3D Modeling of Antarctic Microbial Mats

Quantitative Analysis of Microbial Mat Morphologies via Structure-from-Motion Reconstructions

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Background

Abundant microbial mat communities grow within Lake Joyce, a perennially ice-covered lake in the McMurdo Dry Valleys, Antarctica. The mats range from flat morphologies to webbed pinnacle structures. Direct observation via drop camera surveys has shown that there is morphological heterogeneity on the meter to decimeter scale [1], but little research has been done to quantify the amount of heterogeneity present and the geometric variability of the individual structures. The microbial mats have analogous structures to those observed in late Archean microbialite deposits [2][3]. Being able to reconstruct the morphologies at Lake Joyce in a 3D visualizer will aid in the interpretation of the environmental conditions during growth of microbial communities found in the rock record.

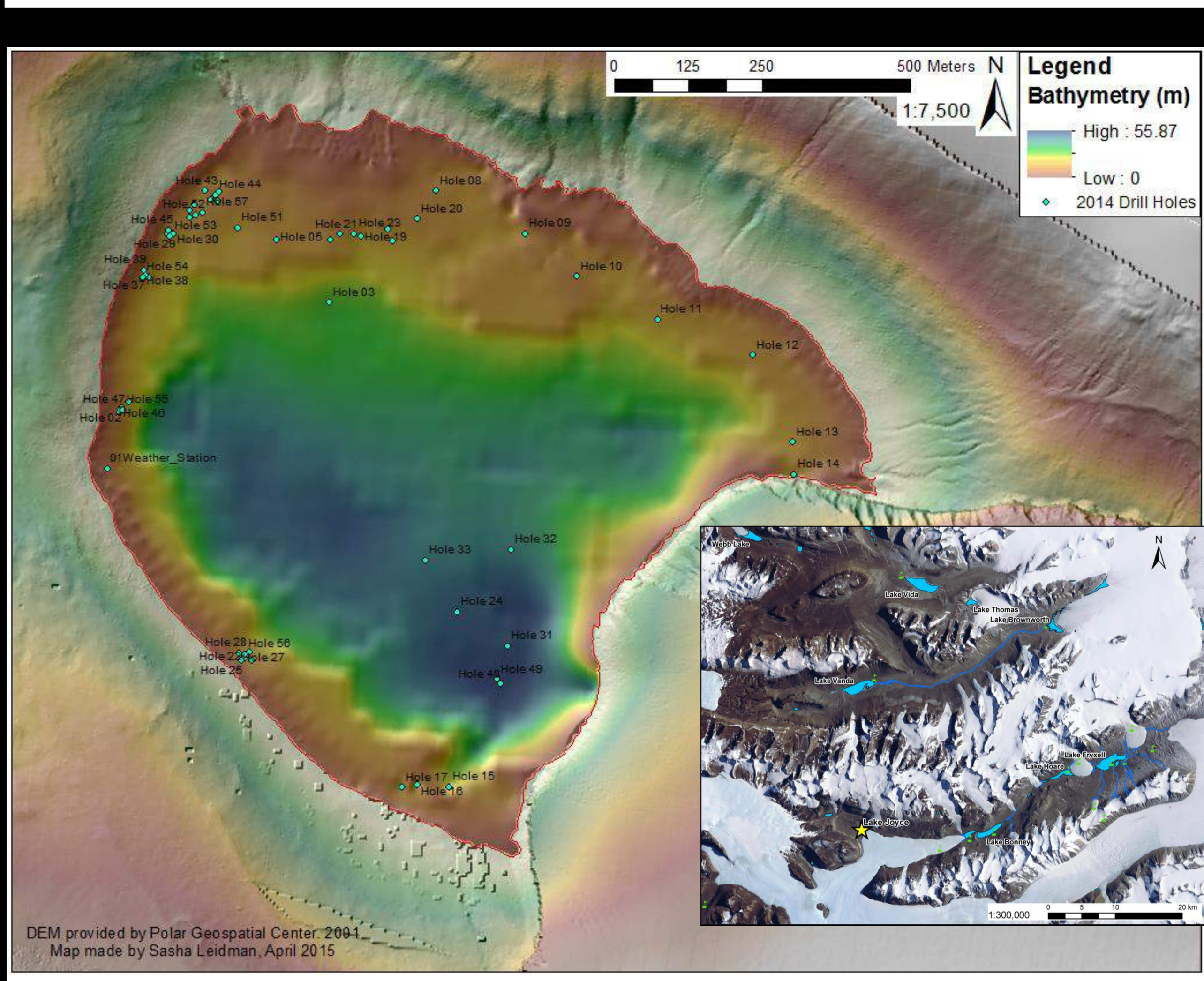


Figure 1: Bathymetric map of Lake Joyce with drill hole locations and McMurdo Dry Valley inset map.

Methods

1. Lower a downward facing, high resolution camera through an ice borehole with a secondary oblique camera attached to a boom roughly 1m long that can be lowered from the surface (Fig. 2).
2. Take high-resolution oblique images of benthic microbial mat communities by rotating a boomed drop camera 360 degrees at 47 different drill holes and a dive site on Lake Joyce (Fig. 1).
3. Roughly 50 images that had minimal rotational blurring were selected for analysis then input into Agisoft Photoscan Pro for 3D modeling. Agisoft® then constructs high resolution point clouds using Structure from Motion, a process in which pixels in 2D images are coupled to reconstruct 3D structures (Fig. 3).
4. Reconstructions were scaled using orthorectified downward facing images and given slope orientations from camera position calculations.
5. 3D models were compared to an object of known geometry to determine reconstruction errors.
6. The model outputs were visualized using the UC Davis Keck CAVES Lidarviewer [4] and CloudCompare software to analyze the geometric parameters of the mats including pinnacle density, slope, and height to width ratios.

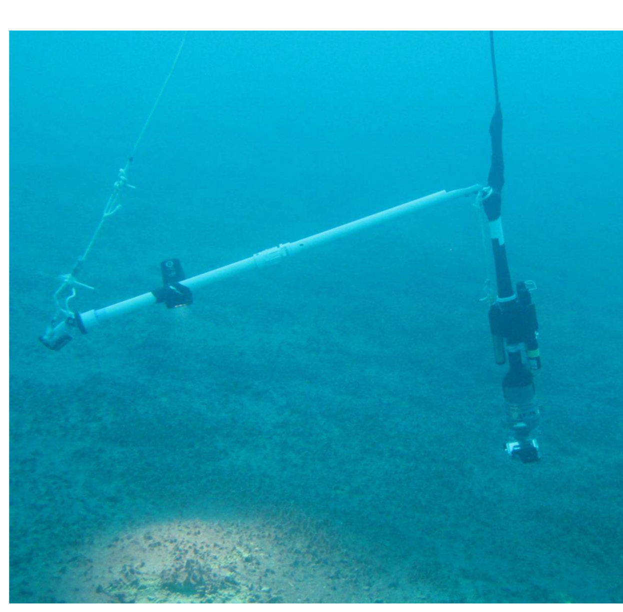


Figure 2: Drop camera set up for oblique photographs of benthic microbial mats

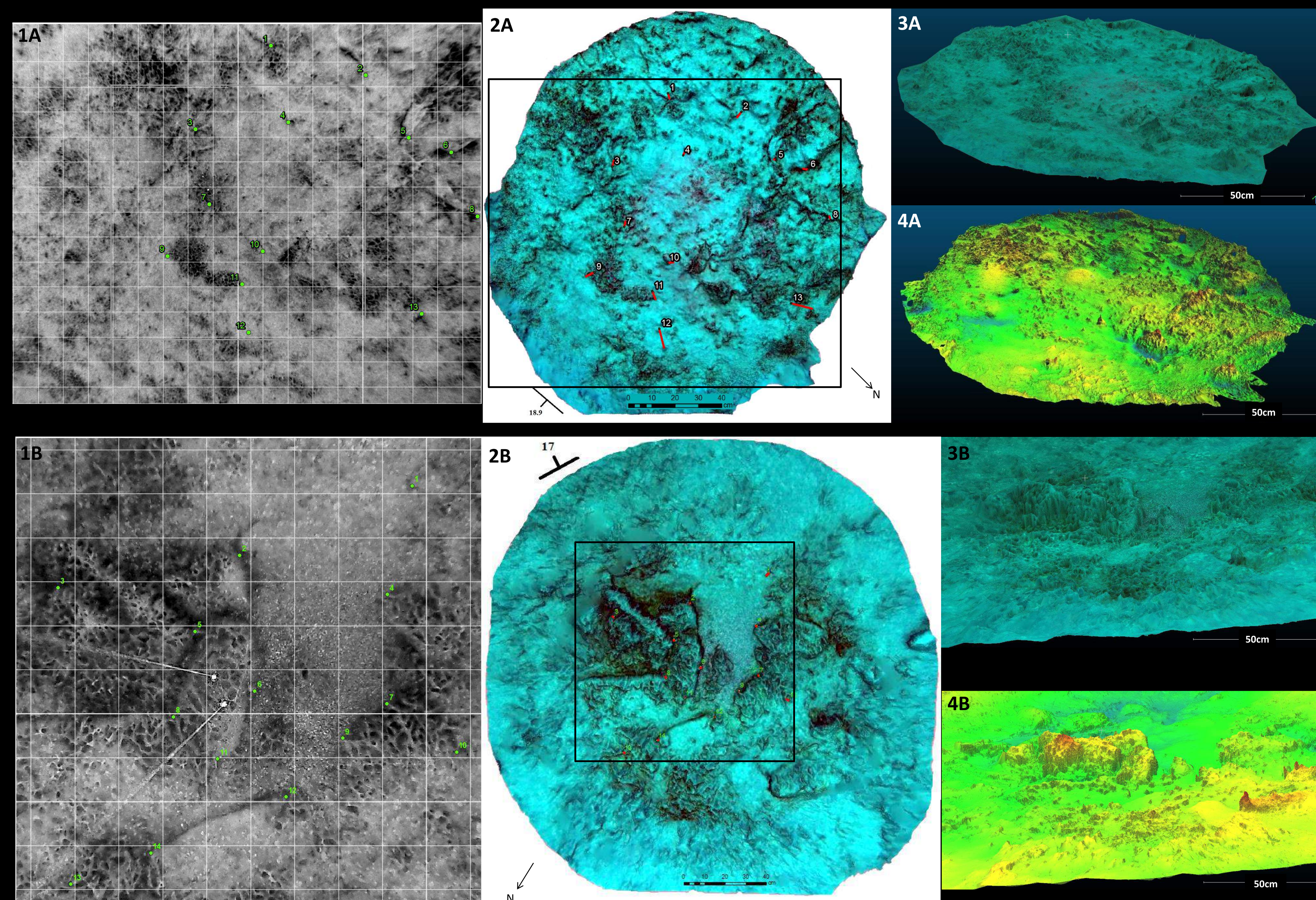


Figure 3: 3D reconstructions of Lake Joyce pinnacles. 1) Downward facing and orthorectified GoPro Hero3 images of the bottom of Lake Joyce at holes 54 (A) and 47 (B) with a 10cmx10cm grid. 2) Agisoft PhotoScan Pro point cloud reconstructions. Red lines indicate distances between similar points (green) distorted from the alignment between the downward photo and 3D model. Strike and dip was calculated from Agisoft camera positioning relative to the reconstruction plane. North arrows were found by orienting the 3D models onto a bathymetric map. All slope values had less than 15% error compared to the bathymetric model. 3) Oblique view of 3D reconstructions with true color. 4) 3D reconstructions colored by distance from ground surface plane.

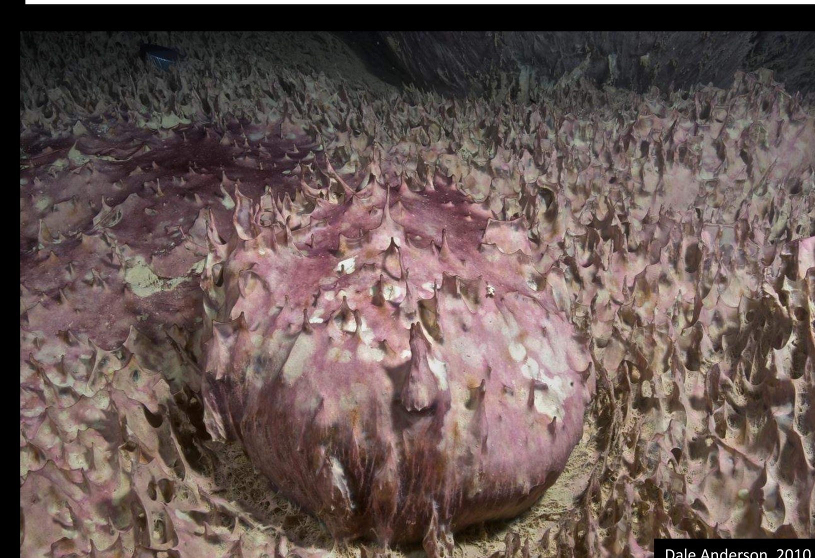
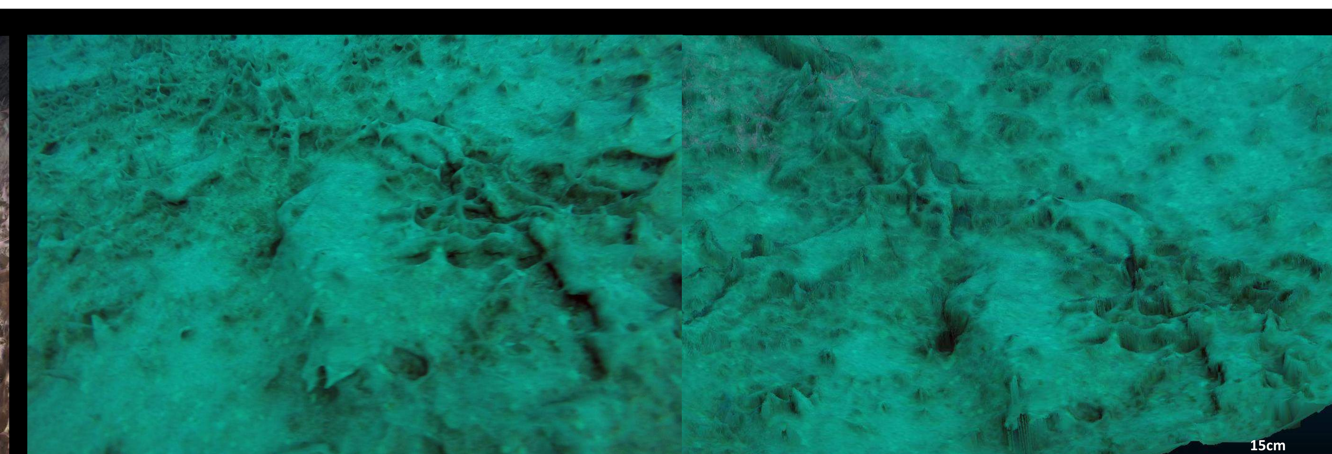


Figure 4: Illuminated image of Lake Joyce pinnacles taken by a diver. Mats seen growing on and around a boulder with pinnacles connected by webs. Boulders seem to create a hallow of pinnacle free mat. Flat mat dominates in the upper left.



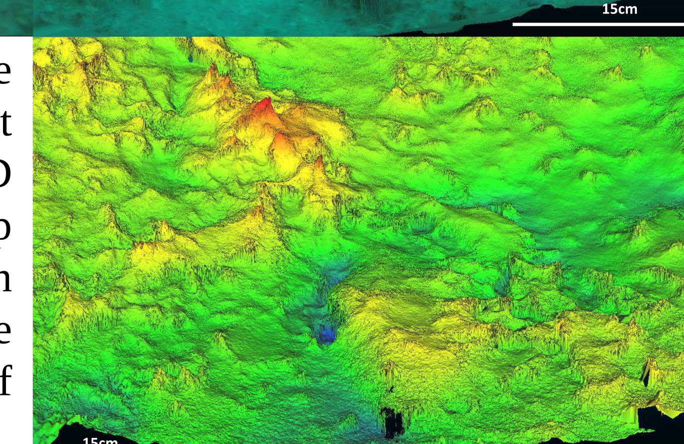


Figure 5: Comparison of oblique camera photo of microbial mat at hole 47 (top left) with 3D reconstructions in real color (top right) and colored by elevation from a plane (bottom right). The model outputs show a density of ~700 points/cm².

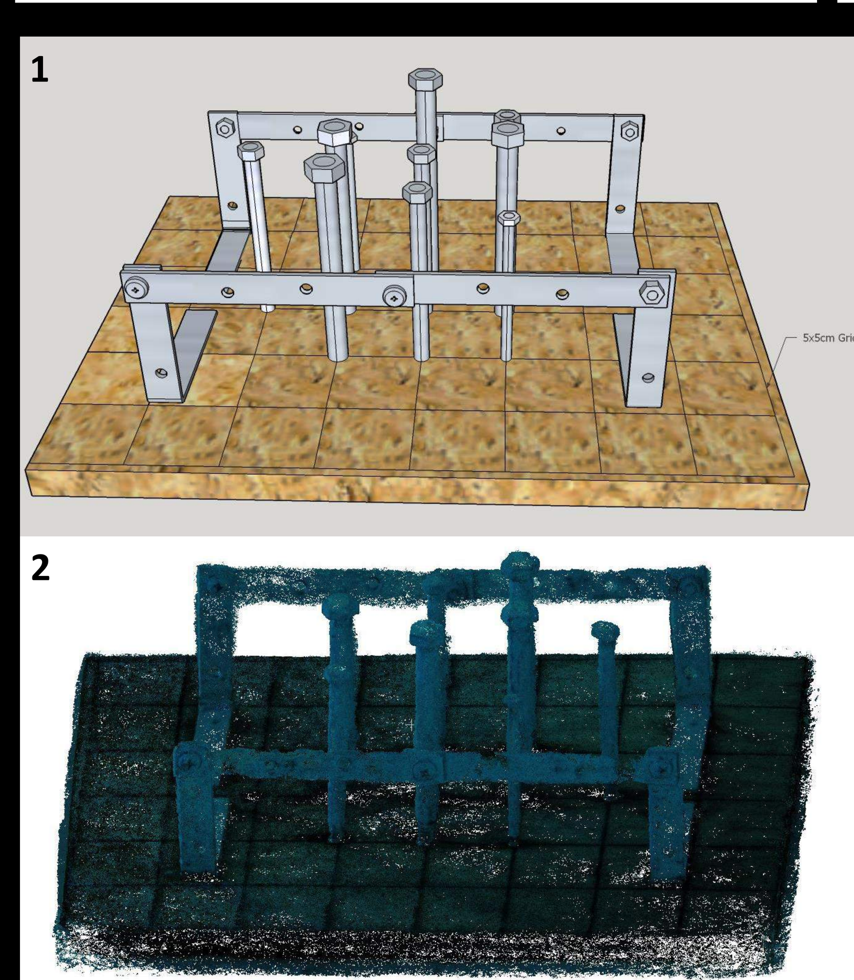
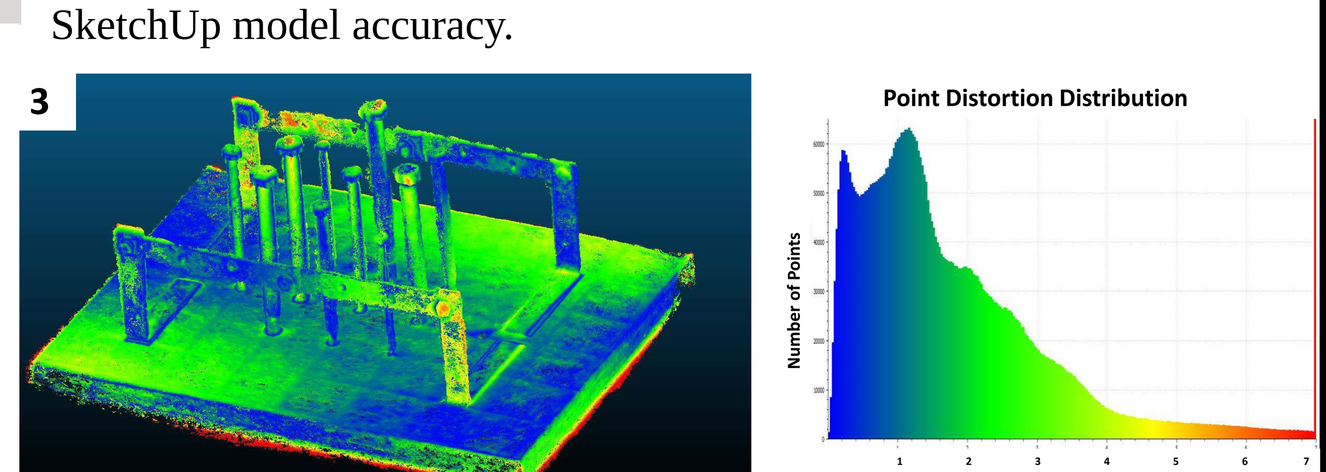


Figure 6: 3D Reconstructions of an object of known geometry for determination of point cloud distortion. 1) Scaled model of the object created in SketchUp and exported to CloudCompare as an obj file. 2) Agisoft PhotoScan Pro reconstruction of object from ~50 GoPro Hero4 images taken in a dark pool with a tripod. Erroneous points were deleted. 3) Point cloud comparison of a SketchUp model to a Agisoft Photoscan reconstruction showing the distance to the nearest point. Distortion seems to be concentrated at the corners but, with a Gaussian mean of 1.8mm, the distortion is within the margin of error for the SketchUp model accuracy.



Results

1. 3D reconstructions show that photogrammetry of images from commercially available cameras can create very high density point clouds (>10 million points) able to pick out individual pinnacles.
2. Comparison with an object of known geometry and downward facing cameras show that there is minimal warping of points with distortion increasing away from the center of rotation.
3. Analysis in the Keck CAVES and CloudCompare produce quantitative measurements of the geometric parameters of the microbial mats which were previously only described qualitatively. The pinnacle slopes and spatial distributions of the mats may aid in the observations from microbialite deposits.

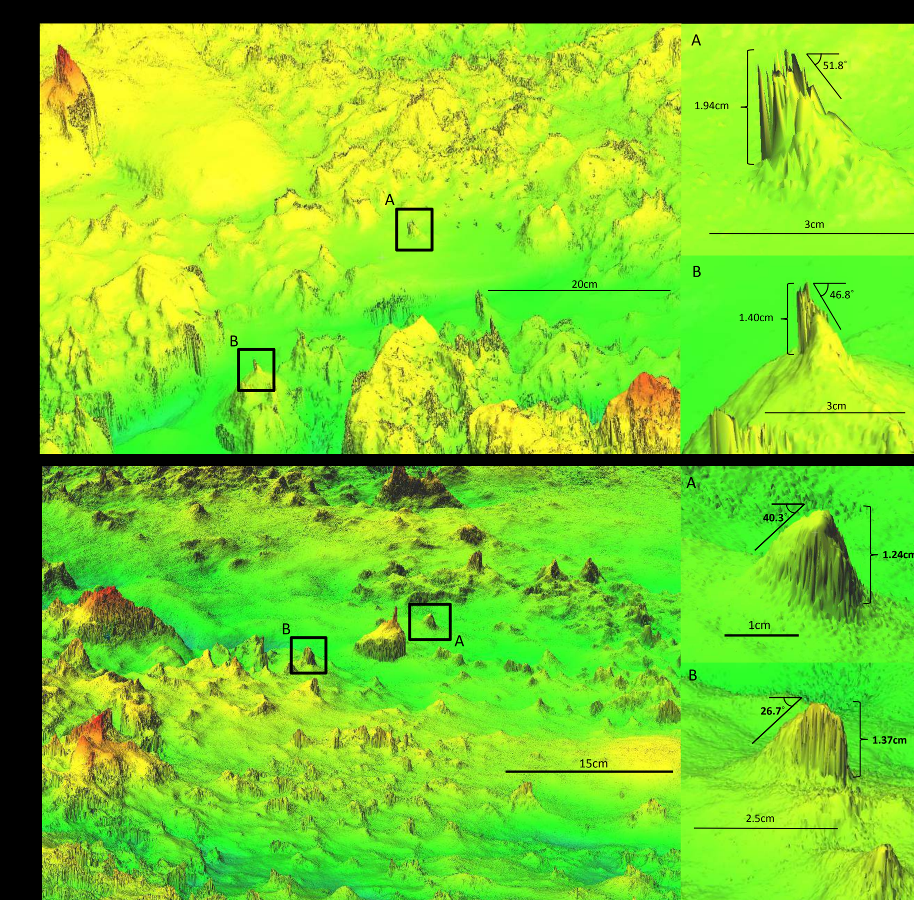


Figure 7: Comparison of two different pinnacles from hole 54 (top) and hole 47 (bottom). All of the pinnacles show a similar shape and size. Pinnacles from hole 54 predominantly have steep faces to the NW and about 50˚ slopes to the SE. Angles represent the lowest slope for each pinnacle

Implications

The methodology described offers a unique technique that allows for relatively inexpensive and nondestructive mapping of benthic microbial structures that can be applied to larger areas than CT scanning and higher resolution than ROV transects. The Structure from Motion 3D reconstructions made from drop camera photographs produce a dataset that allows for microbial mat morphotypes to be compared quantitatively with the 3D structures studied in Archean microbialites [2]. By applying this methodology, direct correlations can be made between the observed geometric parameters of the mat and the microbial communities and physical parameters of their environments.

References

[1] Hawes I. et al. (2011) Geobiology 9, 394-410.
[2] Juarez Rivera M. and Sumner D. Y. (2014) Journal of Paleontology, 88, 4, 719-726.
[3] Sumner D. Y. (1997) PALAIOS, 12, 4, 302-318.
[4] keckcaves.org/research/start

Background Photo Credit: Tyler Mackey

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