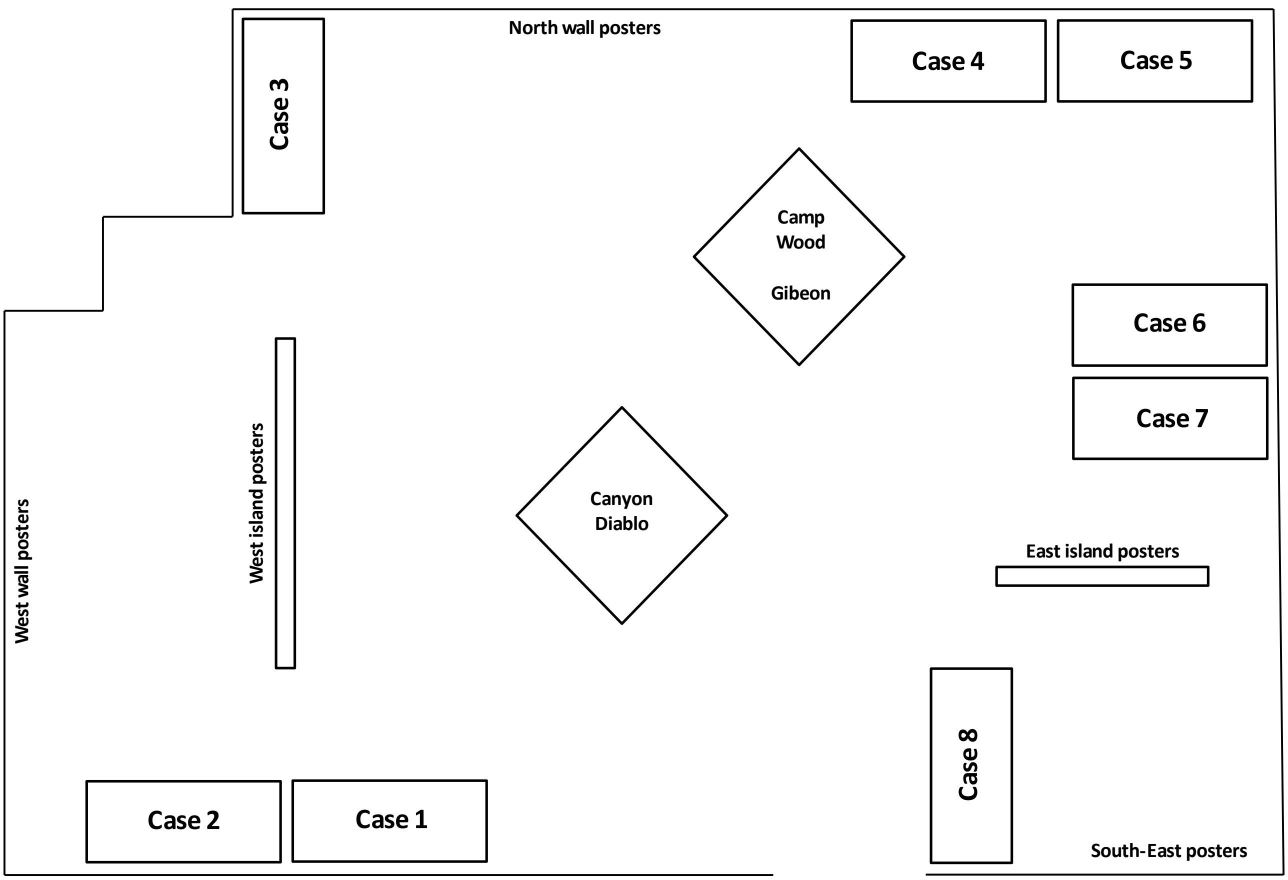
UCLA METEORITE COLLECTION

Teacher's Guide to the UCLA Meteorite Gallery

One approach to enhancing the students' experiences at the UCLA Meteorite Gallery is to explore scientific themes illustrated by the specimens and posters on display. This guide lists four topics (along with sets of basic and advanced questions and answers) that can be explored on your visit.



Schematic Diagram of the cases in the UCLA Meteorite Gallery

Topic 1: Primitive Meteorites

a. The meteorites that formed from the original materials in the solar nebula are known as chondrites. They are sometimes called "primitive" meteorites.

b. There are 12 major classes of chondrites, each derived from a separate asteroid and each containing its own distinctive abundances of chondrules and fine-grained matrix material. In Case 1 there are seven chondritic meteorites – Jilin from the H-chondrite asteroid, Zhaodong and La Criolla from the L-chondrite parent asteroid, Richfield from the LL-chondrite asteroid, NWA 1668 from the R-chondrite asteroid, Indarch from the EH-chondrite asteroid, and NWA 3118 from the CV asteroid.

c. Some closely related chondrite groups are gathered together into clans. The ordinary chondrite groups H, L and LL are called the ordinary chondrite clan. The name ordinary means "common"; they are the most common meteorites observed to fall. La Criolla and Richfield are ordinary chondrites (other ordinary chondrites are at the bottom of Case 2), NWA 1668 is an R chondrite (related to ordinary chondrites but richer in fine-grained matrix material), Indarch is an enstatite chondrite and NWA 3118 is a carbonaceous chondrite. Other carbonaceous chondrites in Case 2 include representatives of the CR, CO, CM and CV-CK parent asteroids.

d. The name chondrite is given to these meteorites because they contain spheroidal grains called chondrules. These are typically sub-millimeter-size igneous (i.e., produced during melting) spherules that formed as droplets of silicate melt in the solar nebula. Chondrule-formation processes are illustrated in Case 2. Chondrules that were mechanically separated from an ordinary chondrite are also shown in Case 2.

Questions – Observe and Explore:

<u>Basic Questions</u>:

1. What is the evidence that different chondrite groups came from different asteroids?
2. Why are some groups of chondrites called "ordinary"?
3. Why are chondrites considered "primitive" meteorites?

<u>Advanced Questions</u>:

4. Why can't we find chondrules in differentiated meteorites?

5. Why are chondrites called the building blocks of the planets?
6. A poster in the west island set notes that the enstatite chondrites are linked to the Earth. What properties of chondrites can be used to link them to planets?

Topic 2: Chondrules

a. Chondrules are spheroidal. They were formed by melting porous clumps of dust in the solar nebula. The spheroidal shapes (like those of water droplets) are the result of surface tension.

b. Mean chondrule sizes range from 0.3 to 1.0 mm. Within each chondrite group they constitute ~50% to 90% of the mass of individual meteorites. The remaining material in chondrites is fine-grained “matrix”. Matrix contents range from ~10 to 50%, a factor of 5.

c. Chondrules in different groups vary in size, abundance and in the proportions of different textural types. This variety can be seen in the specimens in Cases 1 and 2 as well as on the posters on the west wall.

d. Chondrites formed very quickly, on a time scale of seconds to minutes. They had to form quickly because their evaporation temperatures of ~980ºC are much lower than their melting temperatures of ~1580ºC.

e. Chondrules in the same primitive meteorite can have mean $\frac{FeO}{FeO + MgO}$ ratios ranging from about 0.01 to 0.30. Most meteorites experienced high temperatures that caused thermal metamorphism which resulted in partial equilibration of these grains and hence much smaller ranges.

Questions – Observe and Explore:

Basic Questions:

1. What evidence indicates that chondrules formed in the solar nebula?
2. Are silicate chondrules the only solids present in the solar nebula?

Advanced Questions:

3. What processes could have formed chondrules?
4. How might some chondrules (such as those in the central image on the west wall) get their rims?
5. What do rimmed chondrules tell us about the repetitiveness of chondrule formation processes?

Topic 3: Differentiated Meteorites

a. Some asteroids got hot enough to melt some or all of their constituents. The heat may have come from radioactive decay or from high-velocity collisions. Melting destroyed any chondrules that the asteroids may have had inside them. During chondrite melting, two liquids are produced – a metal-sulfide-rich liquid and a silicate-rich liquid. These liquids are immiscible; like oil and water they cannot dissolve in one another. The metal liquid is much denser and sinks to the center of the partially molten asteroid forming a liquid metal core. The silicate liquid is buoyant; it commonly rises towards the surface, leaving behind denser minerals in the unmelted mantle.

b. As time passes, the liquids cool and crystallize. Metal in the core crystallizes into solid iron-nickel. At lower temperatures, the solid metal separates into two iron-nickel minerals – a low-nickel phase called kamacite and a high-nickel phase called taenite. The intergrowth of kamacite and taenite produces the characteristic criss-cross pattern known as the Widmanstätten structure (which reflects octahedral symmetry). Most iron meteorites are samples of the cores of differentiated asteroids. Several examples can be seen in Case 1, e.g., Kinsella, Nazareth (iron), Turtle River, Mount Dooling and Carbo.

c. The most refractory common silicate mineral is a magnesium silicate called olivine. These large green crystals are denser than silicate melts and remain at the bottom of the magma chamber; planetary mantles consist largely of olivine. Olivine meteorites are rare even though the mineral is common. This appears to reflect the fact that olivine-rich meteorites are shattered during collisions in space. Meteorites that formed at the core-mantle boundary are called pallasites: these rocks are made almost entirely of olivine and metal. Two pallasites – Springwater and Seymchan – are on display at the bottom of Case 1; three other pallasites that are back-lit are in Case 3.

d. The first liquid to form during the melting of an asteroid is rich in aluminum, sodium and calcium; rocks with this composition are called basalts. Basaltic liquids are extruded onto the surface of the differentiated asteroids. The common meteoritic basalts are called eucrites. One eucrite from Australia named Millbillillie and one from Northwest Africa (labeled NWA 6694) are on display at the bottom of Case 1. Other eucrites can be found in Case 7. Various types of terrestrial basalts are also on display in Case 7.

Questions – Observe and Explore:

Basic Questions:

1. What heat sources could have melted the asteroids?
2. Why did some asteroids melt while others did not?
3. Why are melted asteroids called "differentiated"?
4. Where did pallasites come from?

Advanced Questions:

5. Why is it a mistake to think that the volumetric proportions of meteorites exactly reflect the relative fractions of these materials in the parental asteroids?
6. Would we expect to find basalts at the surface of chondritic asteroids? Why or why not?
7. If most iron meteorites are from cores buried deep within differentiated asteroids, how did they escape and get to Earth?
8. If the asteroid Vesta (see posters near Case 7) is the parent body of the eucrites, could it also be the parent body of iron meteorites? Why or why not?
9. If iron meteorites had cooled quickly (i.e., if they had quenched), would a Widmanstätten pattern have formed? Why or why not?

Topic 4: Impact Effects

a. Because asteroids are airless bodies, objects collide with the surface without being slowed down by the atmosphere. Consequently, impact effects are quite prominent in meteorites. Rocks that consist of impact-produced fragments are called "breccias." They form from the fragments produced by an impact event. In some cases, pieces of the projectile survive and are incorporated in the breccia; such recognizable fragments are called clasts. On display in Case 4 are several meteorite breccias – Tanezrouft 057, a CK carbonaceous chondrite containing a dark clast; Naryilco and Beeler, LL6 ordinary chondrites containing light-colored metamorphosed clasts residing in a dark matrix; and Mifflin, an L5 chondrite fall also containing light clasts in a dark-colored matrix.

b. In many impacts, parts of the target rock are melted. Many shocked meteorites are "impact-melt breccias" consisting of melted and unmelted material. In Case 4, we can see three ordinary-chondrite impact-melt breccias: Chico has narrow dark channels of silicate melt transecting shocked but unmelted L6-chondrite material; Shaw consists of melted, partly melted and unmelted-L6 material all stuck together; Portales Valley contains metal patches formed from an impact melt surrounding shocked-to-partly-melted H6 clasts. Because melts can flow, solid materials initially several meters away from the point where melts were created may now be adjacent to melt.

c. A mix of metal and sulfide melts at lower temperatures than silicates and can form thin metal-rich veins as in the Estacado H6 chondrite in the bottom half of Case 4 or large metal-sulfide clasts as in the adjacent Mayfield H4 chondrite. In some cases, metal and sulfide form very thin veins and dispersed particles that permeate the meteorite, making it appear rather dark. This phenomenon is called silicate darkening. Two ordinary chondrites in Case 4 that have experienced extensive silicate darkening (or shock blackening) are Farmington (L5) and Taouz 001 (L6).

d. In some cases, enough impact energy is produced that portions of the target rock are vaporized and the resulting meteorite has holes called vesicles marking the place where there were once gas bubbles. A picture of a vesicular chondrite from Antarctica called LAR 06299 is shown at the bottom of Case 4.

Questions – Observe and Explore:

Basic Questions:

1. Which kind of impact events do you think occur more frequently, those involving tiny "micrometeorites" or those involving large projectiles?
2. What determines whether an impact would cause brecciation, melting or vaporization of the target rock?
3. Some ordinary chondrite breccias contain clasts of carbonaceous chondrites inside them. Where could these clasts have come from?

Advanced Questions:

4. Few Earth rocks are impact-melt breccias; why might this be?
5. Would you expect the Moon to have lots of impact-melt breccias? Why or why not?
6. The metal in Portales Valley has a Widmanstätten structure indicating that it cooled slowly. If it is an impact melt, what could have caused it to cool slowly rather than rapidly?
7. How might an impact cause some portions of the target rock to melt, but leave adjacent portions shocked but unmelted?
8. Some asteroidal target rocks are totally melted by impacts and share some textural resemblance to eucrites. Why would this be so?

Topic 5: Tektites and Libyan Desert Glass

a. Tektites are not meteorites. They are earthly materials that chilled to a glass after being melted during an impact event. Tektites come in two physical forms: (1) splash-form (or spin-form) tektites that chilled to a glass while spinning; and (2) layered tektites that formed on the ground as a melt sheet that became thick when it flowed into low spots. The only compositional difference is that layered tektites have slightly higher contents of volatiles such as B, Zn or Ga. Splash-form tektites come in a variety of shapes that are represented on the shelves of Case 5. These shapes include dumbbells, tear drops and disks. The tektites are made of glass formed from viscous silica-rich fluids. These melts were formed by compression in a crater or by baking inside a hot impact plume. Tear-drop tektites form after a rotating dumbbell pulls apart (i.e., "fissions").

b. Layered tektites are sometimes called Muong-Nong tektites. They formed when thin layers of viscous "melt sheet" flowed down-slope on the ground.

c. In some cases, bubbles of gas are trapped inside the solidifying tektites. These can be seen as holes in a few of the display specimens in Case 5, and especially in the layered tektites.

d. The chemical composition of tektites is very similar to that of average continental sediments (note the plot of the rare earth elements) indicating that tektites are made by melting soil-like terrestrial sedimentary materials. The sediments had to have SiO_2 contents >77% in order to form a stable glass.

e. The tektites from Central Europe (known as moldavites and named after the Moldau River in the Czech Republic south of Prague) tend to be green in color. Southeast Asian and North American tektites are characteristically black.

f. Libyan Desert Glass, on display in Case 5, is a kind of layered tektite formed by melting quartz-rich sand (quartz is a form of SiO_2). The bands in these samples illustrate the degrees of heat; cooler materials that had a high content of trapped bubbles appear white.

g. The details involved in the melting of tektites are poorly understood. The traditional view is that tektites formed by impact cratering but another possibility is radiative heating from a hot sky or inside a hot impact plume.

Questions – Observe and Explore:

Basic Questions:

1. Tektites are not meteorites. What evidence indicates this?
2. If tektites are not meteorites, what role did meteorites play in their formation?

3. Why are some parts of Libyan Desert Glass white and foamy?
4. The oldest of the main tektite regions is the North American strewn-field (about 35 million years old); the youngest is the Australasian strewn-field (about 780,000 years old). Which of these two fields do you think has more preserved specimens? Justify your answer.

Advanced Questions:

5. How are teardrops and dumbbells related? Which formed first?
6. Tektites are glasses. Why do some silicate melts readily form glasses but the more common ones (like lavas) largely do not?
7. Why is some Libyan Desert Glass (LDG) yellow-green in color? What types of related materials that are common in the desert might have a similar color?
8. Might we expect some tektites and Libyan Desert Glass samples to have a few mineral grains that formed at high pressure?
9. In the past, some tektite researchers believed that tektites came from the Moon. What evidence is there that tektites are made from terrestrial materials?

Teachers – Answers to these questions are available on request from: meteorites@ucla.edu