Hirams Talk

Eucrite talk

I. Introduction

The title of my presentation is "An introduction to meteorites and the formation of eucrite associated achondrites." The first half of the talk will deal with meteorite petrography; while the second half will cover the origin of certain basaltic composition meteorites. Meteorites are defined as "extra-terrestrial material which falls to the surface of the Earth when captured by the Earth's gravitiational field." (Dict. of Geol.) [Meteors refer to extraterrestrial rocks which have not reached the earth.] Much of the extra-terrestrial material that reaches the earth is in the form of fine dust. In this presentation meteorites will refer to the larger fragments that survive the passage through the atmosphere (DoG). Fragment sizes can range from several grams to 66 tons. Meteorites have been of scientific interest since the late 18th century, when a German by the name of Chladni hypothosized that meteorites were fragments of interplanetary material that had fallen to the earth (McCall, p. 21). Since that time meteorites have been one of the most important sources of information for extra-terrestrial geologic processes and for geochemical composition of the earth's interior.

The origin of meteorites has been a source of much debate. Until the Apollo lunar missions, the moon, asteroids, planets, their satellites, comets and extrasolar bodies all have been suggested as possible sources of meteorites. Recently scientists generally have agreed that with few exceptions most meteorites probably originate from asteroids or comets (Dodd, p. 312).

II. Classes of meteorites

There are three general classes of meteorites: stony, stony-iron, and iron. Stony meteorites are abundant in silicates and sparse in metals. Irons are predominantly metal, while stony-irons are composed of significant amounts of both silicates and metals. The stony meteorites are the most abundant class, and the stony-irons are the least abundant of the three. [slide of Dodd, Table 1.1] In the recovery of meteorites, if the meteor is sighted and the meteorite is recovered, then the recovery is called a fall. If no sighting is associated with a recovery, then it is simply called a find. Among the falls that have been recovered, 99% have been stony meteorites. A roughly equal number of iron (including stony-iron) and stony meteorites have been recovered as finds. This phenomenon reflects differences in preservation and field identification between stony and iron meteorites. Iron meteorites can easily be identified in the field by their hardness and density. Stony meteorites may be missed in the field because of their similarity to terrestrial materials. Furthermore since iron meteorites are less likely to break up as they enter the earth's atmosphere, the larger fragments of metal are more visible in the field (NG, pg. 412). Meteorites in general are most easily recovered in conditions where rocks are rare, easily exposed, and easily preserved. Because of such conditions, numerous meteorites have been recovered in Antarctica (Dodd, p. 9-10).

Meteorites can be classed in several ways. Most of the stony meteorites have a characteristic chondritic texture, which will be discussed later. A few stony, and all of the iron and stony-iron meteorites lack this texture and are referred to as differentiated meteorites. More commonly meteorites are classed by metal content as mentioned previously.

A. Iron meteorites [slide of octahedrite w/ wid. str.]

Iron meteorites are classed on the basis of both the analysis of the chemical content and the texture of the metal phases. Because texture is the more easily determined, it is most often used to infer the chemical content. Texture in iron meteorites most reflects the nickel content of the rock (Dodd, pp. 194-98).

The common mineralogy of iron meteorites consists of kamacite, taenite, troilite, and schreibersite. Both kamacite and taenite are iron-nickel minerals that are distinguished from each other by the amount of iron and nickel present in each mineral. Kamacite is the iron-rich phase, while taenite contains more nickel. Troilite is an iron sulfide (FeS) commonly found as large nodules, and schreibersite is an iron-nickel phosphate (Fe, Ni)$_3$P. All of these minerals are unique to meteorites (Dodd, 198, 199-201).

Taenite and kamacite form an exsolution phase relationship, which is most obvious in the Widmannstätten structures of iron meteorites called octahedrites. In octahedrites kamacite forms bands oriented parallel to the octahedral planes of taenite. The thickness of the kamacite lamellae is inversely proportional to the nickel content of the meteorite. Octahedrites are further subdivided according to the width of the bands of kamacite. Generally, octahedrites contain a nickel weight percent between 6 and 16% (Dodd, p. 198). [slide of phase relationships of t & k?]

Irons with less than 6% nickel are called hexahedrites. [hexahedrite slide] These iron-rich meteorites also contain Widmannstätten structures that are not as visible as those found in the octahedrites. Hexahedrites are commonly denoted by large single kamacite crystals and by Neumann lines reflecting deformational twinning of the kamacite. Ataxites are nickel-rich iron meteorites with Widmanstätten structures that can be seen only at a microscopic level (Dodd, p.198).

B. Stony-irons [slide of pallasite]

Stony-iron meteorites contain silicate and metal components in proportions of a 2:1 ratio for pallasites and 40 to 60% metal in mesosiderites (Dodd, pp. 213 & 253). Pallasites are composed of magnesian olivine and nickel-iron. Olivines are typically found as single crystals or crystal agrregates of millimeter to centimeter size in an nickel-iron mineral matrix. Like the octahedrites, pallasites usually contain Widmannstätten structures. Thus pallasites represent an intermediate class between iron meteorites and stony chondrites, which are abundant in olivines (Dodd, p. 213). Unlike pallasites mesosiderites have a brecciated texture. ~~While~~ Although they are stony-iron meteorites, they are chemically related to the achondrites of the stony meteorites.

C. Stony meteorites

1. Chondrites [slide of chondrite hand specimen & micrograph]

Stony meteorites are the most abundant of the meteorites. The most common type of stony meteorite is the chondrite. Analysis has revealed that chondrites are chemically similar to the sun without its hydrogen, helium, and volatiles. Chondrites have a characteristic texture consisting of an agglomeration of ovoid to spherical silicate masses up to a millimeter in size called chondrules.

The chondrules are set in a fine-grained matrix. Stony meteorites that lack these chondrules are called achondrites. These chondrules have a mineralogy and texture that infer crystallization from a molten state. In most chondrites the chondrules are composed mostly of olivine, pyroxenes, and glass. These minerals tend to have textures unique to meteorites. Olivines sometimes demonstrate a "barred" texture, while low-Ca pyroxenes often show an excentroradial texture. The origin of chondrules is uncertain at this time. Scientists have developed several hypotheses to account for their origin. One suggests that nebular gas condensed through overpressure, subcooling, dust enrichment, or H_2 depletion. Another hypothesizes the fusion of nebular dust particles through lightning, impact, or atmospheric heating. A third explains the formation as the impacting of rock fragments (Dodd, p. 62). Both chondrites and achondrites often exhibit evidence of brecciation. This is assumed to occur mostly when internal disruptive or gravitational mixing within the parent body, or "due to collisions, aggregations together, or shock deformation after the separation of discrete individual meteoroids from the parent body." (McCall p. 173) Such brecciation is noted to have an effect on the mineral phases and chemical composition of the meteorite. Stony meteorites that contain fragments of different chemical groups (or magmas) are called polymict, whereas breccias composed of fragments of one chemical type are called monomict.

Chondrites are described and identified texturally and mineralogically. Chondrites, along with most other meteorites, are known to undergo metamorphism following crystallization and prior to terrestrial impact. This metamorphism causes secondary textures in the chondrites, affecting the distinctness of the chondrule boundaries. Little metamorphism in a chondrite is evidenced by very distinct chondrule boundaries. High metamorphism will result in almost imperceptible chondrite boundaries. The degrees of thermal metamorphism have been broken down into seven petrologic types, with type 1 demonstrating the least metamorphism, and 7 the most. Type 7 chondrites, in fact, can barely be identified as chondrites.

Chondrites are also identified by their chemistry. An early meteoriticist named G. T. Prior noticed a chemical pattern in chondrites which came to be known as Prior's rules. These rules state that "where a chondrite contains little metal, (1) that metal tends to be rich in nickel and (2) the associated Fe-Mg silicates tend to be rich in iron." (Dodd, p. 17) Thus based on the metal iron content and the silicate mineralogy, Prior classed the chondrites into the enstatite chondrites and three other classes that are now known collectively as ordinary chondrites. Later study led to an additional class called carbonaceous chondrites. Carbonaceous chondrites are generally characterized by a significant quantity of volatiles, including water and carbon and sulfur compounds. Carbonaceous chondrites are further subdivided on the basis of their volatile content. There is little metamorphism in these rocks, thus all carbonaceous chondrites fall in petrologic types 1 to 3. These meteorites have gained much publicity, because many of the volatiles found in carbonaceous chondrites are the basic compounds necessary to make life.

Ordinary chondrites are so named on the account of their great abundance. Ordinary chondrites are the most common type of meteorite found on the Earth. This class is broken into 3 subclasses: olivine-bronzite and olivine-hypersthene chondrites and the amphoterites. The distinctions between the subclasses are made in part from Prior's rules. The olivine-bronzites, olivine-hypersthenes, and amphoterites are assigned the letters H, L, and LL respectively. The letters refer to the relative iron content of each subclass. H (olivine-bronzite) has a high iron content, while the LL (amphoterites) are relatively low in iron. In those chondrites with low iron content, much of that iron is oxidized. The olivine-bronzite (H) chondrites tend to be lower in petrologic types (types 3 to 5), and those chondrites with less iron tend to be of higher petrologic types (i.e., LL's undergo greater thermal metamorphism than H's).

Chondrites with a lower iron content than amphoterites fall into the enstatite chondrite class. Enstatite chondrites are believed to form a petrologic association with enstatite achondrites (called aubrites). Enstatite chondrites are composed almost entirely of ironfree enstatite. Enstatite achondrites are likewise predominantly enstatite, but are chondrule free, coarse-grained, and often brecciated. Enstatite chondrites are usually found in the highest petrologic types (4 to 6), thus showing substantial thermal metamorphism. No similar association has been firmly established between the chondrites and any other achondrite.

Stony meteorites without evidence of chondrules are called achondrites. These typically have igneous textures and mafic mineralogy. Achondrites can be subdivided into associated and unassociated classes. Associated meteorites include eucrites, diogenites, howardites, and mesosiderites, all of which are chemically related and possibly came from a similar parent body. The unassociated meteorites, however, cannot be related to other meteorite groups. One piece of evidence for their unrelatedness is their wide range in ages (ranging from 4.55 by to 164 my). The unassociated achondrites include shergotites, nakhlites, chassignites, and ureilites. The first three are often found with cummulate textures.

Shergottites, of which three have been found, resemble terrestrial diabases (basaltic rocks of predominantly pyroxene-plagioclase composition) in texture, chemistry, and mineralogy. One exception mineralogically is that shock-produced maskelynite replaces the Ca-rich plagioclase in the shergottite. (Maskelynite is an igneous glass of plagioclase composition). The dominant pyroxene in the meteorite is pigeonite. Shergottite were once classified with eucrites, but subsequent investigation has clarified distinct though parallel histories for the two. Recent analysis and speculation has even suggested that these meteorites (formed within the past 650 my) may have come from Mars [need to find paper ref. on this].

Nakhlites are augite-olivine achondrites that are also the product of late magmatism.

Chassignites are olivin-rich meteorites whose mineralogy and texture resemble terrestrial and lunar dunnites. The two known specimans of this class also show shock-produced fracturing. Like the previous two types, chassignites are fairly recent rocks at ~1.39 by.

Ureilites, olivine-pigeonite achondrites are among the more interesting unassociated achondrites. In addition to being plag.-poor and olivine- and carbon-rich, these rocks are possibly related to carbonaceous chondrites though how they are related is not clear. Intense shock metamorphism has produced high-pressure mineral phases such as diamond. Due to the lack of datable material in these meteorites, no ages have been firmly established on ureilites.

The associated achondrites--eucrites, diogenites, howardites, and mesosiderites show evidence of similar magmatic origin. This evidence includes serial chemical variations [make slide copy of Fig. 8.2]. Eucrites are the more aluminum-rich members, while diogenites are aluminum poor. Howardites fall between these two extremes. Mesosiderites likewise fall in this region, but contain more metal than do howardites.

Eucrites are pyroxene-plagioclase achondrites often resembling terrestrial basaltic cumulates. Evidence for this comes from preferred crystal orientations and from exsolution textures in the pyroxenes, which suggest slow cooling. The latter textures are also referred to as inverted pigeonite. Eucrites that show these characteristics are called cumulate eucrites. Noncumulate eucrites usually show ophitic and subophitic textures (pyroxenes tend to be optically oriented). Most eucrites are brecciated and show monomict composition.

The mineralogy of eucrites consists of subequal amounts of plagioclase (~An_{85-95}) and orthopyroxene (inverted pigeonite). In noncumulate eucrites the amount of pyroxene is greater than plagioclase. Eucrites also contain accessory phases of tridymite, troilite, ilmenite, chromite, nickel-poor metal, and phosphates.

Diogenites are predominantly orthopyroxene achondrites with small amounts of plagioclase and chromite and trace quantities of ilmenite and phosphate. A few diogenites also contain olivine. Like eucrites, diogenites also show monomict brecciation.

Howardites are polymict breccias consisting mostly of plagioclase and pyroxenes. These achondrites show a variety of textures caused by reheating and shock metamorphism.

Mesosiderites contain a mixture of both eucritic and diogenitic material, but with additional clasts of chondritic material and a metal matrix.