Some of our "questions" from previous lectures

Remote detection of H on Mars

TES & OMEGA TIR spectrometers detected minerals with H e.g., zeolites, clays

Poulet et al., 2005
Some of our "questions" from previous lectures

Remote detection of H on Mars

**Gamma Ray spectrometer**

detected H in the top 1m of the surface

Dark blue <50% H$_2$O in ice

Light blue bound H in minerals

The NS instrument detects neutrons in three energy bands: thermal, epithermal and fast. Each energy class corresponds to the degree to which planetary neutrons have been "moderated", or been in contact with other planetary matter.

Hydrogen is a very good moderator of neutrons and hence the detector is quite sensitive to the presence of hydrogen on the surface (to a depth of about one meter) of Mars.
Review of some geologic terms

• Mineral
Mineralogy of the Martian surface

TES Mineral Map
Clark and Hoefen
USGS

RGB Composite

Overlay

TES Albedo
7.27-micron strength
11-micron Oliv/Pyx
Olivine FeO < 35%
Hematite, coarse grained
Review of some geologic terms

- Mineral
- Rock
Geologic Map of Mars

Rock types

- Basaltic–andesitic
- Soils
- High S, Cl, Mg & Na
- Pancam vs. Fe
- Dust
- Andesite/altered basalt
- Basalt
- Ice/clouds

P. Christensen
Review of some geologic terms

- Mineral
- Rock
- Igneous rock
  - volcanic rock
Volcanic Provinces

Two major provinces:

**Tharsis:** 10km-high bulge, supporting several large volcanoes, including Olympus Mons.

**Elysium:** smaller elevated region with several cone-shaped volcanoes

Relative age dating suggests these are young (<100Ma), may be still active,
Review of some geology terms

• Mineral
• Rock
• Igneous rock
  – volcanic rock
• Sedimentary rock
  – stratigraphy
  – salt
  – concretion
Geomorphologic evidence for surface water

Small valley networks

Outflow channels

Gullies

Paleo-sea ice?
ASTRO/GEO 710
The crust of Mars
Martian meteorites: Sample suite

- Currently 35 meteorites, total mass ~76 kg.
- All are mafic / ultramafic igneous rocks
  - basalts (crust) / cumulates (mantle)
- “Martian meteorites” = “SNC” meteorites
  S = Shergotty; N = Nakhla; C = Chassigny (all falls)

Usage of “SNC” (“snick”) is outdated because the suite of meteorites has expanded greatly since this term was introduced.
Shergotty, 25 cm across
BASALT

Nakhla, 1813g, 1651g, 1318g
CLINOPYROXENITE

Chassigny, 215g
DUNITE

ALH84001, 1931g
ORTHOPYROXENITE
### Martian meteorites (2006)

<table>
<thead>
<tr>
<th>Name</th>
<th>Recovery</th>
<th>Year</th>
<th>Mass (g)</th>
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<tr>
<td><strong>Basaltic Shergottites</strong></td>
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<td>Shergotty</td>
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<td>Name</td>
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<td>Name</td>
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<td><strong>Clinopyroxenites</strong></td>
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<td>Indiana</td>
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</table>

**FALLS**
Martian meteorite types: relative masses (2001)

- Lherzolitic shergottites
- Clinopyroxenites
- Dunite
- Orthopyroxenite
- Basaltic shergottites (Martian crust)
Locations of martian meteorite finds in Antarctica
Lewis Cliff Ice Tongue and Meteorite Moraine, Antarctica.

Ice sheets collide with the Trans Antarctic Mountain Range where they well up and are ablated by the wind. Meteorites become concentrated on the blue ice field.
Meteorite collection in NW Africa

Dar al Gani

Libya
Oxygen Isotopes

Single suite of meteorites.
Mars Fractionation Line: $\Delta^{17}O = +0.32 \%$
Fe/Mn ratios of silicates

Papike et al. 2003 LPSC
Source on Mars

Spallation from craters >10km diameter

Possible source:
34 x 18 km crater formed by a grazing impact
Ejection ages: Date of ejection from Mars surface, measured as cosmic ray exposure ages plus terrestrial residence time.

Specific events ejected specific types of rocks.
Crystallization ages

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<th>Age in B.y.</th>
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<td>Basaltic shergottites</td>
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<td>1</td>
<td>Chassigny (dunite)</td>
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<tr>
<td>5</td>
<td>ALH84001 (orthopyroxenite)</td>
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Impact glass pockets in shergottites have gas compositions that match the Mars atmosphere composition measured by the Viking Landers.
Gas abundances match; Isotope ratios match

Pepin (1985)
## Summary

<table>
<thead>
<tr>
<th>Property</th>
<th>Martian meteorites</th>
<th>Measured on Mars</th>
<th>Proof of Mars origin</th>
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<tbody>
<tr>
<td>Oxygen isotopes</td>
<td>$\Delta^{17}O = +0.32 %$</td>
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<td>no</td>
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<tr>
<td>Fe/Mn in pyroxene</td>
<td>30 – 40</td>
<td>no</td>
<td>no</td>
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<tr>
<td>Ages</td>
<td>&lt;1.3 Ga (also 4.5 Ga)</td>
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<tr>
<td>Atmospheric gases</td>
<td>Various</td>
<td>yes</td>
<td>yes</td>
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</table>
Basaltic Shergottites

Shergotty

Los Angeles

Zagami
**Mineralogy**
Major: Pyroxene (pigeonite and augite); plagioclase.  
Magmatic inclusions in pyroxene.  
Minor: Ilmenite; Titanomagnetite; Chromite.  
Accessory: Sulfides; Phosphates; Glassy mesostasis.

**Characteristics**
Foliated textures (alignment during extrusion).  
Grain size varies from coarse (QUE) to fine (EET-A).

**Shock**
Pyroxene highly fractured.  
Plagioclase typically converted to maskelynite.  
Black impact melt veins visible in hand samples.

**Formation**
Basaltic lava flows, cooling rates (determined from pyroxene exsolution) 0.05 to 0.5 C/day.  
Zoning in pyroxenes shows complicated crystallization paths.
Shock features

Impact melt pocket (lithology C)

2mm
Olivine-phyric Shergottites

Paired with Dar al Gani 476

Dar al Gani 489 - 1.3g slice

Paired with Dar al Gani 476

SaU 005
Mineralogy
Same as basaltic shergottites. 
Olivine and orthopyroxene xenocrysts (10-25 vol%).

Characteristics

Shock
Same as basaltic shergottites.

Formation
Similar to basaltic shergottites. Xenocrysts have similar compositions to the minerals of lherzolitic shergottites.
Olivine xenocrysts in pyx / mask matrix
EETA79001: A geological contact between two lithologies.

Lithology A: olivine-phyric shergottite

Lithology B: basaltic shergottite
Olivine xenocrysts in pyx / mask matrix

2mm

EETA79001 – lithology A
Lherzolitic Shergottites

ALH 77005
Mineralogy
Major: Olivine; Orthopyroxene; Pigeonite; Augite; Plagioclase.
Olivine is poikilitically enclosed by zoned opx.
Minor: Ilmenite; Chromite.
Accessory: Sulfides; Phosphates.
Magmatic inclusions in olivine.

Characteristics
Heterogeneous rocks on the cm scale.

Shock
Pyroxene highly fractured.
Plagioclase typically converted to maskelynite.
Brown color in olivine is caused by oxidation (Fe$^{3+}$) during shock.
Pockets of impact-melted glass with skeletal olivine.

Formation
Olivine and chromite are cumulus phases, rest of rock is closed system fractional crystallization.
Olivine and chromite in opx

2mm

Olivine, maskelynite, chromite, pyroxene

2mm

ALH 77005
Note brown staining in olivine

2mm

Olivine, maskelynite, chromite, pyroxene

LEW 88516
Shock features

1mm

Displacement along fracture

Impact melt pocket (skeletal olivine)

2mm

LEW 88516
Mars Geochemistry

Information about Mars learned from martian meteorites:

- Atmosphere
- Hydrosphere
- Crust
- Mantle
- Core
Atmosphere

Isotopic ratios of H, N, C and O are heavy compared to Earth, due to atmospheric loss of lighter elements to space from Mars.

Water in alteration products has a component from the fractionated atmosphere.
Isotopic Composition of SNC Water

\[ \Delta^{17}O = 0.3 \pm 0.1 \ (2\sigma) \]

- Shergotty
- Whole-rock SNCs
- \( \delta D \)
- EETA 79001A
- Zagami
- Nakhla
- Chassigny
Xe also shows mass fractionation due to atmospheric loss.

Light isotopes are like terrestrial, but heavy isotopes are more abundant.
High D/H and $^{15}$N/$^{14}$N ratios in the atmosphere require that at least 90% of original surface water and 99% of original N have been lost.

Atmospheric $^{40}$Ar abundance is <2% of the amount produced by radioactive decay of $^{40}$K over 4 billion years.
Water in apatite from QUE94201

\[ \delta D_{\text{SMOW}} \] vs \( \text{H}_2\text{O} \) content (wt%)
Mars is volatile-rich compared with Earth. If it accreted with high volatile content, it would also contain a lot of water. But if H$_2$O reacts with Fe to produce FeO, H$_2$ is lost. So the mantle is now depleted in H$_2$O.

Mantle has 36 – 300 ppm H$_2$O, depending on model.