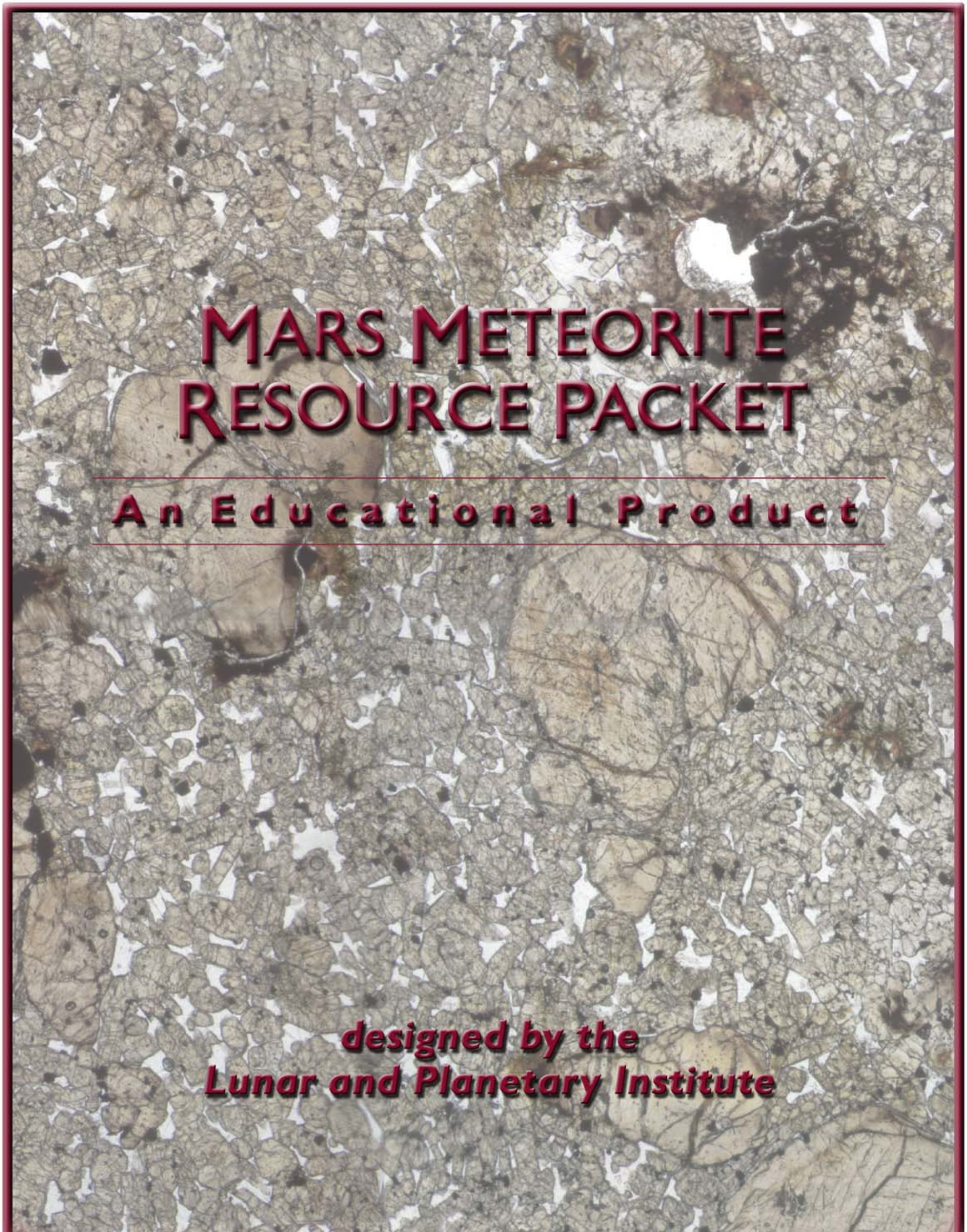


MARS METEORITE RESOURCE PACKET

An Educational Product

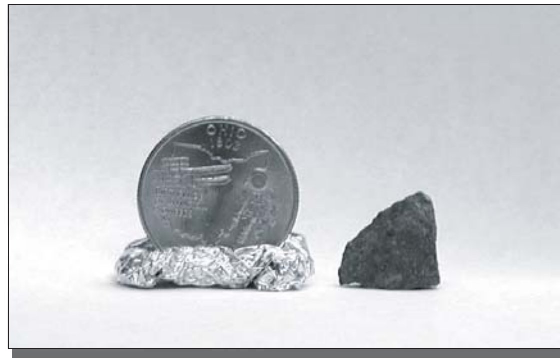
designed by the
Lunar and Planetary Institute

What is a Thin Section?

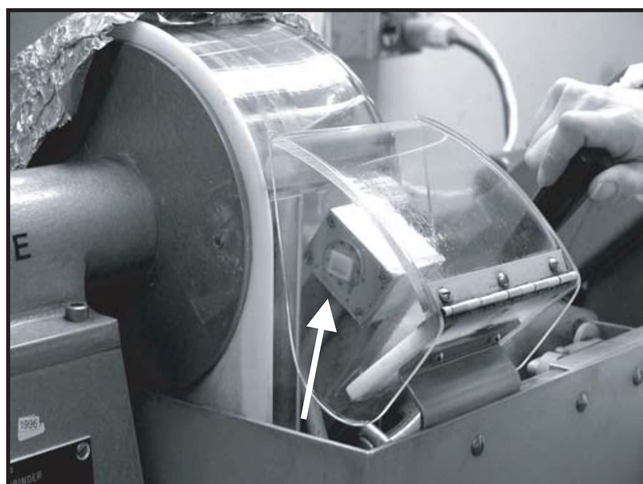
A thin section is a slice of rock thin enough for light to pass through, so that it can be examined using a light microscope (see Light Microscopy). Thin sections are an essential part of geology, and especially important for studying rocks from other planets, such as the Dar al Gani 476 meteorite from Mars.

Here is how a thin section is made:

A chip is broken or cut from the rock.



One side of the rock chip is flattened (by sawing and grinding) and is glued to a glass slide, usually with epoxy. The rock chip is trimmed with a special rock saw, and then thinned on a grinder.



This produces a thin slab of rock glued to the glass, which is thinned to 30 micrometers on a polishing wheel.

Once the section is 30 micrometers thick, it is either covered with a glass slide, or the surface is polished with finer polishing wheels until it is very smooth. Polishing is necessary for electron microprobe analysis.

TYPE OF FEATURE: PROCESSING EFFECTS

EPOXY: This is the glue that holds the thin section together, and keeps it stuck to the glass slide.

SCALE BAR: The picture of the thin section is enlarged about 48 times, so we need a scale bar to tell us the actual size of the objects in the thin section. The "scale" on the scale bar says it is 1000 μm, or micrometers. One micrometer is 10,000 times smaller than a centimeter and about 25,000 times smaller than an inch. A human hair is about 100 micrometers thick.

Exercise: Measure the width of the olivine crystal that has parallel fractures in it with a metric ruler. Then measure the scale bar. How big is the olivine crystal in reality? How far apart are the parallel fractures?

HOLE: Sometimes bits of the minerals are plucked out of the thin section when it is being polished. Which mineral looks like the hole? How could you tell the difference?

What Does a Meteorite Look Like?

Note: It can be difficult to distinguish a meteorite from an Earth rock. An expert should always be consulted.

In general, meteorites have the following properties:

FUSION CRUST: Meteorites enter the Earth's atmosphere at high speed, 45,000 miles per hour (~20 kilometers per second) or more! Friction between the air and the meteorite's surface heats it to melting. This layer of molten rock cools to make a dark glassy rind on a fresh meteorite — its fusion crust.

REGMAGLYPTS: These are depressions in the surface of the meteorite that look like modeling clay that you've pushed your thumb into. They form as the rock is heated in the Earth's atmosphere.

DENSE: Meteorites commonly feel heavier than Earth rocks of similar size. This is because most meteorites are rich in iron, a heavy element, both in iron-nickel metal, and as iron in other minerals.

MAGNETIC: The iron-nickel metal present in many meteorites will attract a magnet.

TYPE OF FEATURE: MINERALOGY

Mineralogy is the study of minerals, which are natural solids made of atoms arranged in specific, ordered ways. This ordering is called the crystal structure of the mineral. The types of atoms (elements) in a mineral determine its chemical composition. A mineral is described most commonly by its mineral formula, which shows the ratios of different elements in the mineral. For example, the formula for fayalite, a kind of olivine (see below), is

Fe_2SiO_4 — where Fe is iron, Si is silicon, and O is oxygen.

The numbers tell us how many of each atom is in the structure. So, there are two iron atoms for every one silicon atom and four oxygen atoms. That, and its specific crystal structure, define the mineral fayalite and distinguish it from other minerals.

Mineral groups are sets of minerals that have the same crystal structures, but contain different atoms.

Which atoms are in a mineral, and the way in which atoms are arranged in a crystal structure, give a mineral its properties. One property is color. The colors of the minerals in Dar al Gani 476 are slightly different due to the iron in them, not only the amount of iron, but the way in which the iron exists in the crystal structure. So the color that you see depends on the arangement of atoms that are too small to see!

The minerals in Dar al Gani 476 include

OLIVINE: This mineral has the formula $(Mg,Fe)_2SiO_4$. Here, we write the formula with Mg (magnesium) and Fe in parentheses because these two atoms can take each other's place. So olivine is usually a mixture of fayalite, which has only Fe and no Mg (Fe_2SiO_4), and forsterite, Mg_2SiO_4.

PLAGIOCLASE: This mineral is a type of feldspar (another mineral group), which is a mixture of albite, $NaAlSi_3O_8$, and anorthite, $CaAl_2Si_2O_6$, where Na is sodium, Al is aluminum, and Ca is calcium. This mineral can be converted to maskelynite by shock (see Shock Effects).

PYROXENE: This is actually a mineral group, because so many different atoms can replace each other in the pyroxene crystal structure. The typical pyroxenes in Dar al Gani 476 can be written with the formula $(Ca,Mg,Fe)_2Si_2O_6$. However, this includes the minerals orthopyroxene, $(Fe,Mg)_2Si_2O_6$, pigeonite, $Ca_{0.25}(Mg,Fe)_{1.75}Si_2O_6$, and augite, $Ca(Fe,Mg)Si_2O_6$.

OPAQUES: This is a general term for minerals that do not transmit light. In Dar al Gani 476, they include minerals such as titanomagnetite, $(Fe,Ti)_3O_4$, and ilmenite, $FeTiO_3$, where Ti is titanium.

WEATHERING PRODUCTS: These are minerals that formed when the rock sat in the Libyan Desert (see Weathering).

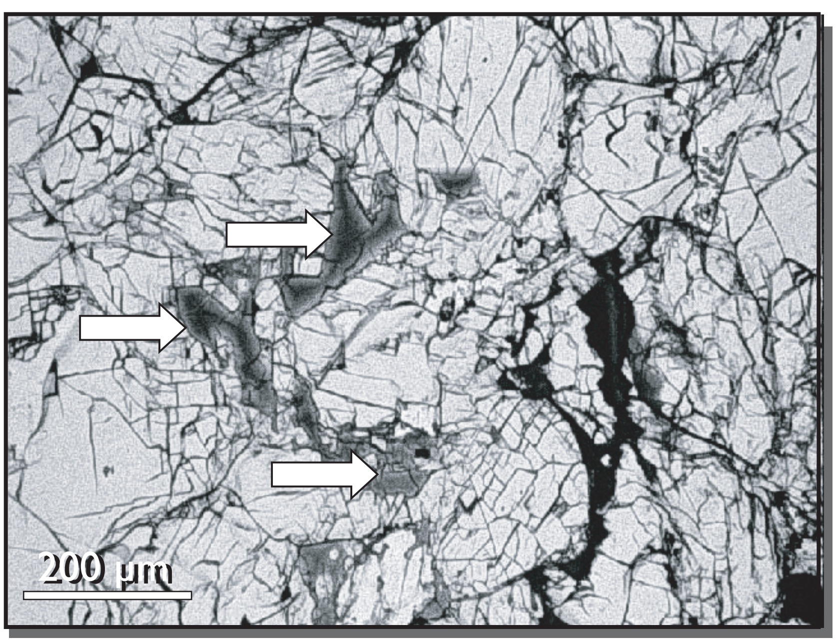
Weathering

The "reddish-brown stuff" in the Dar al Gani 476 martian meteorite is the result of weathering.

Dar al Gani 476 is an igneous rock, one that formed when molten lava cooled and crystallized. This lava (or magma) is very hot when it crystallizes, between 1200˚C and 1000˚C (2200˚F and 1800˚F), or three to four times as hot as a home oven can get. When an igneous rock cools down to the temperature of the planet's surface, it does it too fast for the minerals to change and adapt to that colder temperature. So the minerals are not stable at or near the surface of the planet. If it rains, or if groundwater flows through the rock, then the minerals will react with the water and form minerals that are more stable at the planet's surface. These are called Weathering Products.

An example of this is shown in the Dar al Gani 476 meteorite. In this case, the olivine in Dar al Gani 476 has reacted to form a mixture of tiny crystals, called "iddingsite". This is not really a mineral, but a mixture of several different minerals. The iddingsite formed in the Libyan Desert, where the wind blew and the rain fell for many years before someone found it. This is terrestrial weathering, to distinguish it from weathering that happened to the rock before it left Mars.

Other martian meteorites contain iddingsite that formed when water interacted with the rock on Mars. What does the presence of martian weathering tell you about Mars?



Photograph by Alan Treiman, LPI

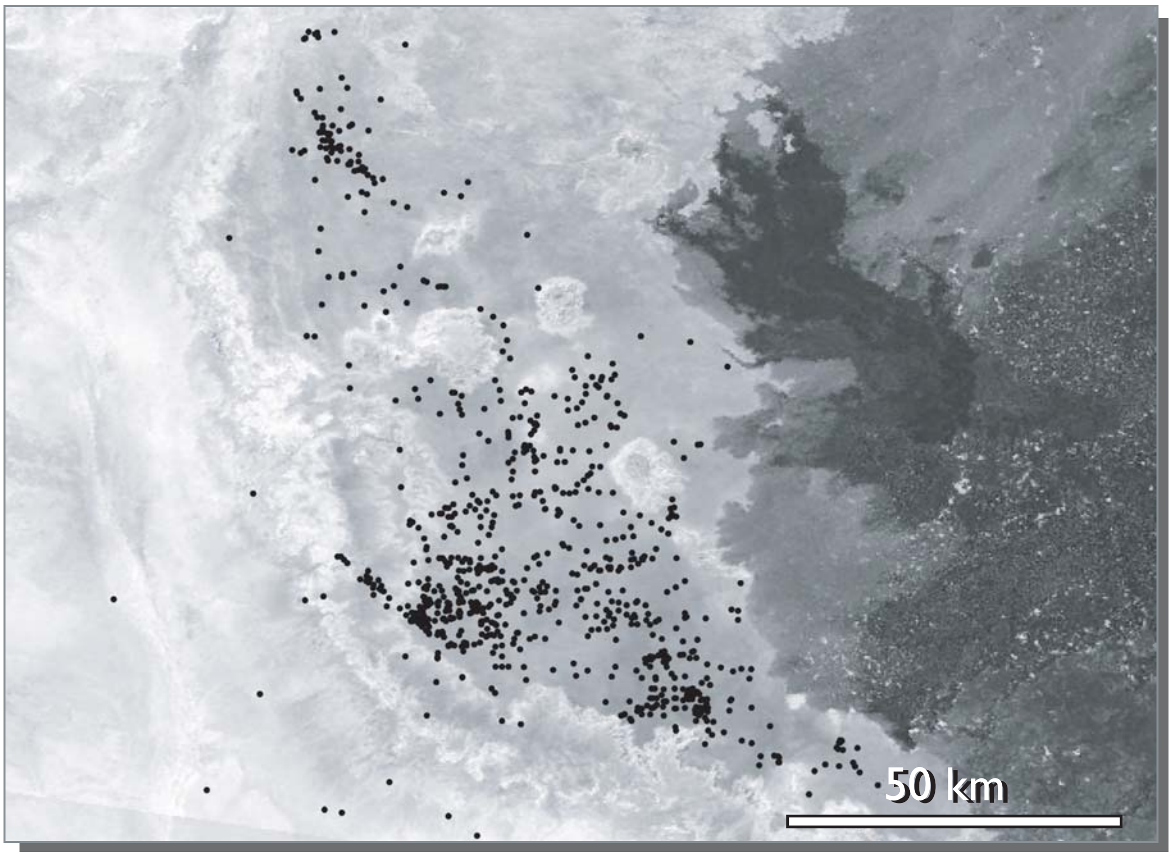
This is a photomicrograph of the Lafayette martian meteorite in thin section. The rock has been fractured by shock, and some of the spaces are filled by iddingsite, as shown by the arrows. This weathering occurred on Mars.

Combing the Deserts

In the hot deserts of the Sahara and the icy deserts of Antarctica, researchers and meteorite hunters have found thousands of meteorites. These regions have special conditions that can make finding meteorites easier.

Instead of randomly searching the deserts, searchers can predict in which area they would most likely find meteorites.

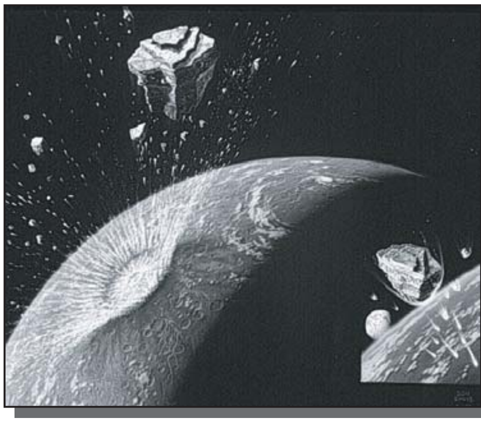
Activity: Libyan Meteorite Search



This is an image taken by the Landsat satellite of the desert in Libya. The black dots are where meteorites have been found so far. The surface on which the meteorites have been found (medium gray in the image) is flat and made of brightly colored, pea-sized rocks. The dark area on the right is a black volcanic rock known as basalt. The bright area to the left is rugged and difficult to search. The bright circular areas are depressions called Qaràrats where, despite lots of searching, no meteorites have been found. Given what you know about this area, and what you've learned about how to identify a meteorite, where would you look next? Why is the dark area on the right not a good place to look? Why do you think the Libyan Desert is such a good place to find meteorites?

From what you've learned about this part of the Libyan Desert, why do you think Antarctica is another meteorite hotspot?

How Did it Get to Earth?



Painting by Don Davis, ©1994, SETI Institute

The martian meteorites that we find on Earth are pieces of Mars that have been blasted off the surface and into space by the impact of an asteroid. The impact leaves behind a depression called a crater. Once the pieces start their journey in space, it might take them millions of years, but eventually, they cross the path of the Earth, and fall to the ground. In this case, the meteorite fell in the Libyan Desert.

How Do We Know it Came from Mars?

There are over 25 meteorites that are known to come from Mars. The research that proved they came from Mars was the study of the gases trapped inside the meteorites. The composition and ratios of these gases matched the 1976 Viking Lander's analysis of the martian atmosphere. They have also been grouped together because they have different oxygen-isotope* ratios compared to the Earth and other meteorites. This is the most common test to see if a meteorite is from Mars. The martian meteorites are also different from other meteorites because they have relatively young crystallization ages, ranging from 4.5 billion to 175 million years. Other meteorites that come from asteroids are 4.5 billion years old, and samples from the Moon are between 4.5 and 3.1 billion years old. The younger ages of the martian meteorites reflect Mars' long-lasting volcanic activity. Due to its size, Mars had volcanism long after the Moon's volcanism "died out" and the asteroids cooled off.

* *Just as people have different masses, so do elements. Atoms of the same element with different masses are called isotopes. The element oxygen has three different isotopes.*

TYPE OF FEATURE: SHOCK EFFECTS

The impact sends a shock wave through the rocks, which causes certain changes to occur in the minerals, as shown on the front of this poster. Shock can result in several kinds of changes, including fracturing of the minerals, destruction of a mineral's crystal structure, and heating of parts of the rock until they melt.

PARALLEL FRACTURES: In this case, olivine is a mineral that does not normally show fractures such as these, but the high stresses of shock have produced parallel fractures.

MASKELYNITE: This is plagioclase feldspar (see Mineralogy) that has lost its crystal structure and been converted to glass by shock.

MELT POCKETS: Some areas of the rock have endured such high shock that the rock is melted. However, the melting is localized to little pockets.

What Does the Rock Tell Us About Mars?

Petrology is the study of how rocks form. If we know how a rock from Mars formed, we can tell a lot about Mars as a planet. The most important tool of petrology is the texture of the rock, which we can easily see in thin section. Describing the texture involves identifying the minerals, observing how the minerals are intergrown, and determining the order in which the minerals formed. An added step for martian meteorites is figuring out which minerals formed on Mars, and which formed after the meteorite landed on Earth (see Weathering), as well as determining what minerals have been affected by shock (see Shock Effects).

Through studies of martian meteorites such as Dar al Gani 476, researchers have determined a lot about Mars

- ♂ Mars has volcanos that were active as recently as 175 million years ago.
- ♂ Mars contains different ratios of elements than the Earth.
- ♂ The martian mantle has more iron than the Earth's mantle.
- ♂ Mars does not have plate tectonics like Earth does.
- ♂ Water on Mars may be supplied by water bubbling out of magmas.
- ♂ Mars has had water flowing through rocks and probably still does.

TYPE OF FEATURE: PETROLOGY

The two most obvious features of the texture of Dar al Gani 476 are the megacrysts and groundmass.

MEGACRYSTS: The olivine crystals are much larger than the other minerals, so we call them megacrysts, meaning large crystals (*mega* = large; *crysts* = crystals). This tells us that they formed before the other minerals, while the rest of the magma was molten. They probably formed deeper within Mars, and were carried along when the magma came up to the surface.

GROUNDMASS: The pyroxene, plagioclase, and opaque minerals formed after the olivine megacrysts, probably when the magma erupted onto the surface of Mars. There, the magma cooled more rapidly, and the crystals that formed were smaller.

Light Microscopy

The thin section of Dar al Gani 476 shown on the front of this poster was photographed using a camera attached to a light microscope. A light microscope allows you to look through the thin section; the way in which light passes through the thin section can tell you which minerals are present (see Mineralogy), and how they are related to each other (see Petrology, Weathering, Shock Effects).

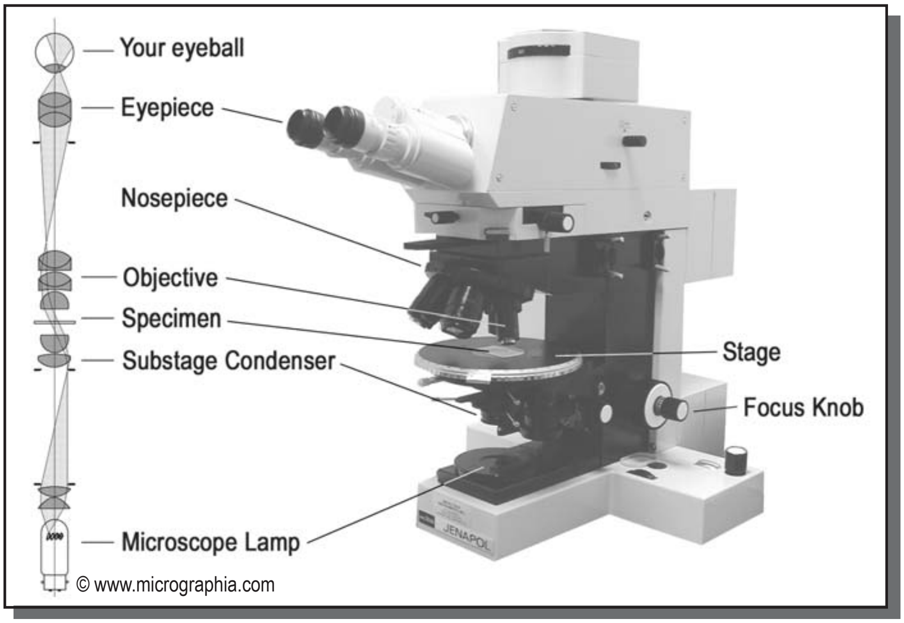


Diagram showing the different parts of a light microscope. The microscope is made up of a series of lenses that focus the light onto the sample, and into the eye. On the left is a ray diagram, which shows the path of light through the lenses.

Electron Microprobe Analysis

An electron microprobe is a very sophisticated machine that allows you to analyze the minerals in a thin section and determine their compositions (see Mineralogy). It is similar to the light microscope, but instead of passing light through the thin section, electrons are focused onto the thin section. The way in which the electrons interact with the minerals can tell you the amounts of each element within them. So the electron microprobe can tell you even more about the minerals than the light microscope.

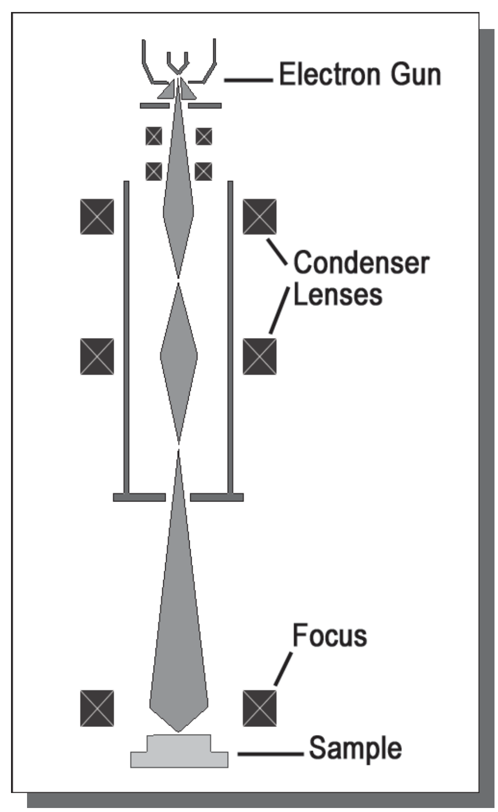


Diagram showing the different parts of an electron microprobe. This is similar to the ray diagram above. Instead of a light source, the electron microprobe has an electron gun, which is located at the top of the column. A series of electromagnetic lenses focus the electron beam onto the sample. The electrons bounce off the sample, and also cause the sample to make X-rays. Both of these are detected and used to analyze the mineral.

Facts About the Planet Mars

Fourth planet from the Sun
Mean Distance from Sun ....227,936,640 km
Orbital Period ....1.88 Earth years
Rotational Period ....24 h 37 m
Diameter ....6,794 km
Mass ....0.11 of Earth's
Gravity ....0.38 of Earth's
Atmosphere (primary component) ....95% carbon dioxide
Temperature Range ....–143°C to +17°C
Moons ....Phobos, Deimos

Additional Resources

Ward's Natural Science — http://www.wardsci.com 1-800-962-2660
Thin sections and matching hand samples, light microscopes, and more.

Martian Meteorites on the Web:
Mars Meteorites Home Page (JPL) — www.jpl.nasa.gov/snc/
An up-to-date listing of martian meteorites.

Mars Meteorite Compendium (NASA/JSC) —
www-curator.jsc.nasa.gov/curator/antmet/mmc/mmc.htm
A compilation and summary of martian meteorite research.

Further Reading:
Schlüter J. et al. (2002) *The Dar al Gani Meteorite Field (Libyan Sahara): Geological Setting, Pairing of Meteorites, and Recovery Density.* Meteoritics & Planetary Science, Vol. 37, pp. 1079–1093.

Credits
Dr. Christopher Herd is primarily responsible for the scientific content. Meredith Higbie assisted with logistics. The images of the thin section were taken using a LeafMicrolumina digital camera on an Olympus BH-2 optical microscope owned by Dr. Jane Selverstone of the Department of Earth and Planetary Sciences, University of New Mexico, and we thank her for its use. The photo of Dar Al Gani 476 in hand sample (on the front) was graciously provided by Dr. Takashi Mikouchi, University of Tokyo. The Libyan Desert image was provided by Jochen Schlüter of the Mineralogical Museum, Hamburg, Germany. Penny Robinson's hands are featured in "What is a Thin Section?", and we thank her for providing details on this subject. Design and production by LPI's Publications and Program Services Department.

This material is based upon work supported by the National Aeronautics and Space Administration under Agreement No. NCC5-679 issued through the Solar System Exploration Division. LPI Contribution No. 1158.