Name:

Lab 3

The Surface of the Moon

3.1 Introduction

One can learn a lot about the Moon by looking at the lunar surface. Even before astronauts landed on the Moon, we had enough scientific data to formulate theories about the formation and evolution of the Earth's only natural satellite. However, since the Moon rotates once for every time it orbits around the Earth, we can only see one side of the Moon from the surface of the Earth. Until we sent the space missions that orbited the Moon, we only knew half the story.

The type of orbit our Moon makes around the Earth is called a synchronous orbit. This phenomenon is shown graphically in Figure 3.1 below. If we imagine that there is one large mountain on the hemisphere facing the Earth (denoted by the small triangle on the Moon), then this mountain is always visible to us no matter where the Moon is in its orbit. As the Moon orbits around the Earth, it turns at just the correct rate so that we *always* see the same hemisphere.

On the Moon, there are extensive lava flows, rugged highlands, and many impact craters of all different sizes. The overlapping of these features implies relative ages. Because of the lack of ongoing mountain building processes, or weathering by wind and water, the accumulation of volcanic processes and impact cratering is readily visible. Thus by looking at the images of the Moon, one can trace the history of the lunar surface. Most of the images in this lab were taken by NASA spacecraft or by Apollo Astronauts.

- *Goals:* to discuss the Moon's terrain, craters, and the theory of relative ages; to use pictures of the Moon to deduce relative ages and formation processes of

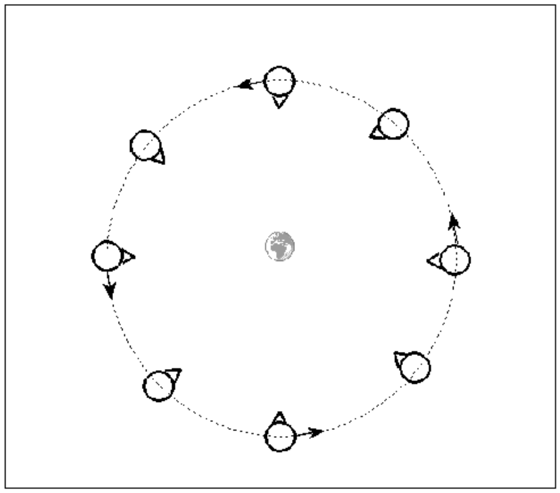

Figure 3.1: The Moon's "synchronous" orbit (not drawn to scale). Note how the Moon spins exactly once during its 27.3 day orbit around the Earth, but keeps the same face pointing towards the Earth.

surface features

- *Materials:* Moon pictures, ruler, calculator
- *Review:* Section 1.2.2 in Lab #1

3.2 Craters and Maria

A crater is formed when a meteor from space strikes the lunar surface. The force of the impact obliterates the meteorite and displaces part of the Moon's surface, pushing the edges of the crater up higher than the surrounding rock. At the same time, more displaced material shoots outward from the crater, creating *rays* of ejecta. These rays of material can be seen as radial streaks centered on some of the craters in some of the pictures you will be using for your lab today. As shown in Figure 3.2, some of the material from the blast "flows" back towards the center of the crater, creating a mountain peak. Some of the craters in the photos you will examine today have these "central peaks". Figure 3.2 also shows that the rock beneath the crater becomes fractured (full of cracks).

Soon after the Moon formed, its interior was mostly liquid. It was continually being hit by meteors, and the energy (heat) from this period of intense cratering was enough to liquify the Moon's interior. Every so often, a very large meteor would strike the surface, and *crack the Moon's crust*. The over-pressured "lava" from the Moon's molten mantle then flowed up through the cracks made by the impact. The lava filled in the crater, creating a dark, smooth "sea". Such a sea is called a *mare*. Sometimes

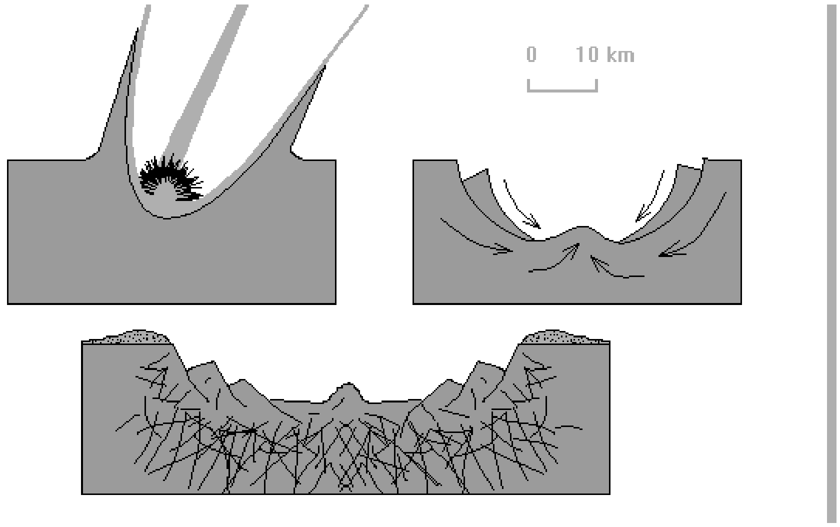

Figure 3.2: Formation of an Impact Crater.

the amount of lava that came out could overfill the crater. In those cases, it spilled out over the crater's edges and could fill in other craters as well as cover the bases of the *highlands*, the rugged, rocky peaks on the surface of the Moon.

3.3 Relative Ages on the Moon

Since the Moon does not have rain or wind erosion, astronomers can determine which features on the Moon are older than others. It all comes down to counting the number of craters a feature has. Since there is nothing on the Moon that can erase the presence of a crater, the more craters something has, the longer it must have been around to get hit. For example, if you have two large craters, and the first crater has 10 smaller craters in it, while the second one has only 2 craters in it, we know that the first crater is older since it has been there long enough to have been hit 10 times. If we look at the highlands, we see that they are covered with lots and lots of craters. This tells us that in general, the highlands are older than the *maria* (*maria* is the plural of mare) which have less craters. We also know that if we see a crater on top of a mare, the mare is older. It had to be there in the first place to get hit by the meteor. Crater counting can tell us which features on the Moon are older than other features, but it can not tell us the absolute age of the feature. To determine that, we need to use radioactive dating or some other technique.

3.4 Lab Stations

In this lab you will be using a 3-ring binder that has pictures organized in several "stations". Each station will have different images of the Moon (or Earth) and a few questions about these images. In some sections we present data comparing the Moon to the Earth or Mars. Using your understanding of simple physical processes here on Earth and information from the class lecture and your reading, you will make observations and draw logical conclusions in much the same way that a planetary geologist would.

You should work in groups of two to four, with one notebook for each group. The notebooks contain separate sections, or "stations", with the photographs and/or images for each specific exercise. Each group must go through all of the stations, and consider and discuss each question and come to a conclusion. Be careful and answer all of the questions. In most cases, the questions are numbered. The point values for all of the questions you must answer are specifically listed. **Remember to back up your answers with reasonable explanations.**

3.4.1 The Surface of the Moon

Station 1: Our first photograph (#1) is that of the full Moon. It is obvious that the Moon has dark regions, and bright regions. The largest dark regions are the "Maria", while the brighter regions are the "highlands". In image #2, the largest features of the full Moon are labeled. The largest of the maria on the Moon is Mare Imbrium (the "Sea of Showers"), and it is easily located in the upper left quadrant of image #2. Locate Mare Imbrium. Let us take a closer look at Mare Imbrium.

Image #3 is from the Lunar Orbiter IV. Before the Apollo missions landed humans on the Moon, NASA sent several missions to the Moon to map its surface, and to make sure we could safely land there. Lunar Orbiter IV imaged the Moon during May of 1967. The technology of the time was primitive compared to today, and the photographs were built up by making small imaging scans/slices of the surface (the horizontal striping can be seen in the images), then adding them all together to make a larger photograph. Image #3 is one of these images of Mare Imbrium seen from almost overhead.

Question #1: Approximately how many craters can you see inside the dark circular region that defines Mare Imbrium? Compare the number of craters in Mare Imbrium to the brighter regions to the North (above) of Mare Imbrium. (*4 Points*)

Images #4 and #5 are close-ups of small sections of Mare Imbrium. In image #4, the largest crater (in the lower left corner) is “Le Verrier” (named after the French mathematician who predicted the correct position for the planet Neptune). Le Verrier is 20 km in diameter. In image #5, the two largest craters are named Piazzi Smyth (just left of center) and Kirch (below and left of Piazzi Smyth). Piazzi Smyth has a diameter of 13 km, while Kirch has a diameter of 11 km.

Question #2: Using the diameters for the large craters noted above, and a ruler, what is the approximate diameter of the smallest crater you can make out in images #4 and #5? If the NMSU campus is about 1 km in diameter, compare the smallest crater you can see to the size of our campus. (*4 Points*)

In image #5 there is an isolated mountain (Mons Piton) located near Piazzi Smyth. It is likely that Mons Piton is related to the range of mountains to its upper right.

Question #3: Roughly how much area (in km^2) does Mons Piton cover? Compare it to the Organs (by estimating their coverage). How do you think such an isolated mountain came to exist? [Hint: In the introduction to the lab exercises, the process of maria formation was described. Using this idea, how might Mons Piton become so isolated from the mountain range to the northeast?] (*6 Points*)

Station #2: Now let’s move to the “highlands”. In image #6 (which is identical to image #2), the crater Clavius can be seen on the bottom edge—it is the bottom-most labeled feature on this map. In image #7, is a close-up picture of Clavius (just below center) taken from the ground through a small telesope (this is similar to what you would see at the campus observatory). Clavius is one of the largest craters on the Moon, with a diameter of 225 km. In the upper right hand corner is one of the best known craters on the Moon, "Tycho". In image #1 you can identify Tycho by the large number of bright "rays" that emanate from this crater. Tycho is a very young crater, and the ejecta blasted out of the lunar surface spread very far from the impact site.

Question #4: Estimate (in km) the distance from the center of the crater Clavius, to the center of Tycho. Compare this to the distance between Las Cruces, and Albuquerque (375 km). (*3 Points*)

Images #8 and #9, are two high resolution images of Clavius and nearby regions taken by Lunar Orbiter IV (note the slightly different orientations from the ground-based picture).

Question #5: Compare the region around Clavius to Mare Imbrium. Scientists now know that the lunar highlands are older than the Maria. What evidence do you have (using these photographs) that supports this idea? [Hint: review section 2.3 of the introduction.] (*5 Points*)

Station #3: Comparing Apollo landing sites. In images #10 and #11 are close-ups of the Apollo 11 landing site in Mare Tranquillitatis (the "Sea of Tranquility"). The actual spot where the "Eagle" landed on July 20, 1969 is marked by the small cross in image 11 (note that three small craters near the landing site have been named for the crew of this mission: Aldrin, Armstrong and Collins). [There are also quite a number of photographic defects in these pictures, especially the white circular blobs near the center of the image to the North of the landing site.] The landing sites of two other NASA spacecraft, Ranger 8 and Surveyor 5, are also labeled in image #11.

NASA made sure that this was a safe place to explore!

Images #12 and #13 show the landing site of the last Apollo mission, #17. Apollo 17 landed on the Moon on December 11th, 1972. Compare the two landing sites.

Question #6: Describe the logic that NASA used in choosing the two landing sites– why did they choose the Tranquillitatis site for the first lunar landing? What do you think led them to choose the Apollo 17 site? (*5 Points*)

The next two sets of images show photographs taken by the astronauts while on the Moon. The first three photographs (#14, #15, and #16) are scenes from the Apollo 11 site, while the next three (#17, #18, and #19) were taken at the Apollo 17 landing site.

Question #7: Do the photographs from the actual landing sites back-up your answer to why NASA chose these two sites? How? Explain your reasoning. (*5 Points*)

Station 4: On the northern-most edge of Mare Imbrium sits the crater Plato (labeled in images #2 and #6). Photo #20 is a close-up of Plato. Do you agree with the theory that the crater floor has been recently flooded? Is the mare that forms the floor of this crater younger, older, or approximately the same age as the nearby region of Mare Imbrium located just to the South (below) of Plato? Explain your reasoning. *(5 points)*

Station 5: Images #21 and #22 are "topographical" maps of the Earth and of the Moon. A topographical map shows the *elevation* of surface features. On the Earth we set "sea level" as the zero point of elevation. Continents, like North America, are above sea level. The ocean floors are below sea level. In the topographical map of the Earth, you can make out the United States. The Eastern part of the US is lower than the Western part. In topographical maps like these, different colors indicate different heights. Blue and dark blue areas are below sea level, while green areas are just above sea level. The highest mountains are colored in red (note that Greenland and Antartica are both colored in red–they have high elevations due to very thick ice sheets). We can use the same technique to map elevations on the Moon. Obviously, the Moon does not have oceans to define "sea level". Thus, the definition of zero elevation is more arbitrary. For the Moon, sea level is defined by the *average* elevation of the lunar surface.

Image #22 is a topographical map for the Moon, showing the highlands (orange, red, and pink areas), and the lowlands (green, blue, and purple). [Grey and black areas have no data.] The scale is shown at the top. The lowest points on the Moon are 10 km below sea level, while the highest points are about 10 km above sea level. On the left hand edge (the "y axis") is a scale showing the latitude. 0^o latitude is the equator, just like on the Earth. Like the Earth, the North pole of the Moon has a latitude of $+90^o$, and the south pole is at -90^o. On the x-axis is the *longitude* of the Moon. Longitude runs from 0^o to 360^o. The point at 0^o latitude *and* longitude of the Moon is the point on the lunar surface that is closest to the Earth.

It is hard to recognize features on the topographical map of the Moon because of the complex surface (when compared to the Earth's large smooth areas). But let's go ahead and try to find the objects we have been studying. First, see if you can find Plato. The latitude of Plato is $+52^o$ N, and its longitude is 351^o. You can clearly see the outline of Plato if you look closely.

Question #8: Is Plato located in a high region, or a low region? Is Plato lower than Mare Imbrium (centered at 32^oN, 344^o)? [Remember that Plato is on the Northern edge of Mare Imbrium.](*2 points*)

Question #9: Apollo 11 landed at Latitude = 1.0^oN, longitude = 24^o. Did it land in a low area, or a high area? (*2 points*)

As described in the introduction, the Moon keeps the same face pointed towards Earth at all times. We can only see the "far-side" of the Moon from a spacecraft. In image #22, the *hemisphere* of the Moon that we can see runs from a longitude of 270^o, passing through 0^o, and going all the way to 90^o (remember 0, 0 is located at the center of the Moon as seen from Earth). In image #23 is a more conventional topographical map of the Moon, showing the two hemispheres: near side, and far side.

Question #10: Compare the average elevation of the near-side of the Moon to that of the far-side. Are they different? Can you make-out the Maria? Compare the number of Maria on the far side to the number on the near side. (*5 points*)

Station 6: With the surface of the Moon now familiar to you, and your perception of the surface of the Earth in mind, compare the Earth's surface to the surface of the Moon. Does the Earth's surface have more craters or less craters than the surface of the Moon? Discuss two differences between the Earth and the Moon that could explain this. *(5 points)*

3.4.2 The Chemical Composition of the Moon: Keys to its Origin

Station 7: Now we want to examine the chemical composition of the Moon to reveal its history and origin. The formation of planets (and other large bodies in the solar system like the Moon) is a violent process. Planets grow through the process of "accretion": the gravity of the young planet pulls on nearby material, and this material crashes into the young planet, heating it, and creating large craters. In the earliest days of the solar system, so much material was being accreted by the planets, that they were completely *molten*. That is, they were in the form of liquid rock, like the lava you see flowing from some volcanoes on the Earth. Just like the case with water, heavier objects in molten rock sink to the bottom more quickly than lighter material. This is also true for chemical elements. Iron is one of the heaviest of the common elements, and it sinks toward the center of a planet more quickly than elements like silicon, aluminum, or magnesium. Thus, near the Earth's surface, rocks composed of these lighter elements dominate. In lava, however, we are seeing molten rock from deeper in the Earth coming to the surface, and thus lava and other volcanic (or "igneous") rock, can be rich in iron, nickel, titanium, and other high-density elements.

Images #24 and 25 present two unique views of the Moon obtained by the spacecraft *Clementine*. Using special sensors, *Clementine* could make maps of the surface composition of the Moon. In Image #24 is a map of the amount of iron on the surface of the Moon (redder colors mean more iron than bluer colors). Image #25 is the same type of map, but for titanium.

Question #11: Compare the distribution of iron and titanium to the surface features of the Moon (using images #1, #2 or #6, or the topographical map in image #23). Where are the highest concentrations of iron and titanium found? (*4 points*)

Question #12: If the heavy elements like iron and titanium sank towards the center of the Moon soon after it formed, what does the presence of large amounts of iron and titanium in the maria suggest? [Hint: do you remember how maria are formed?] (*5 points*)

Table 3.1: Composition of the Earth & Moon

Element	Earth	Moon
Iron	34.6%	3.5%
Oxygen	29.5%	60.0%
Silicon	15.2%	16.5%
Magnesium	12.7%	3.5%
Titanium	0.05%	1.0%

The structure of the Earth is shown in the diagram, below. There are three main structures: the crust (where we live), the mantle, and the core. The crust is cool and brittle, the mantle is hotter, and “plastic” (it flows), and the core is very hot and very dense. The density of a material is simply its mass (in grams or kilograms) divided by its volume (in centimeters or meters). Water has a density of 1 gm/cm^3. The density of the Earth’s crust is about 3 gm/cm^3, while the mantle has a density of 4.5 gm/cm^3. The core is very dense: 14 gm/cm^3 (this is partly due to its composition, and partly due to the great pressure exerted by the mass located above the core). The core of the Earth is almost pure iron, while the mantle is a mixture of magnesium, silicon, iron and oxygen. The average density of the Earth is 5.5 gm/cm^3.

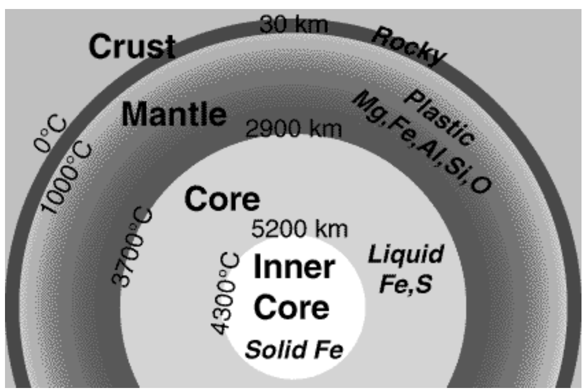

Figure 3.3: The internal structure of the Earth, showing the dimensions of the crust, mantle and core, as well as their composition and temperatures.

Before the astronauts brought back rocks from the Moon, we did not have a good theory about its formation. All we knew was that the Moon had an average density of 3.34 gm/cm^3. If the Moon formed from the same material as the Earth, their compositions would be nearly identical, as would their average densities. In Table 3.1, we present a comparison of the composition of the Moon to that of the Earth. The data for the Moon comes from analysis of the rocks brought back by the Apollo astronauts.

Question #13: Is the Moon composed of the same mixture of elements as the Earth? What are the biggest differences? Does this support a model where the Moon formed out of the same material as the Earth? (*3 points*)

As you will learn in the Astronomy 110 lectures, the inner planets in the solar system (Mercury, Venus, Earth and Mars) have higher densities than the outer planets (Jupiter, Saturn, Uranus and Neptune). One theory for the formation of the Moon is that it formed out near Mars, and "migrated" inwards to be captured by the Earth. This theory arose because the density of Mars, 3.9 gm/cm^3, is similar to that of the Moon. But Mars is rich in iron and magnesium: 17% of Mars is iron, and more than 15% is magnesium.

Question #14: Given this data, do you think it is likely that the Moon formed out near Mars? Why? (*2 points*)

The final theory for the formation of the Moon is called the "Giant Impact" theory. In this model, a large body (about the size of the planet Mars) collided with the Earth, and the resulting explosion sent a large amount of material into space. This material eventually collapsed (coalesced) to form the Moon. Most of the ejected material would have come from the crust and the mantle of the Earth, since it is the material closest to the Earth's surface. In the Table (3.2) is a comparison of the composition of the Earth's crust and mantle compared to that of the Moon.

Question #15: Given the data in this table, present an argument for why the giant impact theory is now the favorite theory for the formation of the Moon. Can you think of a reason why the compositions might not be *exactly* the same? (*5 points*)

Table 3.2: Chemical Composition of the Earth and Moon

Element	Earth's Crust and Mantle	Moon
Iron	5.0%	3.5%
Oxygen	46.6%	60.0%
Silicon	27.7%	16.5%
Magnesium	2.1%	3.5%
Calcium	3.6%	4.0%

3.5 Summary

(*35 points*) Please summarize in a few paragraphs what you have learned in this lab. Your summary should include:

- Explain how to determine and assign relative ages of features on the Moon
- Comment on analyzing pictures for information; what sorts of things would you look for? what can you learn from them?
- What is a mare and how is it formed?
- How does the composition of the Moon differ from the Earth, and how does this give us insight into the formation of the Moon?

Use complete sentences and proofread your summary before handing it in.

3.6 Possible Quiz Questions

1. What is an impact crater, and how is it formed?
2. What is a Mare?
3. Which is older the Maria or the Highlands?
4. How are the Maria formed?
5. What is synchrounous rotation?
6. How can we determine the relative ages of different lunar surfaces?