Why go to Mars for examples of normal fault systems?

- On Earth, even young, active normal faults are modified rapidly by erosion and deposition, obscuring the surface expression of features.
- On Mars, by contrast, one can find relatively pristine normal fault features in which very little modification has occurred.
- Mars normal faults offer an ideal opportunity for students to study the features of real normal fault systems in map view, rather than simply in stylized map-view diagrams in textbooks, and to gain experience in recognizing features in a pristine setting that students can transfer to studying normal fault systems on Earth.
- Mars images also allow students to do simple calculations of fault slip and regional extension that help them put into perspective the kinematics of normal fault systems.

What do students do in this activity?

- Before class, students complete a homework assignment that familiarizes them with accessing and downloading Mars THEMIS images and in which they download images of normal faults in the Ceraunius Fossae of northern Tharsis.
- In class, I start with a short discussion about how THEMIS images are obtained, why the images are in strips, what resolution means, and so on.
- Students then examine their Mars images and identify normal fault features.
- Students determine the range of graben widths and then calculate throw for one fault using shadow width to calculate graben depth.
- Students then calculate heave for the same fault, assuming a fault dip of 60°.
- Students then estimate crustal extension along a line across several grabens.

What prior knowledge do students need?

- This activity is written assuming that students know the general terminology for normal fault systems (graben, horst, relay ramp, hangingwall block, heave, throw, dip, etc.). The exercise also is written assuming that students can figure out how to use trig to solve for fault heave and throw.
- The activity would be very easy to modify, however, so that it could be done by students who have very little background in structural geology or who would struggle trying to figure out the trig part by themselves. For students with less background, the activity could be modified to introduce needed terminology or to give them the trigonometric relationships necessary to solve the problem. With such minor modifications, this activity could, in fact, be used in introductory geology.

Why are THEMIS images ideal?

- Easy access via interactive map, lat/lon, or image # interfaces; superb cataloging
- Parameter table has clickable glossary for all underlined terms.
- Each THEMIS image has data crucial for graben shadow calculations:
  - Image scale and size
  - Direction of illumination (Solar Azimuth)
  - Angle of illumination (Incidence Angle)

Homework

- Students learn to navigate the THEMIS image data base and locate images of normal fault features in northern Tharsis in the area of the box outlined above.
- Each student chooses three THEMIS images that he/she thinks illustrates interesting normal fault features, downloads a jpeg for each, inserts each into a Word doc, and annotates each with information on lat/lon, resolution, solar azimuth, and incidence angle.

In-class Activity

- Students have generally poor intuition about percent elongation necessary to produce features such as the ones on the THEMIS images. So, we do a back-of-the-envelope calculation about percent extension across the region at right. Students do the following:
  - pick a line ~perpendicular to graben trend
  - define throw on sunlit faults
  - use shadow widths to estimate total throw on NE-facing faults along the line
  - assume that each shadowed fault is paired with a sunlit fault of identical throw (because we can't calculate directly the throw on sunlit faults) and double the total throw
  - use the total throw and an assumed fault dip of 60° to calculate a total heave
  - calculate percent extension along the line using (1/2ht)/l x 100

  We then finish by discussing what the uncertainties are, the validity of our assumptions, and how much our answers might have differed if we changed some of our assumptions.

Comments & Suggestions

- Students use solar incidence angle, solar azimuth, and shadow length to calculate graben depth and estimate fault throw. We have a short discussion to put graben size and throw into perspective relative to landmarks in the vicinity of the College.
- This THEMIS image is ideal for having students explore stepovers, relay ramps, changes in slip along strike, fault dips, etc.
- This THEMIS image shows the complex graben of Acheron Fossae
  Image credit: NASA/JPL/Arizona State University