Lunar Meteorites

There is a lot of information on the web about Lunar Meteorites. A Google.com search on the term “Lunar Meteorites” yields 390,000 sites on that search engine alone.

As a geologist, I find it fascinating that impacts on the moon’s surface can product meteorites on the Earth. The moon has a small gravitational field and low escape velocity. Any rocks dislodged by a surface impact on the moon have a chance to escape the moon’s gravitational field. This has also happened on Mars, and there are Mars Meteorites.

Some Definitions:

First here are some definitions related to lunar meteorites, meteoroids, asteroids and planets. From the NASA website:

> "Shooting stars" or meteors are bits of material falling through Earth's atmosphere; they are heated to incandescence by the friction of the air. The bright trails as they are coming through the Earth's atmosphere are termed meteors, and these chunks as they are hurtling through space are called meteoroids. Large pieces that do not vaporize completely and reach the surface of the Earth are termed meteorites.

Asteroids are essentially chunks of rock ranging in size from dust particles to 1,000 km across. Planetoids are planet sized asteroids.

For more information about meteors, meteorites and asteroids I have produced a CD-ROM entitled Falling from the Sky: A Meteorite Resource. This CD includes hundreds of pages of information and many interactive web page links.

Introduction

The following information was taken from the Washington University in St. Louis, Department of Earth and Planetary Sciences website:

http://epsc.wustl.edu/admin/resources/moon_meteorites.html

Meteoroids strike the Moon every day. Lunar escape velocity averages 2.38 km/s (1.48 miles per second), only a few times the muzzle velocity of a rifle (0.7-1.0 km/s). Any rock on the lunar surface that is accelerated by the impact of a meteoroid to lunar escape velocity or greater will leave the Moon’s gravitational influence. Some ejected material becomes captured by the Earth’s gravitational field and lands on Earth within a few hundred thousands of years (much shorter for some). Other ejected material, however, assumes an orbit around the Sun. Some of that material may eventually strike Earth. This can take a long time. Lunar meteorites Yamato-82192/82193/86032 and Dhofar 025 remained in space for 10 and 20 million years before finally landing on Earth.

Lunar meteorites look a lot like some Earth rocks. We know that they came from space, however, because like asteroidal meteorites, lunar meteorites have **fusion crusts** from the melting that occurs as they enter the Earth's atmosphere (the olive-green crusts on the photos above). Also, they contain certain isotopes that can only be produced by reactions with cosmic rays while outside the Earth's atmosphere.

Chemical compositions, isotope ratios, minerals, and textures of the lunar meteorites are all similar to those of samples collected on the Moon during the Apollo missions. Taken together, these various characteristics are different from those of any other type of meteorite or terrestrial rock. For example, all of those meteorites in the **List** that are classified as ***feldspathic breccias*** are rich in the mineral ***anorthite***, which is plagioclase feldspar, mineralogically, and a calcium aluminum silicate, chemically. Consequently, these meteorites all have high concentrations of aluminum and calcium. Because of some unique aspects about how the Moon formed, the lunar highlands are composed predominantly of anorthite. Anorthite is much less common on asteroids and, to the best of our knowledge, on the surface of any other planet or planetary satellite.

The largest single stone is Kalahari 009 at 13.5 kg (30 lbs.). The rest are much smaller. The next biggest are Dar al Gani 400 (1425 grams = 3.1 lbs) and LAP 02205 (1226 grams = 2.7 lbs). Together, the five stones of the LAP 02xxx "pairing" are the second largest lunar meteorite (1875 grams = 4.1 lbs.). Several of the lunar meteorite fragments found in Antarctica and Oman only weigh a few grams (a U.S. nickel weighs 5 grams).

While impact cratering on the Moon can be a very destructive process, it also has the capacity to throw new samples of rock our way. As an impact crater is being excavated, some rocky material can be thrown out of the crater with enough velocity to escape the Moon's gravity and fall to Earth. Since impact craters occur at random locations, lunar meteorites provide a set of samples from all portions of the Moon, including the farside and polar regions, which Apollo astronauts and Luna spacecraft were unable to visit.

Thus far, 15 lunar meteorites have been discovered (see table below). Many of these have been recovered in Antarctica, where they can be preserved in glacial ice for thousands of years after they fall. Some lunar meteorites, however, have also been found in other parts of the world. Generally these are hot desert regions where the meteorites are preserved because there is so little rain to affect them.

Even though the lunar meteorites sample different regions of the Moon than the Apollo and Luna programs, they have some similarities. One common type of lunar meteorite is an *anorthositic breccia.* The word "anorthositic" indicates the rock contains lots of bright white fragments of anorthosite (a plagioclase-rich rock containing some pyroxene, with or without olivine), the type of rock found in the lunar highlands. A "breccia" is a rock that contains the broken fragments of older rocks. These breccias are usually produced by the impact processes, which crush rock, move it around the surface of the Moon, and mix it with broken fragments of other types of rock. There are different types of impact breccias, including fragmental breccias, polymict breccias, and regolith breccias.

Of the >26,000 meteorites listed in the ***Catalogue of Meteorites***, only 1 in 1200 are lunar. Meteorites are very rare rocks; lunar meteorites are exceedingly rare. No lunar meteorites have yet been found in North America, South America, or Europe.

Lunar Meteorites Table

A table of Lunar Meteorites has been compiled by the University of Arizona Space Imagery Center, from the following website:

http://www.lpl.arizona.edu/sic/moon/lunar_meteorites/table_record_impact.html

Impact #	Age of Impact (MA)	Transit Time (MA)	Terrestrial Age (MA)	Meteorite(s)	Classification	Terrane at the Impact Site
1	9 ± 2	9±2	~0.08	Y82192/3 Y86032	Anorthositic fragmental breccia Anorthositic fragmental breccia	Highlands Highlands
2	0.9± 0.1 1.1±0.2	0.9±0.1 1.1±0.2	<0.07 <0.05	Asuka-881757 Y793169	Mare gabbro Mare gabbro	Mare Mare
3	~0.27	0.04	0.21 to 0.25	MAC88104/5	Anorthositic breccia (r/f)	Highlands
4 to 5	<0.07 <0.04	<0.01 <0.02	<0.06 <0.02	EET87521 Y793274	Basaltic fragmental breccia Basaltic regolith breccia	Mare Mare
5 to 6	0.06±0.03	<0.019	0.06 ±0.04	Y791197	Anorthositic regolith breccia	Highlands
6 to 7	0.0115	0.025	0.009	ALHA81005	Anorthositic regolith breccia	Highlands
7 to 8	--------	<0.2	<0.07	Calcalong Creek	KREEP-rich microbreccia	Highlands
7 to 9	0.025-0.06	0.02-0.05	0.005-0.01	QUE93069 QUE94269	Anorthositic regolith breccia Anorthositic regolith breccia	Highlands Highlands
7 to 10*	-	-	-	QUE94281	Basaltic fragmental breccia	Mare
7 to 11*	-	-	-	Dar al Gani 262	Anorthositic polymict breccia	Highlands
7 to 12*	-	-	-	EET96008	Basaltic breccia	Mare

Impact #	Age of Impact (MA)	Transit Time (MA)	Terrestrial Age (MA)	Meteorite(s)	Classification	Terrane at the Impact Site
7 to 13*	-	-	-	Dar al Gani 400	Anorthositic polymict breccia	Highlands
7 to 14*	-	-	-	Dhofar 025	Anorthositic regolith breccia	Highlands
7 to 15*	-	-	-	Dhofar 026	Anorth. crystalline melt breccia	Highlands
7 to 16*	-	-	-	NWA 032	Olivine-pyroxene basalt	Mare
7 to 17*	-	-	-	Dhofar 081	Feldspathic fragmental breccia	Highlands

Based on information presented by Eugster et al. (1991), Nishiizumi et al. (1991), Vogt et al. (1991), Hill et al. (1991), Nishiizumi et al. 1992, Warren (1994), Grier et al. (1995), Kring et al. (1995), Swindle et al. 1995, Kring et al. (1996), Nishiizumi et al. (1996), Bischoff and Weber (1997), Grossman (2000), Grossman and Zipfel (2001).

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The following list of references about lunar meteorites has been compiled by Washington University – St. Louis, Department of Earth and Planetary Sciences. The web site is:
http://epsc.wustl.edu/admin/resources/meteorites/references.html

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