A Semi-automated Method for Rapid, Bulk Fault Displacement Analysis

Franklin D. Wolfe[1], Timothy A. Stahl[2], Pilar Villamor[3], Biljana Lukovic[3]

[1]Harvard University, Cambridge, MA, USA; [2]University of Canterbury, Christchurch, NZ; [3]GNS Science, Lower Hutt, NZ

Contact: wolfe_franklin@g.harvard.edu

Abstract

LiDAR airborne laser swath mapping and graphical user interfaces (GUIs) can facilitate rapid characterization of submeter-scale geomorphic features. Here, we introduce an open source, semi-automated, Python-based GUI for measuring fault slip on individual or bulk fault datasets. When employing this method, the user first defines profiles across fault scarps imaged in high-resolution digital elevation models, and then *interactively* identifies the relevant fault components [e.g., footwall, hanging wall, and scarp]. Displacement statistics are calculated automatically (following Monte Carlo simulation methodology of Thompson et al., 2002) and can be conveniently visualized in GIS for spatial analysis. Fault slip rates also can be calculated when ages of footwall and hanging wall surfaces are known, allowing for temporal analysis. In preliminary investigations of the Central Taupo Volcanic Zone (TVZ), New Zealand, this method reveals spatial and temporal patterns of fault displacement and strain – both along strike of major fault systems and across the TVZ – and suggests northwest-southeast extension rates that are consistent with published estimates from geodetic, topographic, and field studies (Hamling et al., 2015; Villamor and Berryman, 2001). It has also been used to define a horizontal extension rate for the Drum Mountain Fault Zone, which may provide key insights into low-angle normal faulting, eastern Basin and Range Extension, and the Sevier Desert Detachment. This method improves upon similar studies because it allows for rapid analysis of tens to hundreds of faults simultaneously within GIS, and anomalous values can quickly be identified and interrogated. Application of this method may contribute to a wide range of regional and local paleoseismic studies with adequate high-resolution DEM coverage, both regional fault source characterization for seismic hazard and/or estimating geologic slip and strain rates.

① Motivation

Fault zones in some extensional regimes can be extraordinarily complex and require a method for systematically estimating net slip and/or slip rates across them. Currently, the way we do this is by analyzing individual profiles across fault scarps, manually picking fault components on distance vs. elevation plots (e.g., in Excel), exporting statistics and regressions individually to Matlab, and then running unique analyses for each profile, which is very tedious and time consuming. This new tool streamlines and improves on this process by introducing a new Python-based GUI for rapidly estimating fault slip statistics over numerous profiles at once.

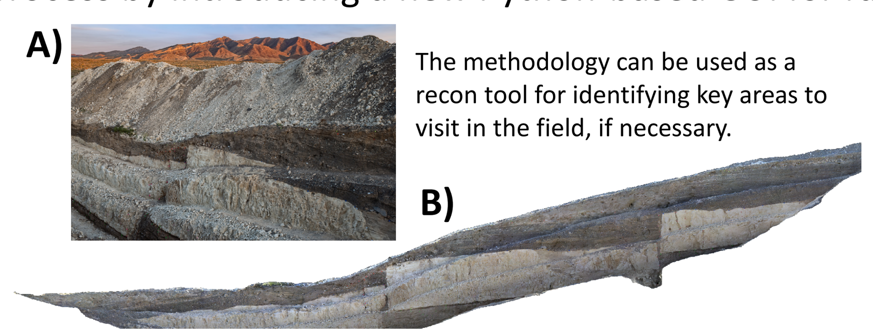
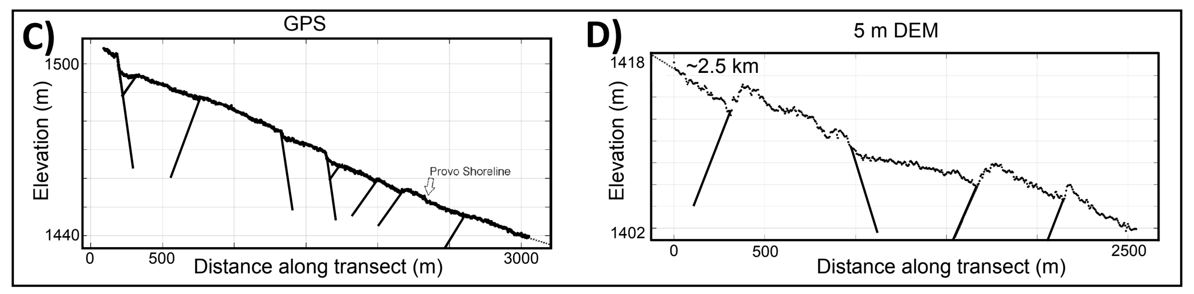


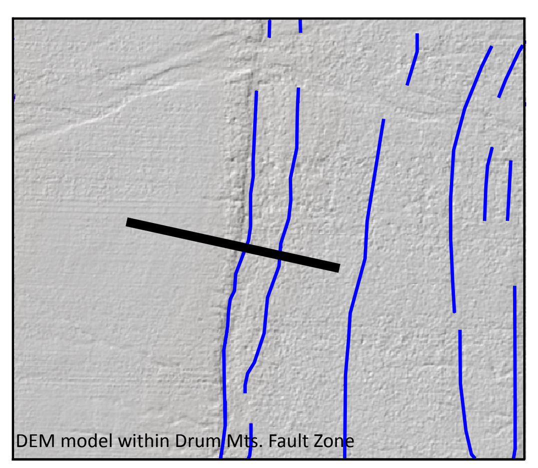
Image (A) and 3D model (B) of Drum Mts. paleoseismic trench. These provided inputs to the algorithm for the Drum Mts., such as fault dip distributions and stratigraphic ages (photo credit: Gregg Beukelman of Utah Geological Survey)



When LIDAR data (D) has adequate resolution, it can be used to identify <5 meter geomorphic features from a workstation. When necessary, higher resolution data can be collected in the field, such as RTK-GPS elevation point data (C). These are two examples of transects used within the Drum Mts. study.

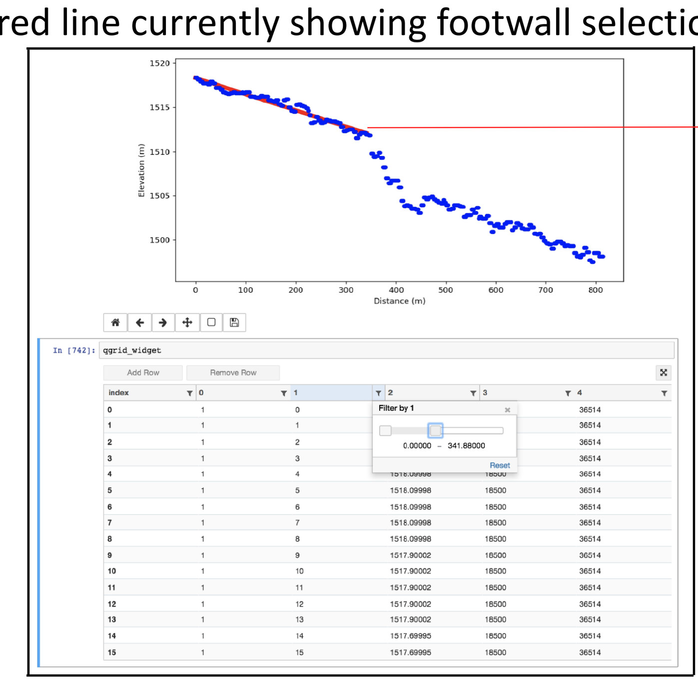
② User Interface

Step 1. Define profile across fault scarp imaged in digital elevation data and represented in GIS software.

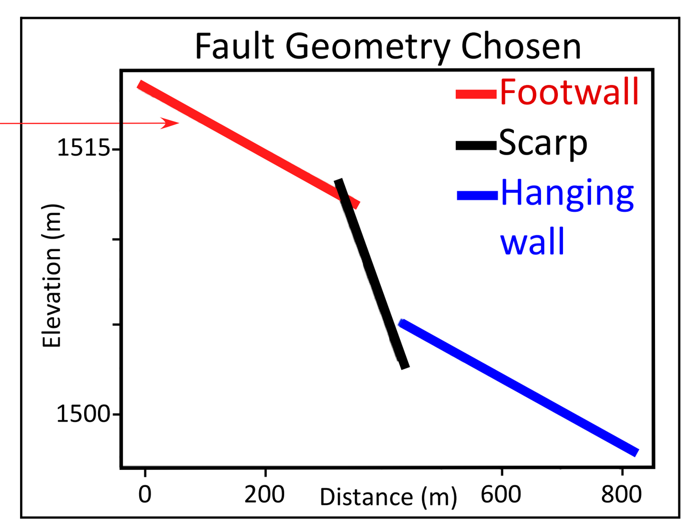


Step 2. Use Python script to extract elevation and distance data along transect. If geologic map is available, ages can also be extracted.

Step 3. Fit regression lines to data points (blue dots) with dataframe 'sliders' to represent fault components (hanging wall, footwall, and scarp; red line currently showing footwall selection)



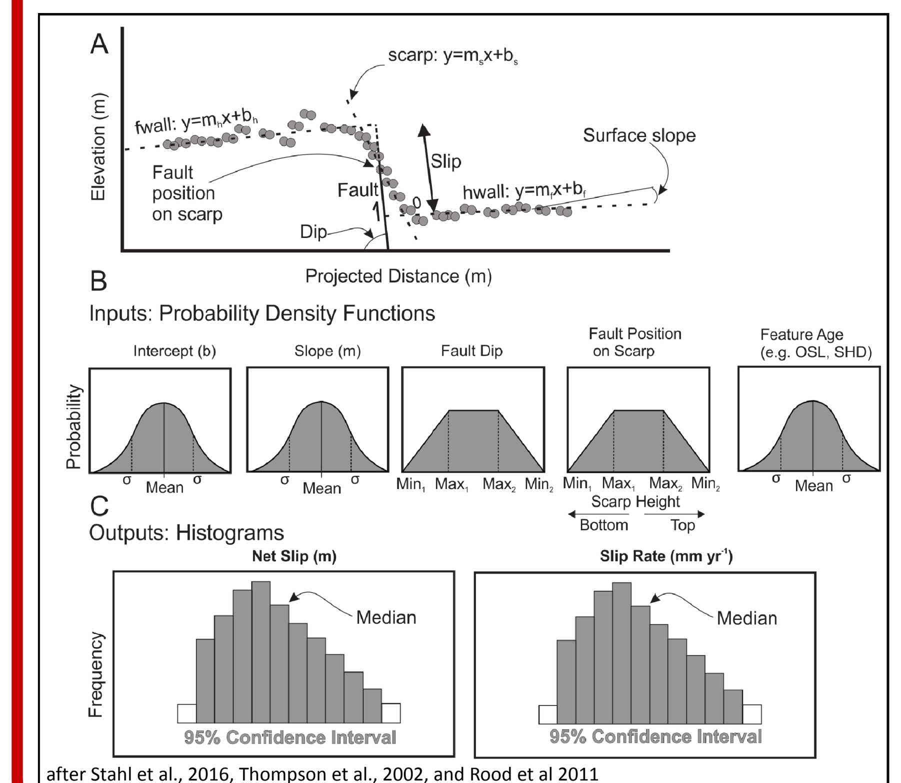
Step 4. Your selections can quickly be checked for accuracy and be updated, if necessary through repeating step 3 until a satisfactory solution is obtained.



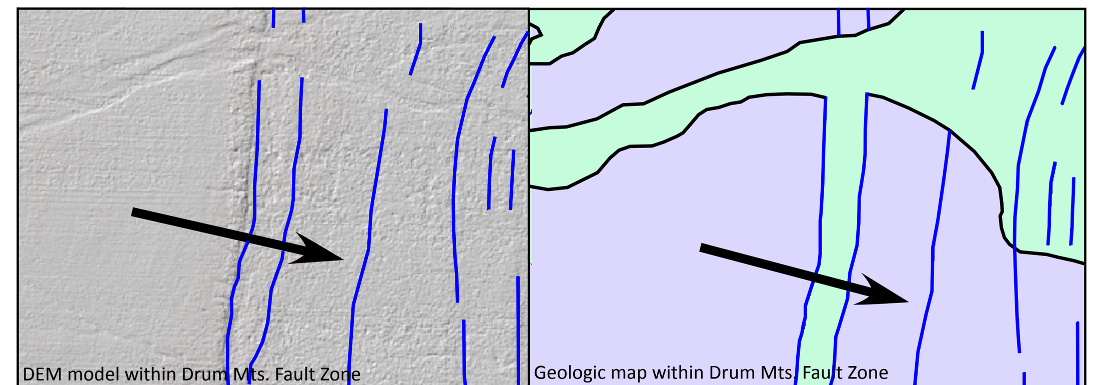
Step 5. When ready, your data will be exported into a new csv format to be read and analyzed by the Matlab script.

③ Algorithm and Outputs

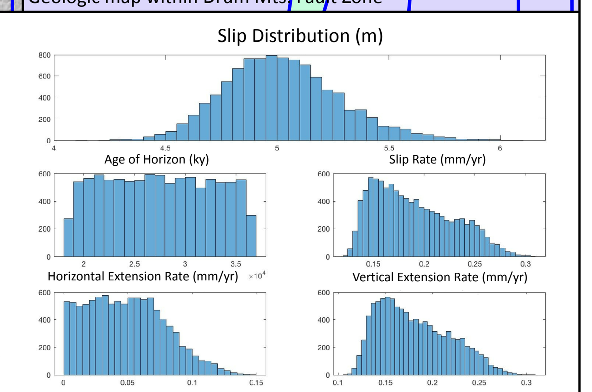
Step 6. Calculate slip statistics. Multiple transects and faults can be analyzed at once, as well as uncertainties in input parameters.



Step 7. Python script will attach slip statistics to original GIS shapefiles for display, including directions of slip vectors normal to fault line segment (assumes perfect dip slip). Script outputs csv table for each transect.

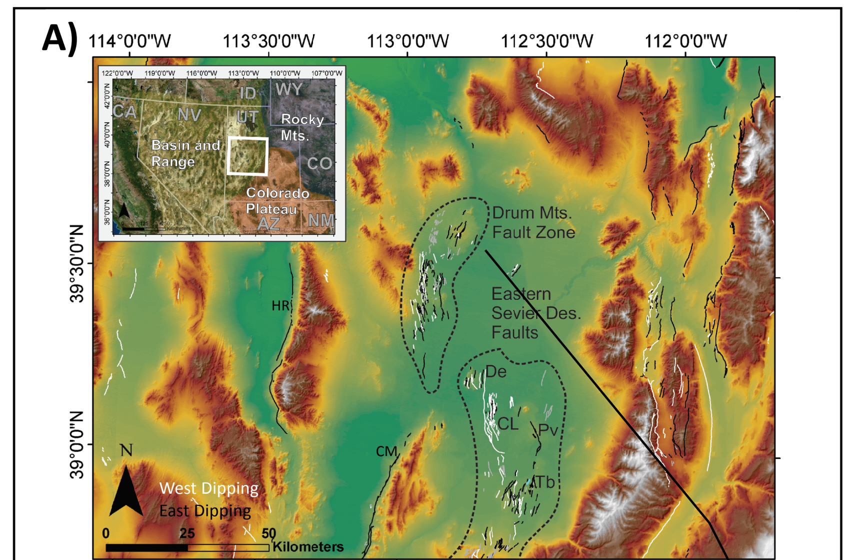


Individual Fault Statistics
Slip Mean: 5.02 m
Slip Rate Mean: 0.19 mm/yr
Horizontal Extension Rate: 0.05 mm/yr
Vertical Movement: 4.98 m
Age of Horizon: 18.5-36.5 ka

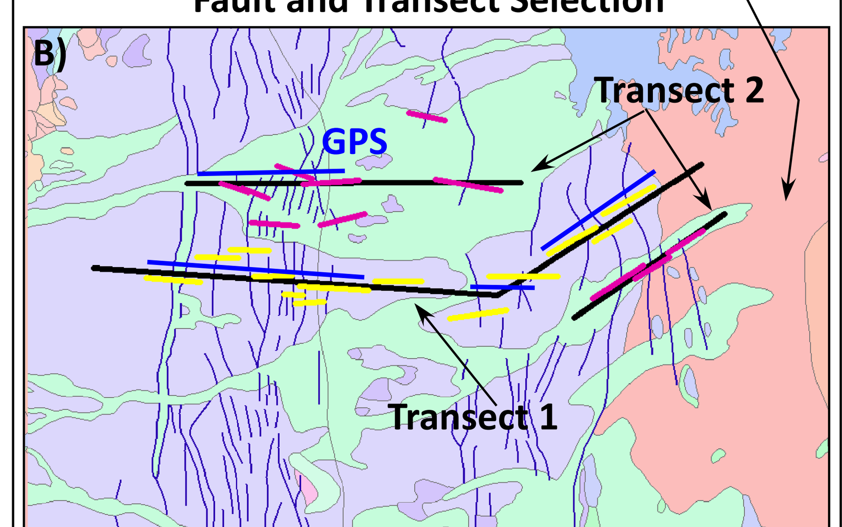


④ Case 1: Drum Mts. Fault Zone, Utah

1. What is the extension rate across the Drum Mts. Fault Zone and can we determine a time-varying displacement history?

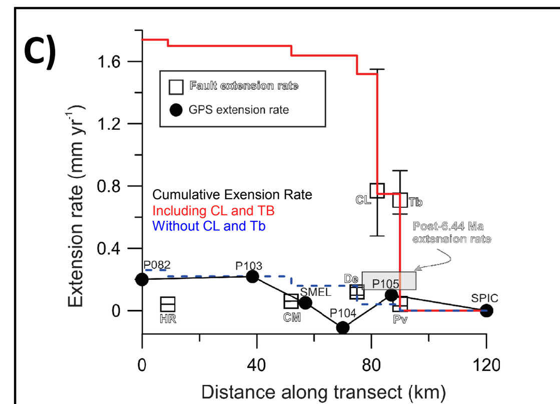


Fault and Transect Selection

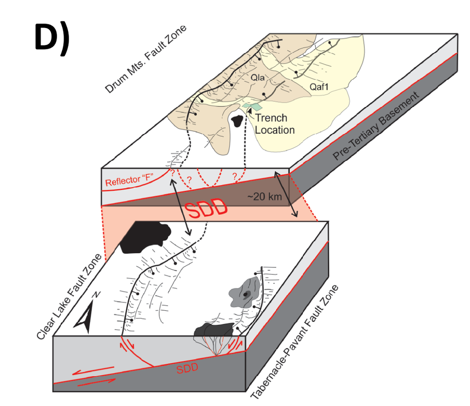


A) Overview map of central Utah tectonics, including the Drum Mts. Fault Zone (Stahl et al.; *in prep*). B) GIS interface showing transects, geologic map, GPS-RTK profiles, and faults used in analysis. Base layer is a simplified geologic map based on Hintze and Davis, 2002).

Extension Across the Sevier Desert



Simplified 3D Model



C) Geologic, paleoseismic, and GPS derived extension rates in the Sevier Desert, excluding the Drum Mts. D) Schematic 3D section of the study area, showing geomorphology, potential relation to deeper structures, and locations of trench sites (Stahl et al.; *in prep*)

	Transect 1	Transect 2
Age of Surface[1]:	18.5-36.5 ka	3.49-18.0 ka
Number of Faults:	13	11
Length of Transect:	9.7 km	7.7 km
Cumulative Slip Rate:	1.16-1.80 mm/yr	1.46-1.55 mm/yr
Horizontal Extension Rate:	0.29-0.49 mm/yr	0.37-0.40 mm/yr
Total Vertical Component:	25-45 m	5-26 m

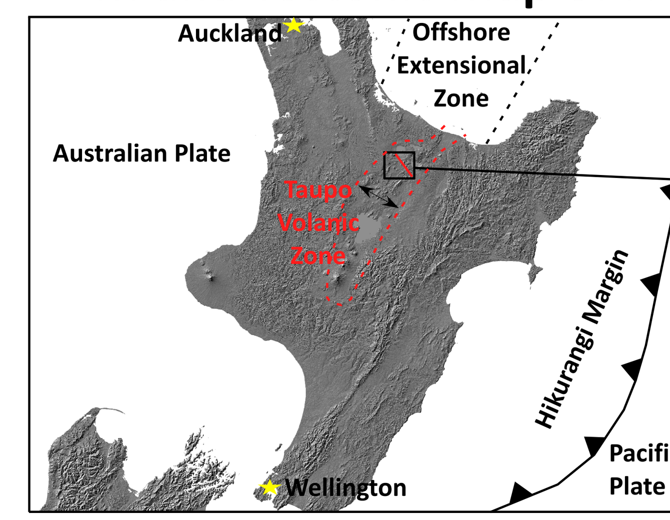
[1]Ages are constrained based on Optically Stimulated Luminescence (OSL) dating and Bonnevile chronology (14C)

Full analysis of both transects and >30 faults required less than 5 hours of work!

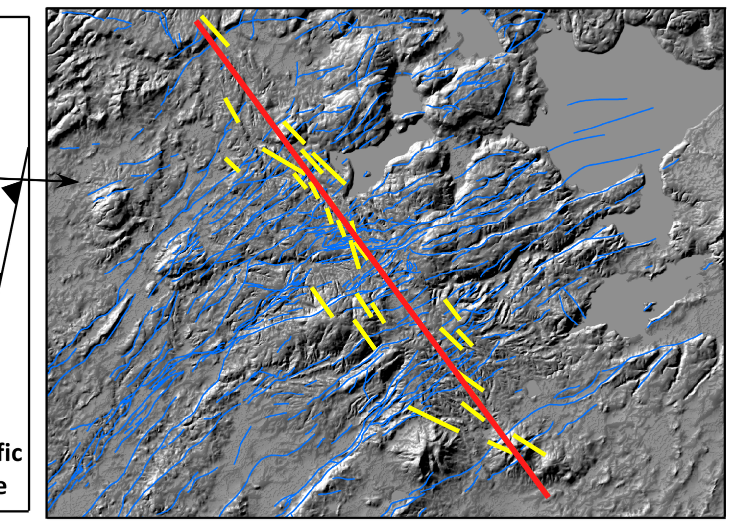
⑤ Case 2: Taupo Volcanic Zone, NZ

What is the horizontal extension rate across the TVZ?

A) DEM and Tectonic Map of NZ



B) Fault and Transect Selection



A/B) Lidar hillshade maps of the North Island and Taupo Volcanic Zone, New Zealand. A) Contains tectonic features of NZ and B) contains the fault profiles and transect used for this analysis. Faults shown in blue.

Number of Faults	26	**Cumulative Slip Rate**	5.5-5.6 mm/yr
Length of Transect	23.5 km	**Horizontal Extension Rate**	1.8-1.9 mm/yr

Compatible with current best estimate of extension of 1.9 mm/yr (1.2-2.8 mm/yr) (Villamor & Berryman, 2001)[1].

There were less than 3 hours spent on this transect at a work station!

[1]Obtained from topographic maps, altimeter measurements taken in the field along transects, and detailed logging of fault exposures in exploratory trenches.

⑥ Conclusions

1. Numerous faults can be interrogated rapidly at a workstation with through an easy-to-learn methodology.
2. Initial slip statistic results provide new insights in the Drum Mountains Fault Zone, Utah and corroborate previous findings in the Taupo Volcanic Zone, NZ.

⑦ Future Work/Code

1. Drum Mts. Fault Zone - Provide insights into Sevier Detachment geometry and slip history and place these findings in context of regional extension.
2. TVZ - Investigate spatial and temporal variations in extension rate.
3. Conduct analysis in contractional setting.
4. Contact Franklin Wolfe for codes or see Github Repository: https://github.com/wolfefranklin/mc_fault_slip_codes

References

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