AQUEOUS ALTERATION IN MARTIAN METEORITES: A COMPARISON BETWEEN NAKHLA AND ALH 84001

V Reunión de Ciencias Planetarias y Exploración del Sistema Solar (CPESS5)

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Mars from MGS (NASA / JPL)

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Contents

1. Introduction

1.1. Current knowledge on Mars

- Scientific interest on Mars
  - Most hospitable climate in the Solar System
    - Mean surface temperature ~ 210K
    - CO_2 atmosphere mainly
    - 1% of Earth's atmospheric pressure
  - Presence of water
    - No liquid water on surface
    - Subsurface could preserve aquifers
  - Planetary embryo
    - Ancient mineralogy preserved (Dauphas and Pourmand, 2011)

Viking (NASA)

- Space missions
  - Many difficulties
  - Sample return not achieved yet

1. Introduction

1.2. Martian meteorites

- **Typical features**
  - **Igneous achondrites**
  - **Iron rich**

- **SNC families**
  - Shergottites
    - Basaltic
    - Olivine-phyric
    - Lherzolitic
  - **Nakhlites**
  - Chassignites
  - **ALH 84001**

Mineral	**Chemical formula**
Chromite	$(Fe,Mg)Cr_2O_4$
Magnetite	$Fe^{2+}Fe^{3+}{}_2O_4$
Maskelynite	$(Ca,Na)Al(Al,Si)Si_2O_8$
Olivine	$(Mg,Fe)_2SiO_4$
Plagioclase feldspar	$(Ca,Na)Al(Al,Si)Si_2O_8$
Pyroxene	$XY(Si, Al)_2O_6$

1. Introduction

- Where

- Few launching sites
- Tharsis and Elysium-Amazonis Planitia
- Syrtis Major Planum (nakhlites and chassignites)
- Southern ancient highlands (ALH 84001)

- When

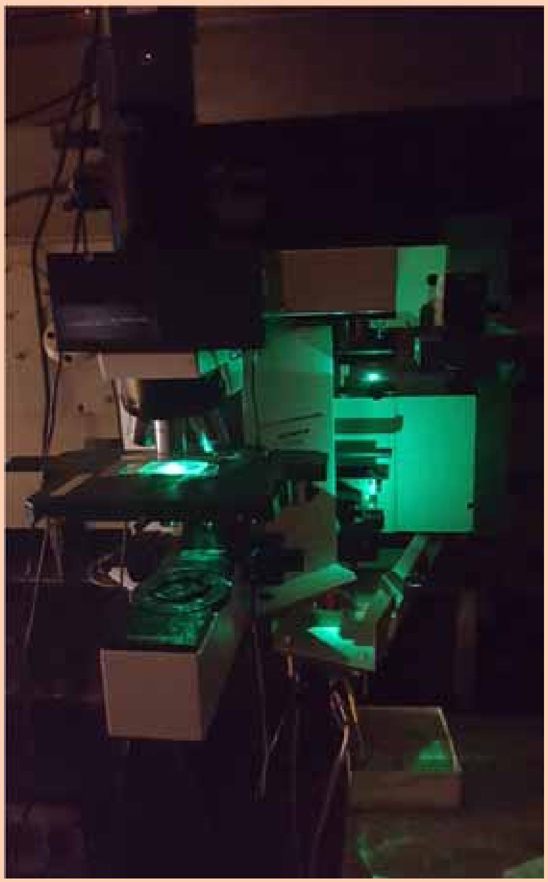
- Crystallization age (Cross-correlated isotopic systems)
    - 165 to 475 Myr (basaltic and olivine-phyric)
    - 180 Myr (lherzolitic)
    - 1300 Myr (nakhlites)
    - 1350 Myr (chassignites)
    - 4100 Myr (ALH 84001)

- Ejection age: 7 groups (terrestrial age + CREAs)
    - 20 Myr: 1 basaltic shergottite
    - 15 Myr: ALH 84001
    - 11 Myr: Nakhlites and probably chassignites
    - 4.5 Myr: 2 lherzolitic plus 3 basaltic shergottites
    - 3 Myr: 4 basaltic plus 1 lherzolitic shergottites
    - 1.3 Myr: 3 basaltic shergottites
    - 0.7 Myr: 1 lherzolitic shergottite

Fresh craters in Syrtis Major region (MGS, NASA/JPL)

2. Experimental procedure

- **Petrographic microscope:**
  - Optical microscope: RL, TL, and PL
- **Reflectance spectrometer:**
  - Reflected spectrum of the meteorite sections
  - Mineral spectra to identify the main composition
- **Raman spectrometer:**
  - Inelastic scattering of monochromatic light (514.5 nm visible laser)
  - Spectra of ROI, Comparison with mineral spectra to identify the specific minerals



2. Experimental procedure

2.2. Applications to meteorite studies

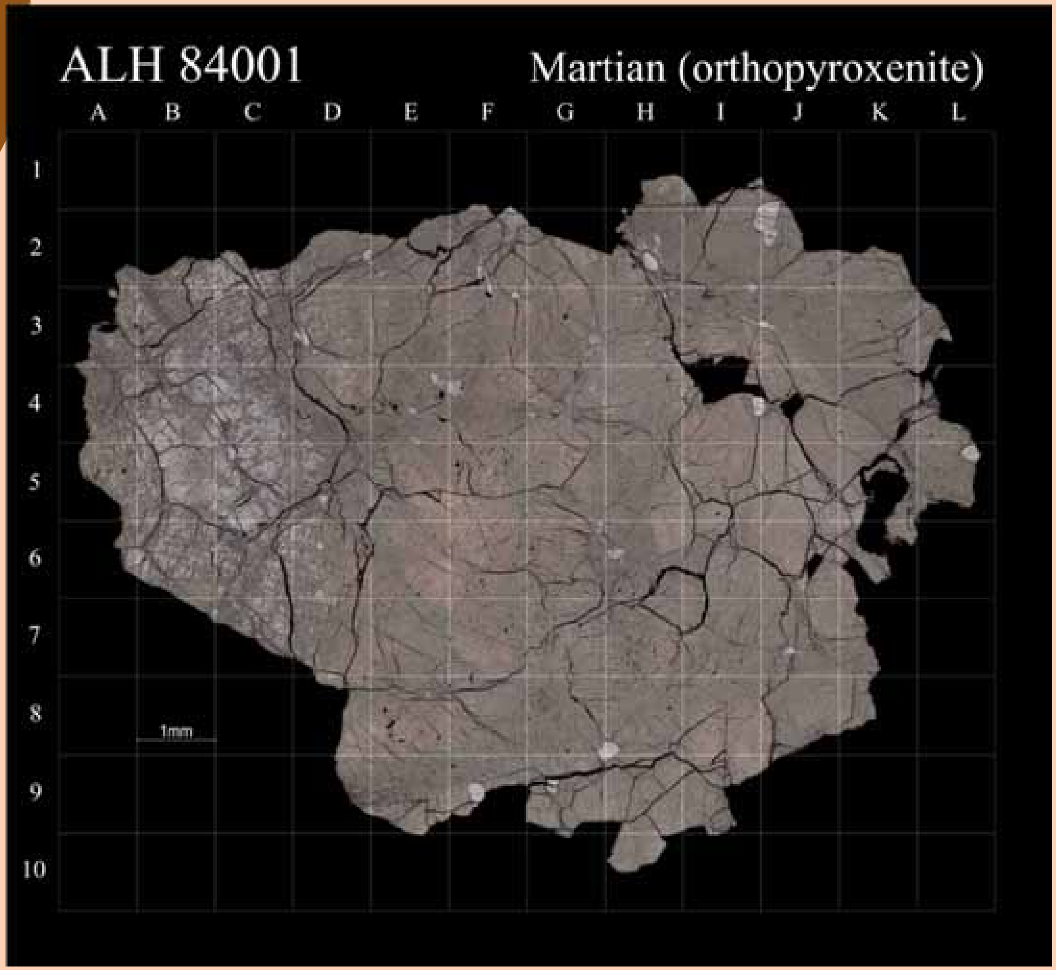
Meteorite	Class	Fall (year)	Formation age (Myr)	Ejection age (Myr)
ALH 84001	Ortho/ pyroxenite	Allan Hills, Antarctica (found 1984)	4500	16
Nakhla	Nakhlite	Egypt (1911)	1270 ± 10	10.75 ± 0.40

Type	Clinopyroxenes	Orthopyroxenes	Olivine	Plagioclase	Main Fe oxides
Nakhlites	Augite	Low	Average 10% content	Birefringent	Ti-magnetite and Ilmenite
ALH 84001	Low, augite	97%	Low	Maskelynite	Chromite

Ages from Nyquist et al, 2001

2. Experimental procedure

- ALH 84001 high resolution mosaic

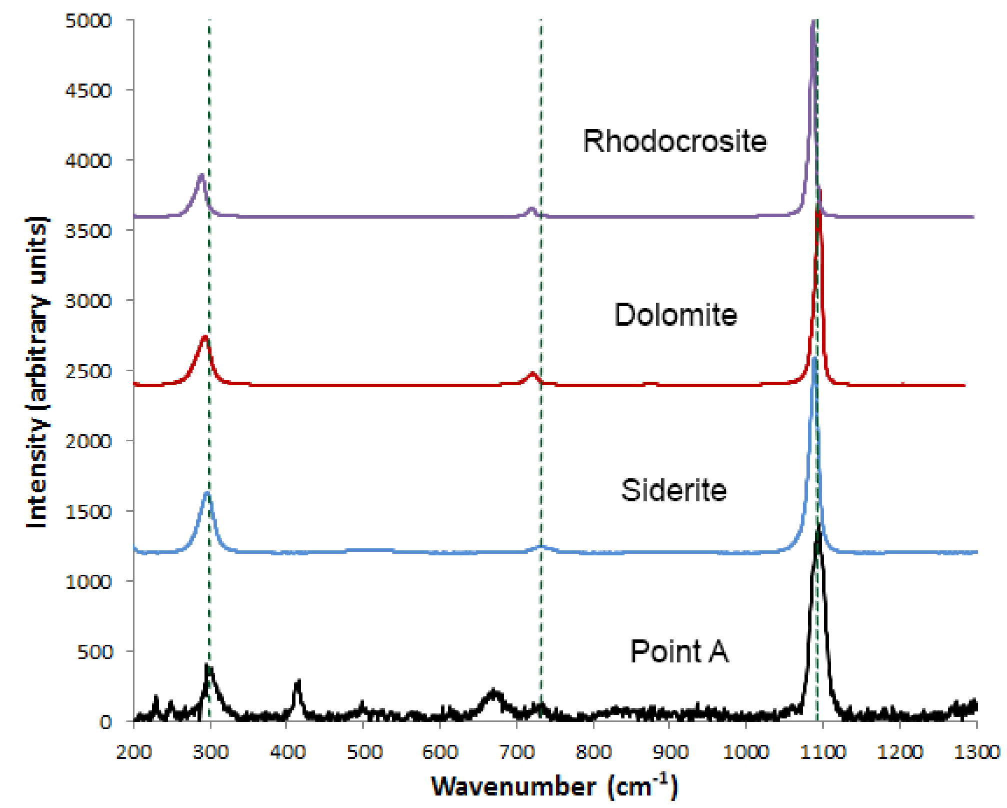


- Fe-Mg-Ca Carbonates
- Orthopyroxenes
- Suggest the presence of water in the form of a CO_2 enriched aqueous fluid

Moyano-Cambero et al, 2012b

2. Experimental procedure

- ALH 84001 Raman spectra

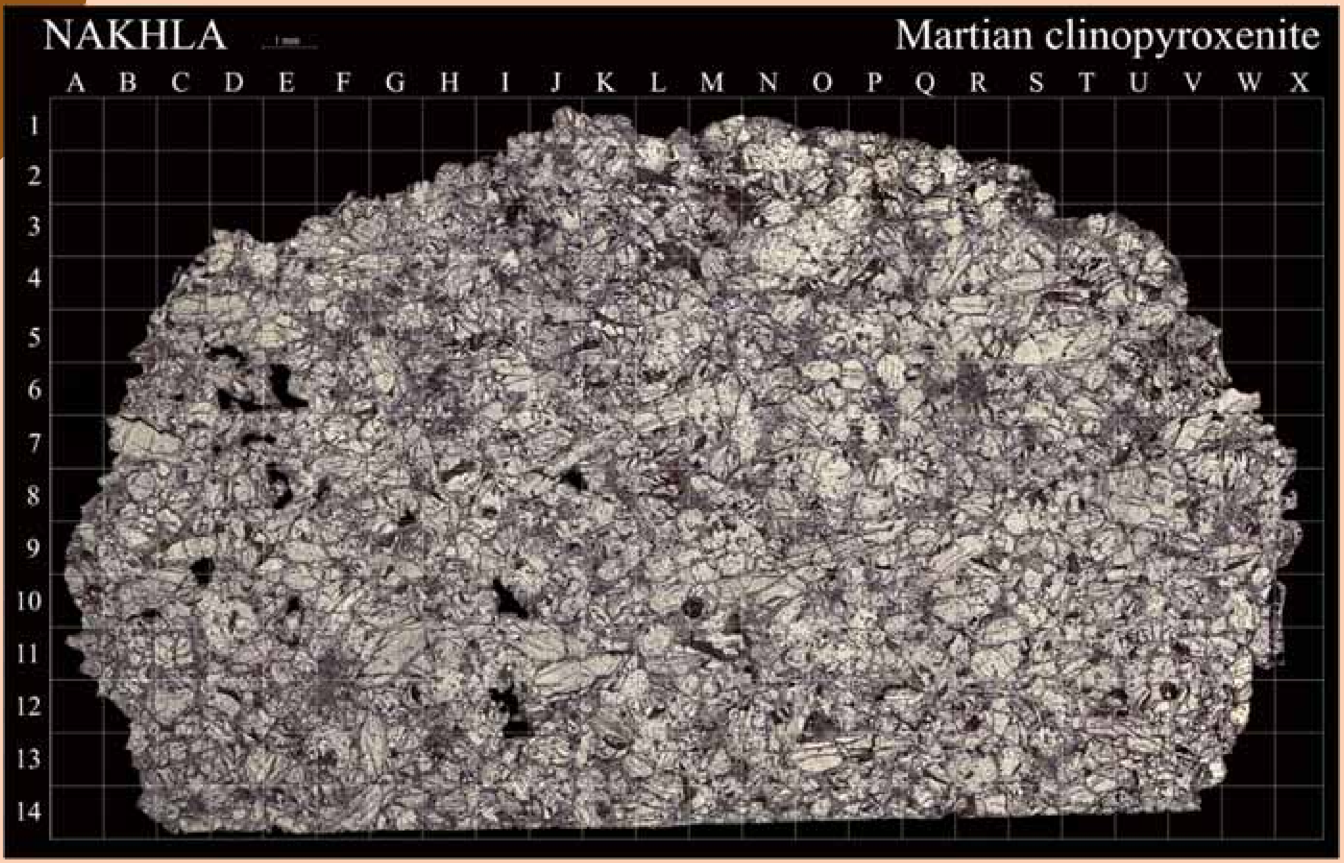


Compared to some normalized and shifted sample spectra from the RRUFF catalogue

Moyano-Cambero et al, 2012b

2. Experimental procedure

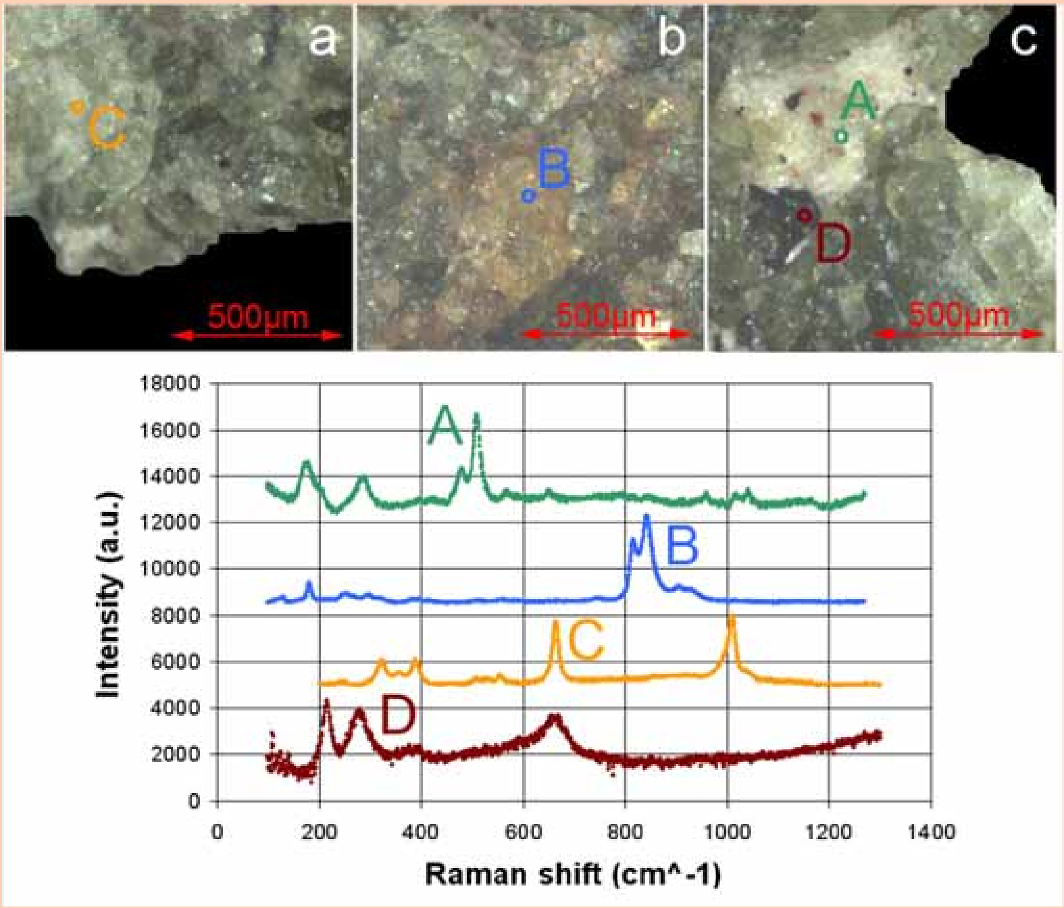
- Nakhla high resolution mosaic



- Fine and well defined grain
- Augite crystals
- Olivine crystals

2. Experimental procedure

- Nakhla Raman spectra



Moyano-Cambero et al, 2012b

- Point A corresponds to plagioclase:
  - Peak at 181 cm^{-1}
  - Peak at 292 cm^{-1}
  - Peak at 481 cm^{-1}
  - Peak at 511 cm^{-1}
- Point B corresponds to olivine
- Point C corresponds to the clinopyroxene augite
- Point D corresponds to a mixture of hematite and magnetite:
  - Peak at 217 cm^{-1}
  - Peak at 274 cm^{-1}
  - Peak at 661 cm^{-1}

3. Discussion

- Shock peak pressures

- Measured through refractive index of maskelynite

Meteorite	Peak pressure (GPa)
ALH 84001	~ 30 ± 5
Nakhla	~ 20 ± 5

Adapted from Nyquist et al, 2001

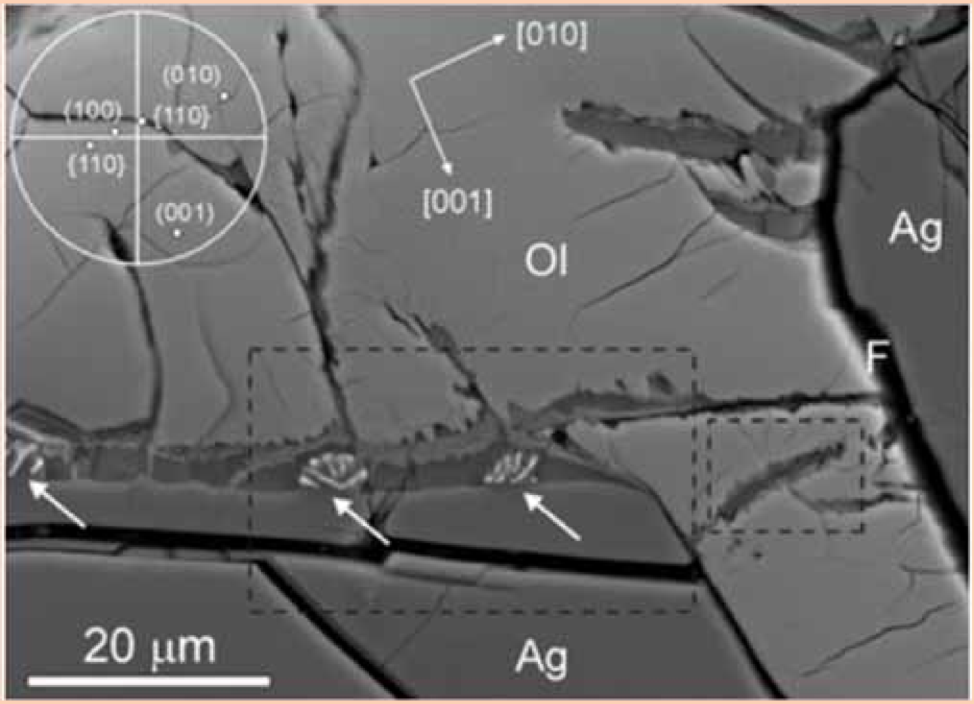
- Implications of shock pressures

- Most Martian meteorites affected by a single impact
- Lherzolitic shergottites and ALH 84001 affected by two or more
- Estimated peak shock pressures could be a defined range
- Information about the impact

3. Discussion

- Aqueous Alteration

- Silicates and others show being submerged in aqueous environment
- Filling cracks and voids in the mineral



M. R. Lee et al, 2013

4. Summary

- Martian meteorites are useful samples to understand Mars' evolution

- Clues can be obtained by using several techniques
  - High resolution mosaics: map of the section, characterization of main lithologies
  - Reflectance spectra: overview of surface composition, and albedo properties
  - Raman spectra: detailed composition

- Main mineralogy of ALH84001 and Nakhla
  - Pyroxene and olivine define the SNC meteorites
  - Evidence of aqueous alteration

- Impact-related features and degree of shock
  - Maskelynite and other shocked phases and veins are good indicators
  - Clues on shock events and parental craters

- Evidence of aqueous alteration
  - Martian magma of different crystallization ages exhibit secondary minerals

MAIN LIST OF REFERENCES

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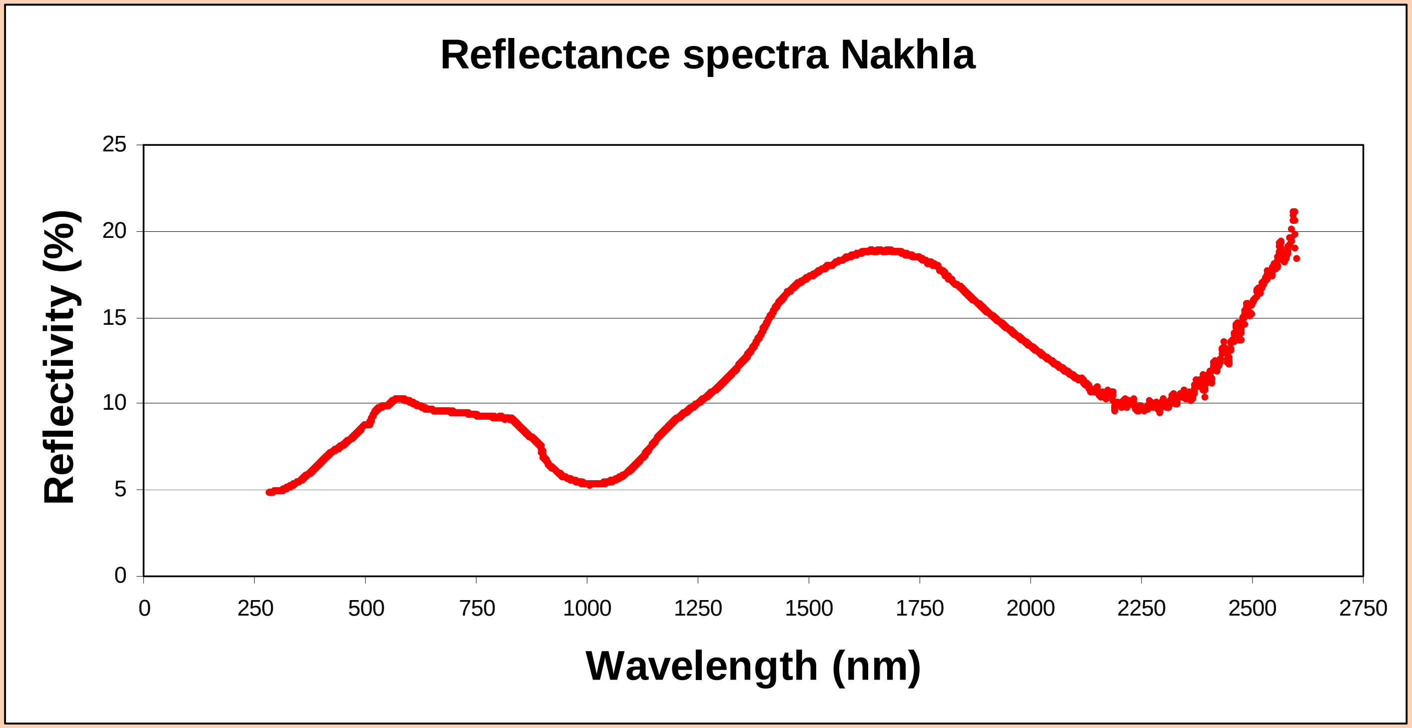
Thank You for Listening!

Back-up slides

Back-up slides

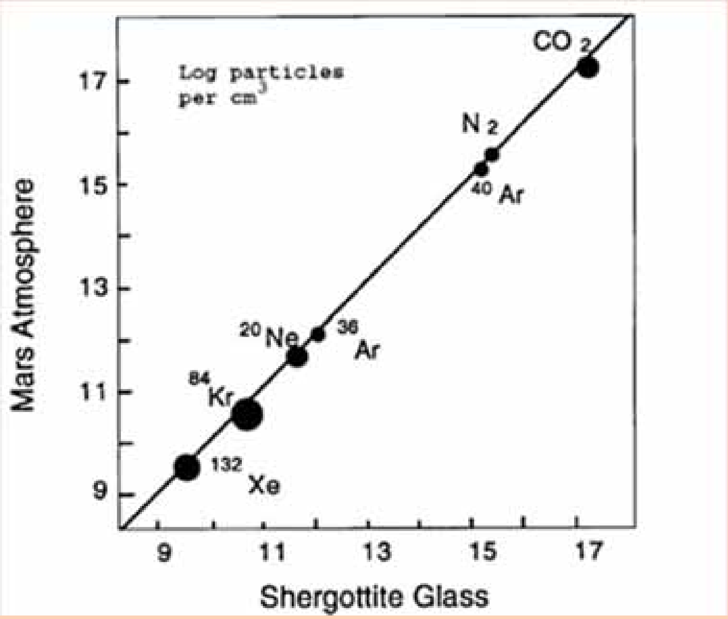
- Nakhla reflectance spectrum

- Clinopyroxene: Main absorptions around 1000 and 2200 nm
- Plagioclase: Main absorption around 1400 nm
- Olivine : Main absorption around 1000 nm



Back-up slides

- **Viking and Elephant Moraine A79001**
  - Gasses trapped within shock glass veins in EETA79001
  - Same proportion measured by Viking (Bogard and Johnson, 1983)
  - Martian meteorites are available samples from Mars



Comparison between Mars' atmosphere composition as reported by Viking and the trapped gases within shock glass veins in Elephant Moraine A79001 (Bogard and Johnson, 1983).

Back-up slides

- Geochemistry of SNC meteorites:

  - Higher Fe and lower Al_2O_3 and CaO than terrestrial igneous rocks

  - Differences between shergottites and Martian basalts

  - Discordance between shergottites and nakhlites in composition reflect different depletion histories

Element	Nakhla	ALH 84001	Earth Crust
Si (%)	22.7 ± 0.8	24.7 ± 0.1	27.7
Fe (%)	16.0 ± 1.2	13.6 ± 0.4	5.0
Mg (%)	7.3 ± 0.2	15.1 ± 0.5	2.1
Ca (%)	10.5 ± 0.5	1.3 ± 0.27	3.6
Al (%)	0.89 ± 0.11	0.68 ± 0.05	8.1