What Can Experimental Petrology Tell Us About Martian Rocks?

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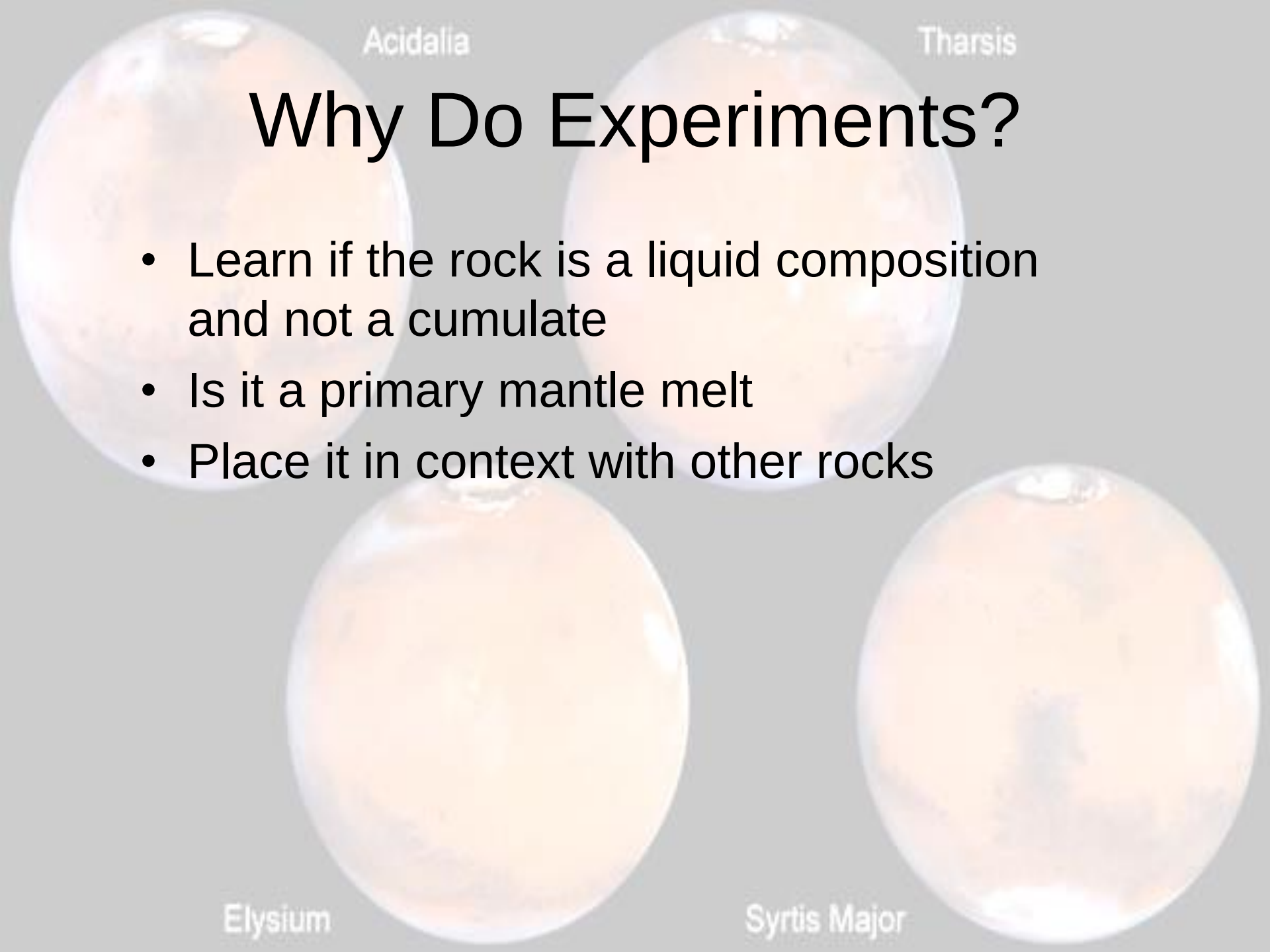
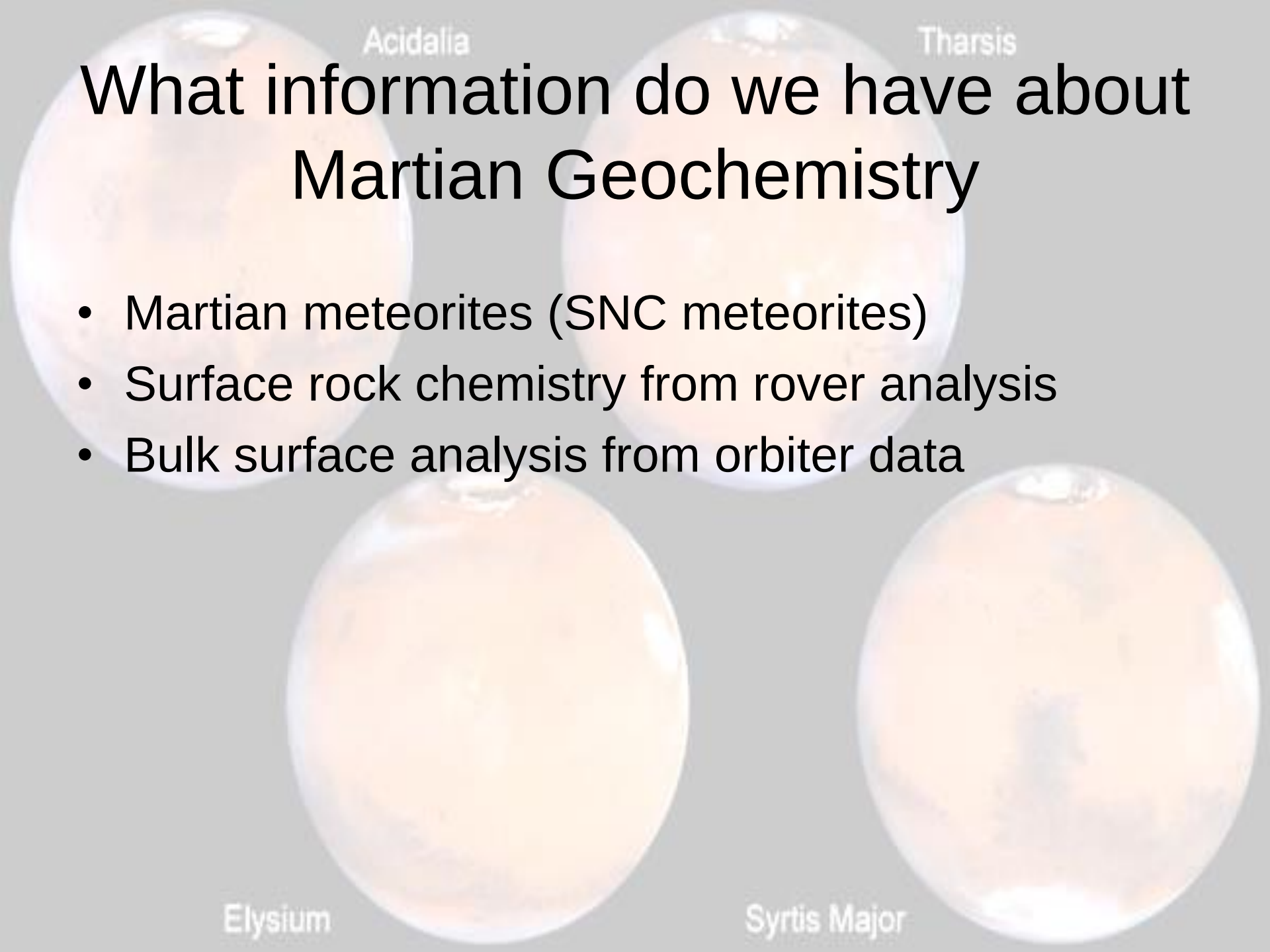


Why Do Experiments?

- Learn if the rock is a liquid composition and not a cumulate
- Is it a primary mantle melt
- Place it in context with other rocks

What information do we have about Martian Geochemistry

- Martian meteorites (SNC meteorites)
- Surface rock chemistry from rover analysis
- Bulk surface analysis from orbiter data



Martian Meteorites

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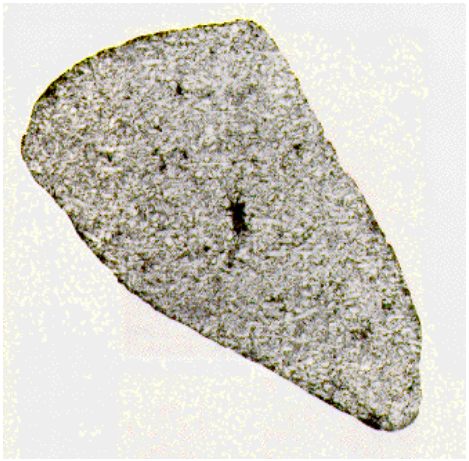
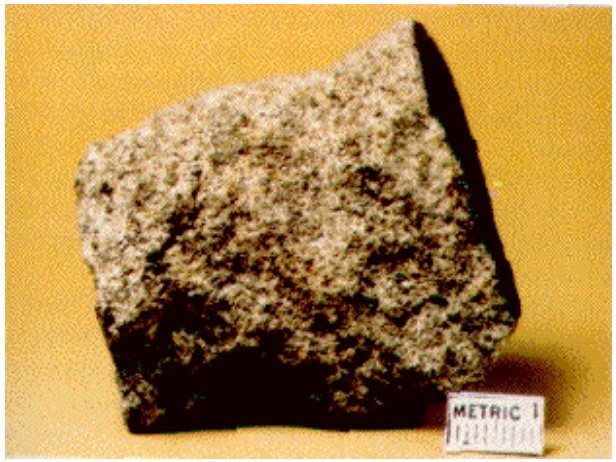


Shergotty

N



Nakhla

C

Chassigny

From the Mars Meteorite Compedium

Shergottites

- Shergottites are Fe-rich basaltic igneous rocks.
- Primarily clinopyroxene (augite)-rich rocks
  - With plagioclase, magnetite, ilmenite, orthopyroxene, and chromite
  - and minor olivine, apatite, and quartz
- Magmatic melt inclusions contain clinopyroxene, amphibole, and spinel (McSween, 1994).
- The olivine phyric shergottites, also contain abundant olivine phenocrysts (Goodrich, 2002).

From the Mars Meteorite Compedium

Nakhlites

- Cumulate clinopyroxenite igneous rocks
- Mineralogy is dominantly clinopyroxene with olivine
- Mesostasis – plagioclase, magnetite, and minor accessory minerals
- Olivine and clinopyroxene contain trapped melt inclusions
  - Magnetite, granitic glass,
  - with rare ilmenite, clinopyroxene, feldspar, chlorapatite, pyrrhotite, silica, and amphibole.

From the Mars Meteorite Compedium

From Treiman (2005)

Chassignites

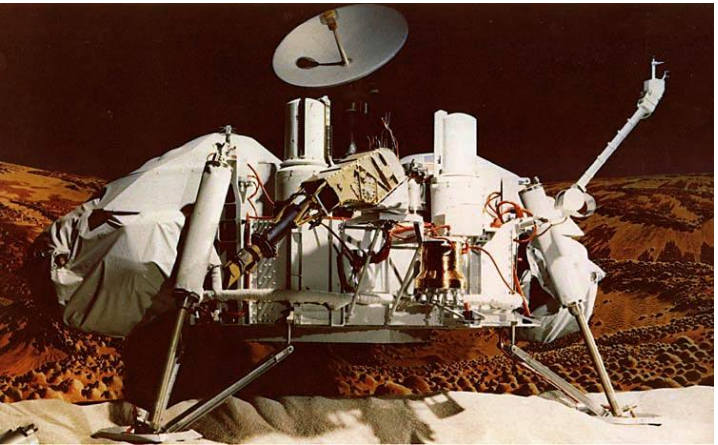
- Cumulate dunitic igneous rocks
- Mineralogy is dominantly olivine with clinopyroxene
- Mesostasis – plagioclase, chromite, ilmenite, chlorapatite, as well as minor accessory minerals
- Olivine contains trapped melt inclusions
  - Amphibole, biotite, pyroxene, apatite, magnetite, chromite, feldspar, and granitic glass.

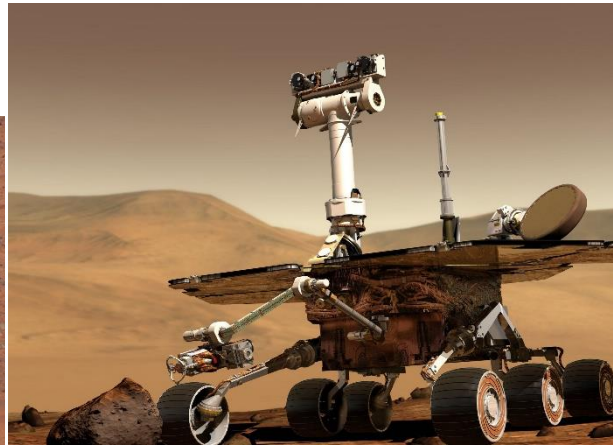
From the Mars Meteorite Compedium

Lander Missions

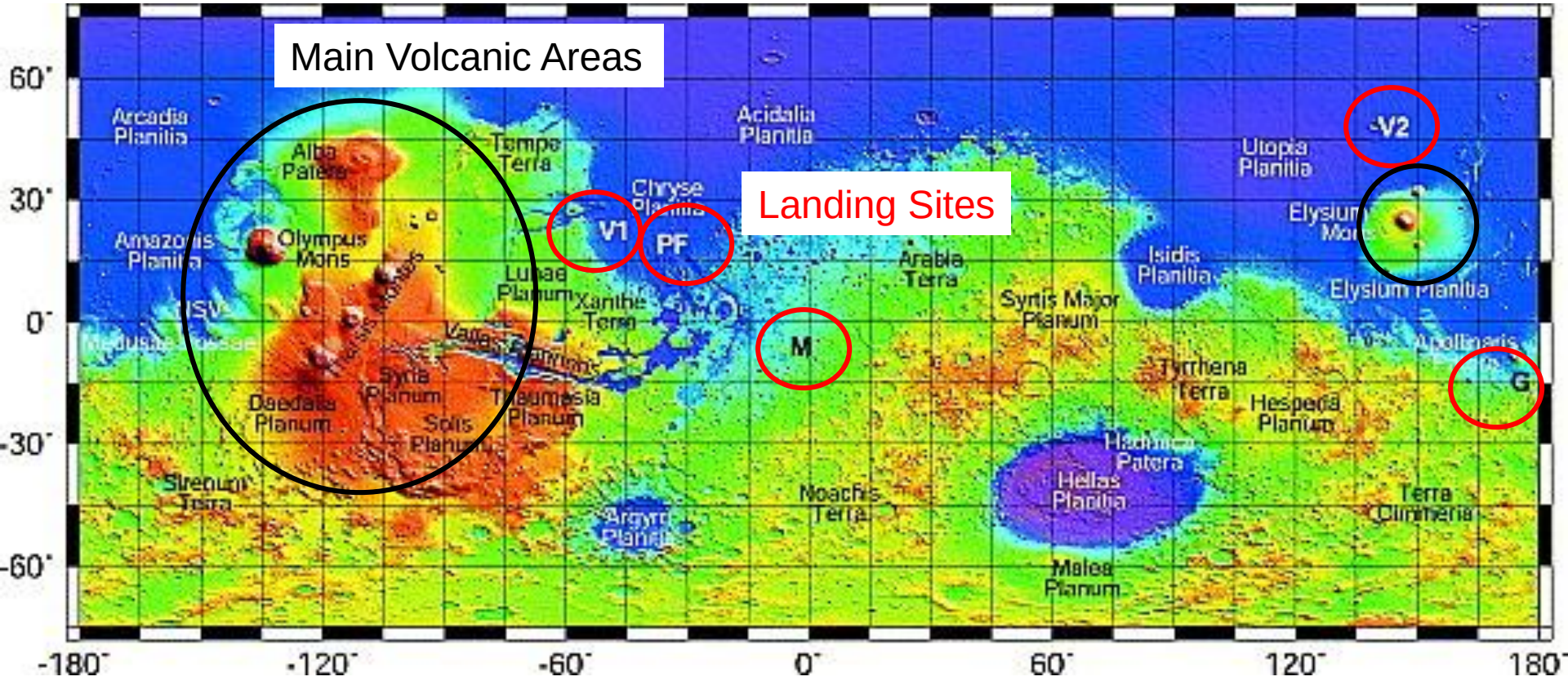
- Viking Mission (1976)
  - 2 Landers
- Pathfinder Sojourner Rover (1997)
- Mars Exploration Rovers (2003)
  - Opportunity and Spirit Rovers

From: NASA/Missions Homepage





Map of Martian Surface and Landing Sites



From: NASA/Missions Homepage

Viking Landers

- **Scientific objectives:**
  - to study the biology
  - chemical composition
  - magnetic properties
  - physical properties of the Martian surface and atmosphere
- These experiments provided no clear evidence for the presence of living microorganisms in soil near the landing sites.
- They provide the only measured link between the Martian meteorites and Mars.

From: NASA/Missions Homepage

Pathfinder Soujourner Rover

Scientific objectives:

- Surface morphology and geology using scaled measurements.
- Petrology and geochemistry of surface materials.
- Magnetic and mechanical properties of the surface.
- Atmospheric structure.
- Rotational and orbital dynamics of Mars.

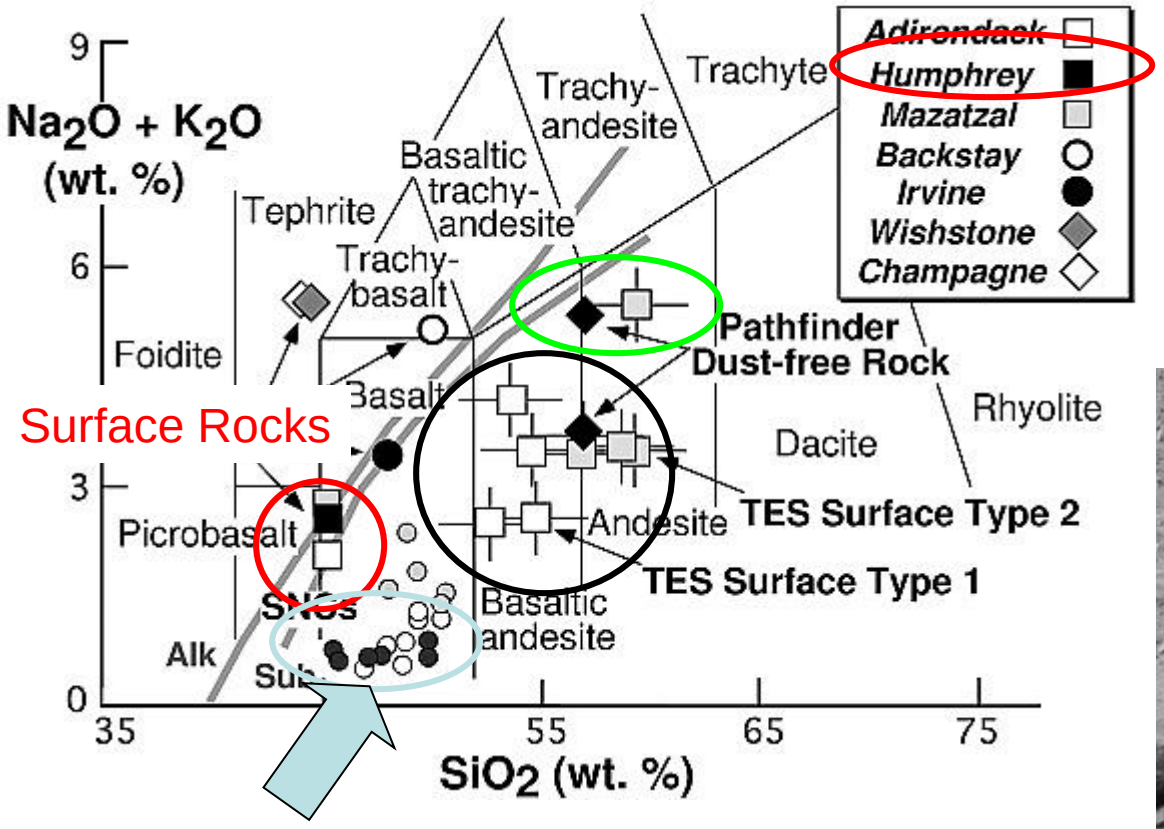
Mars Pathfinder returned 2.3 billion bits of information, including more than 16,500 images from the lander and 550 images from the rover, as well as more than 15 chemical analyses of rocks and soil and extensive data on winds and other weather factors.

From: NASA/Missions Homepage

Mars Exploration Rovers: Spirit and Opportunity

- **Main Scientific Objective:**
  - **Search for water as a clue for evidence of past life.**
- Opportunity's study of "Eagle" and "Endurance" craters revealed evidence for past lakes that evaporated to form sulfate-rich sands.
- Opportunity is examining more sedimentary bedrock exposures along a route leading from "Endurance" to "Victoria Crater".
- Spirit's initial travels in Gusev Crater revealed a more basaltic setting.
- In the "Columbia Hills" the rover found a variety of rocks indicating that early Mars was characterized by impacts, explosive volcanism, and subsurface water.
- Unusual-looking bright patches of soil turned out to be extremely salty and affected by past water.

Rock Data



Surface Rocks

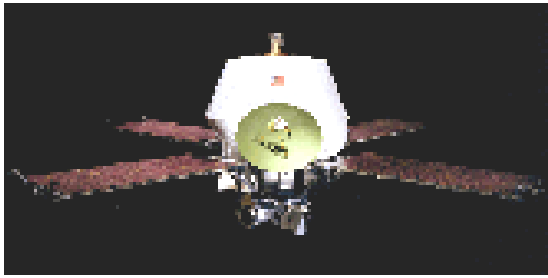
Martian Meteorites

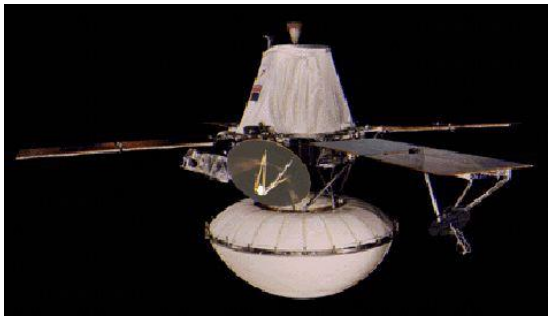
From:McSween et al. (2006)

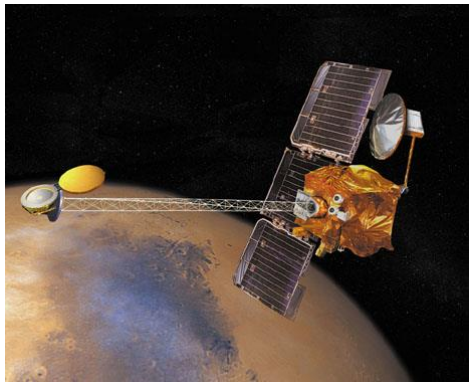
From: NASA/Missions Homepage

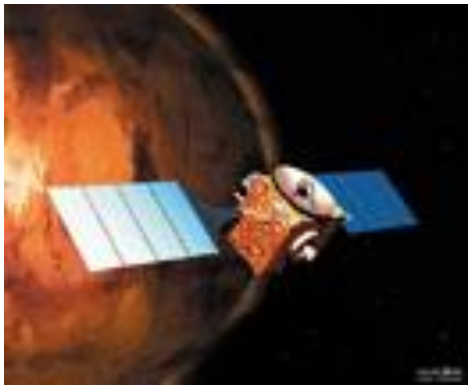
Orbiter Missions

- Mariner 9 (1971)
- Viking 1-2 (1975/1976)
- Mars Global Surveyor (1996)
- Mars Odyssey Orbiter (2001)
- ESA Mars Express (2003)
- Mars Reconnaissance Orbiter (2005)









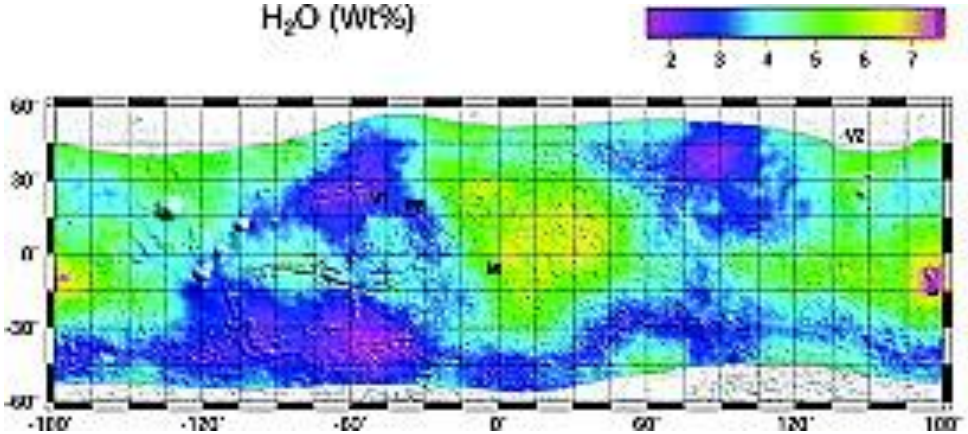
From: NASA/Missions Homepage

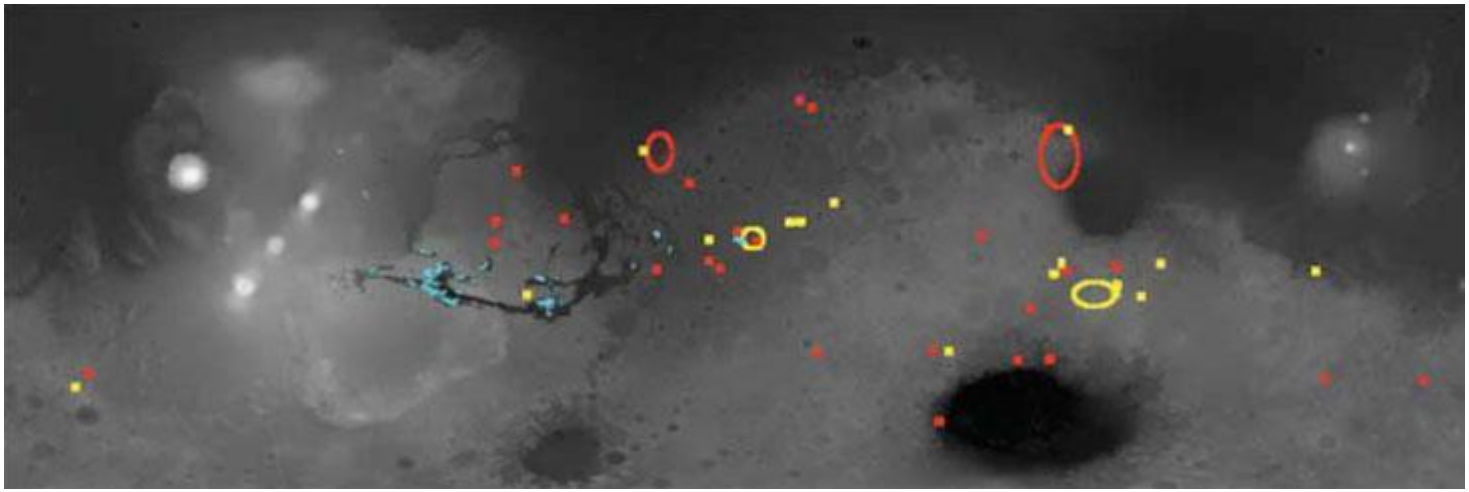
Orbiter Missions

- **Mariner –**
  - viewed global dust storm
  - Photo mapping 100 percent of the planet's surface
- **Viking –**
  - high resolution images of the Martian surface,
  - characterized the atmosphere
  - search for evidence of life
- **Mars Global Surveyor –**
  - observed some dust storms that repeat in the same location within a week or two of the time they occurred in the previous year
  - observed gully formation, new boulder tracks, recently formed impact craters, and diminishing amounts of carbon dioxide ice within the south polar cap
- **Mars Odyssey –**
  - maps of minerals and chemical elements
  - identify regions with buried water ice
- **ESA Mars Express –**
  - main objective is to search for sub-surface water from orbit
- **Mars Reconnaissance Orbiter –**
  - find subsurface water
  - find evidence for worthy landing sites for future exploration

Geochemistry of the surface

- Chemistry map
  - From Mars Odyssey
- Mineral map
  - From Mars Express





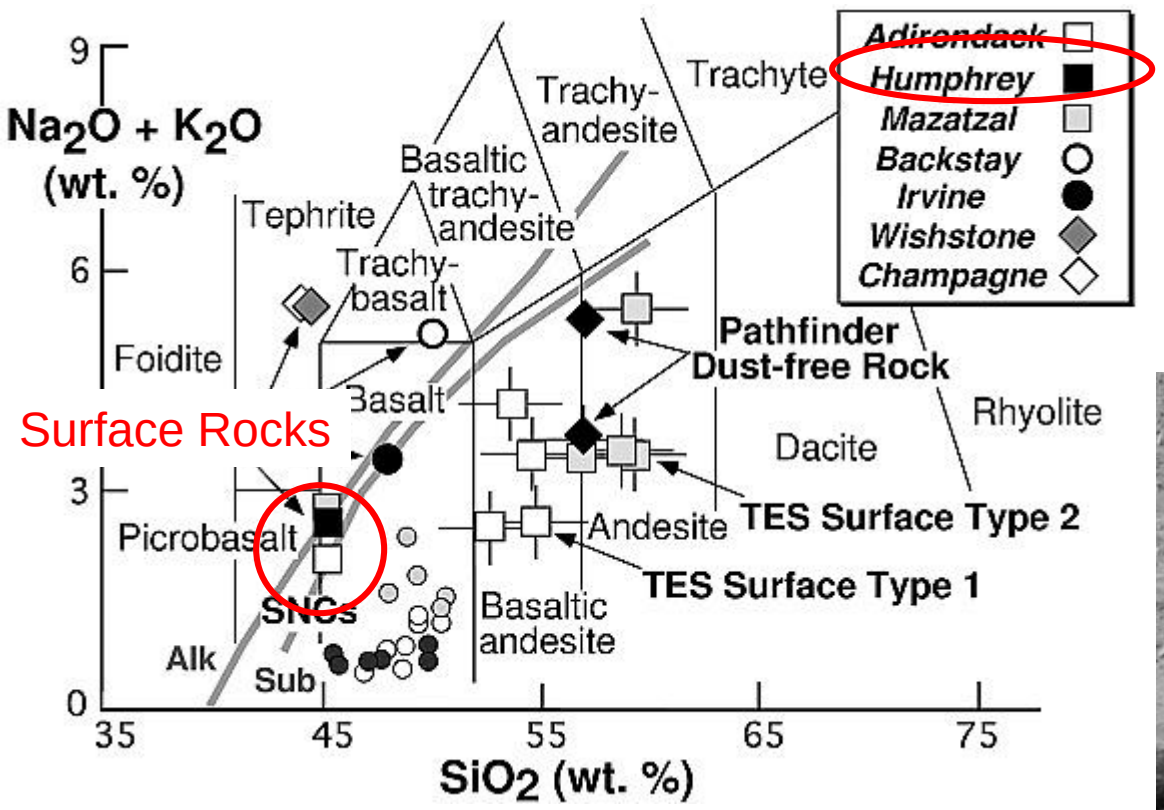
Clays (red), sulphates (blue) and other hydrated minerals (yellow)

What experiments to do? On what compositions?

- Experiments can be done on both meteorite compositions and surface rock compositions

- Crystallize it to see if minerals match hand sample (therefore a liquid composition)
- See if it is a primary mantle melt
- Connect the rock mineralogically with other Martian rocks

Rock Data

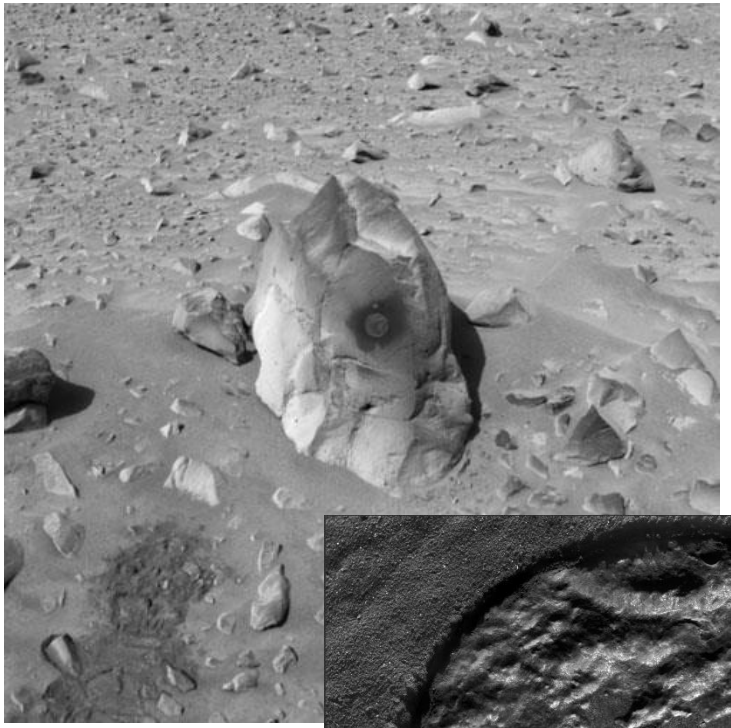


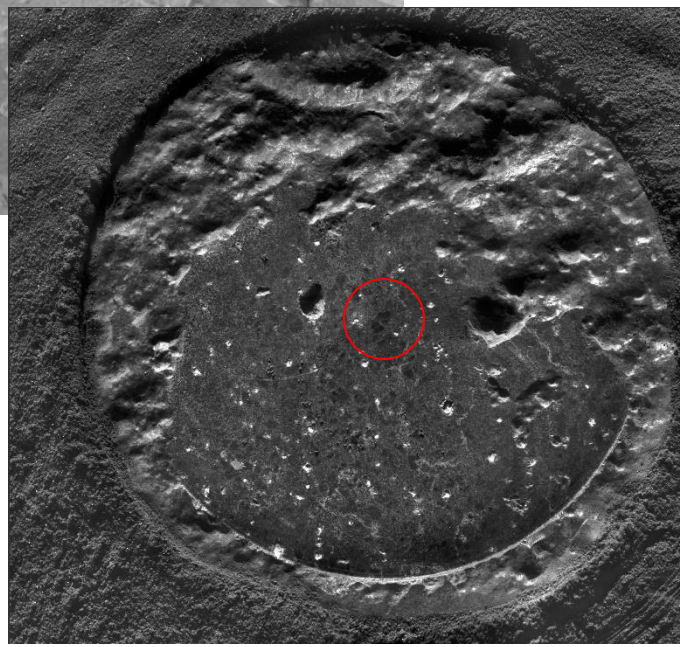
Surface Rocks

From:McSween et al. (2006)

Humphrey Basalt

- Fine grained vesicular rocks
- 25% olivine phenocrysts
- Suggested to represent liquids
- Humphrey contains least alteration products





Experimental Technique

- Synthetic Powder of Humphrey Composition
  - Mix of Chemical oxides (e.g. MgO, SiO_2, Al_2O_3)
  - Fired at 1400°C in an oven
    - Homogenous
    - Anhydrous

	This Study	Gellert et al.	McSween et al.
SiO_2	45.99	46.96	46.49
TiO_2	0.56	0.56	0.59
Al_2O_3	10.89	10.93	10.55
FeO_T	20.01	19.23	18.95
MnO	0.42	0.42	0.43
MgO	10.89	10.65	10.82
CaO	8.12	8.02	8.26
Na_2O	2.44	2.56	2.38
K_2O	0.10	0.10	0.09
P_2O_5	0.58	0.57	0.60
FeS	-	-	0.84
Total	100.00	100.00	100.00

Experimental Technique

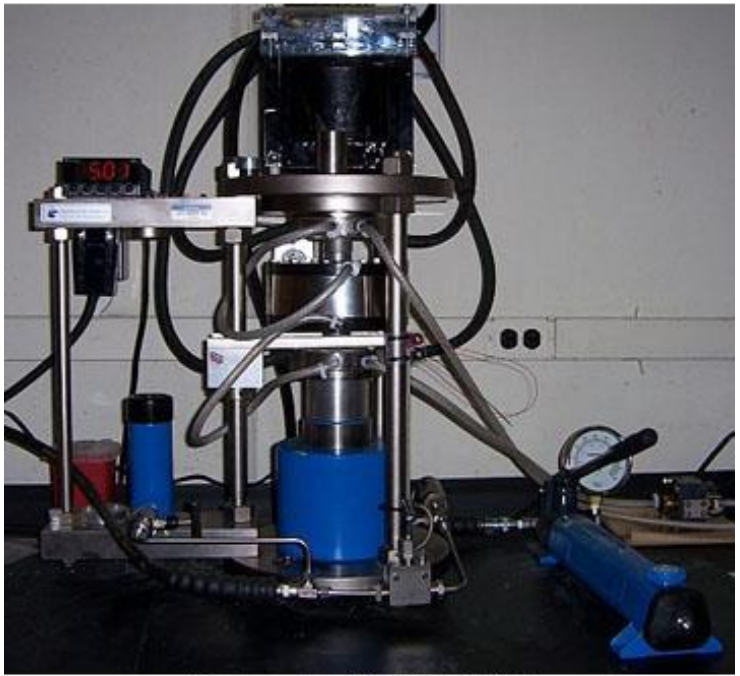
- Synthetic Powder of Humphrey Composition
  - Mix of Chemical oxides (e.g. MgO, SiO_2, Al_2O_3)
  - Fired at 1400°C in an oven
    - Homogenous
    - Anhydrous
- Piston Cylinder
  - Mantle pressures (4-16 kbar)
- 1 bar Furnace
  - Surface eruption conditions

Equipment

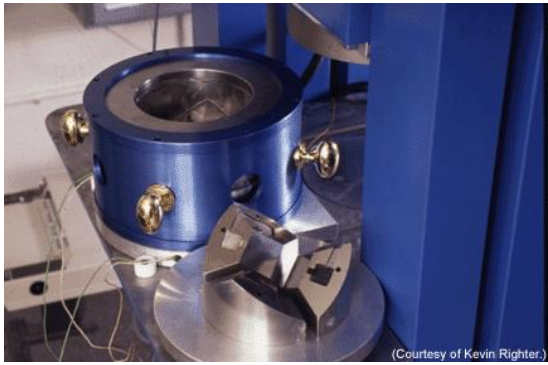
- 1 bar gas mixing furnace
- Piston cylinder (0.3 - 4.0 GPa)
- Multi Anvil (4 GPa - 40 GPa)

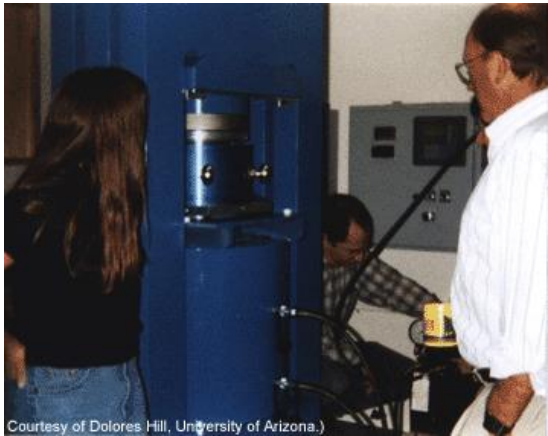
1 bar furnace

Piston Cylinder



Multi Anvil





Analytical Equipment

- Major Elements- Electron Microprobe
- Water analysis- FTIR
- Mineral mapping- SEM

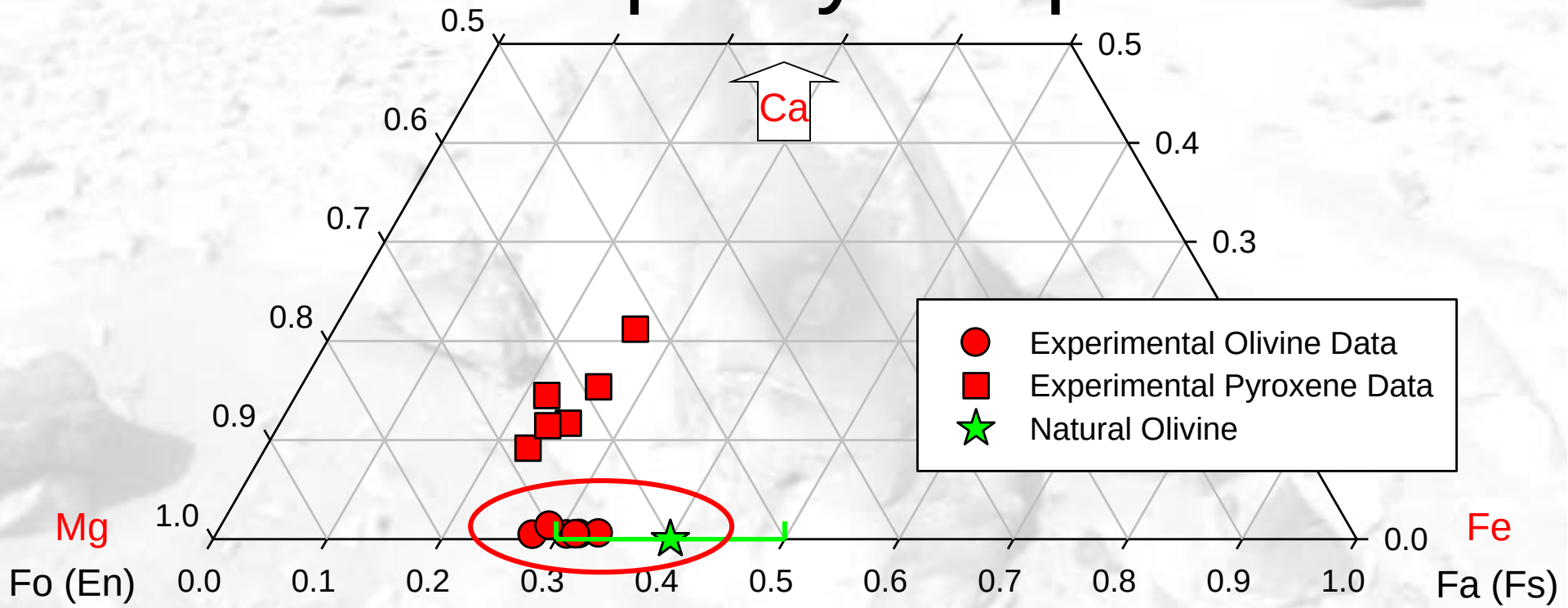
Is Humphrey a liquid?

- Humphrey is a liquid if the experimentally crystallized minerals at 1 bar match the mineral composition in the rock.

Experimental Approach

- Experiments were conducted at 1 bar from high temperature (all liquid) to low temperature (1200°C).

Is Humphrey a liquid?

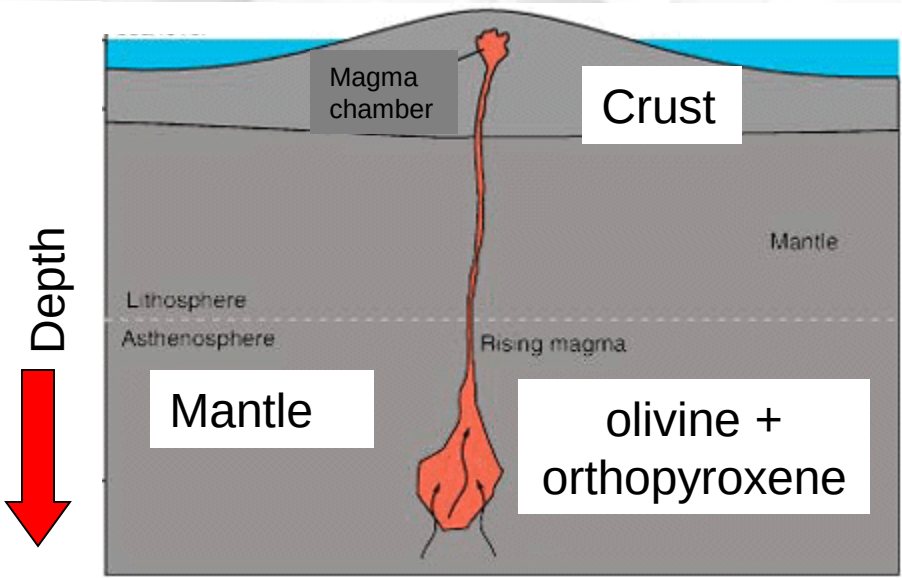


Yes the Humphrey composition represents a liquid composition with no olivine or pyroxene accumulation

Is it a mantle derived liquid?

Only if there is a single experimental pressure and temperature at which the minerals crystallizing on the liquidus have the same composition as those in the mantle that the liquid was derived from (mainly olivine

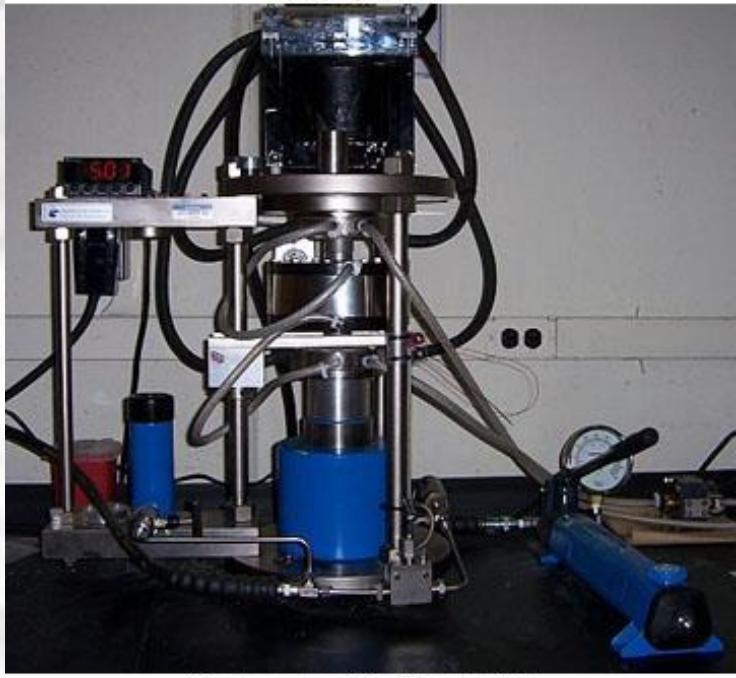
and orthopyroxene).



Experimental Approach

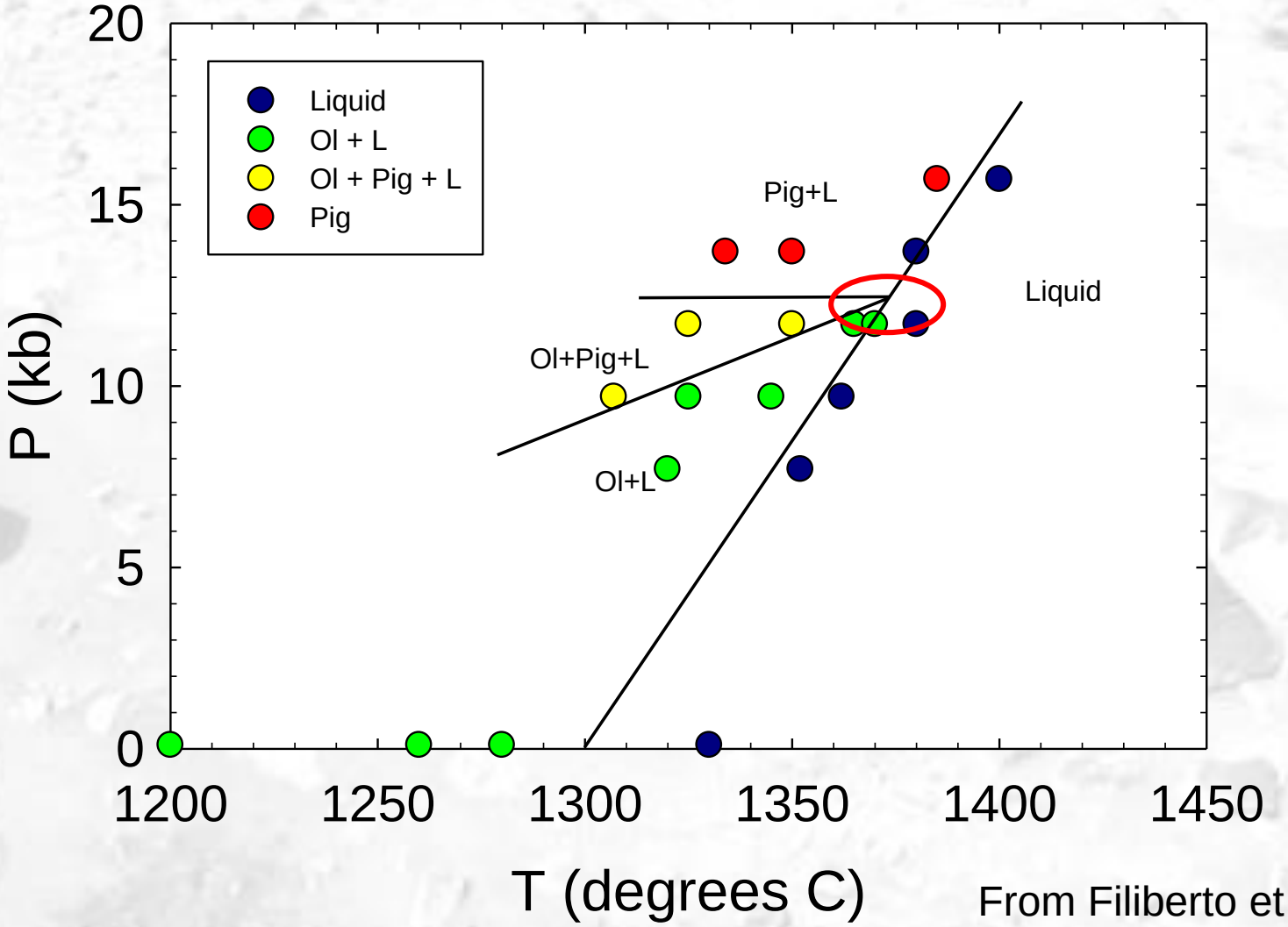
Liquidus, and near liquidus, experiments were conducted on Humphrey composition from 16 kbar – 6 bar.

Quickpress



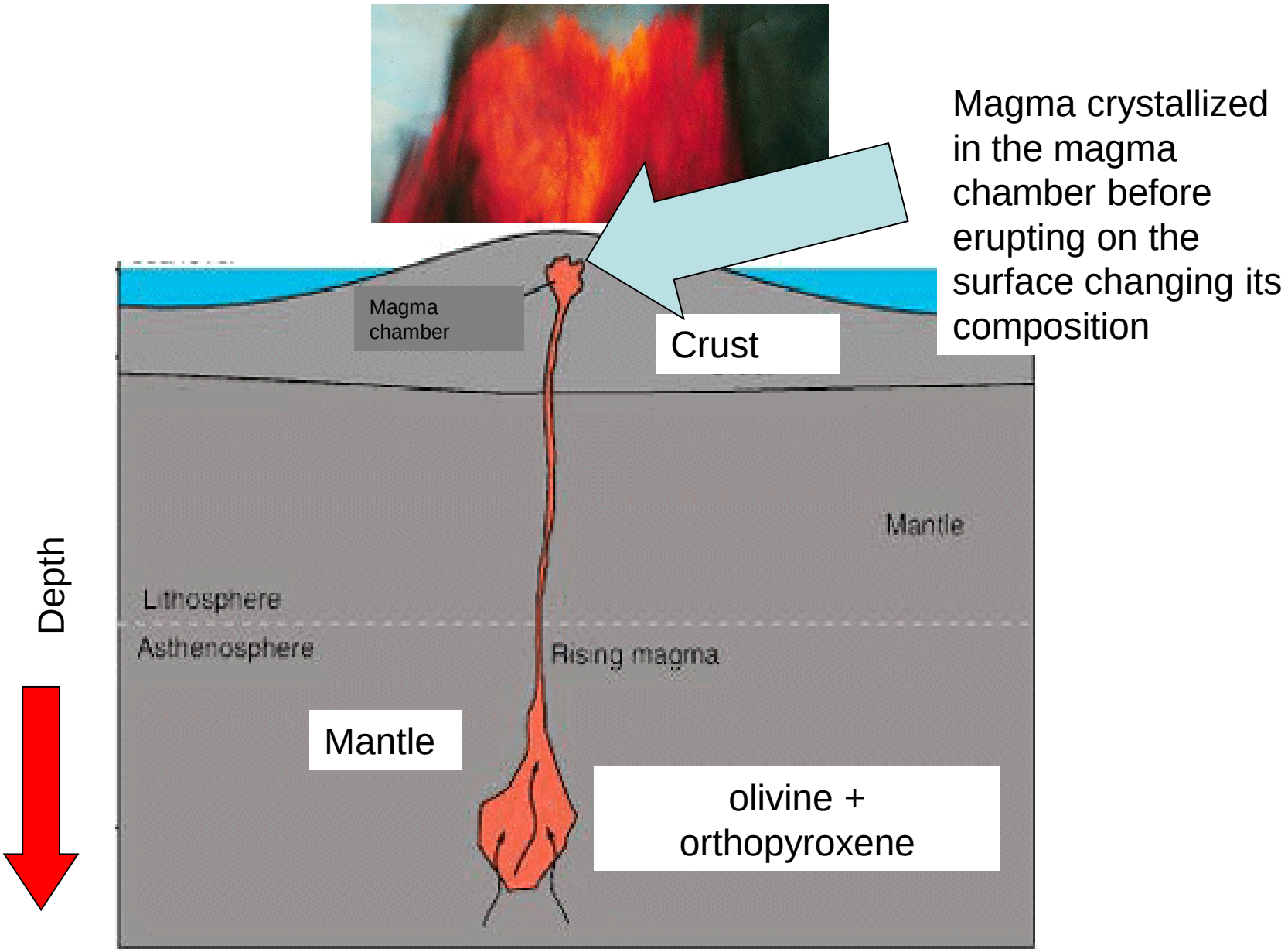
(Photo courtesy of Don Musselwhite.)

Results



From Filiberto et al. (2008)

Humphrey is not a mantle derived melt because it has pigeonite (clinopyroxene) instead of orthopyroxene crystallizing on the liquidus



Magma crystallized in the magma chamber before erupting on the surface changing its composition

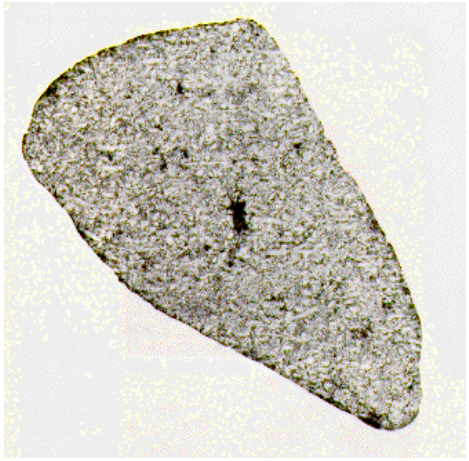
Summary of Experiments

- Humphrey represents a liquid composition and not a cumulate.
- Humphrey is not a primary mantle melt but experienced low pressure fractionation before erupting.

Can We Connect Humphrey with Any Martian Meteorite?

Most Martian meteorites contain cumulate minerals and not liquid compositions.

Can we figure out what crystallized these rocks?



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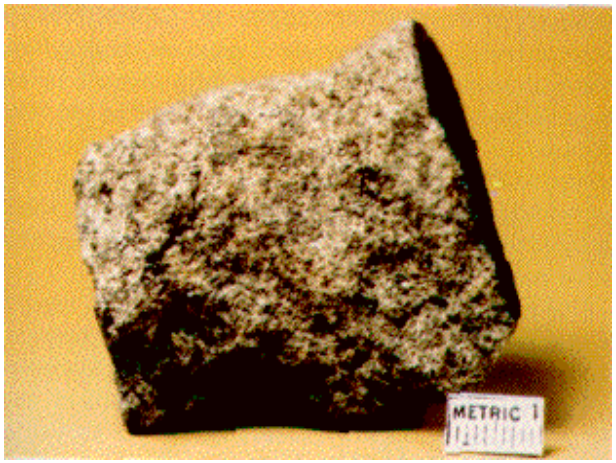
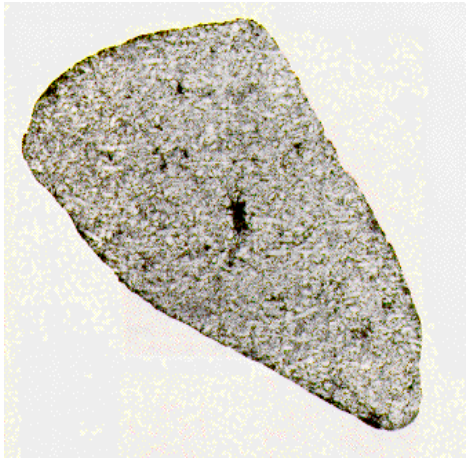


Nakhla

Chassigny

Can we figure out if Humphrey crystallized these rocks?

If experiments on the Humphrey composition result in the same mineral compositions seen in any of the meteorites, then the Humphrey composition could have crystallized that meteorite.



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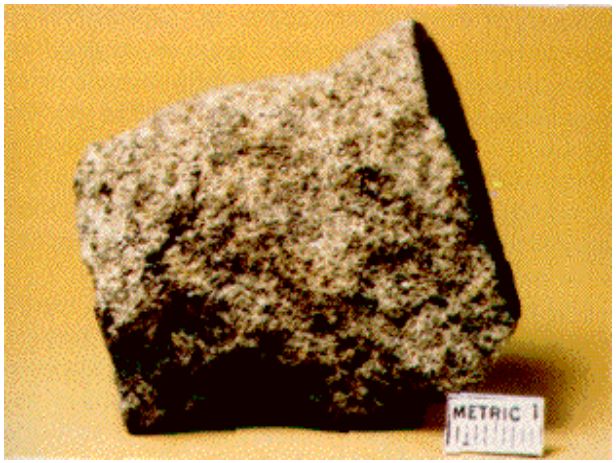

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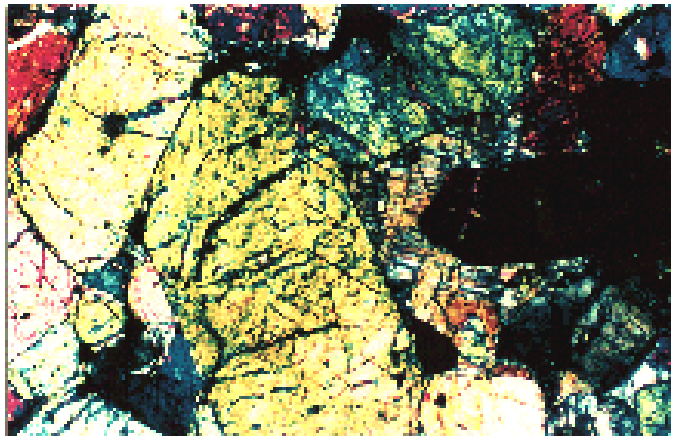
Chassigny

Chassigny

- Chassigny is a dunite with cumulus olivine, Fo_{68}, similar to the olivine, Fo_{71}, crystallizing from the Humphrey experiments.
- In fact geochemical modeling shows the parental liquid to the Chassigny meteorite is similar to the Humphrey composition.



Modeling

Table 8
Calculated parental liquids (from Table 7) compared with original A* and a Martian Adirondack class Gusev basalt

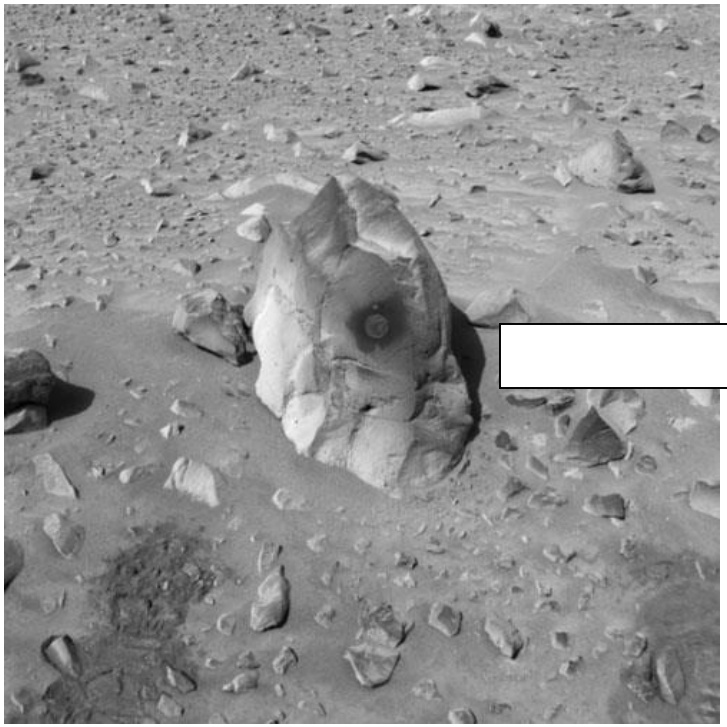
	A*[a]	A* − Fe	A* + Mg	A* − Fe + Mg	A′	Humphrey[b]
SiO_2	50.53	50.39	47.69	48.67	45.55	46.96
TiO_2	1.76	2.51	1.22	1.69	1.35	0.56
Al_2O_3	8.19	11.97	11.32	11.56	11.43	10.93
FeO_T	19.95	7.17	13.87	13.41	20.33	19.23
MnO	0.52	0.75	0.36	0.50	0.50	0.42
MgO	7.42	10.60	17.45	12.95	11.86	10.65
CaO	8.99	12.83	6.25	8.66	6.94	8.02
Na_2O	1.72	2.45	1.19	1.65	1.32	2.56
K_2O	0.43	0.62	0.30	0.42	0.33	0.10
P_2O_5	0.50	0.72	0.35	0.48	0.39	0.57
Total	100.00	100.00	100.00	100.00	100.00	100.00
Mg# (Mg/Mg + Fe)	40	72	69	63	51	50

[a] From Johnson et al. (1991).
[b] From Gellert et al. (2006).

From Filiberto (2008)

A Possible Connection

This suggests that a Humphrey composition could have crystallized the Chassigny meteorite.



Experiments have:

- proven that the Humphrey rock represents a basaltic liquid composition.
- shown that the Humphrey composition is not a direct mantle melt but fractionated on its way to the surface.
- suggested a link between the rocks analyzed on the surface of Mars and the SNC meteorites.