

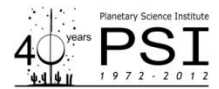
Introduction to Meteorites

Developed and compiled by Larry Lebofsky, PSI



Sikhote-Alin, Iron Meteorite

Photo Credit: Larry Lebofsky



Created in collaboration with The International Meteorite Collectors Association (IMCA)

Big Ideas:

- **At present, meteorites are our only chance to study material from asteroids, Mars, and much of the Moon.**
- **Meteorites are classified into three groups: stone, stony-iron, and iron.**
- **Primitive stone meteorites come from asteroids that have not changed much since the formation of the Solar System 4.57 billion years ago.**
- **Differentiated stone meteorites come from the surfaces of melted asteroids, the Moon, or Mars.**
- **Stony-iron and iron meteorites come from the interiors of melted asteroids.**
- **Asteroids and comets may have brought water and organics to Earth—the building blocks of life.**

Solar System Objects:

- An asteroid is an object that orbits the Sun, but smaller than a planet. They range in size from a few meters to nearly a thousand kilometers across. The image below is of the 525 kilometer diameter asteroid 4 Vesta taken by the Dawn spacecraft. The largest asteroid, 1 Ceres, is 940 kilometers in diameter and is big enough to be “round.” It is also considered to be a dwarf planet.

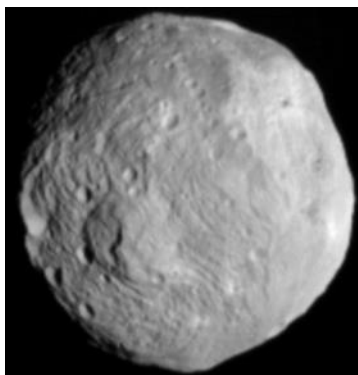


Photo Credit: NASA

- A meteoroid is an object that orbits the Sun, but is smaller than an asteroid. They range in size from a speck of dust to a few meters across.
- A comet is an object that orbits the Sun. Comets are mostly icy and so, when close to the Sun, they display a visible coma and sometimes a tail. Comets range in size from a few tens of meters to tens of kilometers across. The image below is of Comet McNaught taken in 2007.



Photo Credit: Sebastian Deiries/ESO

Objects in the Atmosphere:

- When a meteoroid enters the Earth's atmosphere, it is heated up as it passes through the atmosphere. The glow of the meteoroid and the trail of heated gas and particles is called a meteor. Incorrectly called "shooting stars," most will burn up completely in the atmosphere.
- Meteor showers can be seen from any location, but it is better to get away from city lights to see them. Most are related to material from comet tails.



Photo Credit: NASA

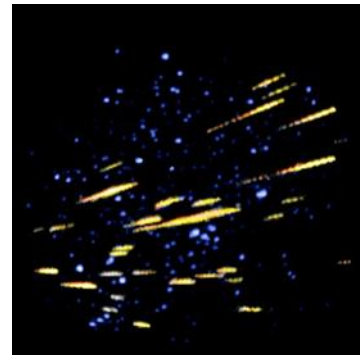


Photo Credit: NASA

- A **fireball** is a brighter-than-usual meteor. It is usually defined as a meteor brighter than the planet Venus at its brightest. The image below is a Geminid fireball over the Mojave Desert.



Photo Credit:: Wally Pacholka

Objects on the Ground:

- A meteoroid or piece of a small asteroid (large objects may get totally vaporized upon impact) that has survived passage through the atmosphere is called a meteorite. The meteorite on below is called Hammada al Hamra 335 and was found in Libya in 2004. Meteorites are named for the location where they were found. It is about 2.5 cm (1 inch) across and weighs 46 grams (1.6 oz).



Photo Credit: Dr. Svend Buhl, IMCA #6540
www.niger-meteorite-recon.de

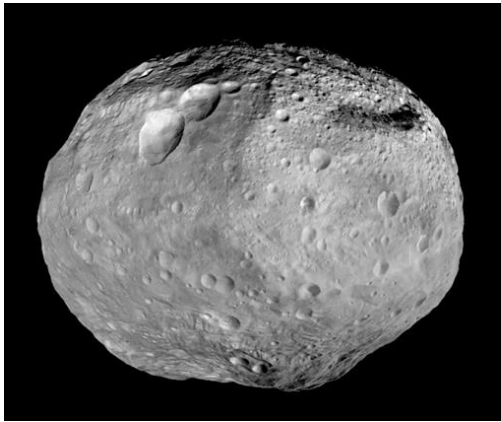
- The only other rocks from another world (other than meteorites) are **lunar rocks**. **Lunar rocks** are rocks brought back from the Moon by US astronauts, though a small amount of lunar material was brought back by robotic missions from the Soviet Union. Below is a lunar rock brought to Earth by the Apollo 17 crew.



Photo Credit: NASA

Where Meteorites Come From:

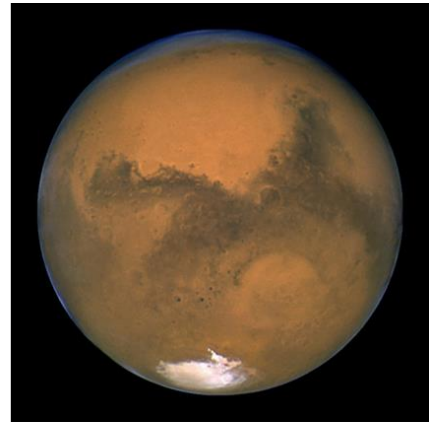
- Most meteorites come from asteroids, but, rarely, they come from the Moon or Mars. There are no *known* meteorites from a comet.
- Meteorites are the only way that we can study material from asteroids, the Moon (other than Moon rocks), or Mars (other than the Mars rovers).



Asteroid 4 Vesta
Mean Diameter About 525 km
Photo Credit: NASA, Dawn Mission



Moon
Diameter = 3,474 km
Photo Credit: Gregory H. Revera,
Wikimedia Commons



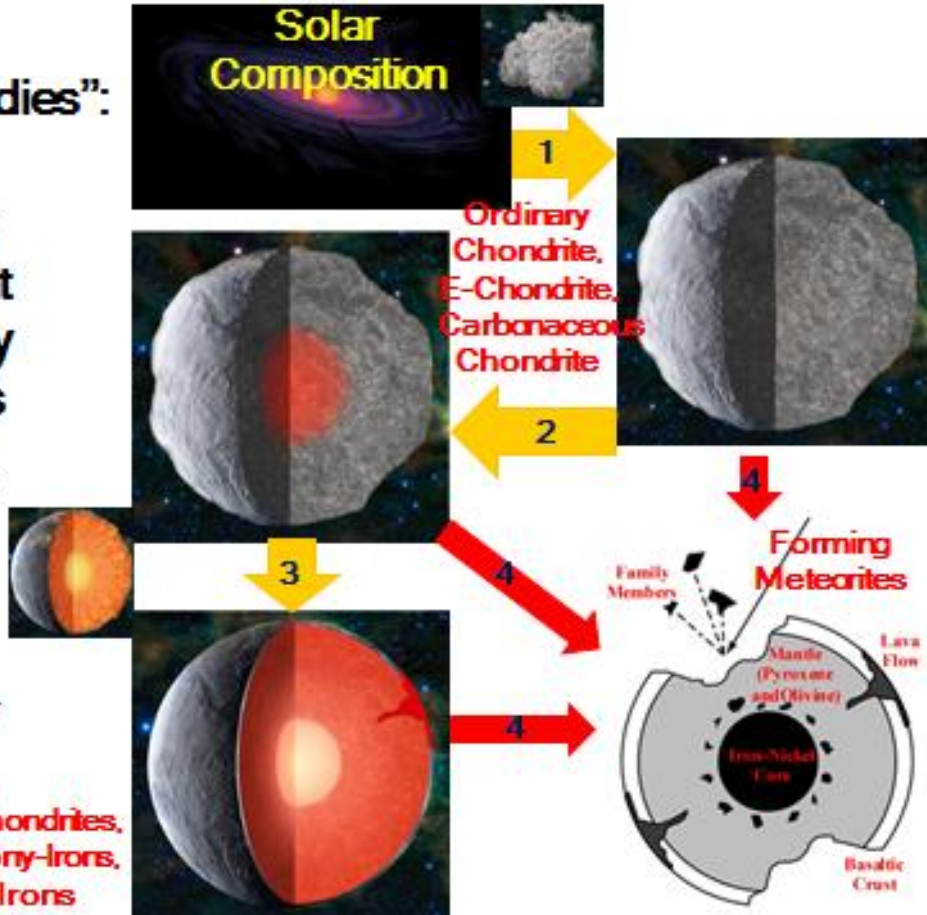
Mars
Diameter = 6,672 km
Photo Credit: Hubble Space Telescope

Asteroid "Parent Bodies":

Relations Between Important Planetary Materials

1. Solids condense, lose hydrogen and helium (accretion)
2. Low heat (some melting or hydration), lose carbon and water
3. High heat, differentiation
4. Meteorites form from any asteroid

**Achondrites,
Stony-Irons,
Irons**



Meteorite Types



Stone

Franconia
Photo Credit: Larry Lebofsky

Stony-Iron



Esquel
Photo Credit: Wikimedia
Sikhote-Alin
Photo Credit: Larry Lebofsky

Iron



Stone Meteorites:

- Stone meteorites fall into two major groups, primitive and differentiated.
 - Primitive: Chondrites—sometimes heated, but NOT to the point of melting
 - Some may be metamorphosed due to heating or aqueous alteration (water).
 - Differentiated: Achondrites—heated to the point of melting
 - The result of differentiation, but sometimes due to local melting (impacts)



Allende, 48g
Photo Credit: Anne Black



NWA 4483 — Lunar Achondrite



NWA 2774 — Ordinary Chondrite
Photo Credit: Greg Hupe

Chondrites and Chondrules:

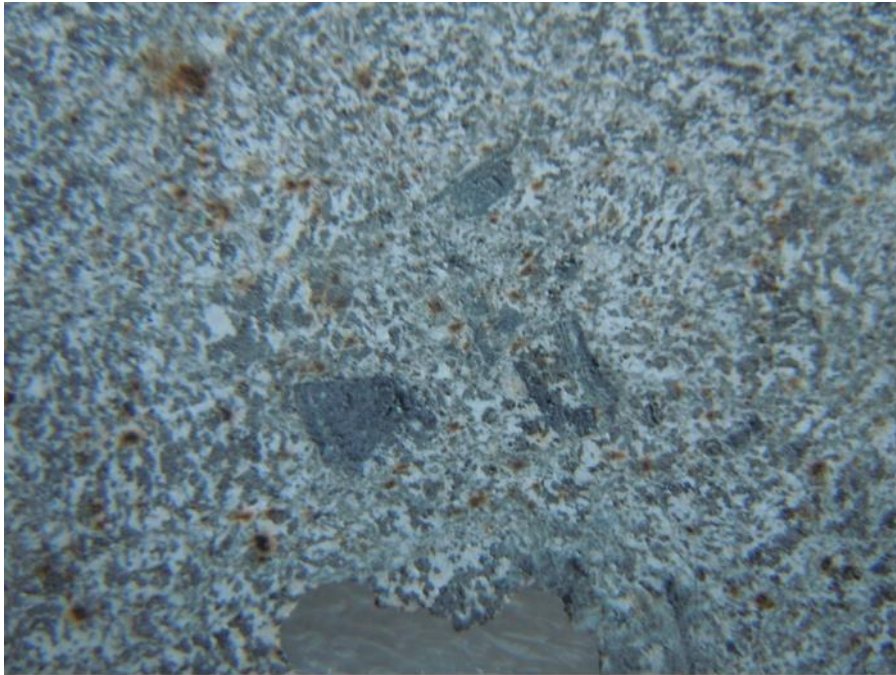
- Primitive meteorites are called **chondrites**. Chondrites represent the primitive building blocks of the Solar System.
- **Chondrules** are the major constituent of most chondritic meteorites. Chondrules formed as molten or partially molten droplets before becoming part of the chondrite parent bodies, forerunners of asteroids and planets.
- Most chondrites also contain distinctive silvery-colored flakes of iron-nickel metal.
- Terrestrial rocks do not contain chondrules.



Photo Credit: Greg Hupe, IMCA #3163

Achondrites:

- Differentiated meteorites are called achondrites.
- Because they have melted, achondrites do not contain chondrules.
- Also, because gravity separates the heavier iron-nickel metal from the lighter rocky material, achondrites do not contain the shiny metal seen in chondrites.
- Pictured below is an enlarged image of NWA 3137. Eucrites are achondrite meteorites that are thought to come from the asteroid Vesta.



NWA 3137, Eucrite
Photo Credit: Larry Lebofsky

Stony-Iron Meteorites:

- **Stony-iron** meteorites consist of almost equal amounts of nickel-iron (FeNi) alloy and silicate minerals.
 - The **pallasite** subgroup is characterized by olivine crystals surrounded by an FeNi matrix. Pallasites are thought to be the core-mantle boundary of differentiated asteroids.
 - The **mesosiderite** subgroup consists of silicates in the form of heterogeneous aggregates intermixed with FeNi alloy. Thought to be formed by local melting by impacts.



Brenham—Pallasite
Photo Credit: McCartney Tayler



NWA 1879—Mesosiderite
Photo Credit: Adam Hupe



Fukang—Pallasite
Photo Credit: Anne Black

Iron Meteorites:

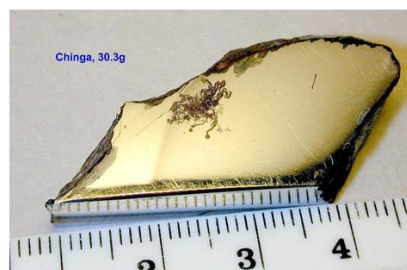
- Characterized by the presence of two nickel-iron (FeNi) alloys: kamacite (Ni poor) and taenite (Ni rich)
- Iron meteorites are further classified by sub-groups:
 - **Hexahedrites** (4-6% Ni)
 - **Octahedrites** (6-12% Ni)
 - **Ataxites** (12+% Ni)
- The octahedrite below shows a **Widmanstätten pattern** which depicts the structure of kamacite and taenite crystals in many iron or stony-iron meteorites. It is revealed when the surface of an iron or stony-iron meteorite is etched with a weak acid.



Fredericksburg—Hexahedrite
Photo Credit: Anne Black



Cape York—Octahedrite
Photo Credit: Anne Black



Chinga—Ataxite
Photo Credit: Anne Black

Best Places to Find Meteorites:

- Antarctica
 - The best place in the world to find meteorites is Antarctica. Meteorites fall on the ice and are preserved in it. Since 1969 scientists have found thousands of meteorites in Antarctica.
- Deserts
 - Hundreds of meteorites fall to Earth each year, but most are not seen because they land in the ocean or unpopulated areas. Many are found in deserts because the heat and dryness keep them from rusting away.



Photo Credit: NASA

Tektites:

- **Tektites** are pieces of natural glass that are created when large meteorites impact the Earth's surface. The released energy, in the form of heat, melts the silicates in the surrounding soil, creating this natural glass.
- Tektites are often shaped like spheres, dumbbells, or teardrops.
- The unique shape of tektites is now believed to be a result of how they spin as they cool rather than aerodynamically-shaped. Aerodynamically-shaped tektites (button-shaped) are rare.



Photo Credit: Unknown

Earth Rocks vs. Meteorites

While Earth rocks can be broadly classified as igneous, metamorphic, and sedimentary, meteorites are broadly classified, based on composition, as iron, stony-iron, and stony. However, based on how they were formed, meteorites are classified as differentiate and undifferentiated—was the parent body of the meteorite (an asteroid, the Moon, or Mars) large enough for the object to have melted and formed a crust, mantle, and core? Or, was the meteorite parent body too small and thus represent material that has been relatively unaltered since the parent body first formed out of the solar nebula?

In the Meteorite Mini-kits are four meteorites and an impact rock, a tektite.

Stony Meteorite:

Stone meteorites represent about 97% of all of the meteorites either found or seen to fall. This group of meteorites includes *chondrites* and *achondrites*. See http://meteorites.wustl.edu/meteorite_types.htm for statistics on all meteorites.

Primitive Meteorite:

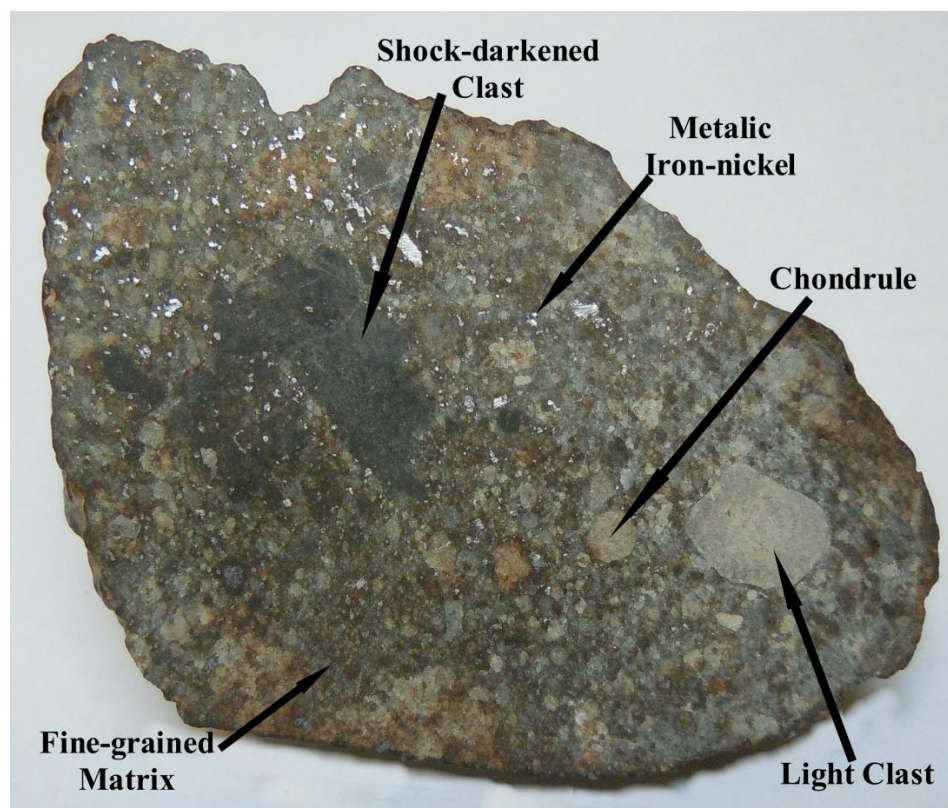
A primitive meteorite refers to a meteorite that has a composition similar to that of the Sun, minus the “volatile” elements (hydrogen, helium, for example). These are thought to come from undifferentiated asteroids, some of which may have been mildly heated. These meteorites include the *chondrites* as well as the primitive achondrites. Very characteristic of chondrite are relic chondrules and chemical compositions close to the composition of [chondrites](#). These observations are explained as melt residues, partial melting, or extensive recrystallization. <http://www.meteoris.de/basics/class2.html>, http://en.wikipedia.org/wiki/Primitive_achondrite, Dr. Alan Rubin: “Secrets of Primitive Meteorites,” in *Scientific American* February 2013.

Chondrites:

Stony meteorites make up about 97% of all known meteorites and chondrites make up about 95% of the stony meteorites. Ordinary chondrites make up more than 95% of the known chondrites (hence the term “ordinary.”) Chondrites are primitive (undifferentiated) meteorites. Chondrites are stony (non-metallic) meteorites that are made up mostly of silicates, traces of iron, and sometimes carbon and water. Many, but not all, chondrites contain chondrules. Chondrules form as molten or partially molten droplets in space before being [accreted](#) to their parent [asteroids](#). Chondrites represent one of the oldest solid materials within our Solar System and are believed to be the building blocks of the [planetary](#) system. Chondrites have not been modified due to melting or differentiation of the of the parent body. Three of the meteorites in Mini-kits are ordinary chondrites.

The whole and one of the cut meteorites are NWA 869s—the 869th meteorite found in Northwest Africa to be classified. While all of the NWA 869s show weathering, the whole ones show more weathering and so are not as valuable as the less-weathered ones. NWA 869 is an ordinary chondrite and specifically a chondritic breccia. Regolith breccias are rocks composed of broken fragments of [minerals](#) or rock [cemented](#) together by a fine-grained [matrix](#). The rock formed from impact ejecta which was later buried by newer impacts and [lithified](#) (solidified) due to the pressure from overlying layers. However, the pressure was not enough to heat and destroy the chondrules.

The other cut meteorite is also a chondrite. In this case, the rock has been heated enough (most likely impact shock heating).



Metamorphism:

Metamorphism is the change of [minerals](#) or [geologic texture](#) (distinct arrangement of minerals) in pre-existing [rocks](#), without the rock melting into liquid [magma](#) (a [solid-state](#) change). The change occurs primarily due to heat, pressure, and the introduction of chemically active fluids (water). The [chemical components](#) and [crystal structures](#) of the minerals making up the rock may change even though the rock remains a [solid](#). Metamorphism typically occurs between about 200°C and melting at about 850°C. Three types of metamorphism exist: [contact](#), dynamic and [regional](#). <http://en.wikipedia.org/wiki/Metamorphism>. In meteorites, metamorphism usually occurs through alteration by water or by impact shock heating.

Iron Meteorite

Iron meteorites are differentiated meteorites and are thought to represent the cores of differentiated asteroids. Iron meteorites consist of almost pure metallic iron with small amounts of nickel and sulfur. Polished faces are commonly treated with dilute nitric acid to bring out the Widmanstätten pattern—parallel patterns of lines intersecting at various angles delineating bands of crystals of kamacite (low nickel) and taenite (high nickel) iron alloys. Iron meteorites were once completely molten and, as indicated by sizes of some individual crystals as large as several meters, cooled slowly over millions of years. It is estimated that the parent bodies of the iron meteorites ranged from a little over 100 km to nearly 1,000 km (the size of Ceres) in diameter. Irons are grouped by chemical composition. Known irons originate from 60–70 parent bodies.

Tektite:

A tektite is an Earth rock that has been melted (or vaporized) by hypervelocity impact. The material has been ejected from the impact crater and, as the molten material reenters the atmosphere, cools rapidly forming unusual shapes due to passage through the atmosphere, spinning, and landing while still slightly soft. While it is the result of the impact of a large “rock from space,” it is not a meteorite, it is an impactite.

Tour of the Meteorite Mini-Kit



- Determine your audience's prior knowledge about meteorites
- Demonstrate that one way of identifying a meteorite is by weight (density) and why
- Lead your audience through a series of investigations of the rocks in the Mini-Kit, having them guess which ones they think are meteorites and why
 - Look at the rocks or sketch them without picking them up
 - Pick them up
 - Examine the rocks with the tools they have been given (magnifier and magnets)
 - For closure, tell them that this is exactly what scientists do

Discussion Questions (for interpretation):

- Comparing the pumice to the Earth rock, why is one heavier than the other? (The pumice has holes and the other does not.)
- Why is the whole meteorite heavier than the pumice or Earth rock? (The meteorite is made of heavier "stuff.")
- Why is the little meteorite attracted to a magnet (it is not magnetic!)? (It is made of metal—iron.)
- Are the meteorites attracted to a magnet? (Yes.)
- When you look at the surfaces of the two cut meteorites, what do you see? (Little shiny flakes.)
- Why are the meteorites attracted to a magnet? (They contain little flakes of iron.)
- Why are the meteorites heavier than the Earth rock? (They contain little flakes of iron!)

Information About the Meteorites

- All of the meteorites are older than the Earth. They are the “building blocks” that made the Earth. They are 4.56 billion years old!
- There are no Earth rocks that contain pure metal (iron and nickel) as do the meteorites (others are attracted to magnets, but the flakes of metal are unique to meteorites).
- No Earth rocks contain chondrules.
- The iron meteorite is from the core of an asteroid.
- The chondrite meteorites came from asteroids that were too small to have melted, so we are seeing the iron as it was when the Solar System was forming.

Tie Into NGSS:

- The Next Generation Science Standards (NGSS) Performance Expectations include: “What makes up our solar system?” NGSS emphasizes the Crosscutting Concepts of Patterns and Scale, Portion, and Quantity. NGSS also states that the Nature of Science (NOS) should be an “essential part” of science education. NOS topics include, for example, understanding that scientific investigations use a variety of methods, that scientific knowledge is based on empirical evidence, that scientific explanations are open to revision in light of new evidence, and understanding the nature of scientific models.
- The Mini-Kits lend themselves perfectly for incorporating the Nature of Science into an activity that also introduces teachers and their students to meteorites.