A semi-automated method for rapid fault slip analysis from topographic scarp profiles

User manual

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Overview

Wolfe et al. (2019) introduces an open source, semi-automated, Python-based graphical user interface (GUI) called the Monte Carlo Slip Statistics Toolkit (MCSST) for estimating dip slip on individual or bulk fault datasets. Using this toolkit, profiles are defined across fault scarps in high-resolution digital elevation models (DEMs) and then relevant fault scarp components are interactively identified (e.g., footwall, hanging wall, and scarp). We reference hanging wall and footwall throughout because this code was developed for use in a rift setting; however, upthrown and downthrown are equally viable terms considering the underlying math should be consistent for reverse faults as well.

Displacement statistics are calculated automatically using Monte Carlo simulation (Thompson et al., 2002) and can be conveniently visualized in Geographic Information Systems (GIS) for spatial analysis. Fault slip rates can also be calculated when ages of footwall and hanging wall surfaces are known, allowing for temporal analysis. This method allows for rapid analysis of tens to hundreds of faults in rapid succession within GIS and a Python coding environment. Application of this method may contribute to a wide range of regional and local earthquake geology studies with adequate high-resolution DEM coverage, both regional fault source characterization for seismic hazard and/or estimating geologic slip and strain rates, including creating long-term deformation maps. An ArcGIS version of these functions are available, as well ones that utilize free, open source Quantum GIS (QGIS) and Jupyter Notebook Python software.

This manual provides step by step directions for implementing the workflow. Whether using a QGIS or ArcGIS interphase, instructions are provided on how to extract data from profiles drawn across fault scarps imaged in high resolution digital elevation data. Next, instructions on how to implement the MCSST to rapidly calculate slip statistics for the faults in question. Lastly, instructions are provided on how to visualize the results in the QGIS and ArcGIS interphases.

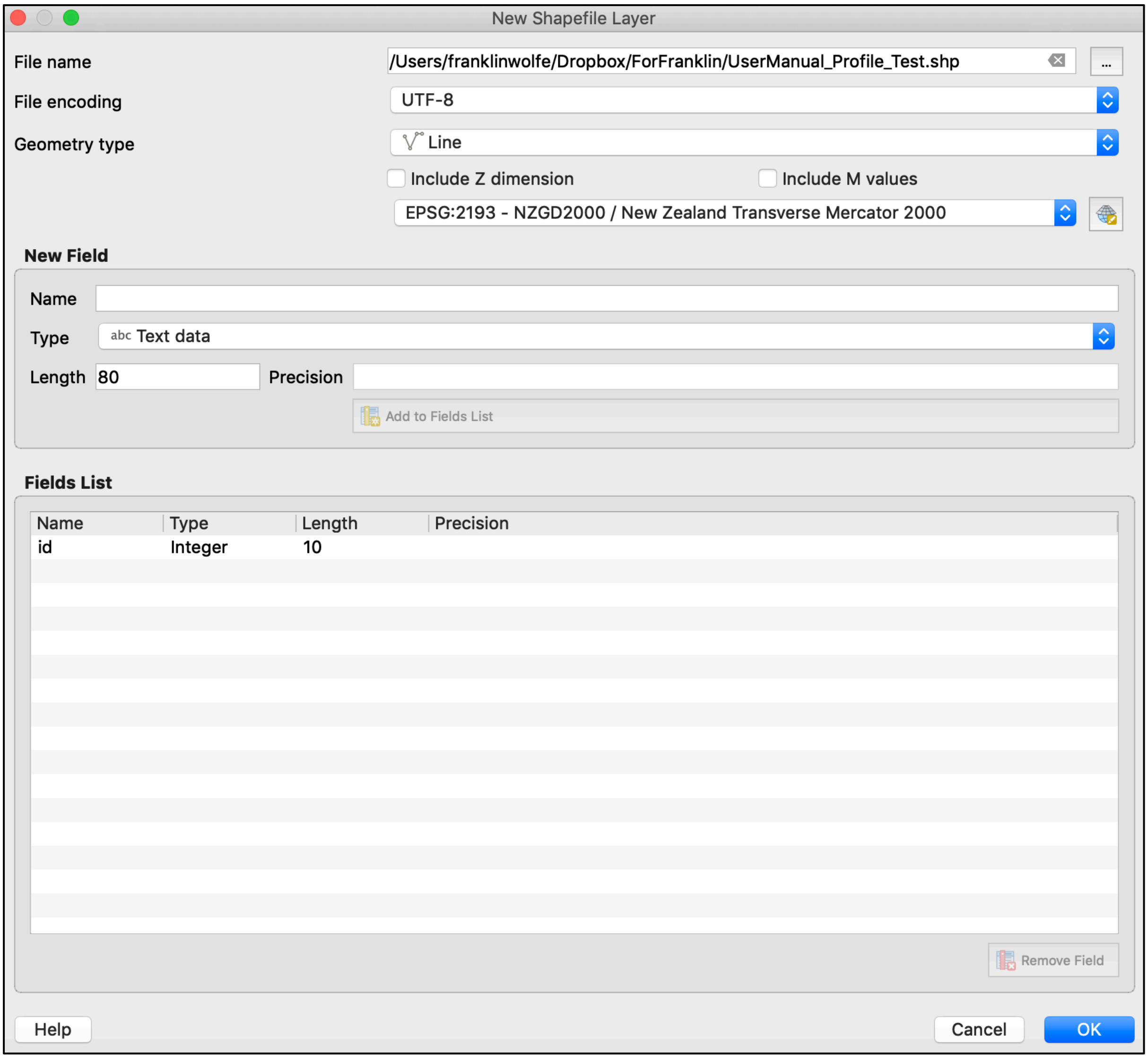
All of these scripts and notebooks are available for download at the GitHub repository. The scripts were developed in Python 2.7.13 (to be compatible with ArcGIS). ArcGIS v 10.5.1 was used for testing but it might work in other 10 versions

Profile Selection

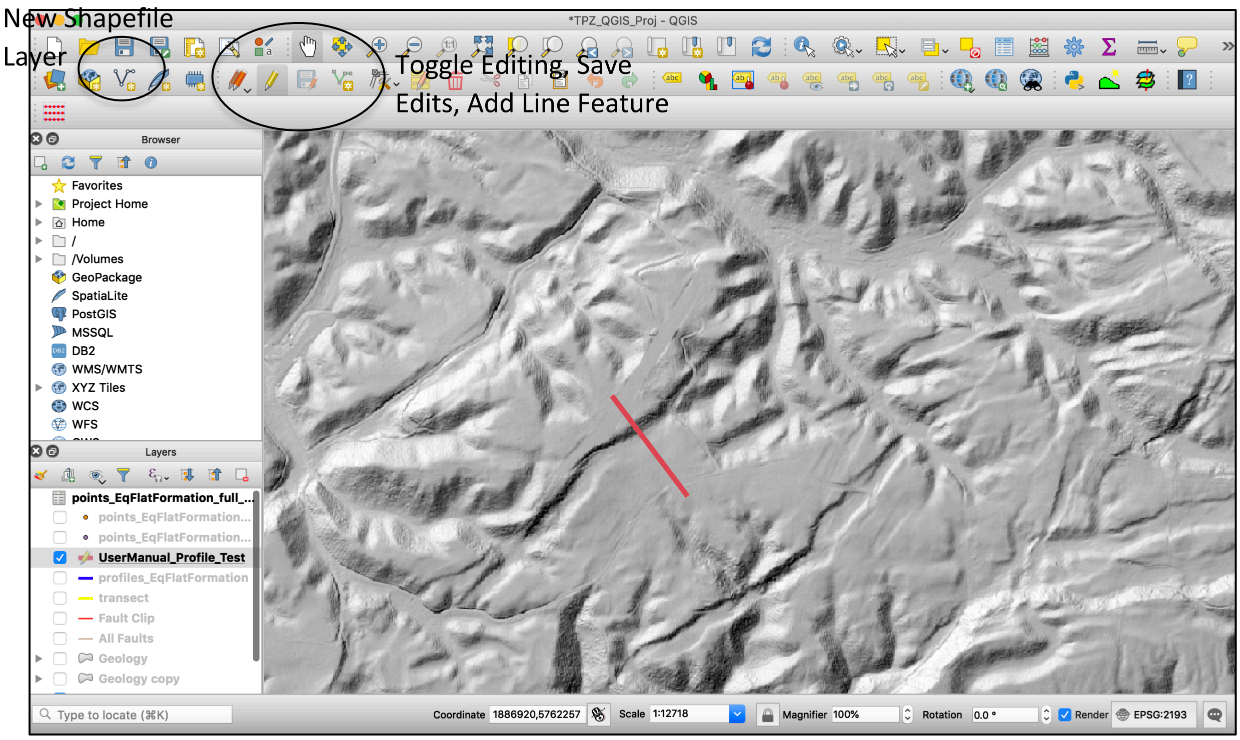
The first step is to define profiles across fault scarps imaged in digital elevation data.

A) QGIS

- Create a new Shapefile Layer
  - Layer -> Create Layer -> New Shapefile Layer
  - Geometry Type -> Line

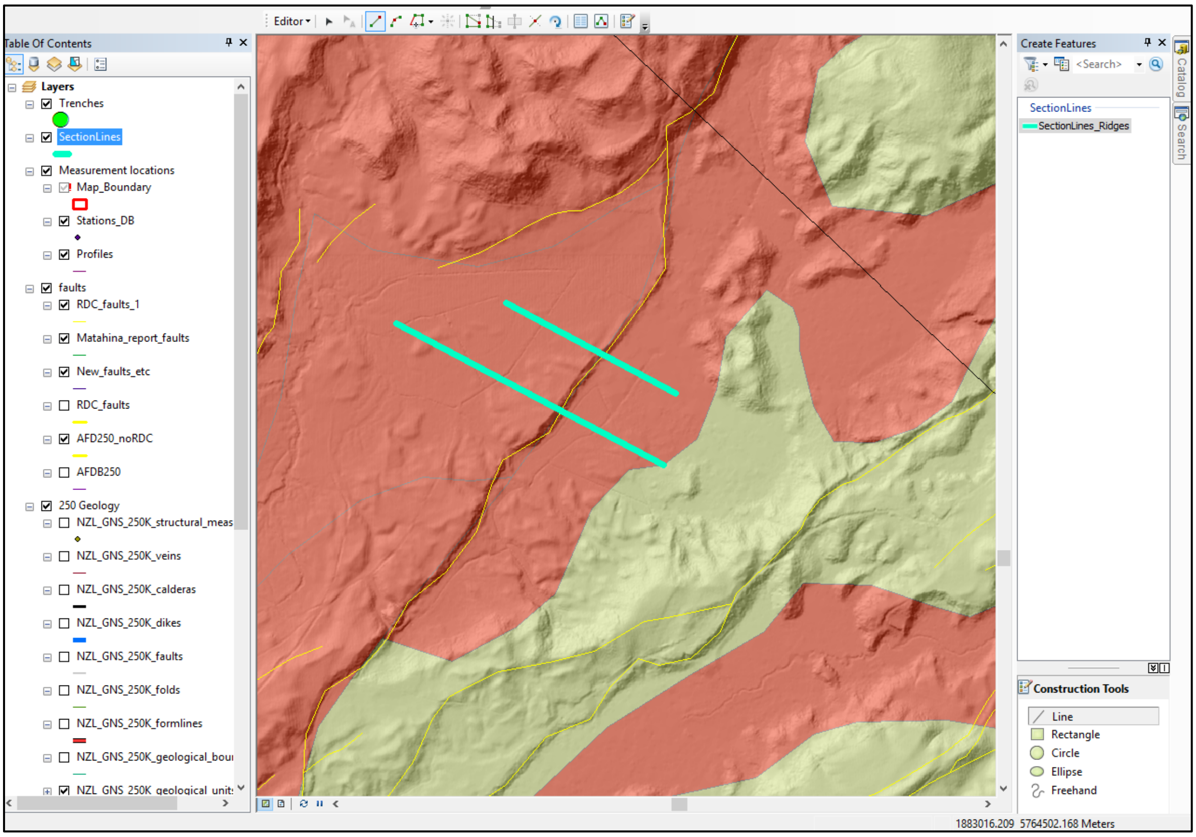


- The newly-created Shapefile layer show up in the Layers inventory.
- To draw a profile and assign it to this layer, Toggle Editing on this layer.
  - Add Line Feature to draw your profile. Both Toggle Editing and Add Line Feature can be found in the banner of icons at the top of the program (see image below).
  - You may want to edit the Style of the lines so that they will have greater visibility.
- Next, Save Layer Edits to permanently create your profile lines within the Shapefile layer.



B) ArcGIS

- Click on the Catalogue tab
  - Navigate to a folder where you would like to store your files
  - Right click and select New File Geodatabase
  - Right click on the newly created File Geodatabase and select New Feature Class
    - Give Name
    - Type: Line Features
    - Pick Coordinate System
- Within the Table of Contents and Layers panel:
  - Right click on your new Line Feature Class
    - Select Edit features then start editing. Click continue on prompt of ‘warnings’.
    - Display the Editor Tool Bar from Customize -> Toolbars -> Editor
    - Click the Create Features Icon
    - Click on your new Line Feature Class in menu to the right
    - In Construction Tools below, click Line
    - Draw line and double click to finish
    - When you are finished digitizing your new profiles, select Editor (drop down feature from Editor Toolbar), Save Edits, Stop Editing.



- The Section Line Feature Class must have a "id" field. This is a field that may need to be added manually to the attribute table. To do this, open the attribute table, add field titled "id", and then run an operator on the new "id" field to populate this field with the values of the "ObjectID" field. The operator tool is called the "Field Calculator" tool. You will see that when you open this tool, a blank dialogue box appears. You also see the beginning of a calculation right above. Fill in the rest of the calculation as "= ObjectID". Next hit OK. You will only be able to undo your edits if you are in an edit session, so to be cautious, do this before you "stop editing".

Profile Data Extraction

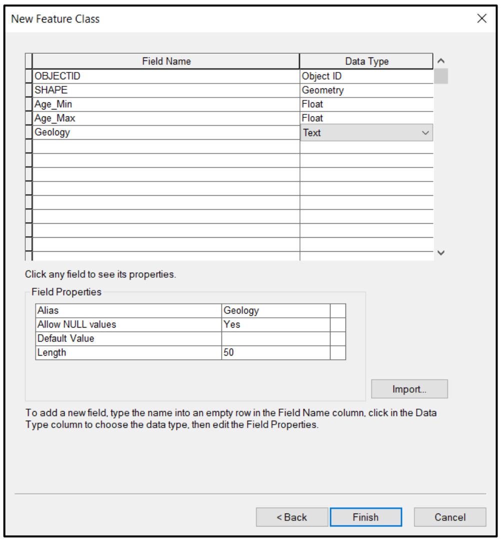
Once you have defined your profiles, the next step is to generate data along the profile. Plug-ins for ArcGIS and QGIS can be utilized for this process.

If you do not have geologic data (e.g., age, formation name, etc.) you will need to quickly generate this data by following this workaround for ArcGIS and QGIS.

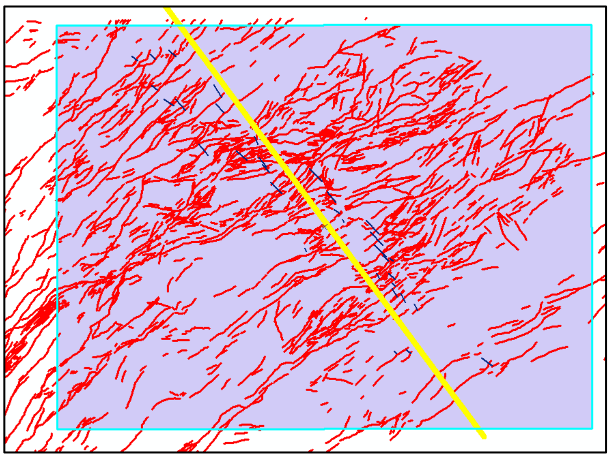
A) ArcGIS

The goal of this workflow is to create a new polygon feature class to contain user-generated geologic data so that the toolbox will function in the following step to extract data.

- Create a new polygon feature class
  - Navigate to the ArcGIS Catalog
  - Right click on a geodatabase
  - Generate a new Polygon Feature Class
  - Include new fields for age and geology as is shown in image below

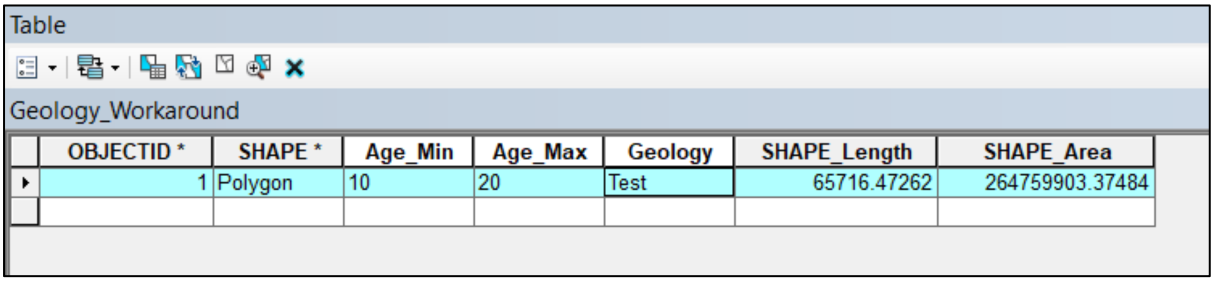


  - Right click on the new Feature class and choose Start Editing
  - Create a polygon feature that encompasses the entire study area.



  - Create a polygon feature that encompasses the entire study area.

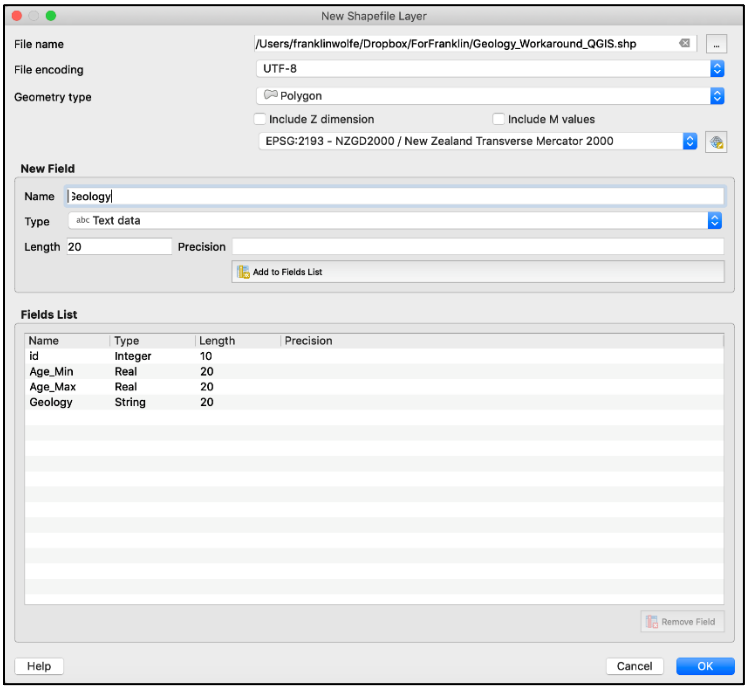
- Manually input data into the Attribute Table



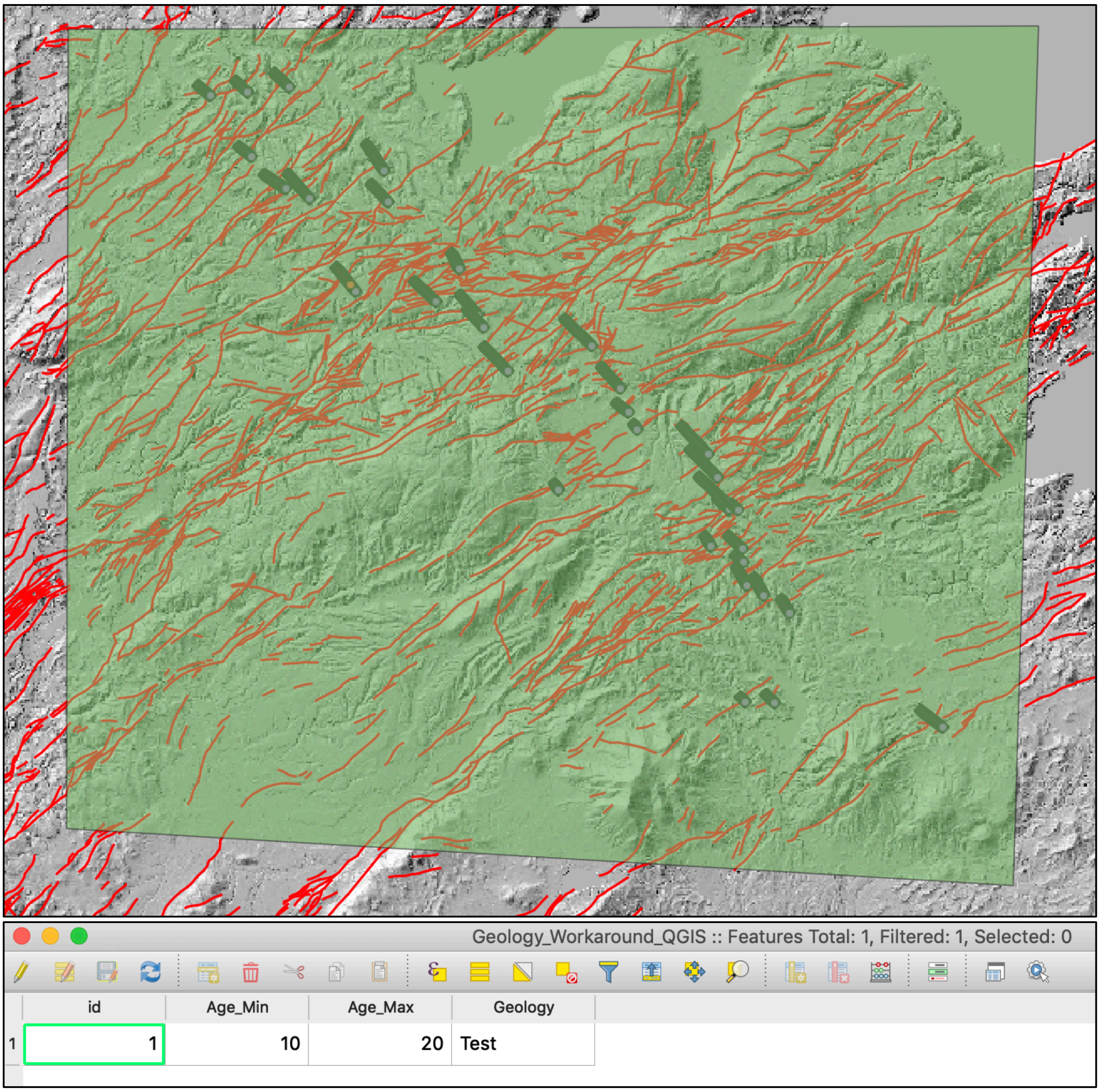
- Save Edits and Stop Editing

B) QGIS

- Create a new polygon Shapefile Layer
- Add new fields for age and geology



- Toggle Editing
- Draw new Polygon Feature encompassing entire study site and input information for age and geology when prompted.
- Toggle Editing to Save Edits



Extracting Data

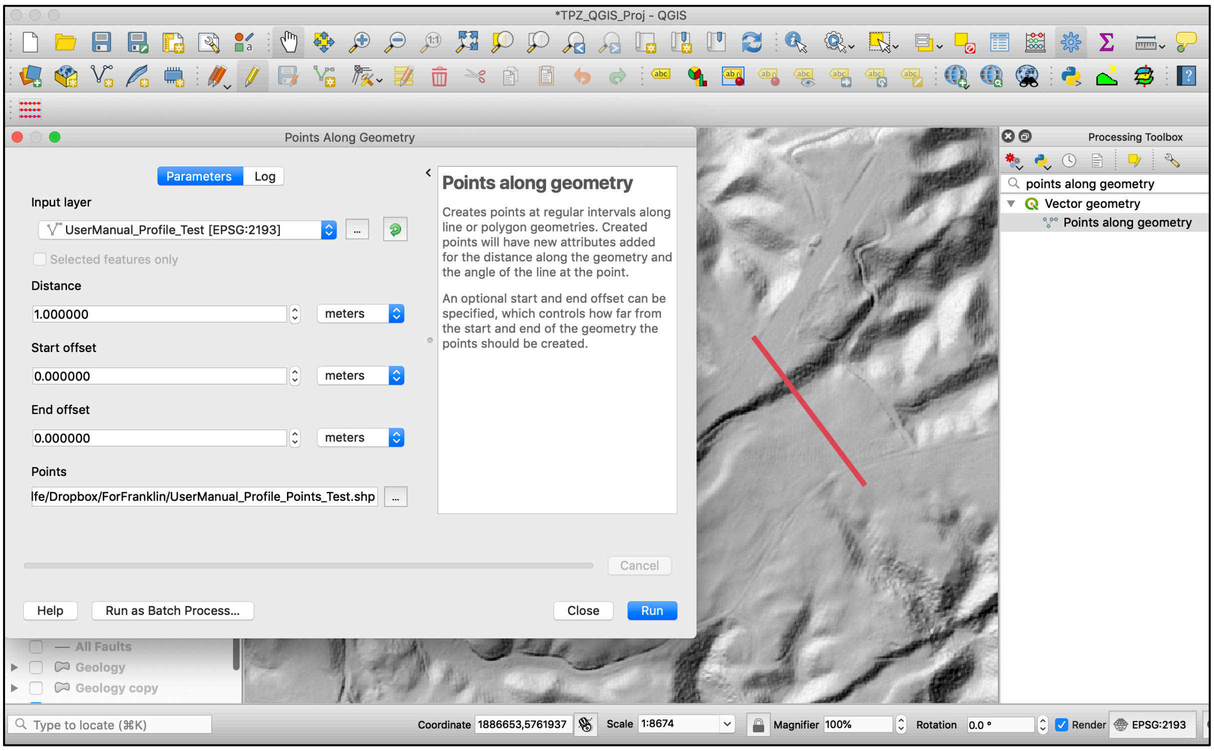
C) QGIS

Previously compiled GUIs can be employed to extract distance, elevation, and geologic age data along the fault profiles at variable spacing. The user will employ the Points Along Geometry and Point Sampling Tool plugins, which are within the QGIS environment.

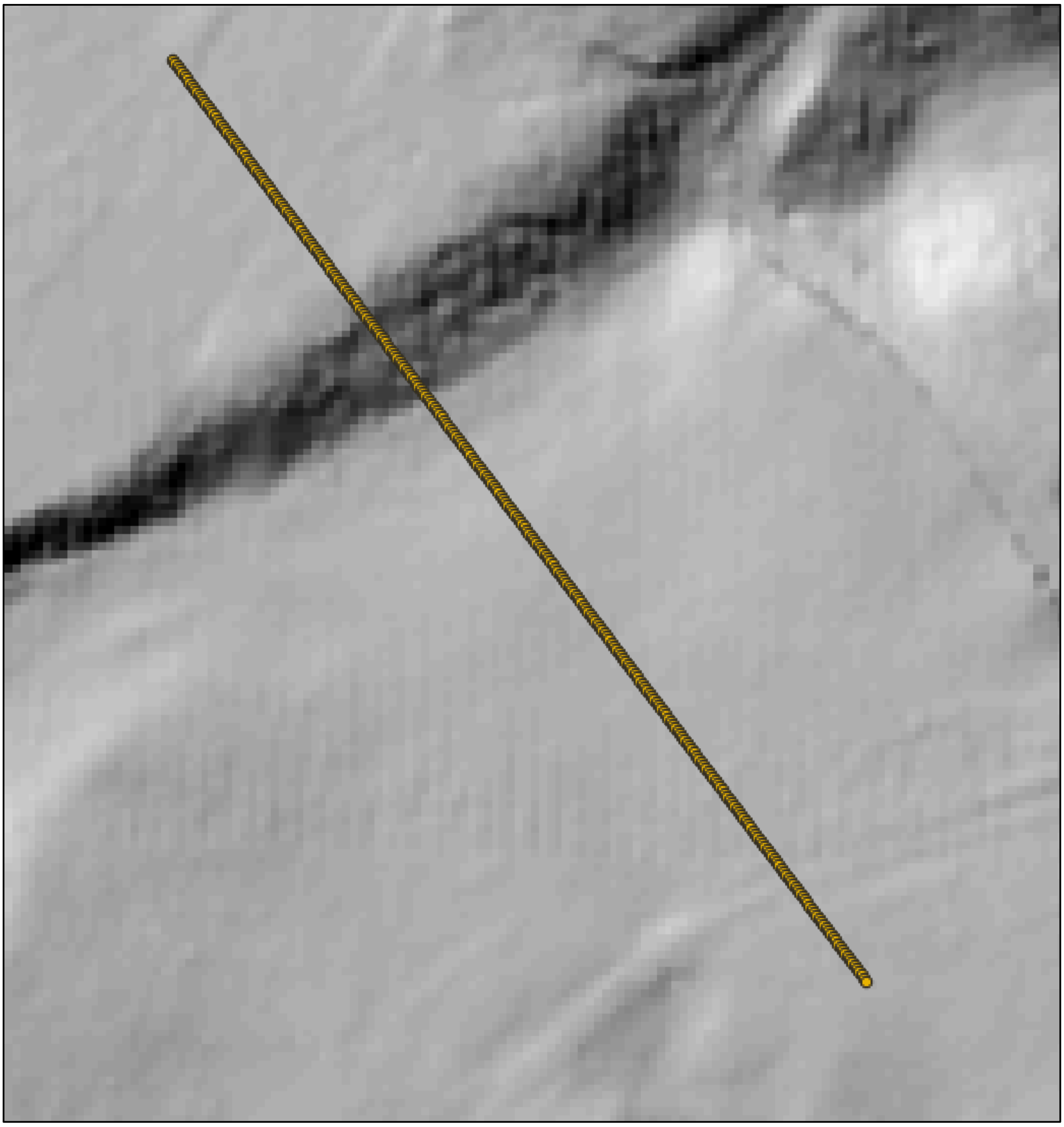
The Points Along Geometry Tool plugin creates points at regular intervals along line or polygon geometries. Created points have new attributes added for the distance along the geometry and the angle of the line at the point. An optional start and end offset can be specified, which controls how far from the start and end of the geometry the points should be created. This can be useful if you do not want to include the entire fault scarp profile; however, it is often simplest to start and end at the terminal points of the profile.

If you do not see these tools, you can find them in the Manage and Install Plugins feature of QGIS.

- Within the Toolbox, navigate to and open the Points Along Geometry Tool.



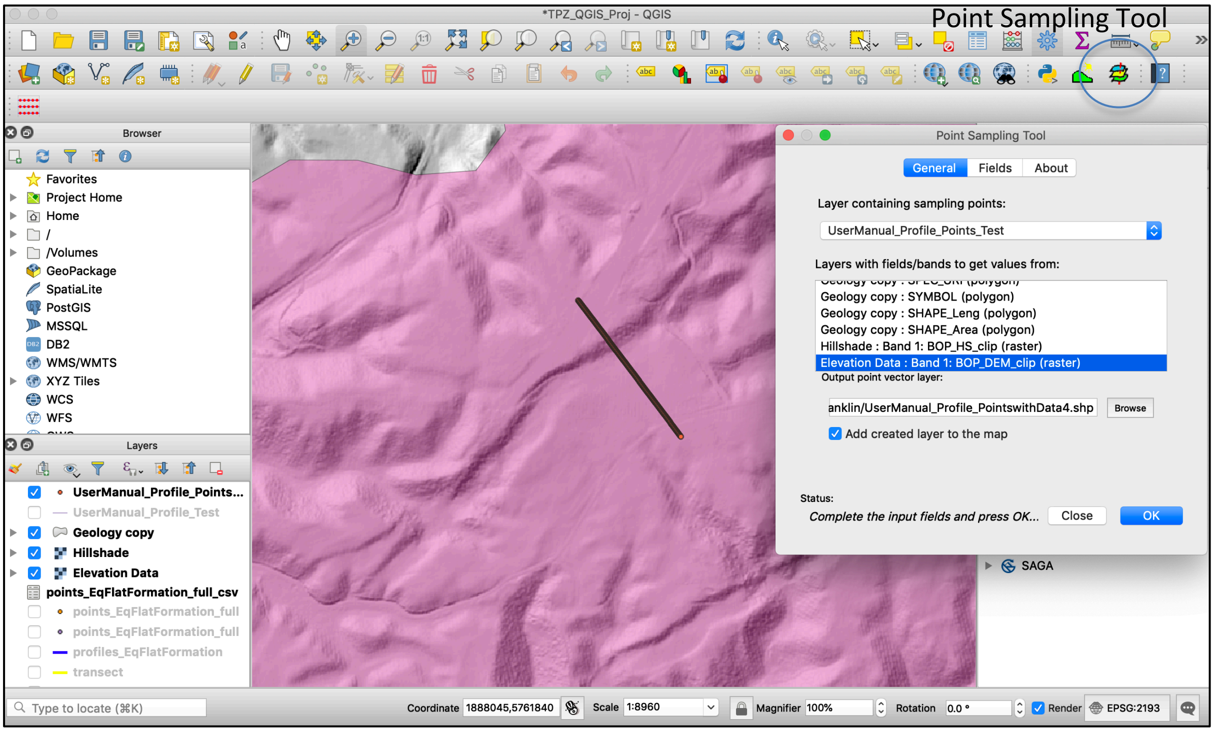
- Set your density of points along the profile. Here I have set it to 1 meter.
- Add a file path and new file name to create a new file for the points in the final dialogue box.

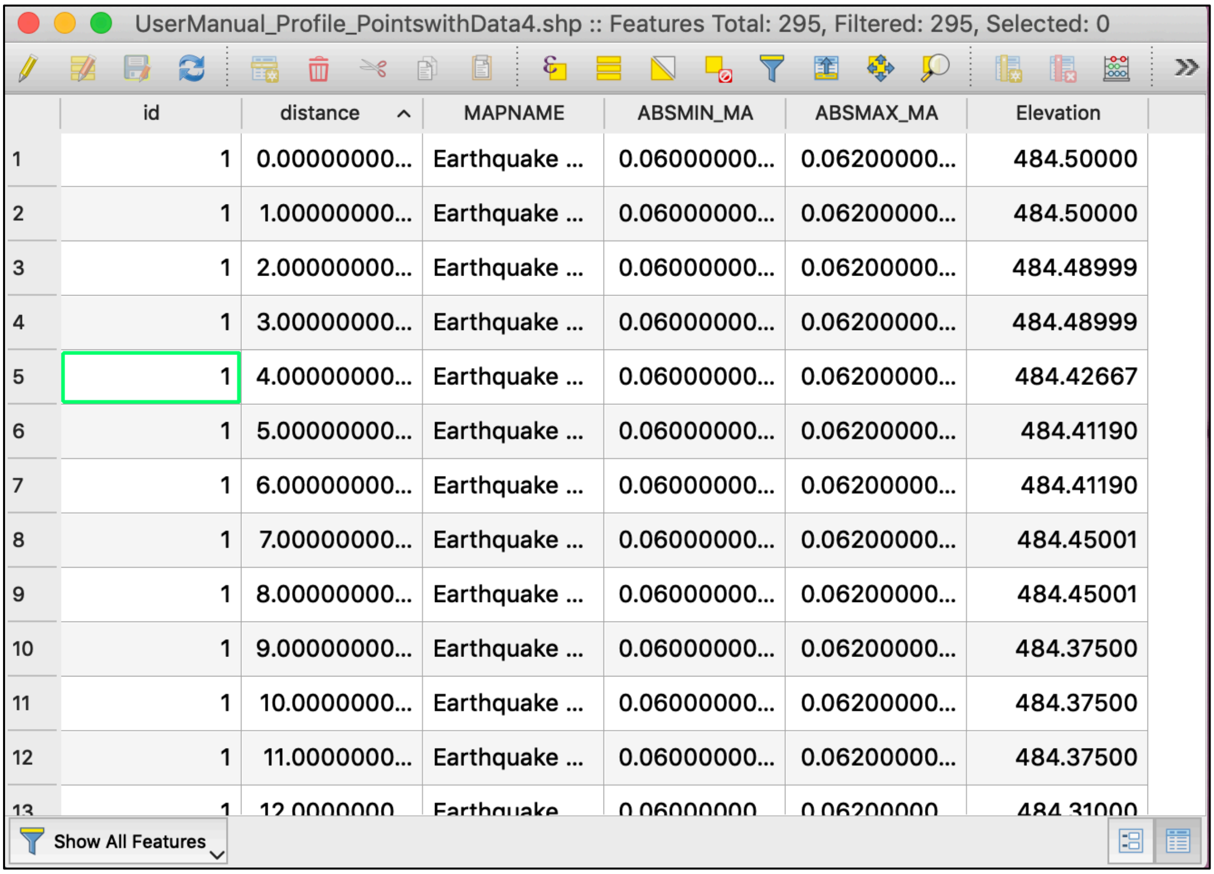


- You can now see that the profile is composed of many points spaced at 1 meter.

The Point Sampling Tool plugin collects polygon attributes and raster values from multiple layers at the specified sampling points created using the Points Along Geometry Tool plugin. The user needs a point layer (our newly created points) with locations of the sampling points and at least one polygon or raster layer from which to probe values (the elevation and geologic age data). The plugin creates a new point layer with locations given by the sampling points and attributes taken from the underlying polygon or/and raster cells, which represent the data that can be extracted from the high-resolution DEM and geologic map.

- You may need to install the Point Sampling Tool from the Manage and Install Plugins function
- Make active all layers you wish to extract data from (e.g., Geology and Elevation Data).
- Designate name for output file and save it as a Shapefile. The default is Geopackage.





	id	distance	MAPNAME	ABSMIN_MA	ABSMAX_MA	Elevation
1	1	0.00000000...	Earthquake ...	0.06000000...	0.06200000...	484.50000
2	1	1.00000000...	Earthquake ...	0.06000000...	0.06200000...	484.50000
3	1	2.00000000...	Earthquake ...	0.06000000...	0.06200000...	484.48999
4	1	3.00000000...	Earthquake ...	0.06000000...	0.06200000...	484.48999
5	1	4.00000000...	Earthquake ...	0.06000000...	0.06200000...	484.42667
6	1	5.00000000...	Earthquake ...	0.06000000...	0.06200000...	484.41190
7	1	6.00000000...	Earthquake ...	0.06000000...	0.06200000...	484.41190
8	1	7.00000000...	Earthquake ...	0.06000000...	0.06200000...	484.45001
9	1	8.00000000...	Earthquake ...	0.06000000...	0.06200000...	484.45001
10	1	9.00000000...	Earthquake ...	0.06000000...	0.06200000...	484.37500
11	1	10.0000000...	Earthquake ...	0.06000000...	0.06200000...	484.37500
12	1	11.0000000...	Earthquake ...	0.06000000...	0.06200000...	484.37500
13	1	12.0000000	Earthquake	0.06000000	0.06200000	484.31000

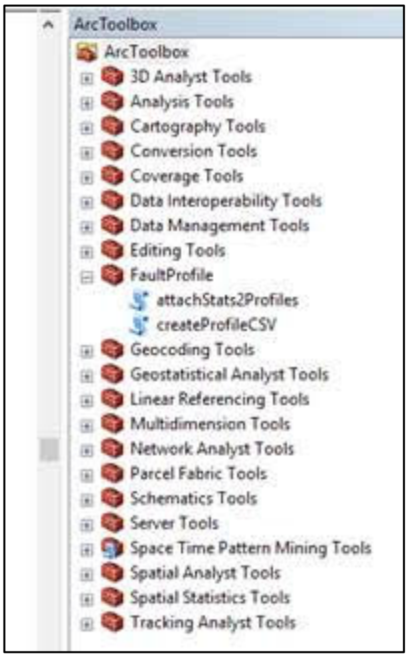
- The above photo is the output of the process. You can see that at each point, geologic age and elevation data have been extracted.

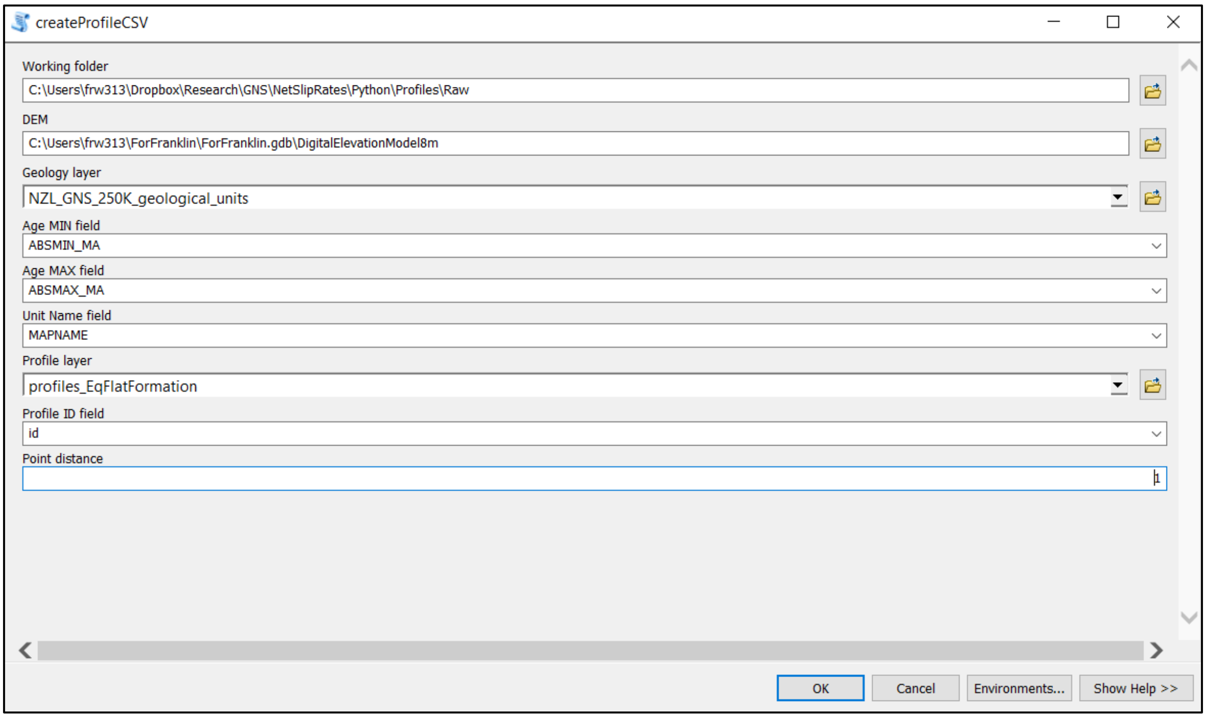
D) ArcGIS

The user has two options to complete this process with ArcGIS. The first is with an ArcToolbox and the second is with a Stand Alone Python script. Both of these were developed for this study. Please note: The scripts were developed in Python 2.7.13 (to be compatible with ArcGIS), ArcGIS v 10.5.1 was used for testing but it might work in other 10 versions, and the user will require the ArcGIS (for both) and Spatial Analyst (for createProfileCSV.py only) licenses to run these scripts

ArcToolbox Approach

- The ArcGIS_Toolbox folder contains the ArcGIS Toolbox together with the scripts that are called from it. The user will have to copy the whole folder to their machine (to maintain relative paths within the toolbox) and add the toolbox to their ArcMap project or ArcCatalog. The scripts could be run from there and ArcGIS has an interface for entering inputs (see below).
- Within ArcGIS, the user must navigate to their ArcToolbox, right click, and select Add Toolbox.
- Add the FaultProfile Toolbox to the working environment through this process.
- Double click on the 'createProfileCSV' tool within this newly added toolbox.





- Fill in the dialogue boxes as appropriate
  - The Working folder is the location to output your soon to be created profile data. It would make sense to make the output folder the working directory for your Jupyter Notebook environment so that you can easily navigate to the newly created profiles in the fault scarp analysis step.
  - The DEM is the elevation file from which you wish to extract the elevation data
  - The Geology layer is the shapefile layer that contains the age and unit name information
  - Select the age fields and unit name fields from the drop-down menus. These are headers within the Geology layer chosen.
  - The Profile layer is the shapefile layer created in the previous step that contains profiles drawn across fault scarps.
  - Select the unique id field for each profile of the Profile layer.
  - Select the point sampling density from which you would like to extract data along the profiles.
- The resulting profile data will be stored in a new folder within the Working folder assigned in the previous step. Each profile will be saved as a separate CSV. The name of the folder will be "outputs_" + the name of your profile shapefile.

Python Stand Alone Approach

- The createProfileCSV.py code can be used in a python standalone environment to complete the same workflow. It requires the user to manually input the entries for the dialogue boxes of the ArcToolbox approach, including the full path to each file. The user will be prompted to fill these in once the script is launched.

  - The code will create a csv file for each section line and put each file into a folder called "Outputs_(name of your Line Feature Class)".
  - The file for each profile will include a list of points at which the data was extracted.

Table

profile_1.csv

PointID	ProfID	Distance	Geology	Age_Min	Age_Max	Elevation
0	1	0	Earthquake Flat Formation (Okataina Group) ignimbrite of Okataina Volcanic Centre	0.061	0.061	435.133698
1	1	1	Earthquake Flat Formation (Okataina Group) ignimbrite of Okataina Volcanic Centre	0.061	0.061	435.133698
2	1	2	Earthquake Flat Formation (Okataina Group) ignimbrite of Okataina Volcanic Centre	0.061	0.061	435.133698
3	1	3	Earthquake Flat Formation (Okataina Group) ignimbrite of Okataina Volcanic Centre	0.061	0.061	435.133698
4	1	4	Earthquake Flat Formation (Okataina Group) ignimbrite of Okataina Volcanic Centre	0.061	0.061	435.133698
5	1	5	Earthquake Flat Formation (Okataina Group) ignimbrite of Okataina Volcanic Centre	0.061	0.061	435.133698
6	1	6	Earthquake Flat Formation (Okataina Group) ignimbrite of Okataina Volcanic Centre	0.061	0.061	435.123047
7	1	7	Earthquake Flat Formation (Okataina Group) ignimbrite of Okataina Volcanic Centre	0.061	0.061	435.123047
8	1	8	Earthquake Flat Formation (Okataina Group) ignimbrite of Okataina Volcanic Centre	0.061	0.061	435.123047
9	1	9	Earthquake Flat Formation (Okataina Group) ignimbrite of Okataina Volcanic Centre	0.061	0.061	435.123047
10	1	10	Earthquake Flat Formation (Okataina Group) ignimbrite of Okataina Volcanic Centre	0.061	0.061	436.405579
11	1	11	Earthquake Flat Formation (Okataina Group) ignimbrite of Okataina Volcanic Centre	0.061	0.061	436.405579
12	1	12	Earthquake Flat Formation (Okataina Group) ignimbrite of Okataina Volcanic Centre	0.061	0.061	436.405579
13	1	13	Earthquake Flat Formation (Okataina Group) ignimbrite of Okataina Volcanic Centre	0.061	0.061	436.405579
14	1	14	Earthquake Flat Formation (Okataina Group) ignimbrite of Okataina Volcanic Centre	0.061	0.061	436.405579
15	1	15	Earthquake Flat Formation (Okataina Group) ignimbrite of Okataina Volcanic Centre	0.061	0.061	436.405579
16	1	16	Earthquake Flat Formation (Okataina Group) ignimbrite of Okataina Volcanic Centre	0.061	0.061	436.405579
17	1	17	Earthquake Flat Formation (Okataina Group) ignimbrite of Okataina Volcanic Centre	0.061	0.061	436.405579
18	1	18	Earthquake Flat Formation (Okataina Group) ignimbrite of Okataina Volcanic Centre	0.061	0.061	436.16864
19	1	19	Earthquake Flat Formation (Okataina Group) ignimbrite of Okataina Volcanic Centre	0.061	0.061	436.16864
20	1	20	Earthquake Flat Formation (Okataina Group) ignimbrite of Okataina Volcanic Centre	0.061	0.061	436.16864
21	1	21	Earthquake Flat Formation (Okataina Group) ignimbrite of Okataina Volcanic Centre	0.061	0.061	437.281738
22	1	22	Earthquake Flat Formation (Okataina Group) ignimbrite of Okataina Volcanic Centre	0.061	0.061	437.281738
23	1	23	Earthquake Flat Formation (Okataina Group) ignimbrite of Okataina Volcanic Centre	0.061	0.061	437.281738
24	1	24	Earthquake Flat Formation (Okataina Group) ignimbrite of Okataina Volcanic Centre	0.061	0.061	437.281738
25	1	25	Earthquake Flat Formation (Okataina Group) ignimbrite of Okataina Volcanic Centre	0.061	0.061	437.281738
26	1	26	Earthquake Flat Formation (Okataina Group) ignimbrite of Okataina Volcanic Centre	0.061	0.061	437.281738
27	1	27	Earthquake Flat Formation (Okataina Group) ignimbrite of Okataina Volcanic Centre	0.061	0.061	437.281738
28	1	28	Earthquake Flat Formation (Okataina Group) ignimbrite of Okataina Volcanic Centre	0.061	0.061	437.281738
29	1	29	Earthquake Flat Formation (Okataina Group) ignimbrite of Okataina Volcanic Centre	0.061	0.061	437.281738
30	1	30	Earthquake Flat Formation (Okataina Group) ignimbrite of Okataina Volcanic Centre	0.061	0.061	436.625732
31	1	31	Earthquake Flat Formation (Okataina Group) ignimbrite of Okataina Volcanic Centre	0.061	0.061	436.625732
32	1	32	Earthquake Flat Formation (Okataina Group) ignimbrite of Okataina Volcanic Centre	0.061	0.061	437.704865
33	1	33	Earthquake Flat Formation (Okataina Group) ignimbrite of Okataina Volcanic Centre	0.061	0.061	437.704865
34	1	34	Earthquake Flat Formation (Okataina Group) ignimbrite of Okataina Volcanic Centre	0.061	0.061	437.704865
35	1	35	Earthquake Flat Formation (Okataina Group) ignimbrite of Okataina Volcanic Centre	0.061	0.061	437.704865
36	1	36	Earthquake Flat Formation (Okataina Group) ignimbrite of Okataina Volcanic Centre	0.061	0.061	437.704865
37	1	37	Earthquake Flat Formation (Okataina Group) ignimbrite of Okataina Volcanic Centre	0.061	0.061	437.704865
38	1	38	Earthquake Flat Formation (Okataina Group) ignimbrite of Okataina Volcanic Centre	0.061	0.061	437.704865
39	1	39	Earthquake Flat Formation (Okataina Group) ignimbrite of Okataina Volcanic Centre	0.061	0.061	437.704865

70 (0 out of 283 Selected)

profile_1.csv

Fault Scarp Analysis GUI

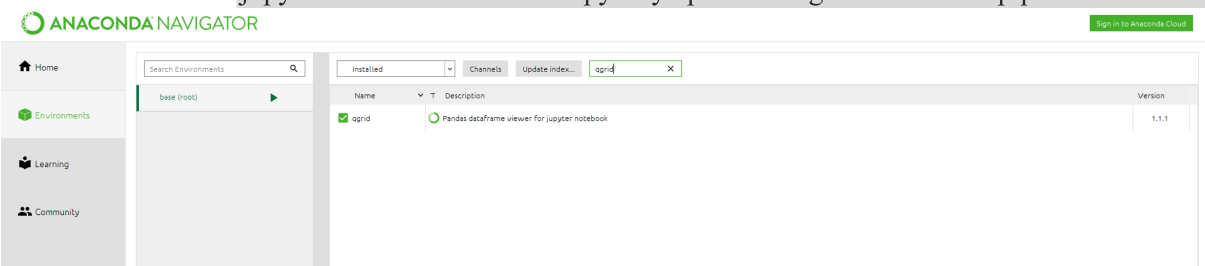
Next, each fault scarp profile can be analysed in preparation for net slip calculations.

- An easy-to-use GUI is used to manually select the data to represent the Hanging wall, Footwall, and Scarp for each profile generated in the previous steps.
- The program of choice for running this section of the code is Jupyter Notebook, which can be downloaded online free by downloading Anaconda https://www.anaconda.com/download/#windows
- Launch the Jupyter notebook script.
- You will need a few packages that might not come already installed. You can install these easily within your computer's terminal.
    - If you are using a Mac, type the following (followed by an enter command) in your command terminal.

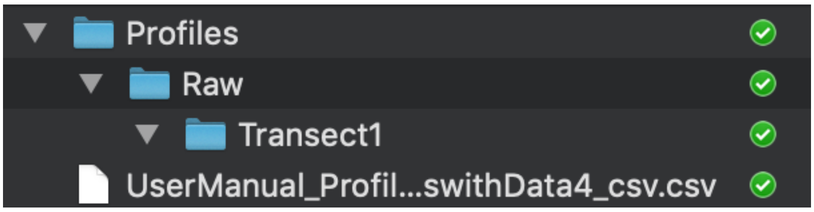
```
pip install setuptools
pip install msgpack
pip install qgrid
jupyter nbextension enable --py --sys-prefix qgrid
jupyter nbextension enable --py --sys-prefix widgetsnbextensionpip install
jupyterlab
jupyter labextension install @jupyter-widgets/jupyterlab-manager
jupyter labextension install qgrid
```

- If you are using a Windows environment, download the packages through the Anaconda interphase by navigating to the Environments tab within the Anaconda Navigator. The extensions must then be enabled via the Anaconda Prompt terminal.

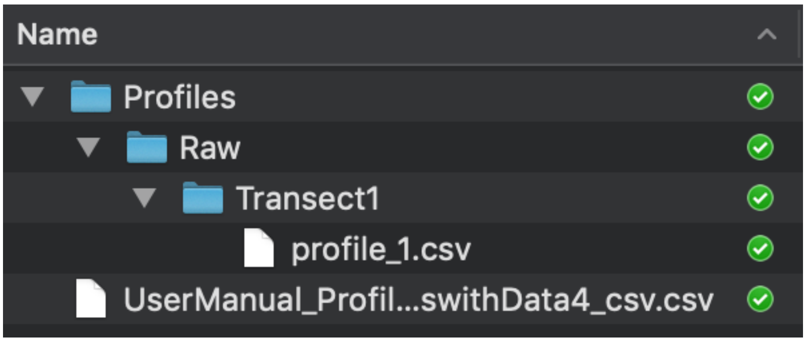
```
jupyter nbextension enable --py --sys-prefix qgrid
jupyter nbextension enable --py --sys-prefix widgetsnbextensionpip install
```



- Next, load the jupyter notebook from the Anaconda Prompt terminal.
- Now, you are ready to start analysing the fault scarp profiles.
- With the Jupyter Notebook up and running, make sure that the working directory is set to the location of the folder that contains the csv file. You can check this by typing 'ls 'and entering the command. If it is not, you can navigate to that folder by typing 'cd "subfolder in current location"'. Or by typing 'cd ..' to step back one folder level.
- If you used the QGIS version of the data extraction process, then you will first need to separate your CSV file into separate files with one for each profile. The first step of the Python notebook will do this for you.
    - You will need to create a file structure similar to this one:
        - Folder Name: Profiles
        - Subfolder Name: Raw
        - SubSubFolder Name: Transect 1
        - The original CSV file with the data you exported from QGIS



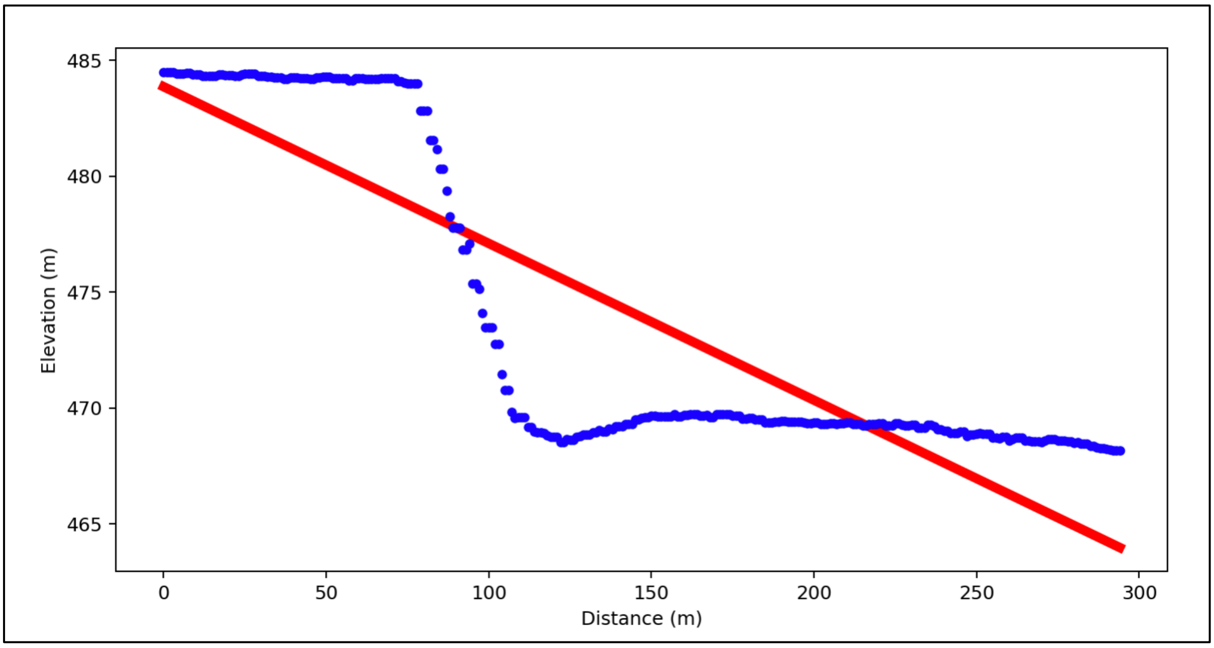
- After running this portion of the notebook, you should see individual profiles in the Raw folder.



- If you used the ArcGIS version, your files should already be separated into their individual profiles.
- It is likely that the headers of your CSV will not be the same as those used in the development test case. Thus, you will need to manually change the header names in this tab so that the notebook will read in the data correctly.

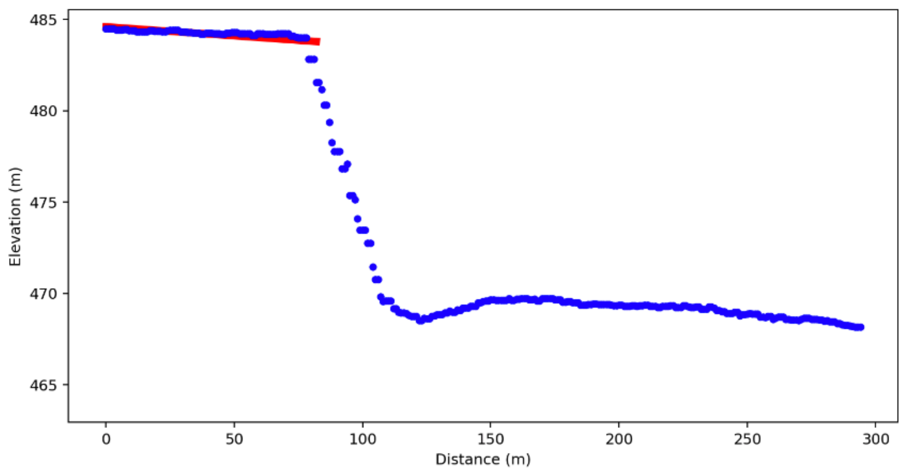
```
data = pd.read_csv(my_dir + folder + my_transect + profile)
data = data.rename(index=str, columns={"Unnamed: 0": "Point", "PointID": "Point", "ProfID": "Profile Number", "id": "Profile Numb
                                       "distance": "Distance","MAPNAME": "Map Name", "Geology" : "Map Name",
                                       "ABSMIN_MA": "Minimum Age (MA)", "Age_Min": "Minimum Age (MA)",
                                       "ABSMAX_MA": "Maximum Age (MA)", "Age_Max": "Maximum Age (MA)",
                                       "rvalue_1": "Elevation"})

# Call all the widget
qgrid_widget = qgrid.show_grid(data,show_toolbar=True)
qgrid_widget

hide_toggle()
```

- Running the next set of commands will launch the data manipulation widgets and display your first profile.



- By running the following command box, you will launch an interactive data table. Manipulate and filter the data to fit the red line to the surface you believe represents the footwall. You can do this by clicking the filter button at the top of each column and then sliding the bar to only contain data within the range you would like to view. The red line should update in accordance with the subset of data that remains in the data frame.
- Sometimes, the interactive table and subsequent line of best fit created from the subset of data selected can be buggy. Often times, it was necessary to chose a subset of data with the sliders and then re-load the graph above. Then it would allow the user to interactively update the polyline choice in real time.
- This is only necessary on the first profile when launching the notebook to get the widget started. Then it should work cleanly throughout the analysis.

Figure 1



Out[15]: Toggle show/hide

Launch the interactive sliders to filter the data for fault components.

In [16]:
```
# Here you will launch the data filtering sliders
qgrid_widget
```

Add Row | Remove Row

Filter by Distance
0.00000 - 82.32000
Reset

index	Point	Profile Num	Distance	Map Name	Minimum A	Maximum A	Elevation
0	0	1	0			0.062	484.5
1	1	1	1			0.062	484.5
2	2	1	2			0.062	484.48999
3	3	1	3			0.062	484.48999
4	4	1	4			0.062	484.42667
5	5	1	5	Earthquake...	0.06	0.062	484.4119
6	6	1	6	Earthquake...	0.06	0.062	484.4119
7	7	1	7	Earthquake...	0.06	0.062	484.45001
8	8	1	8	Earthquake...	0.06	0.062	484.45001
9	9	1	9	Earthquake...	0.06	0.062	484.375
10	10	1	10	Earthquake...	0.06	0.062	484.375
11	11	1	11	Earthquake...	0.06	0.062	484.375
12	12	1	12	Earthquake...	0.06	0.062	484.31

- Once you have made your selection, run the box that saves the data within the FW variable. It is important to not run the HW and SC boxes until you have completed a similar process for each.

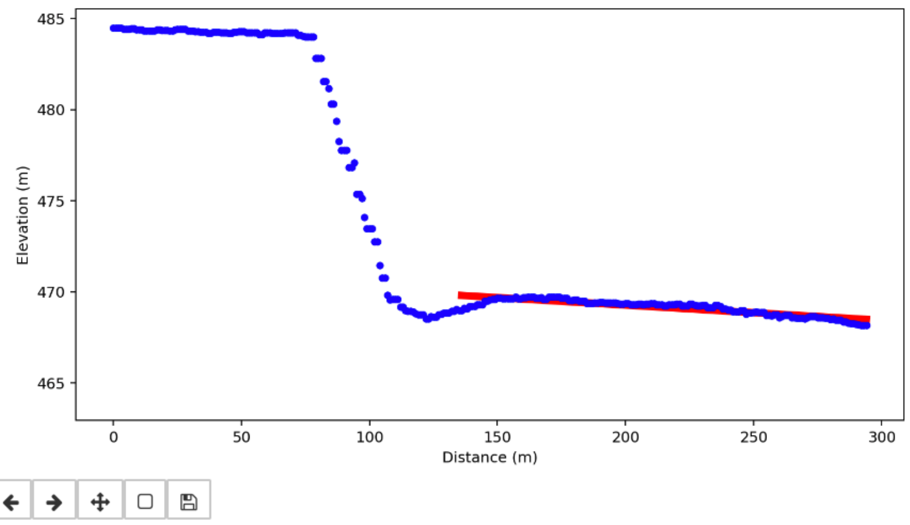
Save values for each component of the fault scarp

In [17]:
```
# Save the data points for the FW
FW = qgrid_widget.get_changed_df()[['Distance','Elevation']]
```

In [18]:
```
# Save the data points for the HW
HW = qgrid_widget.get_changed_df()[['Distance','Elevation']]
```

In [18]:
```
# Save the data points for the SC
SC = qgrid_widget.get_changed_df()[['Distance','Elevation']]
#SC.dropna(axis=1);
```

- Next, re-filter the data within the interactive data frame so that the red line fits the hanging wall surface. You can remove you previous filtered selection by clicking the filter button on the row and then selecting reset.



Out[15]: Toggle show/hide

Launch the interactive sliders to filter the data for fault components.

In [16]:
```
# Here you will launch the data filtering sliders
qgrid_widget
```

Add Row | Remove Row

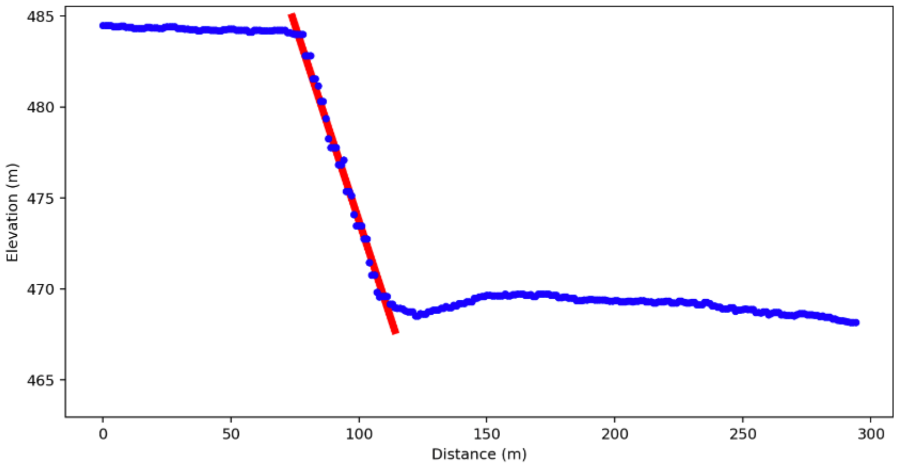
index	Point	Profile Num	Distance	Map Name	Minimum A	Maximum A	Elevation
136	136	1	136			0.062	468.97
137	137	1	137			0.062	469.10999
138	138	1	138			0.062	469.07999
139	139	1	139			0.062	469.21832
140	140	1	140			0.062	469.21832
141	141	1	141	Earthquake…	0.06	0.062	469.21832
142	142	1	142	Earthquake…	0.06	0.062	469.32001
143	143	1	143	Earthquake…	0.06	0.062	469.32001
144	144	1	144	Earthquake…	0.06	0.062	469.32001
145	145	1	145	Earthquake…	0.06	0.062	469.48999
146	146	1	146	Earthquake…	0.06	0.062	469.48999
147	147	1	147	Earthquake…	0.06	0.062	469.57501
148	148	1	148	Earthquake…	0.06	0.062	469.59
149	149	1	149	Earthquake…	0.06	0.062	469.59
150	150	1	150	Earthquake…	0.06	0.062	469.65668
151	151	1	151	Earthquake…	0.06	0.062	469.65668

Filter by Distance

135.24000 - 294.00000

Reset

- Now run the HW box to save this data as the HW variable, just as was completed for the FW.
- Do the same for the Scarp.



Out[15]: Toggle show/hide

Launch the interactive sliders to filter the data for fault components.

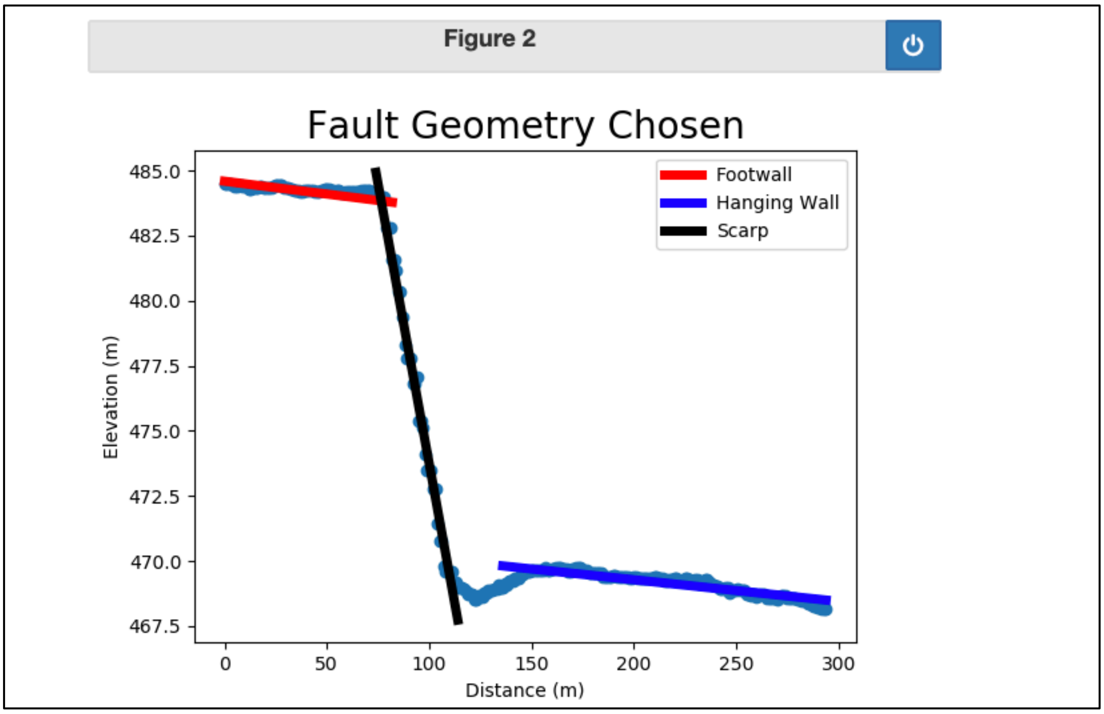
In [16]:
```
# Here you will launch the data filtering sliders
qgrid_widget
```

Add Row | Remove Row

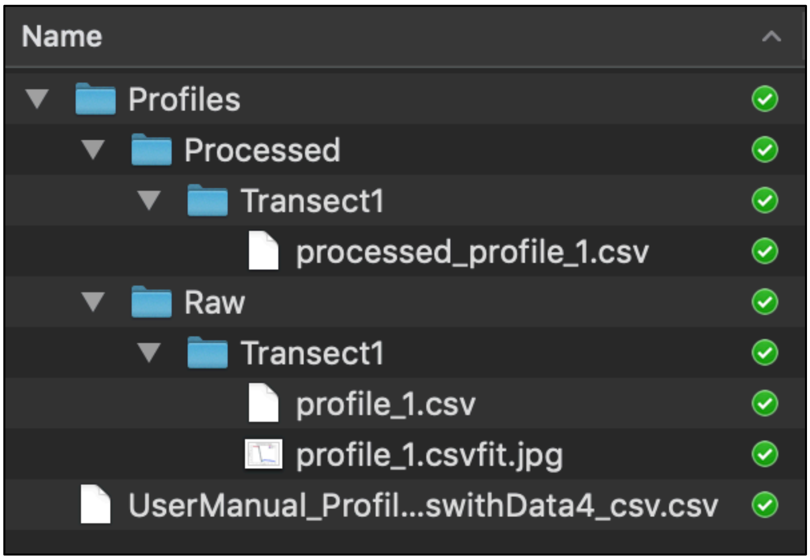
Filter by Distance
73.50000 - 114.66000
Reset

index	Point	Profile Num	Distance	Map Name	Minimum A	Maximum A	Elevation
96	96	1	96			0.062	475.35999
97	97	1	97			0.062	475.12717
98	98	1	98			0.062	474.08936
99	99	1	99			0.062	473.47815
100	100	1	100			0.062	473.47815
101	101	1	101	Earthquake…	0.06	0.062	473.47815
102	102	1	102	Earthquake…	0.06	0.062	472.76035
103	103	1	103	Earthquake…	0.06	0.062	472.76035
104	104	1	104	Earthquake…	0.06	0.062	471.44379
105	105	1	105	Earthquake…	0.06	0.062	470.79053
106	106	1	106	Earthquake…	0.06	0.062	470.79053
107	107	1	107	Earthquake…	0.06	0.062	469.815
108	108	1	108	Earthquake…	0.06	0.062	469.57001
109	109	1	109	Earthquake…	0.06	0.062	469.59
110	110	1	110	Earthquake…	0.06	0.062	469.59
111	111	1	111	Earthquake…	0.06	0.062	469.59

- Run the SC box.
- Next, the GUI will allow you to visualize your choices while displaying the original data. If you do not like your choices, you can do the previous process again and re-save new data as you see fit.



- This is a simplified representation of the fault profile broken down into its three components (HW, FW, and SC) based on the selections you have chosen. If you like the selection, run the next box to save the file. The script will save the new filtered data as a separate file and also save a JPG image of this fault geometry to keep for your records.
- The file will be saved within the same folder, but will have the title 'processed' in front. The script will create the processed folder for you if it does not already exist.
- You should now have the following files:



- Now you are ready to load in the next fault scarp profile and complete the process over again.

Monte Carlo Slip Statistics Calculation

Now that you have processed all of the fault profiles, the jupyter notebook can calculate all of the slip statistics at once in a batch process. Running this process multiple times will just rewrite the output files for each individual profile, so it does not matter whether you run this step last or throughout. There are plots created for each profile, as well as a summary table with the statistics for each.

- The first box will allow you to set up a fault geometry distribution.
- You can set the dip of the fault and the position of the fault's intersection with the scarp

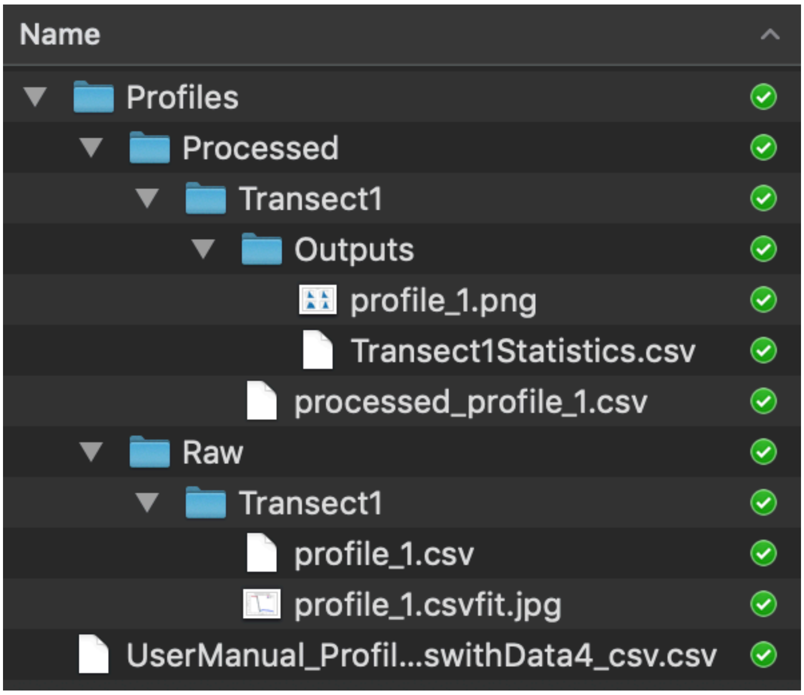
Toggle this cell on if you would like to change the fault geometry, number of samples, or directory of your transect profiles. The directory should contain the folders of transects that contain the individual fault profile geometries. Run this cell to initialize these values.

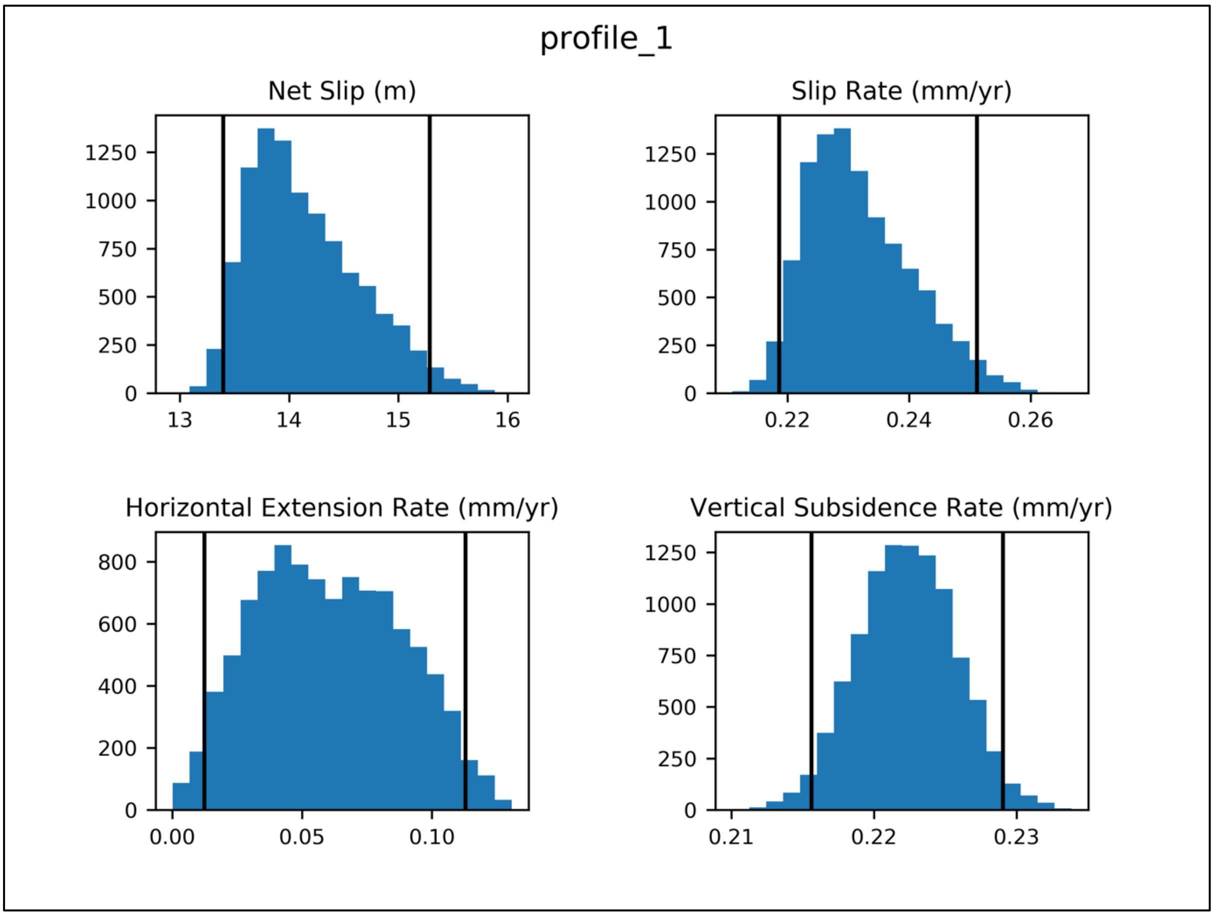
```
# Create table to contain fault components
# Fault is arranged as follows:
# Row 1: Dip mean, Dip deviation, Position mean, Position deviation
# Row 2: Dip min, max1, max2, end (trapezoidal distribution of dips)
# Row 3: Position min, max1, max2, end
# If trapezoidal distribution is goal, use rows 2 and 3
Fault = [[0,0,0,0],[60,70,80,90],[0,0,0.50,0.10]]

# Number of samples for Monte Carlo simulations
nsamples = 10000

# Define directory for inputs and outputs
my_dir = processed_folder_path

hide_toggle()
```

- Running the next box will calculate the statistics for each fault profile.

Outputs

- The output of the code will include slip statistics and histograms of slip statistics for visualization. These will also be saved as individual files in a new folder the script creates called Outputs.



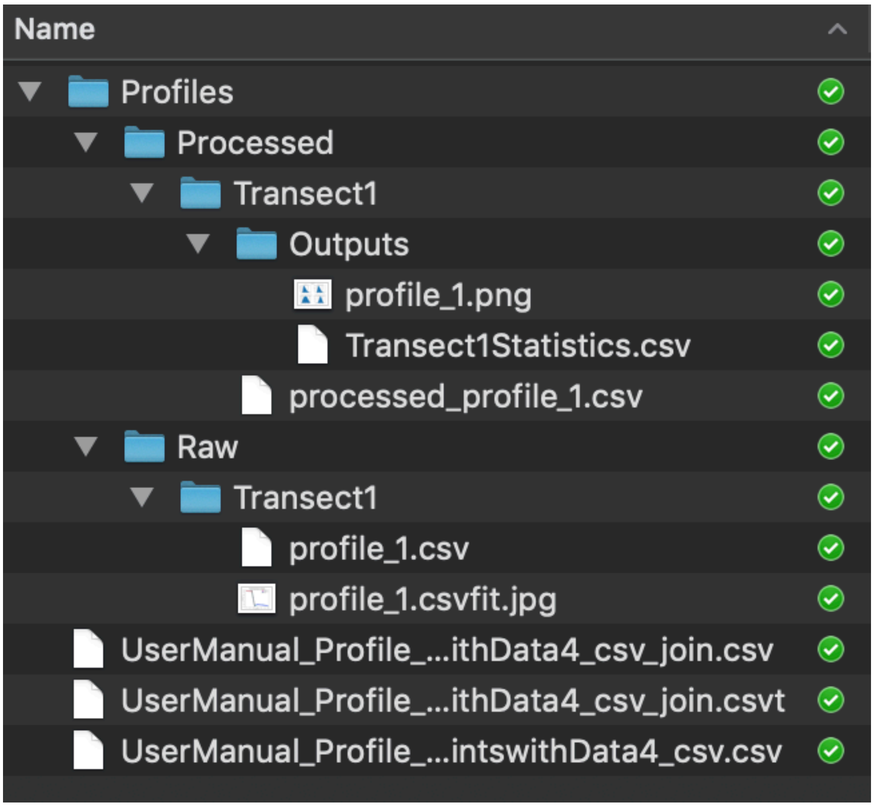


	Transect1	
	profile_1	**Cumulative**
Slip Mean (m)	14.15	14.15
Slip Median (m)	14.05	14.05
Slip Min (m)	13.40	13.4
Slip Max (m)	15.29	15.29
Slip 2STD (m)	1.02	1.02
Slip Rate Mean (mm/yr)	0.23	0.23
Slip Rate Median (mm/yr)	0.23	0.23
Slip Rate Min (mm/yr)	0.22	0.22
Slip Rate Max (mm/yr)	0.25	0.25
Slip Rate 2STD (mm/yr)	0.02	0.02
Slip Rate Horizontal Mean (mm/yr)	0.06	0.06
Slip Rate Horizontal Median (mm/yr)	0.06	0.06
Slip Rate Horizontal Min (mm/yr)	0.01	0.01
Slip Rate Horizontal Max (mm/yr)	0.11	0.11
Slip Rate Horizontal 2STD (mm/yr)	0.06	0.06
Slip Rate Vertical Mean (mm/yr)	0.22	0.22
Slip Rate Vertical Median (mm/yr)	0.22	0.22
Slip Rate Vertical Min (mm/yr)	0.22	0.22
Slip Rate Vertical Max (mm/yr)	0.23	0.23
Slip Rate Vertical 2STD (mm/yr)	0.01	0.01
Age Min (Ma)	0.06	N/A
Age Max (Ma)	0.06	N/A

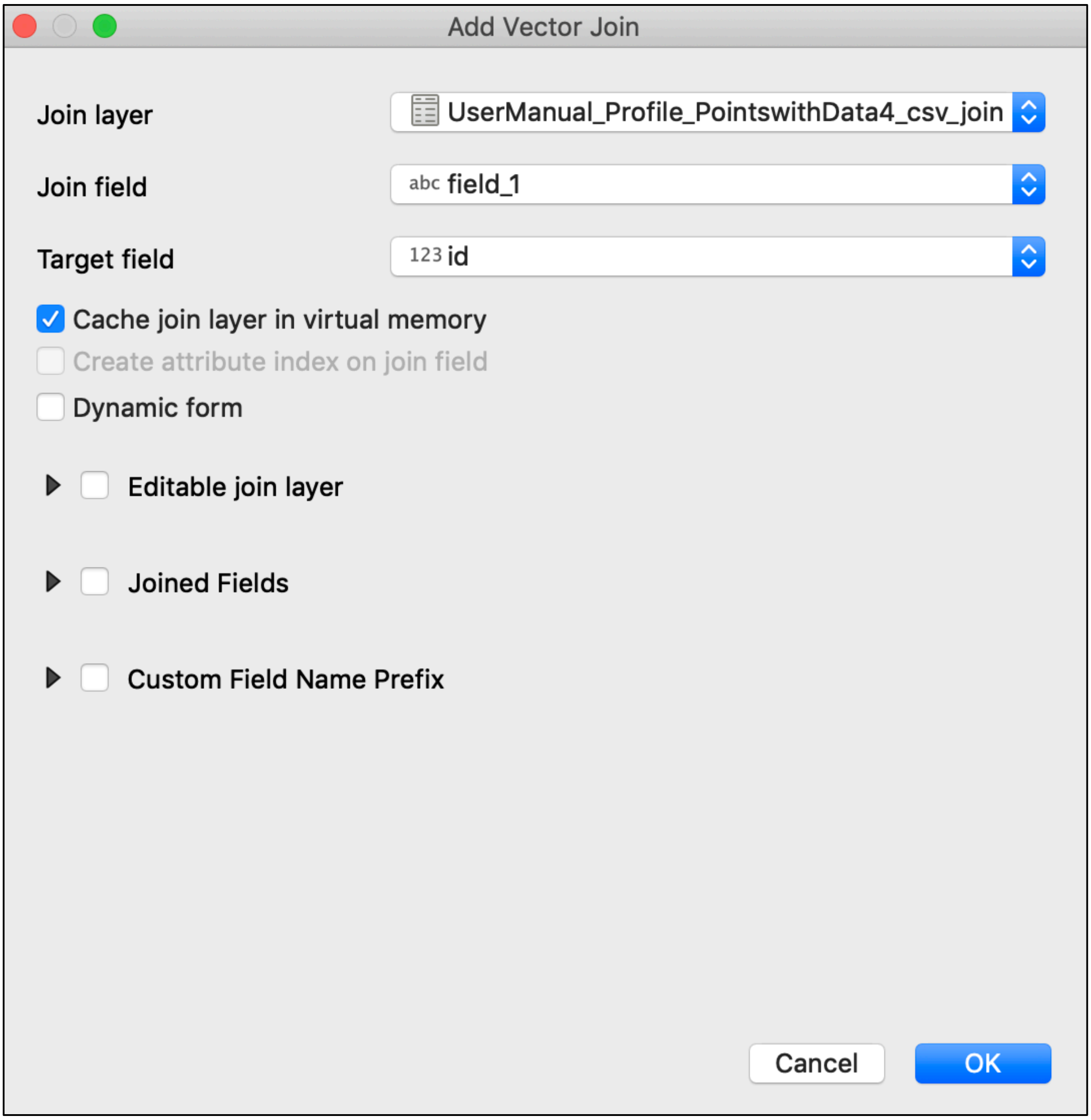
```
time =  1.1865930557250977  seconds
```

Data Display in GIS

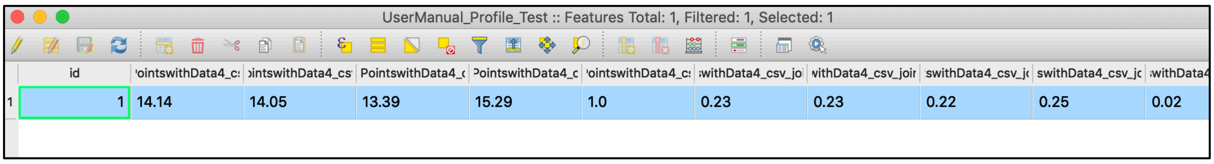
a) QGIS



- To display in QGIS and associate these statistics with the original profiles, we will use the Join Fields tool.
- Load your CSV where the final part of the file name is "_join" into QGIS.
- Open the Properties of the original Shapefile and navigate to the Joins tab.
- Click the "+" sign to add a new Join.
- Select your csv file with the extension "_join" as the Join Layer.
- Select the ID fields of the Join Layer and the Shapefile layer as the Join Field and Target Field.
- Hit OK and then Apply.



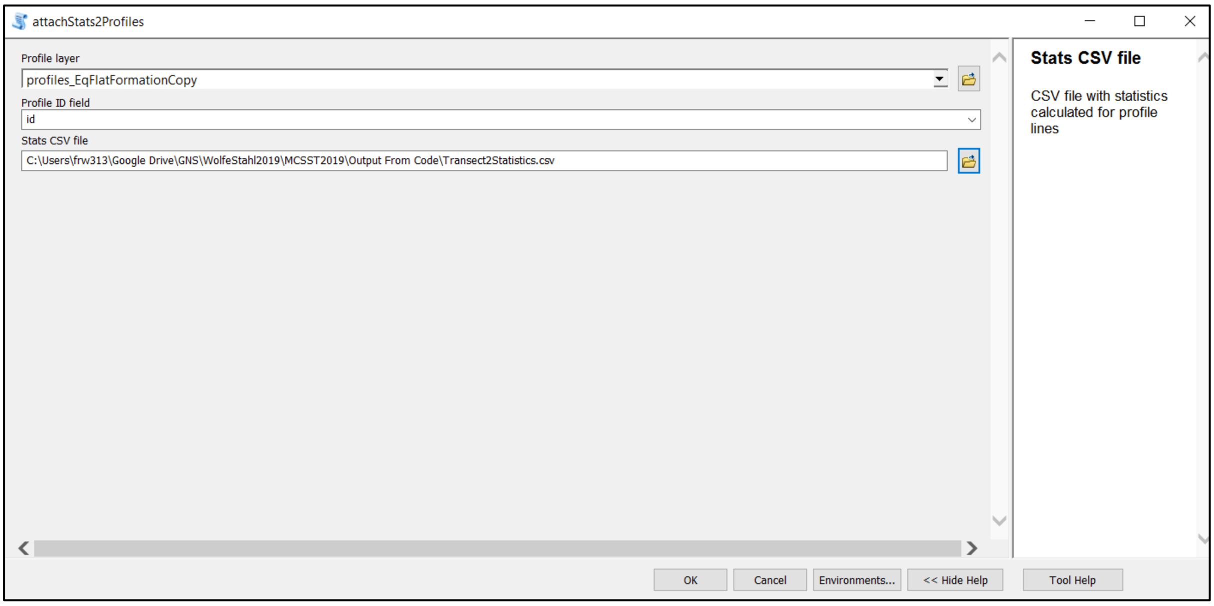
- Now open your Attribute Table and the datasets should be joined.



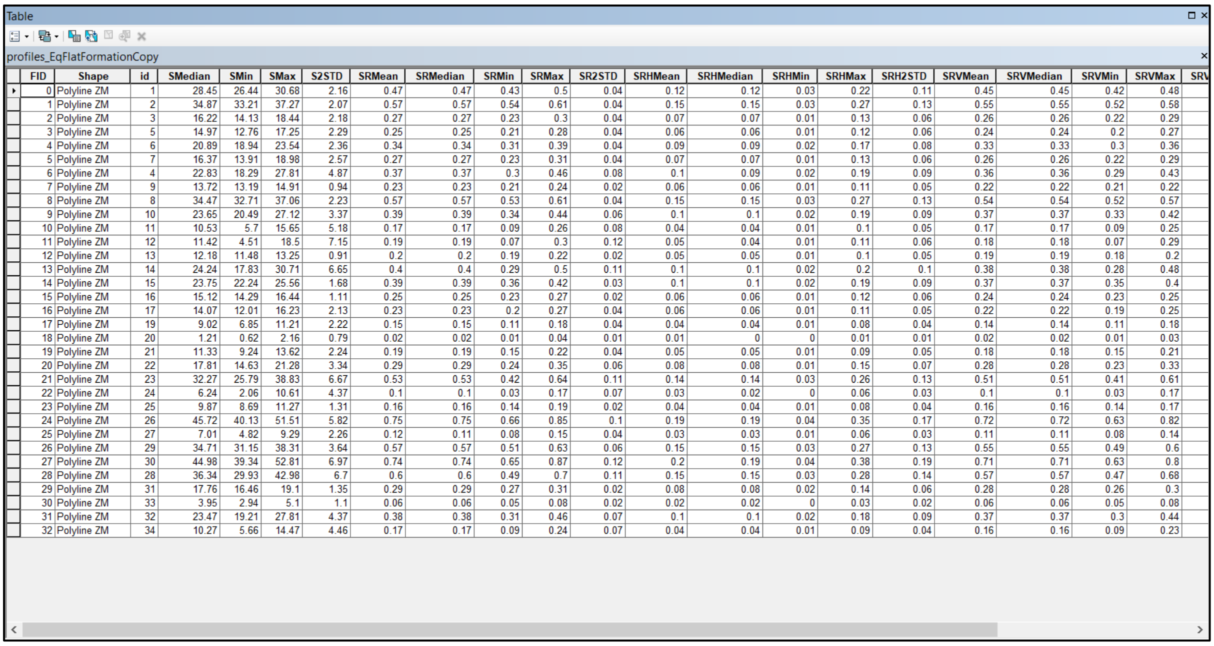
b) ArcGIS

A toolbox was created to make attaching statistics to the original profiles seamless.

- Launch the tool titled, "attachStats2Profiles"
- Enter the required dialogue boxes including the full file path for the Stats CSV file



- The statistics from the CSV file should now be attached to the profiles originally digitized in ArcGIS
- Alternatively, the Python standalone script can be used. This will require manual entry to the full data file paths.



Table

profiles_EqFlatFormationCopy

FID	Shape	id	SMedian	SMin	SMax	S2STD	SRMean	SRMedian	SRMin	SRMax	SR2STD	SRHMean	SRHMedian	SRHMin	SRHMax	SRH2STD	SRVMean	SRVMedian	SRVMin	SRVMax
0	Polyline ZM	1	28.45	26.44	30.68	2.16	0.47	0.47	0.43	0.5	0.04	0.12	0.12	0.03	0.22	0.11	0.45	0.45	0.42	0.48
1	Polyline ZM	2	34.87	33.21	37.27	2.07	0.57	0.57	0.54	0.61	0.04	0.15	0.15	0.03	0.27	0.13	0.55	0.55	0.52	0.58
2	Polyline ZM	3	16.22	14.13	18.44	2.18	0.27	0.27	0.23	0.3	0.04	0.07	0.07	0.01	0.13	0.06	0.26	0.26	0.22	0.29
3	Polyline ZM	5	14.97	12.76	17.25	2.29	0.25	0.25	0.21	0.28	0.04	0.06	0.06	0.01	0.12	0.06	0.24	0.24	0.2	0.27
4	Polyline ZM	6	20.89	18.94	23.54	2.36	0.34	0.34	0.31	0.39	0.04	0.09	0.09	0.02	0.17	0.08	0.33	0.33	0.3	0.36
5	Polyline ZM	7	16.37	13.91	18.98	2.57	0.27	0.27	0.23	0.31	0.04	0.07	0.07	0.01	0.13	0.06	0.26	0.26	0.22	0.29
6	Polyline ZM	4	22.83	18.29	27.81	4.87	0.37	0.37	0.3	0.46	0.08	0.1	0.09	0.02	0.19	0.09	0.36	0.36	0.29	0.43
7	Polyline ZM	9	13.72	13.19	14.91	0.94	0.23	0.23	0.21	0.24	0.02	0.06	0.06	0.01	0.11	0.05	0.22	0.22	0.21	0.22
8	Polyline ZM	8	34.47	32.71	37.06	2.23	0.57	0.57	0.53	0.61	0.04	0.15	0.15	0.03	0.27	0.13	0.54	0.54	0.52	0.57
9	Polyline ZM	10	23.65	20.49	27.12	3.37	0.39	0.39	0.34	0.44	0.06	0.1	0.1	0.02	0.19	0.09	0.37	0.37	0.33	0.42
10	Polyline ZM	11	10.53	5.7	15.65	5.18	0.17	0.17	0.09	0.26	0.08	0.04	0.04	0.01	0.1	0.05	0.17	0.17	0.09	0.25
11	Polyline ZM	12	11.42	4.51	18.5	7.15	0.19	0.19	0.07	0.3	0.12	0.05	0.04	0.01	0.11	0.06	0.18	0.18	0.07	0.29
12	Polyline ZM	13	12.18	11.48	13.25	0.91	0.2	0.2	0.19	0.22	0.02	0.05	0.05	0.01	0.1	0.05	0.19	0.19	0.18	0.2
13	Polyline ZM	14	24.24	17.83	30.71	6.65	0.4	0.4	0.29	0.5	0.11	0.1	0.1	0.02	0.2	0.1	0.38	0.38	0.28	0.48
14	Polyline ZM	15	23.75	22.24	25.56	1.68	0.39	0.39	0.36	0.42	0.03	0.1	0.1	0.02	0.19	0.09	0.37	0.37	0.35	0.4
15	Polyline ZM	16	15.12	14.29	16.44	1.11	0.25	0.25	0.23	0.27	0.02	0.06	0.06	0.01	0.12	0.06	0.24	0.24	0.23	0.25
16	Polyline ZM	17	14.07	12.01	16.23	2.13	0.23	0.23	0.2	0.27	0.04	0.06	0.06	0.01	0.11	0.05	0.22	0.22	0.19	0.25
17	Polyline ZM	19	9.02	6.85	11.21	2.22	0.15	0.15	0.11	0.18	0.04	0.04	0.04	0.01	0.08	0.04	0.14	0.14	0.11	0.18
18	Polyline ZM	20	1.21	0.62	2.16	0.79	0.02	0.02	0.01	0.04	0.01	0.01	0	0	0.01	0.01	0.02	0.02	0.01	0.03
19	Polyline ZM	21	11.33	9.24	13.62	2.24	0.19	0.19	0.15	0.22	0.04	0.05	0.05	0.01	0.09	0.05	0.18	0.18	0.15	0.21
20	Polyline ZM	22	17.81	14.63	21.28	3.34	0.29	0.29	0.24	0.35	0.06	0.08	0.08	0.01	0.15	0.07	0.28	0.28	0.23	0.33
21	Polyline ZM	23	32.27	25.79	38.83	6.67	0.53	0.53	0.42	0.64	0.11	0.14	0.14	0.03	0.26	0.13	0.51	0.51	0.41	0.61
22	Polyline ZM	24	6.24	2.06	10.61	4.37	0.1	0.1	0.03	0.17	0.07	0.03	0.02	0	0.06	0.03	0.1	0.1	0.03	0.17
23	Polyline ZM	25	9.87	8.69	11.27	1.31	0.16	0.16	0.14	0.19	0.02	0.04	0.04	0.01	0.08	0.04	0.16	0.16	0.14	0.17
24	Polyline ZM	26	45.72	40.13	51.51	5.82	0.75	0.75	0.66	0.85	0.1	0.19	0.19	0.04	0.35	0.17	0.72	0.72	0.63	0.82
25	Polyline ZM	27	7.01	4.82	9.29	2.26	0.12	0.11	0.08	0.15	0.04	0.03	0.03	0.01	0.06	0.03	0.11	0.11	0.08	0.14
26	Polyline ZM	29	34.71	31.15	38.31	3.64	0.57	0.57	0.51	0.63	0.06	0.15	0.15	0.03	0.27	0.13	0.55	0.55	0.49	0.6
27	Polyline ZM	30	44.98	39.34	52.81	6.97	0.74	0.74	0.65	0.87	0.12	0.2	0.19	0.04	0.38	0.19	0.71	0.71	0.63	0.8
28	Polyline ZM	28	36.34	29.93	42.98	6.7	0.6	0.6	0.49	0.7	0.11	0.15	0.15	0.03	0.28	0.14	0.57	0.57	0.47	0.68
29	Polyline ZM	31	17.76	16.46	19.1	1.35	0.29	0.29	0.27	0.31	0.02	0.08	0.08	0.02	0.14	0.06	0.28	0.28	0.26	0.3
30	Polyline ZM	33	3.95	2.94	5.1	1.1	0.06	0.06	0.05	0.08	0.02	0.02	0.02	0	0.03	0.02	0.06	0.06	0.05	0.08
31	Polyline ZM	32	23.47	19.21	27.81	4.37	0.38	0.38	0.31	0.46	0.07	0.1	0.1	0.02	0.18	0.09	0.37	0.37	0.3	0.44
32	Polyline ZM	34	10.27	5.66	14.47	4.46	0.17	0.17	0.09	0.24	0.07	0.04	0.04	0.01	0.09	0.04	0.16	0.16	0.09	0.23