Lab 13 - Introduction to the Geology of the Terrestrial Planets

Introduction

There are two main families of planets in our solar system: the inner Terrestrial planets (Earth, Mercury, Venus, and Mars), and the outer Jovian Planets (Jupiter, Saturn, Uranus, and Neptune). The terrestrial planets are rocky planets that have properties similar to that of the Earth. While the Jovian planets are giant balls of gas. Table 1 summarizes the main properties of the planets in our solar system (Pluto is an oddball planet that does not fall into either categories, sharing many properties with the "Kuiper belt" objects where many comets come from.

Body	Mass (Earth Masses)	Size (Earth Radii)	Density (g/cm ³)
Mercury	0.055	0.38	5.5
Venus	0.815	0.95	5.2
Earth	1	1	5.5
Earth's Moon	0.0123	0.27	3.3
Mars	0.107	0.53	3.9
Jupiter	318	10.8	1.4
Saturn	95	9	0.7
Uranus	14.5	3.93	1.3
Neptune	17.2	3.87	1.6
Pluto	0.002	0.178	2.1

Table 1: The Properties of the Planets.

Table 1 shows that the planets in our solar system span a considerable range in sizes and masses for example, the Earth has 18 times the mass of Mercury, while Jupiter has 318 times the mass of the Earth. But the separation of the planets into Terrestrial and Jovian is not based on their masses or physical sizes, it is based on their densities (the last column in the table). What is density? Density is simply the mass of an object divided by its volume: M/V. In the metric system, the density of water is set to 1.00 gm/cm3.

If we examine Table 1 we see that the terrestrial planets all have higher densities than the Jovian planets. Mercury, Venus and Earth have densities above 5 gm/cm3, while Mars has a slightly lower density (1.4 gm/cm3). The Jovian planets have densities very close to that of water (in fact, the mean density of Saturn is lower than that of water)! The density of a planet gives us clues about its composition. Figure 1 illustrates the four terrestrial planets.

The mean densities of the terrestrial planets are about halfway between those of silicon and iron. Both of these elements are highly abundant throughout the Earth, and thus we can postulate that the terrestrial planets are mostly composed of rocky material (most igneous rocks present in the crust and mantle) and iron metal (that forms the core). Conversely, the Jovian planets are composed of lighter elements, such as hydrogen and helium. These worlds consist mostly of gas. In fact, the Jovian planets have similar densities to that of the Sun: 1.4 gm/cm3. The Sun is 70% hydrogen, and 28% helium. Except for small, rocky cores, the Jovian planets are almost nothing but hydrogen and helium.

The terrestrial planets share other properties, for example they all rotate much more slowly than the Jovian planets. They also have much thinner atmospheres than the Jovian planets (which are almost all atmosphere!). Finally, the terrestrial planet have few moons (Mercury and Venus = 0; Earth = 1; Mars = 2). Whereas, all of the Jovian planets have dozens of moons and can be thought of as mini-solar systems.



Figure 1. The four terrestrial planets. From left to right: Mercury, Venus, Earth, and Mars.

QUESTIONS

1. Does the difference in density between the terrestrial and Jovian planets make sense in terms of how the composition of these two types of planets. Explain.

2. Compare the density of Mars versus the other terrestrial planets. Based on this fact comment on the relative size of the metal core within the red planet compared with the other terrestrial planets.

3. From space the Earth looks like its made of water but surface appearances can be deceiving. However, the average density of Earth is much higher than that of water. What type of materials comprise most of our planet.

4. In our solar system is it true that planetary size and mass are inversely correlated with density. Justify your answer.

Overview of Surface Processes

There are a variety of processes that can affect planetary surfaces. These processes can be grouped into three categories.

(1) Tectonic - Internal planetary forces that manifest themselves on the surfaces in terms of volcanoes and lava. Also the development of mountain ranges. Where planetary crust is shifted faults can develop forming fault valleys.

(2) Extraterrestrial - Impact craters formed by asteroids or comets striking a planetary surface.

(3) Surface - The action of water and wind can also shape a planetary surface. Wind can blow sand into dunes and water can carve stream valleys. Even airless worlds can over billions of years be affected by space weathering.

Planetary bodies can be divided between active and geological dead planets. Planets without tectonic or surface processing are only altered by the occasional impacting body. The longer a planetary surface is dead the more impact craters will appear on it. The lunar highlands on Earth's moon is a good example of a surface that has not changed in over 4 Ga. and as a result has a high density of craters on its surface.

Larger planetary bodies retain their primodial heat longer that smaller bodies. This heat causes magma to form internally driving tectonic activity. Additionally, this fact explains why the Earth and Venus are still geologically active worlds with relatively thick atmospheres (for terrestrial worlds, Table 2). Atmosphere's are formed and maintained by volcanic outgassing. Mercury and Earth's moon have been geologically dead for billions of years. The somewhat larger Mars died in the very recent geologic past. Although some geologists argue that this body still may support volcanic activity in the future.

Body	Pressure (Earth Standard)	Atmosphere Composition	Hydrosphere (In Order of Abundance)
Mercury	None	None	Ice in Craters
Venus	90	C0 ₂ , N ₂	Atmosphere
Earth	1	N ₂ , O ₂ , H ₂ O (vapor), Ar	Oceans, Glaciers, Groundwater
Earth's Moon	None	None	Ice in Craters
Mars	0.07	C0 ₂ , N ₂ Ar	Glaciers, Groundwater

Table 2: Comparison of Atmosphere and Hydrosphere of the Terrestrial Planets.

QUESTIONS

5. Discuss the relationship between the size of a terrestrial planet and whether it is geological active or dead.

6. Discuss the relationship between the size of a terrestrial planet and the pressure of its atmosphere.

7. The following type of terrestrial planet that has relatively thick atmospheres is also?

Geological Active or Geological Dead

8. What is the only terrestrial planet that has evidence for life based on the composition of its atmosphere? What type of gas provides an unmistakable signal for the existence of life?

9. It is interesting that all of the terrestrial bodies have significant water. What phase (vapor, liquid, solid) is the dominant form of water on these bodies

Body	Water (Vapor, Liquid, Solid)
Mercury	
Venus	
Earth	
Earth's Moon	
Mars	

Lunar Geologic History and Surface Features

We know the geologic history of Earth's moon with some level of detail as this is the only world people have landed on and explored. Over 800 pounds of moon rocks have been returned to earth and NASA scientists have spent decades studying this material. Therefore, we have absolute age dates of these rocks that allows us to develop a geologic time scale (Figure 3). Lunar geologic history is different from earth. Remember the moon is a smaller body than earth and this world has been geological dead for over 3 Ga.

Before discussing the history of the moon let's consider that when you look at this body that it has two distinctively different types of crust. The lunar highlands consists of the oldest crust on the moon (Figure 4), which developed soon after this body formed during the **Pre-Nectarian period**. This crust is light in color and is made of an igneous rock called anorthosite. Anorthosite is dominated by the mineral plagioclase, which explains the appearance of this crust. You may note that the highlands have a high density of craters. Remember the older the crust the more craters will be present in worlds without an atmosphere. The **Pre-Nectarian and Nectarian periods** (4.6 to 3.9 Ga.) are commonly referred to as the Era of Asteroidal Bombardment. During this era most of the debris left over from the formation of the solar system rained down on the newly formed planets.

The next period is the **Imbrian** (3.9 to 3.2 Ga.) which was a time of intense geologically activity on the moon's surface with faults and active volcanism. During this period the second type of crust on the moon formed known as the Lunar Maria. The flat maria superfacially look like seas but are not and are in fact are vast flows of basaltic lava that erupted during this period. The lunar basalts chemically are nearly identical to basalts on earth, which have a dark color (Figure 4). Note the maria have relatively few craters as it formed after the Era of Asteroidal Bombardment.

During the last two periods **Erotsthenian and Copernican** (3.2 Ga. to Present) the moon has been geologically dead with the only the occasional impact crater that affects its surface. The difference between these periods is that the bright rays that form from impacts have been removed by space weathering processes for craters from the Erotsthenian. The younger craters of the Copernican period still retain their bright ray systems that extend away from crater.

Figure 3 (On next page). Geologic Time Scales for the Earth and Earth's Moon.







Figure 4. Earth's Moon with labeled features.

QUESTIONS- Examine the two rock samples in the front of the lab that represent rocks present on the Moon. 10. Sample A is what type of rock?	
11. This type of rock formed during which lunar geological period?	
12. Sample B is an anorthosite and is mostly made of the following mineral	
13. This type of rock formed during which lunar geological period?	

14. On figure 4 indicate and highlight the lunar highlands and maria.

15. The maria have comparatively few craters compared with the highlands. Does this make sense based on the ages of these two different types of crust. Explain.

16. What is the difference betwen the Erotsthenian and Copernican impact craters.

17. Examine Figure 5 on the next page and determine the relative geologic history of this area.

	you	ingest

oldest



18. Detemine the lunar geologic period for each geologic feature in the above diagram.

 youngest

oldest

19. In terms of absolute time, when did the moon become geologically dead?

Ga.

20. Of the three types of processes (tectonic, extraterrestrial, surface) indicate which occured during the following lunar periods.

Pre-Nectarian and Nectarian

Imbrian

Erotsthenian and Copernican

Martian Surface Features

The Red Planet has an interesting geologic history. While people have yet stepped foot on this planet we have gathered quite a bit of knowledge from robotic missions that have scanned the planet from orbit and rovers that have examined the surface in detail. Additionally, there is a group of rare meteorites that we believe where blasted from the planet into space. These rare rocks have allowed geologists to begin to develop a geologic history for this planet.

Even through the planet today is close to geologic death, there is much evidence to indicate activity in the past. The crust is mostly made of the igneous rock basalt but there is also some andesite showing that magma underwent the process of differentiation as it does on earth. This volcanism forms the tallest mountain in the solar system, Mons Olympus (Fig. 6a), which is twice as high as Everst and about the size of Ohio. This mountain is thought to form at a hot spot where magma upwelled to the surface. On Earth this happens in several place such as Hawaii. The planet also has large fault valleys (ie Valles Marineris, Fig. 6b) indicating that there was significant tectonic activity in the past.

The thin atmosphere has allowed many impact craters to be preserved. More interesting are features that can be related to flowing water. On the Martian surface that are ancient stream valleys that look like those found on Earth (Fig. 6c). There is no good evidence that liquid water was present on Mars for over 3 Ga. Mars is smaller than the Earth so over geologic time is gradually lost most of its atmosphere. Without a thick atmosphere, liquid water is not stable. Today water is mostly present in the polar ice caps; although there are some indication that groundwater may exist below the surface where elevated pressure allows water to become stable. Over the last decade the Martian rovers have discovered mineral deposits that can only be formed from water. Minerals include sulfates like gypsum that on Earth form in oceans that experience great evaporation. The importance of liquid water on Mars cannot be understated because where there is water there may be life. Finally, today the Martian surface is reshaped by wind. Sand dunes are present and even dust devils have been seen on the surface by the rovers (Fig. 6d).



Figure 6. Various surface features present on Mars.

QUESTIONS - Examine the three rock samples in the front of the lab that represent rocks present on Mars. 21. Sample C is what type of rock?

22. Sample D is what type of rock?

23. Samples C & D are from which rock group?

24. Sample E is both a mineral and sedimentary rock. This material is very common here in Laredo. What is it? 25. Is Mars geologically dead?

26. From the martian surface give an example of a feature formed by?

Tectonic Processes

Extraterrestrial Processes

Surface Processes

27. Discuss the evidence that supports the presence of liquid water on the martian surface in the past.

28. How likely do you think it is that life on Mars existed in the geologic past. Explain your reasoning.