THE UNIVERSITY OF VERMONT
COLLEGE OF ARTS AND SCIENCES

USING UNMANNED AERIAL VEHICLE (UAV) PHOTOGRAMMETRY TO REVISIT A CLASSIC OUTCROP: SHELBURNE BOAT ACCESS (SBA), WEST-CENTRAL VERMONT2

VERMONT
AGENCY OF NATURAL RESOURCES
Vermont Geological Survey

Samantha Portnoy (sportnoy@uvm.edu)[1], Jonathan Kim (Jon.Kim@vermont.gov)[2], Keith Klepeis (kklepeis@uvm.edu)[1], and John Van Hoesen (vanhoesenj@greenmtn.edu)[3]
[1]Department of Geology, University of Vermont, Burlington, VT [2]Vermont Geological Survey, 1 National Life Drive Main 2, Montpelier, VT [3]Geology & Environmental Studies, Green Mountain College, Poultney, VT

ABSTRACT

A 50 m long and 2 m thick outcrop of well-bedded ferruginous quartzite from the Early Cambrian Monkton Formation extends northward into Shelburne Bay from the Vermont state boat launch. These quartzites lie in the hanging wall of the Champlain Thrust and were emplaced over the Stony Point Shale during the Ordovician Taconian Orogeny. To build on the work of Stanley (1974), we used a UAV to survey the outcrop from an elevation of ~11m, assembled a photo mosaic using Photosynth, and analyzed structures from the composite image in GIS. In addition, the attitudes of all structures (bedding, fractures, faults, and veins) were measured in the field and detailed meter-scale photo mosaics were constructed at key locations.

Stanley's analysis supports the interpretation of two generations of structures, an older primary generation forming during the Middle to Late Devonian Acadian orogeny and a younger secondary generation resulting from the interchange of primary stress fields. The E/W oriented wrench faults are suggested to have formed during the first generation, along with fractures and en echelon arrays, then N/S oriented faults and fractures developed as stress fields became interchanged due to further displacement on first generation faults. The second generation, however, does not have any associated array features. With the implementation of photogrammetry, our investigation was able to provide more extensive and detailed data of the study area than was previously possible. A preliminary statistical analysis of our field data has identified three distinct groups of structural lineaments, rather than two as previously defined by Stanley (1974).

Further investigation will involve a detailed statistical analysis of the azimuths and lengths of all lineaments derived from the UAV mosaic, as well as a Mohr circle analysis of field data. By varying illumination angles on digital elevation models (DEM) from LiDAR data we were able to highlight large-scale lineaments within central Vermont. Our ongoing work has involved comparing the lineament data from DEMs to the structural data from Shelburne Boat Access in order to develop an understanding of how this detailed outcrop fits into the context of central Vermont's regional geology. Beyond the regional setting, we are also assessing how these localized features fit into the Paleozoic-Mesozoic tectonic history of the Northern Appalachians and Southern Quebec.

METHODS

The initial goal for this project was to approach a well-known outcrop using photogrammetry to re-evaluate the structural context of the study area and understand how this approach changes data aquisition. The UAV was used at a height of ~11 m above the study area to take detailed photos which were then stitched together creating a drone map (Figure 6). Using this map, we chose significant zones in the field to collect data from and analysed features in GIS.

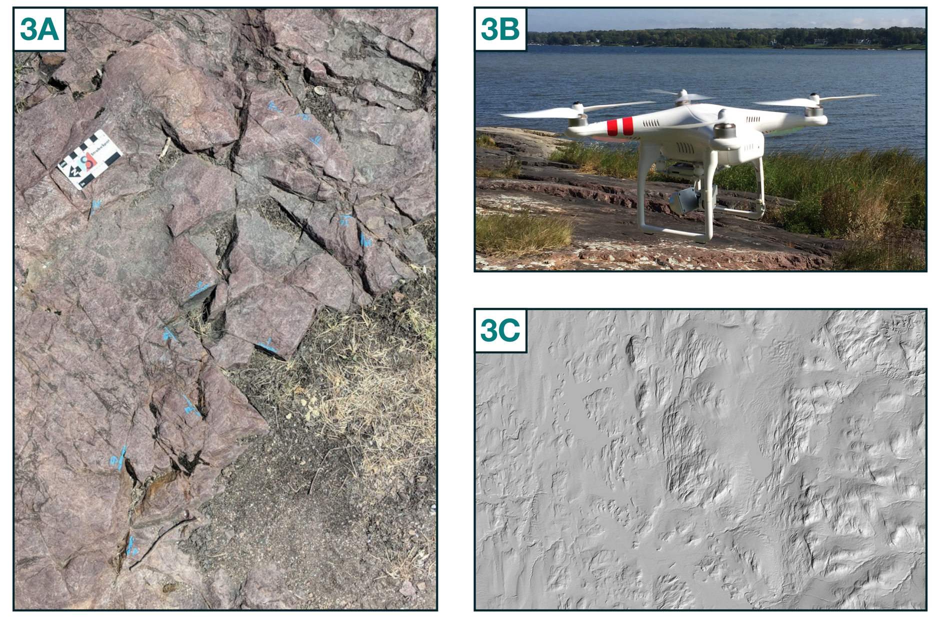
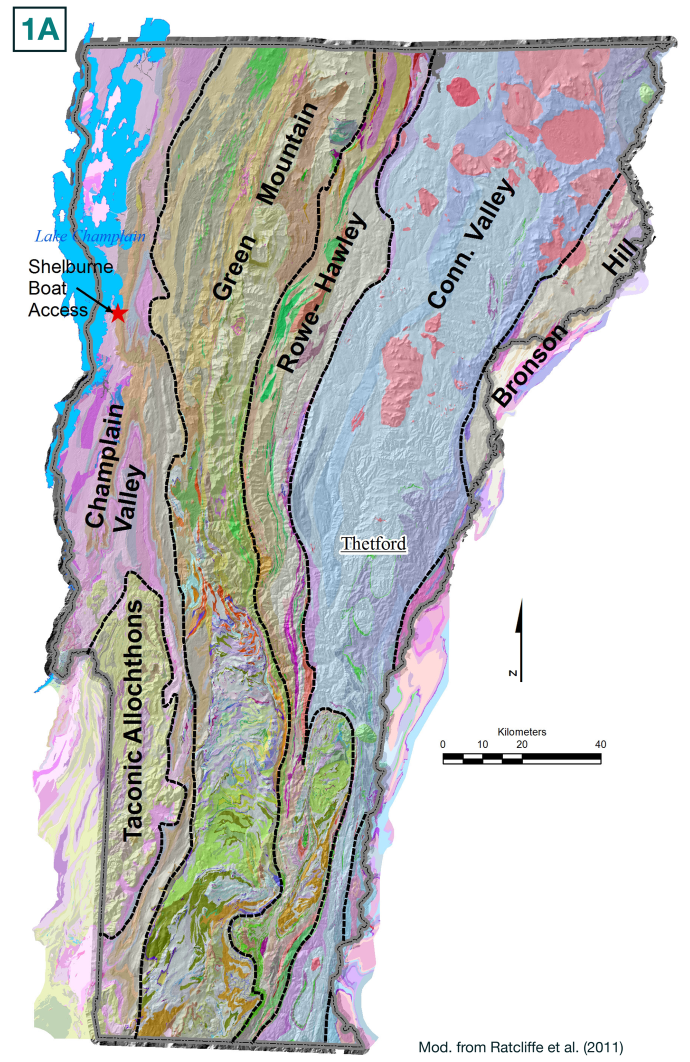


Figure 2.
Method development.

Figure 3.
A) Step 4 in our workflow graphic involved marking each structure with chalk, measuring its orientation, and later using a photo like this one to annotate detailed mosaics (Figure 8). **B)** UAV used to capture mosaic images. **C)** Hillshades derived from digital elevation models allowed us to manually annotate inconspicuous features.

STUDY AREA



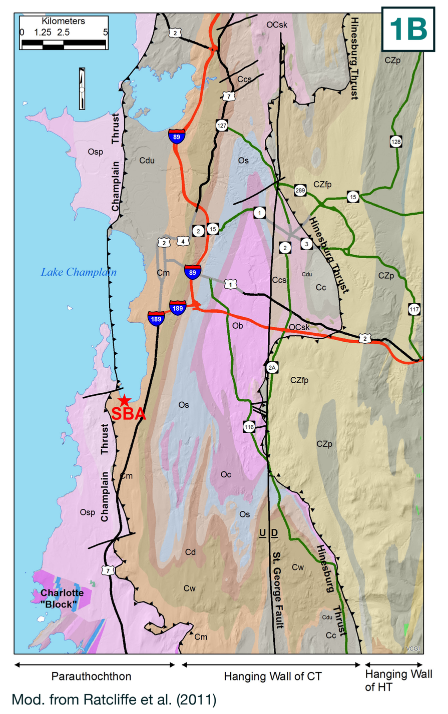
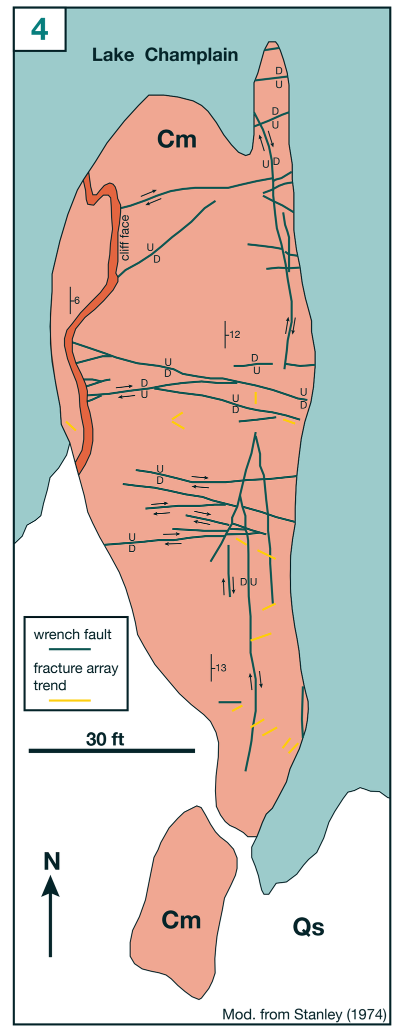
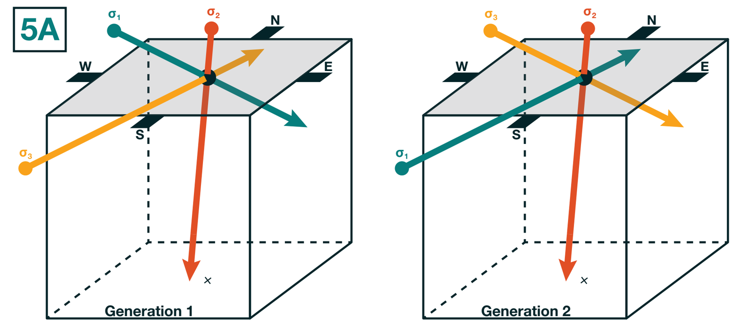


Figure 1.
A) Vermont state geologic map with study area identified (red star).[1] **B)** Shelburne Boat Access study area (SBA).[1] Note: E/W faults offset the Champlain Thrust (CT) near SBA.

BACKGROUND



- Compared data to Rolfe Stanley's SBA work (1974)
- Methods: macroscopic (field data collection via stations) and microscopic structural analyses
- Two generations of structures:(G1) E/W; (G2) N/S
- G1 related to Acadian Orogeny, forming during Devonian (Figure 9A (2))
- G2 forming later from interchanged stress field



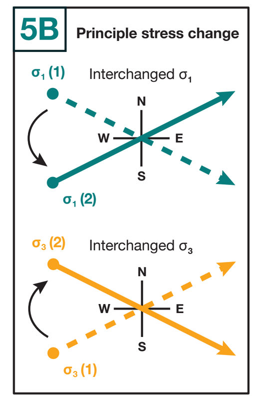


Figure 4.
A summary of Stanley's structural evaluation at SBA.[2]

Figure 5.
A) Principle stress orientations for the two-generation deformation model defined by Stanley. **B)** σ_1 and σ_3 stress fields interchange from deformation events (1) to (2).

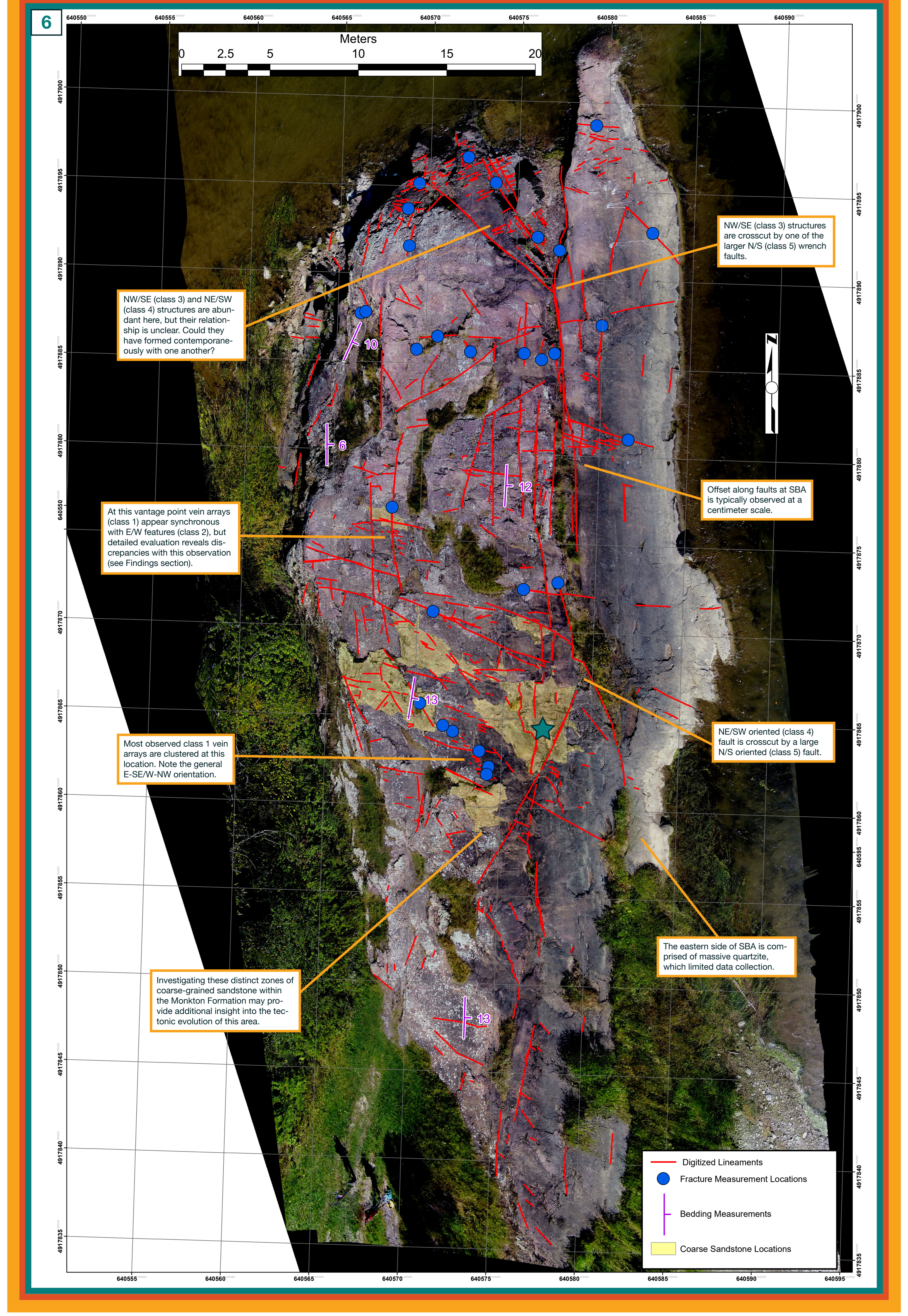
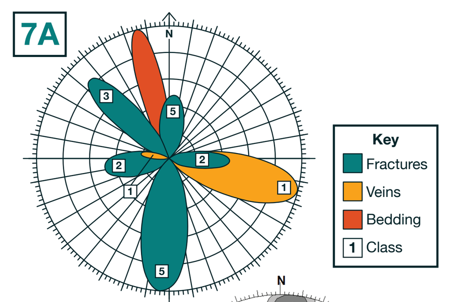


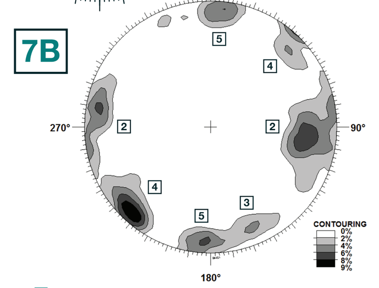
Figure 6. Aerial map of Shelburne Boat Access study area created by stitching together numerous aerial photos captured by an unmanned aerial vehicle (UAV) (Figure 3B). Lineaments were annotated (red lines) manually in GIS both before and after field data (blue dots and purple bedding measurements) was collected.

FINDINGS

CLASSES By conducting both manual and automated statistical analyses, we found five classes of features: (1) E-SE/W-NW veins and fractures; (2) E/W fractures and wrench faults; (3) NW/SE fractures and faults; (4) NE/SW veins, fractures, and faults; (5) N/S fractures and wrench faults. Classes 1-3 and 5 shown in Fig. 7A; 2-5 in Fig. 7B.

RELATIONSHIPS Detailed field measurements and photo mosaics (Figure 8) show that class 1 vein arrays have instantaneous strain axes (ISA) averaging ~4° less than finite strain axes. Class 2 crosscuts class 1. Classes 3 and 4 crosscut classes 1 and 2, but their relationship to each other is inconclusive, and class 5 crosscuts all other classes.





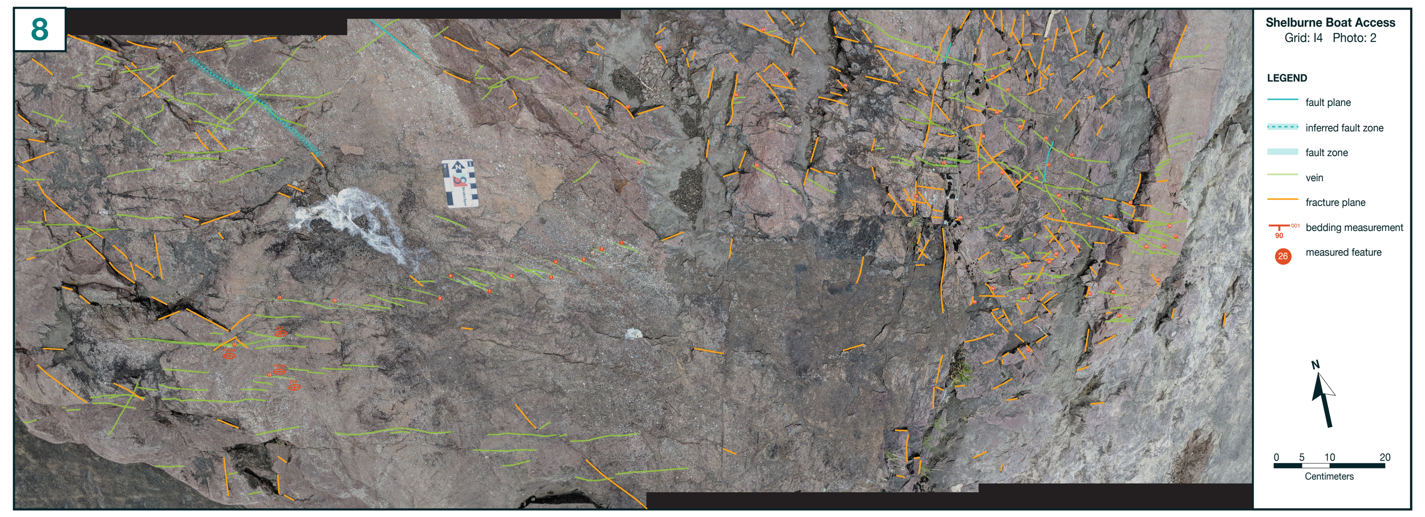


Figure 7.
A) Rose plot of fractures, veins, and bedding. **B)** EAN for fractures.

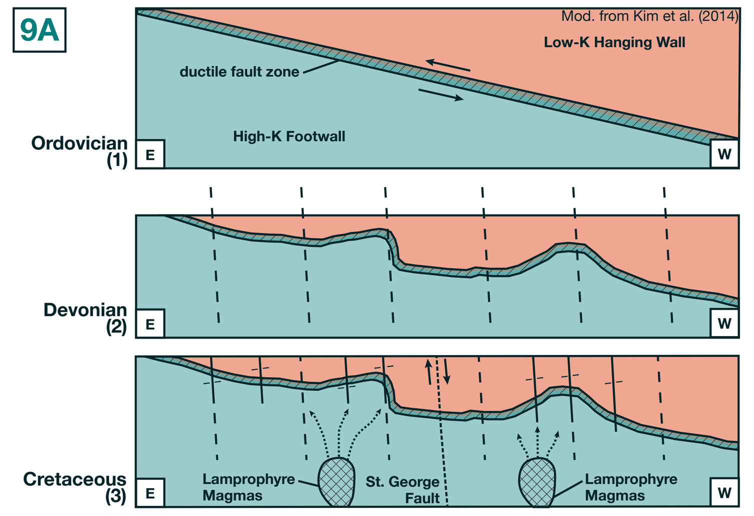
Figure 8.
Detailed mosaic (star on Figure 6).

CONCLUSIONS & FUTURE PLANS

CONCLUSIONS This advanced method allowed us to gain a more detailed structural evaluation at SBA, enhancing our understanding of local tectonics. Stanley recognized two generations of features at this site, but we were able to distinguish at least three (Figure 9A): (G1) class 1 features form from Ordovician ductile metamorphism related to thrust faulting (D1); (G2) class 2 structures develop from deformation related to the Devonian Acadian Orogeny (D2); (G3) interchanged stress fields form class 5 as the Atlantic opens (D3). Classes 3 and 4 could potentially be related to this transition (Figure 9B).

CONTINUED WORK Future plans for this project could include the following tasks and goals:

- Conduct a Mohr-Coulomb analysis to validate deformation event conditions
- Evaluate regional LIDAR data in order to compare SBA structures to regional structural patterns
- Further investigate how class 3 and class 4 structures relate to each other and to other classes



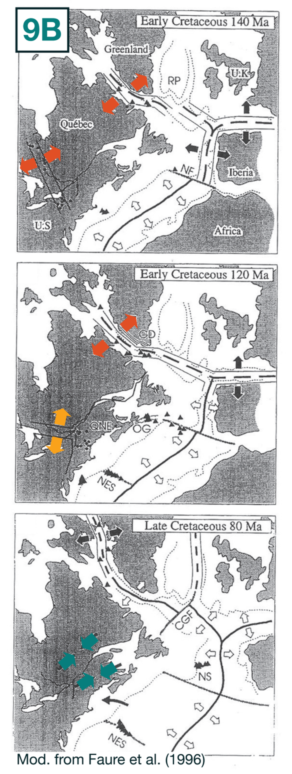


Figure 9. ***Possible Tectonic Scenarios (Greater SBA Area)***
A) (1) Thrusting-related ductile structures form (D1). (2) Folding and cleavage developement occur (D2). (3) Fractures develop with some localized along D2 cleavage planes and lamprophyre dikes intrude, some via existing structures (D3).[3]
B) Continental-scale Cretaceous tectonics.[4]

ACKNOWLEDGEMENTS

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1. Ratcliffe, NM, Stanley, RS, Gale, MH, Thompson, PJ, and Walsh, GJ, 2011, Bedrock Geologic Map of Vermont: USGS Scientific Investigations Series Map 3184, 3 sheets, scale 1:100,000.
2. Stanley, RS, 1974, Environment of Deformation, Monkton Quartzite, Shelburne Bay, Western Vermont, Geological Society of America Bulletin (1974) 85, 233-246.
3. Kim, J, Ryan, P, Klepeis, K, Gleeson, T, North, K, Bean, J, Davis, L, and Filoon, J, 2014, Tectonic evolution of a Paleozoic thrust fault influences the hydrogeology of a fractured rock aquifer, northeastern Appalachian foreland, Geofluids (2014) 14, 266–290.
4. Faure, S, Tremblay, A, and Angelier, J, 1996, State of intraplate stress and tectonism of northeastern America since Cretaceous times, with particular emphasis on the New England-Québec igneous province, Tectonophysics (1996) 255, 111-134.
5. Tremblay, A, Long, B, and Massé, M, 2003, Supracrustal faults of the St. Lawrence rift system, Québec: kinematics and geometry as revealed by field mapping and marine seismic reflection data, Tectonophysics (2003) 369, 231-252.

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