

Getting a Feel for Lunar Craters
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What is it about the Moon that is so inspirational to you? Maybe it conjures up stories of mythological beginnings? Does it stir up memories of the past? If you are blind, maybe it is the verbal descriptions you have heard about it. Maybe you have a memory of once seeing it or perhaps you can actually see it when it looms high and illuminates the dark sky.

For those with vision, the Moon often baffles us by being visible even during the day. It also intrigues us as we watch the visible portion of the round orb gradually change. These changing “phases” are due to the Moon’s revolution about the Earth and therefore the Moon’s change in position with respect to the Sun that illuminates it and the Earth that holds it in orbit. The phases bring the Moon to life and highlight the complex moonscape of hills and ridges and dark and light areas.

Whatever it is that draws you to the Moon, you can be sure that you are not the only one that has been fascinated with our nearest neighbor in space! For millennia, those who observed the sky wondered about the significance of our Moon, its origin and what has shaped and textured its landscape. As early as 300BC, observers began to use the Moon to make predictions about the scale of our solar system and expand our understanding of Earth’s place in the cosmos.

Today, our understanding of the Moon has been enhanced by human exploration, orbiting satellites, and increased technology and imaging that has enabled scientists to map the surface and subsurface. Soon, robotic missions will go to the Moon and return more rock samples and future explorers will once again place their footprints in the Moon's "soil" or regolith, just as the Apollo astronauts did over 40 years ago. Until then, we continue to learn more about the dynamics that have shaped the Moon's landscape by "viewing" the Moon through the eyes of instruments that uncover clues that lead us ever closer to understanding the Moon and its significance. This book is designed to give you the basics about the craters that are found on the Moon.

Tactile 1 – The Full Moon

Let's start our exploration by observing the overall appearance of a "Full" Moon. Study the lunar surface featured on Tactile 1. Note that the tactile number and title is centered at the top of each tactile. The scale of each tactile is found in the upper right-hand corner and represents how many kilometers each centimeter on the tactile represents. A centimeter bar found just below the scale will help

remind you how big a centimeter is. It may be helpful for you to use your fingers and determine which of your fingers is closest to being a centimeter across so that you can use that finger on each tactile as a guide. But remember, each tactile has a different scale so your finger will represent a different amount of kilometers for each tactile.

On Tactile 1, move your hands around the outer perimeter of the Moon and you will feel a ridge line meant only to define the shape or outline of the Moon. The real Moon is actually a sphere, or like a ball. Here it is represented as a circle and the half you are exploring with your hands would come up “out” of the page towards you.

To give you some sense of scale, the Moon has a diameter of about 3,476 kilometers (km). This tactile is 20 centimeters (cm) in diameter, therefore, each cm = 174 km (you can arrive at that by dividing 3476 km by 20 cm). Note that this information is also given in the upper right hand corner of the page above the centimeter bar.

Do you notice the relatively smooth regions and the rougher regions? The smooth regions are those that appear darker than the surrounding region when looking at the Moon with the naked eye. These smooth areas are called maria (mare for just one),

which is Latin for “seas” or “oceans”. They once were seas of molten lava called basalt that poured from the Moon’s interior and cooled to solid rock.

Find the mare near the middle labeled “A”. Now move your finger from left to right, horizontally through the Braille “A,” to get a better idea of the size of the mare. To the left of the “A” is a rough area and to the right of the “A” is a rough area. How many finger widths is it across? If you multiply your number of finger widths times 174 km, what is your prediction for how large that particular mare is? You probably got just over three finger widths or about 522 km (3 x 174). This is a mare called the Sea of Serenity. Since it is not perfectly round, it ranges from 522 km to 700 km across. If you measure just below the “A,” you will find it to be about four finger widths across. How did you do?

The rough regions or “highlands” are marked with many pocks or holes called craters. From samples returned to Earth by the Apollo astronauts, scientists were able to determine that the basalt is younger in age than the lighter colored rock found in the highland regions. If the maria are younger in age, why do you suppose they are smoother?

Explore Tactile 1 some more. From the center of the tactile graphic which is just below the “A” one

finger width and to the left one finger width, trace your finger straight down to the six o'clock position. At the edge of the Moon, move two finger widths to the left and one up to find a large round crater that your finger tip will fit into. This is where our journey about craters really begins.

Craters come in two varieties. Some are formed by volcanic activity and others are formed by asteroids and comets traveling in space that collide with the Moon. Up until the late 1800's, most scientists believed that the craters on the Moon were formed by volcanism. However, in 1892, American geologist G.K. Gilbert postulated that craters on the Moon were formed by objects in space impacting the surface of the Moon. Gilbert used experimentation and his keen observations of debris fields to arrive at his conclusions.

The crater on Tactile 1 you just explored was formed by an impact with a large object sometime in the past. Impact craters can be further classified as simple or complex. Simple craters have a bowl-shaped depression with raised rims that are 15 kilometers (km) across or less. Complex craters are greater than 15km in diameter and have shallow, relatively flat floors, a raised central dome, and giant terraces around their walls. Some craters larger than 300km across have concentric rings rather than

central mountains and are classified as impact basins.

Once again, find the crater located at the edge of the Moon tactile at the 6 o'clock position and two finger widths to the left and one up. This crater is called Tycho and was named after the great 16th century astronomer Tycho Brahe. The crater Tycho is about 85 km in diameter and is visible to the naked eye. Would it be considered a “simple” or “complex” crater?

Tactile 2 - Tycho

Turn to Tactile 2 in the book. Be sure and touch the centimeter bar in the upper right hand corner of the tactile and note the number above it to get an idea of the scale.

Tactile 2 shows two views of the crater Tycho. The tactile towards the top of the page represents a top-view or bird’s-eye view from high above the crater. This tactile shows how the crater would appear if we were soaring high above the crater looking down on it.

The second view on the bottom of the page is a cross-section view of Tycho. Imagine this... you slice an apple into two pieces and then observe the

peel, edible part and core; that would be the equivalent of a cross-sectional view of an apple. That is the same idea of what the bottom tactile represents... the view of a crater from the side including what's above ground and what's below ground.

Now go back and feel the top bird's-eye view. Start from the left hand side and trace your finger around the rim of the crater. Sighted assistance may help you determine the rim of the crater. Now notice that the central uplift, right in the middle of the tactile, is very prominent in Tycho. This is evident in the top-view and is about 3 scale cm across. Using the scale for this tactile, about how wide is the central uplift?

The central uplift is also noticeable in the bottom tactile or cross-section. In the cross-section, the "surface" of the Moon trails off to the left and to the right of the hole representing the crater. Starting on the far left trace your finger along the surface of the Moon and notice that it rises up to a peak and then down into the crater floor. As you continue to sweep your fingers along the floor, you will notice the central uplift region that is found in the center of Tycho. Central peaks form by the rebound of rocks that were highly compressed at ground zero of the impact. The lines below the crater represent the

fractured rock beneath the surface. Because the physical forces involved in an impact the size of Tycho and larger craters are so much more than the necessary forces to make rock fracture, the surface around an impact area behaves much like water! Therefore, scientists can learn a great deal about impacts by studying slow motion film of water droplets hitting a surface. Most of the same features seen in water droplets are also accounted for in impact basins, including the central uplift which is formed as debris in the middle is pushed up due to the slumping or “falling” of the sides of the crater shortly after impact.

Tactile 3 - Moltke

Tactile 3 presents a top-view and cross-section of the crater Moltke. This crater is 7km in diameter. What kind of crater is Moltke – simple or complex? Is there a central uplift? Using your “scale” finger on the cross-section view, what can be concluded about the depth of the crater with respect to its diameter, or its depth/diameter ratio? Taking into account the differences in scale, what can be said about the depth/diameter ratio of the crater in Tactile 3 compared to Tactile 2? In other words, are smaller craters deeper compared to their diameter or more

shallow compared to their diameter, when compared to larger craters?

Tactile 4 – Schrodinger Basin

Tactile 4 represents a complex crater system that is so large, it is considered an impact basin which significantly alters the geology of the surrounding area. This particular basin is known as Schrodinger Basin and is 320 km in diameter! Notice that it has an uplift ring within the outer rim of the crater itself. This can be found on the bird's-eye view and the cross-section view.

Tactile 5 - Theophilus

Now it's your turn. Explore Tactile 5 and the corresponding scale. This is the crater called Theophilus. What is your estimate of the diameter of Theophilus? Would it be considered a complex or simple crater? On the cross-sectional view at the bottom of Tactile 5, explore the lines emanating down beneath the crater. These represent fissures and fractures where the underlying rock is cracked.

It is evident that craters come in many different sizes and that the features of craters are largely a function of the size of the object that makes the

impact. But what about really large impacts? Could there be impacts that are even larger than Theophilus (Tactile 5) or even Schrodinger (Tactile 4)? Remember Schrodinger is 320 km in diameter! The answer is absolutely. In fact the largest impact basin known on the Moon, and possibly the solar system, is referred to as SPA or the South Pole Aitken basin. SPA was first discovered by Soviet probes in the early 1960s. Because of SPA's observable patterns being spread over such a large area, it was not recognized as an impact basin until years later.

Tactile 6 - SPA

The size of the basin is immense at approximately 2500 km across and about 12 km deep. That means that it stretches over nearly a quarter of the Moon. Tactile 6 is a tactile creation of SPA. Again, check out the scale under the title in the upper right hand corner of the tactile. As you explore the overall tactile, notice how different it feels than Tactile 1 which is a tactile of what we call the "near side" of the Moon.

Turn back and check out Tactile 1 again. Because the Moon makes one rotation for every revolution, the same side of the Moon always faces

us. Therefore, observers from Earth always see the same side. It wasn't until probes and other missions flew around the Moon that the "far side" of the Moon was photographed and mapped. Do you notice how Tactile 6 does not have nearly as many smooth areas, or maria, as Tactile 1? Most scientists agree that this is because of a difference in crustal thickness. A thinner crust on the near side allowed much more outpouring of lava into basins than on the far side.

Although it is barely visible, chances are you will not be able to feel the large circle within the outer rim of the Moon that indicates SPA. This highlights the subtleties, or hidden characteristics, that scientists must often pick out from visual images.

Tactile 7 – Raised line diagram showing size of SPA to size of Moon

Now check out Tactile 7 where we have represented the outline of the Moon with a raised line. Notice also the inner raised line that represents the size of SPA without all the other details in Tactile 6. Using Tactile 7 as a guide go back and explore Tactile 6 and see if you can discover the SPA basin. Tactually, it is virtually impossible to find, however, with sighted assistance it may be recognizable.

All the craters explored in this book are real examples of craters found on the Moon. These impacts occurred a long time ago, and we rarely are able to see an impact “live.” So what really happens when a large object impacts the Moon, or any other solar system object for that matter?

Computer modeling and studies of impact craters on Earth have allowed us to better understand the dynamics of what happens during an impact. Keep in mind that objects are typically moving about 20 km/s when they impact the Moon and that the angle of impact will affect cratering also. It should likewise be noted that the object that impacts the Moon does NOT leave behind a crater the same size as the object. Estimates put the size of the crater left behind by a typical impact at 10 to 20 times larger than the object itself! That is why even a relatively small object can do a lot of damage when it impacts the Moon, or for that matter, the Earth.

To better understand impact events, we have divided impacts into 3 stages based on a book by Bevin French (1998) *Traces of Catastrophe: A Handbook of Shock-Metamorphic Effects in Terrestrial Meteorite Impact Structures*.

Tactile 8 – Impact Stages

The 3 stages include compression, excavation and modification. Explore Tactile 8 to get a better idea about what happens at each stage. Each of these are cross-section views. The horizontal line on each of the three stages represents the Moon's surface. Starting on the left and moving to the right, allow your finger to trace along the Moon's surface until you find the point of impact.

Stage 1 is the initial impact and compression of the surface. Notice the one dot in the crater that represents the object impacting the Moon. Also notice the lines below the crater representing compression cracks below the Moon's surface.

Stage 2 represents the displacement of the material, which excavates the crater. During this stage, debris (called *ejecta*) is thrown out of the growing crater and falls back to the lunar surface as an *ejecta blanket*, including long *ejecta rays*. On the tactile, you will find lines and bumps above the crater floor representing the ejecta being thrown out of the crater. The lines below the crater floor represent further cracking and fracturing occurring below the surface. Eventually the debris being thrown from the crater will fall back to the surface and form ejecta rays. Ejecta rays extend out from

the crater Tycho and can be seen with binoculars from Earth. Go back to Tactile 1 and see if you can discern the ejecta rays emanating outwards from Tycho. Note that sighted assistance may be necessary for this observation.

Stage 3 includes the modification of the crater shortly after impact. Once again, starting on the far left of the bottom tactile and moving to the right, notice the layer, or blanket, of material on the surface of the Moon, but you find no debris above the crater since it has all settled back down to the surface.

Although not all impacting has the same effect due to angle of incidence, speed at which the object strikes, size, and composition of impacting object; these 3 stages are usually found to some degree or another.

Final Impacts to Ponder

It is interesting to note that SPA is thought to be formed from an object moving at a relatively slow speed with respect to the motion of the Moon and at a high angle of incidence, thus accounting for the relatively shallow crater formed.

What a sight that would have been to witness such an event from Earth! Aren't you glad you weren't on the Moon when that occurred? It is humbling to realize that the Moon has been hit so many times in the past and yet, is Earth immune? Why is it that we don't find as many impact craters on the Earth? What factors would prevent us from finding craters on Earth? Impacts and cratering are an inevitable part of the evolution of any planetary body – it has happened in the past and will continue to mold landscapes in the future. This book has highlighted some of the most common types of craters and has allowed you to explore what these craters are like. For more information on cratering, please see Bevan French's book, *Traces of Catastrophe*, which is available online <http://www.lpi.usra.edu/publications/books/CB-954/CB-954.intro.html>, or one of several web sites that may explain this process in more detail such as...

The Earth Impact Database:

<http://www.unb.ca/passc/ImpactDatabase/index.html>

and

NASA's Remote Sensing Tutorial – Impact Craters:

http://rst.gsfc.nasa.gov/Sect18/Sect18_1.html

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