Meteorites

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Topics that will be covered include: A brief history of early meteoritics, chondrule/chondrite formation (latest theories), weathering in space, asteroidal heat sources, differentiation, achondrites/iron meteorites, evolving solar system structure, atmospheric passage, and hunting for meteorites.

Meteorites are the material record of the formation of the solar system. The current body of known meteorites includes rocks ranging from 4.568 billion-year-old nebular condensates to ~200 Ma Martian basalts, and fragments from the crusts, mantles, and cores of at least 50 to 100 differentiated planetesimals, most of which have since been destroyed or ejected from the solar system.

The field of meteoritics is a young one. Despite heliocentrism being proposed as early as the third century BCE, it was largely ignored until Copernicus adopted the idea in the 16th century. But an immaculate view of the solar system persisted for some time after the first asteroids were discovered in the early 19th century. In short, no one had any reason to guess that meteorites might originate beyond the Earth until 1801, with the discovery of the first asteroid. Since then, a series of technological advancements – the discovery of new elements, radioactivity, isotopes, and of novel techniques such as different methods of radiogenic dating –have rapidly accelerated our understanding in the field. Prior to 1956, we had almost no way to determine the context of any rock not found in stratigraphic relation with another.

Chondrites are a complex group of quasi-igneous rocks that formed (we're not sure exactly how) in the solar nebula, between approximately 4.568 and 4.566 billion years ago. Their shared defining feature are chondrules: small spherical 'droplets' of rocky material that formed at ~1000 – 1500 K. They are usually composed of olivine and pyroxene, with lesser amounts of feldspar and feldspathic glasses. Different chondrite classes are characterized by their bulk chemistry; we'll discuss and have a look at some examples of different types, as well as how they might have formed. Leading theories include planetary-scale impacts, nebular lightning, and magneto-gravitational interactions between planetesimals and a dense dusty nebular disk. The planets (except perhaps Mars) exhibit bulk elemental abundances that differ appreciably from every known group of meteorites. Possible reasons and evidence for this will be briefly discussed; see Dauphas & Pourmand, 2011 and Dodson-Robinson et al., 2009.

Few meteorites have avoided large impacts at least a few times in their history. These violent, hot events are well suited to dating using most methods we have today. They help to tell us about major impacts in the asteroid belt, and to show relationships between meteorite groups. Early heating sources would have also included the radioactive decay of short-lived radionuclides; it might not have taken an impact to melt even asteroids ~50 km in diameter. Aqueous alteration has driven much of the low-temperature metamorphism we see in meteorites, and is important for the formation of organic molecules. Cosmic rays constantly bombard the upper few meters of every body, at a ~constant rate, driving a low level of nuclear reactions.

Radiogenic heating and shock melting have altered many asteroids. Many are recrystallized and differentiated to different extents; some formed metallic cores, cumulate mantles, and felsic crusts, and others appear to have cooled prematurely, preserving a frozen record of planetary formation. Isotopic heterogeneities between bodies and the partitioning of chemically similar elements are especially important when studying texturally similar rocks from (potentially) different parent bodies. Some of these rocks have been shown to come from the Moon and Mars; we don't yet know enough about other parent bodies to tell where other meteorites such as these originated. The field of dynamical modeling has become an increasingly important aspect of cosmochemistry. Models have been devised to help explain the current distribution of asteroids, and of the planets as we now see them. A currently popular model is the Nice model, which hypothesizes that the giant planets have interacted, resulting in orbital changes that have disrupted most smaller bodies in the inner solar system -- and Kuiper Belt Objects; the late heavy bombardment will be addressed; see Chapman, Cohen, and Grinspoon, 2007.

Most objects that enter the atmosphere are microscopic, and are slowly decelerated by the upper atmosphere before drifting down to Earth's surface. The abundance of particles in the solar system rapidly declines with particle size roughly as an exponential probability density function. 'Shooting stars' are usually sand-grain sized bits of material, with meteorites resulting from much larger bolides. Ablation is rapid, occurring mostly above an altitude of 20 km (60,000 ft). Between ~40 and ~25 km, the incoming meteoroid usually fragments. Ablation is rapid, resulting in the vaporization of surface material, but material is removed so rapidly that it cannot penetrate more than ~1 cm, in extreme cases. Differences in surface area – mass ratios result in a rough size gradation; wind resistance slows smaller fragments more rapidly, while larger fragments travel farther. The resulting distribution of meteorites is usually ~elliptical, although prevailing winds can bend or invert fields if strong enough.

When hunting for meteorites, it is important to keep a few important facts in mind:

1) meteorites fall uniformly across the surface of the Earth
2) older surfaces, esp. deflation surfaces, are places where a rock might sit on the surface for an extended period of time or be exposed if buried
3) ~90+% of meteorites contain ~5 to 25% iron
4) deserts will preserve meteorites for longer than wet areas
5) meteorites lack sedimentary layering, and often possess a fusion crust from coming through the atmosphere – this weathers over time, often leaving a distinctive surface texture

Biography

Jason started collecting meteorites with his father in 1998, and they have been enthusiasts since then. Jason has recovered ~400 meteorites, most from California. He received his bachelors in geology and psychology from UC Berkeley in 2013, and is now starting his second year as a cosmochemistry PhD student at UCLA. Research topics include the formation of primitive achondrites, early solar system chronology, and meteor size-luminosity variations with material properties.