Imaging Active Tectonics Unit 2: Identifying Faulting Styles, Rates and Histories Through Analysis of Geomorphic Characteristics – Student Exercise

Bruce Douglas, Indiana University
Gareth Funning, University of California, Riverside

2.1 Introduction

The advent of airborne Lidar has been a boon for studies of fault geomorphology as applied to seismic hazard. Large and well-funded projects, such as the B4 survey of the Southern California Earthquake Center and the GeoEarthScope project, have led to the collection of high-resolution topographic data over many of the active faults in the United States and across the globe. The ability to measure returns from the ground, rather than the tops of trees or bushes, is especially useful in vegetated areas. Due to the open data policy of funding agencies such as the National Science Foundation (which funded a lot of the data collection efforts), we can access the full resolution data ourselves, from the OpenTopography online portal.

This unit will have two elements. First, we will identify locations where the signature of active faulting (strike-slip faulting, normal faulting, and thrust faulting) is captured in the landscape, and learn to interpret those geomorphic features associated with each fault type. Such features might include fault scarps, altered stream drainage patterns including basin asymmetry, wind and water gaps, and scarps or benches. These features represent the interplay between tectonic processes such as earthquakes, and surface processes such as stream erosion/deposition and climate. Second, we will use the different scales and ages of offset features on a number of faults such as the San Andreas Fault to estimate both a slip rate and a recent slip history of large earthquakes. In this unit we will use freely available high-resolution hillshaded imagery in combination with optical imagery from Google Earth.

2.2 The geomorphic expression of strike-slip, normal, and thrust faulting

Here, we will "visit" a number of different faults in the Western Cordillera of North America, as well as other faults in active tectonic settings from around the world, that show diagnostic geomorphic features that reflect the characteristic displacement pattern for the main end member fault types.

2.2a Identifying diagnostic fault features

Initially you will work in a small group exploring a particular fault to develop a procedure and set of criteria for evaluating the Lidar and optical (satellite or air photo) images. You will then need to make a summary presentation to the rest of the class describing the geomorphic features and analysis techniques that you determined to be the most robust indicators of the specific fault type you were working with. Groups will be assigned faults that will include the three major fault types so that after the presentations are made, all students will have acquired a set of criteria for recognizing the three fault types.

- Using either a computer or paper copies, create overlays and annotations of the fault and primary geomorphic features that are found in association with the fault that help in defining what type of fault it is.
- Make a presentation to the class to present your group's findings, outlining a procedure and criteria for determining the type of fault based on the characteristic topographic features you can identify.
- In your presentation, consider how robust the criteria that you have identified are, and what potential sources of error there might be. Compare these with the findings of other groups—could differences in approach lead to differences in interpretation between groups? Could similar features appear be associated with different types of faults?

2.2b Putting it into practice

Following this initial work, you are tasked with examining a minimum of four different sites (ensuring that all three types of faults are included) and reporting your findings in a written document (online document preparation is an option if resources are available). The document should contain short descriptions, illustrations and interpretations of each feature for each of the localities.

Complete this for four of the following sites, making sure to have at least one each of the three different types of faults (normal, reverse, and strike-slip). Your instructor will advise you on whether you have a good variety of sites and give you directions on how to download the data.

Site 1: Denali fault

Site 2: Wasatch fault

Site 3: Garlock fault

Site 4: Teton fault

Site 5: Seattle fault zone

Site 6: Shoshone Lake fault

Site 7: San Andreas fault

Site 8: Wheeler Ridge fault

Site 9: San Cayetano fault

Site 10: Mirror Plateau fault

- Produce a document (e.g. an online Google document), give it an appropriate name (e.g. the lab number and your name) and share it with the instructor (paper copy turn in, email or Dropbox location to be provided).

- Write an introduction describing the benefit of using bare earth Lidar hillshade imagery in combination with the imagery and topography that Google Earth provides (you may want to wait until you have looked at a few of the sites).
- For each site you analyze, complete the following:
    - Identify the trace of the fault type in question, and its accompanying geomorphic features.
    - Create topographic profiles perpendicular to the fault trace.
    - Write a short, one-paragraph summary describing and interpreting the features that you find, noting the three primary ones that you consider to be the most diagnostic for the particular fault type found in the area. Include the answers to the specific questions that are asked below.
    - Include with the paragraph one or more annotated images that show these features. Refer to these images in your text.
    - Supply appropriate section headings and figure captions to make your answer understandable.

Google Earth Tips

a. Make topography profiles:
   Add > Path
   Make path where you want to profile > Ok
   Right-click on the path in the Places window > Show Elevation Profile
b. Note: Google Earth elevation data is not pulled from the lidar data but from the less-detailed general topographic data it uses for the background. In some places fault offsets will be visible in the elevation profiles and in other places the offsets will not show up in the profiles. In that case just estimate as best you can from the shaded relief
c. It can help to look at the optical imagery as well as the lidar shaded relief imagery.
d. In the Layers pane, have Terrain unchecked for sites with significant vegetation. In some areas Google Earth does seem to have the terrain tied to treetop elevations. Having Terrain off can lead to better visibility for the shaded relief image. However, when looking at the topographic profiles, you will probably want to have Terrain on because it makes them easier to view.
e. Sometimes you have to zoomed in further to see the lidar image. Try playing with zooming in and out if you have trouble viewing it.

Questions to answer about each of the four selected sites

1. What is the sense of the faulting here, and how can you tell?
2. What is the orientation of the fault? Is it possible to determine the dip direction of the fault? Does it seem to be exposed at the surface?
3. What is the relationship between the characteristic topographic features such as small ridges or drainage(s) adjacent to, or crossing the fault and the surficial processes that create these features?
4. How can you use geomorphic features to determine the sense of faulting?
5. How can the topographic profiles be used in your analysis of the fault type and amount of displacement?
6. Given an estimated average slip rate of 10 mm/yr, how much time is represented by the largest geomorphic feature offset?

7. Comment on the interplay between fault displacement creating changes in the topographic relief and the ongoing surficial processes that work to redistribute surficial materials resulting in erosion and/or deposition and modification of new (e.g. a fault scarp) and existing features such as stream channels or alluvial fans.

2.3: Fault slip rates and slip per event: The San Andreas fault at Wallace Creek

(Adapted from exercise by Open Topography [Sarah Robinson] and UNAVCO [Shelley Olds])

Wallace Creek (35.271°N -119.827°E) is one of the most famous offset streams in the world, and it is an excellent place to study fault geomorphology. It is located within the Carrizo Plain National Monument, within a segment of the San Andreas fault that is both straight and (relatively) fast moving. We can use this large stream offset, and the smaller offsets of its neighbors, to understand the earthquake history and earthquake potential of this part of the San Andreas. Again, you will be asked to interpret these features, and report your findings in a document.

- Open the Wallace Creek kmz files.It includes Wallace Creek on the northwest side of the lidar area and 4-km section of the San Andreas Fault to the southeast.
- Make a new section in your document with an appropriate heading.
- Estimate the slip rate of the San Andreas Fault at Wallace Creek. Complete the following tasks and write a paragraph in your document detailing the answers:
    - Measure the offset of Wallace Creek. Provide reasonable estimates of uncertainty in this measurement (e.g. what are the maximum and minimum possible values?)
    - Sieh and Jahns (1984) dated the sediments in the channel on both sides of the fault to have been deposited 3700 ± 150 years ago, from charcoals found through trenching. What does this imply in terms of an average slip rate for the last few millennia?
    - Combine the uncertainties in the two measurements to estimate a combined uncertainty for the slip rate estimate. (Propagation and Compounding of Errors http://statpages.org/erpropgt.html with additional Internet sites includes those from SERC to be listed for information on "combining uncertainties.")
- Write a short paragraph on the different drainages seen across the Lidar data set, how deeply they incise, and how widely, and how this may relate to offset.
    - Look at the different offset streams seen throughout the area covered by Lidar. What controls the size and depth of incision of each incising stream? Comment on this in your document.
    - How might the sizes of streams relate to the scale of offsets? In which streams are you more likely to see multiple earthquakes? Individual earthquakes? Comment on this in your document.
- Write a paragraph, providing illustration as required, on the recent earthquake history in the Carrizo Plain. Please include the following:

- Look at the small-scale offset streams (< 30 m). Being careful to use the same approach for each offset (e.g. measuring from the center of the channel each time) produce a histogram of offset distances for all the small-scale stream offsets in the whole Lidar data set, and add that to your online document. Use an appropriate precision for your measurements, and an appropriate interval for your histogram (e.g. 5 m). Note: You can make a histogram using an online option (ex. http://www.shodor.org/interactivate/activities/Histogram/) or use Excel (https://www.excel-easy.com/examples/histogram.html)
- Comment on the distribution of offsets as seen in your histogram. What are the likely causes of any peaks?
- Directly measure, or otherwise estimate the average slip per earthquake in the Carrizo Plain, and the maximum and minimum time we would expect between earthquakes.
- The last event on the Carrizo Plain occurred in 1857, and ruptured all the way to the Cajon Pass. In what time frame might we expect a repeat event?