DRONE-BASED MEASUREMENT OF STRATIGRAPHIC COLUMNS AND CROSS-SECTIONS

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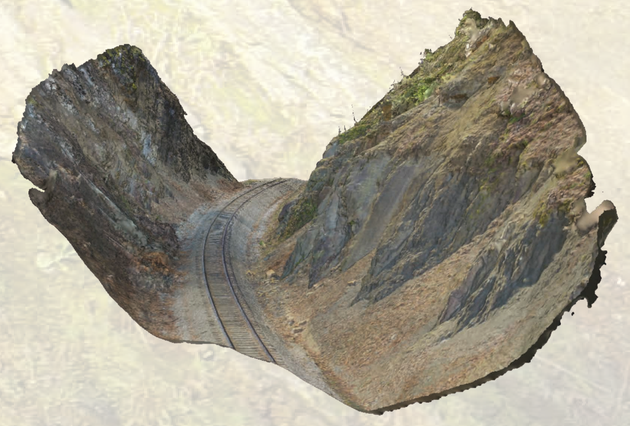
ABSTRACT

Measurements of stratigraphic columns and cross-sections are commonly hampered by topography, such as ravines and steep cliffs, which make some areas inaccessible and cause gaps in data coverage. Structural tilting can also complicate these measurements. We describe a solution to both problems using drone-based photogrammetry, which we have developed and tested on an exposure previously measured with traditional jacob-staff techniques. We begin by obtaining a series of photographs of an outcrop using a DJI Phantom 3 Advanced quadcopter drone, and merging these into a photomosaic and a 3-D point cloud, using Agisoft Photoscan. Multiple x-y-z coordinates along a dipping bed were obtained with LAStools and processed with an R script (available on the UGA Stratigraphy Lab website) to calculate the strike and dip, which was then used to rotate the entire exposure such that all beds are restored to stratigraphically horizontal positions. In this configuration, the Z-coordinate of any horizon in the point cloud is its stratigraphic elevation, which permits accurate measurement of a stratigraphic column. Comparison of this approach to a traditionally measured section through the Silurian Clinch Formation at the Hagan railroad cut in southwest Virginia produced comparable results. Ginn (2014) reported an average strike of 257° and an average 52° dip to the north, which compares well to our drone-based strike of 266° and dip of 51°. Differences in strike may be the result of differences in a magnetic vs. geographic reference frame. An interval of strata that Ginn (2014) measured as 35.9 m thick is 38.7 m thick when measured from the drone, and this difference more likely reflects the difficulties of accurate measurements with a Jacob Staff. This drone-based approach has promise not only for the measurement of relatively simple vertical columns, but also for three-dimensional characterization of outcrops that show considerable lateral variation in facies and thicknesses. Similar approaches have potentially wide application across the earth sciences, including volcanology, glaciology, structural geology, and planetary geology.

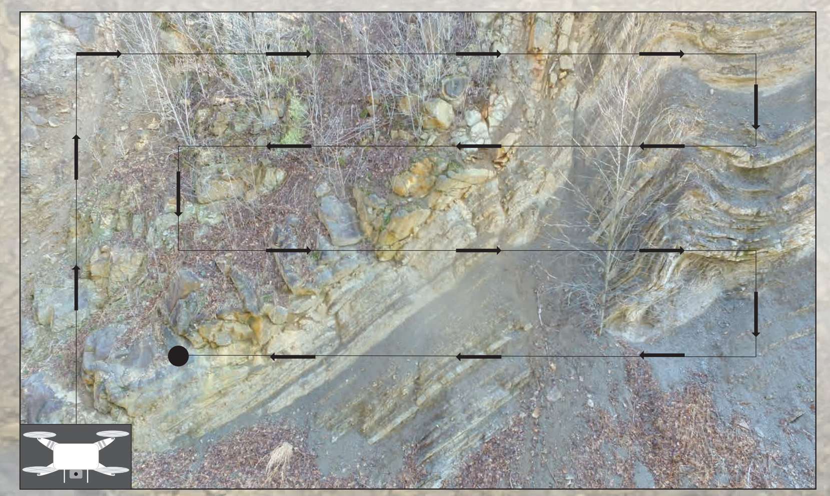
INTRODUCTION AND STUDY AREA

We conducted our drone-based stratigraphic measurement near Hagan, Virginia, USA. The outcrop was chosen because it is in a railroad cut that provides a third dimension to the outcrop geometry, ideal for generating point cloud models. Additionally, this stratigraphic column was previously measured using traditional methods (Ginn, 2014), allowing us to test the drone-based methods of measuring stratigraphic sections.



STEP 1: FLY DRONE AND COLLECT IMAGES

A DJI Phantom 3 Advanced was used for this study. Image collection was accomplished by flying in a vertical pattern as shown below. Photos were taken frequently to provide the image overlap necessary for generating 3D point clouds. Areas in excessive shade or sun were flown twice to ensure that uneven lighting would not hinder photo alignment.

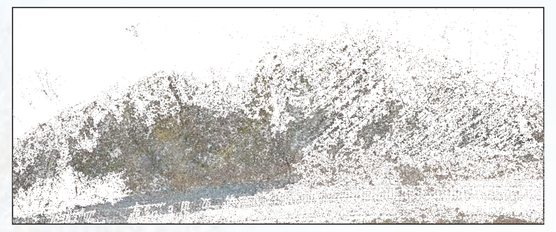


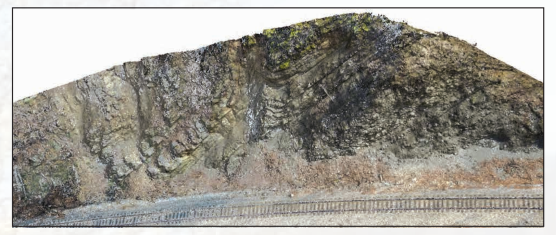
STEP 2: GENERATE 3D POINT CLOUD

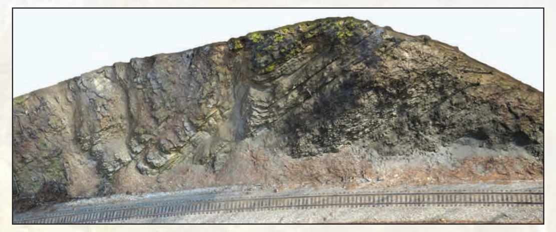
A dense point cloud was generated from the collected images using Agisoft Photoscan. First, photos were aligned using the high-alignment setting to produce a sparse point cloud, followed by a dense point cloud, also using the high setting. The dense point cloud was edited to remove unnecessary features such as the sky and trees. The point cloud can then be used to produce a 3D mesh for interpretation, or it can be exported as a .las file for farther processing, such as orientation and scaling.

Align photos → Build dense cloud → Build 3D Mesh

Build dense cloud → Export file → Orient Axis → Calculate Scaling Factor → Scale Model



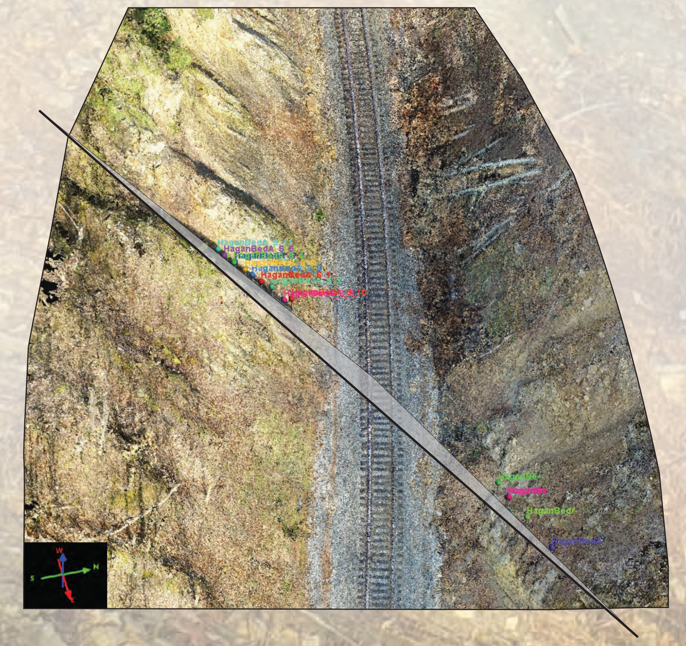




For stratigraphic section measurement, the 3D point cloud was scaled and oriented so that the x-axis ran east-west, the y-axis ran north-south, and the z-axis was vertical. Orienting the point cloud along the east-west and north-south axes is easier if a marker is placed in the study area during data collection. The model was scaled using the las2las tool from the LAStools suite. A marker of known length must be present in the model to calculate the scaling factor, and this is then applied to the model. We accomplished this by including several Jacob staffs in our photographs, but an object of higher visibility, would be ideal.

STEP 3: IDENTIFY BED

Digital measurement of stratigraphic section requires that the model must first be rotated such that beds are horizontal. This process begins by identifying a stratigraphic horizon that is easily recognizable. Points along this horizon are selected in Quick Terrain Reader, which provides the x-y-z coordinates defining the bedding surface. We used a recognizable resistant sandstone bed, shown below with a plane approximating the bedding surface.



STEP 4: CREATE AND ROTATE PLANE

The x-y-z coordinates on each bedding surface are used to calculate a best-fit plane (using least-squares), and from that plane, the strike and dip of the bed. The R script for doing this is available on the UGA Stratigraphy Lab website. We tested several scenarios based on different beds, different numbers of points used, and different point geometries. Our measurements of different beds are comparable to Brunton-based field measurements. The average of our digitally-measured dips disagree by 2° and strike differs by 3°. The number of points used to identify a bed doesn't greatly affect the R-squared or strike and dip measurements, point geometry, however, does. Points on a bed must be dispersed, rather than bunched, to achieve the best result.

Comparison of model measurements to actual measurements:

Bed Tested	Number of Points	R^2 of Plane	Model Strike/Dip (°)	Deviation from Field Strike/Dip (°)
Bed A	32	0.997	262/56	-1/+1
Bed B	15	0.999	266/54	+6/-1
Bed D	12	1.000	265/49	-2/+2
Bed E	10	0.996	269/54	+9/-4
Bed F	15	0.999	264/51	+1/-5
Bed H	7	0.999	267/47	1/-1
Bed I	10	1.000	271/48	-2/0

Variation in measurements based on number of points:

Bed Tested	Number of Points	R^2 of Plane	Model Strike/Dip (°)	Deviation from Field Strike/Dip (°)
Bed A	4	1.000	263/58	0/+3
Bed A	8	0.999	262/58	-1/+3
Bed A	16	0.998	260/57	-3/+2
Bed A	32	0.997	262/56	-1/+1

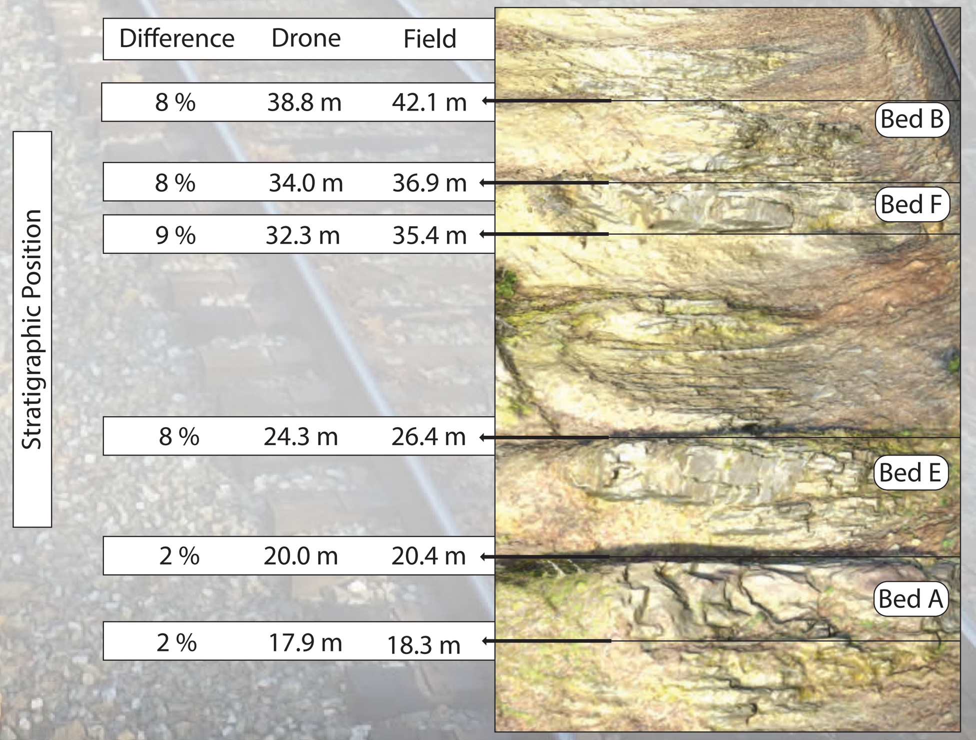
Variation in measurements based on point geometry:

Point Geometry	Number of Points	R^2 of Plane	Model Strike/Dip (°)	Deviation from Field Strike/Dip (°)
Square	4	0.996	259/58	-4/+3
Bunched Line	4	0.999	230/71	-33/+16
Dispersed Line	4	0.999	261/57	-2/+2
Random	4	1.000	265/59	+2/+4
Opposite pairs	4	1.000	264/57	+1/+2
Corners	4	1.000	265/55	+2/0

STEP 5: MEASURE SECTION

The strike and dip of the beds is used to rotate all points in the cloud so that bedding is horizontal, with the z-axis increasing in value stratigraphically upwards. This is done in R using a script available on the UGA Stratigraphy Lab website. Because bedding after this rotation is horizontal, the z value of any point corresponds to its stratigraphic position, allowing the column to be measured digitally. When tested, a 35.9 m thick interval at Hagan measured by Ginn (2014) was 38.7 m when digitally measured. Differences in measurement may be caused by incorrectly matching beds, so a field check was conducted to farther resolve the accuracy of the method. A 42.1 m interval from the field check was 38.8 m when digitally measured, a difference of 8 %. A portion of the measured section is show below. Differences more likely reflect error in field measurements across difficult terrain, and we are more confident in the accuracy of the drone method then the traditional field measurements.

Difference	Drone	Field
8 %	38.8 m	42.1 m
8 %	34.0 m	36.9 m
9 %	32.3 m	35.4 m
8 %	24.3 m	26.4 m
2 %	20.0 m	20.4 m
2 %	17.9 m	18.3 m



OTHER APPLICATIONS

Drone and 3D model methods are useful to describe lateral facies variation at large outcrops and also provide a more efficient way to trace stratigraphic contacts in the field. This may aid in understanding complicated surfaces such as those with erosional relief. Depth of incision on erosional surfaces, such as the one shown below from the Sundance Formation of Wyoming, could be easily measured with this drone technique, allowing sequence stratigraphic relationships to be better understood.

CONCLUSIONS AND ADVICE

This study illustrates one of the methods by which new technology can be integrated with traditional stratigraphy methods when access to an exposure is limited or difficult. Stratigraphic section measurement was completed successfully with a drone with only minor variations from traditional methods. These variations are just as likely to be from field measurement error as from digital measurement error, especially considering the difficult terrain. Because these methods are new, developing them was a process of trial and error, and based on this, we have some advice:

1. Place highly visible compass orientation and scale markers (shown at right) in field area before capturing images with the drone. It is ideal for section measurement if the orientation and scale marker has a vertical component.
2. Choose the time of day for the drone flight to avoid uneven lighting, heavy shade, or facing into bright sun.
3. Avoid heat and dust. The iPad and drone are both sensitive to these elements. When the iPad overheats, visual guidance is lost. If dust gets into the motors it can cause them to overheat, which causes the drone to spin uncontrollably and crash, or it can burn out the sensor on the main board.
4. If the drone crashes, clean all of the debris out of the motors before attempting to start them. This can be accomplished by blowing air into the motors with an air compressor while holding the drone upside down.
5. Back up all data, which can be extensive. The photographs needed to assemble a large point cloud can collectively exceed 8 Gb.
6. Large point clouds (>75 million points) can be time consuming to process or too large for R to handle. This can be resolved by splitting the file using the LAStool lassplit, rotating them individually, and merging them using lasmerge.

REFERENCES

Ginn, C.L., 2014, Sequence stratigraphy of the Silurian Clinch Formation, northeastern Tennessee and southwestern Virginia [M.S. thesis]: University of Georgia, 75 p.

ACKNOWLEDGEMENTS

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The UGA Stratigraphy Lab