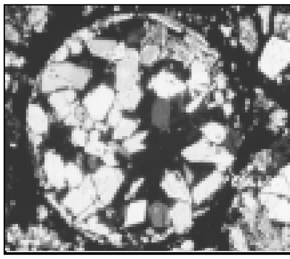

Meteorites

I. OBJECTIVES

Earth is constantly being bombarded by debris left over from the formation of the solar system. Approximately one ton of material falls to Earth every day. Most of this material is comprised of small dust grains that burn up in the atmosphere producing streaks of light that called “shooting stars” or ***meteors***. Occasionally, larger objects survive their passage through Earth’s atmosphere and reach the surface. They are called ***meteorites***.

In this lab, you will:

•examine several types of meteorites;
•determine the cosmic histories of these meteorites;
•distinguish meteorites from terrestrial rocks;
•infer conditions in the early solar nebula;
•hypothesize the origin and evolution of the asteroid belt.

II. PRE-CLASS PREPARATION

Examining meteorite samples is a very special opportunity. Few students get to touch extraterrestrial samples, particularly in an undergraduate course. In order to spend as much time as examining the samples in the laboratory, read the background material in **Section III** ***before*** coming to lab.

In addition to the background material, you will be given a booklet entitled **Meteorites and Their Properties**. This booklet is intended to supplement the lab manual and answer questions that occur to you after the exercise is complete. It can also help you to identify a meteorite on your own!

III. BACKGROUND

A. NEBULAR AND PLANETARY ACCRETION PROCESSES. The first geologic processes in the solar system occurred long before Earth existed. About 4.5 billion years ago, the solar system was a huge cloud of gas and dust. The cloud was so cold, only 10 K (-442 °F), that complex molecules were able to condense from the gas. These regions are called ***molecular clouds*** and they still exist in space. The Orion Nebula, visible with a telescope on any clear night in the northern hemisphere, is an example of a molecular cloud. These clouds contain clumps of slightly denser material called ***molecular cloud cores***. Often, molecular cloud cores become gravitationally unstable and begin to collapse beginning the process of forming a solar system.

As the cloud collapses, it spins faster. Some of the material from the molecular cloud core is drawn to the center of the cloud where it feeds a growing ***protostar***. The rotation of the cloud eventually squeezes the remaining gas and dust into a disk surrounding the protostar. As more material is added to the protostar, the temperatures and pressures in its core became high enough to initiate nuclear fusion. The onset of nuclear fusion marks the transition from protostar to star. In the case of our solar system, the protostar became the Sun; and from the disk surrounding the protosun (called the ***solar nebula***) came the planets, moons, asteroids, and comets.

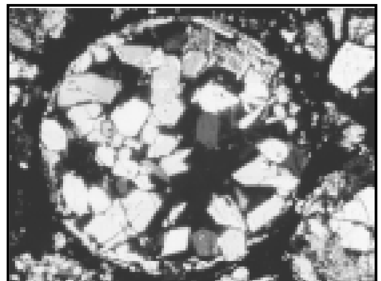

FIGURE 1: A close-up of a chondrule. Notice that it has a glassy texture and a circular

As the solar nebula cooled, the dust ***accreted*** (clumped together) to produce larger particles. Occasionally some of the larger dust particles were melted in brief, but intense, heating events producing molten droplets which have been described as fiery rain. Since the heating events were brief, the molten droplets were soon ***quenched*** (cooled rapidly) to produce spherically-shaped, millimeter-size rocky beads called ***chondrules*** (see Figure 1). Within about 10 million years, the solid material in the solar nebula (*e.g.* dust grains, chondrules) accreted into small ***planetesimals*** with diameters of a few kilometers to perhaps a few hundred kilometers. The planetesimals, in turn, accreted together in a few regions of the solar system to form even larger planetary bodies. About 100 million years after the molecular cloud core collapsed, planets like Earth and Mars had grown to the approximate sizes that we see today.

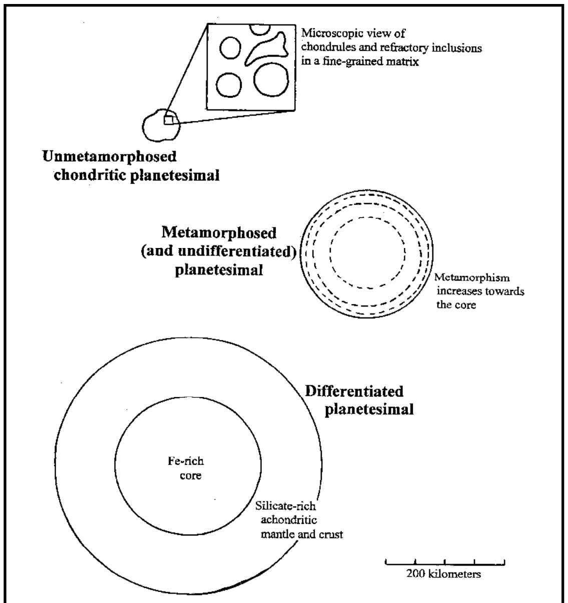

FIGURE 2: Planetary differentiation.

B. PLANETARY DIFFERENTIATION. In cases where a planetary body is hot enough to become partially or wholly molten, materials with different densities can separate. This process is called ***planetary differentiation***. On Earth, for example, dense metallic liquids fell towards the center of the planet to form an iron-nickel rich core, while lighter rocky material rose toward the surface to create the crust and mantle. The same differentiation processes that produced an iron-nickel-rich core in Earth also produced cores in other planetary bodies (*e.g.,* Mars, Venus).

Some of the differentiated asteroids between Mars and Jupiter collided with each other, exposing their metallic-rich cores. The collisions that disrupted the asteroids ejected both stony chunks from the asteroid crusts and iron chunks from their cores. Many of these chunks fall to Earth in the form of stony and iron meteorites.

C. CLASSES AND TYPES OF METEORITES. In this lab, a distinction will be made between two classes of meteorites: chondrites and achondrites. For the purposes of this lab, ***chondrites*** are meteorites that have not been significantly processed since their ***parent body*** (the planetary body on which the meteorite originally formed) accreted. They retain "memories" of the early solar system and solar nebula processes. In fact, many chondrites contain primitive particles like chondrules. ***Achondrites*** are meteorites that have been significantly processed either through volcanic activity or planetary differentiation.

This lab also makes a distinction between three types of meteorites based upon their compositions: iron, stony, and stony-iron. ***Iron*** meteorites come from the iron-nickel cores of differentiated planetary bodies. All iron meteorites are achondrites. ***Stony*** meteorites come from the outer rocky layers of a planetary body. Stony meteorites that have chondrules or that otherwise show a "jumbled" interior are usually chondrites. Stony meteorites which have a uniformly smooth interior, and which contain no obvious inclusions are generally achondrites that come from the crust or mantle of a differentiated planetary body. ***Stony-iron*** meteorites almost always come from differentiated planetary bodies. Nearly all stony-iron meteorites are achondrites.

D. WIDMANSTÄTTEN PATTERNS. The iron-nickel core is the last part of a differentiated planetary body to cool because it is insulated by the outer layers of rock. The weight of the outer layers squeezes the iron core as it cools. The combination of slow cooling and constant compression produces a criss-cross pattern of crystals that is preserved when the iron core finally solidifies. When the cut face of an iron meteorite is etched with acid, the pattern becomes visible. This pattern observed in etched iron meteorites is called a ***Widmanstätten pattern***. Several of the iron meteorites you will examine in this lab have been etched to expose the Widmanstätten pattern.

E. FUSION CRUSTS. During its passage through Earth's atmosphere, the outer surface of a meteorite can be heated to temperatures as high as 30,000 K. This causes the outer surface of the meteorite to melt. After the meteorite lands, the outer surface cools very quickly forming a blackened crust called a ***fusion crust***. Table 1 contains meteorite fall and find statistics.

F. METEORITE FALLS AND FINDS. Any meteorite that is seen falling to Earth and that is subsequently recovered is called a meteorite ***fall***. Meteorite falls are usually collected very soon after falling so the samples are nearly pristine. Meteorite samples that were not observed to fall are called meteorite ***finds***. Nearly all meteorites that are recovered are meteorite finds.

Meteorites may sit unnoticed on the surface for decades, centuries, or even millennia before they are collected. Indeed, the majority of meteorites are never recovered. Meteorite finds are usually made when the meteorite stands out from its surroundings. For example, an iron meteorite sitting on a rocky plain will certainly attract some attention; but a stony meteorite sitting on the same rocky plain may be mistaken for just another terrestrial rock. Many professional meteorite hunters prefer to do their hunting in Antarctica specifically because meteorites easily stand out from the surrounding ice.

IV. THE APPARATUS

- meteorites
- thin section(s)
- microscope

A. METEORITES AND THIN SECTIONS. You will be provided with several meteorite samples to examine. Some of the meteorites will be chunks you can hold in your hands. Other meteorites will be mounted in protective plastic cases.

You will also examine at least one meteorite thin section. ***Thin sections*** are slices of a meteorite that are so thin that light can shine through them. The thin sections will be mounted in glass slides. Be careful not to break them or get them dirty.

Please be careful when handling all samples. Some samples will break in your hands if you are not gentle with them. Other samples will break your foot if you lose your grip and drop them. Pay attention to the sample you are handling to avoid damage and injuries!

B. THE PRECISION MICROSCOPE. In this lab, you will use a ***microscope*** for some observations. The microscope has a number of settings to help you make the best observations possible. To begin, notice that there are two disks that can be placed on the microscope platform for viewing. The first is a transparent disk used ***only*** for viewing thin sections. Placing meteorites on the transparent disk will scratch or otherwise damage it. The second disk is a plastic disk with a black side and a white side. This is the disk you will use for viewing meteorites. You may use either side.

Once you have placed the proper disk in position, turn on the light. For viewing thin sections, pull the toggle switch *toward* you. This turns on a light underneath the transparent disk that will shine through the thin section. For viewing meteorites, push the toggle switch *away* from you. This turns on an overhead lamp that will shine on the rock for easy viewing.

Look through the lenses to see the meteorite. You may need to adjust either the position of the meteorite or the ***focus***. To adjust the focus, slowly turn the knobs at the side of the top portion of the microscope. Continue to turn them, in either direction, until the meteorite comes into focus. If you can no longer turn the knob and the object is still not in focus, ***don't force the knob***! If you try to force the focus knob, you may strip the screws and damage the microscope. Instead, you will need to move the whole top portion of the assemblage up or down. ***Ask your instructor for help doing this.***

You can change the ***magnification*** of the microscope. If you turn the microscope so that the eyepieces point away from you, you will notice writing on the black cylinder above the rock. On one side you will see a 2x and when you rotate it you will see a 4x. When the 2x is facing outward, the view you will get in the microscope is a magnification factor of 2. When the 4x is facing outward, the view you will get in the microscope is a magnification factor of 4.

Remember to turn the light off when you are finished with the microscope! Leaving the light on for long periods of time will burn out the bulb.

Table 1: Meteorites

Meteorite Name	Class and Type	Are Chondrules Present?	Parent Body Differentiated or Undifferentiated	Evidence For or Against Differentiation
Odessa				
Toluca				
Gibeon				
Millbillillie				
Allende				
Goa				
Pallasite				

V. THE LAB SESSION

You should describe and sketch all meteorites you examine in detail. Your sketches and descriptions should include details like color, particle size, particle shape, number of different mineral components (***phases***), presence or absence of fusion crust, *etc*. Fill in the table provided in addition to your own notes. Detailed descriptions will help you later!

Many steps in the lab have questions associated with them. These questions are designed to aid in your interpretations of the histories of the meteorites. ***You should answer these questions while you have the meteorites in front of you!***

1. Iron Meteorites.

STEP 1: Begin by examining three ***iron*** meteorite samples. One of the meteorites is a large hand specimen. It is a fragment of the ***Odessa*** meteorite that produced the Odessa impact crater in west Texas. The large meteorite slab is from the ***Toluca*** (Mexico) meteorite. Examine both sides of the specimen. One side shows the appearance of the meteorite when first cut. The other side shows the appearance of the meteorite after it was etched with a solution of nitric acid to accentuate the Widmanstätten pattern. The third specimen is encased in plexiglass. Please handle it carefully and do not scratch the plexiglass. This specimen is from the ***Gibeon*** (Australia) meteorite. Sketch and describe these meteorites.

- How are the meteorites in this group similar to each other? Are there any significant differences between them (ignoring the fact that they are cut differently)?

- Were the parent bodies of these meteorites differentiated? If so, where in the parent body did these meteorites form? How can you tell?

- Do you think iron meteorites retain any “memory” of solar nebula processes? Why or why not?

- Were these meteorites ejected into space by a surface impact or by a violent collision between two similar size objects?

- How thick are the fusion crusts? What does this imply about the amount of time the meteorites spent traversing the atmosphere?

- Can you reconstruct the histories of these meteorite?

2. Stony Meteorites.

STEP 2: The next three samples are stony meteorites. They are each encased in a plexiglass case. Try to avoid scratching the plexiglass so that others can see the meteorites unobscured. Examine the sample labeled ***Millbillillie*.** This is a meteorite that fell in Australia. Sketch and describe what you see.

STEP 3: Now examine the meteorite that is labeled ***Allende***. Sketch and describe the meteorite.

STEP 4: There is also a thin section of Allende which you can examine with your microscope. Augment your description from **STEP 3** with any new observations. The chondrules in the thin section should appear similar to the chondrule shown in **Section III. A**.

STEP 5: Examine the meteorite sample labeled ***Goa***. This sample is a metamorphic rock that was once buried on a fairly small planetary body (probably a few hundreds of kilometers in diameter). This sample is much less complicated than Allende and contains two obvious phases. Sketch and describe what you see.

- Are there any chondrules present in any of the stony meteorites? If so, which ones?

- Which of these meteorites appear to be unprocessed? Which ones appear to be the products of planetary differentiation? How can you tell?

- Which of these meteorites retain a “memory” of primitive solar nebula processes?

- Which of these meteorites would you label as chondrites? Achondrites? Why?

- Were these meteorites ejected into space by surface impacts or by violent collisions?

- How thick are the fusion crusts? What does this imply about the amount of time the meteorites spent traversing the atmosphere?

- As a group, how are these meteorites similar to the iron meteorites? How are they different from the iron meteorites?

- Can you reconstruct the histories of these meteorite?

3. Stony-Iron Meteorite.

STEP 6: The meteorite labelled ***Pallasite*** is a unique stony-iron meteorite. Sketch and describe this meteorite.

- Is this meteorite processed or unprocessed? How can you tell?

- If this meteorite is from a differentiated planetary body, what part of that body did it come from? If it is from an undifferentiated planetary body, how do you think the unique pattern of this meteorite was created?

- Does this meteorite retain a “memory” of primitive solar nebula processes?

- Was this meteorite ejected into space by a surface impact or by a violent collision?

- How is this meteorite similar to the iron meteorites? How is it different?

- How is this meteorite similar to the stony meteorites? How is it different?

- Can you reconstruct the history of this meteorite?

4. Additional Meteorite Samples.

STEP 7: If there are additional samples available, examine them and describe them below. Use what you have learned so far to interpret your observations.

5. Meteorite Identification.

STEP 8: Now that you have seen several meteorite samples, you might wonder how you would identify a meteorite from an ordinary terrestrial rock (see Table 2 for real meteorite fall and find statistics). Your instructor will mix some meteorites into a collection of ordinary terrestrial rocks. Using your experience with the meteorites in this lab and your intuition, try to identify ***all*** of the meteorites and ***only*** the meteorites. Be able to justify your choices!

Table 2: Statistics of Meteorite Falls and Finds*

	Falls		Finds		Antarctic Finds	
	#	%	#	%	#	%
Iron	31	4.4	459	47.3	5	5.1
Stony Iron	8	1.1	47	4.8	1	1
Stony	668	94.5	465	47.9	93	93.9
Totals	***707***	***100***	***971***	***100***	***99***	***100***

* Adapted from Meteorites: Classification and Properties by John T Wasson, 1985
and Cassidy & Harvey, Geochemica et Cosmochemica Acta, 1991, **55**, 99-104.

STEP 9: Before leaving the lab, you should attempt the **DISCUSSION** sections. Then re-examine the meteorites to verify that your conclusions are consistent with your observations.

VI. DISCUSSION

The following points should be addressed in the Discussion section of your lab report. Your discussion should not necessarily be limited to these points.

A. METEORITE DESCRIPTIONS.

- Describe the three types of meteorites. What part of the parent body does each type of meteorite come from? Distinguish between differentiated and undifferentiated planetary bodies. What would you expect to see in a meteorite that came from an undifferentiated planetary body?

B. METEORITE HISTORIES.

- Comets are too small and too cold to differentiate. They are composed of rock and ice with little or no metal. What type of meteorite would you expect to find? What class of meteorite would it be? Explain.

- Construct histories for each type of meteorite that you studied. Begin with the formation of the parent body and finish with the meteorite’s arrival on Earth.

- Can you identify chondrules in any of the meteorites? What do the presence of chondrules imply about the thermal histories of the meteorites they are found in?

- Consider the scenario that the asteroid belt formed from a planet that exploded. Would you expect most meteorites to be chondrites or achondrites? Why? Now, suppose that the asteroids are just small bodies that never accreted into a planet. Would you expect most meteorites to be chondrites or achondrites? Why? More than 90% of all meteorites are chondrites. What does this imply about the history of the asteroid belt?

C. IDENTIFYING METEORITES.

- Describe how you might distinguish meteorites from terrestrial rocks. What factors cause meteorites to stand out from their surroundings? Why do you think meteorite hunters go to Antarctica to look for meteorites when meteorites fall all over the world? Which type of meteorite do you think is most commonly found and why?

D. PLANETARY SCIENCE.

- Why are meteorites important to planetary scientists? Why are meteorites important to you?

- How does the study of meteorites relate to other topics in this course? Consider how the meteorites were created, where they come from, and how they got to Earth.