USING DRONE SURVEYS TO INTERPRET THE GEOMETRY AND KINEMATICS OF A MESOZOIC FAULT ZONE IN DOLOSTONES OF THE CHAMPLAIN VALLEY BELT, WEST-CENTRAL VERMONT II

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Abstract

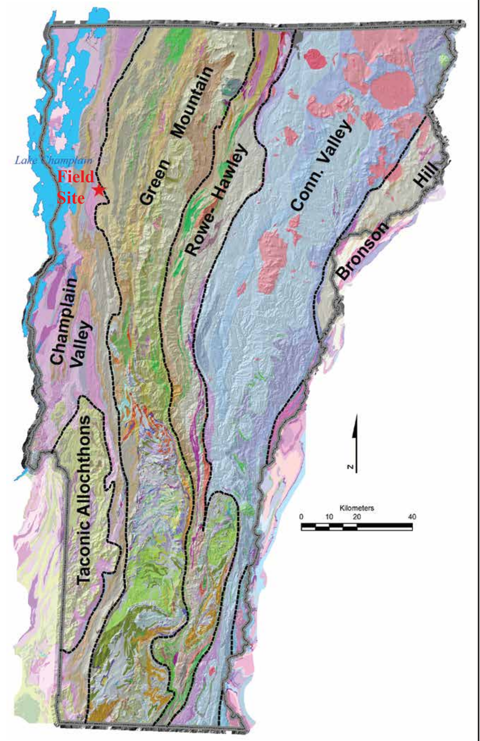
The Champlain Valley Belt of west-central Vermont consists of Cambrian-Ordovician, weakly-metamorphosed, carbonate and clastic sedimentary rocks and is informally subdivided into 3 east-dipping lithotectonic slices, which are (from east to west): 1) the hanging wall of the Hinesburg Thrust (HWHT), 2) the hanging wall of the Champlain Thrust (HWCT), and 3) the Parautochthon. These thrust slices were juxtaposed during the Ordovician Taconian Orogeny and later modified by Acadian (Devonian) folding and Mesozoic extension. Our field area lies in the HWCT in a sliver of the Clarendon Springs Formation dolostone. This sliver is bounded by the Ordovician Muddy Brook Thrust (east) and the Mesozoic down-to-the-east St. George Fault (west).

The field area consists of a 100m x 200m rectangle of continuous outcrop in a bedrock channel of the Winooski River at the Williston/Essex border. The northeast striking (~067) and steeply-dipping fault zone was first identified in 2014-2015 through detailed field mapping and structural analysis, however, drone surveys from altitudes of 41m (base map) and 26m (2 subdomains) were necessary to evaluate the geometry and kinematics of this zone. Field mapping of fractures and bedding were conducted at multiple scales using scangrids, scanlines, and pace and compass techniques.

Photolineaments (n=715) were digitized using imagery captured by a UAV. The dominant azimuths are 067° (30%), 028° (29%), and 295° (14%). Average photolineament lengths for these groups are 3m, 2m, and 3m, respectively. By correlating photolineaments with field data, we confirmed that they represent steeply-dipping planes. The fault zone is defined by en echelon fractures with sub-horizontal slickensides that strike 067° and step to the NW. Meter-scale scangrid arrays of the major fracture sets also corroborate this stepover direction. The style of deformation in stepovers will be used to determine fault zone kinematics. With the exception of local open folds, bedding strikes NW and dips moderately eastward, suggesting minimal displacement on all faults.

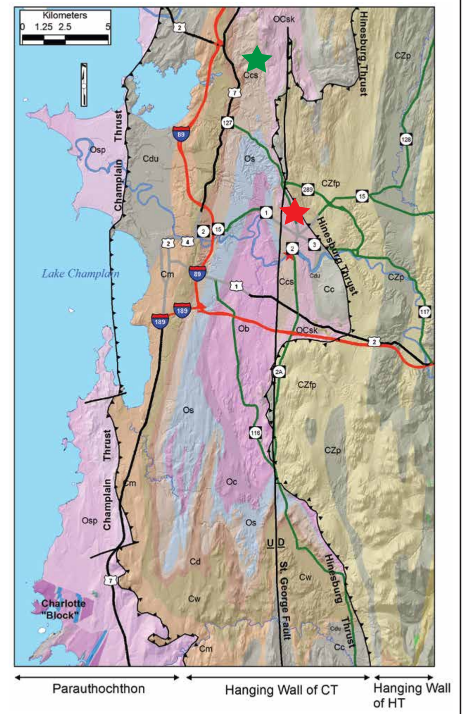
Detailed mapping in other areas of west-central Vermont has identified other en echelon fault zones that strike toward 067° and cut across Paleozoic ductile structures. We suspect that they are related to motion on the St. George Fault.

Figure 1- Lithotectonic Base Map



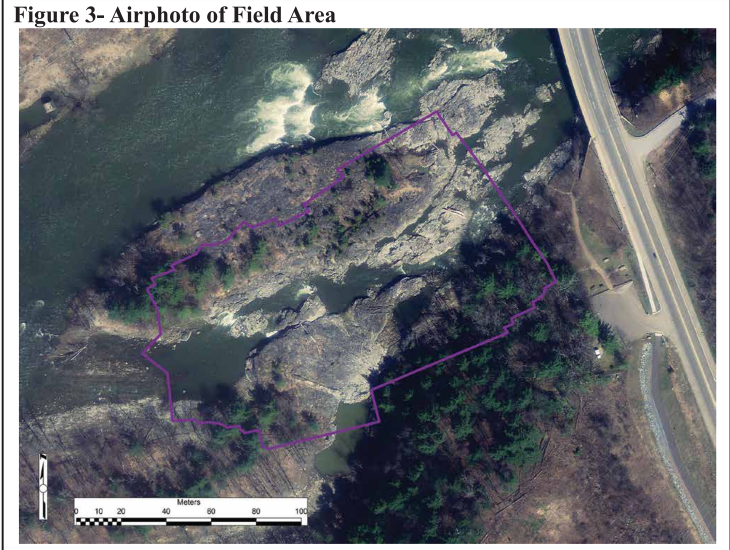
Modified from Ratcliffe et al. (2011)

Figure 2- Field Area Map



Field area shown with red star. Correlative fault zone in the Colchester Quadrangle shown with green star. Modified from Ratcliffe et al. (2011)

Figure 3- Airphoto of Field Area

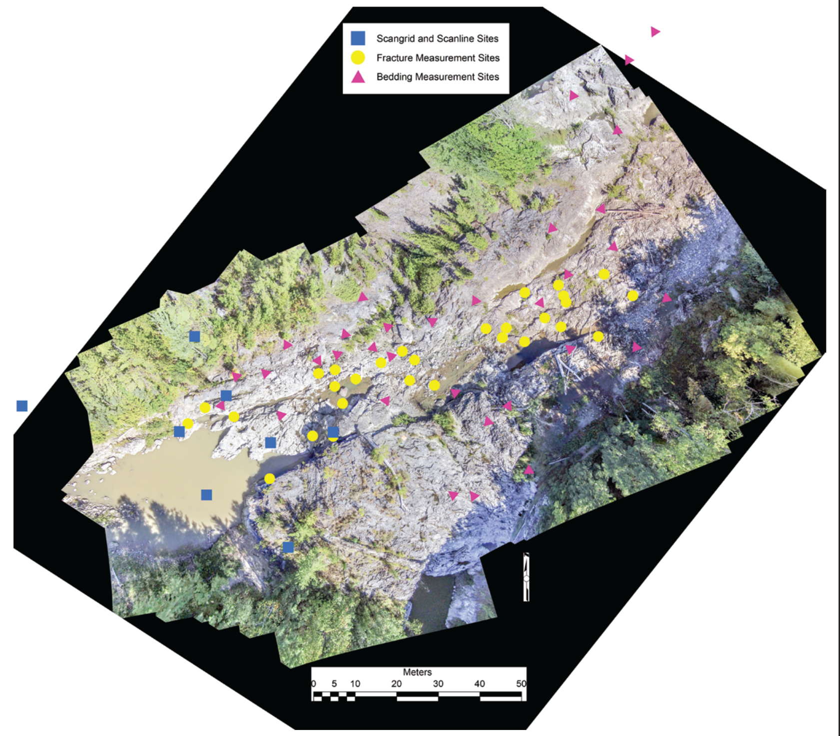


Air photo of field area (purple polygon), which is a bedrock spillway for the Green Mountain Power Co. dam.

Figure 4- Drone Surveys

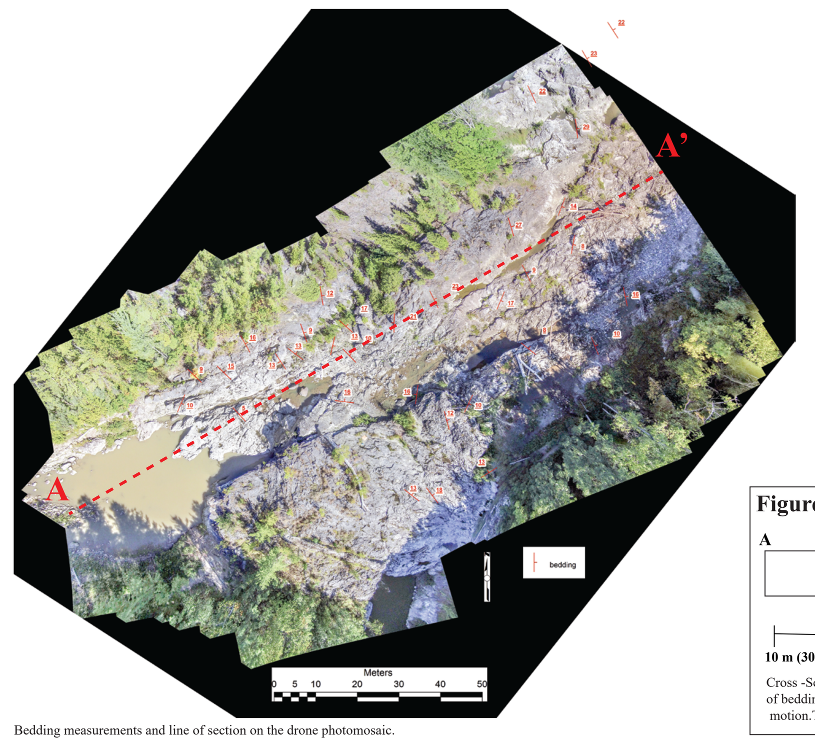
Drone (UAV) surveys of the Winooski River spillway field area were flown at altitudes of 41 m (135') and 26 m (85') by John Van Hoesen.

Figure 5- Field Sites



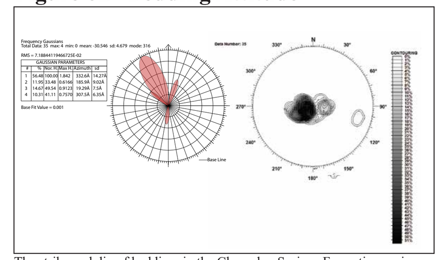
Field area map showing sites where fractures were measured (yellow circles), bedding was measured (blue squares), and scan grids or scan lines were completed.

Figure 6A- Bedding Base Map



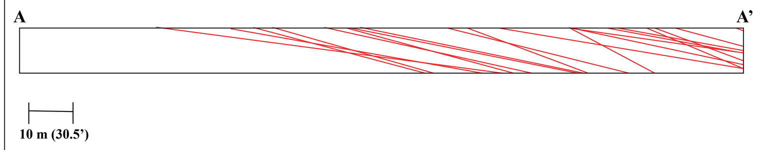
Bedding measurements and line of section on the drone photomosaic.

Figure 6B- Bedding Attitude



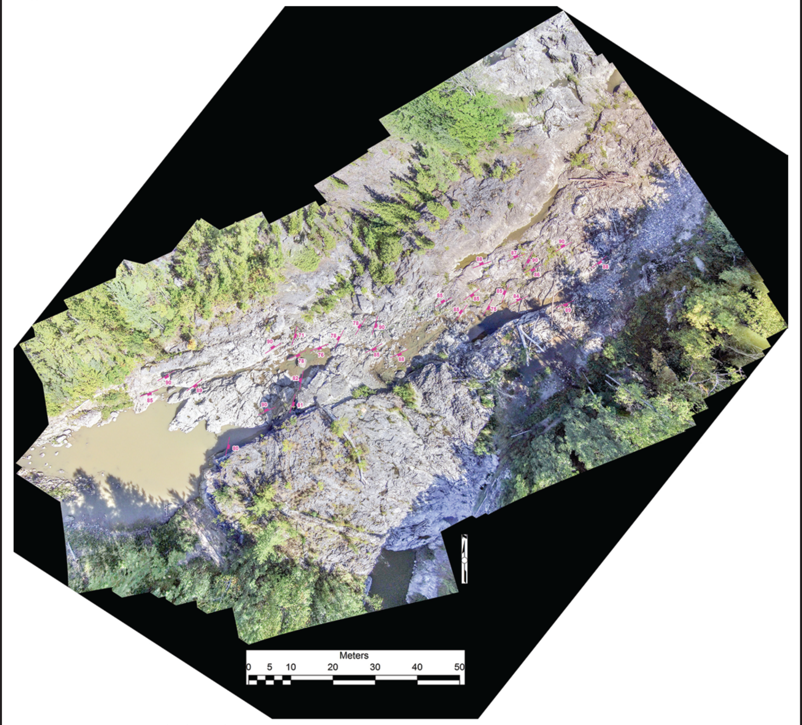
The strike and dip of bedding in the Clarendon Springs Formation varies little in the field area.

Figure 6C- Bedding Cross-Section



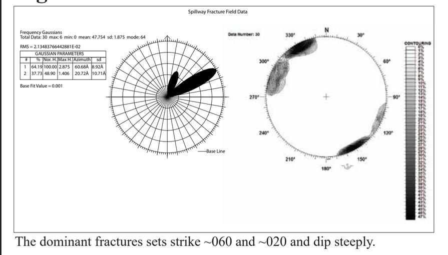
Cross -Section A-A' was constructed ~parallel to the 060 fault zone and ~perpendicular to bedding, to see if the fault affected the attitude of bedding. Although the dip of bedding wobbles from station to station, there does not appear to be any major deflection caused by fault motion.The gentle folding is likely Paleozoic.

Figure 7A- Fracture Base Map



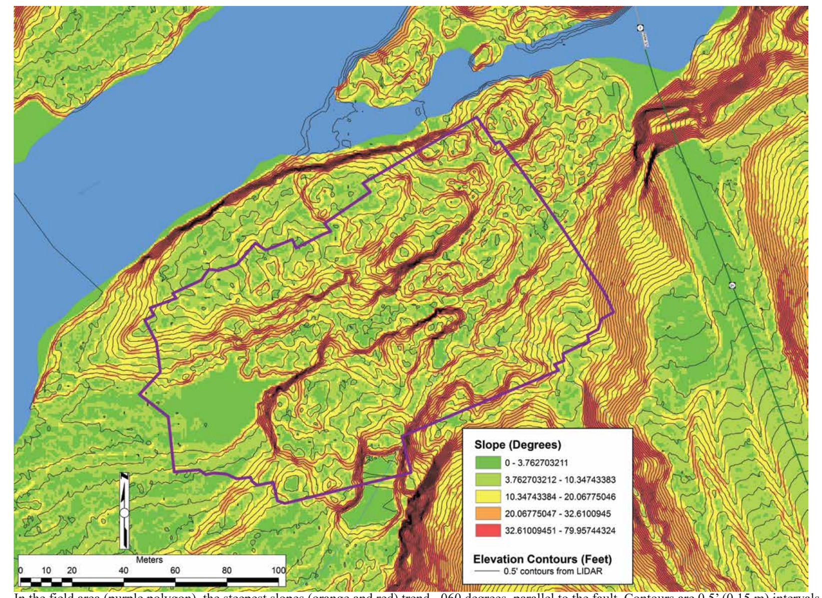
Fracture measurements on the drone photomosaic.

Figure 7B- Fracture Attitudes



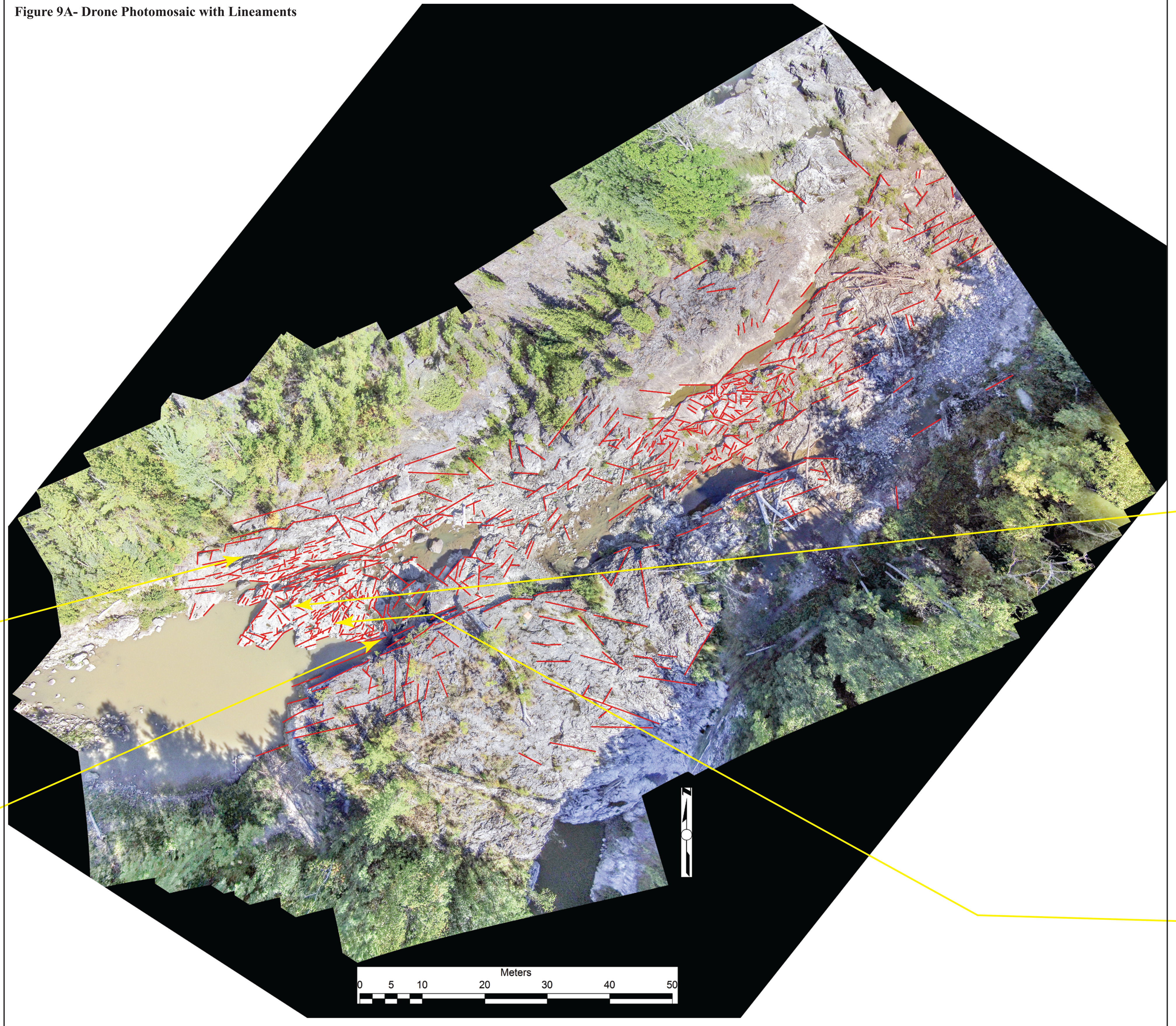
The dominant fractures sets strike ~060 and ~020 and dip steeply.

Figure 8- Slope Map from LIDAR Data



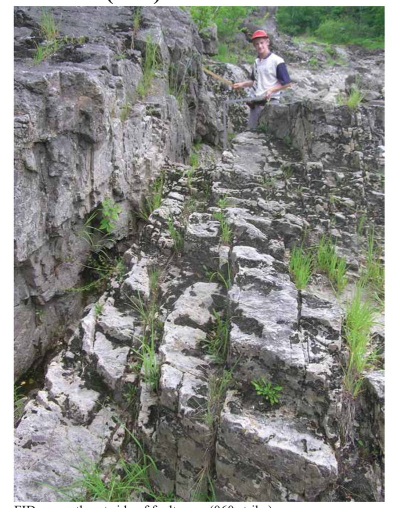
In the field area (purple polygon), the steepest slopes (orange and red) trend ~060 degrees, parallel to the fault. Contours are 0.5' (0.15 m) intervals.

Figure 9A- Drone Photomosaic with Lineaments



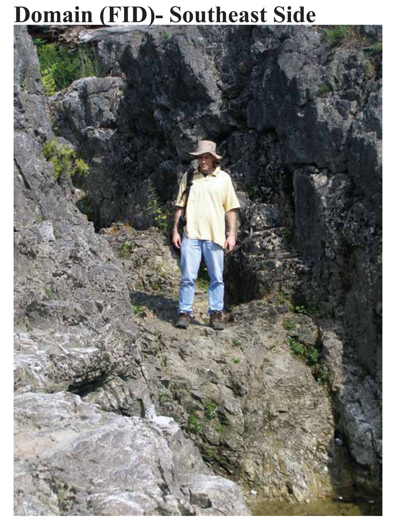
This photomosaic was constructed in GIS from multiple photos shot by the drone from an altitude of 41 m (135'). Photolineaments were digitized onto the mosaic using ArcMap software.

Figure 9B- Fracture Intensification Domain (FID)- Northwest Side



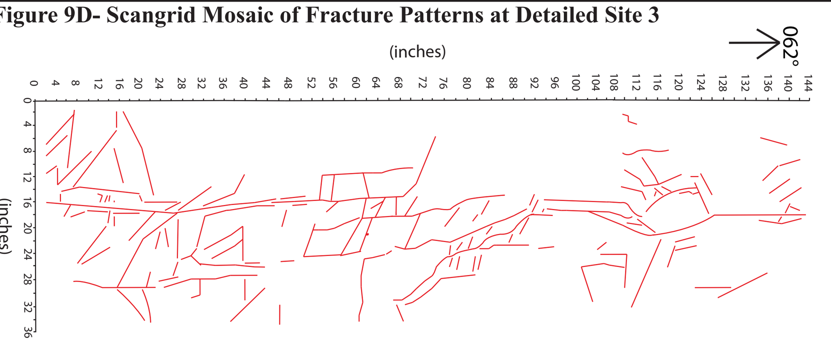
FID on southeast side of fault zone (060 strike).

Figure 9C- Fracture Intensification Domain (FID)- Southeast Side

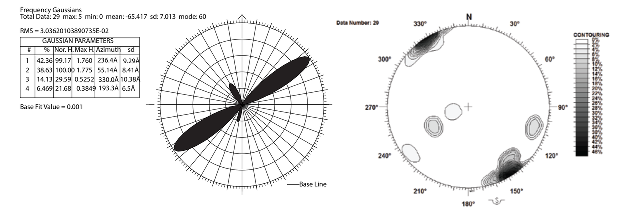


FID on southeast side of fault zone (060 strike). Subhorizontal slickensides found on vertical outcrop wall to the right.

Figure 9D- Scangrid Mosaic of Fracture Patterns at Detailed Site 3

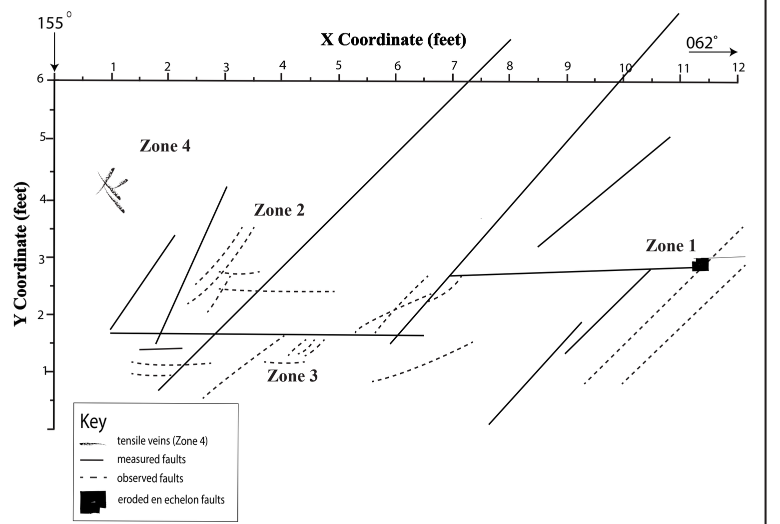


Using a series of four adjacent scangrids (a 3' square composed of stainless-steel rulers), which were photographed, undistorted in Adobe Photoshop, and assembled in Adobe Illustrator, we were able to characterize the fracture network at the outcrop scale in detail in the southwestern part of the field area. The pattern seen at this scale is generally similar to that of the whole field area. Technique adopted from R.D. Jacobi.



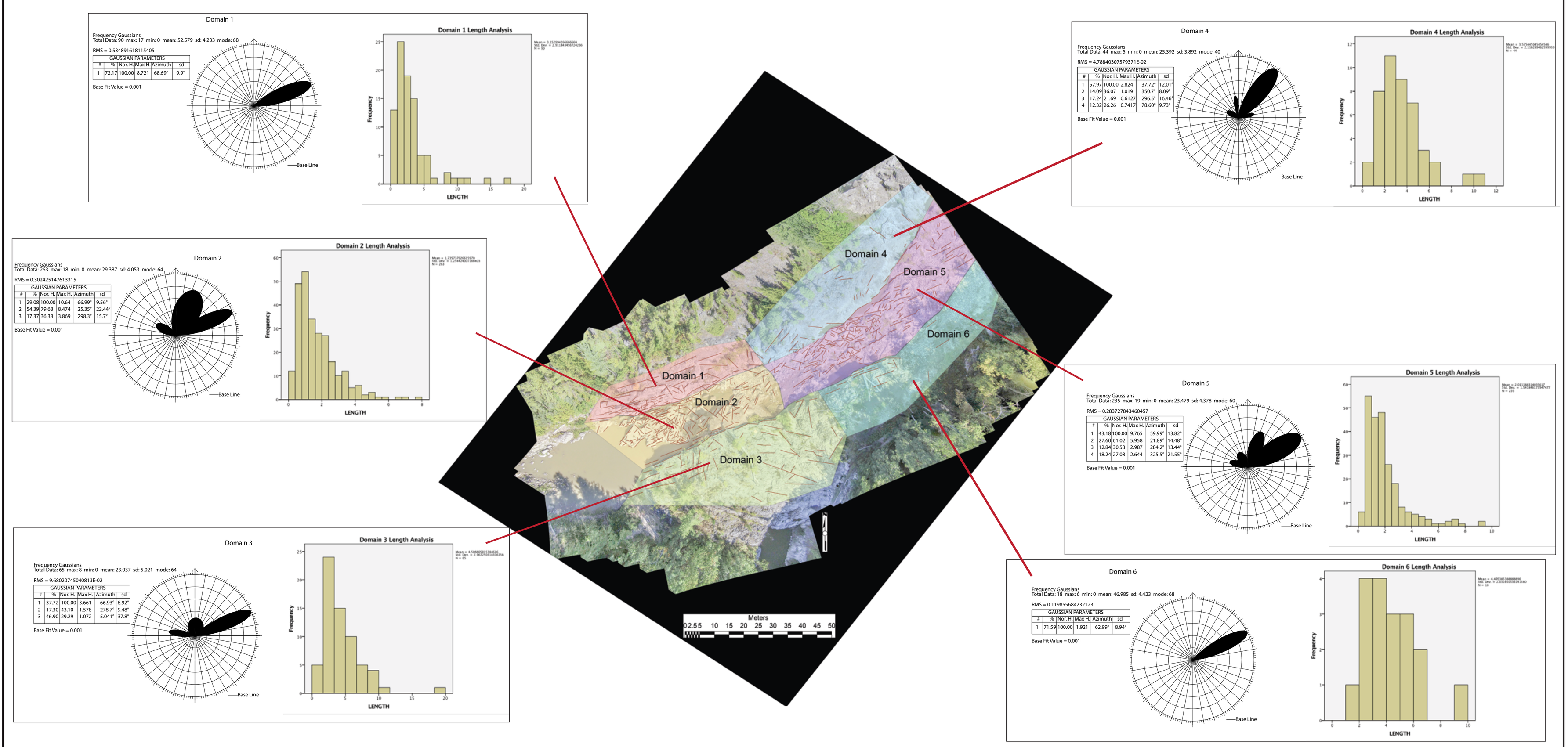
The fractures that were measured in the scangrid mosaic dominantly strike 055/236 and dip steeply, parallel to the fault zone. Subordinate sets strike to the northwest (330) and southwest (193) and also dip steeply.

Figure 9E- Orthogonal Scanlines Show Fracture Patterns at Detailed Site 2



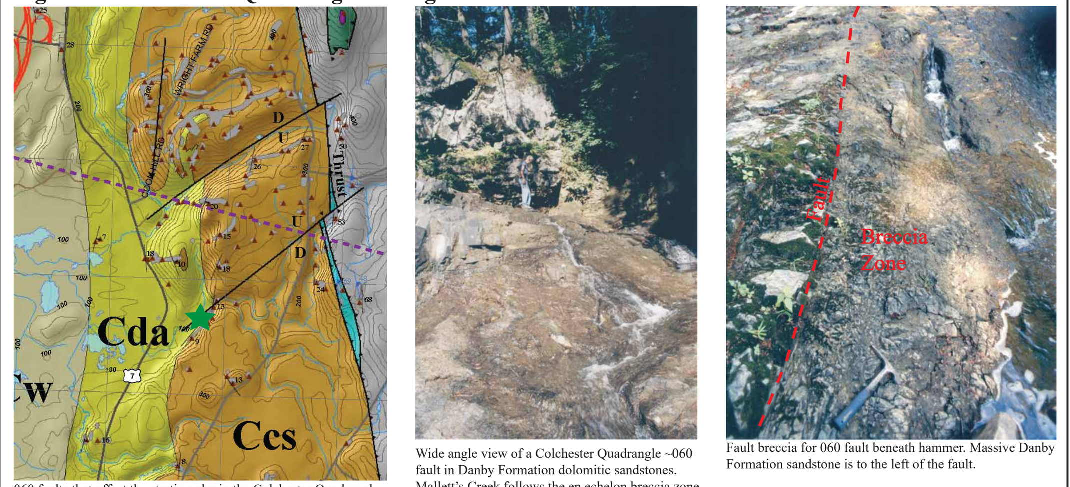
The configuration of faults and veins in this small part of of the field area indicates left-lateral motion. Veins in Zone 4 are the youngest of the four zones, and are extensional. Areas between en echelon faults have been eroded by the Winooski River.

Figure 10- Statistical Analysis of Lineaments



The field area was subdivided into six domains which were created using the shape of the fault zone to define the boundaries. Domain 1 features lineaments oriented 069 with a mean length of 3.15m. Domain 2 comprises part of the main fault zone and contains three populations of lineaments oriented at 067, 025, and 298 with a mean length of 1.74m. Domain 3 features three populations of lineaments oriented at 067, 279, 005 with a mean length of 4.51m. Domain 4 contains four populations of lineaments with orientations of 038, 351, 297, and 079. These lineaments have a mean length of 3.58. Domain 5 comprises the other section of the main fault zone and contains four populations of lineaments oriented at 060, 022, 284, and 326, with a mean length of 2.01m. Domain 6 features lineaments oriented at 063 with a mean length of 4.48m. Domains 1 and 6 exhibit the same lineament orientations. Domains 2, 5 and 3 contain lineaments with a similar trend. Domain 4 is unique because 038 is the dominant orientation and 060 lineaments are absent. The domains can be paired based on similarities in mean length: (1, 4), (2,5), and (3, 6). The length of the lineaments appear constant across a horizontal transect. The inner domains representative of the main fault zone exhibit shorter lineaments compared to the surrounding domains. The dominant lineament population in all the domains is ~060 with ~020s being the subordinate lineament orientation; the northwest-oriented lineaments fall within one standard deviation and can be expressed as one population around 295.

Figure 11 - Colchester Quadrangle Analogue

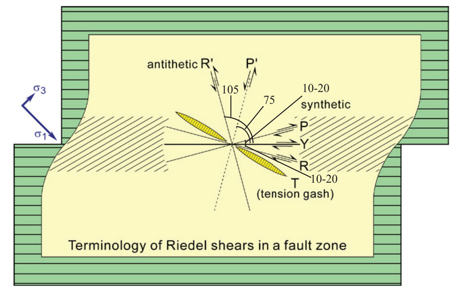


060 faults that offset the stratigraphy in the Colchester Quadrangle. The green star shows the location of the photos to the right (Mallett's Creek Fault).

Wide angle view of a Colchester Quadrangle ~060 fault in Danby Formation dolomitic sandstones. Mallett's Creek follows the en echelon breccia zone.

Fault breccia for 060 fault beneath hammer. Massive Danby Formation sandstone is to the left of the fault.

Figure 12- Where Does This Fit?



The Riedel shear model applies to fractures that are coeval and propagate out of a strike-slip fault zone. This model illustrates the fault pattern and the possibility of up to five directional familes of associated fractures. The main fault zone exhibits an orientation of 060 (Y). Using the Riedel shear model, we would expect to find fractures orientated 075 (R), 045 (P), 345 (P'), and 315 (R'). These features of the Riedel model do not account for the prevelance of 060 and 020 fractures in the field area. Although some of the orientations are present at the Winooski Spillway, they are not the dominant orientations and are not prevelant through all domains. This model cannot be used to explain the features present at the Winooski Spillway.

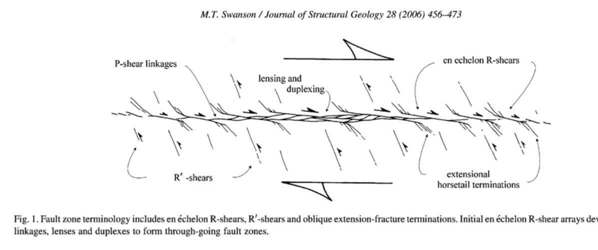


Fig. 1. Fault zone terminology includes en échelon R-shears, R′-shears and oblique extension-fracture terminations. Initial en échelon R-shear arrays develop P-shear linkages, lenses and duplexes to form through-going fault zones.

The Swanson model is used to describe strike-slip faults segmented by en echelon shear fractures and step-over zones. These zones deform to accommodate displacement and eventual linkage to a through-going fault zone. The geometry of the step-over zones and linkage faults control the syle of fault zone deformation. Relative to the fault zone at the Winooski Spillway, this model predicts R' shears with an orientation of 315 and R shears at 075. This model also predicts eventual P shear linkage with lensing and duplexing occuring. These features are not present at the Winooski Spillway and demonstrate that these two models do not apply.

References:

1. Kim, Jonathan and Thompson, Peter J., 2001, Bedrock Geology of the Colchester Quadrangle, Vermont: VGS Open-File Report VG01-1, 4 plates, scale 1;24,000

2. 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

3. Strike-slip Faulting, https://www.researchgate.net/file.PostFileLoader.html?id=5583ea375e9d97a6848b45d6&assetKey=AS%3A273798413127682%401442290036640

4. Swanson, 2006, Late Paleozoic Strike-Slip Faults and Related Vein Arrays of Cape Elizabeth, Maine, Journal of Structural Geology 28 456-473, 2006 Elsevier Ltd

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Citation:
Remington, C., Kim, J.J., Klepeis, K., and Van Hoesen, 2017, Using Drone Surveys to Interpret the Geometry and Kinematics of a Mesozoic Fault Zone in Dolostones of the Champlain Valley Belt of West-Central Vermont II: Vermont Geological Survey Technical Report VGTR2017-1.