Photogrammetric Mapping and Measurement of Eroding Shorelines, Bedrock Surfaces, and Geologic Samples.

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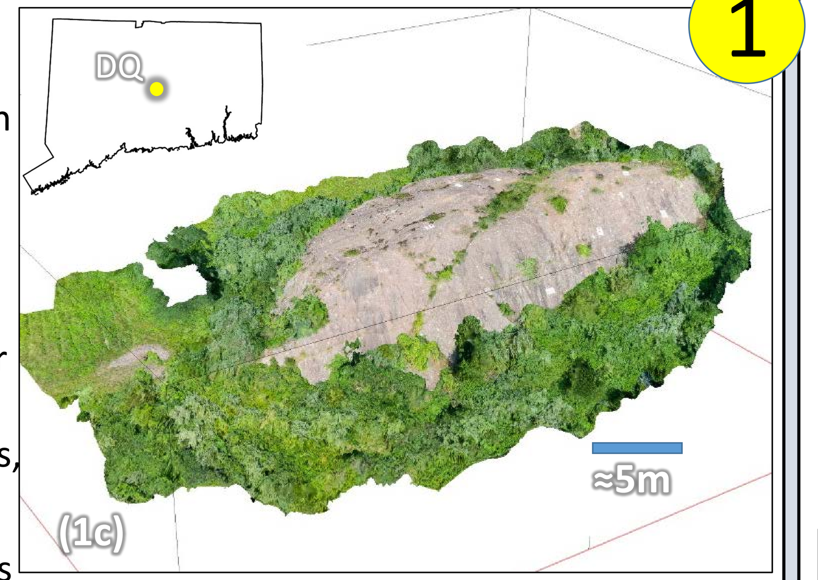
1 Introduction and Study Objectives:

Ground-based digital photogrammetry (DP) fieldwork was undertaken at Clay Head (CH) Beach, Balls Cove (BC), and West Beach (WB) on Block Island and, using a Mavic Air drone, over Jurassic conglomerates at Dufford Quarry (DQ) in CT. (***Fig.1***). Images and survey data (see ***Panel 3***) were used to construct detailed 3D models of these sites and related samples to visualize and measure erosion and deposition at Block Island and bedrock characteristics at DQ. Our overriding objectives are to:

(1) learn to image, map, and model these sites using DP techniques,

(2) create related maps and 3D printed models, and

(3) Analyze change (erosion/deposition) and topographic variations to better understand geologic conditions at these sites.



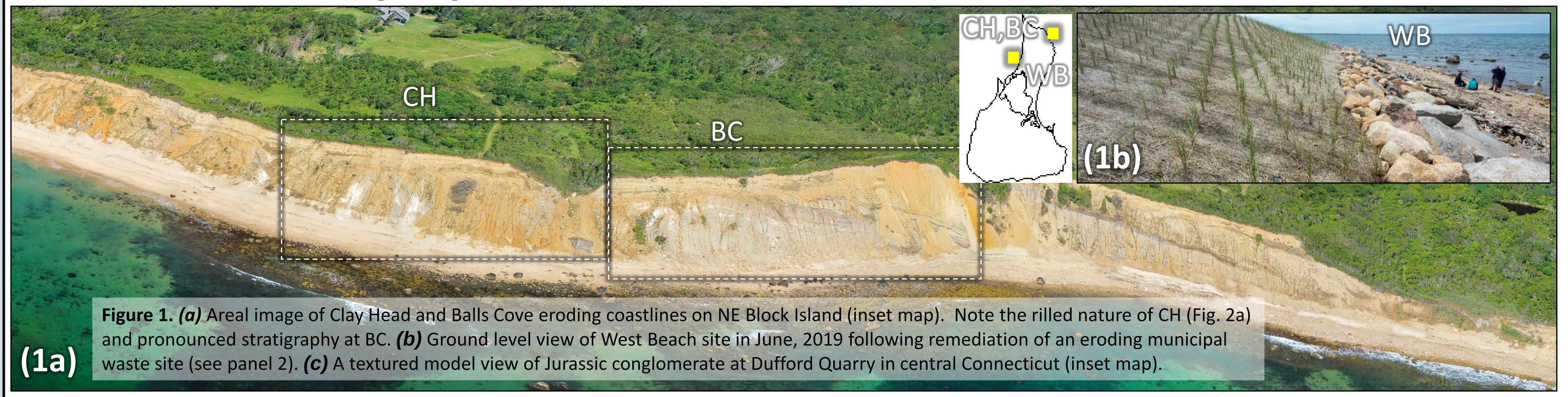


Figure 1. ***(a)*** Areal image of Clay Head and Balls Cove eroding coastlines on NE Block Island (inset map). Note the rilled nature of CH (Fig. 2a) and pronounced stratigraphy at BC. ***(b)*** Ground level view of West Beach site in June, 2019 following remediation of an eroding municipal waste site (see panel 2). ***(c)*** A textured model view of Jurassic conglomerate at Dufford Quarry in central Connecticut (inset map).

Field Work - Imaging and Mapping:

Ground-based DP Images were captured using a Nikon D610 in aperture priority (f/16, ISO=100, S= 1/40th of a second) on a tripod to minimize motion blur. For Block Island sites (***Fig. 3a,b***) images were captured at ≈ 1.5 m intervals along 5 shore-parallel to shore-oblique lines so as to ensure >60% overlap. Scale bars were placed at varying elevations and surveyed using RTK GPS to providing ground control for 3D models.

Images at DQ (***Fig. 3c***)were captured wit a Mavic Air drone at 5s interval while fly-ing 0.8 m/s. 3 imaging runs were flown following a circular path from heights 5, 20, and 30 m above the outcrop.

Cobble samples from CH, metal debris from WB, and an intricate goat scull were imaged on a turntable in a light tent from 3 positions while rotating the sample 360°. These images were used to build full 3D models.

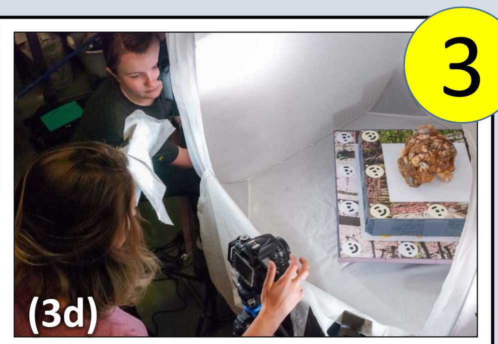


Figure 3. ***(a)*** Image capturing at CH using a Nikon D600. ***(b)*** Gathering GPS coordinates at varying elevations along CH using RTK surveying. ***(c)*** Drone imaging at DQ. ***(d)*** Image capturing of related artifacts in a light tent using a Nikon D600. ***(e)*** camera positions around the goat skull model with 3D print.

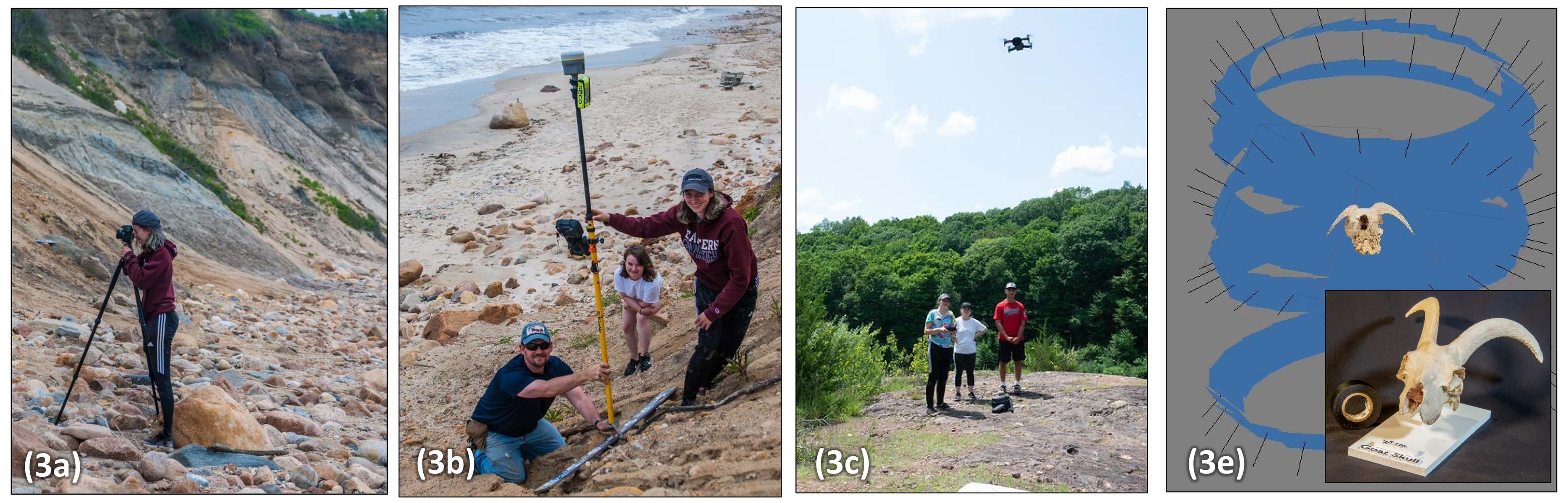


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Image Processing, Model Building and Refinement

Agisoft Photoscan (AP) was used to prepare models from field/lab images that were processed to remove chromatic aberration and apply camera profiles in ***Lightroom.*** ***Agisoft Lens*** established and applied initial camera metrics.

A standard AP workflow was used to align images (***Fig. 4a***), generate a tie point cloud of x-y-z coordinates. DP markers in images (*e.g.* ***Fig. 2d, 3b,d***), were identified in AP, refined and assigned GPS coordinates, and used to build scale bars. Tie point were then filtered to remove low quality points, optimize, and generate dense clouds. Additional point filtering was performed and textured meshes were created. Table 4.1 summarizes point/image counts and accuracies for all models. Complex 3D objects like our samples (***Fig. 33, 4c-e***) were modelled in chunks following a similar workflow, although chunks were merged prior to generating a final point cloud, and mesh.

3D prints can be useful educationally, and for direct measures of scaled artifacts. We built printable files by exporting AP models as .ply polygon files for processing in ***Blender*** where a base, scalebar and labels were added (***Fig. 4c***). The model is exported as a .stl file for 3D printing on a MakerBot additive printer which adds support material as needed (***Fig. 4d,e***).

Topographic representation and geospatial analyses were performed on point cloud derived data using **Cloud Compare (CC)** software and using raster DEM and orthomosaic files in ArcGIS (see Panel 5).

Table 4.1. Summary of images, cloud density and accuracy estimates for all models.

Site	No Photos	Dense Cloud Pts	No. Ground Control Points, Accuracy	Scale bars Number (accuracy)
Block Island Coastlines (Nikon D610):				
Balls Cove	79	256.3 million	6, (1.9 cm)	15 (1.4 mm)
Clay Head	197	81.3 million	8, (3.0 cm)	14 (2.5 mm)
West Beach	327	73.8 million	10, (9.4 cm)	22 (5.4 mm)
Samples				
Cobbles	138	2.57 million	NA	16, (1.2 mm)
Metal	153	1.45 million	NA	20 (1.2 mm)
Goat Head	122	1.79 million	NA	19 (4.1 mm)
DQ Drone Models (Mavic Air):				
Map 3: 5 m height	27	15.14 million	6, (2.9 cm)	NA
Map 2: 25 m height	40	7.49 million	10, (2.9 cm)	5 (9.2 mm)
Map 1: 30 m height	81	11.1 million	10, (3.9 cm)	14 (7.2 mm)

Note Point totals are based on refined clouds, GCP's are comparisons between modelled and GPS coordinates, Scale bars are estimates of local accuracies for linear measurements on the models.

Figure 4. ***(a)*** Views of stages in the AP workflow from CH including (left to right) tie point clouds, dense point cloud, and textured mesh with inset depicting mesh geometry. ***(b)*** A large iron-cemented cobble at CH coming to rest on the beach. Similar samples imaged in the lab (Fig. 3d) and processed in ***(c)*** AP/Blender create 360° models for ***(d)*** the cobble (Fig. 3) and ***(e)*** other samples for 3D printing and hand-painting (for fun!).

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2 Geologic / Environmental Context:

The **CH to BC coastlines** (***Fig. 1a, 2a,b***) reveal wave and slope eroded sea cliffs that range in height from 15-30 m. Bluffs at BC and CH consist of basal tills, stratified deltaic beds, lake floor deposits, and glacially sheared Cretaceous clay blocks with a discontinuously cap of <2m of loess. Iron cemented cobbles, gravel (***Panel 4***), and sand occurs at the base of the bluffs (Boothroyd and Sirkin, 2002; Veeger *et al*., 1996). Erosion occurs by surface runoff, undercutting at headwalls and stratigraphic boundaries, while deposition along the toe of the slope builds small fans, and colluvial blocks. Ground-based DP data sets (panels 3-4) are used to estimate change.

Wave erosion at **WB**, particularly since storms in 2010 and Superstorm Sandy (2012) have exposed metal, glass and plastic debris from a former landfill site (***Fig. 1c***). This debris has been transferred to the beach and littoral zone (Monieson, 2013). Historical imagery and GPS survey data (Oakley, pers. comm., 2020) indicates northward transport of sediments along the beach was impeded by the New Harbor Inlet to the south (Espinoza, 2015) exacerbating erosion at WB. In May, 2019 a $1.9 million revetment was constructed (Shuman, 2018) to stabilize WB (Fig. 1b).

The **DQ site** exposes coarse conglomerates of the lower Jurassic, Portland formation. These conglomerates are interpreted as capping a fan delta associated with the Hartford basin paleo depositional environments (LeTourneau *et al.*, 2015). Numerous well-developed glacial striations, grooves, and polish occur on the outcrop. We use drone-based PG to determine whether these features in the conglomerates can be recognized and measured digitally.

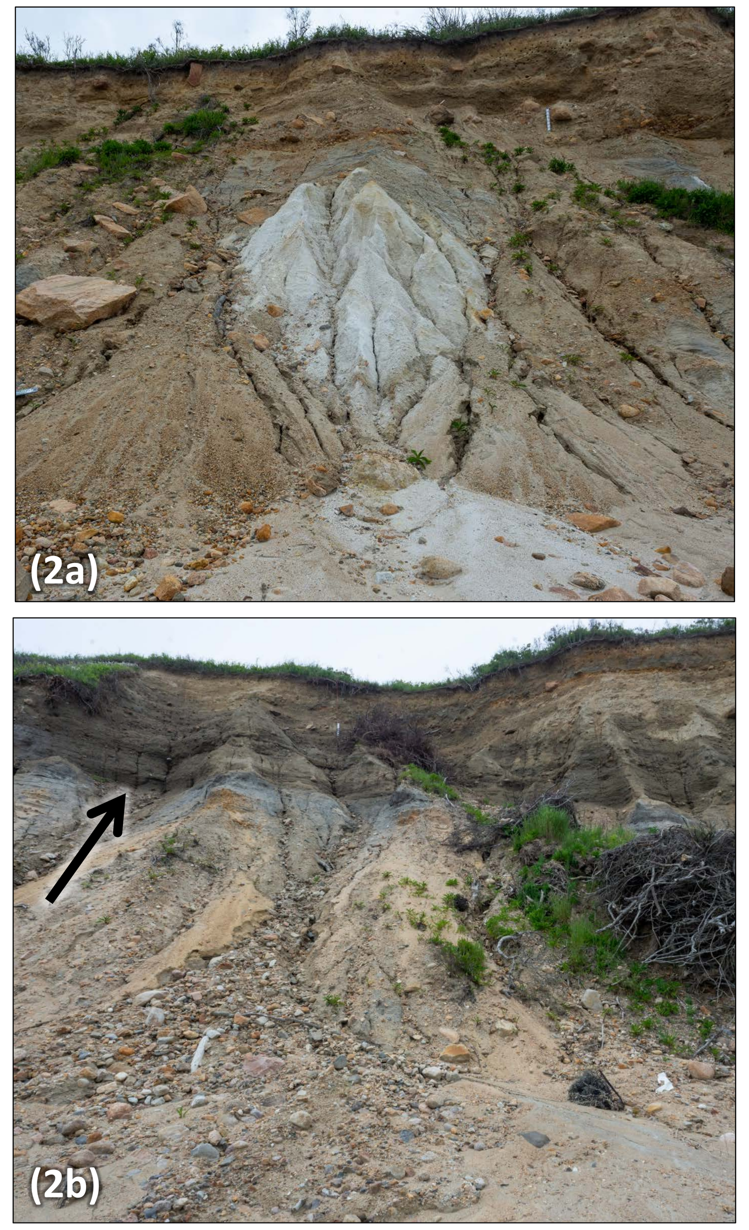

Figure 2 ***(a)*** Talus cones with well developed erosional rills occur along the base of the bluffs at Clay Head. ***(b)*** Similar conditions occur at Balls Cove, although pronounced lake-bed stratigraphy (arrow) causes some undercutting near the top of the bluff. ***(c)*** Ground-view of WB prior to remediation (summer, 2018). Note metal eroding out of the bluff). ***(d)*** Ground view of Jurassic conglomerate at DQ with a large photogrammetric target used to scale models into survey space and assess accuracies.

Topographic Change in Cloud Compare and ArcGIS

The value of detailed point cloud data sets is that models of the same site, but built using images collected at different times, may be used to quantify and measure topographic change (or other characteristics). We use 2 different approaches to characterize change at Block Island sites and compare models for DQ based on drone images captured at varying heights above the conglomerates.

Cloud Compare analyses at WB and CH/BC import AP point cloud files constructed from 2017, 18, and 19 (***Fig. 5a,b***). Elevation distances measured between similar points and are represented by colored "scaler" view. These visualizations depict rapid erosion for WB and more subdued change at CH & BC.

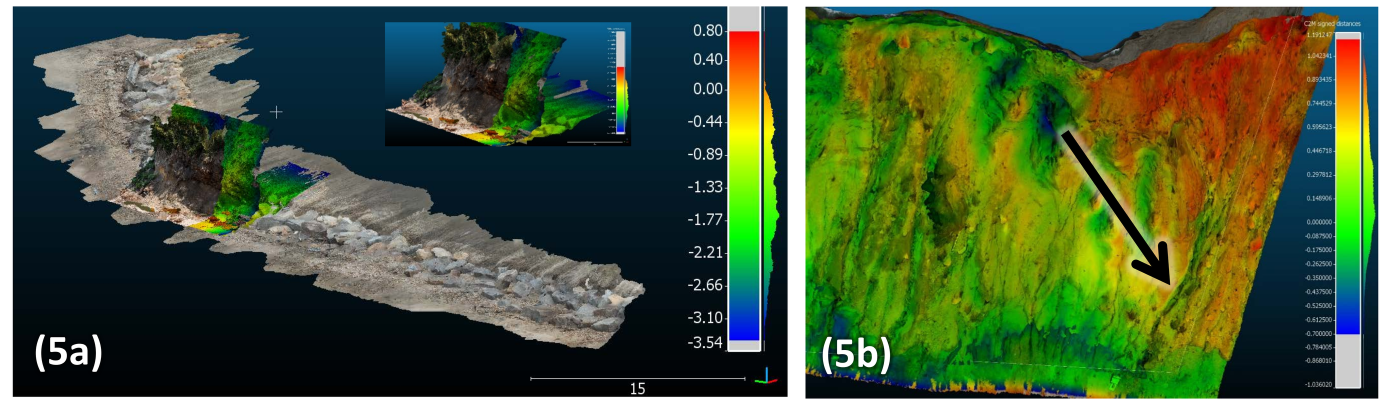

Figure 5. ***(a)*** CC models for all of west beach in 2019 (tan), with overlay showing scalers that identify the positions and meters of change (see color bar) for 2017, 18, and 19. Inset shows more detail of these scalers which indicate approximately 1 m retreat from 2017 to 2018, and then complete change in 2019 due to remediation of the site. ***(b)*** Scaler depiction of change for a portion of CH showing an erosional rill (green). More substantial erosion (≈1 m) in red occurs at the top of the bluff due to cliff retreat, while deposition is evident at the base (blue/green ≈0.7 m) due to the build up of talus/colluvial materials (Fig. 2a,b).

ArcGIS (ArcMap) change detection for CH (***Fig. 5c***) compares coastal elevations from 2018 air-borne LiDAR data (down-loaded from RIGIS) with ground-based DP measures from 2017, 18, and 19. In ArcMap we represent elevation loss (erosion) in red and deposit-ion in blue. Erosion at the top of the bluff is due to undercutting and slumping. Deposition at the base is from colluvium which is then eroded by waves.

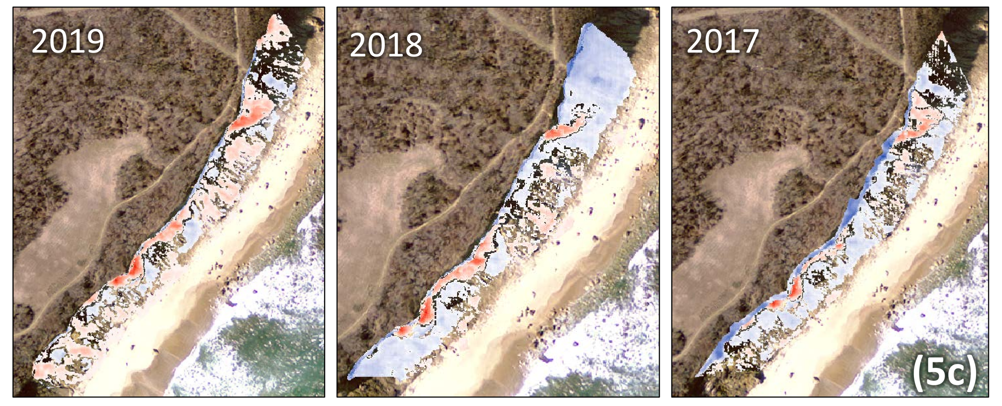

Figure 5c. Comparisons of topographic change between 2018 Lidar and 2019, 2018, and 2017 DP point clouds. Erosion (red) is common at the top of the bluff likely due to undercutting and retreat. Deposition on occurs mostly at the cliff base as talus before it is wave-eroded. Coverage differs slightly for each year and is systematically higher at the northeast end of the survey data for 2018 (likely due to limited ground control points in that area). Note: COVID-19 changes prevented us from returning to the lab to add scale bars for erosion and deposition).

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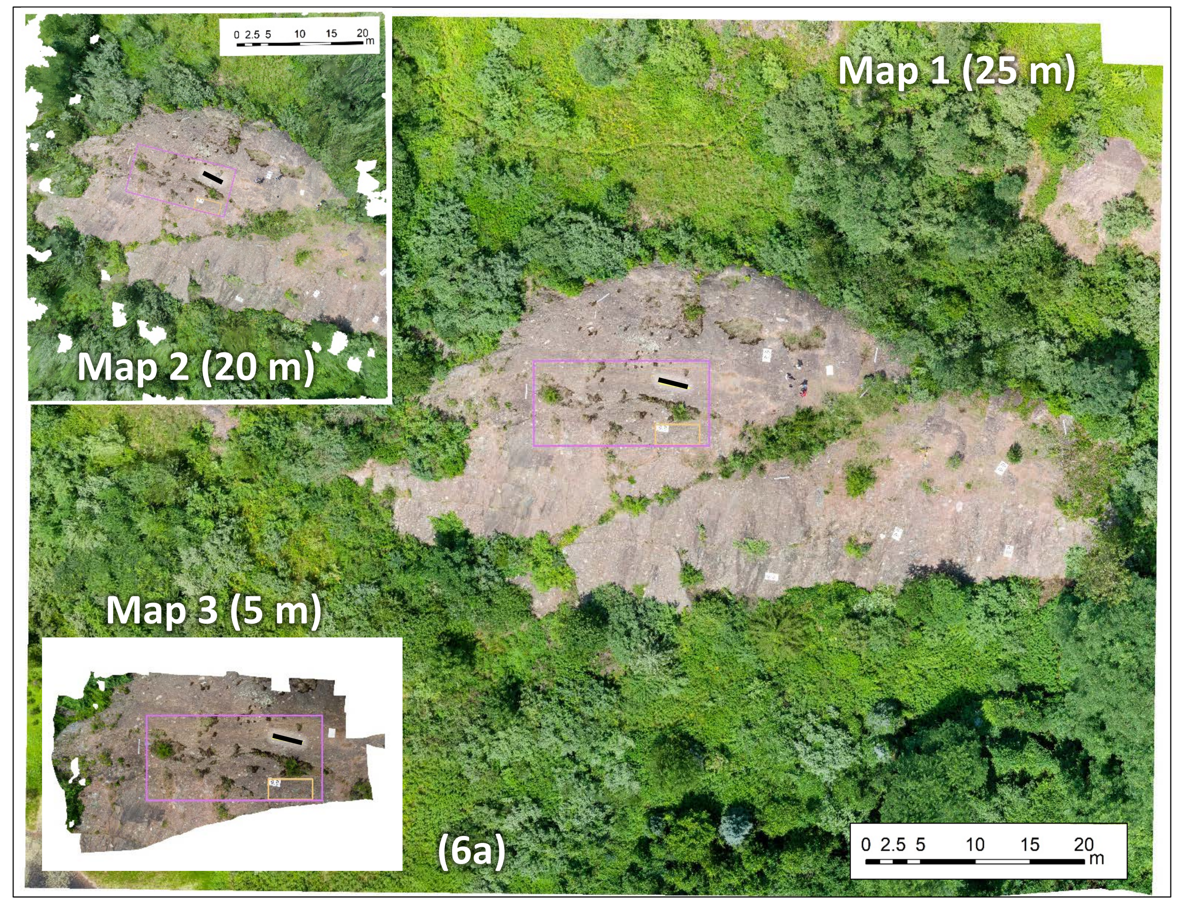
Dufford Quarry and Drone Mapping

Dufford Quarry PG models built from drone images captured from ≈5, 20, and 25 m heights (***Fig. 6a***) provide differing resolutions and levels of detail for measuring topographic change. Lower imagery provides the greatest detail. Cross-sections extracted for the same profile line from all maps reveal similar trends caused by glacially eroded striations and grooves. However, offset between the lines most likely caused by differing angles of imaging flight lines (***Fig. 6b***).



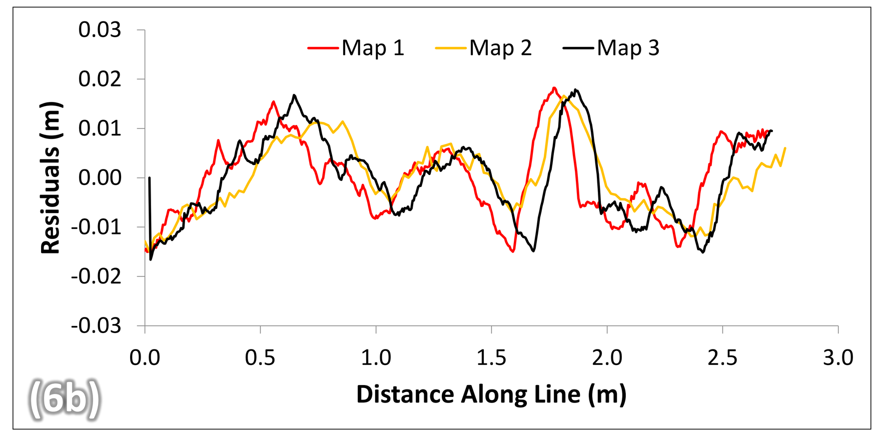


Figure 6. ***(a)*** Ortho-photomozaic and inset model views of DQ site as mapped using image heights indicated in the figure. ***(b)*** Comparison of topographic profile data for the same line from all 3 maps that show residual changes in elevations along the profile line (bold black dash with white glow on all three maps). Note similar elevation changes with some lateral offset.

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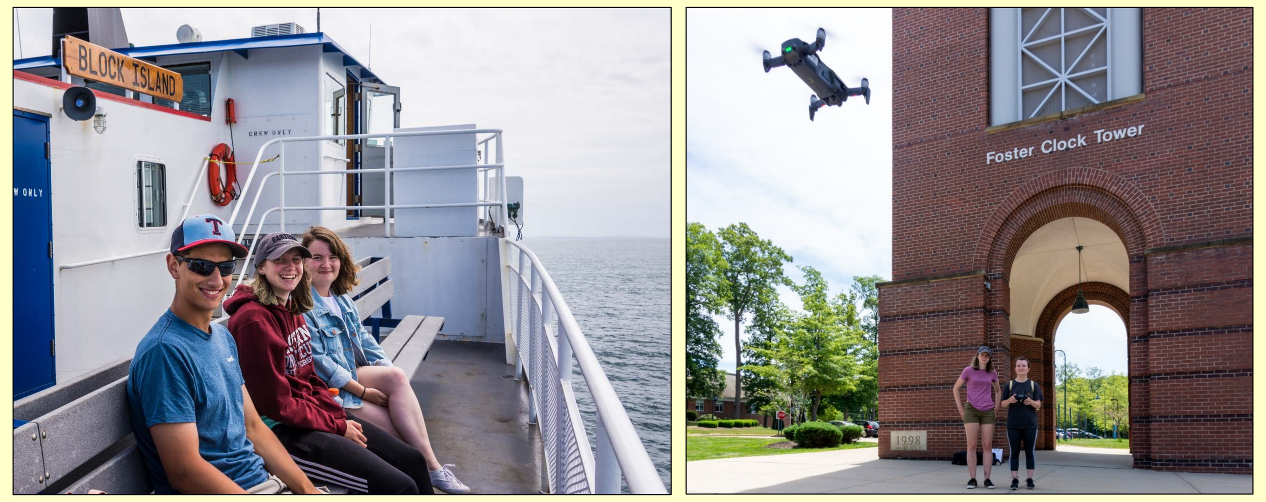
Summary

This project has introduced a range of imaging, modeling, mapping, and measurement techniques that we apply to geologic sites to:

- Learn digital photogrammetric techniques including image capture, camera calibration, and image management using a variety of software (Adobe Lightroom, Agisoft PhotoScan, Blender, Cloud Compare, ArcGIS).
- Generate 3-D point cloud models for geologic targets ranging from several 100 m² in size to desktop hand samples.
- Master DP software to align images, generate and optimize tie points, generate and refine dense point clouds, create and texture 3D meshes.
- Safely operate a drone and capture images for modeling outcrop from heights of 5-30 m to measure detailed topography of the rock surface.
- 3D print replicas of hand samples, and use ArcGIS to analyze Block Island coastal change and compare micro-topography of conglomerate outcrop.



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Citations

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