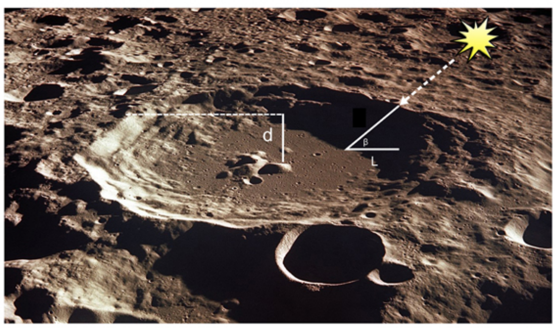
Measuring the depth of Meteor Crater and the height of its rim

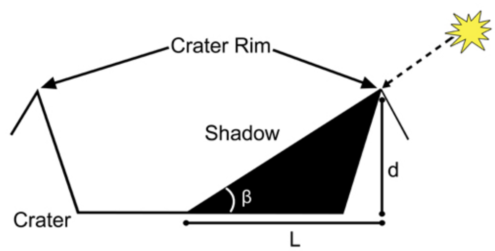
A classic image analysis technique is to use shadow lengths to determine vertical dimensions. In planetary science, shadow lengths are often used to determine the depths of impact craters (on the Moon, Mars, and elsewhere) and the heights of their rims.

The principles of the method are:

The depth of a crater can be determined from the length of the shadow cast by the crater rim and the angle of the incoming light source. If the angle of incoming light and image scale are provided with an image, you can measure shadow lengths and calculate crater depths.



Lunar complex crater Daedalus. Detail of NASA Image AS11-44-6609.



As illustrated in the figures above, using the geometry of triangles, if we know β, the angle of incoming light, and can measure L, the length of the shadow, we can calculate d, the crater depth:

The tangent function relates d, L, and β as follows:

$$\tan \beta = d / L$$

Given L and β, multiply both sides by L to get:

$$d = L * \tan \beta$$

Image Credit: LPI (Andrew Shaner & David A. Kring)

The same method can be applied to Barringer Meteorite Crater (aka Meteor Crater) using an image the astronauts captured from the International Space Station on March 3, 2014 from an altitude of 221 nautical miles. To conduct this exercise, we will use ImageJ, which is a public domain Java image processing program that was inspired by NIH Image.

Open ImageJ

The instructions that follow are for the PC version of ImageJ. The program works on MAC platforms, too, although there may be minor variations in how the menu bar looks and how the mouse works. ImageJ can be downloaded from http://imagej.nih.gov/ij/.

Open file

Save the ISS image of the crater from the laboratory website (http://lpi.usra.edu/exploration/training/resources/measuring_meteor_crater/). The filename is Barringer_iss038e067508. From the ImageJ menu bar, select "File." From the pull-down menu, select "Open." Select "Barringer_iss038e067508.jpg" from the path where you save the image. The image should open in a new window.

The field of view – getting oriented

Barringer Meteorite Crater (aka Meteor Crater) appears in the right center of the image. It is approximately 1.25 km in diameter. The Canyon Diablo cuts across the landscape along the bottom of the image. The canyon is west of the crater. Interstate 40 cuts across the far left side of the image and runs roughly east-west.

Set scale of image

There is a gravel road a few hundred meters west of the crater. If you zoom in (Ctrl +), you will see smaller dirt roads intersecting the gravel road. Two intersections are marked "A" and "B."

From the menu bar, select the line tool icon. If it is not already preselected for "Straight Line," select "Straight Line."

Place the cursor at the intersection marked "A," click on that point, and then move the cursor along the road to the intersection marked "B" and click again. The pixel-length will appear along the base of the menu bar.

From the menu bar, select "Analyze" and then "Set Scale" from the pull-down menu. The distance in pixels measured from A to B should automatically appear in that box. If it does not, you can manually enter the number you measured from A to B. In the "Known distance" box, insert the value "1.322." In the "Unit of length" box, insert "km." The scale in units of pixels/km should then appear above the button "OK." Select the button "OK."

Sun angles

As illustrated above, the method depends on knowledge of the sun angle. In this case, the sun angle relative to the surface (or sun elevation) was 17 degrees.

The azimuth of the sun is also important, because that indicates the direction along which shadows are cast on the ground. In this case, the azimuth of the sun was 249 degrees as measured clockwise from the north.

To determine the azimuth of the sun on the image, select the angle tool icon. This tool works in 180 degree swaths (rather than a full 360 degree circle). Thus, one needs to first subtract 180 degrees from 249 degrees to obtain the angle (69 degrees) needed for the tool.

We will use the road between "A" and "B" as a reference line. That road is oriented 3.5 degrees east (clockwise) of north. Thus, we need to subtract 3.5 degrees from 69 degrees to obtain the final angle (65.5 degrees) we will use with the angle tool.

Using the angle tool, click on the intersection at "B." Then move the cursor to the intersection at "A" and click again. Finally, move the cursor towards the west (towards the sun). Adjust the position of the cursor (left or right) until the angle along the base of the menu bar reads 65.5 degrees. Click again. You now have a line that is oriented along the azimuth of the sun. Shadows will fall parallel to that line towards the east. If you like, you can swing the angle tool 180 degrees to create a shadow fall line in the direction of the crater.

Use the pencil tool to draw one or more lines parallel to that shadow fall line. In the next step of the exercise, the angle tool will disappear, so these lines will be needed to help guide shadow measurements.

Measuring for crater depth

Select the line tool icon from the menu bar. Begin a line on the west rim of the crater where a shadow begins and draw the tool opposite the sun's azimuth (i.e., parallel to the lines established in the preceding step) until you reach the edge of the shadow on the crater floor. The length of that shadow will appear along the base of the menu bar. Because the scale was set in units of km/pixel, the length of the shadow will be in units of km. Record that number.

Repeat the measurement at several locations from the west rim of the crater and tabulate the data.

Using the trigonometric expression in the illustration box above, use those shadow lengths and a sun elevation angle of 17 degrees to calculate crater depth.

Discuss the results. Is the calculated depth the same at each location? If not, why not? Crater depth/diameter ratios for simple bowl-shaped craters are often about 0.20. Is that the value you obtained? If not – and assuming your measurements and calculations are correct – what might that imply?

Measuring for crater rim height

Select the pencil tool from the menu bar. Begin a line on the east rim of the crater where a shadow begins and then draw the tool opposite the sun's azimuth (i.e., parallel to the lines established previously) until you reach the edge of the shadow on the slope around the crater. The length of the shadow will appear in units of km along the base of the menu bar.

Repeat the measurement at several locations from the east rim of the crater and tabulate the data.

Using the trigonometric expression in the illustration box above, plug in those shadow lengths and a sun elevation angle of 17 degrees to calculate crater rim height.

Discuss the results. Is the calculated rim height the same at each location? If not, what does that imply?

Finally, use both the crater depth measurements from the previous section and the rim height data in this section to determine the depth of the crater beneath the level of the landscape that surrounds the crater.

For those who are interested:

Additional ISS and STS images of Meteor Crater can be found at http://www.lpi.usra.edu/publications/books/barringer_crater_guidebook/shuttleiss/

Examples of ISS images of other terrestrial impact craters can be found at http://www.lpi.usra.edu/lunar/analogs/impactcraters/

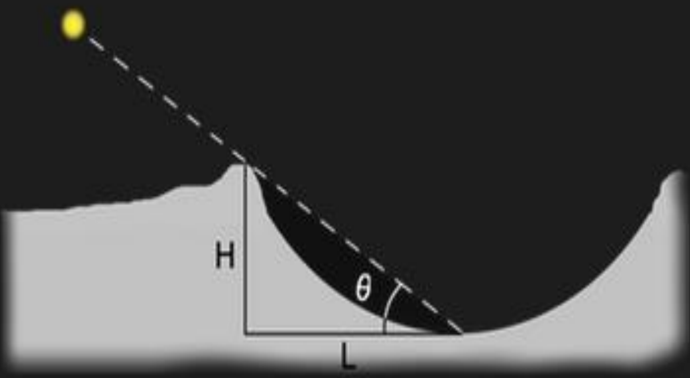
A complete inventory of ISS and STS images can be found at The Gateway to Astronaut Photography of Earth (http://eol.jsc.nasa.gov/).

Finally, we thank the crew of Expedition 39 and the NASA Johnson Space Center's Earth Science and Remote Sensing Unit for capturing the image used in this laboratory exercise.

Part 3: Measure the Height of Lunar Craters

« Part 2: Observing Lunar Features   Observing Lunar Features

Sizes of Lunar Craters



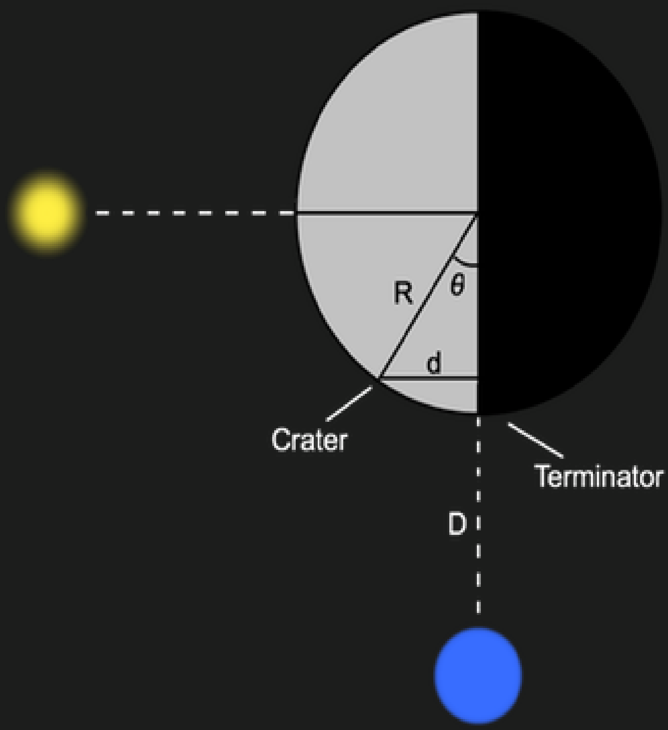
It is possible to approximate the height of various surface features (like impact craters), by measuring the shadows they cast.

As shown in the diagram to the right, a crater with a height, H, casts a shadow with a length (as seen from above), L. The angle θ is the angle that the shadow makes with the lunar surface.

The relationship between the height and the length then can be expressed as:

$$\tan\theta = \frac{H}{L}$$

The terminator (the division between the illuminated and dark halves of the Moon) forms another triangle with the Sun and the Earth. As shown in the diagram to the right.



Here, θ is the angle formed between the line from the terminator to the Eath, and the line from the Moon's center to the crater, which can be expressed as:

$$\sin\theta = \frac{d}{R}$$

Where **R** is the radius of the Moon, and **d** is the linear distance from the crater to the terminator.

As a crater comes closer and closer to the terminator line, both angles become smaller. For small angles (<10 degrees) we can approximate the values as:

$$\tan\theta = \sin\theta = \theta$$

Making this small angle approximation, we are able to determine the height of a feature on the moon using images.

Height of Lunar Craters

By measuring the angular size of the crater's shadow, and the angular distance from the crater to the terminator, using the method for converting angular to linear distances learned in the parallax lab - We can now approximate the height of the crater as:

$$H \cong L \times \frac{d}{R}$$

Using the small angle formula, we can solve for the height. Here D is the average surface-to-surface distance from the Earth to the Moon, about 375,900 km.

$$d_{km} = \left(\frac{\theta_d}{206265''}\right) \times D_{km}$$