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ABSTRACT

Yosemite Valley has experienced over 600 rock falls since 1850, but determining the exact source areas, volumes, and failure mechanisms for these rock falls has previously been difficult because of a lack of comprehensive imagery of the cliff faces. We obtained high-resolution imagery, acquired before and after large rock falls in Yosemite Valley, California, by combining of gigapixel panoramic photography and terrestrial laser scanning (LiDAR). Following comprehensive baseline image acquisition of Glacier Point in eastern Yosemite Valley, two large rock falls occurred from within the imaged area in October of 2008. We used repeat gigapixel photography acquired with GigaPans to characterize the rock-fall detachment surface and adjacent cliff area in high resolution. Coupled with LiDAR analyses, these photos reveal that the rock falls consisted of a near planar, vertically oriented rock slab with a detachment surface area of 2,409 m2 and a volume of 5,663 m3. These data inform hazard assessment for this and other rock-fall events in Yosemite. Our results demonstrate the utility of high-resolution imaging techniques for quantifying rock falls from the large vertical rock faces of Yosemite Valley.

Keywords

rockfall, gigapixel photography, terrestrial laser scanning, Yosemite, geologic hazards

INTRODUCTION

Yosemite Valley is a ~1 km deep glacially carved canyon in the Sierra Nevada mountains of California that hosts some of the largest granitic rock faces in the world. These steep walls are shaped by rock falls that typically occur by exfoliation of large rock slabs (Matthes, 1930; Huber, 1987). Over 600 rock falls and other slope movements have been documented in Yosemite since A.D. 1857, resulting in several fatalities, numerous injuries, and damage to infrastructure (Wieczorek and Snyder, 2004 and subsequent observations). Recognition that rock falls pose a significant natural hazard to the nearly 4 million visitors annually has prompted detailed documentation and investigation of rock fall triggering mechanisms, causative factors, and runout dynamics to better assess geological hazard and risk in Yosemite (Wieczorek and Jäger, 1996; Wieczorek and Snyder, 1999, 2004; Wieczorek et al., 1999, 2000, 2008; Guzzetti et al., 2003). Quantifying individual rock-fall events is a critical component of hazard analysis, but the sheer scale of the cliffs of Yosemite Valley, and their relative inaccessibility, has previously made rock-fall quantification difficult.

New gigapixel imaging tools such as the GigaPan offer opportunities for reducing measurement uncertainties for large rock faces. High-resolution digital photography and laser scanning (LiDAR) are both emerging remote sensing techniques that enable precise locating, measuring, monitoring, and modeling of rock falls and other slope movements (e.g., Lim et al., 2005; Derron et al., 2005; Lato et al., 2008; Sturznegger and Stead, 2009). Laser scanning is a valuable tool for quantifying rock-falls, identifying failure mechanisms, assessing stability, and monitoring cliff faces, especially when repeat laser scans permit change detection (e.g., Rosser et al., 2005, Abellán et al., 2006; Jaboyedoff et al., 2007; Collins and Sitar, 2008; Rabatel et al., 2008; Oppikofer et al., 2008); the imaging power of LiDAR is particularly enhanced when integrated with high resolution photographs. Here, we use integrated gigapixel panoramic photography and LiDAR data to image a large rock fall that occurred in Yosemite Valley in October of 2008.

We collected baseline airborne and terrestrial laser scanning data and gigapixel panoramic photographs for Glacier Point in eastern Yosemite Valley (Figure 1) in September 2006, October 2007, and May 2008,respectively. Subsequently, two large rock falls occurred within the imaged area on October 7 and 8, 2009. The rock masses free fell ~220 m, impacted a prominent east-dipping joint-controlled ledge, and fragmented into numerous boulders and smaller debris. Much of this debris traveled down a talus slope into Curry Village, causing minor injuries and damaging structures. In the ten days following the second rock fall, we repeated the terrestrial laser scanning and high-resolution photography of Glacier Point. The resulting pre- and post-rock fall data allow us to image the failed rock mass in high-resolution and quantify key aspects of the event, such as the exact area of the detachment surface and the volume of the failed rock mass.

METHODS

Gigapixel photography

We obtained baseline high-resolution digital photography by simultaneously photographing the rock faces of Yosemite Valley from 20 locations along the valley rim. At each location we collected approximately 400-700 high resolution overlapping digital photographs using a motion controlled camera tripod (GigaPan beta unit w/ Canon G9 w/ 2x extender, effective 300mm focal length). We then aligned the overlapping photographs, stitched them together using PTGui software, and rendered the stitched images in Adobe .psb large document format to create 20 individual gigapixel panoramic images of Yosemite Valley. These images can be viewed at http://GigaPan.org/GigaPans/most_popular/?q=xrez. During this orchestrated shoot one of the images we captured was a 3.7-gigabyte panoramic photograph (63232 x 20224 pixel resolution) of the cliffs beneath Glacier Point on 28 May 2008 from a position on the opposite valley wall (Figure 1). Two days after the 8 October 2008 rock fall, we repeated the high-resolution photography of Glacier Point, creating a detailed panoramic image of the rock-fall source area and surrounding cliff before and after failure (Figure 2).

Integrating gigapixel photography with terrestrial laser scanning

To aid our three-dimensional imaging of Glacier Point, we integrated the gigapixel photographs with LiDAR data using 3d point cloud meshing and 3d animation software. Because the terrestrial point cloud data has large gaps near the top of the cliff, we unified the terrestrial LiDAR data with airborne LiDAR data. We imported the unified terrestrial and airborne ascii point cloud data into VRMesh 5.0 and interpolated surfaces from the point cloud according to standard workflow in VRMesh. We then imported the surface model in Maya 2009 3d animation software as an exported .obj file from VRMesh and properly scaled and positioned it. We chose a poly face normal smoothing angle to create clean shading along the surface, then projected UV mapping coordinates onto the surface in order to establish texture-mapping placement. Finally, we applied a texture map derived from the gigapixel photograph onto the surface (Figure 3a), providing a three-dimensional form of the photographic imagery that reveals the morphology, structure, and texture of the cliff below Glacier Point in high resolution (Figure 3b).

Three-dimensional image analysis of the repeat gigapixel and LiDAR data sets reveals the rock-fall detachment surface in high resolution. The photographs allow for precise delineation of the rock-fall surface area, and the integrated photo and LiDAR imagery shows that that the cumulative rock fall (October 7 and 8 events) consisted of a near planar, vertically oriented rock slab with a detachment surface area of 2,409 m2 and a volume of 5,663 m3 (Stock et al., in review). This level of precision in quantifying rock-fall source areas is made possible by the integrated techniques described above.

CONCLUSIONS

Repeat high-resolution digital photography and terrestrial laser scanning provides accurate and precise volume estimates and three-dimensional geologic characterization of the October 2008 rock-fall source area that could not be accurately attained by traditional assessment methods. The vast improvements in volumetric, structural, and stability analyses for tall cliffs resulting from high-resolution imaging techniques should lead to a reduction of related uncertainties in rock-fall hazard assessments that rely on these analyses.

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FIGURES

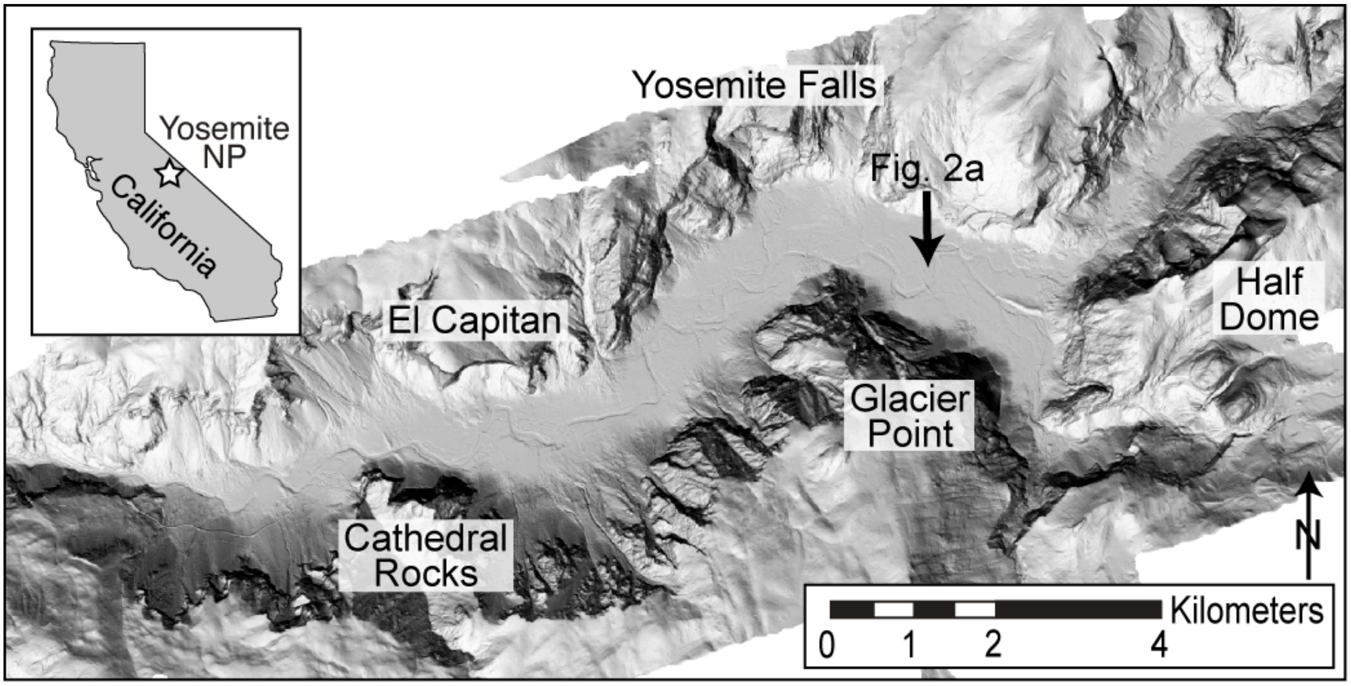

Figure 1. Shaded relief image derived from 1 m airborne LiDAR data showing the location of Glacier Point in eastern Yosemite Valley. White arrow shows the perspective of the gigapixel panoramic photo shown in Figure 2a.

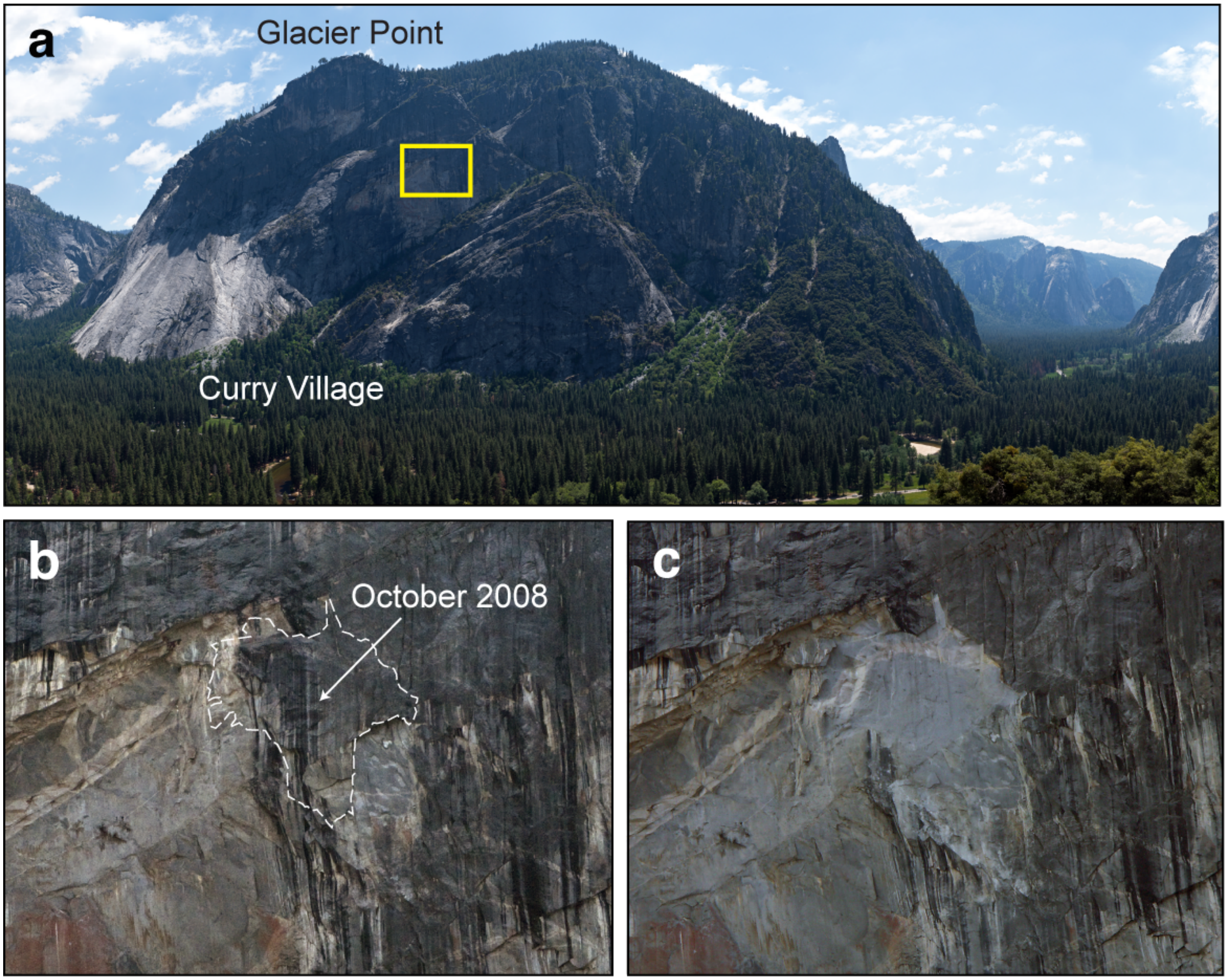

Figure 2. High-resolution digital photography of the rock-fall detachment area. (a) Gigapixel panoramic image of Glacier Point. Yellow box (150 x 200 m) encloses the rock-fall detachment area shown in b and c. (b) Zoomed-in view of the rock-fall detachment area taken in May 2007, prior to the 2008 rock fall. 2008 rock-fall detachment area shown by white dashed lines. (c) Same view showing rock-fall detachment area after the October 2008 rock falls. All project images viewable at http://GigaPan.org/GigaPans/most_popular/?q=xrez

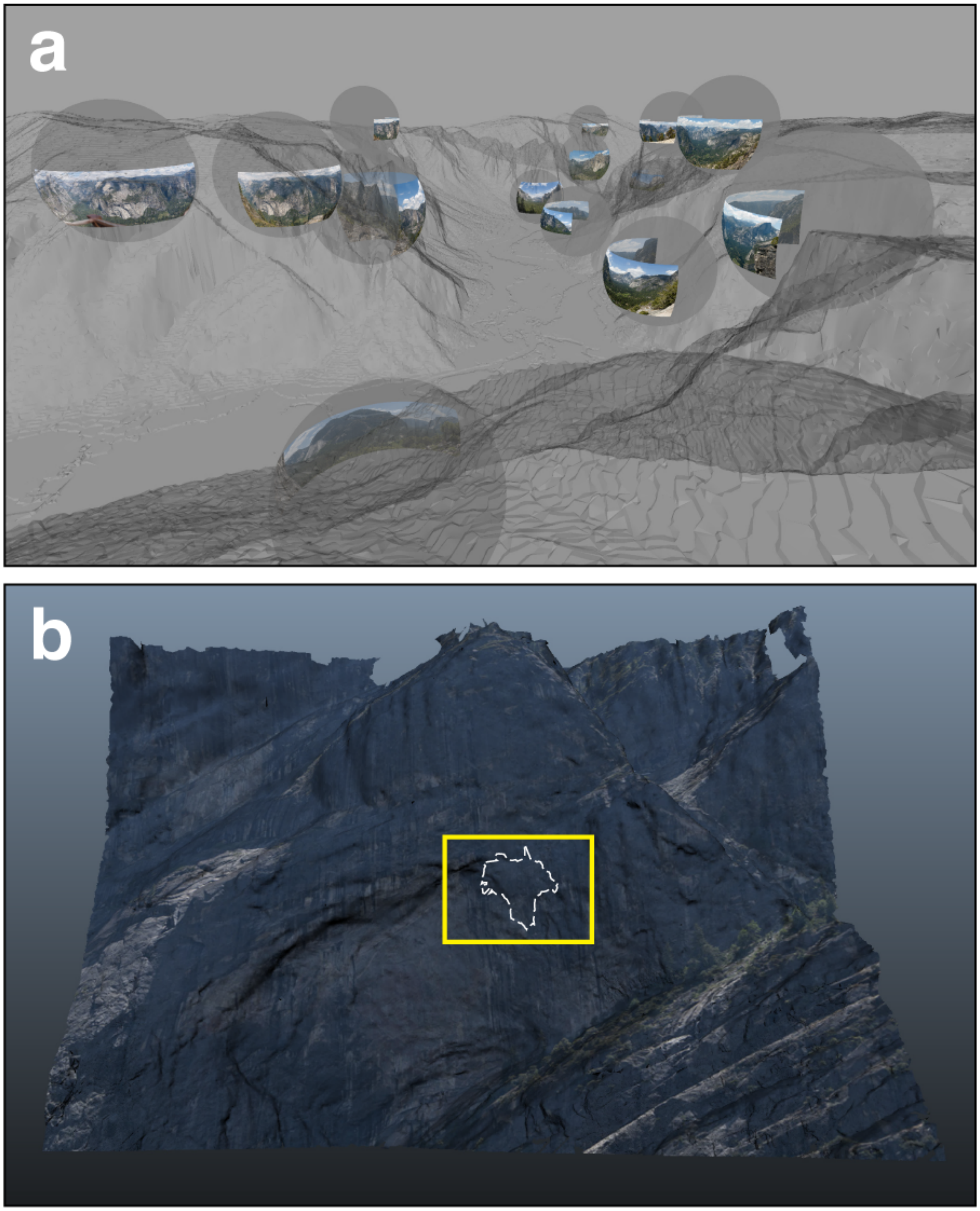

Figure 3. Integrated gigapixel photography and laser scanning data. (a) Gigapixel panoramic photographs aligned before projecting onto an interpolated surface model produced from laser scanning data. (b) Gigapixel photograph projected onto the interpolated surface model. Yellow box (150 x 200 m) encloses the October 2008 rock-fall detachment area and white dashed line marks the rock-fall detachment area.