Using THEMIS Images of Mars Graben in a Structural Geology Course

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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.

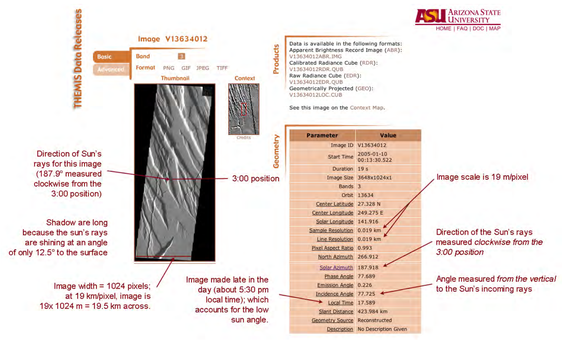
What do students do in this activity?

- 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 graben.

What prior knowledge do students need?

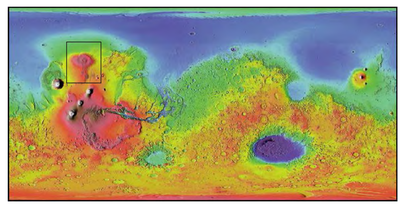
- This activity is written assuming that students know the general terminology for normal fault systems (graben, horst, relay ramp, hangingwall block, heave, throw, dip, etc.). The exercise also is written assuming that students can figure out how to use trig to solve for fault heave and throw.
- The 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?



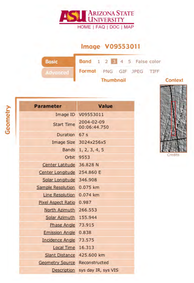
- Easy access via interactive map, lat/lon, or image # interfaces; superb cataloging
- Parameter table has clickable glossary for all underlined terms.
- Each THEMIS image has data crucial for graben shadow calculations:
  - Image scale and size
  - Direction of illumination (Solar Azimuth)
  - Angle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

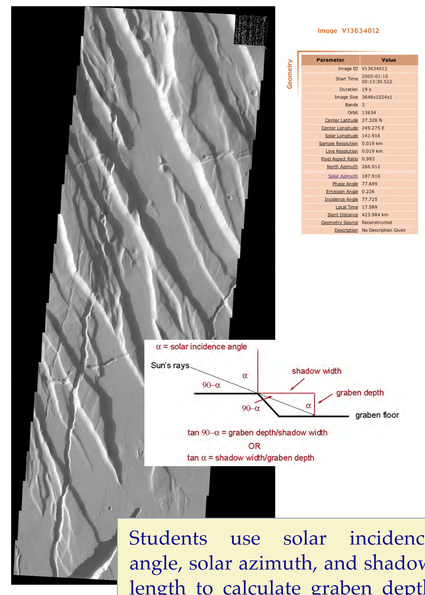
In-class Activity



This THEMIS image is ideal for having students explore stepovers, relay ramps, changes in slip along strike, fault dips, etc.

- In class, students compare homework printouts and identify normal fault features in map view (horst, graben, hangingwall and footwall blocks, relay ramps, stepped graben, en echelon geometry, etc.).
- Students then work with the image at left to explore specific aspects of normal fault slip.
- After determining throw as described at right, students discuss what they would need to know in order to calculate heave for the same fault. After discussion of the issues, students calculate the heave assuming a fault dip of 60°.

- Students have generally poor intution 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 across as much of the image as possible
  - 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 $(l_f - l_o)/l_o \times 100$
- 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.



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.

Believe it or not, this BOE calc gives extensions in the range of 4-10%, depending on the line and on how carefully students estimate. This is within the range of published values for Ceraunius Fossae. Students are always surprised by how little extension is needed to produce these spectacular features.

Borraccini, F., Lanci, L., Wezel, F.C., and Baioni, D., 2005, Crustal extension in the Ceraunius Fossae, northern Tharsis region, Mars: Journal of Geophysical Research, v. 110, EO6006, doi:10.1029/2004JE002373. *Calculated extension using MOLA data along two profiles to be 4-6%, with local max extension up to about 13%. Assumed fault dip of 60°.*

Golombek, M.P., Tanaka, K.L., and Franklin, B.J., 1996, Extension across Tempe Terra, Mars, from measurements of fault scarp widths and deformed craters: Journal of Geophysical Research, v. 101, no. E11, p. 26,119-26,130. *Used measurements of normal fault scarp width plus average scarp slope data on Viking images. Calculated strains of 2-3%. Fault dip assumed to be 60°±15°. Also determined extension using deformed Noachian craters, which gave mean strain of 2%.*

Golombek, M.P., Franklin, B.J., Tanaka, K.L., and Dohm, J.M., 1997, Extension through time across Thaumasia, Mars: 28th Lunar and Planetary Science Conference.

Hauber, E. and Kronberg, P., 2005, The large Thaumasia graben on Mars: is it a rift? Journal of Geophysical Research, v. 110, E07003, doi: 10.1029/2005JE002407. *Extension determined using gridded MOLA topography; strain calculated at 1-3%. Assumed fault dip of 60°.*

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Wilson, Lionel and Head, James W., III, 2002, Tharsis radial graben systems as the surface manifestation of plume-related dike intrusion complexes: models and implications: Journal of Geophysical Research, v. 107, no. E8, 5057, 10.1029/200IJE0001593.

Comments & Suggestions

Background image shows the complex graben of Acheron Fossae
Image credit: NASA/JPL/Arizona State University