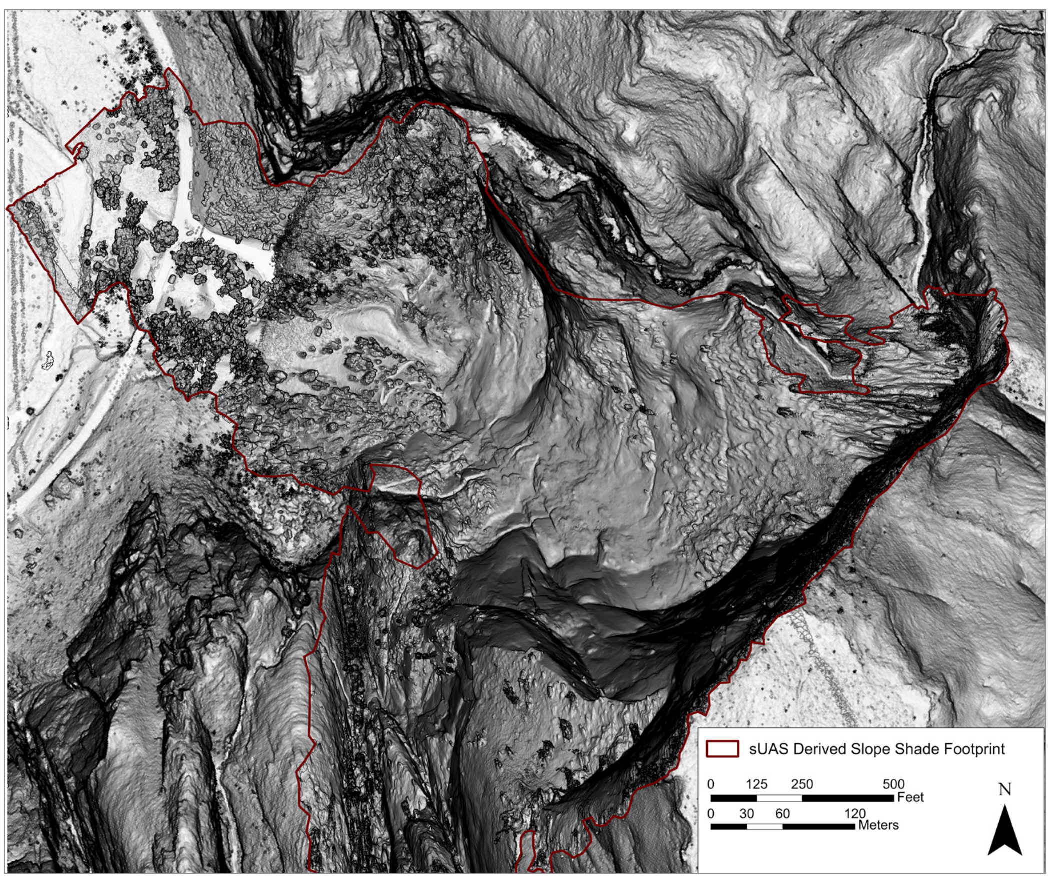


Figure 9. A. *The East Rim trail is visible in the 2015 1-meter lidar (AGRC, 2015).* ***B.*** *The slope shade created from the sUAS imagery data shows where the trails have been covered by debris from the Cable Mountain rock avalanche.*

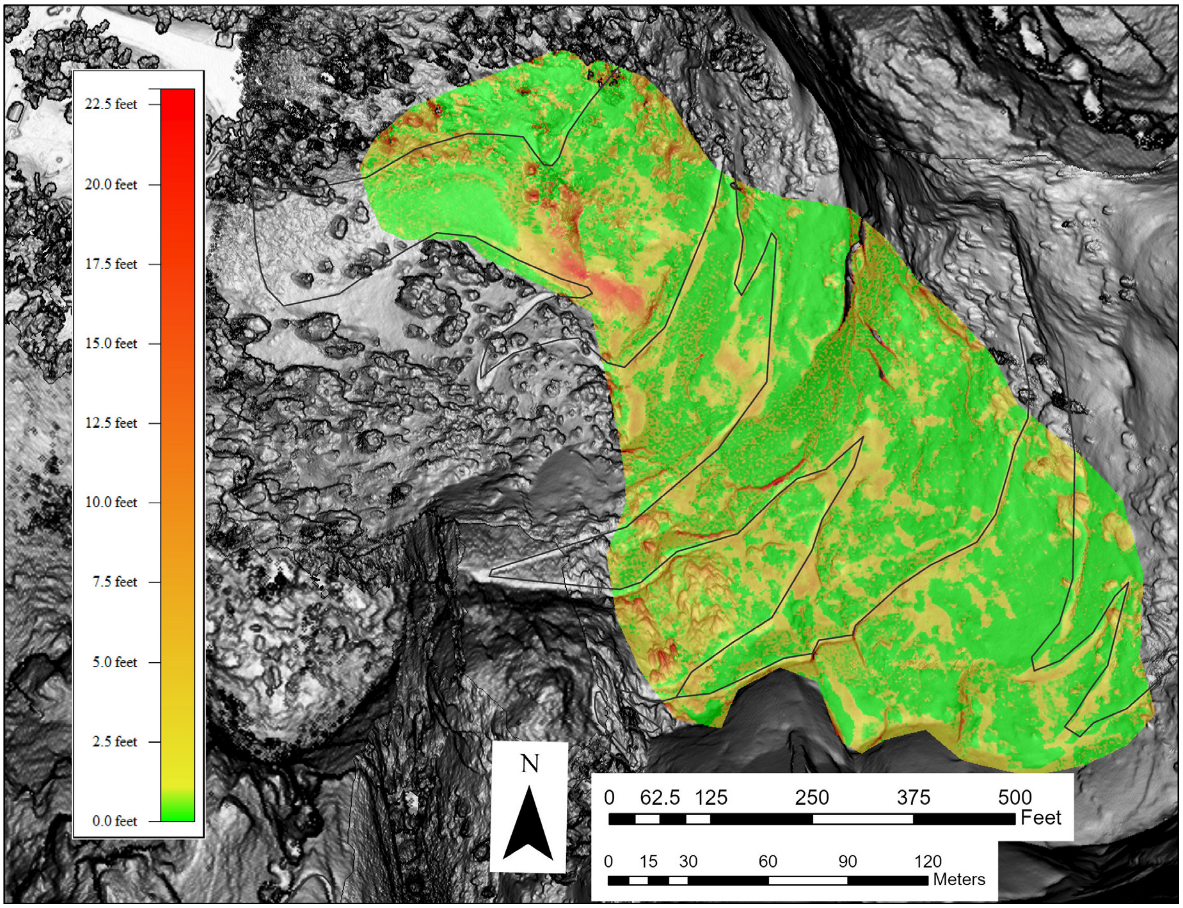


Figure 10. *Differencing result comparing the 2015 lidar elevation data and sUAS model data showing estimated debris deposit depths. The base imagery is a combination of the sUAS model and 2015 lidar DTM. The dark gray line is the East Rim trail system in the area.*

Figure 11. *sUAS image showing the Hidden Canyon trail switchbacks (arrow), the January 19, 2019, rockfall (circled), and the proximity to the Cable Mountain rock avalanche debris (lower left corner). Photo date: October 25, 2019.*

Figure 12. *Hidden Canyon rockfall scar. The rock to the north (left) of the scar is highly fractured (area 1) and a larger slab with a long vertical fracture (area 2, the bottom of this slab is not shown in the photo and the line at the base is inferred) is below area 1. Photo date: October 24, 2019.*

Canyon trail closures by the NPS undeniably saved lives in this event. There are many places on the Cable Mountain cliff where unstable rocks exist, and these unstable rocks could fall at any time. The East Rim trail is severely impacted by the Cable Mountain rock avalanche.

A large rock slab with void space behind it, like the slab that fell, is located northeast on the Cable Mountain cliff face, adjacent to the August 24, 2019, rockfall scar. The acquired sUAS imagery data show this large rock that is highly fractured and semi-detached from the main cliff. The area near the rockfall scar, especially on the lower left side, is highly fractured and possibly unstable, posing a high rockfall hazard.

Thick deposits of unconsolidated material, ranging from sand particles to boulders with vegetation, cover the switchbacks and present a hazard for people on or immediately below the switchbacks. Measurements using the sUAS model data indicate that deposit thickness ranges from 0.82 feet (0.25 m) to 8.2 feet (2.5 m) on the trail surfaces. Rockfall mitigation is not generally practical for high, steep cliffs. In this environment the recommended solution in this situation is to attempt a rockfall risk estimate and then to (1) avoid the rockfall hazard, as best as possible, including not building structures and limiting access in areas having frequent rockfall and/or (2) accept the risk knowing that the consequences of this option could result in loss of life and damage to property. The second option should include an effort to make individuals aware of the rockfall hazard, such as appropriate signage. Mitigation options such as rock scaling, and/or closure of areas after significant weather events (high precipitation, freeze/thaw, extreme temperatures, or extreme temperature fluctuations) may contribute to the risk reduction on a short-term basis but will do little to eliminate the larger hazard.

ACKNOWLEDGMENTS

We would like to thank the Zion Forever Foundation for funding a portion of the sUAS project. We thank Robyn Henderek, Cass Bromley, Shauna Ertolacci, and Greg Bartin for accelerating the compliance allowing us to fly the sUAS in Zion National Park. Jason Pietrzak, Wildlife Crew Lead and Janice Stroud-Settles, Wildlife Biologist, provided assistance as visual observers and protecting the California condors and other wildlife. James Brown, Trails Crew Supervisor provided assistance and support. Adam Hiscock, Geologist/sUAS Pilot, and Tyler Knudsen, Senior

Geologist, with the UGS operated the sUAS, conducted field reconnaissance, and processed data.

REFERENCES

Automated Geographic Reference Center, 2015, 1-meter bare earth LiDAR: Online, State Geographic Information Database, https://gis.utah.gov/data/elevation-and-terrain/2015-lidar-zion-np/, accessed October 2019.

American Geosciences Institute (AGI), 2006, The geoscience handbook, compiled by Carpenter, M.B., and Keane, C.M., 478 p.

Collins, B.D., and Stock, G.M., 2016, Rockfall triggering by cyclic thermal stressing of exfoliation fractures: Nature Geoscience no. 9, p. 395–400.

De Blasio, F.V., 2011 Introduction to the physics of landslides: Springer, 408 p., DOI 10.1007/978-94-007-112-8.

Lund, W.R., Knudsen, T.R, and Sharrow, D.L., 2010, Geologic hazards of the Zion National Park geologic-hazard study area, Washington and Kane Counties, Utah: Utah Geological Survey, Special Study 133, 95 p., 9 plates, https://doi.org/10.34191/SS-133.

Lund, W.R., Knudsen, T.R, and Bowman, S.D., 2014, Investigation of the December 12, 2013, fatal rockfall at 368 West Main Street, Rockville, Utah: Utah Geological Survey, Report of Investigation 273, 20 p., https://doi.org/10.34191/RI-273.

Utah Climate Center, 2019, Climate data for weather station ZION NP: Utah State University, online, http://climate.usurf.usu.edu/mapGUI/mapGUI.php, accessed October 23, 2019.