Rockfall monitoring in the National Parks

Eric L. Bilderback[1]

[1] National Park Service, Geologic Resources Division, Lakewood, CO, USA.

Corresponding author information: Eric_Bilderback@nps.gov, 1-720-556-4406

In National Park Service managed lands across the country, rockfall affects roads, trails, and other infrastructure related facilities. Rockfall is a recurrent and frequent hazard in areas of spectacular landscape and high relief. Rockfall risk reduction strategies in the National Park Service include quantitative risk estimation for specific rockfall hazards, monitoring of potential rockfall areas with vibrating wire crackmeters, exploring radar and thermal monitoring techniques, and an Unstable Slope Management Program. In areas where rockfall hazards with high potential consequences have been identified, rapid quantitative risk estimation techniques are helping managers put rockfall risk into a societal context. Rock fracture monitoring with vibrating wire crackmeters is shedding light on rockfall source areas and may help us better understand: triggering mechanisms, the extent of thermoelastic rock deformation, and potentially aid in identifying pre-failure warning signs. At Arches National Park, monitoring since 2015 shows significant thermoelastic deformation. At Grand Teton National Park, a large wintertime rockfall event was captured, allowing precursory deformation analysis. Instruments at Hawaiʻi Volcanoes National Park capture brittle rock response to volcanic process and earthquakes and instruments at Zion and Chaco Canyons are monitoring potential rockfall source areas. Through these efforts, the National Park Service strives to reduce risk from rockfall hazards.

Vibrating wire crackmeters with hundredths of a millimeter resolution (Figure 1) are relatively low cost, automated, monitoring solutions for areas where there are questions about rock facture behavior. These systems can monitor crack displacement frequently; current practice uses a 10-minute recording frequency. The primary goal of the crack monitoring systems is to gain more understanding of the brittle fracture systems that could lead to rockfall, thus increasing our understanding of a natural hazard. Because these systems are automated and can be network connected, early warning of unusual rock fracture behavior is possible, provided there is enough time to collect a baseline understanding of fracture behavior and all the various portions of the crackmeter system are operating correctly and maintaining connectivity. Using the experience of the monitored 2018 rockfall in Grand Teton National Park, a simple, first-order velocity alert can be programed into network connected crackmeter systems. This alert serves as a trigger for a geologist to check the recent displacement records for any trends and to be on alert for any indication of acceleration.

Current crackmeter installations in the National Park Service range in environmental conditions from the high, dry continental interior of Chaco Culture National Historical Park at over 1,900 m ASL with annual temperature swings between -7 and 40 degrees C, to installations underground in Nāhuku lava tube at Hawaiʻi Volcanoes National Park, where the annual temperature range is between 14 and 18 degrees C. Long-range vibrating wire extensometers are monitoring caldera bounding fractures on Kīlauea volcano that appear to be responding to volcanic process such as inflation and deflation, but don't seem to be closely correlated temporally with other volcanic monitoring data such as tilt. This suggests some unexamined process between inflation or deflation and the observed deformation of the facture system around the caldera. Both long-range instruments and the crackmeters in Nāhuku lava tube have also only been sensitive to the largest of local earthquakes, like the M 6.2 October 10, 2021, earthquake just south of the Island of Hawai'i. Of the sites with more than a year of recorded displacement data, two sites are showing unambiguous permanent deformation at different scales. These sites are: the toppling hazard 18-meter-tall pillar of Springdale Sandstone in Zion National Park and two different large basalt flakes in Nāhuku lava tube (Figure 2). The near continuous monitoring of rock fracture systems is providing data that raises even more questions about rock damage process across many different environments, but also is giving the National Park Service a better understanding of brittle rock facture that is a potential hazard to people, natural, and cultural resources.

Figure 1. Photograph of a vibrating wire extensometers (crackmeter) in Cliff House Sandstone at Chaco Culture National Historical Park, New Mexico. Crackmeters such as these can be installed across rock fractures ranging from several millimeters to several meters wide. The crackmeters are anchored into the rock with epoxy and then covered with a plastic or aluminum cover to keep the sensor shaded from direct sun and keep any potential snow weight off the sensor. (National Park Service photograph).

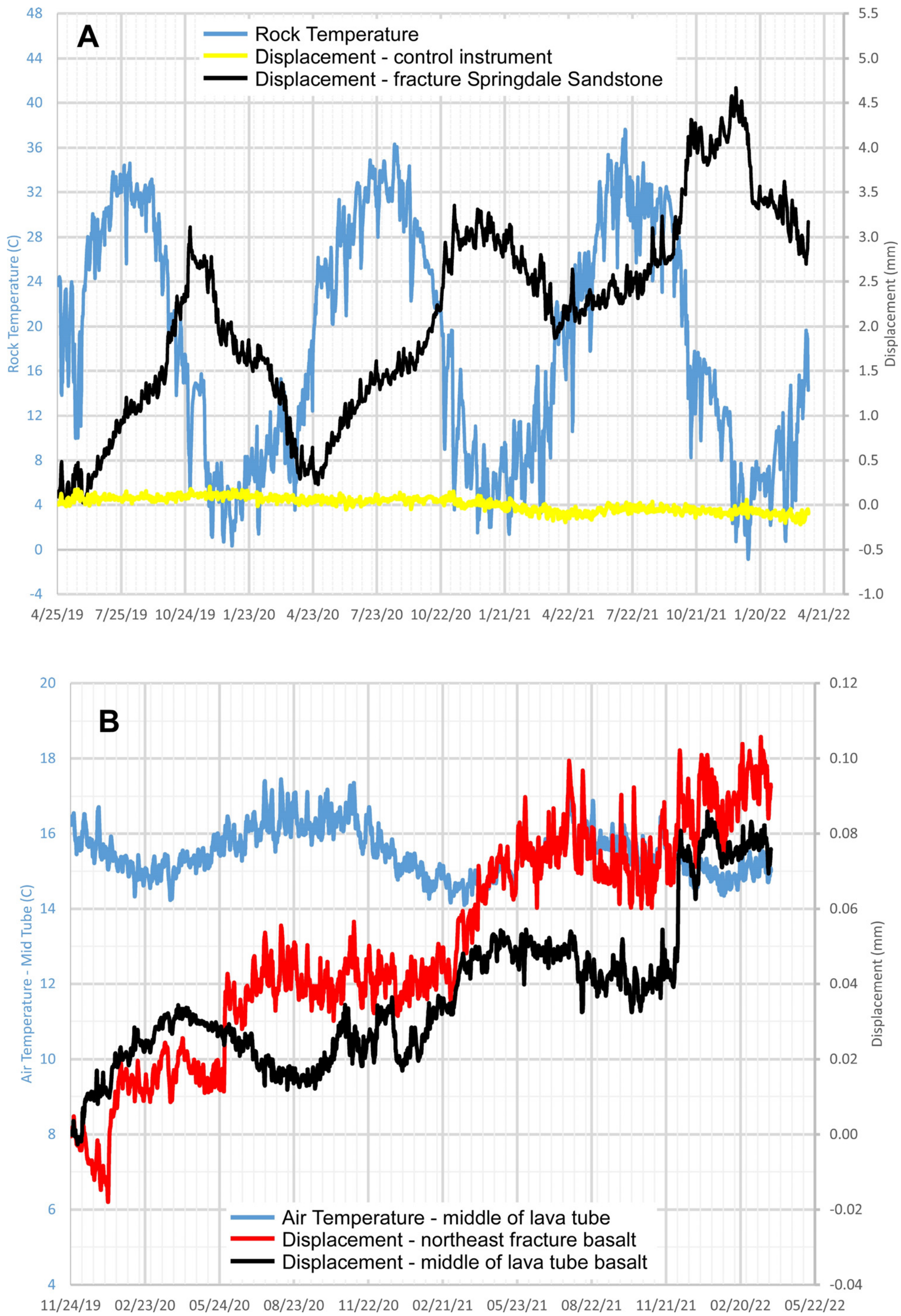

Figure 2. Graphs showing measured crack width (displacement) vs. time on the right axis and temperature vs. time on the left axis. Both graphs are displaying 24-hour running averages of both displacement and temperature to smooth the diurnal temperature signal. Graph A is almost three years of displacement data from the top of the Springdale Sandstone pillar in Zion National Park. Rock temperature is from a sensor 10 cm deep in the sandstone next to the crackmeters. The displacements shown are for same model crackmeter instruments, one installed between the cliff face and the top of the detached pillar (fracture) and one that is installed on largely intact sandstone (control) less than two meters from the instrument monitoring pillar displacement. The displacement signal for both instruments is filtered assuming that the control instrument exhibits thermoelastic motions that are dependent on temperature. The three-year control instrument temperature-displacement linear regression is applied to both records to remove some instrumental and rock thermoelastic signal. Graph B is more than two years of displacement data from two different basalt sheets that are partially detached from the Nāhuku lava tube walls in Hawai'i Volcanoes National Park. Displacement data in graph B is not filtered to remove thermoelastic signal because the temperature range is so small. Based on USGS earthquake records, there does not appear to be a clear correlation with larger deformation events and significant ground motion.