Lunar and Planetary Institute

Impact Cratering Lab

The Impact Cratering Lab exercises found on this website introduce a geologic process that has had major consequences for the geology of all solid bodies in the solar system and for the biology of Earth. It is becoming the focus of interest for scientists in many fields including physics, geology, and biology. The exercises found on this website introduce the fundamental concepts of impact cratering including cratering mechanics, crater morphology, and crater ejecta. These exercises also introduce basic image processing techniques.

The image processing software used in these activities is ImageJ. ImageJ is a public domain, Java-based image processing program inspired by NIH Image for the Macintosh. (If you do not have Java installed on your computer you can download it **here** for free.) ImageJ can display, edit, analyze, process, and print 8-bit, 16-bit, and 32-bit images. It can read many image formats including TIFF, GIF, JPEG, BMP, DICOM, FITS, and "raw". If you are not familiar with ImageJ, or NIH Image, it is recommended that you work through the **Quick Tutorial for Using ImageJ** before continuing to the **Impact Cratering Lab activities**. *NOTE: The ImageJ software does NOT need to be downloaded separately. The ImageJ software will automatically open with the images in the activities sections.

For High School Teachers

Though the Impact Cratering Lab has been used extensively in undergraduate courses, it is also appropriate for advanced high school students. These laboratory exercises can be integrated into a planetary geology unit or can stand alone as a way to illustrate physical concepts such as forces and energy.

The Impact Cratering Lab aligns with the following National Science Education Standards for Physical Science and Earth and Space Science:

Physical Science

- Motions and forces
- Conservation of energy
- Interactions of energy and matter

Earth and Space Science

- Origin and evolution of the earth system

The ancient highlands of the Moon are heavily cratered. This oblique view featuring the 160 km-wide Keeler Crater (background, right) on the Moon's surface was photographed by the Apollo 10 astronauts in May of 1969. Note the terraced walls of the crater and central cone. Several smaller simple craters dot the landscape, both within and adjacent to Keeler Crater. NASA Image AS10-32-4823

For University Instructors

This laboratory has been successfully used in undergraduate classes for non-science majors and in upper division classes for science majors.

Background Materials and Exercises

Quick Tutorial for Using ImageJ

Part 1 Background: Impact Cratering Mechanics and Crater Morphology

Part 1 Exercises: Impact Cratering Mechanics and Crater Morphology

Part 2 Background: Features and Motion of Crater Ejecta

Part 2 Exercises: Features and Motion of Crater Ejecta

After completing the laboratory exercises, students who are interested in calculating the sizes of impact craters on the Moon that are produced by asteroids might want to use the **Lunar Impact Cratering tool**.

Lunar and Planetary Institute

Impact Cratering Lab

Quick Tutorial for Using ImageJ

The purpose of this tutorial is to introduce a few basic image processing techniques and tools that will be necessary to complete the impact cratering activities.

Processing Images
It is often necessary to process, or "clean up" an image, and/or make certain features stand out more than others. In ImageJ, these functions can be found under the Process menu and include **Smooth** and **Sharpen** among others. The Smooth function blurs (softens) an image. It can be used to reduce "noise" in an image. An image with noise may appear speckled with random black, white, gray, or colored dots. The Sharpen function increases contrast and accentuates detail in an image. However, this function can produce, or contribute to, unwanted "noise" in the image. The **Enhance Contrast** function can also be useful in bringing out detail.

Sometimes one particular area of an image may need to be processed instead of the entire image. Selecting a particular area within an image can be done using one of a variety of selection tools. These tools can be found on the tool bar on the ImageJ applet window (Figure 1).
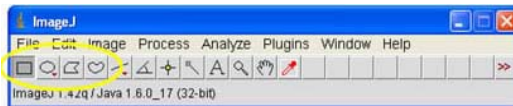

Figure 1. ImageJ selection tools include rectangular, circular, polygon, and free-hand.

TRY IT!!
Open the **Mercury_47** file. Use the various selection tools and image processing functions described above to enhance different areas of this image of the planet Mercury. This is an opportunity to experiment with the different image processing functions and tools.

IMAGE PROCESSING TOOLS

In most situations it is not just enough to "clean up" an image. It is also important to know something about the features seen in the image. Craters, boulders, lava flows, mountains, and channels are geologic features seen on many planetary bodies. Image processing tools can be used to determine the different properties of these objects such as length, width, depth, diameter, etc. Tools important to the impact cratering activities are the **Straight Line Selection** tool, useful for measuring distances between two points, and the **Angle Tool**. (Using the Angle Tool requires selecting three points in an image.) Another tool that may be useful is the **Magnifying Glass** which is used to zoom in and out of particular areas of an image. All three of these tools can be accessed from the ImageJ applet window (Figure 2).
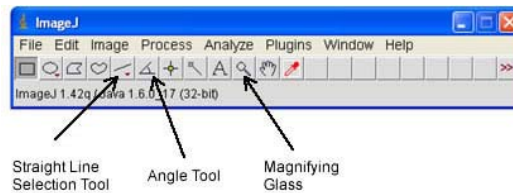

Figure 2. Location of ImageJ Straight Line Selection tool, Angle Tool, and Magnifying Glass.

TRY IT!!
Open the **Mercury_47** file. Before taking any measurements it is important to set the scale of the image. If you know the scale, measurements in different units, such as kilometers, meters, etc., can be made. The scale for the **Mercury_47** image is 0.14 kilometers per pixel. To set the scale, select Analyze -> Set Scale. Enter the measured distance as 1 pixel, and the known distance as 0.14 km. Enter "kilometer" in the "Unit of Length" field.

Using the Straight Line Selection Tool draw a line between the largest crater on the left edge of the image and any crater near the top of the image. Select ANALYZE -> MEASURE. A "Results" box will appear. Notice there are several different types of measurements reported in this box, including angle, area, and length. (In this instance, the length is the only measurement that means anything.) The number that appears under "Length" is the distance between the two craters. The units are in kilometers because that is what the scale was set in.

**Impact Cratering Lab home page**

Impact Cratering Lab
Part I: Impact Cratering Mechanics & Crater Morphology

Part I of this lab introduces the mechanics of crater formation and the morphology of different types of craters. The lab exercises in Part I utilize movies of impact experiments to demonstrate the formation and structure of impact craters. The diversity of crater morphologies is illustrated by images of craters.

BACKGROUND

Every body in the solar system has been subjected to the impact of objects such as comets, asteroids, or accretionary debris. The Moon, Mars, and Mercury all have heavily cratered surfaces that are the result of tens of thousands of impacts. Most satellites in the outer solar system also display thousands of impact craters. These heavily cratered surfaces record the period of an intense, solar-system-wide bombardment that ended about 3.8 billion years ago. All traces of this period have been erased from the surfaces of the Earth and Venus because these two planets have undergone relatively recent activity, including tectonic, volcanic, and erosional activity. Since this period of intense bombardment, the impact rate has been about 100 times less. However, during the past 500 million years there have been several very large impacts on Earth that have affected the entire planet.

Today, impacts from comets and asteroids still occur on all bodies in the solar system (Figure 1), including Earth. Meteor Crater (1.2 kilometers diameter, 183 meters deep, with a rim height of 30–60 meters) in northern Arizona was created by the impact of a 25-meter-diameter iron asteroid approximately 49,000 years ago. In 1908 a small asteroid exploded in the atmosphere over an unpopulated region of Tunguska in Siberia, creating an atmospheric shock wave so strong that it devastated a 10-km^2 area. In July 1994, about 20 fragments of Comet Shoemaker-Levy 9 impacted the atmosphere of Jupiter and created atmospheric disturbances larger than Earth.
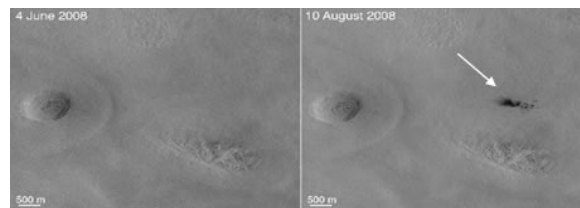

Figure 1. New martian crater. A new crater (white arrow) formed in the western Arcadia Planitia region of Mars between June 4, 2008, and August 10, 2008. Image Credit: NASA/JPL/MSSS.

IMPACT CRATERING MECHANICS

When a high-speed object strikes a surface, it produces an enormous amount of energy. This is called **kinetic energy** because it is caused by motion. The amount of energy produced in this way depends on the mass of the impacting object and the velocity with which it strikes the surface:

$$KE = \tfrac{1}{2}mv^2$$

where m is the mass of the object and v is its impact velocity. Asteroids hitting Earth have impact velocities from about 11 to 25 kilometers per second (about 25,000 to 56,000 miles per hour). Very large amounts of energy are released by impacts because the amount of energy released is proportional to the square of the velocity. For instance, an iron meteorite 1 kilometer in diameter hitting the surface at a velocity of 15 kilometers per second will release more than 4×10^{27} ergs of energy, the equivalent of about 100,000 one-megaton hydrogen bombs. The crater formed by such an event would measure about 10 kilometers in diameter. In an impact event the motion of the projectile (meteorite or comet) rapidly transfers kinetic energy to the planetary crust. Most of this energy takes the form of shock or pressure waves that travel at supersonic speeds through both the surface and projectile. These shock waves spread outward beneath the point of impact in a hemispherically expanding shell (Figure 2).
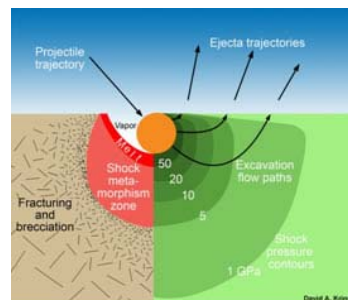

Figure 2. Diagram of the pressure field and flow of material in the excavation of an impact crater. The arrows show the upward and outward flow of material left behind the rapidly expanding shock wave. Ejecta fragments are initially ejected at a 45° angle. The green contours represent the peak pressures as the shock wave moves through the target material. The material lining the growing transient cavity is impact melt and the open area behind the impactor is vaporized target material. Ejecta near the impact site travels at very high speeds, whereas ejecta that emerges at greater distances travels at slower velocities. Image Credit: Illustration from an educational poster, Geological Effects of Impact Cratering, David A. Kring, NASA Univ. of Arizona Space Imagery Center, 2006. Modified from a figure in Traces of Catastrophe, Bevan M. French, 1998.

The strength of the shock waves is so great that the rocks are subjected to enormous pressures. The interaction of the shock waves with the unconfined surface, called a **free surface**, is responsible for excavating the crater. After passage of the shock wave, the compressed rock snaps back along the free surface. This produces a tensional wave — called a **rarefaction wave —** that decompresses and fractures the rock, setting it into motion along fracture planes. The net effect is to momentarily convert the rock into a fluid-like material that moves laterally upward and out of a steadily growing excavation cavity. In the meantime, the projectile has been largely destroyed by shock waves generated within it.

IMPACT CRATERING MORPHOLOGY

In general, impact craters have a raised rim with the floor at a much lower level than the surrounding terrai... surrounded by low, hilly terrain and swarms of small craters caused by material ejected from the crater. Th... overturned flap of target material. The upper layers of the rim consist of material that originally occurred at... therefore older. The deeper layers in the rim occurred at a shallower depth and are therefore younger. This **stratigraphy** (Figure 3) because the age of the rim material gets younger with depth in the rim.
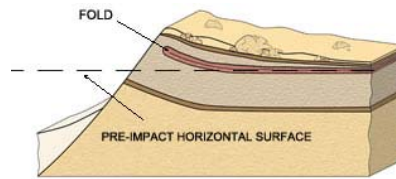

Figure 3. Illustration of inverted stratigraphy. Image Cred...
Guidebook to the Geology of Barringer Meteorite Cra...
Crater), ©2007, David A. Kring, Lunar and Planetary Inst...
No.1355.

The size of an impact crater depends not only on the amount of energy released by the impact, but also on... planet or satellite, and certain properties of the projectile and surface rocks. For a given size impact, a larg... planet with a weaker gravity field because it is easier to excavate the material. In all cases, a crater is man... projectile that formed it. Although the diameter of a crater depends on the complex interaction of many fact... approximation is that the excavation crater will be about 10 times larger than the projectile that formed it. T... considerably less than the diameter. For example, simple craters on the Moon have a depth/diameter ratio... diameter is about 5 to 7 times greater than the depth. For complex craters on the Moon (larger than 20 kilo... depth/diameter ratio ranges from 0.1 to 0.05, i.e., the diameter is from 10 to 20 times larger than the depth... slumping of the inner walls and formation of the central peak causes a shallower depth.

There are two basic types of impact crater, **simple** (Figure 4) and **complex** (Figure 5). A simple impact cra... no interior structure. The size of simple craters corresponds closely to the maximum diameter of the excav... larger diameters, the crater begins to change form. This takes place at a critical diameter called the **transit**... which generally depends on the gravity field of the planet or satellite. The transition diameter usually is sm... larger gravity field.

Complex craters have interior terraces and flat floors surrounding central peaks. In large craters the excav... by inward slumping of the crater walls. This produces **terraces** on the interior walls. The energy of impact i... fraction of the impacted material is melted to produce **impact melt**. Some of the impacted material is vapo... combination of impact melt and broken-up floor material called **impact breccia**. The mountains near the c... called **central peaks**. The sudden excavation of a crater causes the rocks beneath the impact point to und... high to very low pressures in an extremely short period of time. This causes the center of the floor to spring... central peak. At large diameters the central peak develops into a **peak ring**. Very large complex craters ha... are caused by large sections of the crust collapsing into the enormous excavation cavity.
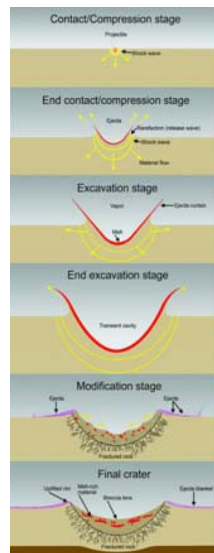
Figure 4. Formation of a simple crater. Image Credit: Illustration from an educa...
Geological Effects of Impact Cratering, David A. Kring, NASA Univ. of Arizon...
Center, 2006. Modified from a figure in Traces of Catastrophe, Bevan M. Fren...
from a figure in Impact Cratering on the Earth, Richard A. F. Grieve, Scientific A...
−73, 1990.

Figure 5. Formation of a complex crater. Image Credit: Illustration from an...
Geological Effects of Impact Cratering, David A. Kring, NASA Univ. of A...
Center, 2006. Modified from a figure in Traces of Catastrophe, Bevan M. ...
from a figure in Impact Cratering on the Earth, Richard A. F. Grieve, Scient...
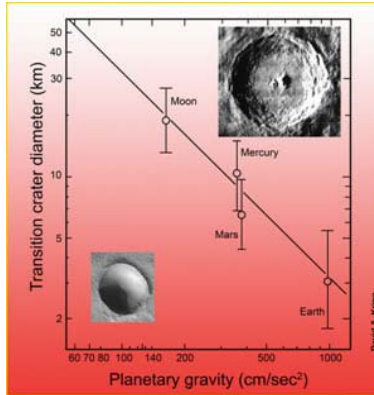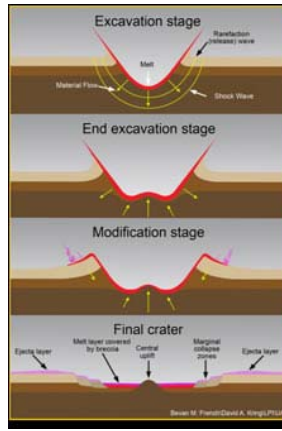*−73, 1990.*

Figure 6. *Transition diameters for the terrestrial planets and*
*Credit: Illustration from an **educational poster, Geological***
***Cratering**, David A. Kring, NASA Univ. of Arizona Space Im*

Part 1 Exercises: Impact Cratering Mechanics and Crater Morphology

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Lunar and Planetary Institute

Impact Cratering Lab Exercises
Part I: Impact Cratering Mechanics & Crater Morphology

Impact Cratering Mechanics

The Vertical Impact Stack file is a movie made of a stack of 24 individual images, or frames. It is a movie of an experimental vertical impact at the NASA Ames Research Center. This type of experiment uses small projectiles fired into targets, mostly composed of quartz sand, to simulate the physical properties of solid rock at very high velocities. The experiments take place in a vacuum chamber to simulate atmosphereless conditions. A projectile is fired from an ultra-high-speed gas gun at a velocity of 6 kilometers per second. Although the impact velocity is high by most standards, it is relatively slow compared to celestial body impacts, which mostly take place at velocities between approximately 10 and 72 kilometers per second. Nevertheless, experimental impacts such as these give us good insights into the formation of large impact craters.

Open the **Vertical Impact Stack** file. The scale of these images is 1 pixel = 0.156 centimeters. Set the scale of these images; Analyze > Set Scale. Enter the measured distance as 1 pixel, and the known distance as 0.156 centimeters. Enter "centimeter" in the "Unit of Length" field.

From the IMAGE menu, select STACKS > START ANIMATION. [A shortcut to starting, and stopping, any movie is to press the \ (backslash) key. There are also controls for starting/stopping the animation, and stepping through the frames, in the right side of the ImageJ applet window. Click on the double arrows (>>) then select **Stack Tools**.] Watch the movie. Notice how the crater's depth and diameter grow, and how the ejecta curtain moves. Slow down the movie to get a better view of the crater formation and ejecta curtain movement. Use the number keys (1-9) to run the movie at different speeds. (The higher the number, the faster the movie plays.) Next, cycle through the movie one frame at a time using the left or right arrow keys. Notice that each frame is numbered consecutively, with 1 being the first frame.

1. Compare the stages of formation of this experimental crater with those shown for a simple crater in the previous background section.

    a. On which frame of the experimental impact does the crater reach maximum depth? Measure the depth and record your answer.
    b. On which frame does it reach maximum diameter? Measure the diameter and record your answer.

2. Calculate the depth/diameter ratio of this crater.

3. On the second or third frame, measure the angle of the ejecta curtain with respect to the surface using the Angle Tool, and record your result.

Close this stack of images.

Open the **Oblique Impact Stack** file. This is another movie of an experimental hypervelocity impact in a vacuum chamber at the NASA Ames Research Center. This time the impact occurs at an angle of 30° from the vertical in order to show the effect of an oblique impact on the distribution of ejecta. Animate the stack, then step through the frames one at a time. Impacts that occur at angles to the surface form ejecta deposits that are asymmetrical, with most of the ejecta deposited on the *downrange* side of the crater.

4. On the second frame, measure the angle that the ejecta curtain makes with the surface on both the left and right side of the impact, and record your results.

    a. In what direction in the images was the projectile traveling?
    b. How did you reach this conclusion?

5. Is the shape of this crater different from a crater formed by a vertical impact? Explain your answer.

Close this stack of images.

Impact Crater Morphology

Open the **LO Crater** file. This is an image of a small crater on the Moon taken in 1965 by Lunar Orbiter III. You will measure the diameter and depth of this crater and calculate the depth/diameter ratio for comparison with the depth/diameter ratios of the experimental crater and simple craters on the Moon. There are two basic types of impact crater, simple and complex. A simple crater is bowl-shaped with little interior structure. A complex crater has terraced inner walls, a central peak or peaks, and a flat floor. Simple craters on the Moon have a depth/diameter ratio from 0.14 to 0.2, i.e., the diameter is about 5 to 7 times greater than the depth. For complex craters on the Moon (larger than 20 kilometers in diameter), the depth/diameter ratio ranges from 0.1 to 0.05, i.e., the diameter is from 10 to 20 times larger than the depth. This is because slumping of the inner walls and formation of the central peak causes a shallower depth.

In this image 1 pixel = 2.15 meters. Set the scale.

6. Measure the diameter of the crater and record your result.

7. Measure the length of the shadow cast by the crater rim and determine the depth of the crater. The depth of the crater can be determined from the length of the shadow cast by the crater rim on the floor of the crater. The depth of the crater is the shadow length times the tangent of the Sun angle, or $D = L \tan \beta$, where D is the depth, L is the shadow length, and β is the Sun angle. When this image was taken the Sun was 17.88° above the horizon. (If you have not yet been introduced to trigonometric functions, e.g., tangent, see your instructor.) Click here for more information on determining crater depth.

8. Determine the depth/diameter ratio of this crater.

    a. Does it agree with the ratio for the experimental crater you measured earlier, and the ratio for simple lunar craters?
    b. What does this tell you about this crater?

Open the **Ammonius and Lambert** files. **Tile** the images to make it easier to view both at the same time.
These lunar craters where photographed by the Apollo astronauts in orbit around the Moon. The interior st
very different. One is a complex crater and the other is a simple crater. On the Moon, the change from sim
at diameters between 15 and 20 kilometers.

9. Describe the major morphological differences between the craters and state which one is simple

10. From the characteristics alone, which crater is the largest? Explain your answer.

Cascade the images. Select WINDOW > CASCADE. The scale for the Ammonius image is 1 pixel = 0.038
scale of the Lambert image is 1 pixel = 0.0835 kilometers.

**11. Measure the diameters of Ammonius and Lambert. Do your measurements agree with your ans
above?**

Open the **Meteor Crater** file. This is a picture of Meteor Crater in northern Arizona. Its diameter is 1.2 kilor
183 meters. The crater was formed approximately 49,000 years ago. It is the largest, most well-preserved
Relatively few (about 120) impact craters have been identified on Earth because they are rapidly erased by
tectonics. Seventy percent of Earth's surface is water, so many craters formed on the ocean floors and we
However, impact craters are well preserved on other planets and the Moon. This is the reason you have be
craters on the Moon.

12. What type of impact crater is Meteor Crater? How did you reach your conclusion?

**13. How does this crater differ from the same type of crater on the Moon? What are some possible
differences?**

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Impact Cratering Lab
## Part II: Features and Motion of Crater Ejecta

Part I of this lab introduced the mechanics of crater formation and the morphology of simple and complex craters. The formation and structure of impact craters was demonstrated by movies of experimental impacts. The diversity of crater morphologies was illustrated by images of simple and complex craters. Part II of this lab introduces the features and motion of crater ejecta. The lab exercises make use of movies of experimental impacts to demonstrate the motion of ejecta. Calculations of the motion of ejecta will be performed using the ballistic equation.

Background

An impact crater is much more than a mere hole in the ground. The material excavated from the crater and deposited on the surrounding terrain is called **ejecta** (Figure 7). Ejecta deposits can be just as diverse as the crater morphology. Differences in the character of ejecta deposits indicate differences in the target material, partitioning of kinetic energy, and planetary environmental factors, such as surface gravity and atmospheric effects. In general, ejecta takes two forms: a continuous hilly covering of material from the crater rim outward to a distance of about a crater radius (called the **continuous ejecta blanket**), and swarms of smaller craters (called **secondary craters**) formed by the impact of individual fragments and clots of fragments thrown from the crater, mostly beyond the continuous ejecta blanket. **Crater rays** are bright material excavated by small secondary craters. Individual particles of ejecta travel on looping paths called **ballistic trajectories**, similar to the paths of artillery shells. The distance that ejecta can be thrown on a ballistic trajectory depends both on the angle and velocity at which the material is ejected and on the gravity field of the planet. This distance, d, is called the ballistic range and is mathematically expressed by

$$d = (V^2 \sin2\theta)/g$$

where V is the ejection velocity, θ is the ejection angle from the horizontal (surface), and g is the planet's gravity field. (This expression does not take into account the radius of curvature of the planet or satellite, or the decrease in gravity with height.)
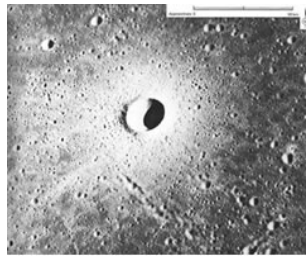
Figure 7. Bright ejecta around a lunar crater. NASA Image AS15-9348.

As you can see from this expression, for a given ejection velocity and angle, ejecta will travel farther on a planet with a weaker gravity field. Also, on the same planet (constant g) and for the same ejection velocity, ejecta will travel farther when ejected at an angle of 45° because the sine of angles greater or less than 90° (2 × 45°) is <1. In large impacts, ejecta can be dispersed over very wide areas of a planet or satellite. On the Moon, some rays and secondary craters extend for thousands of kilometers from their source crater. If a fragment is ejected at a velocity greater than the escape velocity of the planet or satellite, it will leave the planet altogether. Certain meteorites originated from the Moon and Mars, where they were accelerated by impacts to velocities greater than the escape velocities of these bodies.

Ejecta deposits can take several forms depending on the target properties, impact conditions, and other environmental factors. On the airless Moon and Mercury, the ejecta deposits are characterized by a hilly continuous deposit surrounding the crater, called the continuous ejecta blanket. This continuous deposit grades into strings (Figure 8) and clusters of small craters called secondary craters. Secondary craters are formed by the impact of large pieces of ejecta. The ejecta can travel great distances because of the low gravity field (see above equation) and the lack of an atmosphere. Some rays from the lunar crater Tycho extend for over 2000 kilometers. The bright rays on the Moon and Mercury are mostly strings of secondary craters that have disturbed the soil and brightened the surface.

Ejecta deposits are not always evenly distributed around an impact crater. Sometimes there is more ejecta on one side of the crater than the other. Impacts that occur at a relatively low angle spray ejecta preferentially in the direction of impact, the downrange direction. There is often a zone on the uprange side of the crater with little or no ejecta. The shallower the impact, the more asymmetrical the ejecta deposit.

In this activity you will study an experimental impact that divides the ejecta into packets to demonstrate ballistic trajectories of individual particles in the ejecta curtain. You will also make various measurements and analyses, including ejection velocity, asymmetry of ejecta blankets, and extents of outflow ejecta.

Figure 8. Chain of secondary craters on the lunar surface. Image Credit: *NASA/ Goddard Space Flight Center/Arizona State University*.

Part 2 Exercises: Features and Motion of Crater Ejecta

Impact Cratering Lab home page

Lunar and Planetary Institute

Impact Cratering Lab Exercises
Part II: Features and Motion of Crater Ejecta

Experimental Impacts: Following a Ballistic Trajectory

Open the Impact Ejecta Stack file. This is a movie of another experimental hypervelocity impact in a vacuum chamber at the NASA Ames Research Center. Animate the stack and observe what happens. This experiment has an aluminum plate with holes that split the ejecta curtain into packets. Notice that each component of the ejecta curtain is on a looping path called a ballistic trajectory. Click the double arrowheads (>>) in the ImageJ applet window and select **StartupMacros**. This activates the **pencil tool, paintbrush tool,** and **flood fill tool.** For this activity, you will use the **pencil tool** to mark individual pieces of ejecta.

Before continuing, you MUST convert the stack of images from grayscale to RGB color. To convert the stacks from grayscale to RGB color, select IMAGE > TYPE > RGB COLOR**.** Next, double-click the **color picker** (looks like an eyedropper). This opens the **Color Palette**. Choose a color that will stand out against the darker animation background. Click on the color and verify that the top of the larger two boxes below the palette is the color you chose. Right-click on the pencil tool and change the Pencil Width (pixels) to 10.

In the movie, choose three packets of ejecta that emerge from frame 15 or later. Mark the chosen ejecta packets with the pencil tool on each frame. Use the right or left arrow keys, or the Stack Tools, to flip through the frames. When you have marked 10–15 successive frames, run the animation at a slower speed. Notice the ballistic trajectory of the ejecta components you selected.

Stop the movie. Select IMAGE > STACKS > Z project. (NOTE: If at this point you are prompted to increase ImageJ's memory close both the image window and the ImageJ applet window and start over.) Select "OK" when the **ZProjection** window appears. This creates a new image that is an average of all 35 images that make up the movie. You should be able to see the marks you made with the pencil tool. Notice again the ballistic trajectory of each packet of ejecta. The highlighted packets of ejecta may be difficult to see. Enhance the image to emphasize these highlighted packets. (HINT: Select only the area surrounding the highlighted packets.) Print this enhanced image and include it with your lab writeup.

Lunar Ejecta

Open the Full Moon file. This is an Earth-based telescopic image of part of the full Moon. The bright and dark areas show brightness variations across the lunar surface. The arrow points to a small bright haloed impact crater. The reason this small crater is so prominent is because it is fresh. Most of the brightness you see in this image is the ejecta surrounding the crater. This image has its scale preset (in kilometers).

1. Measure the diameter of the bright halo and record your result. (Hint: A more accurate measurement can be made by using the Zoom Tool.)

Open the LO Crater file. This image was taken by Lunar Orbiter III in 1965. It is an image of the crater shown as a bright spot in the Earth-based telescopic full Moon image. The scale is 1 pixel = 2.15 meters. Use the top right corner box on the image to view the whole image on your screen.

2. Compare these two images of this crater.

> **a. Based on what is seen in the Lunar Orbiter picture, what is responsible for the brightness in the Earth-based image?**
> **b. What does the ejecta around this crater appear to be made up of (referring to texture not composition)?**

3. Measure the diameter of the crater and record your result.

4. How many times larger is the halo you measured on the Earth-based photograph than the crater that formed it?

Open the LO Crater Detail file. This image shows part of the crater and its ejecta blanket in more detail. Its scale has been preset (in meters). In this image you will study some of the characteristics of the ejecta deposit and determine the velocity of a boulder ejected from the crater. The distance, d, traveled by a fragment of ejecta is called the ballistic range and is mathematically expressed by:

$$d = (V^2 \sin 2\theta)/g$$

where V is the ejection velocity, θ is the ejection angle from the horizontal (surface), and g is the planet's gravity field. The Sun angle for this image is 17.88° above the horizon.

5. Measure the length and height of the rock marked A. To determine the height, measure the length of the rock. Then measure the length of the shadow it casts and derive its height from the same calculation used to find the crater depth in Part I. Record your results. What size room (in ft^2) would be needed to store this rock?

6. Is the position of rock A the exact position where it initially landed? Explain your answer. (Hint: From question 5 you should have found out this is a pretty large rock. Think about what a rock this size would do to the lunar surface when ejected from a crater. Can you see rock A's original landing spot?)

7. Calculate the ejection velocity of rock A from the ballistic equation by measuring its distance from point C in the crater. Assume an ejection angle of 45°. Lunar gravity is 1.62 meters per second squared. Be careful where you measure the distance from (as discussed in question 6). Can you drive this fast (legally) in a car (you will need to convert from meters per second to miles/hour?

The impact cratering lab exercises you have just completed demonstrate how images of the surface of a planet, or moon, can be used to make detailed measurements. These measurements reveal information about the physical properties of the planet in the image. This is the point of "remote sensing" — we don't have to actually set foot on the surface of another planet to learn about it. It is cheaper and easier to take pictures of the surface, either from orbit or from Earth, and then analyze them in labs. However, in order to understand the surface processes of another planet, we need to perform laboratory experiments like those used in this lab.

Such lab experiments are completely under our control. Laboratories try to simulate what we see in picture
another planet. In this way, a theory or model of what we think has taken place on the surface can be teste

Part II: Features and Motion of Crater Ejecta Background page

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