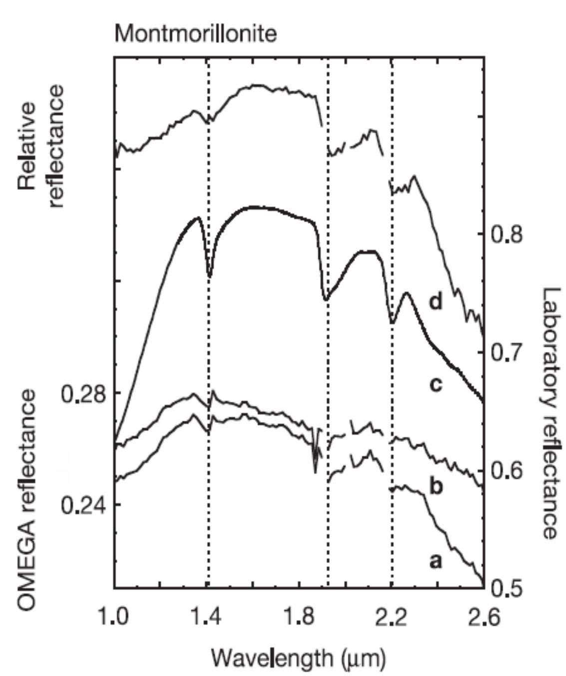
Some of our "questions" from previous lectures

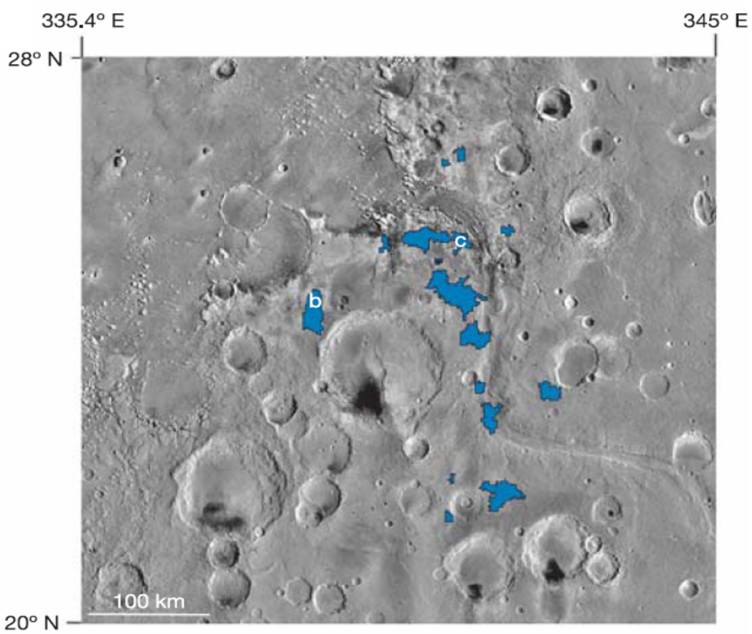
Remote detection of H on Mars

TES & OMEGA

TIR spectrometers detected minerals with H

e.g., zeolites, clays





Poulet et al., 2005

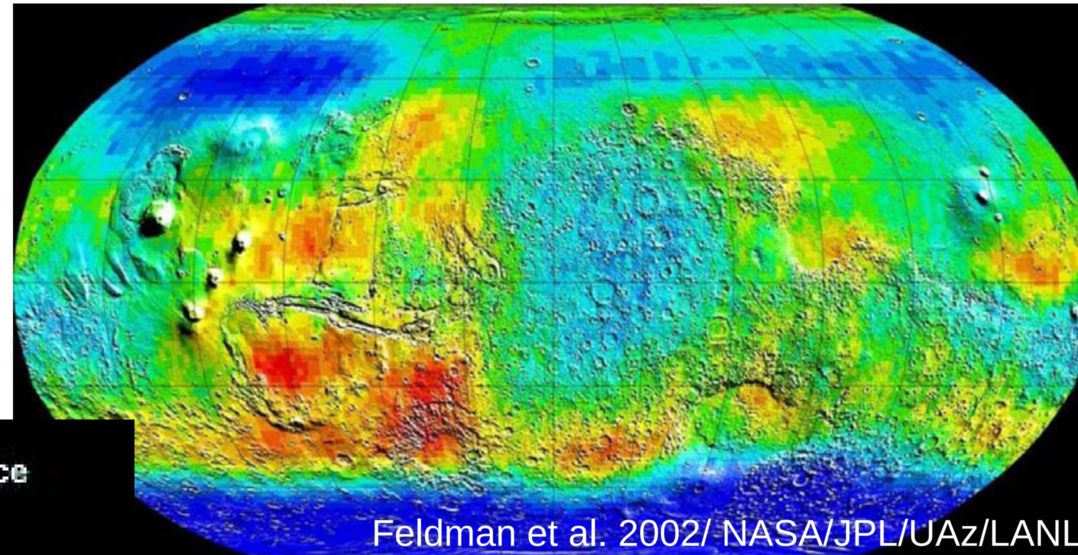
Some of our "questions" from previous lectures

Remote detection of H on Mars

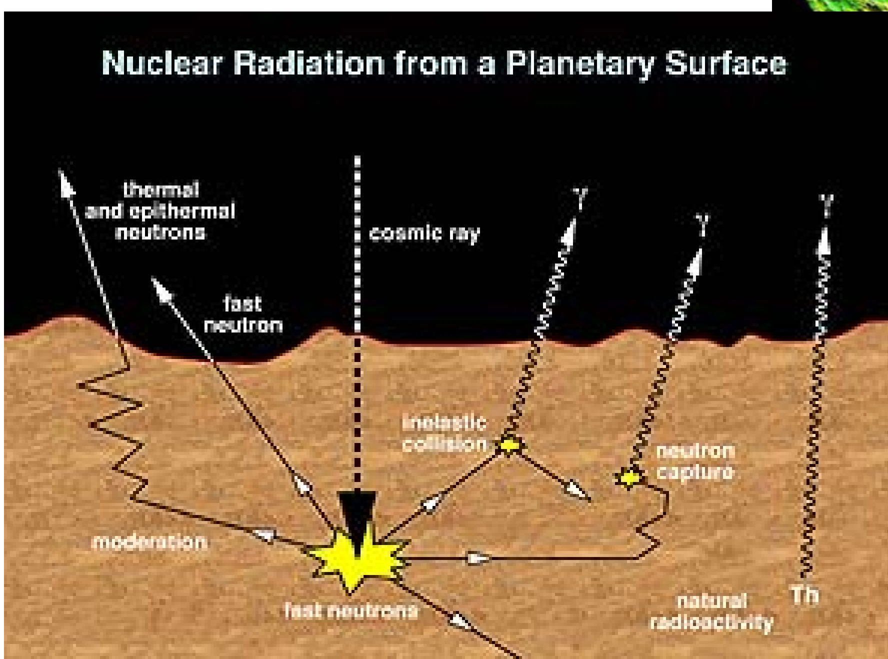
Gamma Ray spectrometer detected H in the top 1m of the surface

Dark blue <50% H_2O in ice

Light blue bound H in minerals



Feldman et al. 2002/ NASA/JPL/UAz/LANL



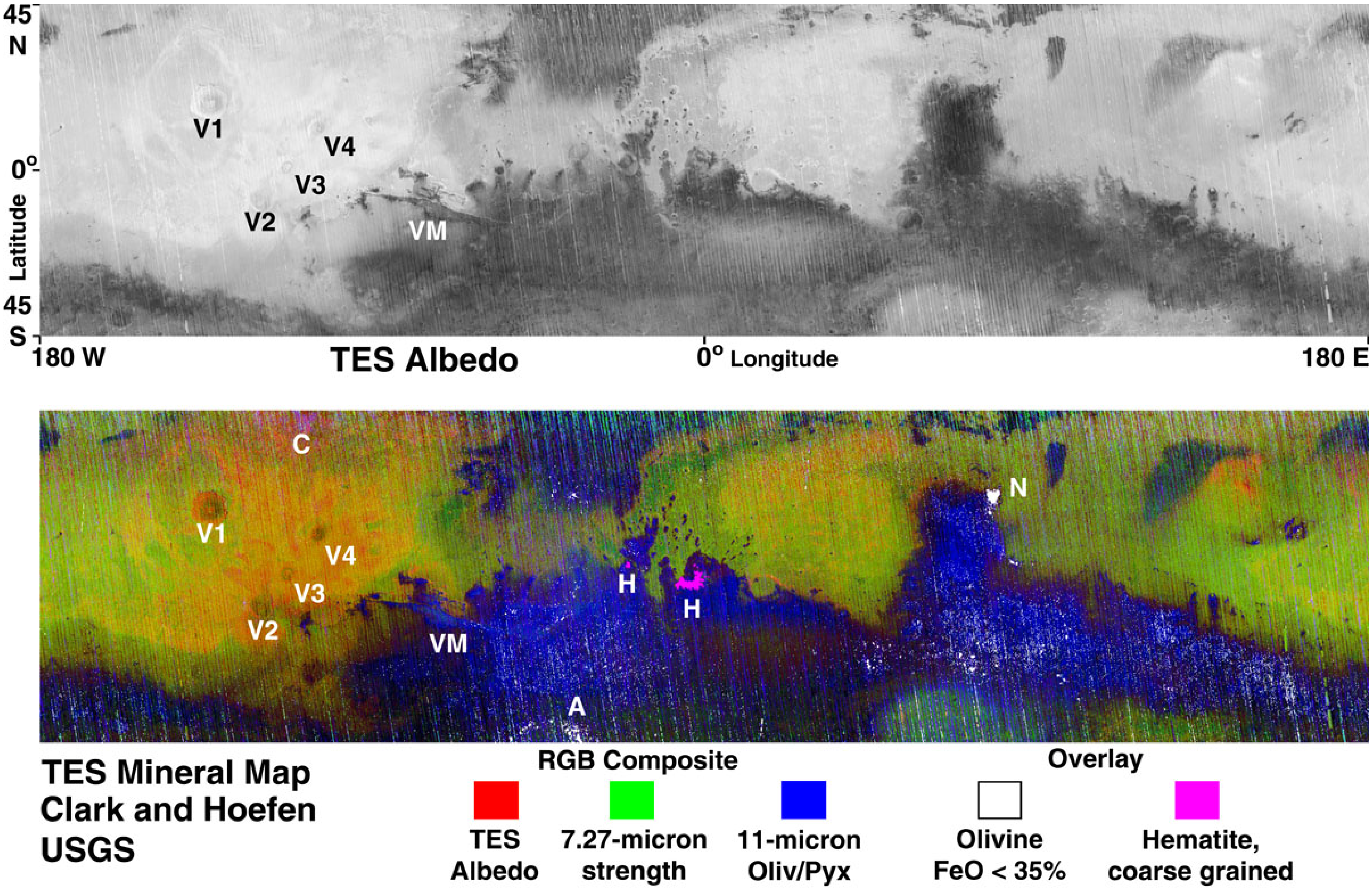
The NS instrument detects neutrons in three energy bands: thermal, epithermal and fast. Each energy class corresponds to the degree to which planetary neutrons have been "moderated", or been in contact with other planetary matter.

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

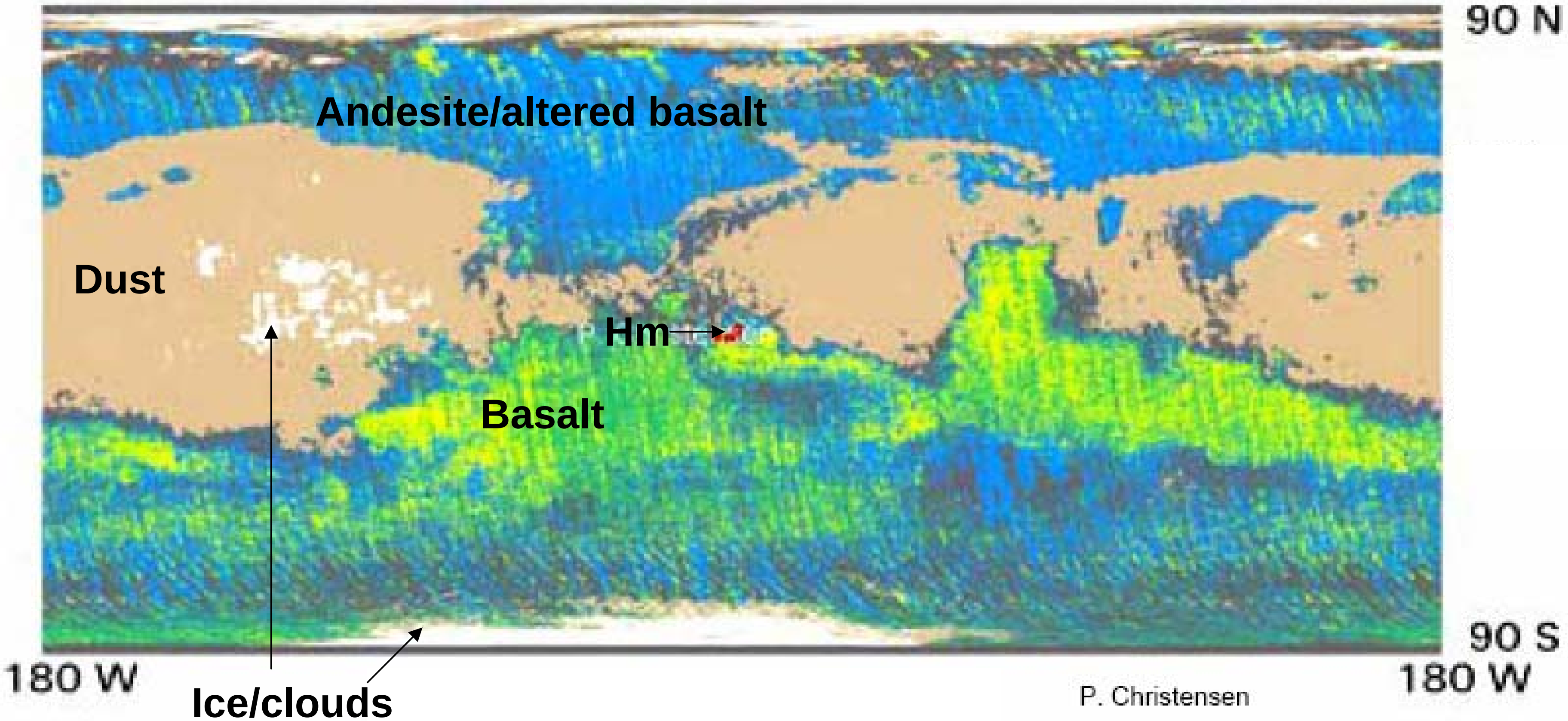


Review of some geologic terms

- Mineral
- Rock

Geologic Map of Mars

Rock types



Review of some geologic terms

- Mineral
- Rock
- Igneous rock
  - volcanic rock

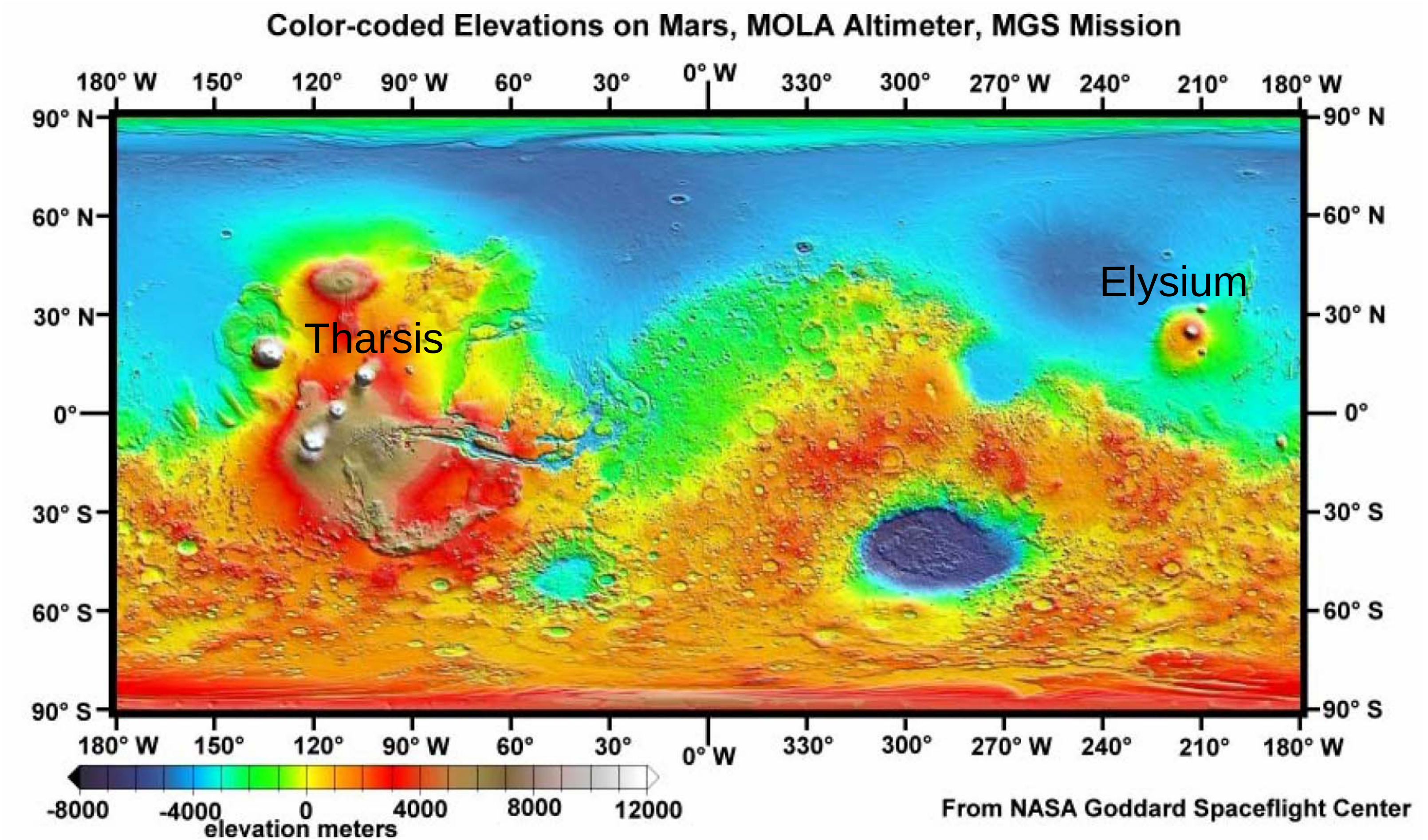
Volcanic Provinces

Two major provinces:

Tharsis: 10km-high bulge, supporting several large volcanoes, including Olympus Mon

Elysium: smaller elevated region with several cone-shaped volcanoes

Relative age dating suggests these are young (<100Ma), may be still active,



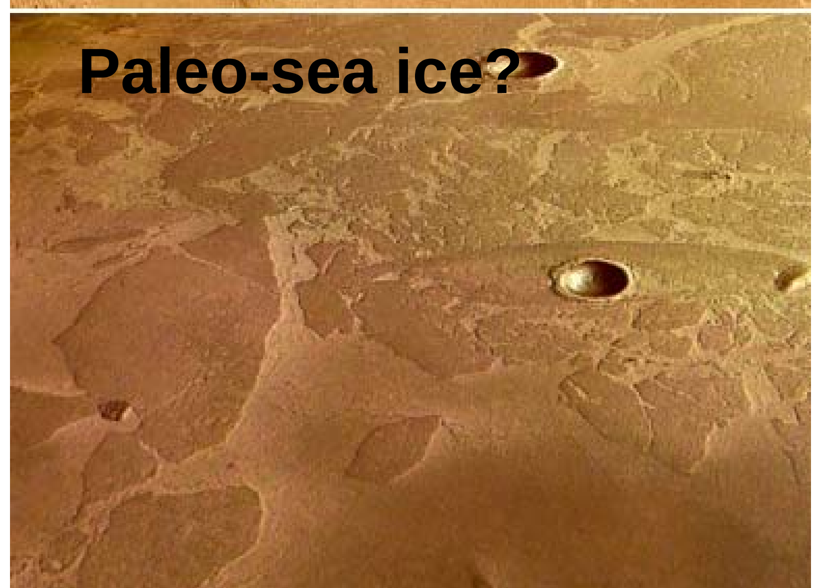
Review of some geology terms

- Mineral
- Rock
- Igneous rock
  - volcanic rock
- Sedimentary rock
  - stratigraphy
  - salt
  - concretion

Geomorphic evidence for surface water

Small valley networks

Outflow channels



NASA/JPL

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)

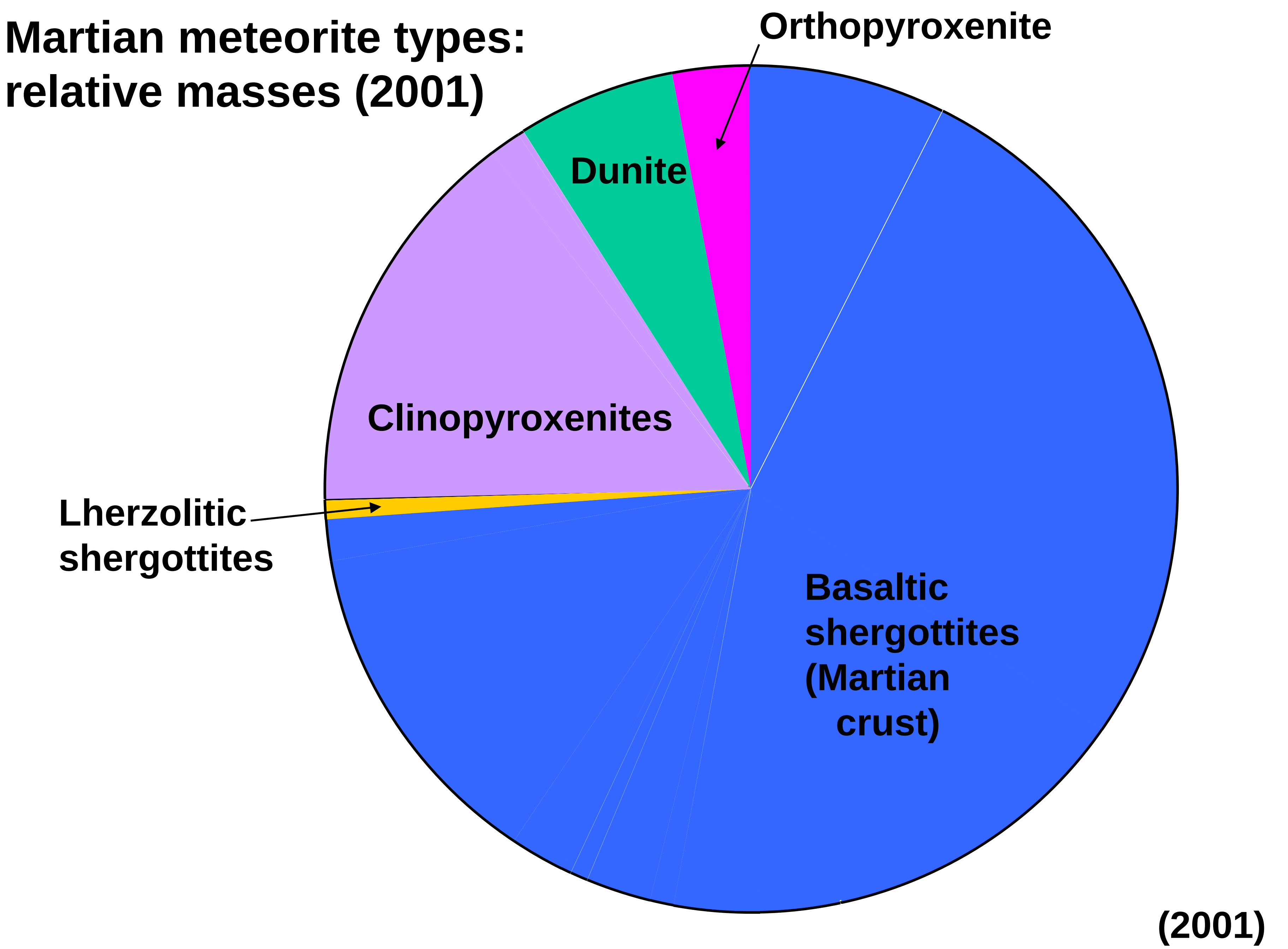
Name	Recovery	Year	Mass (g)
Basaltic Shergottites			
Shergotty	**India	1865	5000
Zagami	**Nigeria	1962	18000
EETA79001 (lith B)	Antarctica	1980	7900
QUE94201	Antarctica	1994	12
Los Angeles	California	1999	668
Dhofar 378	Oman	2000	15
NWA 480	Morocco	2000	28
NWA 856	Morocco	2001	320
NWA1669	Morocco	2001	36
NWA3171	Algeria	2004	506
NWA 2975	Morocco	2005	701

**FALLS

Name	Recovery	Year	Mass (g)
Lherzolitic Shergottites			
ALHA77005	Antarctica	1977	480
Yamato 793605	Antarctica	1979	18
LEW88516	Antarctica	1988	130
Grove Mountain 99027	Antarctica	2000	10
NWA1950	Morocco	2001	797
GRV020090	Antarctica	2005	7
NWA2646	NW Africa	2005	9
YA1075	Antarctica		55
Olivine-phyric Shergottites			
Dar al Gani 476/489	Sahara Desert	1997-98	4161
EETA79001 (lith A)	Antarctica	1980	7900
Yamato 980459	Antarctica	1998	82
Sayh al Uhaymir 005	Oman	1999-2001	1577
Dhofar 019	Oman	2000	1056
NWA 1068/1110	Morocco	2001-02	772
NWA 1195	Morocco	2002	315
NWA2046	Algeria	2003	64
NWA2626	Morocco	2004	31

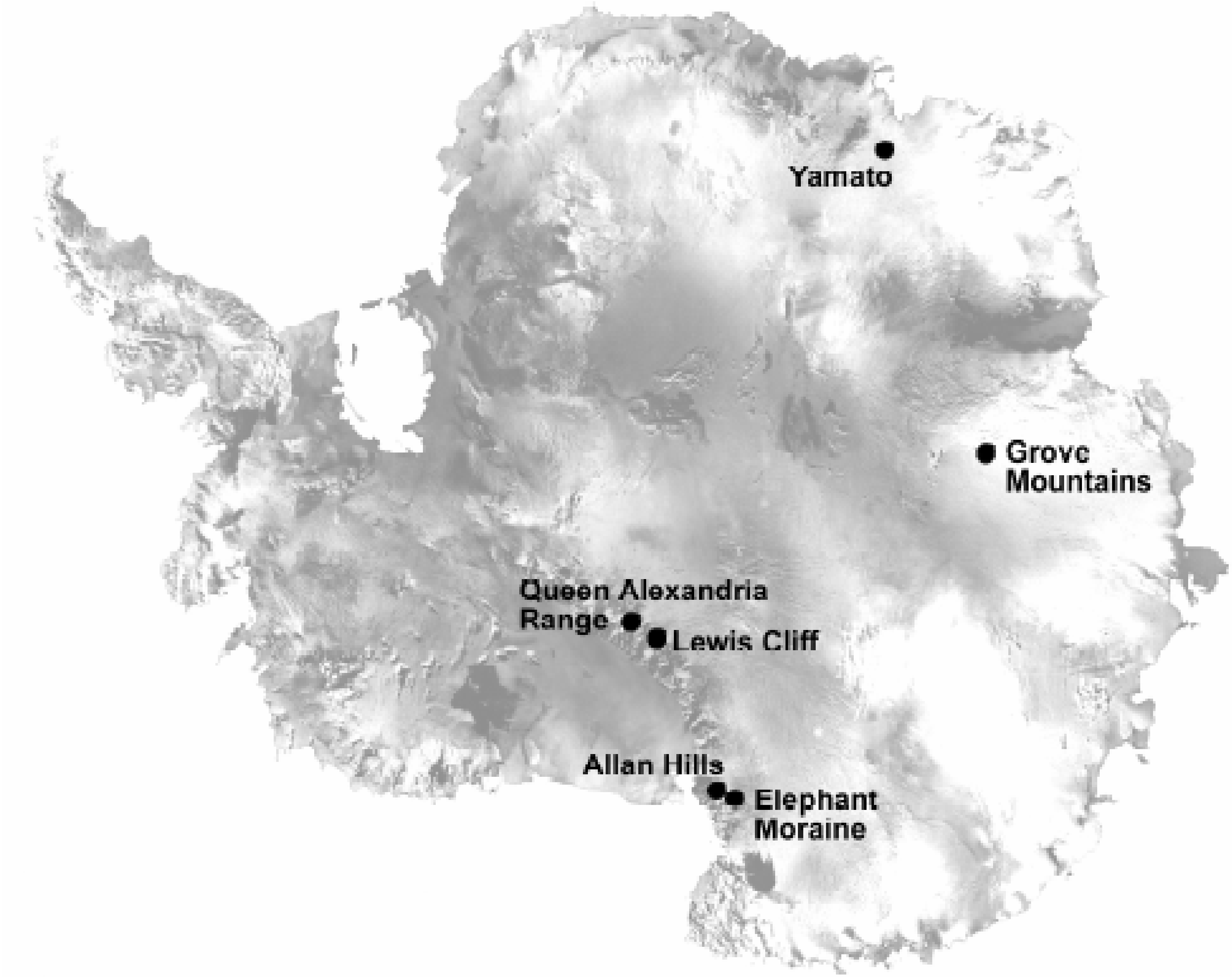
Name	Recovery	Year	Mass (g)
Clinopyroxenites			
Nakhla	**Egypt	1911	10,000
Lafayette	Indiana	1931	800
Governador Valadares	Brazil	1958	158
MIL03346	Antarctica	2003	715
NWA 817	Morocco	2000	104
NWA 998	NW Africa	2001	456
Yamato 000593	Antarctica	2000	15,000
Dunites			
Chassigny	**France	1815	4000
NWA2737	Morocco	2004	611
Orthopyroxenite			
ALH84001	Antarctica	1984	1934

**FALLS



Martian meteorite types:
relative masses (2001)
Orthopyroxenite
Dunite
Clinopyroxenites
Lherzolitic shergottites
Basaltic shergottites (Martian crust)
(2001)

Locations of martian meteorite finds in Antarctica



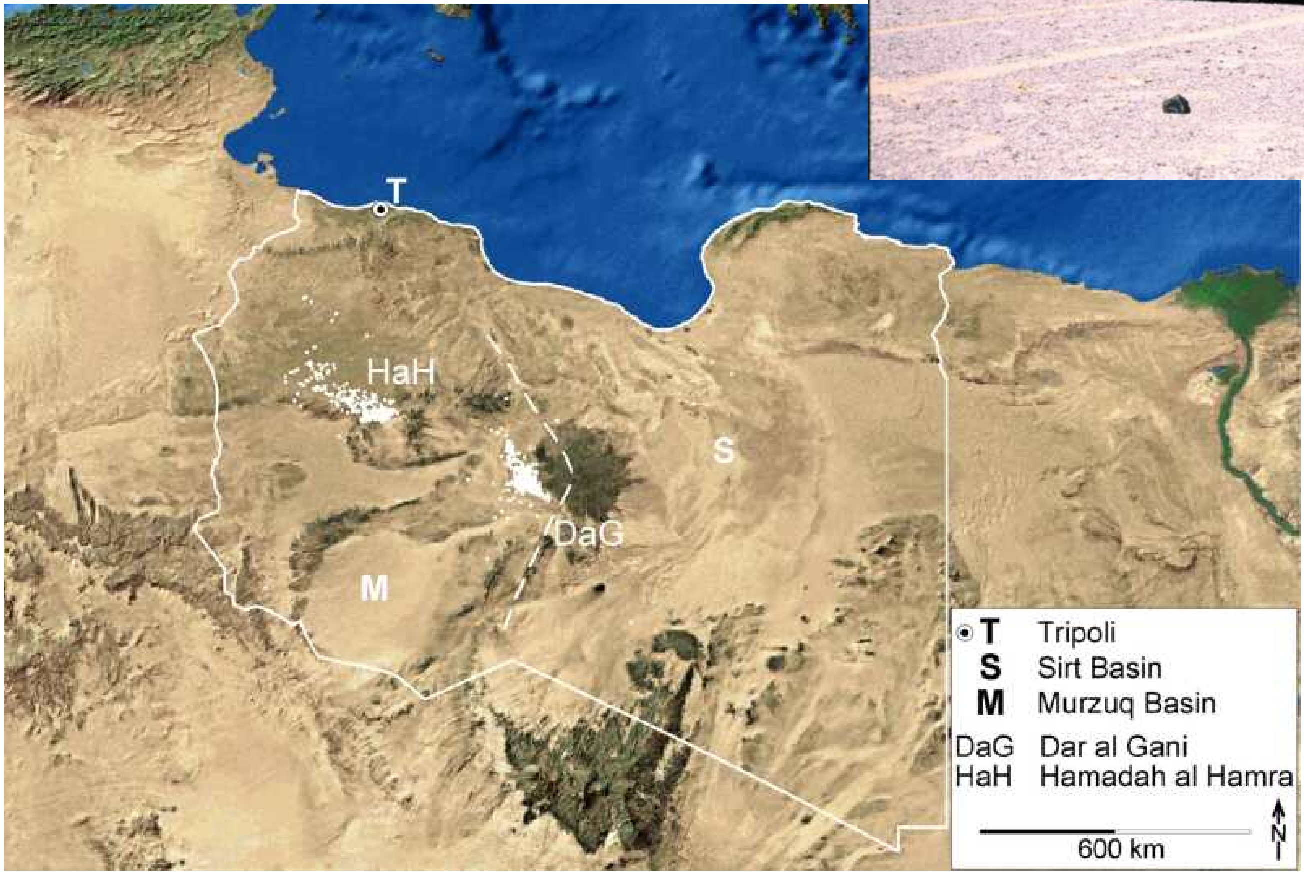
EETA 79001

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.

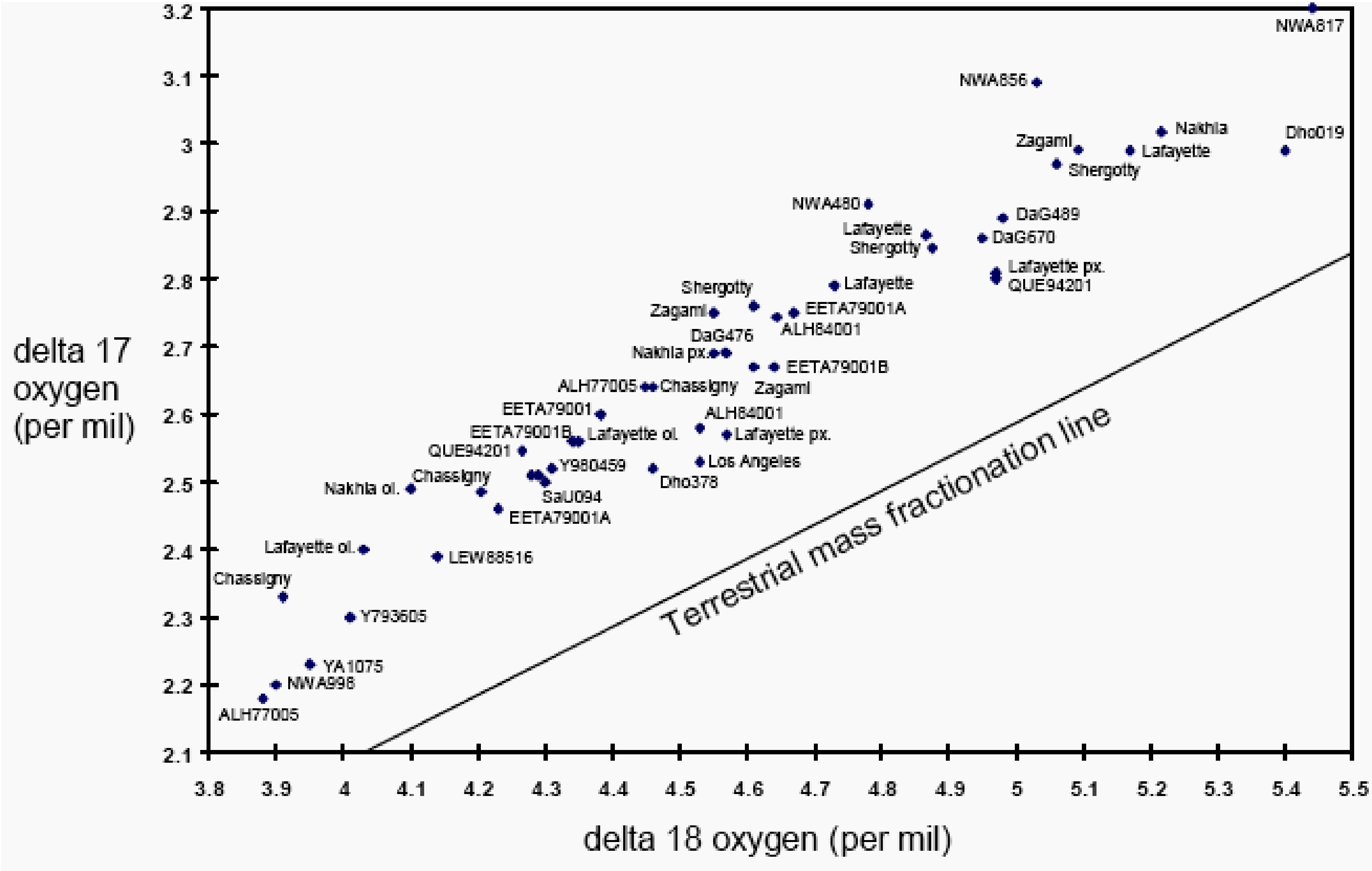
Meteorite collection in NW Africa

Dar al Gani



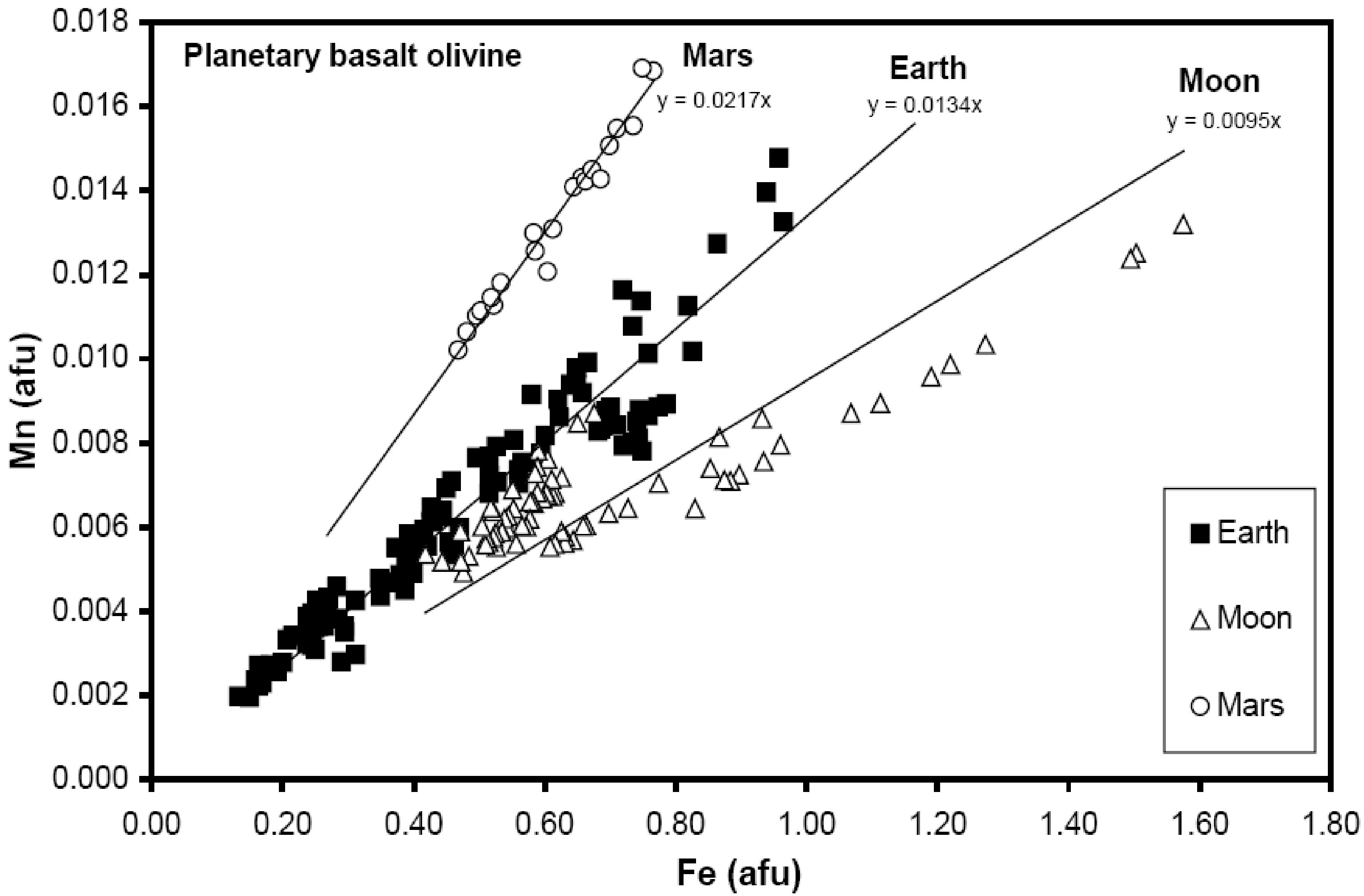
Libya

Oxygen Isotopes

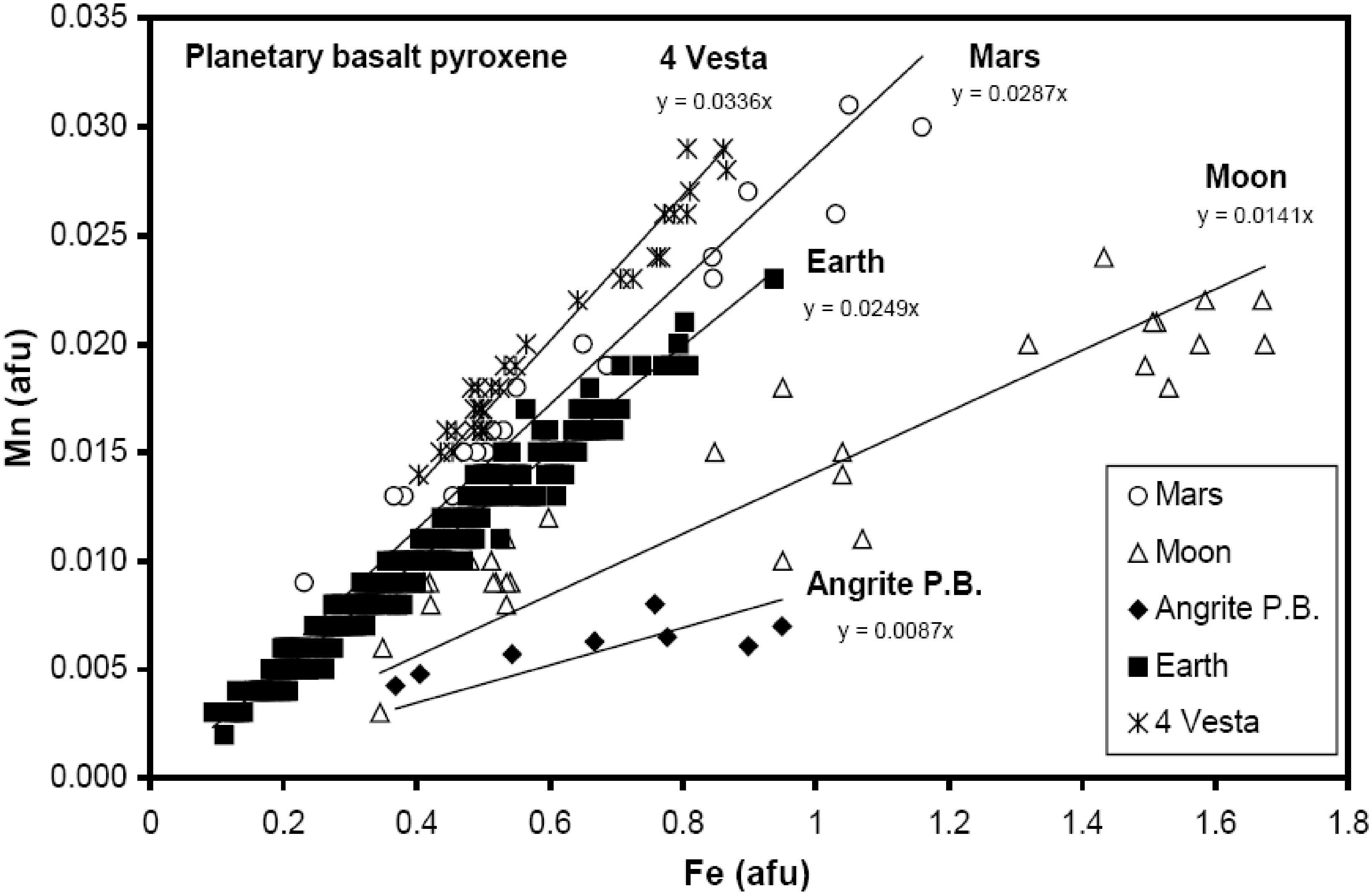


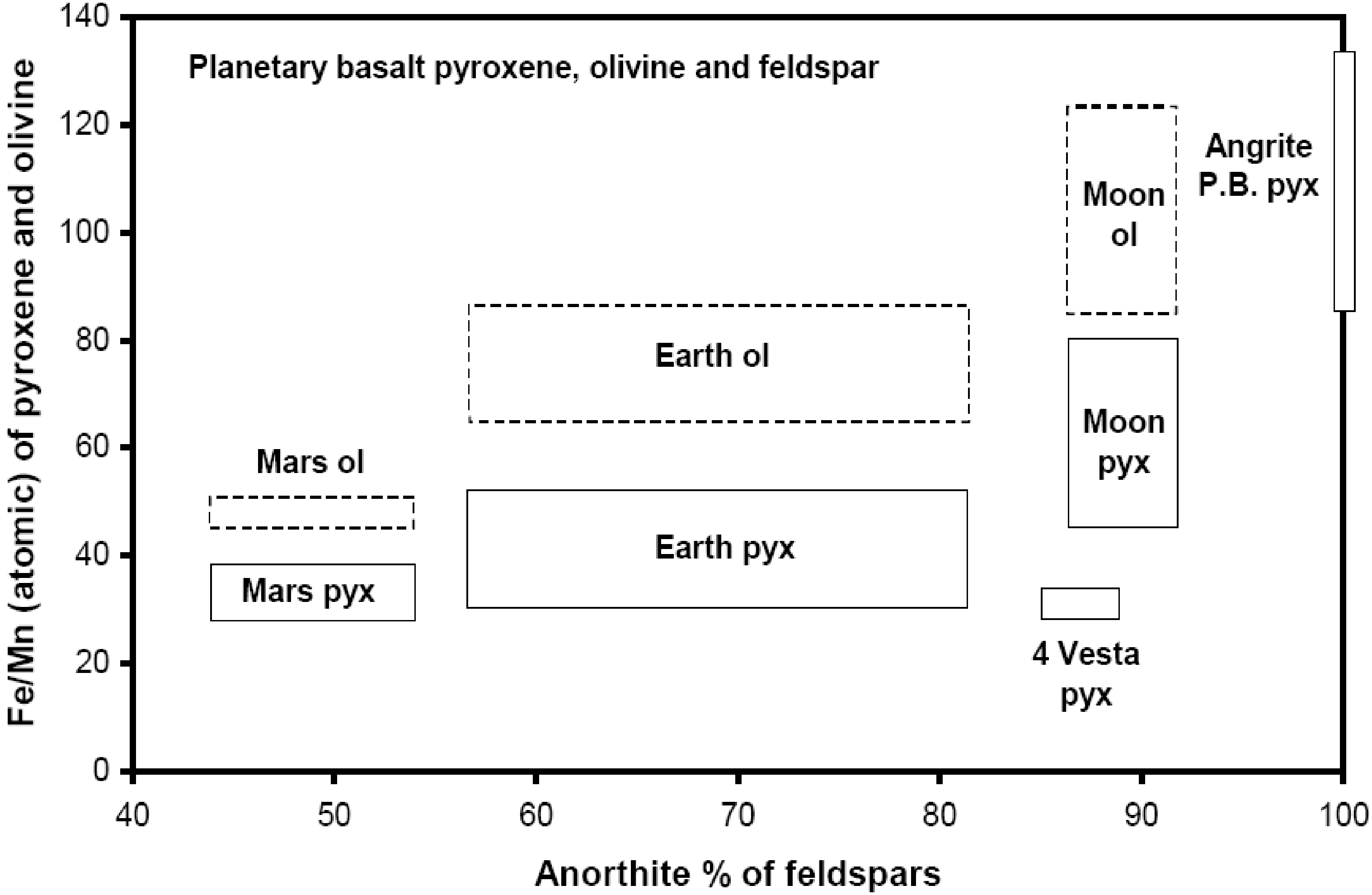
Single suite of meteorites.
Mars Fractionation Line: $\Delta^{17}O = +0.32$ ‰

Fe/Mn ratios of silicates



Papike et al. 2003 LPSC

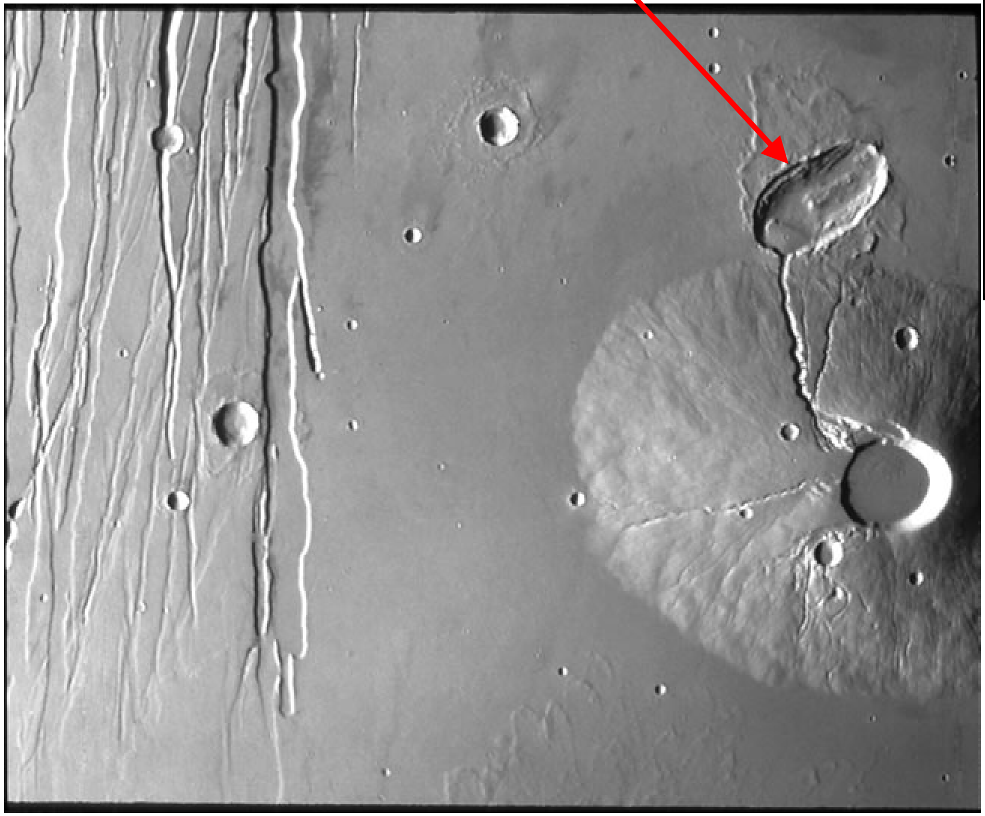

Planetary basalt pyroxene
4 Vesta
y = 0.0336x
Mars
y = 0.0287x
Moon
y = 0.0141x
Earth
y = 0.0249x
Angrite P.B.
y = 0.0087x
Mars
Moon
Angrite P.B.
Earth
4 Vesta
Mn (afu)
Fe (afu)
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8

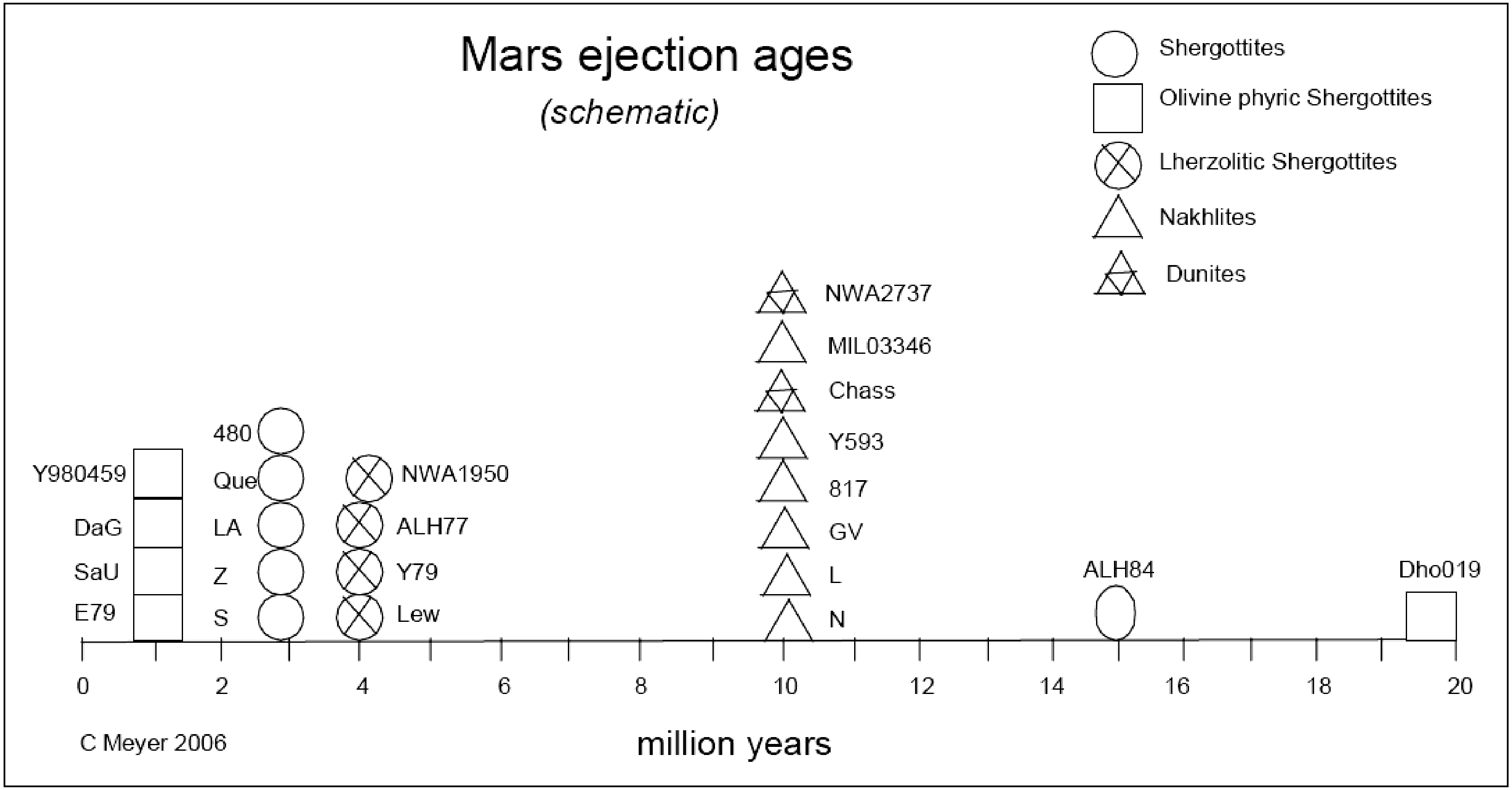

Planetary basalt pyroxene, olivine and feldspar
Fe/Mn (atomic) of pyroxene and olivine
Anorthite % of feldspars
0
20
40
60
80
100
120
140
40
50
60
70
80
90
100
Mars ol
Mars pyx
Earth ol
Earth pyx
Moon ol
Moon pyx
4 Vesta pyx
Angrite P.B. pyx

Source on Mars

Spallation from craters >10km diameter

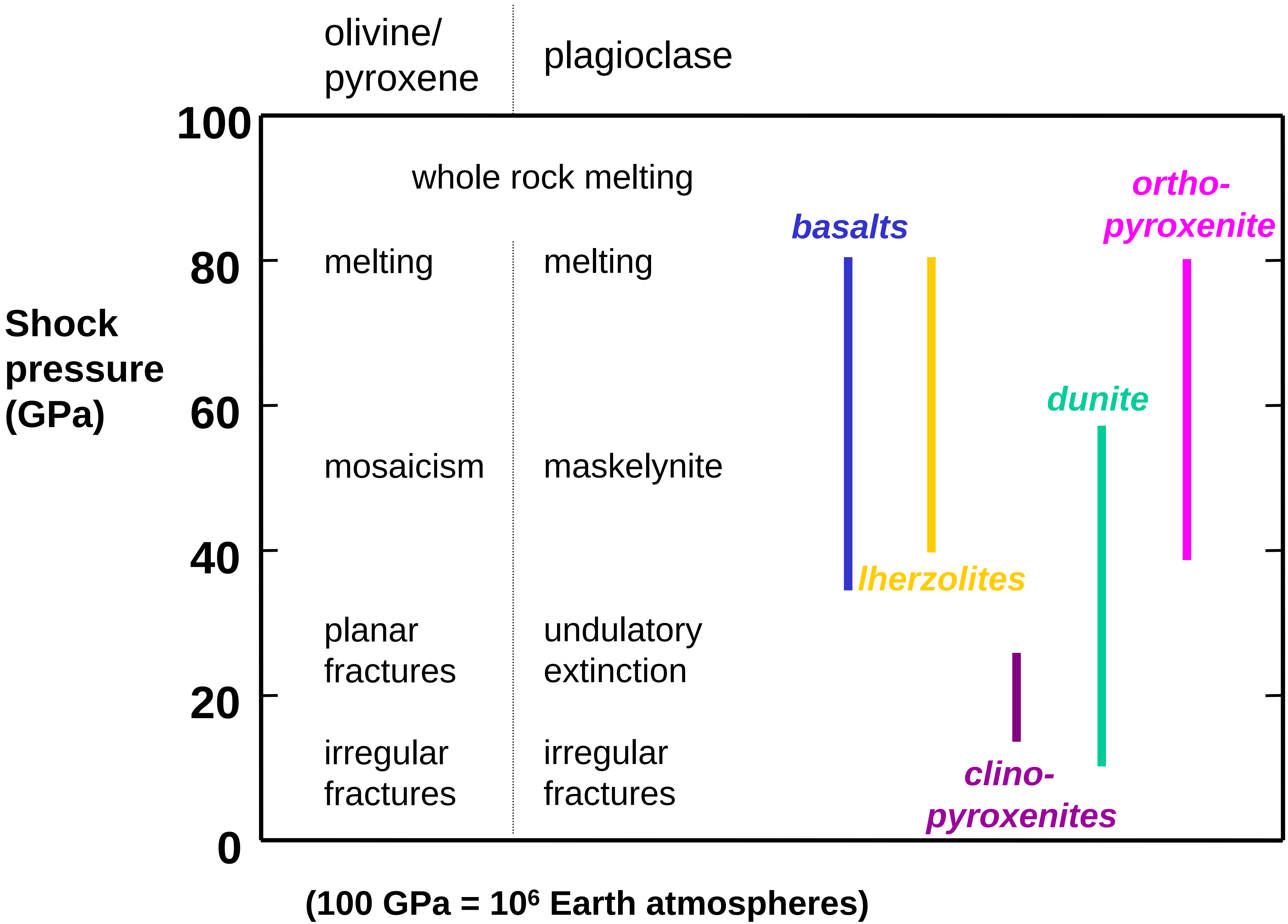
Possible source:
34 x 18 km crater formed
by a grazing impact



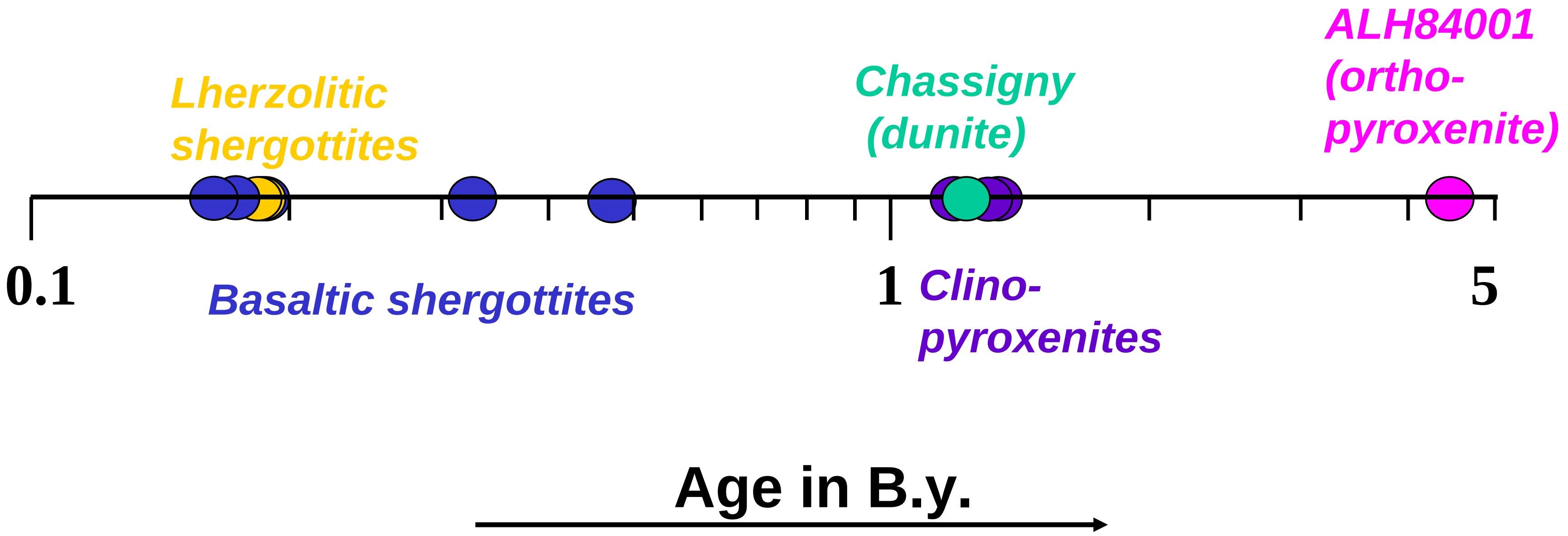


Ejection ages: Date of ejection from Mars surface, measured as cosmic ray exposure ages plus terrestrial residence time.

Specific events ejected specific types of rocks.

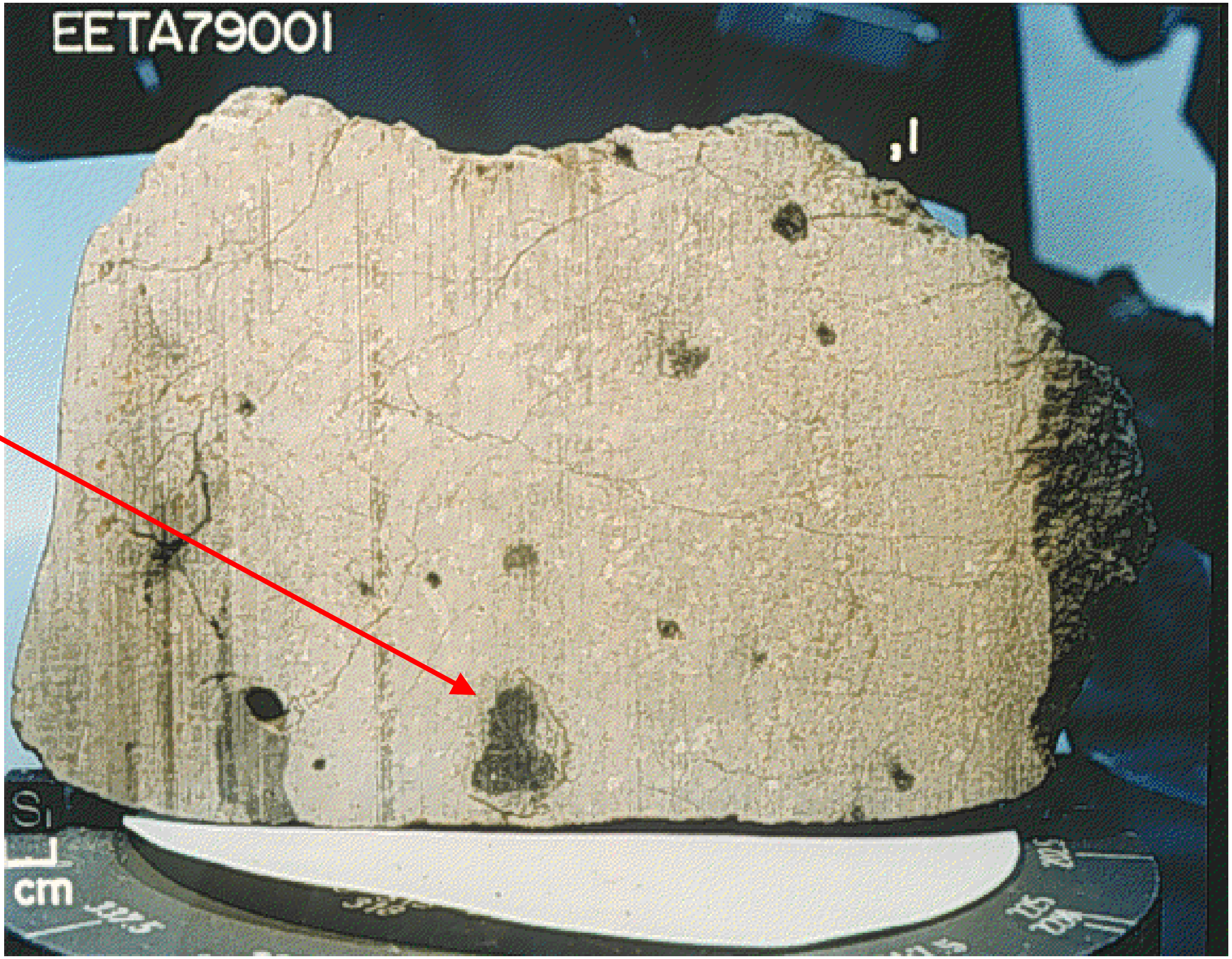

olivine/
pyroxene
plagioclase
100
whole rock melting
basalts
ortho-
pyroxenite
80
melting
melting
Shock
pressure
(GPa)
60
dunite
mosaicism
maskelynite
40
lherzolites
planar
fractures
undulatory
extinction
20
irregular
fractures
irregular
fractures
clino-
pyroxenites
0
(100 GPa = 10^6 Earth atmospheres)

Crystallization ages

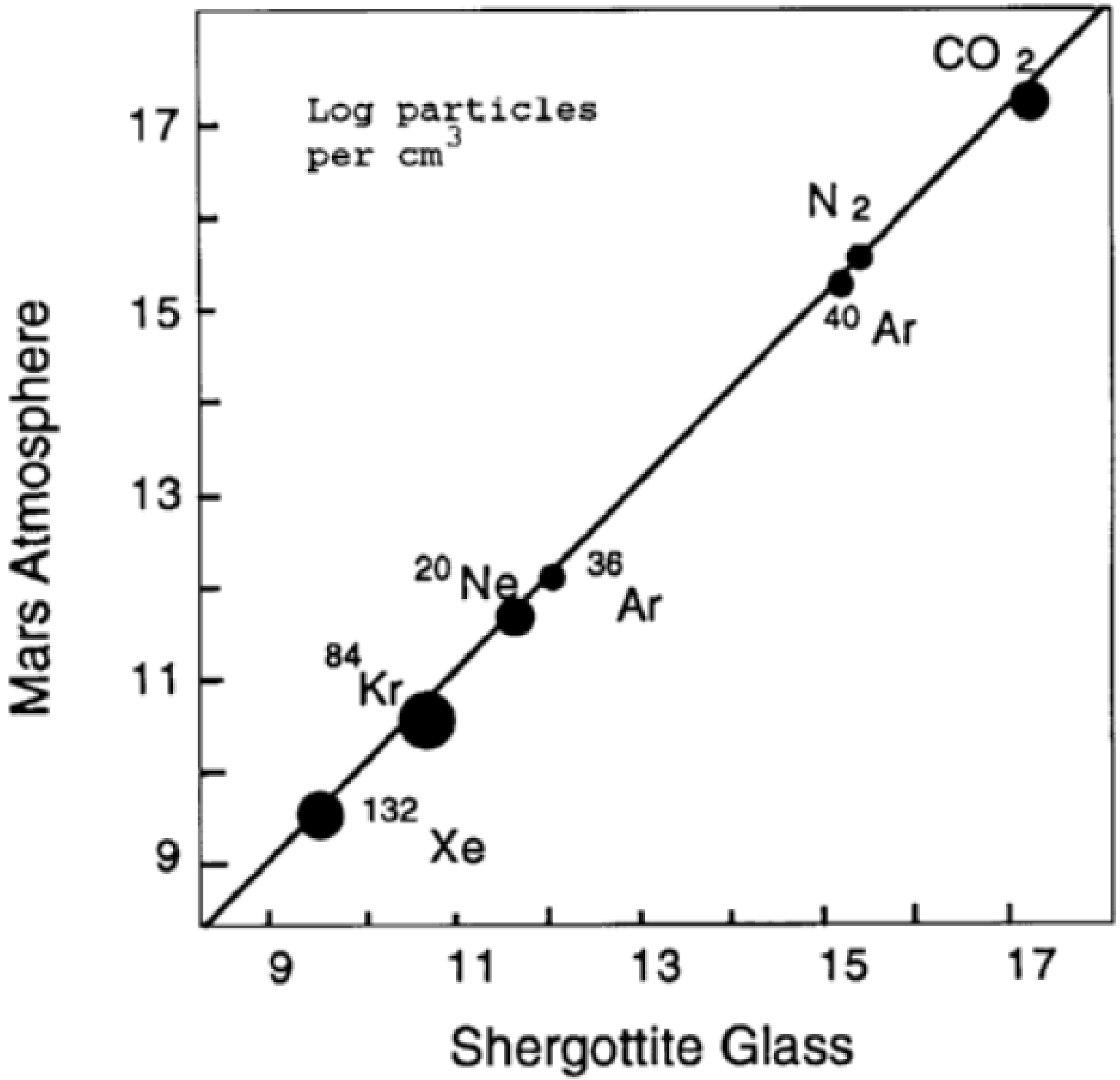


Mars Origin

Impact glass



Impact glass pockets in shergottites have gas compositions that match the Mars atmosphere composition measured by the Viking Landers.



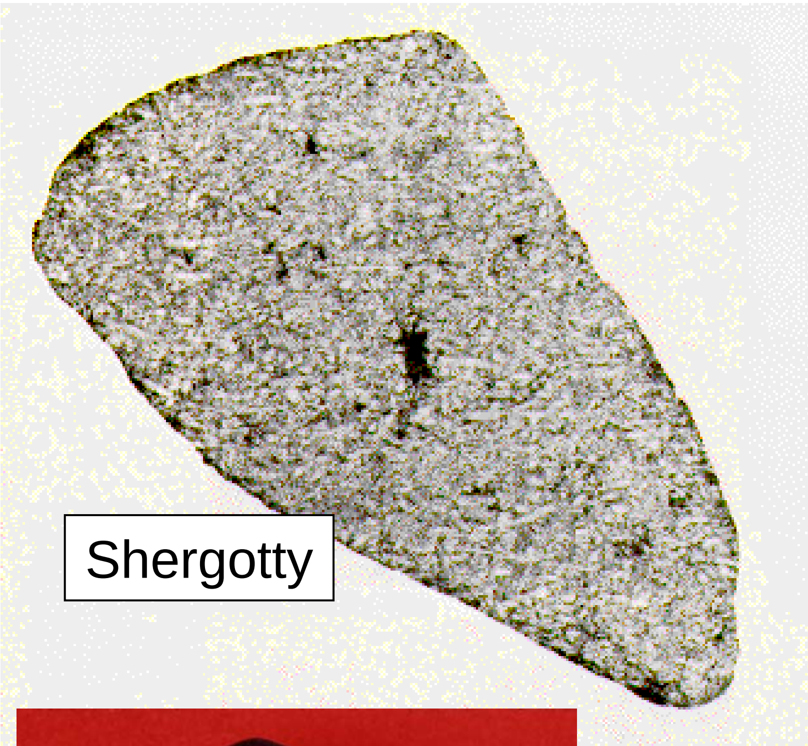
Pepin (1985)

Gas abundances match; Isotope ratios match

Summary

Property	Martian meteorites	Measured on Mars	Proof of Mars origin
Oxygen isotopes	$\Delta^{17}O = +0.32$ ‰	no	no
Fe/Mn in pyroxene	30 – 40	no	no
Ages	<1.3 Ga (also 4.5 Ga)	no	no
Atmospheric gases	Various	yes	yes

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

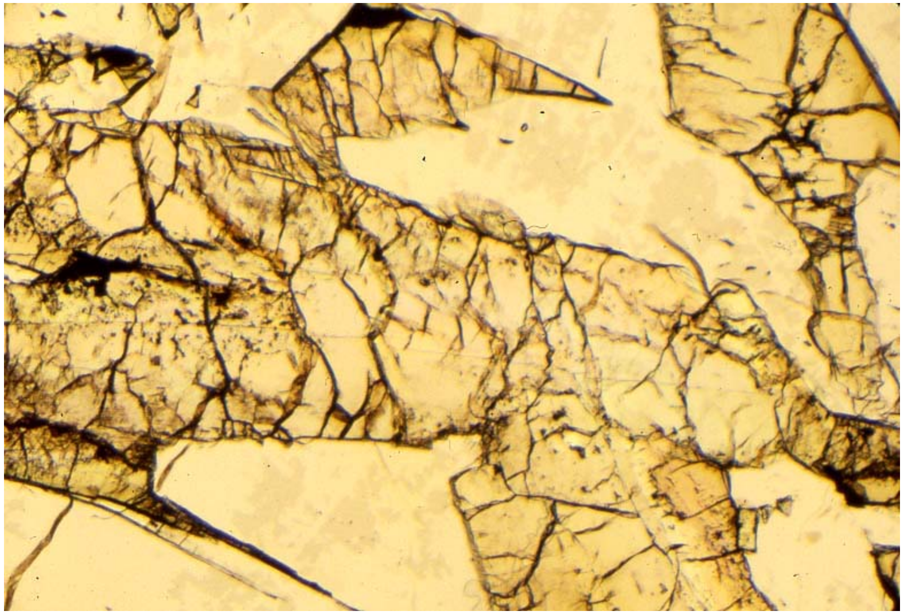
Foliated textures (alignment during extrusion).
Grain size varies from coarse (QUE) to fine (EET-A).

Shock

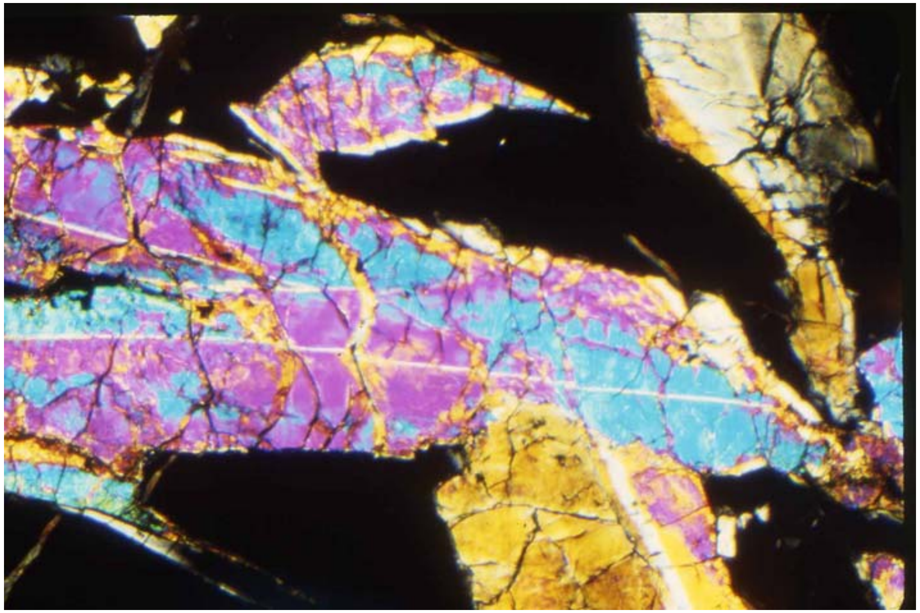
Pyroxene highly fractured.
Plagioclase typically converted to maskelynite.
Black impact melt veins visible in hand samples.

Formation

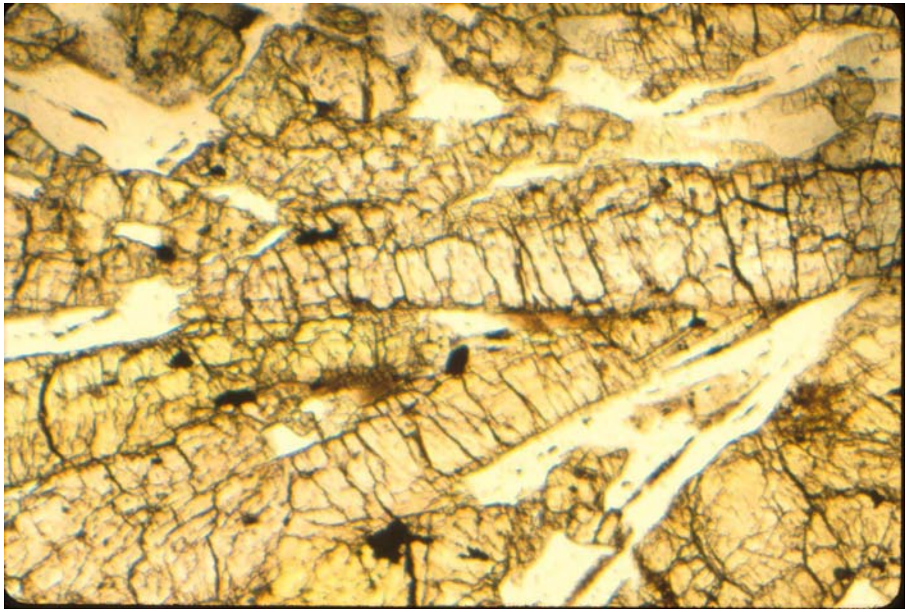
Basaltic lava flows, cooling rates (determined from pyroxene exsolution) 0.05 to 0.5 C/day.
Zoning in pyroxenes shows complicated crystallization paths.



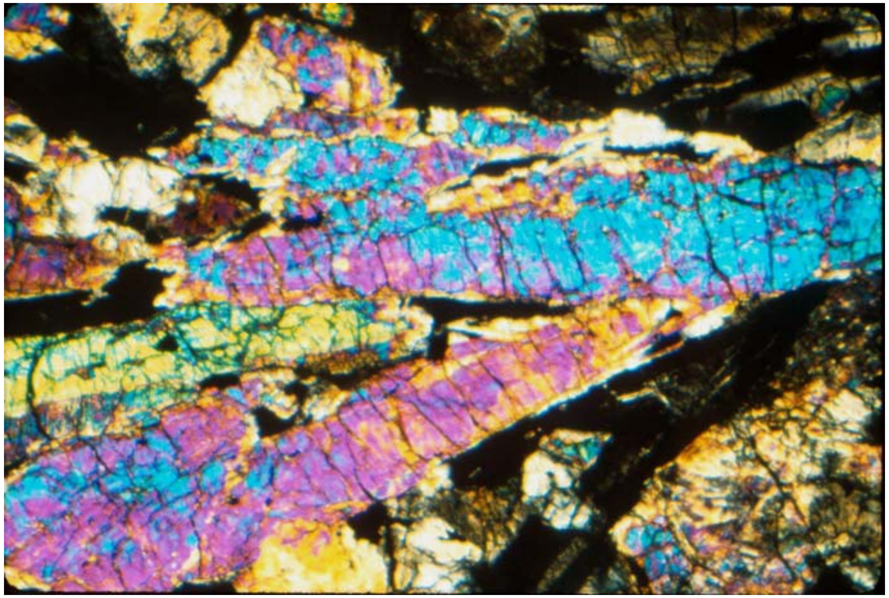
2mm Pyroxene / maskelynite / oxides



QUE94201

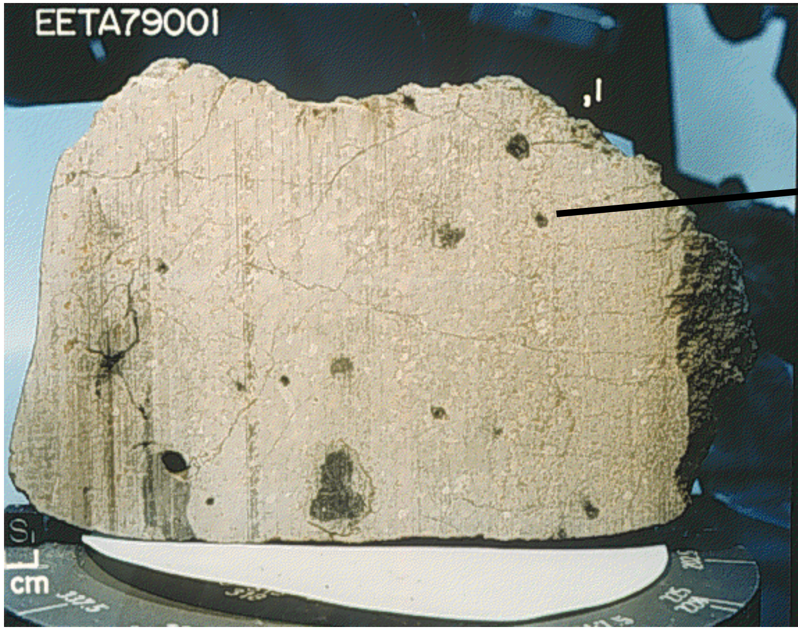


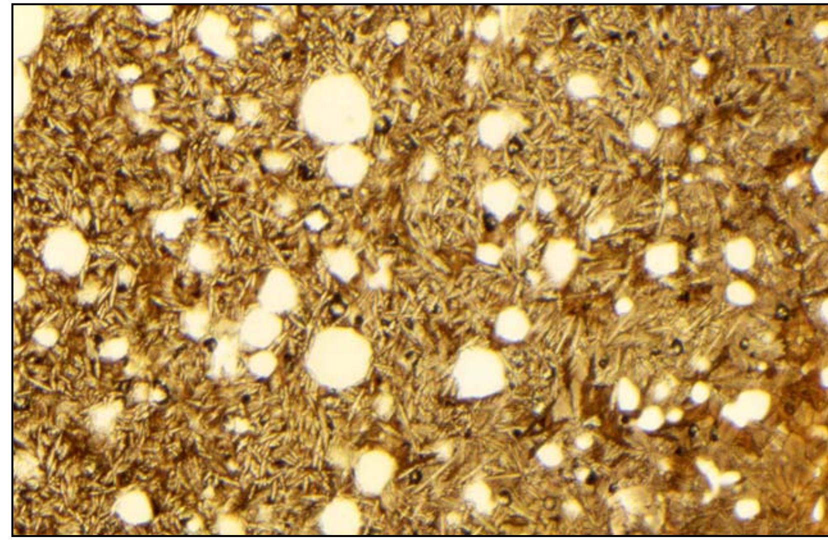
2mm Pyroxene / maskelynite / oxides



Zagami

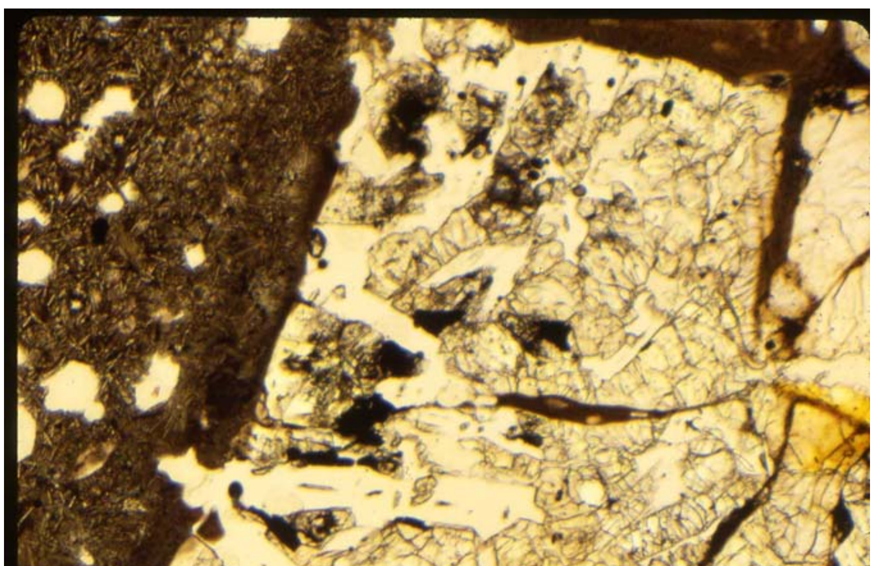
Shock features

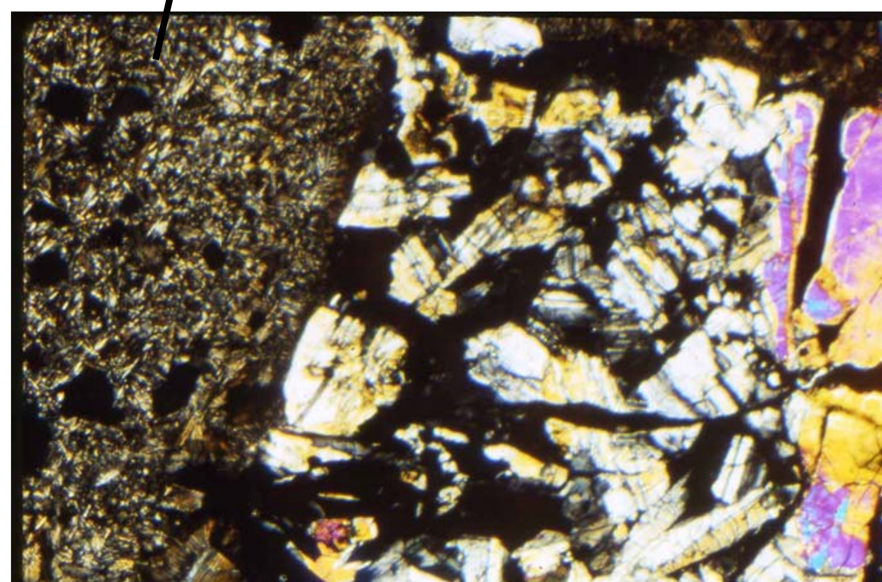




Impact melt pocket
(lithology C)

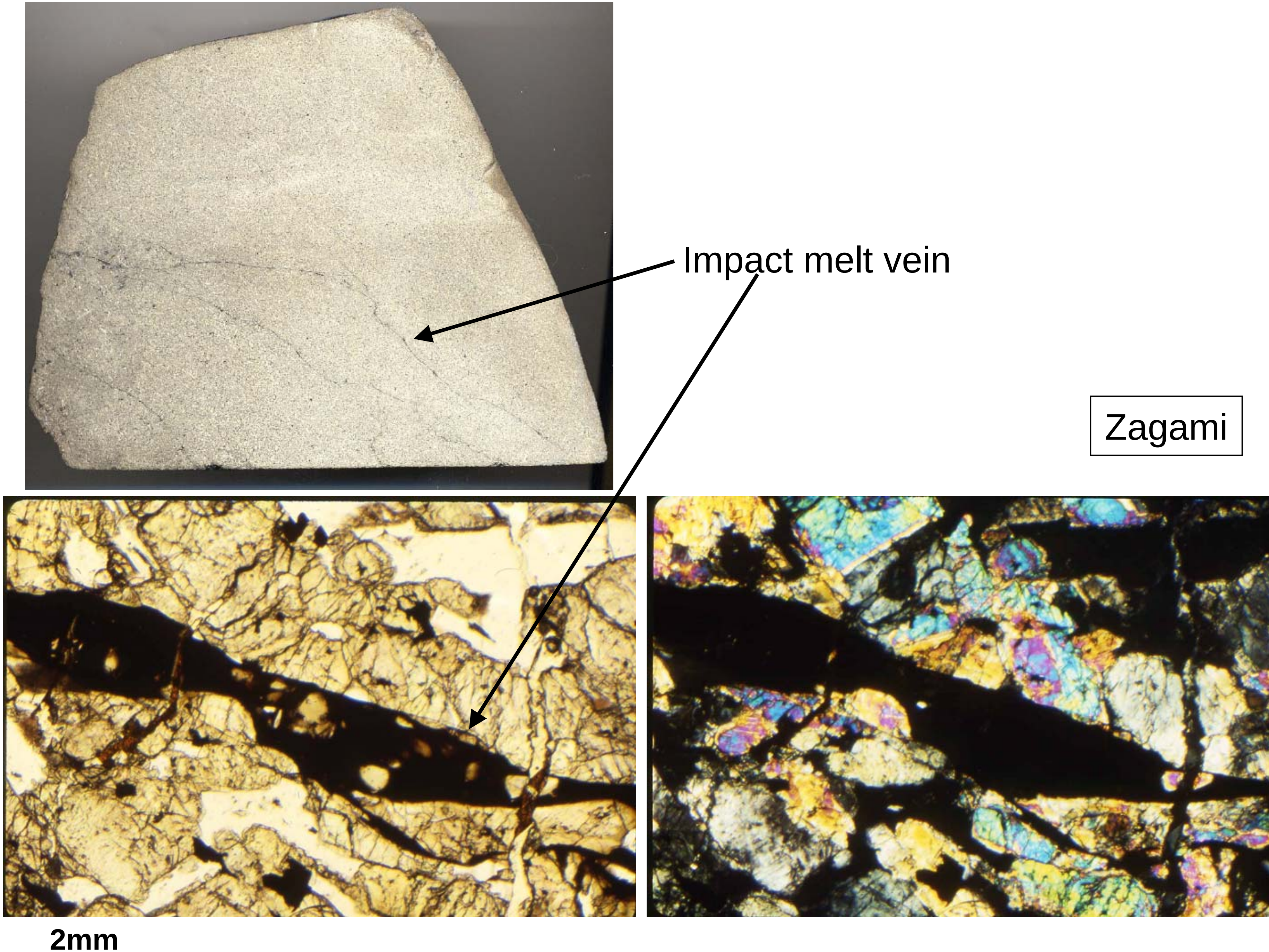
2mm





2mm

EETA79001


Impact melt vein
Zagami
2mm

Olivine-phyric Shergottites

Paired with Dar al Gani 476

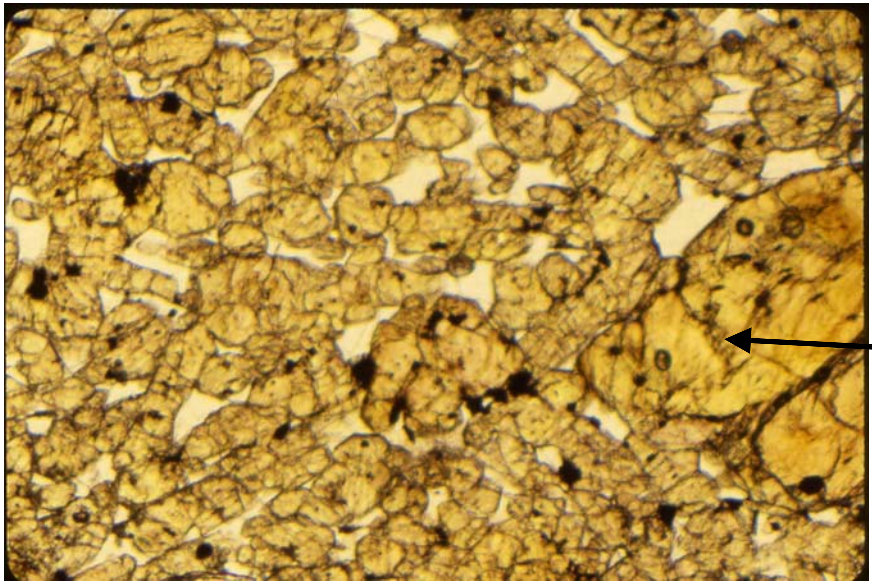
SaU 005

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

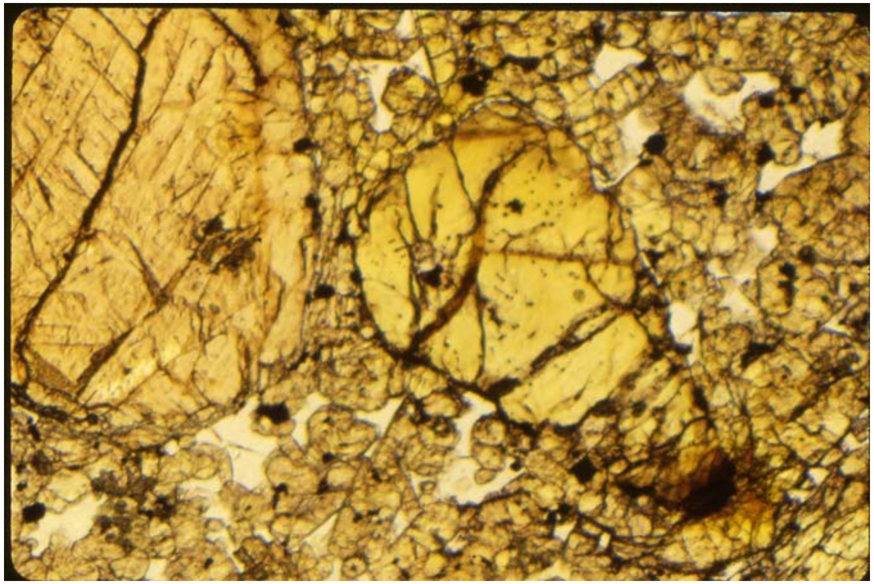
Characteristics

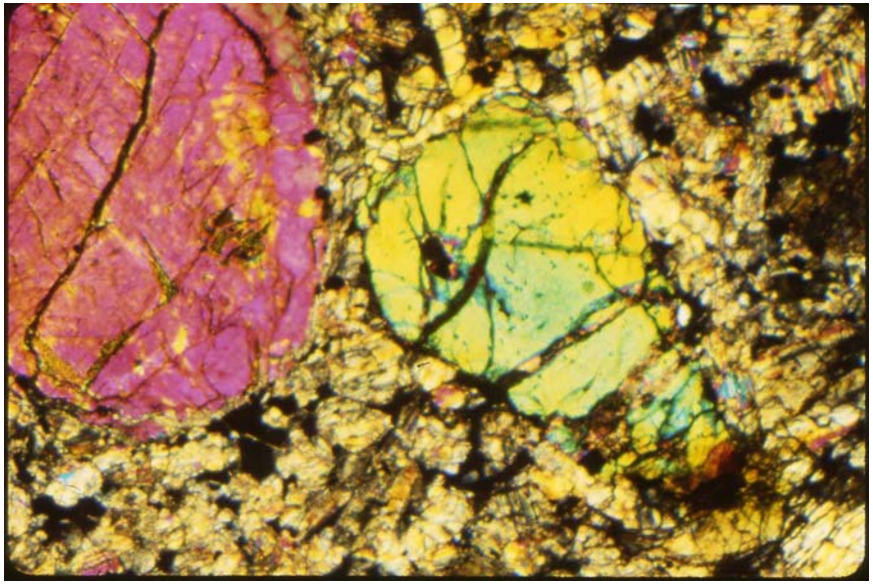
Shock
Same as basaltic shergottites.

Formation
Similar to basaltic shergottites. Xenocrysts have similar compositions to the minerals of lherzolitic shergottites.



2mm



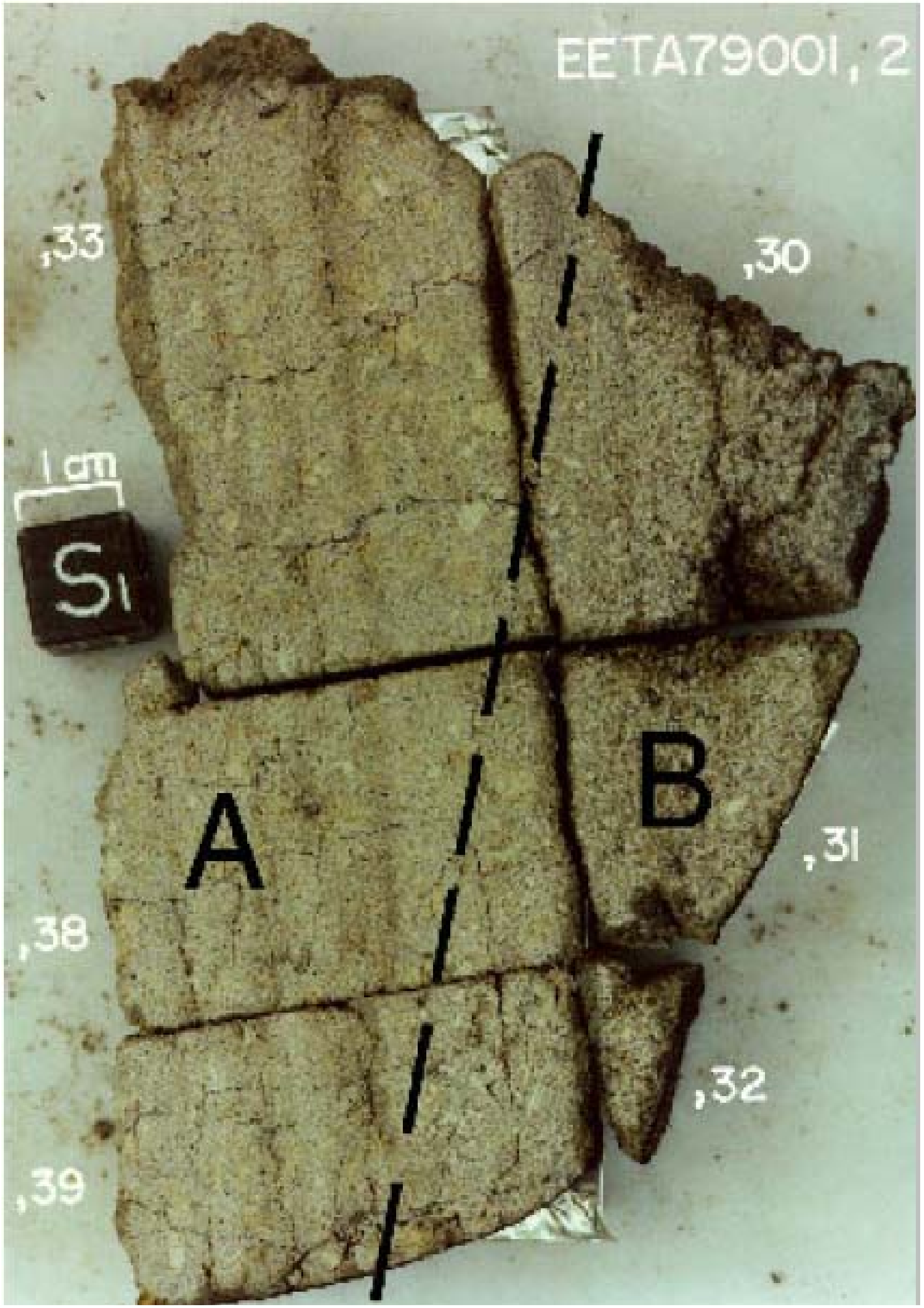


2mm

Olivine xenocrysts in pyx / mask matrix

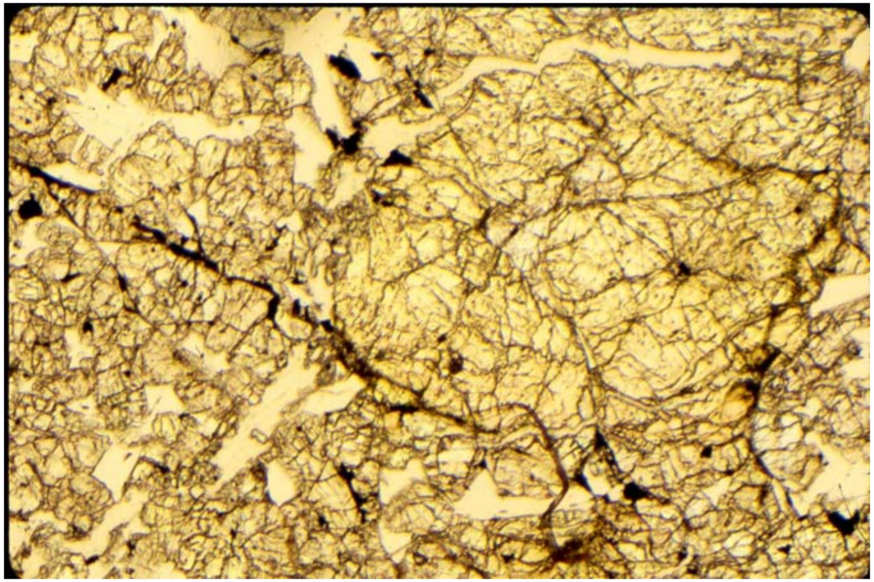
Dar al Gani 476

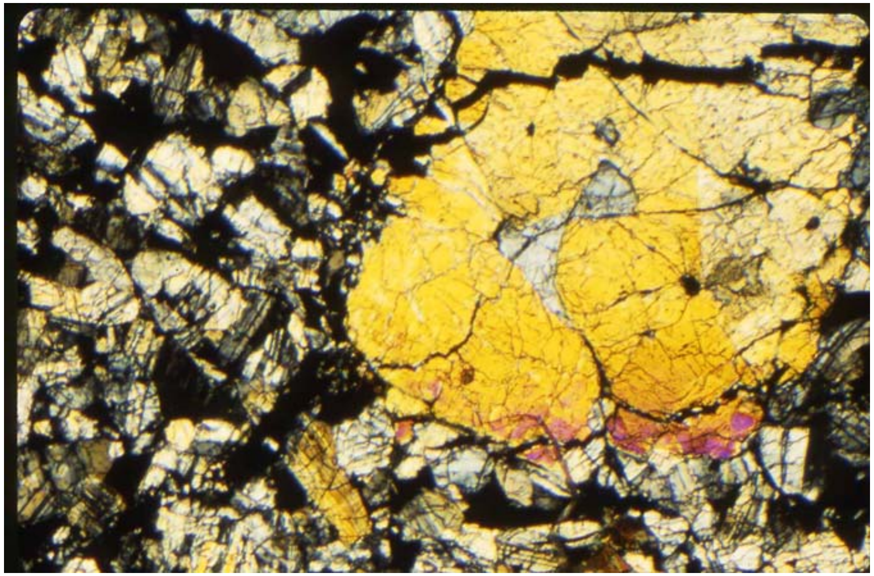
EETA79001:
A geological contact between two lithologies.



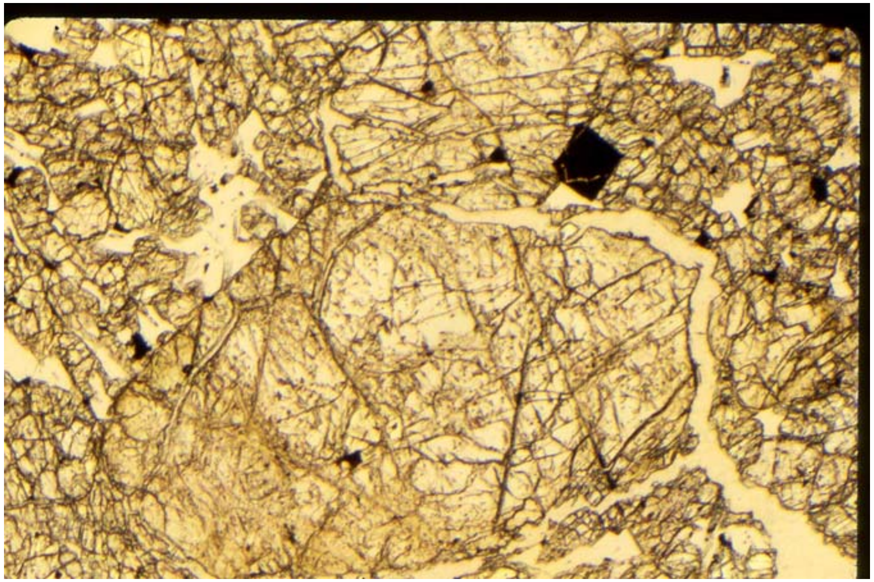
Lithology A:
olivine-phyric shergottite

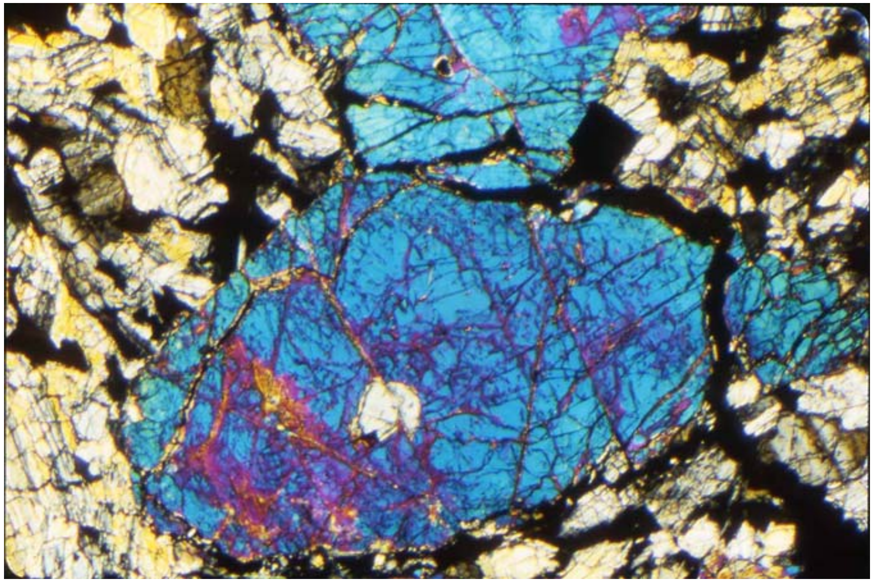
Lithology B:
basaltic shergottite





2mm





2mm **Olivine xenocrysts in pyx / mask matrix**

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

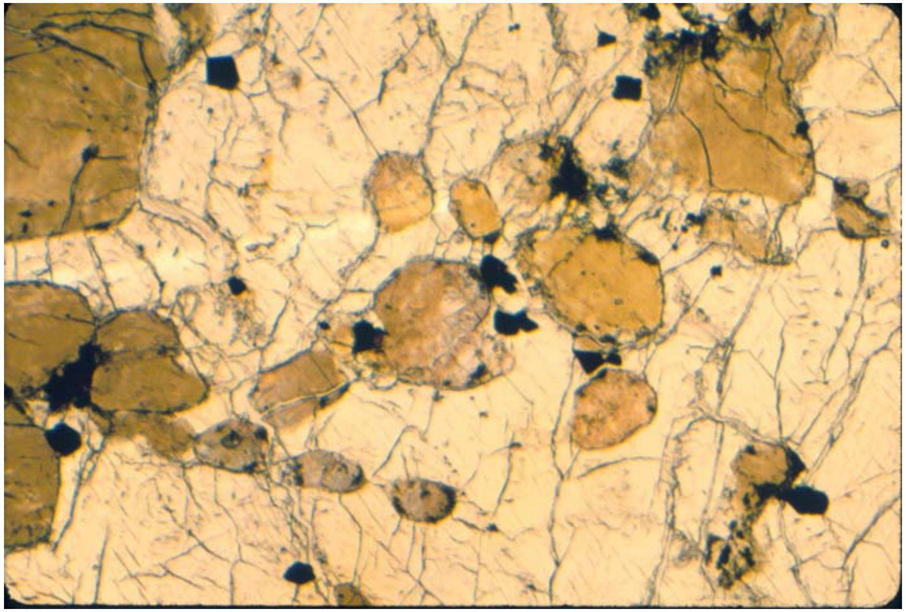
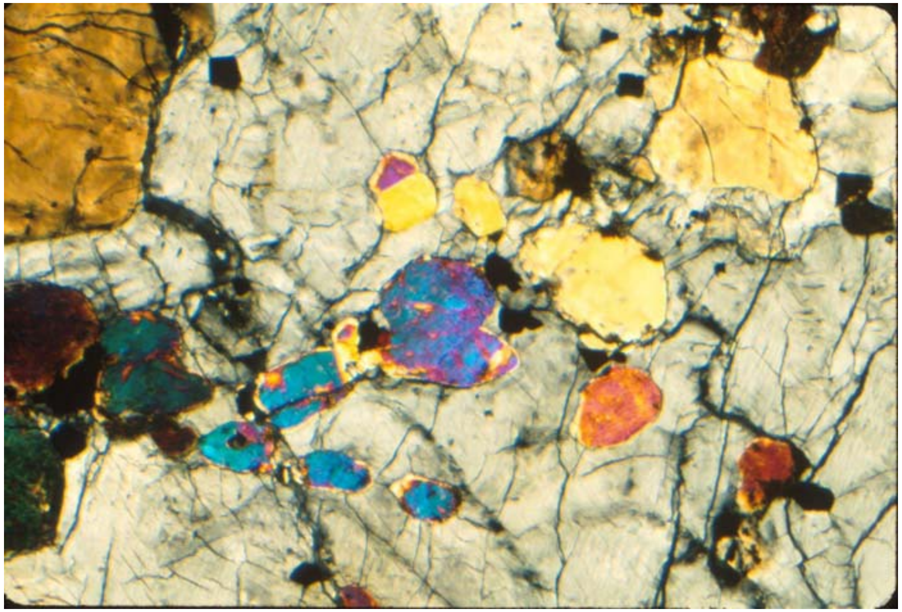
Heterogeneous rocks on the cm scale.

Shock

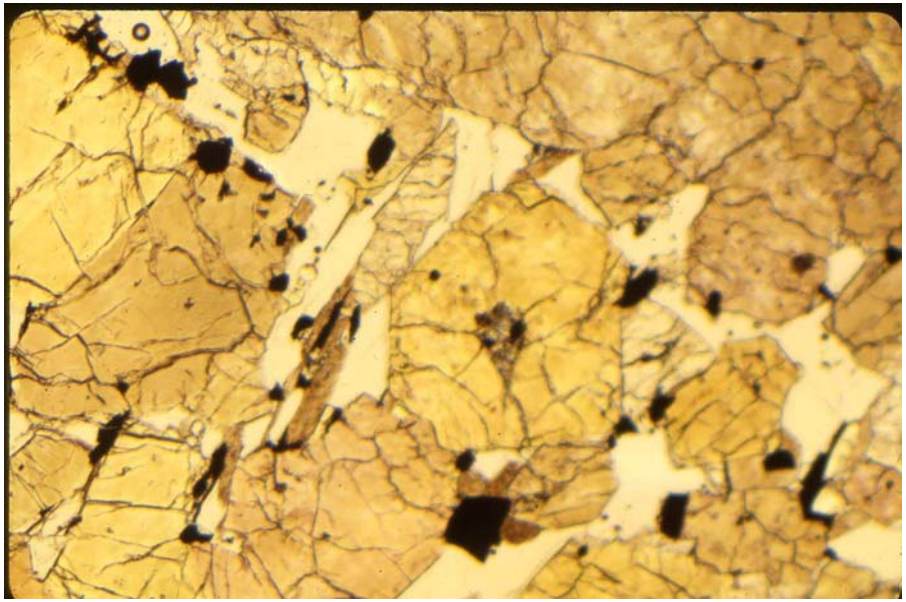
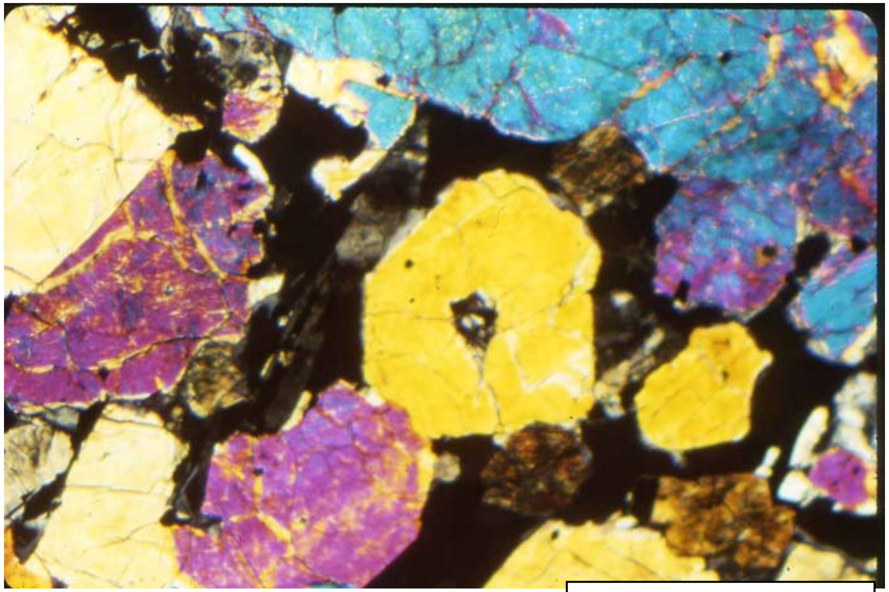
Pyroxene highly fractured.
Plagioclase typically converted to maskelynite.
Brown color in olivine is caused by oxidation (Fe^{3+}) during shock.
Pockets of impact-melted glass with skeletal olivine.

Formation

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

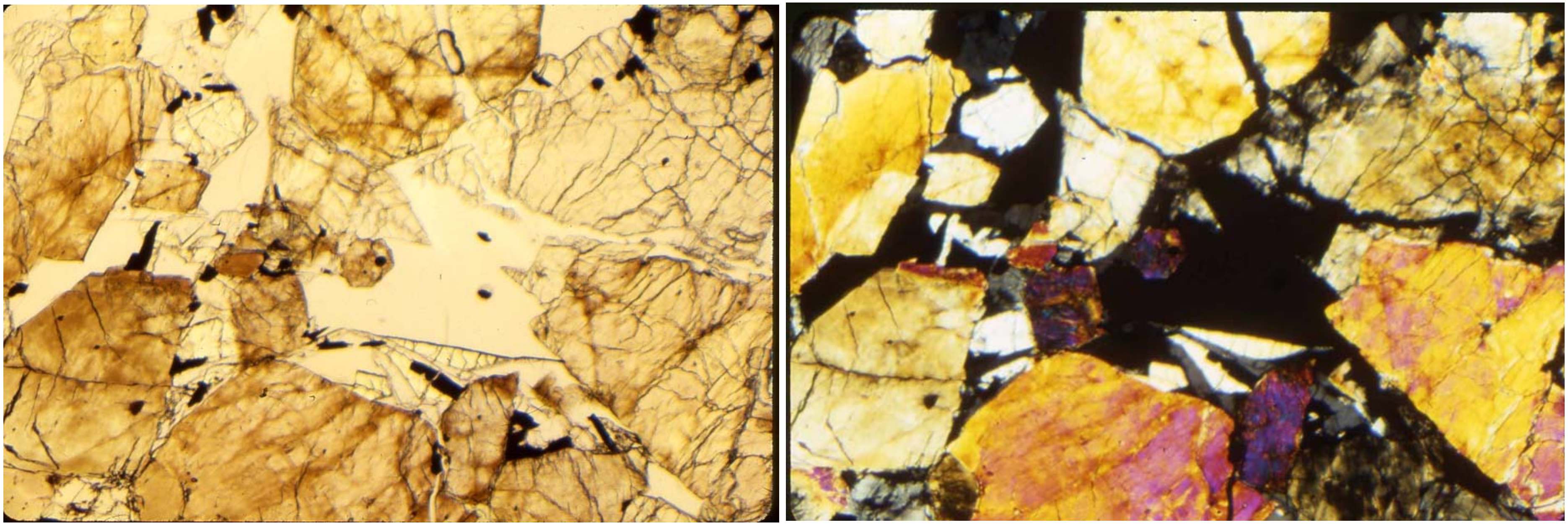
2mm **Olivine and chromite in opx**

2mm **Olivine, maskelynite, chromite, pyroxene**

ALH 77005

Note brown staining in olivine

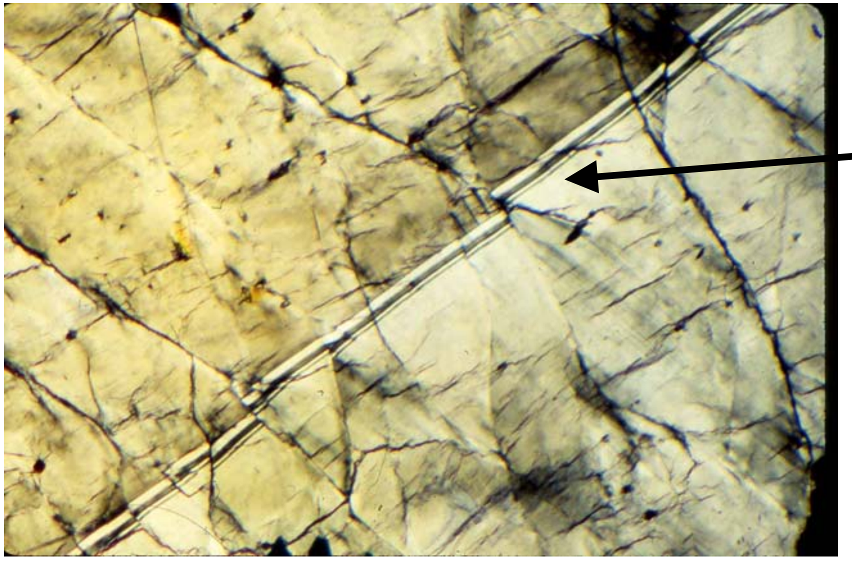


2mm

Olivine, maskelynite, chromite, pyroxene

LEW 88516

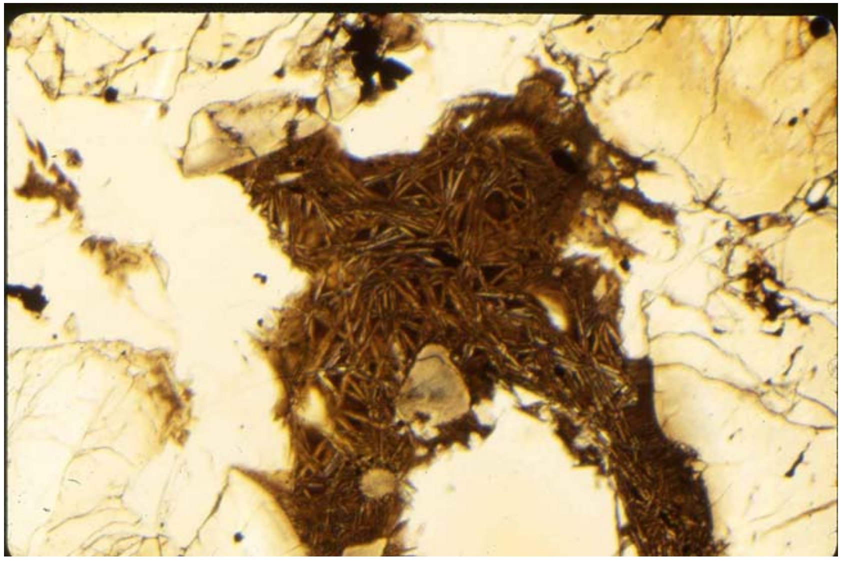
Shock features

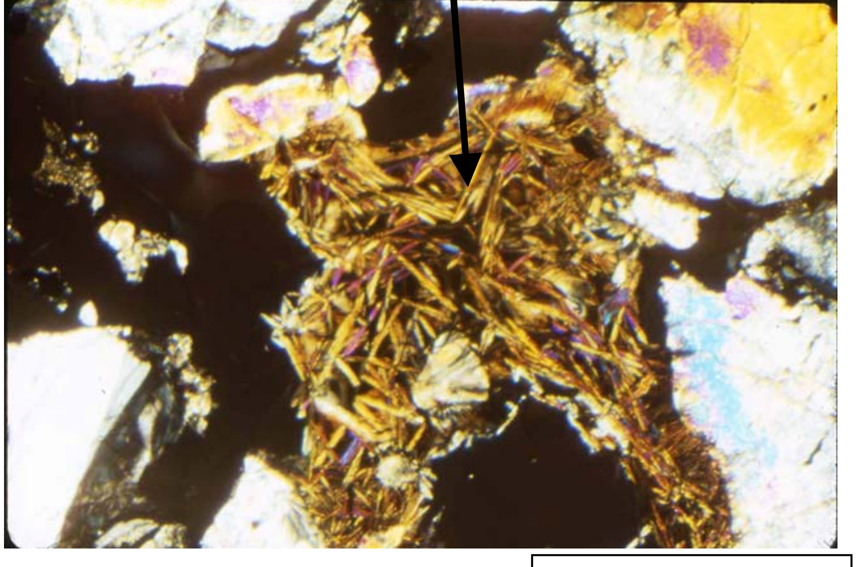


Displacement along fracture

1mm

Impact melt pocket
(skeletal olivine)





2mm

LEW 88516

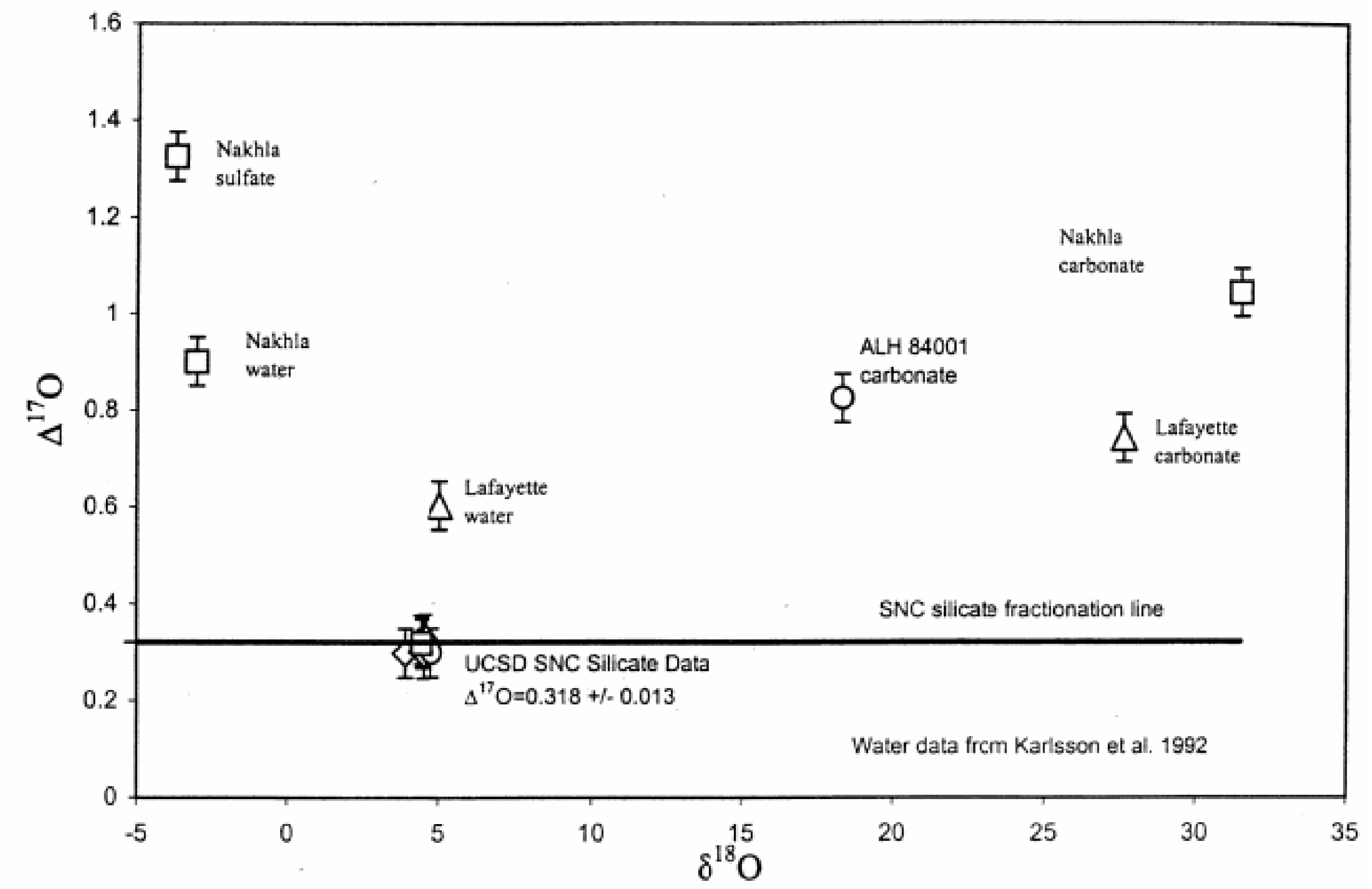
Mars Geochemistry

Information about Mars learned from martian meteorites:

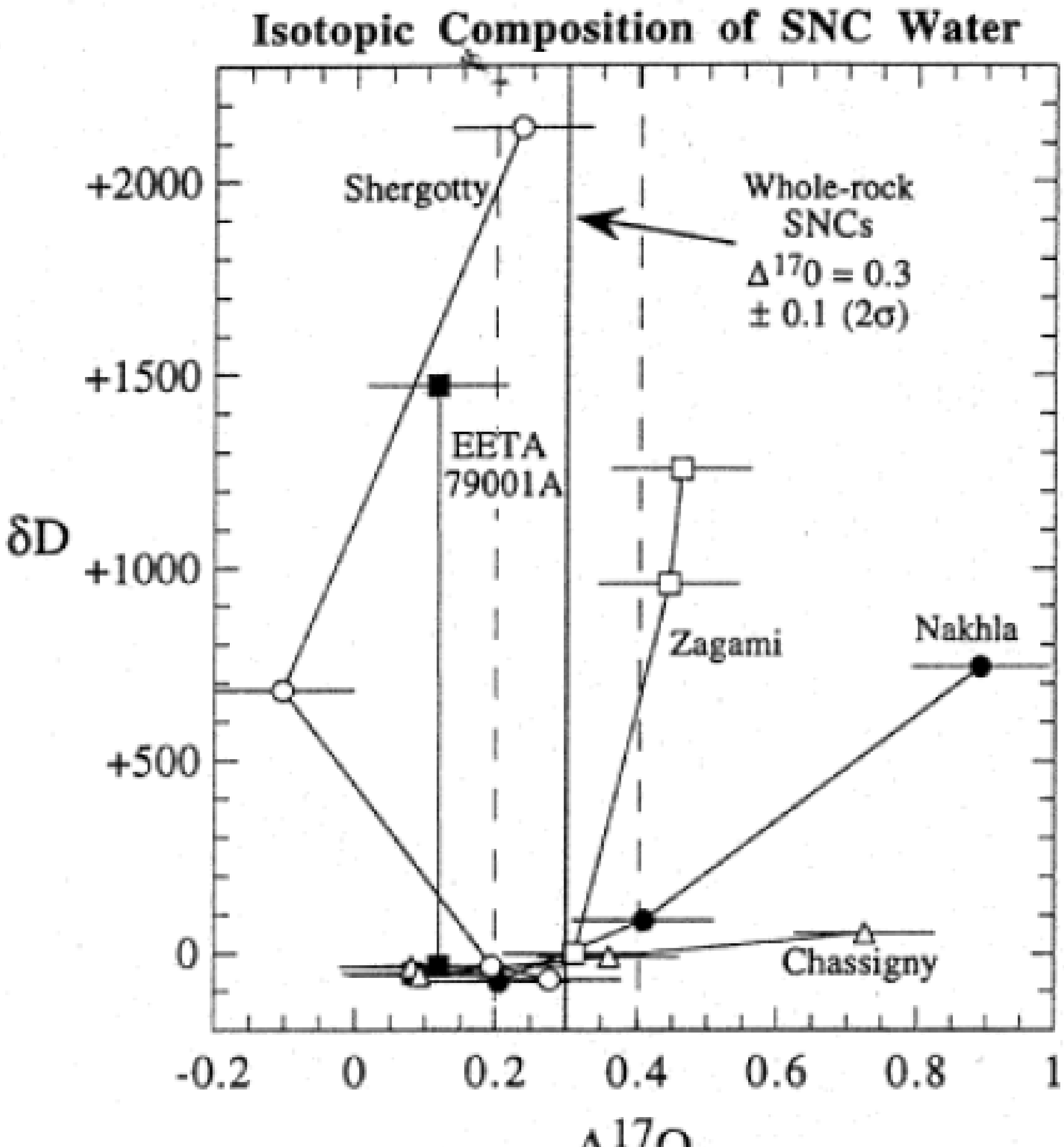
- **Atmosphere**
- **Hydrosphere**
- **Crust**
- **Mantle**
- **Core**

Atmosphere

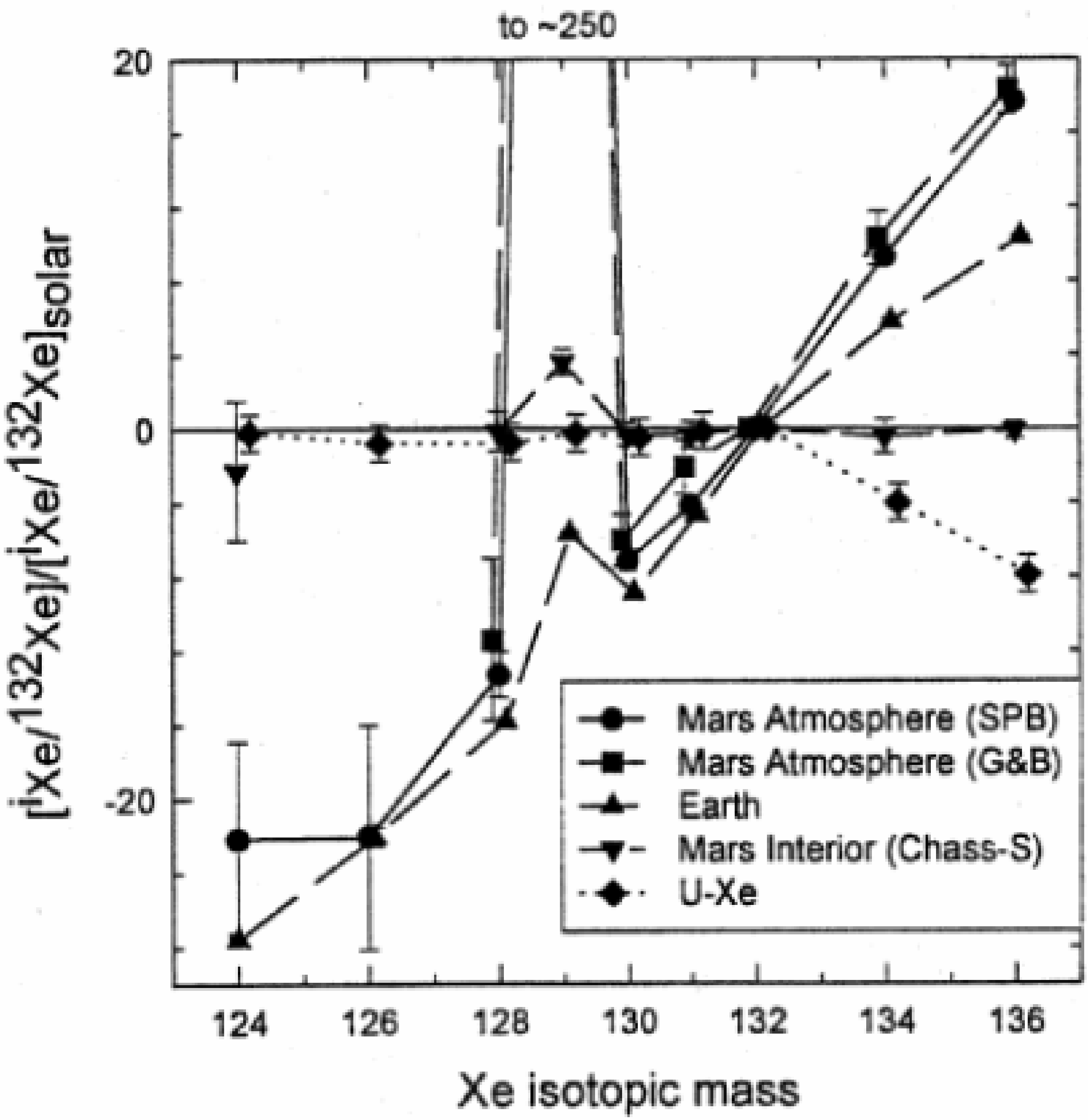
Isotopic ratios of H, N, C and O are heavy compared to Earth, due to atmospheric loss of lighter elements to space from Mars.



Water in alteration products has a component from the fractionated atmosphere.


Isotopic Composition of SNC Water
Shergotty
Whole-rock
SNCs
Δ17O = 0.3
± 0.1 (2σ)
EETA
79001A
Zagami
Nakhla
Chassigny
δD
+2000
+1500
+1000
+500
0
-0.2
0
0.2
0.4
0.6
0.8
1
Δ17O

Xe also shows mass fractionation due to atmospheric loss.



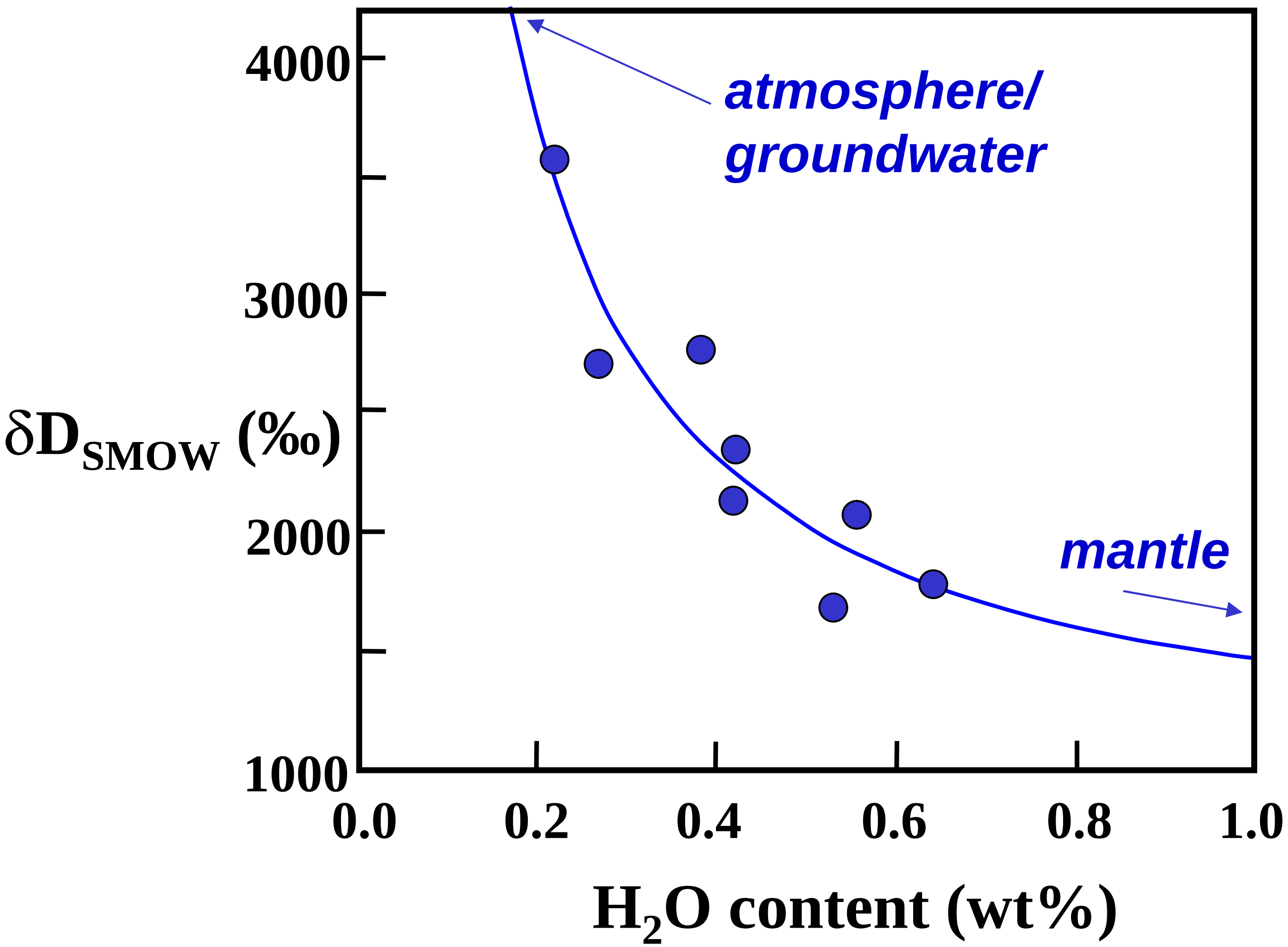
Light isotopes are like terrestrial, but heavy isotopes are more abundant.

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

Water in apatite from QUE94201



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_2O reacts with Fe to produce FeO, H_2 is lost. So the mantle is now depleted in H_2O.

Mantle has 36 – 300 ppm H_2O, depending on model.