Astronomy 1002 Name: ______________________________

Meteorites and Impact-Related Objects (20pts) *Credits: Adapted from "Learning Astronomy by Doing Astronomy: Collaborative Lecture Activities" by Stacy Palen & Ana M. Larson*

Introduction

Meteorites are fragments of other worlds that have survived entry into the Earth's atmosphere. Most meteorites originate in the asteroid belt from bodies that formed very early in the history of the Solar System. Almost all of the information we have learned about the Solar System, such as its age, history, and chemical composition is due to the detailed study of meteorites.

There are three basic types of meteorites to will learn about in this class: **stony**, **stony-iron**, and **iron**. Meteoriticists recognize many more types of meteorites and have reconstructed a marvelously detailed history of the Solar System from their subtle differences.

When a large meteorite strikes the Earth, the kinetic energy of the meteorite is converted to thermal, mechanical, and acoustic energy that creates a shockwave that passes through the ground and distorts, fractures, and ejects pieces of the surface. This modified surface material is often all that remains of a crater after millions of years of geologic activity. Therefore the recognition of this material plays an important role in understanding impact events. The most common types of impact-modified material we will investigate are: **impact breccia**, **shatter cones**, and **tektites**.

Basic Descriptions of Sample Types

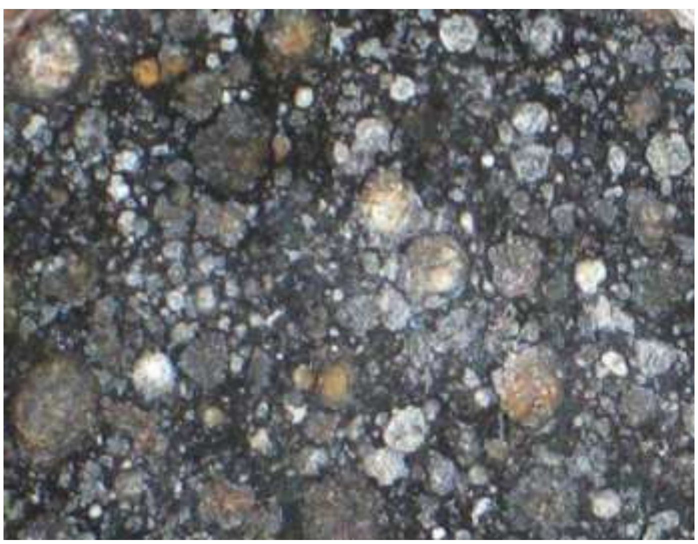
<u>Stony Meteorites</u>

Stony meteorites are a broad class of meteorites encompassing several subtypes you will study in this exercise. They are the most common meteorites that fall to Earth. Since they tend to have similar appearance and density to Earth rocks, stony meteorites are difficult to recognize in the field. Unless someone sees them fall, they usually go uncollected. Therefore although stony meteorites are the most common type out in space, they are rarer than iron meteorites in collections on Earth.

Stony meteorites show a wide variety of appearances: some light, some dark, some coarse grained, some fine grained, but almost all stony meteorites contain some metallic iron. Chemically they are also diverse, though they all have a telltale composition that tells us they are not from Earth. Most stony meteorites are from an asteroid that suffered destruction by collision. Some are pieces of lava flows from the surface (**Achondrites**), some are pieces of impact breccia (also Achondrites), and some are pieces of material that apparently never existed in a much larger body (**Ordinary** or **Carbonaceous Chondrites**).   Meteorites that come from such small, undifferentiated bodies are called primitive meteorites.

Carbonaceous Chondrite Meteorites

An especially important meteorite is the Carbonaceous Chondrite Meteorite, a specific type of stony meteorite that originates from **primitive** asteroids. In this context, primitive means that the asteroid has been altered very little over the age of the Solar System. More specifically, it means that the asteroid has not been heated to the point that would change the original material that makes up the asteroid. Carbonaceous Chondrite Meteorites are black to dark gray in color (see image to the left), are rich in carbon (thus their dark, black appearance), and contain small, spherical, droplet-like inclusions called **chondrules**. The image below is a slice of a type of carbonaceous chondrite.

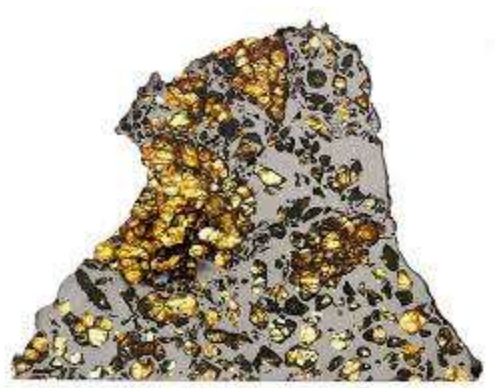


Note the numerous chondrules (the small, light-colored spherical inclusions) in the image.   Carbonaceous Chondrite Meteorites are among the most primitive objects in the Solar System, having survived almost *unchanged* for 4.6 billion years.

Carbonaceous chondrites were the first place amino acids were found *outside* of Earth, and it has been recently learned that some of the materials in these meteorites were formed outside of our Solar System *before our Solar System was even formed* so they are not only an important probe into our early Solar System history, but they may supply us with samples of materials from beyond our Solar System! Carbonaceous chondrites are rare among meteorites that fall to Earth (about 4%). Added to the fact that they look like Earth rocks, means that they are very rare in collections. They also weather very easily and do not survive very long on the surface of Earth.

Stony-Iron Meteorites

Stony-Iron meteorites are the rarest class of meteorites, comprising only about 1% of meteorites that fall to Earth. There are two broad classes of stony-iron meteorites: *Pallasites* and *Mesosiderites*. Pallasites are composed primarily of iron with crystals of a rock mineral, called olivine, embedded in it. The image to the left shows a polished slice of a pallasite meteorite. The roundish chunks of embedded material are the rocky material, olivine, surrounded by metallic iron. Pallasites are thought to be a material from the boundary zone between the iron cores and stony outer mantels of destroyed asteroids. Mesosiderites are theorized to be formed when an impact on an asteroid mixes material from the rocky mantel with iron from the core (a type of Impact Breccia).



Iron Meteorites

Iron meteorites are the most easily recognizable meteorites. Since even a casual examination shows that they are not ordinary rocks, they tend to be very common in collections although they are rare in space, comprising only about 5% of all meteorites. They are very dense and except for a thin crust made by the melting of the exterior during their passage through the atmosphere, they look and feel like metal. Chemically they are composed mostly of iron with a few percent nickel and a little cobalt. When sawed in half, polished, and etched with a mild acid, they display a geometrical pattern called a **Widmanstätten** pattern as in the figure to the right. The pattern is actually crystals of iron and nickel that form as a result of the meteorite having cooled very slowly (about 1^{o}C per 1 million years) under very high pressure. The existence of a Widmanstätten pattern is our best evidence that iron meteorites were once the cores of larger, differentiated bodies. Buried deep in a body, the mass of the overlying rocks provide the high pressure and insulation for slow cooling.

Impact Breccia

Impact breccias form when a crater-forming meteorite shatters, pulverizes and melts the world’s surface material. They are composed of rock and mineral fragments embedded in a matrix of fine-grained material. The fragments are usually sharp and angular, and vary greatly in both size and shape. The composition of the fragments depends on the surface material.

Impact breccias often have the appearance of poorly mixed concrete (see images above). On airless, impact-covered worlds like the Moon, impact breccias are a very common type of rock. The most common type of sample returned by the Apollo lunar missions was impact breccia. Unfortunately, rocks that look a lot like impact breccias can be formed by volcanic and tectonic processes, so finding a breccia is not always a clear indication of an impact event.

Shatter Cones

Shatter cones form when the shockwave from a meteorite impact event passes through the surface rocks and modifies them. The resulting rocks have distinctive, curved, striated fractures that typically form partial to complete cones like the one in the image to the right. Shatter cones can form in all types of surface rocks. The better-looking shatter cones form in fine-grained rocks like sandstones. They can range in size from centimeters to many tens of meters. Shatter cones are now accepted as a unique identifier of a meteorite impact event. This means that if you find a shatter cone, you have found a place where a meteorite has hit. Since the Earth is such a dynamic world, it will erase impact craters over a short period of time. Often, shatter cones are all that is left to identify an impact crater. An interesting feature of shatter cones is that the tips point toward the origin of the shockwave. This means that you can use shatter cones to reconstruct the size and shape of ancient impact craters that have subsequently been modified by other processes.

Tektites

Tektites have been controversial objects since their discovery, with both their origin and source being subject to hot debate for more than a century. Tektites are small, glassy objects with shapes like spheres, ellipsoids, dumbbells and other forms characteristic of isolated molten blobs (see figure below). They are typically black, but can be brown, gray or even green.

Tektites look a lot like volcanic glass (e.g. obsidian) but are chemically distinct. The most telling chemical difference is that unlike volcanic glasses, tektites contain virtually no water. Current scientific consensus are that tektites are terrestrial material that has been melted and ejected from an impact event. Their shape is derived from cooling aerodynamically, during flight from the impact. Tektites are fairly common all over the Earth. However, linking them with particular impact events has proven problematic. When exactly the tektites are formed during the impact event, and why they are found at only a few craters are two of the more obvious problems that have yet to be satisfactorily solved.

Goals

Meteorites and impact-related objects are an important part of this course, therefore it helps to have some first-hand understanding of their physical properties. ***Samples*** are also an important component of this class. The meteorites, after all, are samples from worlds in the Solar System that we would otherwise not have access to. The goal of today's experiment is to simply familiarize you with the look and feel of these objects and give you a chance to see the objects that result from the tremendous energy released during these impact events. And hey, let's face it, touching space rocks with your very own hands is just plain fun!

Procedure

Some of the tables in the section rooms have been setup with a number of different types of labeled samples. Examine them carefully, with the idea that afterwards you will be identifying samples for which the types are not going to be given (unknown samples). *You may see one of these on the final exam so pay particular attention to the details of each!* In the first data table (Table 1), record all information that you feel will help you characterize and identify each object. Note that we do not have a stony-iron meteorite sample for you to investigate (they are quite rare). Your TA will show you examples in our display case. A description of the stony-iron meteorite sample is given as an example in Table 1.

Other tables in the section rooms have been setup with several numbered unknown samples. In the second data table (Table 2), write down the meteorite or impact rock you think the unknown sample is and why you classified it as such. One or more of the rocks might not be meteorites or impact rocks at all. If you think one of the samples is not a meteorite or impact rock, take a guess as to what you think it might be or just write "ROCK" as its sample type if you are completely unsure. You need only hand in to your TA the last page containing Table 1 and Table 2.

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Table 1: Characterizing the Samples (10 pts)

Sample Type	Density	Color and Texture	Other Notable Characteristics
Iron Meteorite			
Stony Meteorite			
Stony-Iron Meteorite	Feels heavier or weightier than a stony meteorite. Probably has density of 5g/cc (rock & iron).	Mix of dark/colorful material and brighter metallic materials. Rough dark material and smooth, shiny material.	Not an equal distribution of dark and metallic material in each sample. Some dark regions are spherical.
Carbonaceous Chondrite			
Impact Breccia			
Shatter Cone			
Tektite			

Table 2: Unknown Sample Identification (10 pts)

Unknown Sample Type	Comments and Reason for Identification
1.	
2.	
3.	
4.	
5.	
6.	
7.	
8.	

Relative ages and craters. Plate Tectonics on Mars? (18 pts)

Introduction

One of the reasons given in lecture for the very large scale of the volcanoes on Mars was the lack of plate tectonics. I showed how, on the Earth, the Hawaiian Islands never grow to Mars proportions due to the plate tectonics dragging the islands off of the volcanic hotspot.

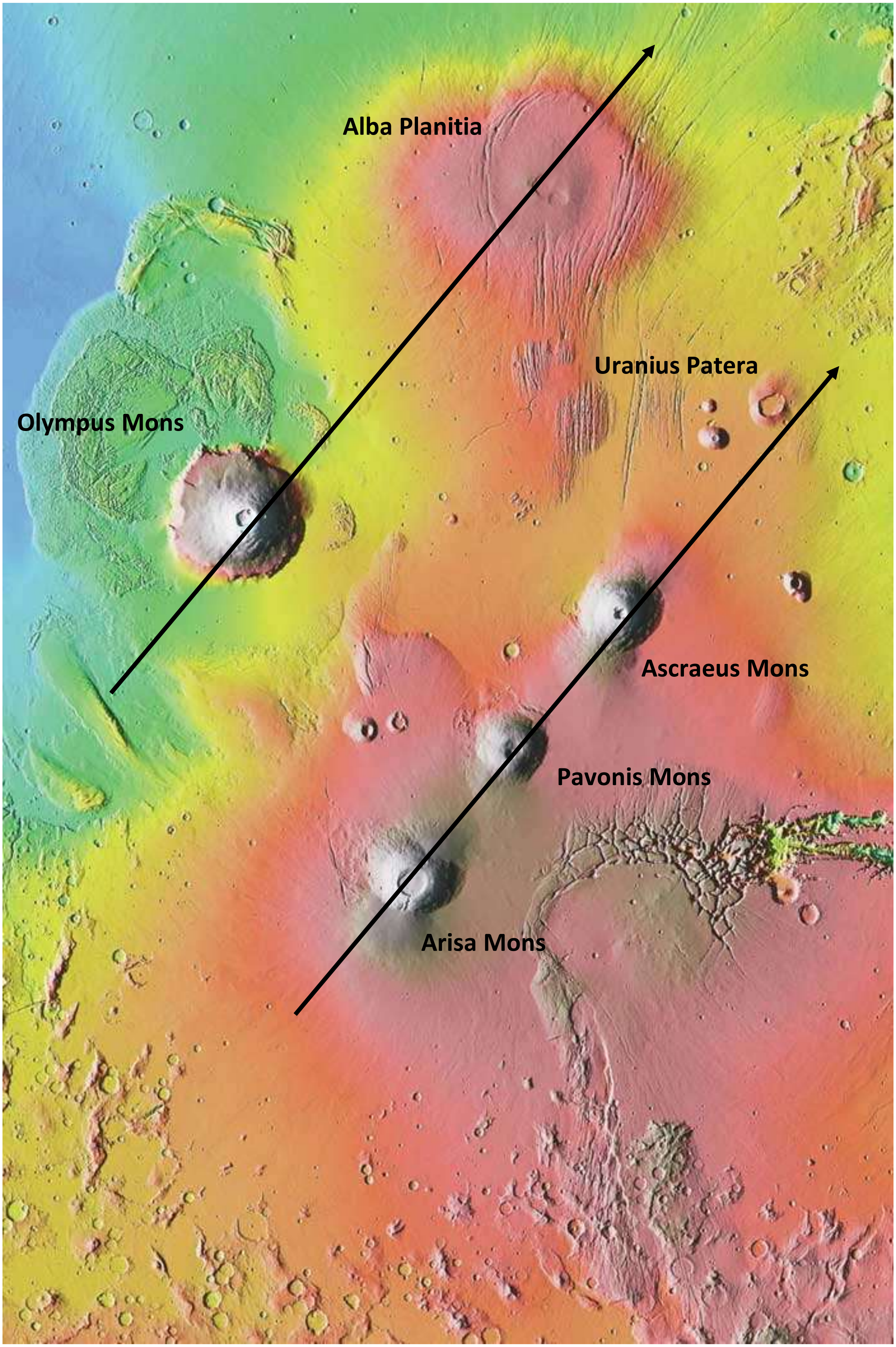
As it turns out, some scientists now argue that Mars ***may*** have had plate tectonics in the ***past***. One of the pieces of evidence that they point to is that the large Tharsis volcanoes lineup (see Arisa, Pavonis, and Ascraeus Mons and maybe Uranius Patera in the image below). Similarly, it can be argued that Olympus Mons and Alba Planitia also lineup. The idea is that in both cases these volcanoes have been dragged to the northwest (upper right in this image) over a hotspot by plate tectonics.

Goals

One of the great things about theories is science is that they are testable. If they are not testable, they are not science. This does not mean that the tests of a theory have to be easy or can be done with current technology. Your goal is to test whether plate tectonics could have ever existed on Mars. One idea for a test of the plate tectonic theory for Mars could involve looking at the relative ages of the individual volcanoes.

Procedure

As you may know, plate tectonics are responsible for the malleability of the continents on Earth, as well as Earthquakes. The basis of the principle is that the Earth's crust is a dynamic body because it sits on up of fluid rock. You will use the following image of the Tharsis region to determine if plate tectonics could have ever functioned on Mars by comparing the locations and relative ages of the labeled volcanoes that lie along each great circle (represented by the black lines).


Alba Planitia
Uranius Patera
Olympus Mons
Ascraeus Mons
Pavonis Mons
Arisa Mons

Questions

1. (3pts) Using the image and comparing the volcanoes on the previous page, explain how the **relative age** of each of the volcanoes could be determined in a model where there ***was*** plate tectonics on Mars in the past.

2. (2pts) Where (e.g N, S, NW, etc) is the likely location of the hotspot for the Arisa, Pavonis, Ascraeus lineup? For the Olympus and Alba lineup?

3. (3pts) Using the image and comparing the volcanoes, explain how the **relative age** of each of the volcanoes could be determined in a model where plate tectonics on Mars ***never existed***.

4. (2pts) How could you determine the ***absolute ages*** of the individual volcanoes ***from orbit***?

5. (2pts) Recall your calculated uncertainties from the Crater Counting exercise. How accurate (use numbers) would your age determination from question 4 be?

6. (2pts) The difference in age of the individual Hawaiian Islands is about 1 million years (e.g. Oahu is 1 million years older than Maui). Could you determine this age difference using the technique you described in question 4? Explain.

7. (2pts) If you were not limited by current technology, what would be the ***best*** way to determine the ***absolute ages*** of the Martian volcanoes? Time travel is not an option…

8. (2pts) Given your analysis above, which model do you believe is correct for Mars - the plate tectonic model or the model with no plate tectonics? Explain.