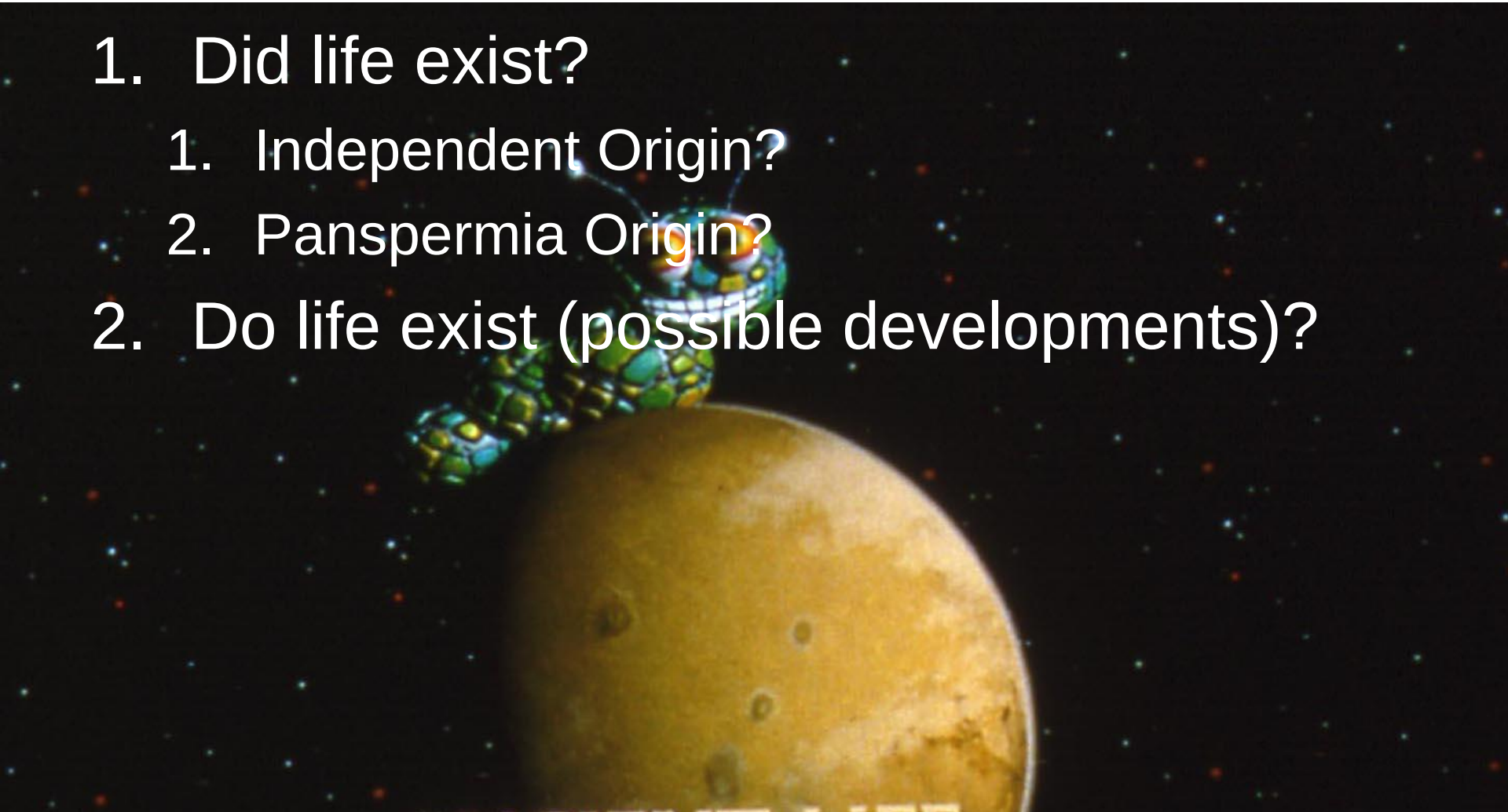
Astrobiology and Mars



1. Did life exist?
    1. Independent Origin?
    2. Panspermia Origin?
2. Do life exist (possible developments)?

Astrobiology and Mars

What directions?

1. Searching for present life
2. Searching for past life
3. Searching for habitats

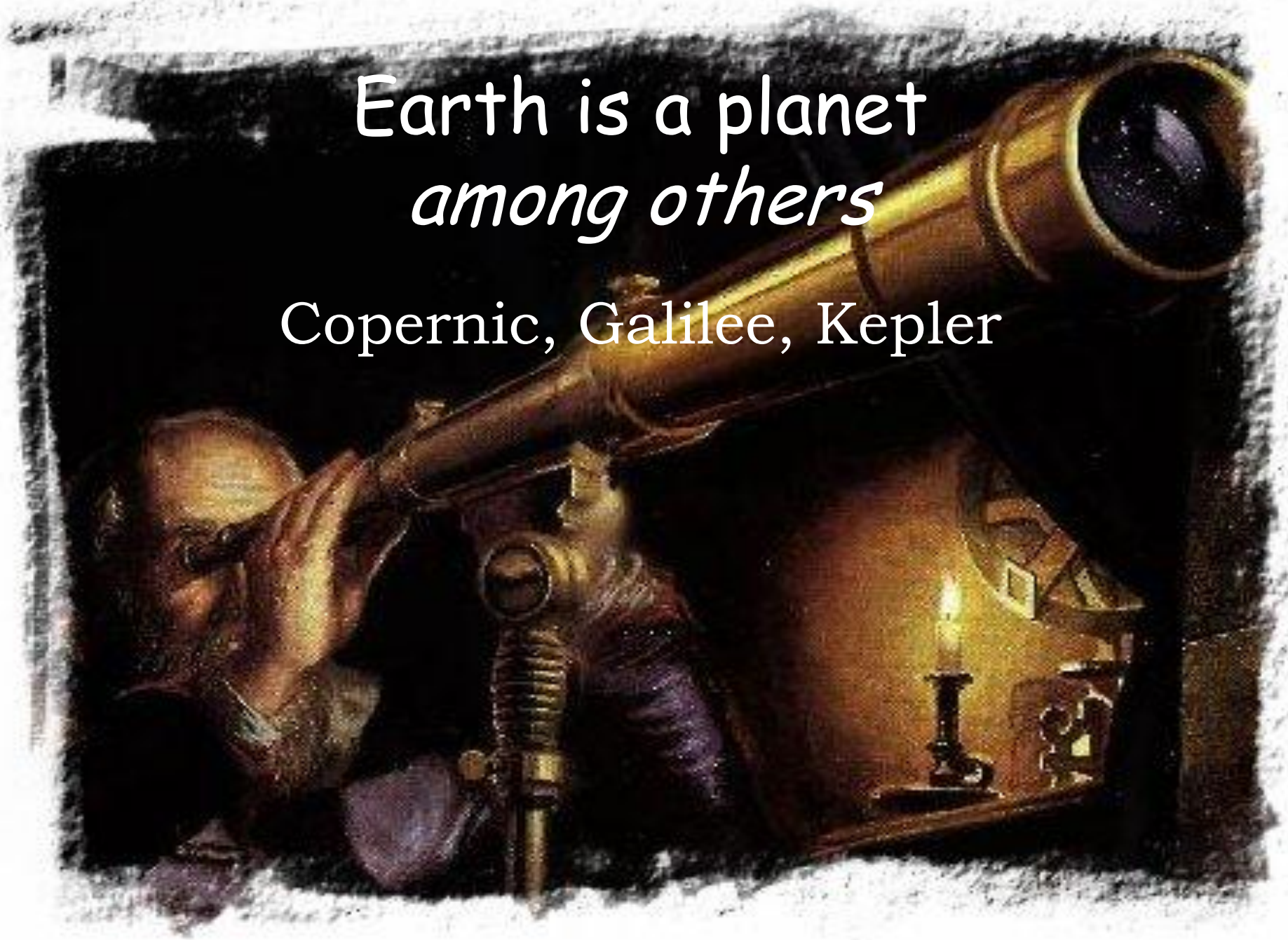
Astrobiology and Mars

What directions?

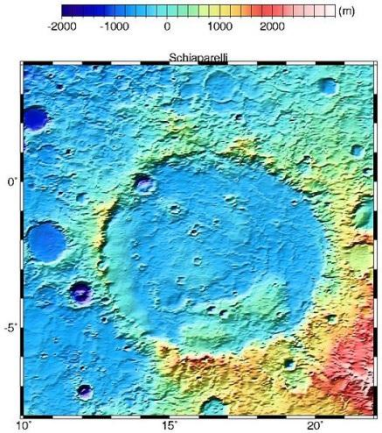
1. Searching for present life
2. Searching for past life
3. Searching for habitats

Earth is a planet *among others*

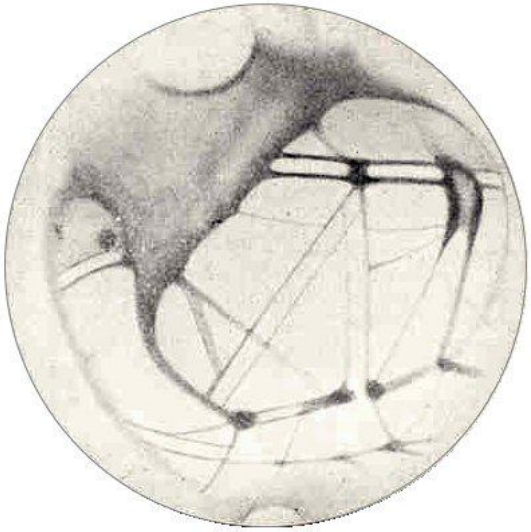
Copernic, Galilee, Kepler



THE MYTH OF MARTIAN CANALS



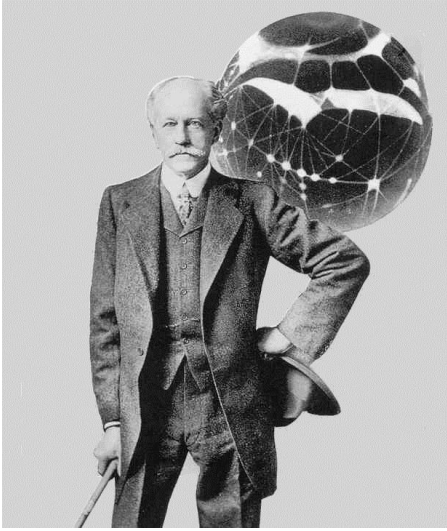
1877 : Schiaparelli's observations



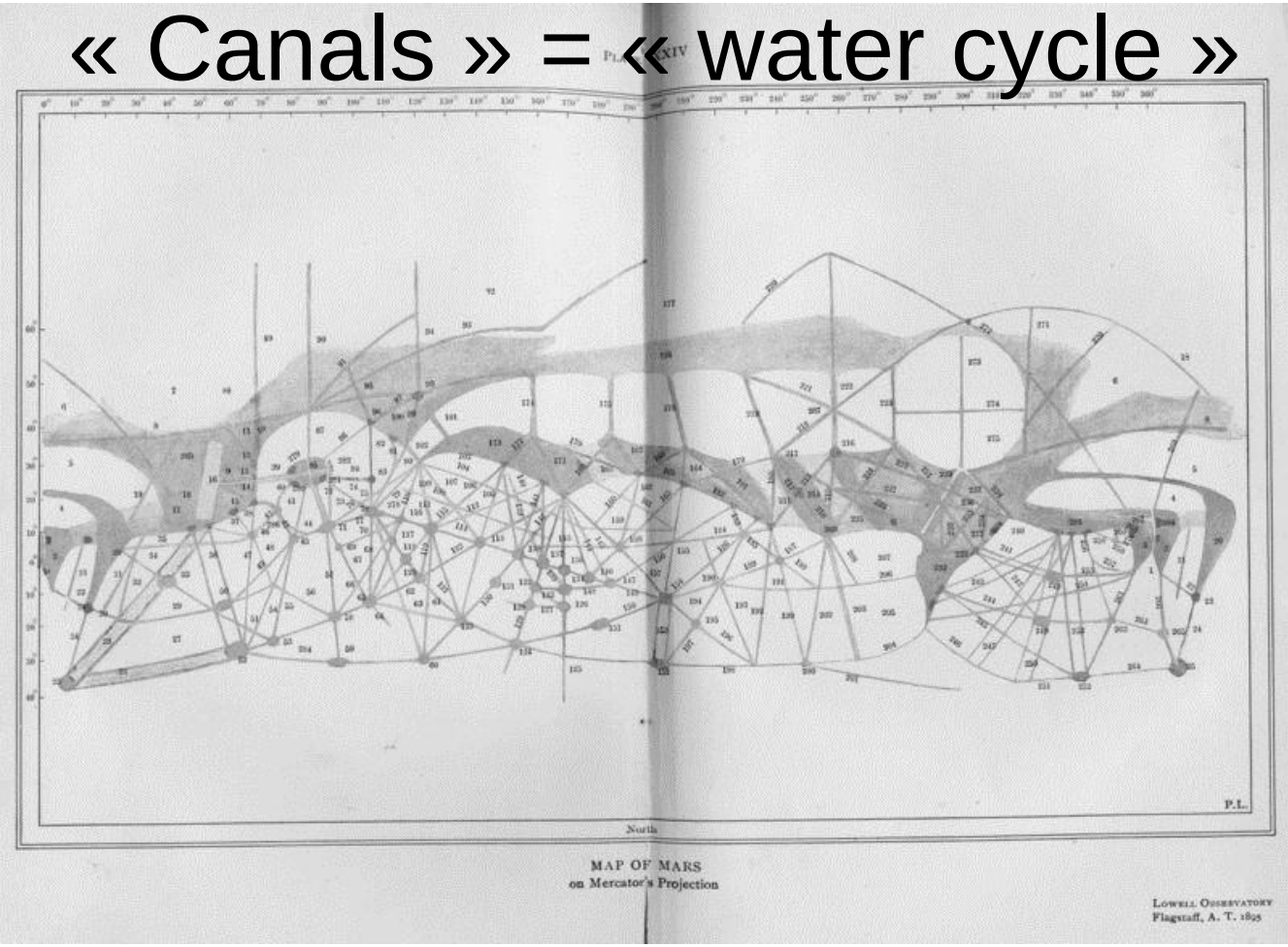
"a dense network of linear structures on the surface of Mars ("canali" in Italian)"

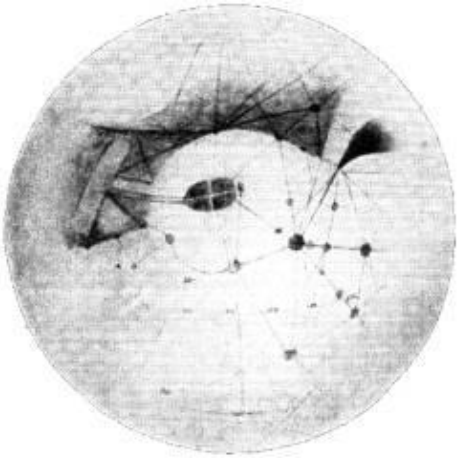
Canali mean channels but the term was mistranslated into English as "canals"

MARS SEEN BY PERCIVAL LOWELL



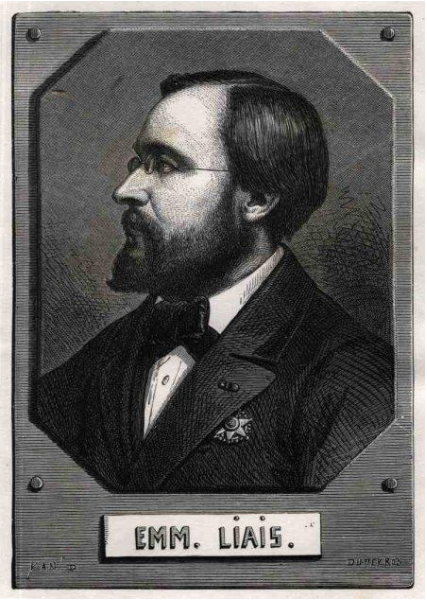
« Canals » = « water cycle »

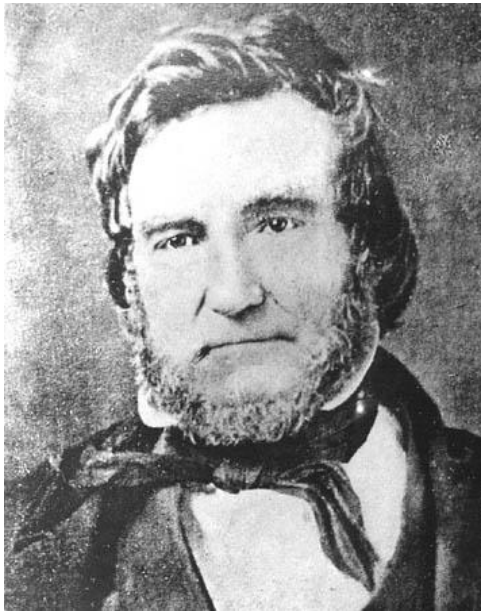


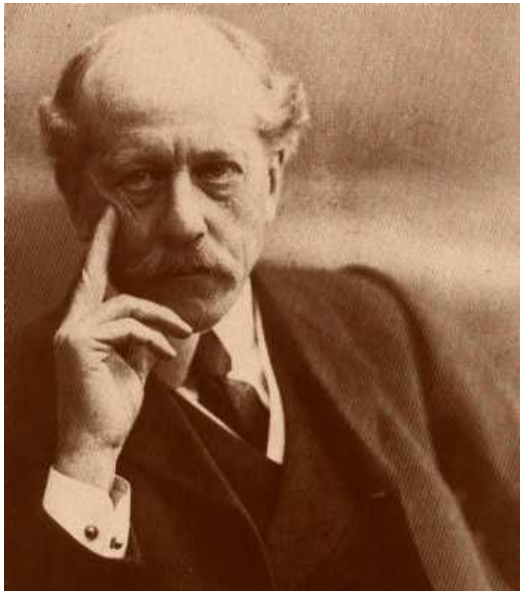


THE HYPOTHESIS OF MARTIAN VEGETATION

Emmanuel Liais, William Pickering, Percival Lowell, etc…

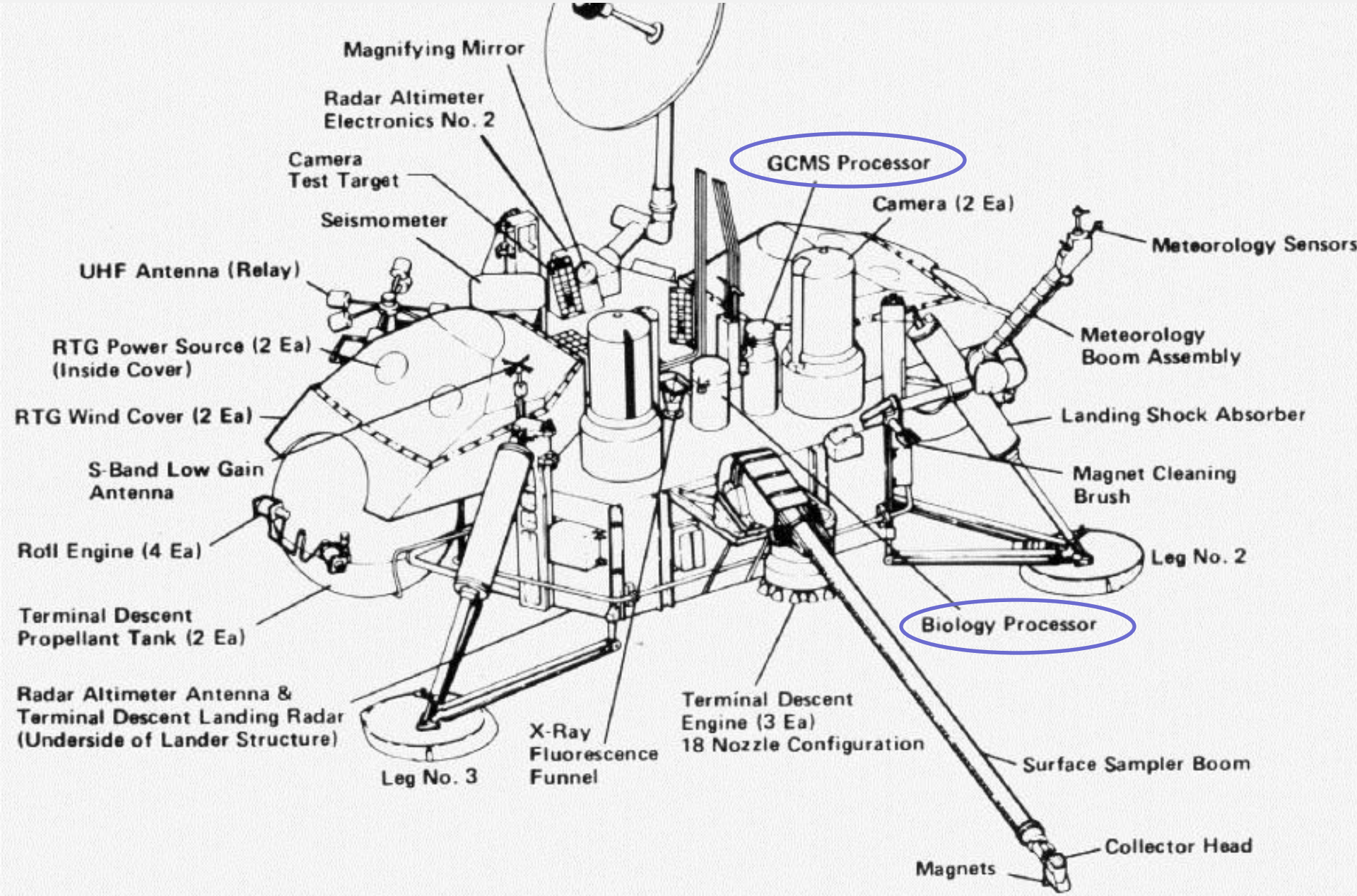


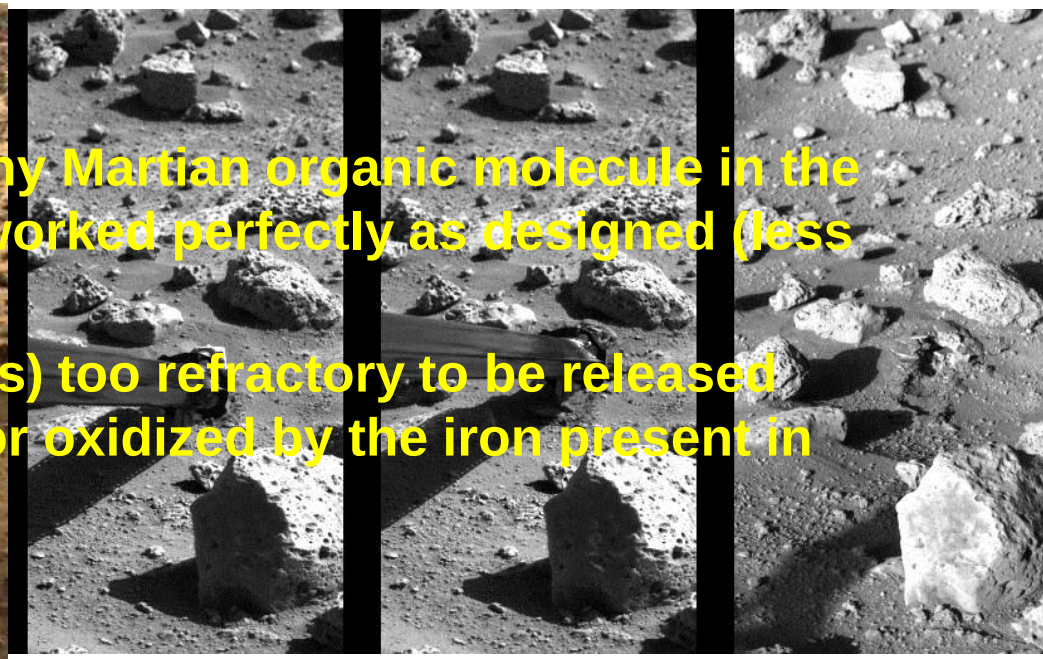




…. Mariner 4, 6, 7

The Viking lander (1976): Search for microorganisms

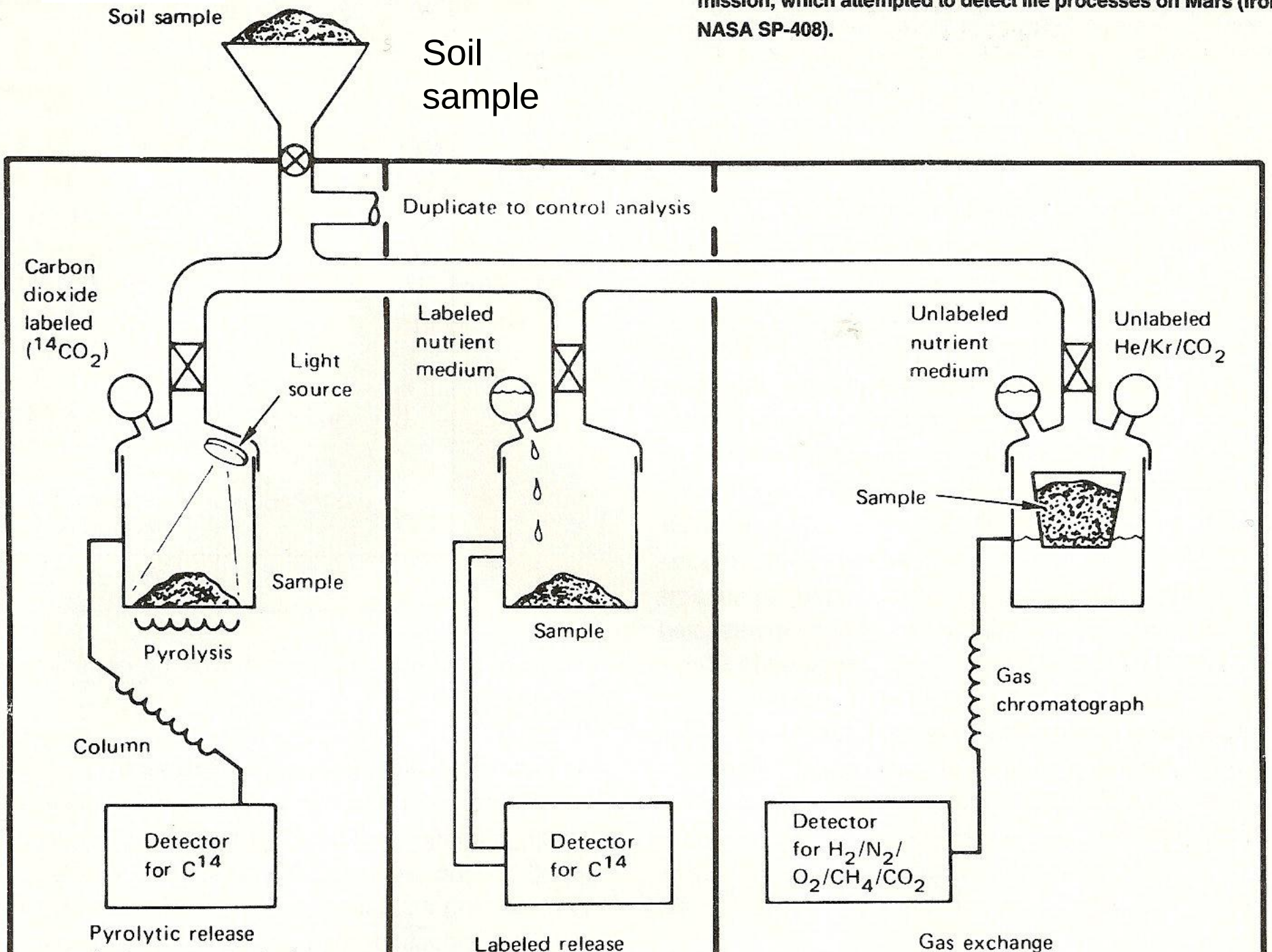




Viking GC-MS did not detect any Martian organic molecule in the soil, although the instrument worked perfectly as designed (less carbon than lunar soils).

Organics (present in meteorites) too refractory to be released at the temperatures achieved or oxidized by the iron present in the soil.

Figure 7.2 - Diagram of the biological experiments of the Viking mission, which attempted to detect life processes on Mars (from NASA SP-408).



Experiment	Response for sample	Response for heat-sterilized control
Testing terrestrial life		
PR	Carbon detected	None
GEX	O_2 or CO_2 emitted	None
LR	Labelled gas emitted	None
Mars sample in absence		
PR	None	
GEX	None	
LR		None
Ac[illegible]ts with Martian samples		
PR	[illegible]n detected	Carbon detected
GEX	O_2 emitted	O_2 emitted
LR	Labelled gas emitted	None

The results of the Viking biology experiments can be explained by purely chemical processes that do not require the presence of life

BUT…

Since 2010, the controversy rises again due to the detection of perchlorate $Mg(ClO_4)_2$ by the rover Phoenix.

Organic carbon mixed with magnesium perchlorate and heated in the conditions similar to those of Viking, nearly all the organics present are decomposed to water + carbon dioxide + chlorohydrocarbons; these components have been detected by Viking (and interpreted to be terrestrial contaminants).

=> TWO LESSONS FROM VIKING:

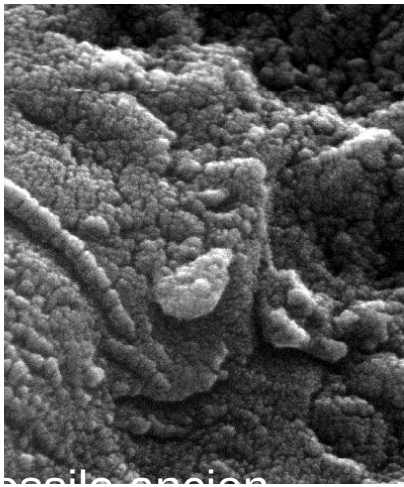
- We need to understand the environments before we start searching (present and past) life
- We need to better define the organic biomarkers

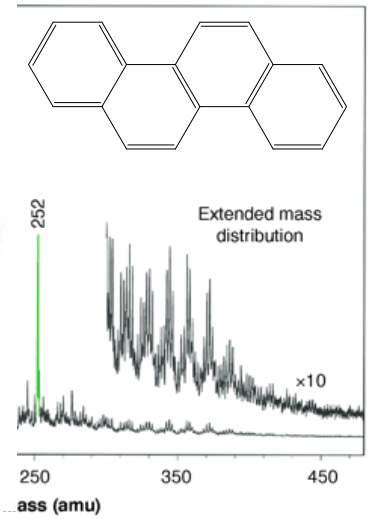
Astrobiology and Mars

What directions?

1. Searching for present life
2. Searching for past life
3. Searching for habitats

Past Martian life in SNC ALH84001 ?





Past Martian life in SNC ALH84001 ?

Available online at www.sciencedirect.com

ELSEVIER

Geochimica et Cosmochimica Acta 73 (2009) 6631–6677

himica et
ıochimica
Acta

www.elsevier.com/locate/gca

Origins of magnetite nanocrystals in Martian meteorite ALH84001

K.L. Thomas-Keprta [a,*], S.J. Clemett [a,*], D.S. McKay [b], E.K. Gibson [b], S.J. Wentworth [a]

[a] *ESCG at NASA/Johnson Space Center, Houston, TX 77058, USA*
[b] *KR, ARES, NASA/Johnson Space Center, Houston, TX 77058*

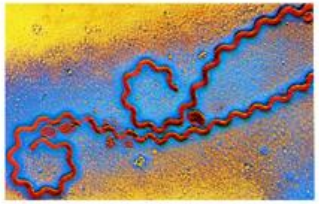
Received 20 July 2008; accepted in revised form 18 May 2009; 2009

The results are not conclusive

…. We suggest th majority of ALH84001 magnetites has an ionous origin and was added to the carbonate system from an outside source. This origin does not exclude the possibility that a fraction is consistent with formation by biogenic processes, as proposed in previous studies.

What directions?

The terrestrial example



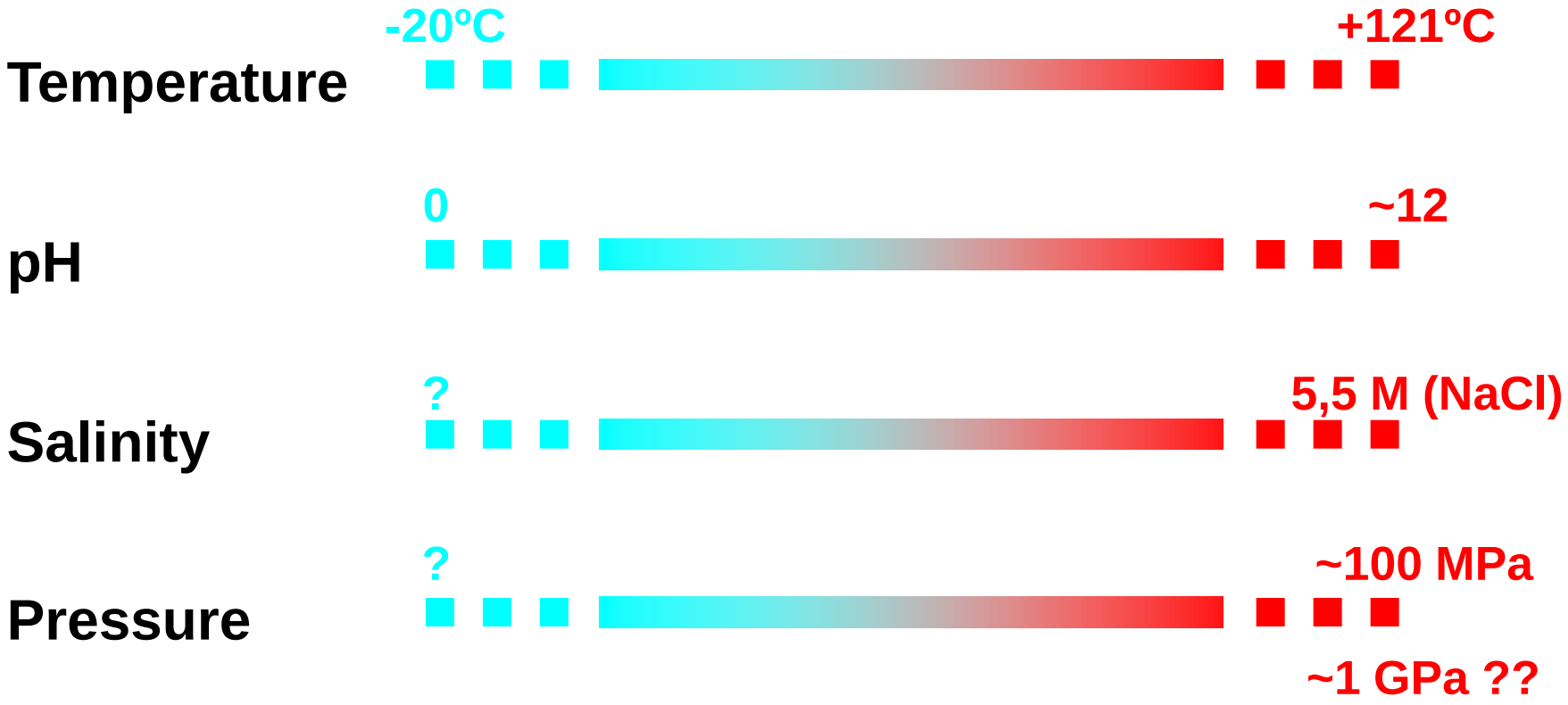
TOTAL NUMBERS OF KNOWN SPECIES

Bacteria	~ 10,000
Archaea	~ 5000
Fungi	~ 101,000
Plants	~ 260,000
Animals	~ 1,200,000
TOTAL	~ 1.6 million

What directions?

The terrestrial example

Extremophiles and limits for terrestrial life

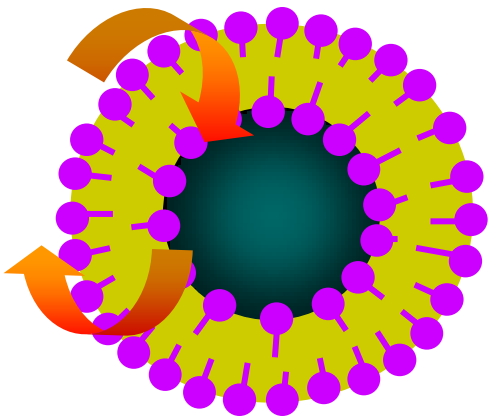


What directions?
Definition of Life

- Life is a chemical system, self-maintained and capable of Darwinian evolution (NASA)

- 2 main characteristics: auto-replication and evolution

- ***Minimal life***: a system delimited by a semi-permeable membrane formed by the system itself, able of self-maintenance and producing its own constituting elements by transformation of exogeneous nutriments and energy through its own processes of production (P. L. Luisi)



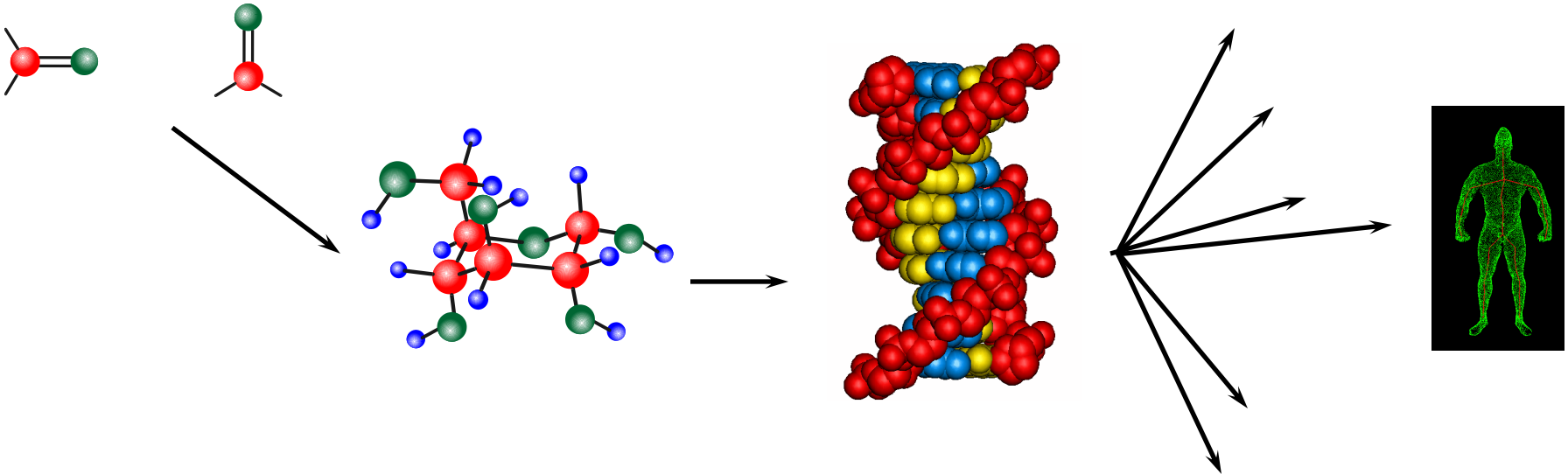
Life on Earth

Until mid-19th : Spontaneous generation

End 19th – early 20th : Panspermia

Since 1924: Chemical evolution (Oparin 1924; Haldane 1929)
A long spontaneous (thermodynamically speaking) evolution of organics from simple molecules to complex organics including macromolecules capable of self-replication, preceding the biological evolution

Organic matter + Liquid water + Energy



Astrobiology and Mars

What directions?

1. Searching for present life
2. Searching for past life
3. Searching for habitats

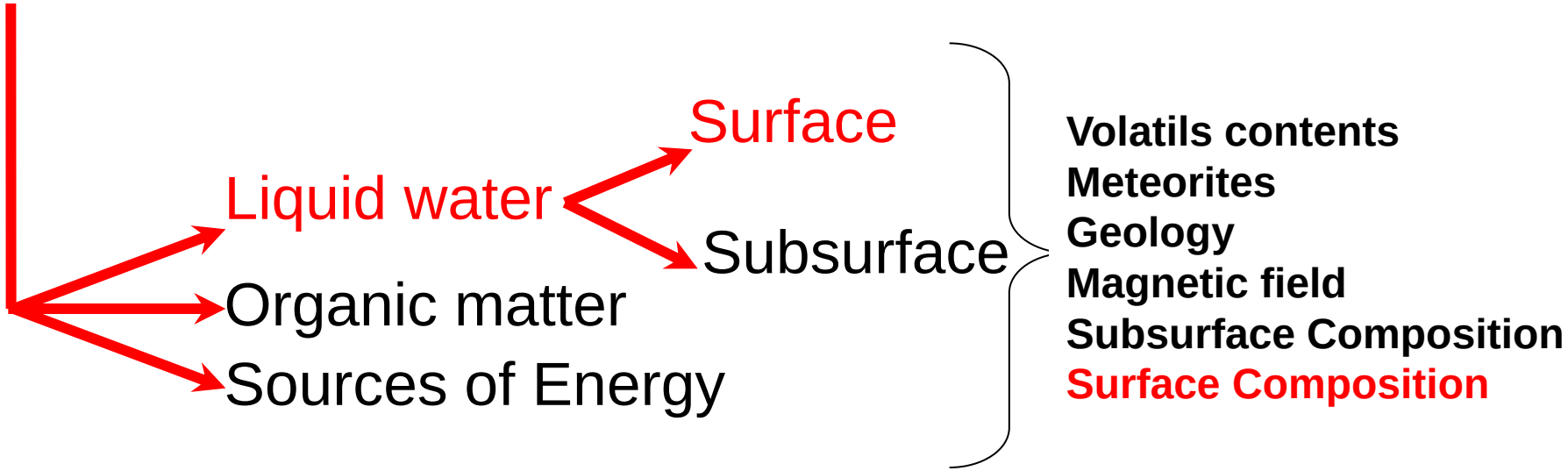
- Liquid water
  - Surface
  - Subsurface
- Organic matter
- Sources of Energy

Volatils contents
Meteorites
Geology
Magnetic field
Subsurface Composition
Surface Composition

Astrobiology and Mars

What directions?

1. Searching for present life
2. Searching for past life
3. Searching for habitats



=>Mars : a target with astrobiological interest?

YES! (Early Mars)

☑ Organics

☑ Energy

☑ Liquid water

Outline

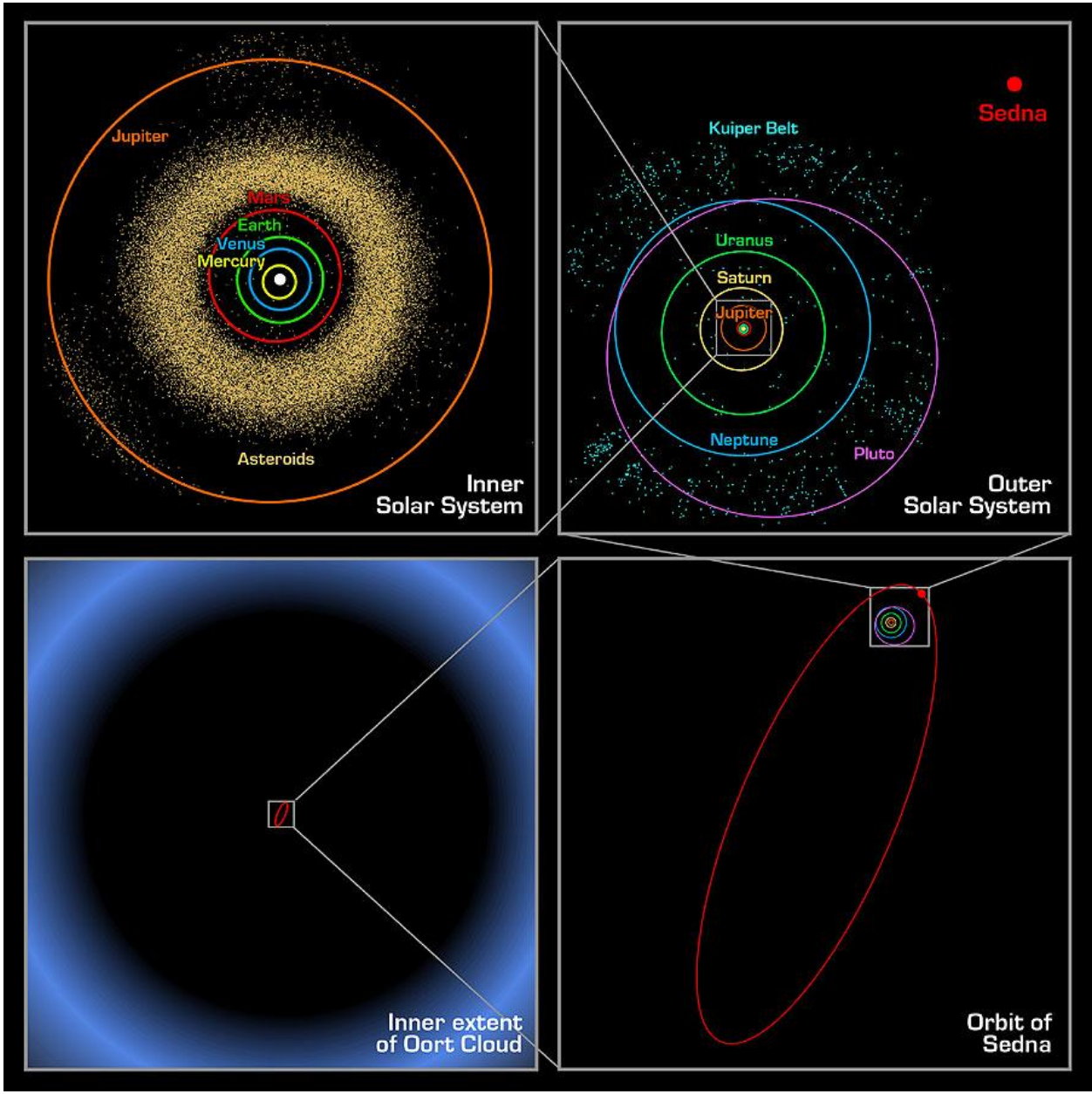
- The starting point (a short review of the surface characteristics of Mars)
- Study of planetary surfaces (methods and observations)
- Forming planetary surface (crust)
- Mars surface : a planetary surface with very high astrobiological interests

Outline

- The starting point (a short review of the surface characteristics of Mars)
- Study of planetary surfaces (methods and observations)
- Forming planetary surface (crust)
- Mars surface : a planetary surface with very high astrobiological interests

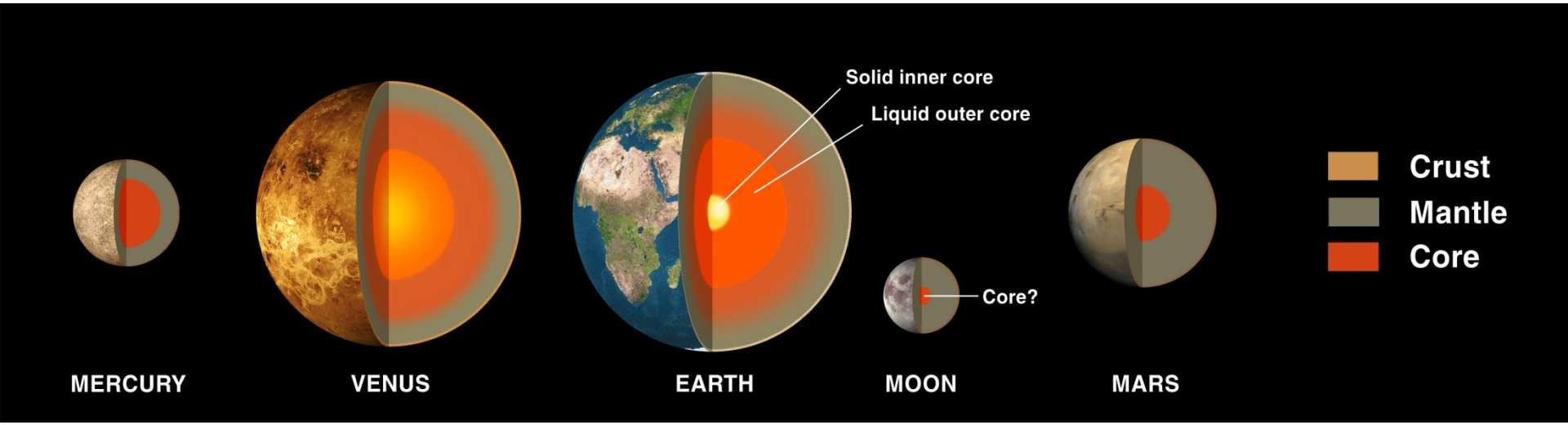
The starting point: Overall solar system structure

- Inner rocky planets
  - Mercury 0.39 AU
  - Venus 0.72 AU
  - Earth 1.00 AU
  - Mars 1.52 AU
- Asteroid belt (2-4 AU)
  - Thousands of members
  - Several groups
  - Sizes from dust to ~950 km (Ceres)
- Giant planets
  - Jupiter 5.2 AU
  - Saturn 9.6AU
  - Uranus 19.2 AU
  - Neptune 30.1 AU
- Kuiper Belt (30-50 AU)
  - Contains Pluto
  - Several groups
  - Sizes from dust to >2400 km (Eris)
- Oort cloud
  - Long period comet reservoir
  - Affected by passing stars



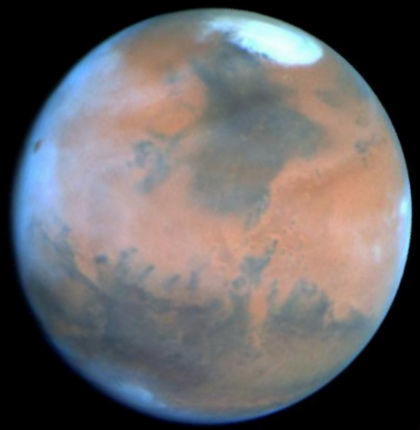
The starting point: Inner planets

- Differentiated into iron cores and silicate mantles
- All very different – fewer bodies than free variables
- Surface processes have commonalities



	Mercury	Venus	Earth	Moon	Mars
Craters	X	X	X	X	X
Volcanism	X	X	X	X	X
Tectonics	X	X	X		X
Aeolian		X	X		X
Fluvial			X		X

Planetary Evolution



Unlike the Moon, Mars is large enough to have undergone all major evolutionary planetary steps, including a period of large internal activity.

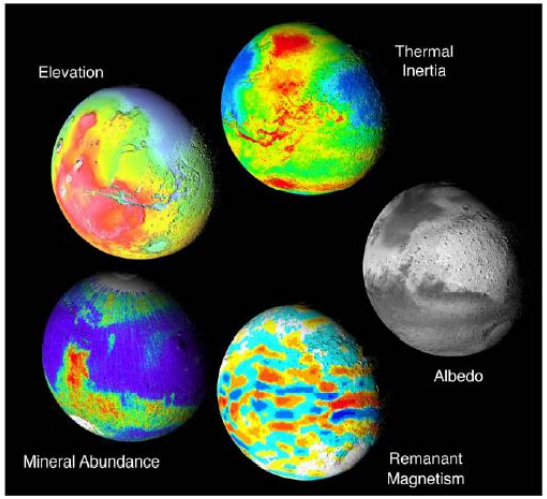
On the other hand, Mars is small enough not to have been remodeled by global surface resets, as was the Earth.

Its intermediate mass has thus enabled Mars to record most major events: early heavy bombardment, tectonic and volcanic activities, alteration and weathering on long to small timescales.

These records are preserved in :

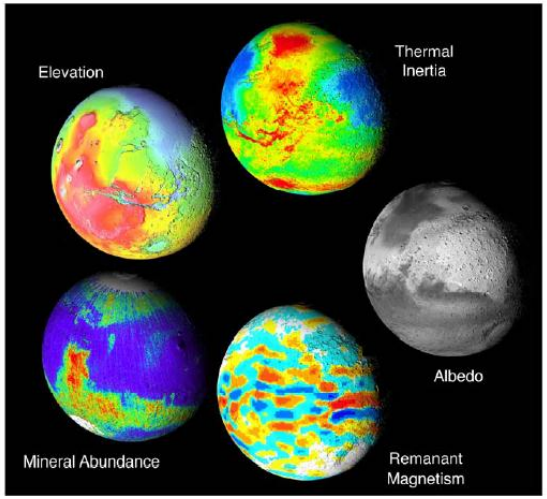
- Surface structures
- Surface composition

Mars: the starting point

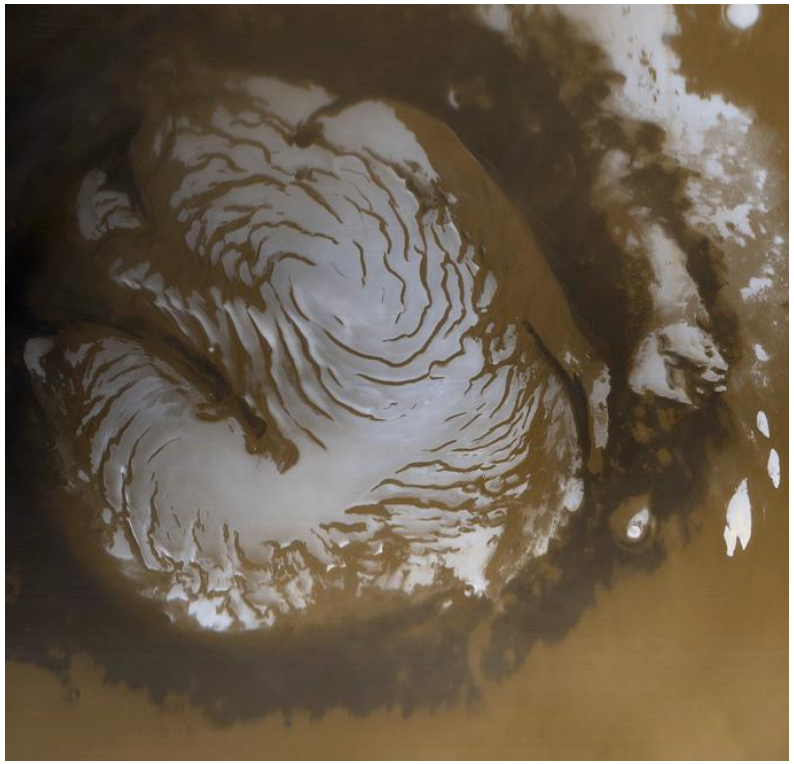


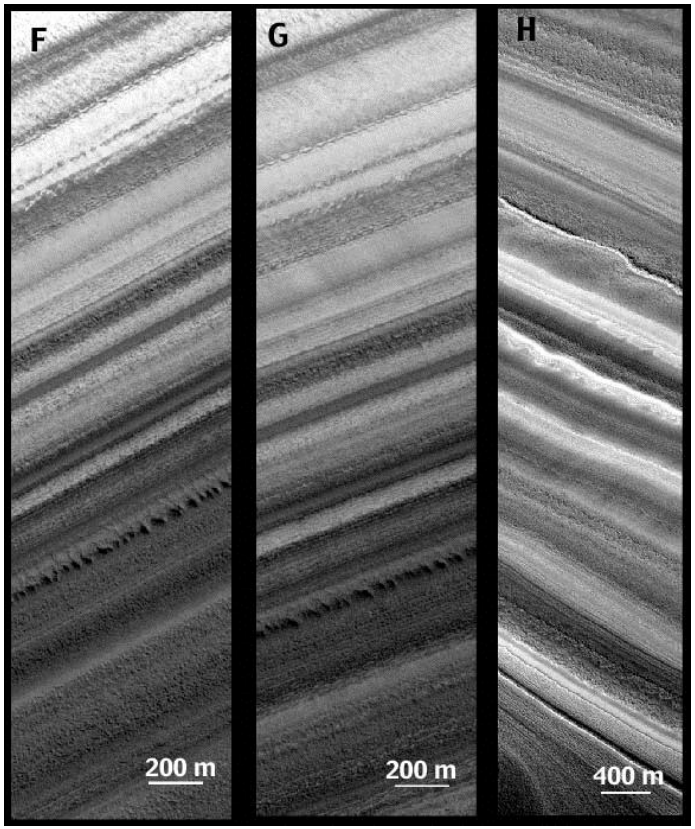
- Mars has marked seasons

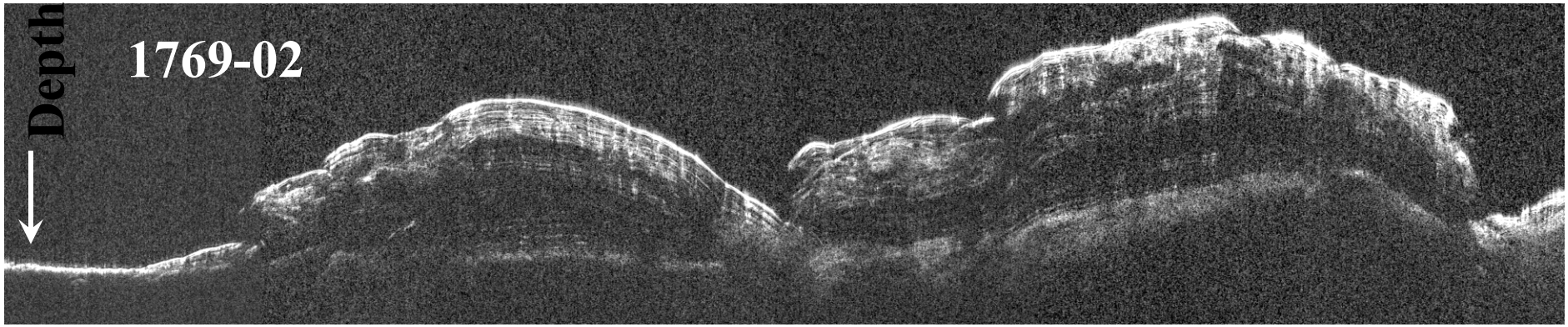
Mars: the starting point



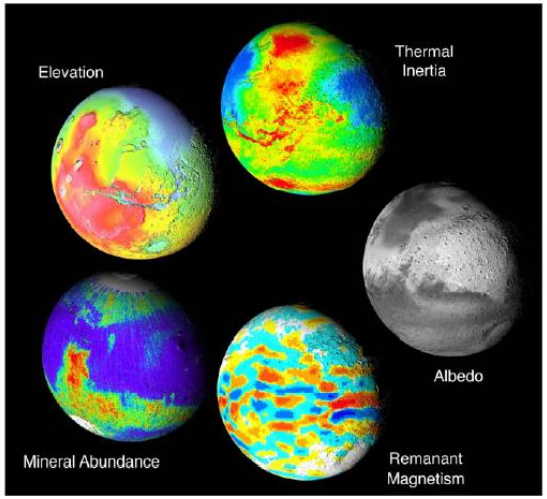
- Mars has marked seasons
- Mars has icy polar caps



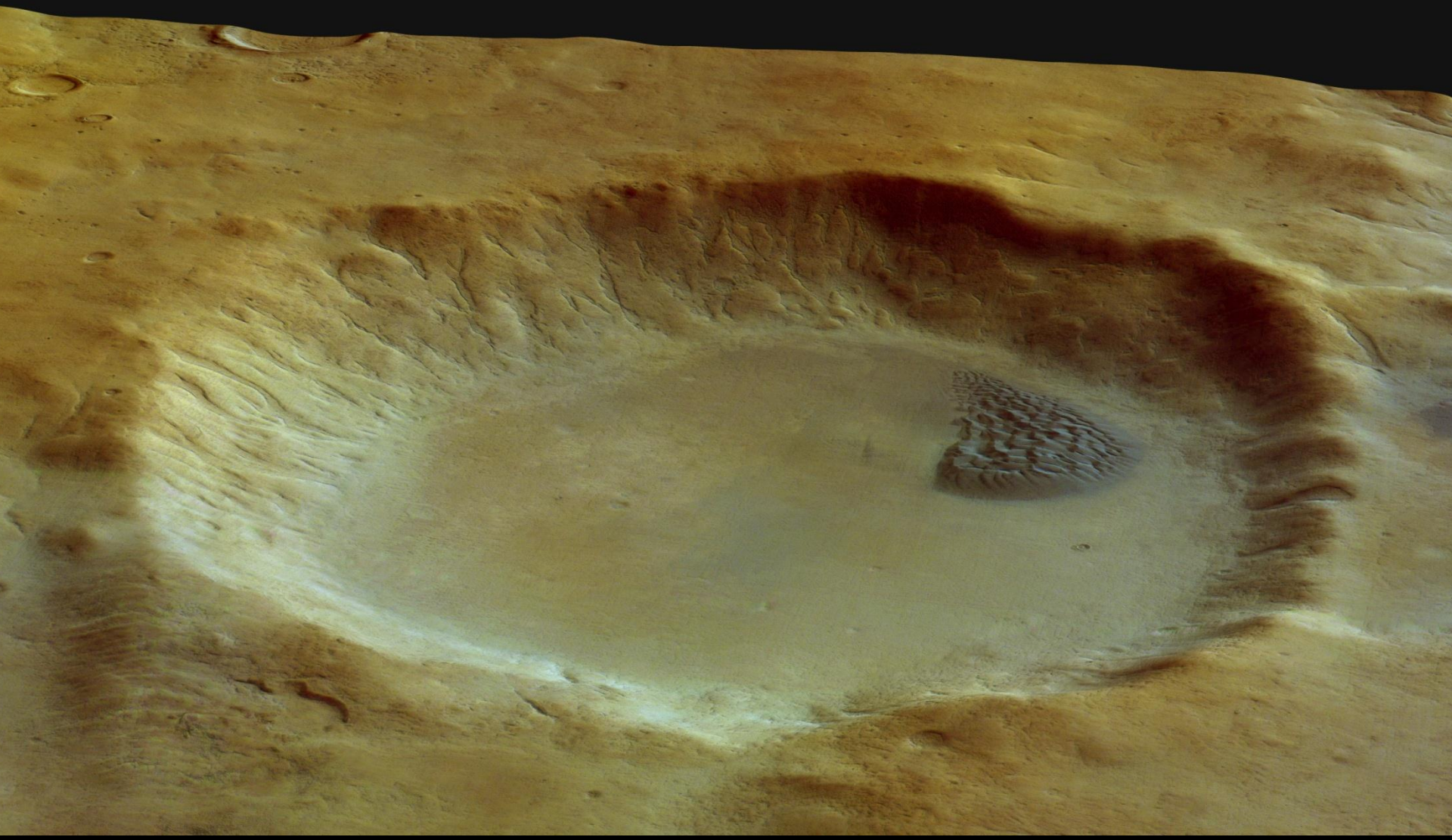

F
G
H
200 m
200 m
400 m

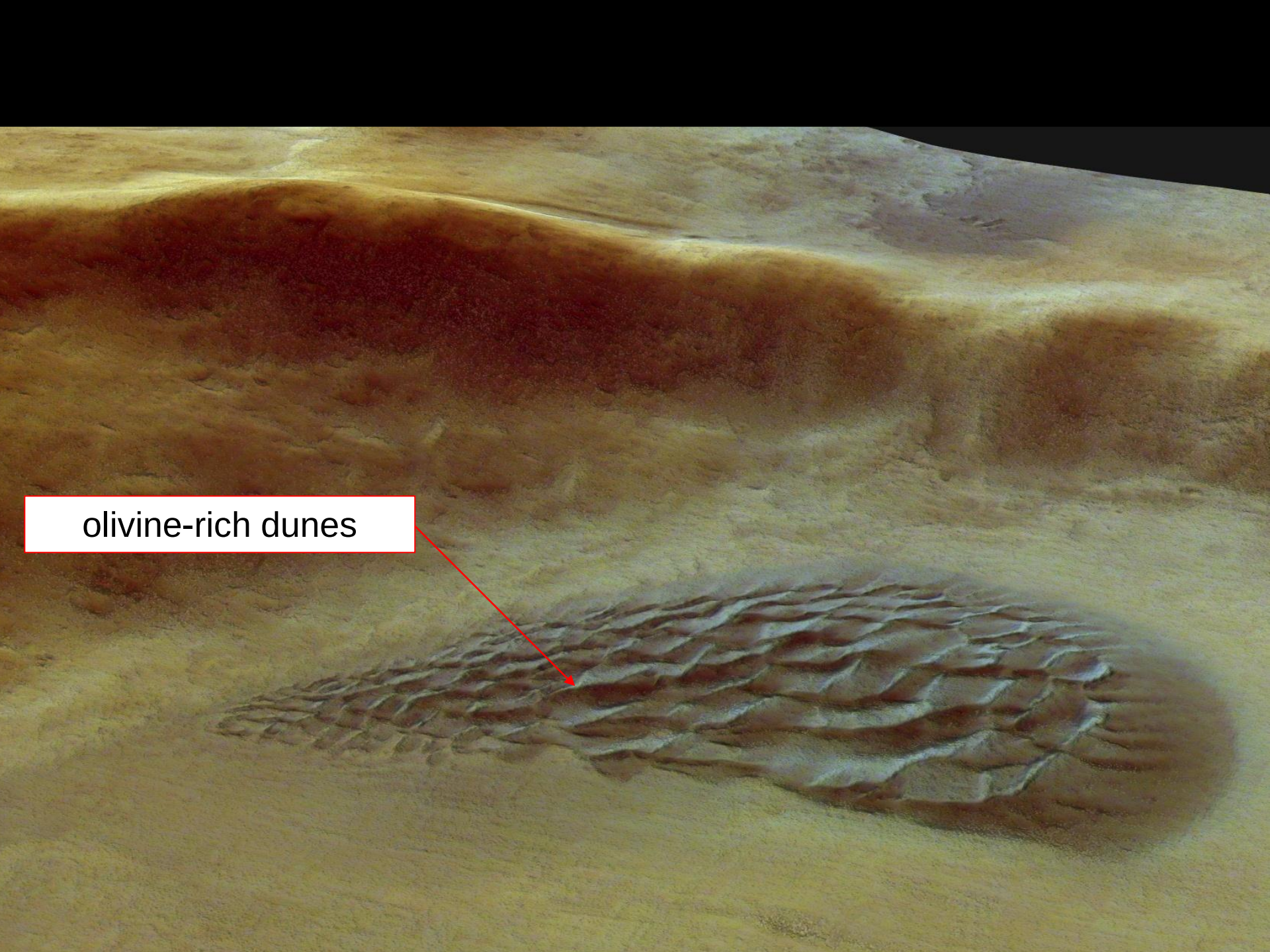

Depth
1769-02

Mars: the starting point

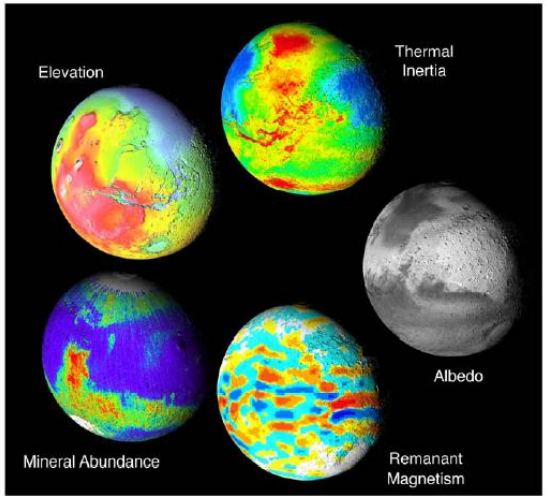


- Mars has marked seasons
- Mars has icy polar caps
- Mars present atmosphere is very tenuous and CO_2 rich (96 %) (and Methane?)

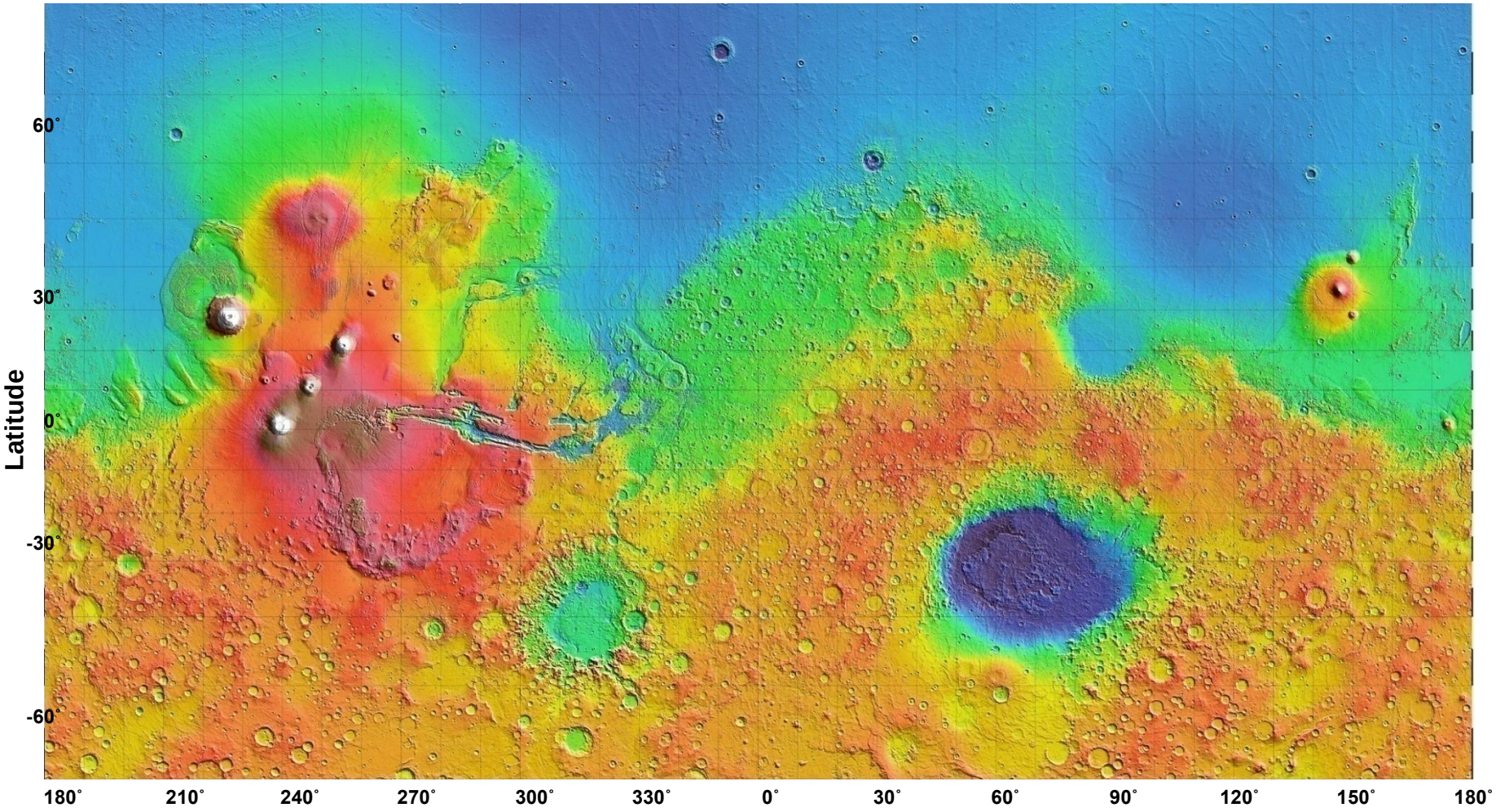



olivine-rich dunes

Mars: the starting point

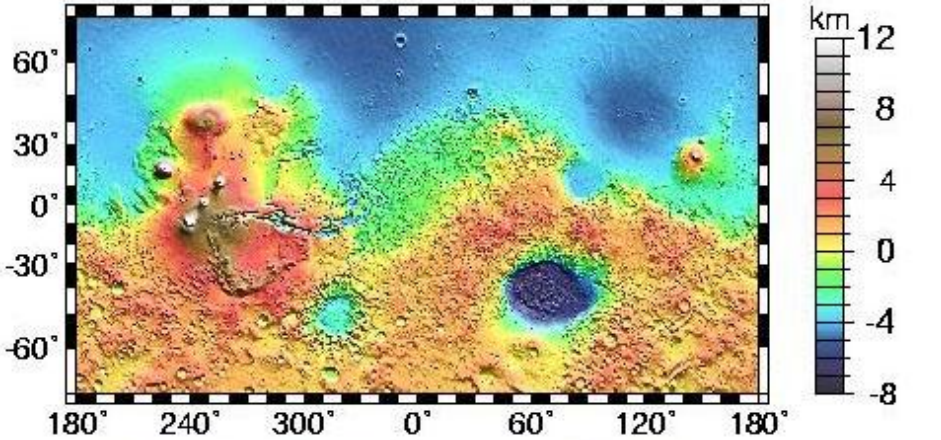


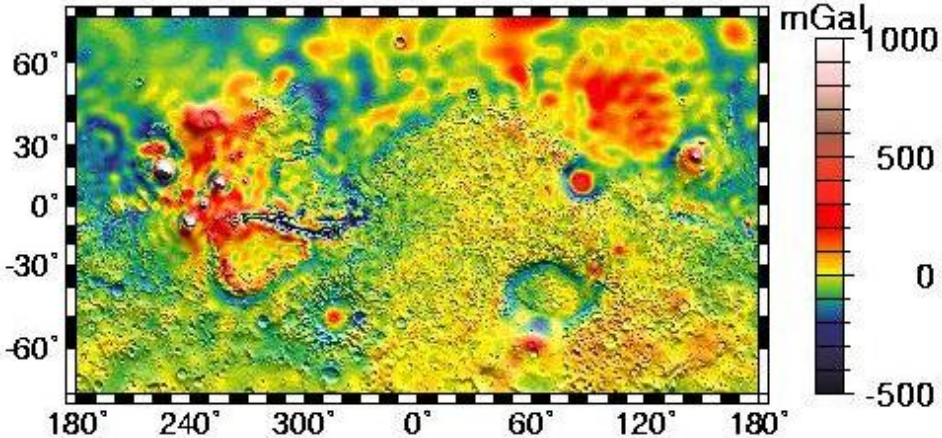
- Mars has marked seasons
- Mars has icy polar caps
- Mars present atmosphere is very tenuous and CO_2 rich (96 %)
- Mars has kept the record of its ancient bombardment

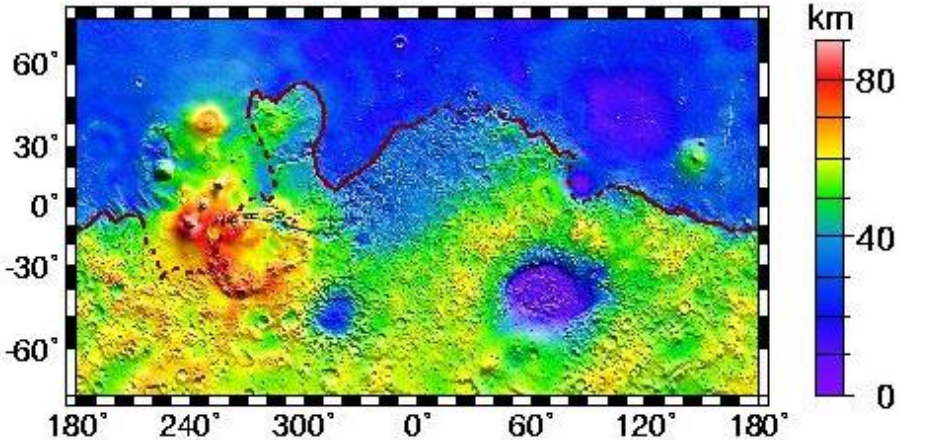

Latitude
60˚
30˚
0˚
-30˚
-60˚
180˚
210˚
240˚
270˚
300˚
330˚
0˚
30˚
60˚
90˚
120˚
150˚
180˚

Mars: Crustal Dichotomy

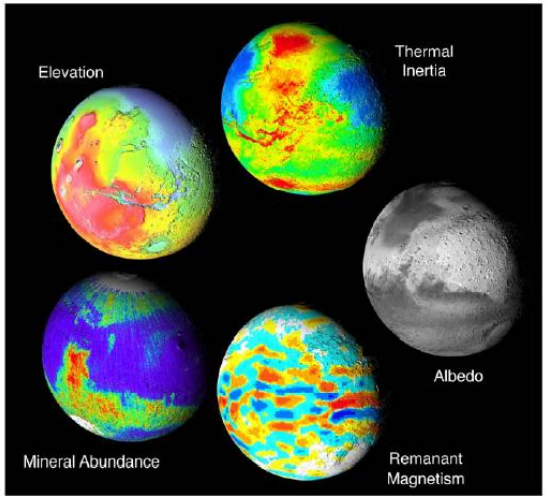
- Northern and southern hemispheres of Mars are very distinct:
  - North
    - Low elevation
    - Few Craters – Young
    - Smooth terrain
    - Thin Crust
    - No Magnetized rock
  - South
    - High elevation
    - Heavily cratered – Old
    - Rough terrain
    - Thick crust
    - Basaltic composition
    - Magnetized rock
- Dichotomy boundary mostly follows a great circle, but is interrupted by Tharsis
- Theories on how to form a dichotomy
  - Giant impact
  - Several large basins
  - Degree 1 convection cell
  - Early plate tectonics





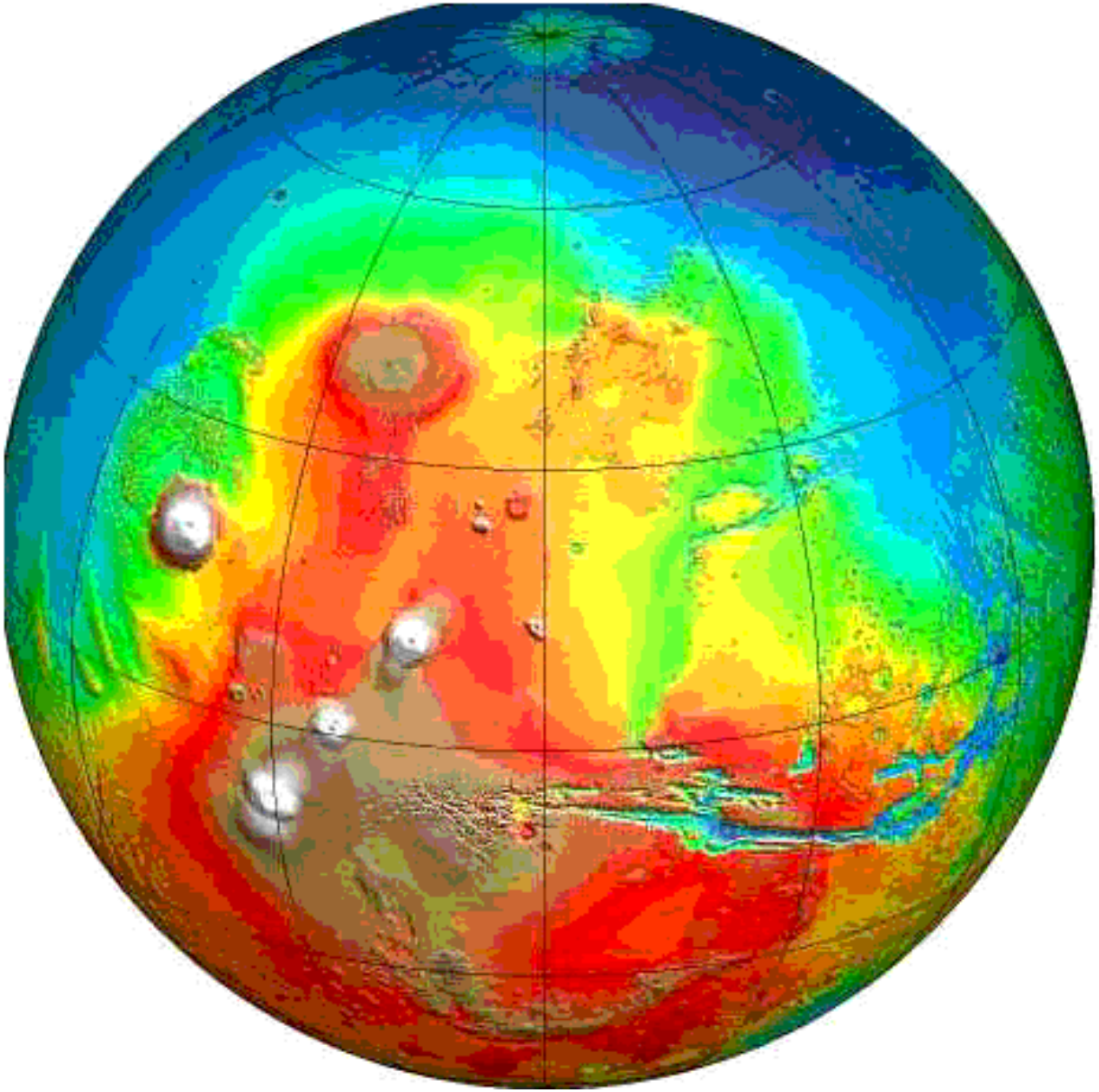


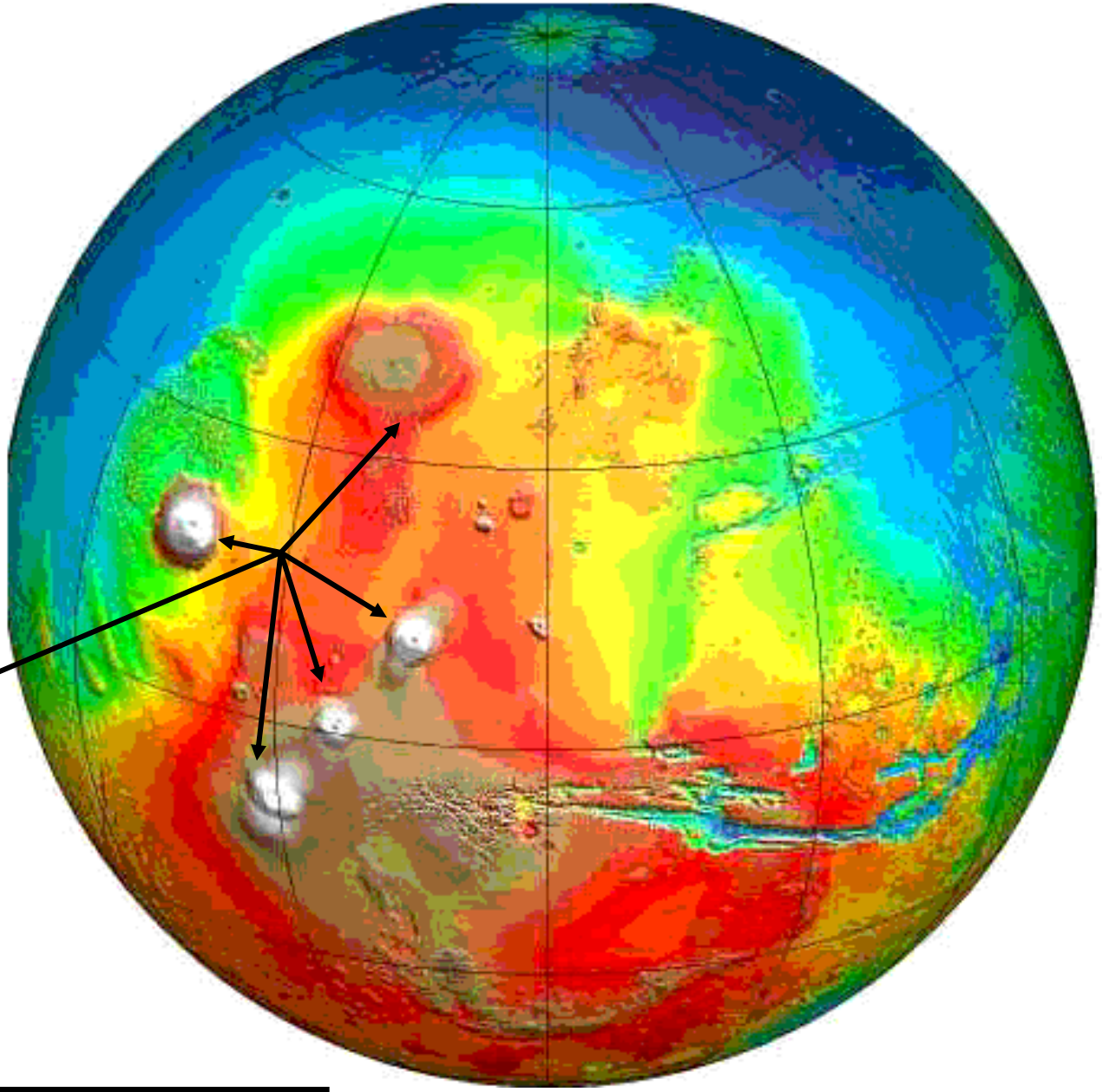
Mars: the starting point



The starting point

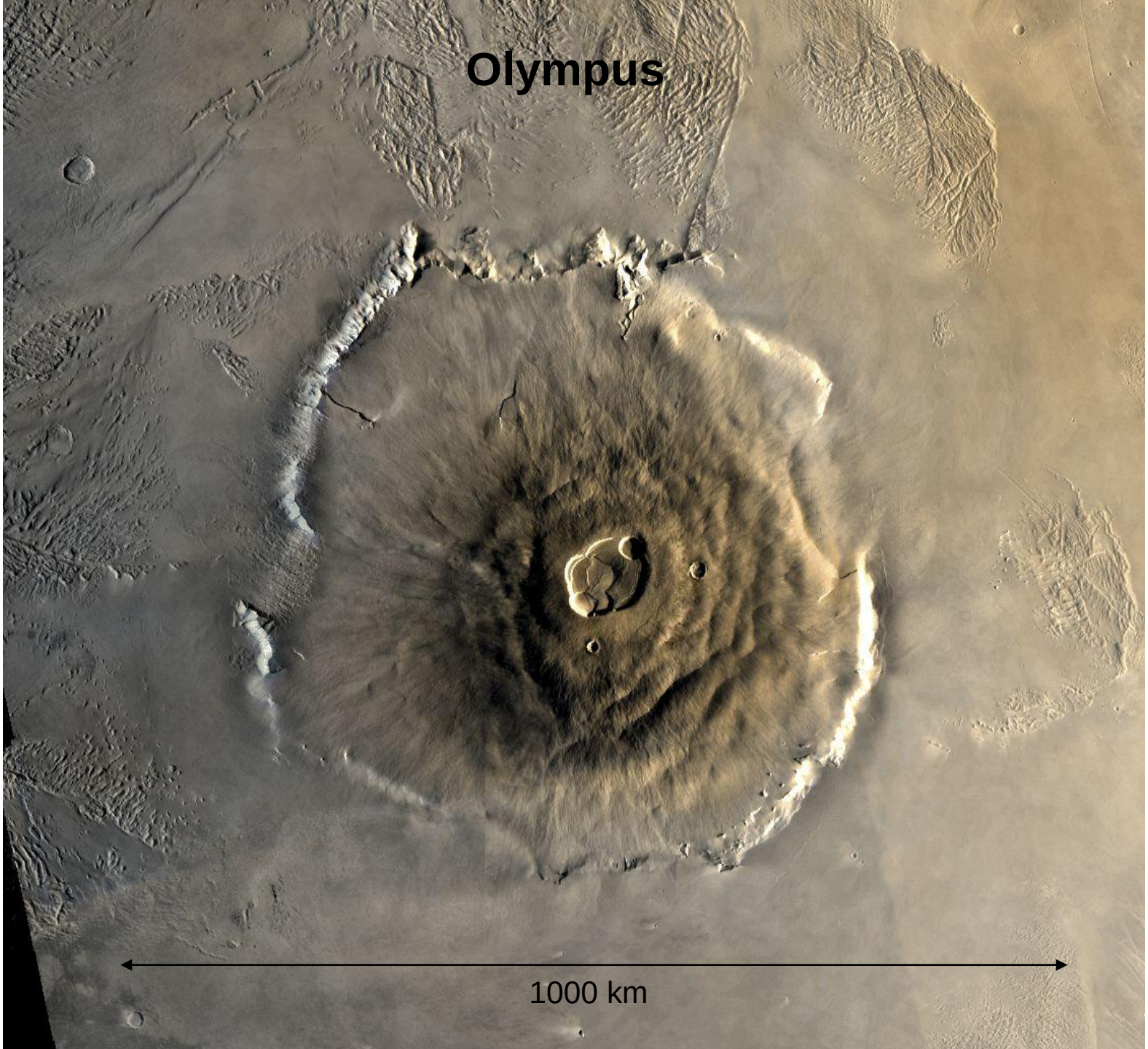
- Mars has marked seasons
- Mars has icy polar caps
- Mars present atmosphere is very tenuous and CO_2 rich (96 %)
- Mars has kept the record of its ancient bombardment
- Mars underwent massive volcanic episodes





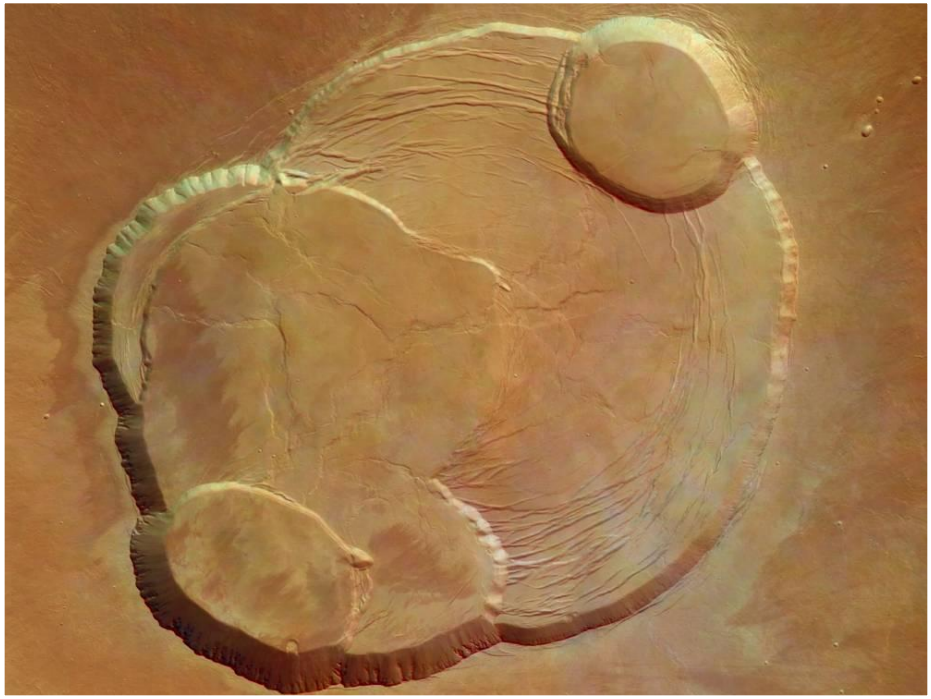
building of Tharsis

> 4.0 10^9 years


Olympus
1000 km

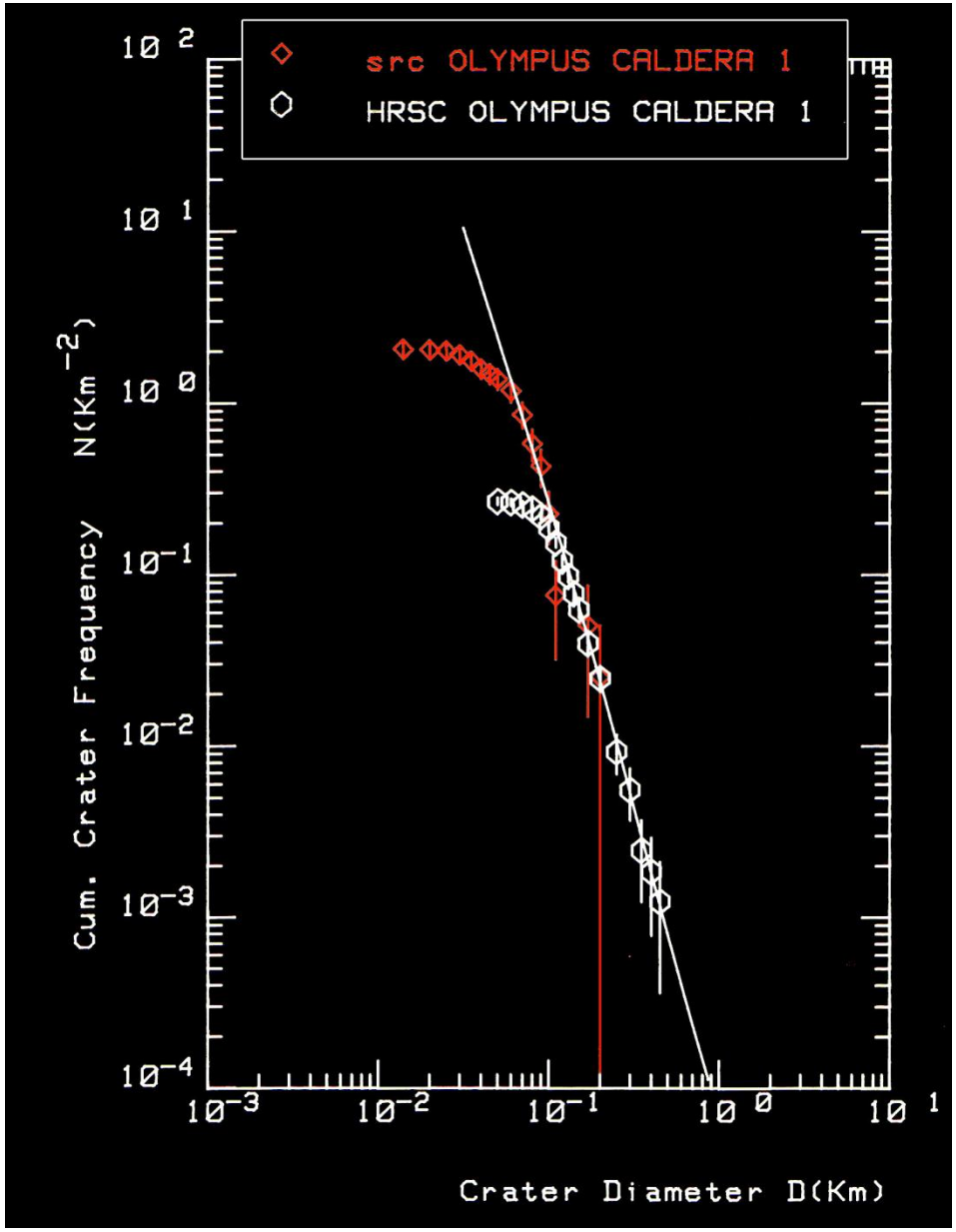
HRSC

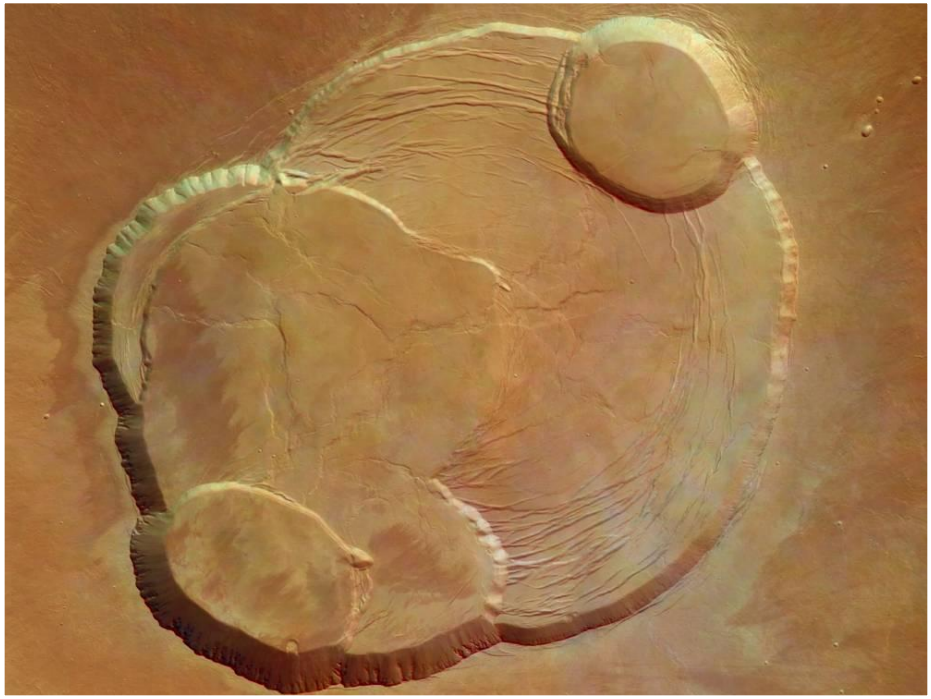
caldera age

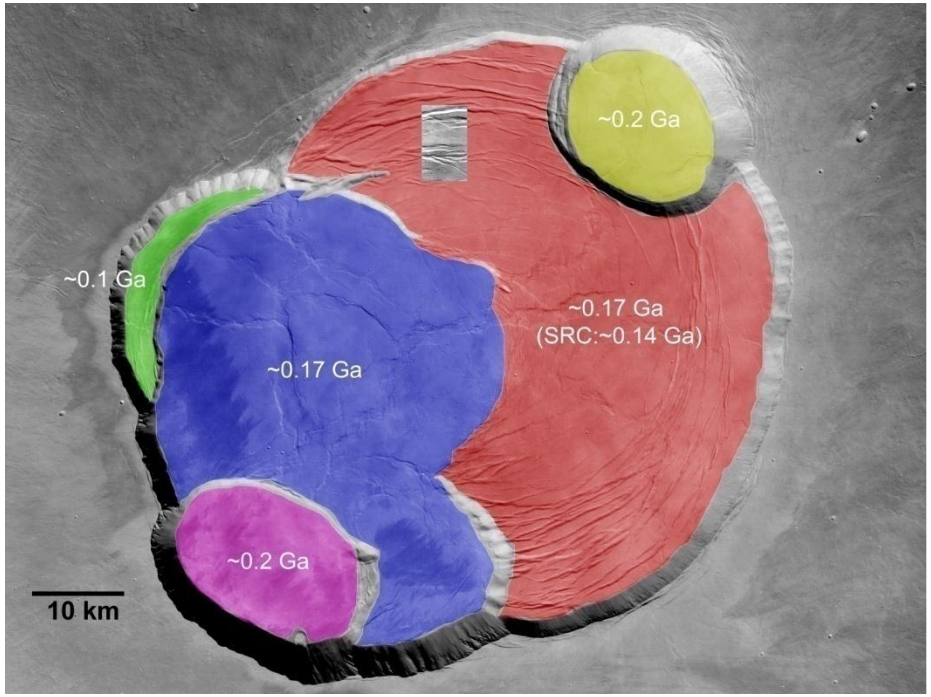


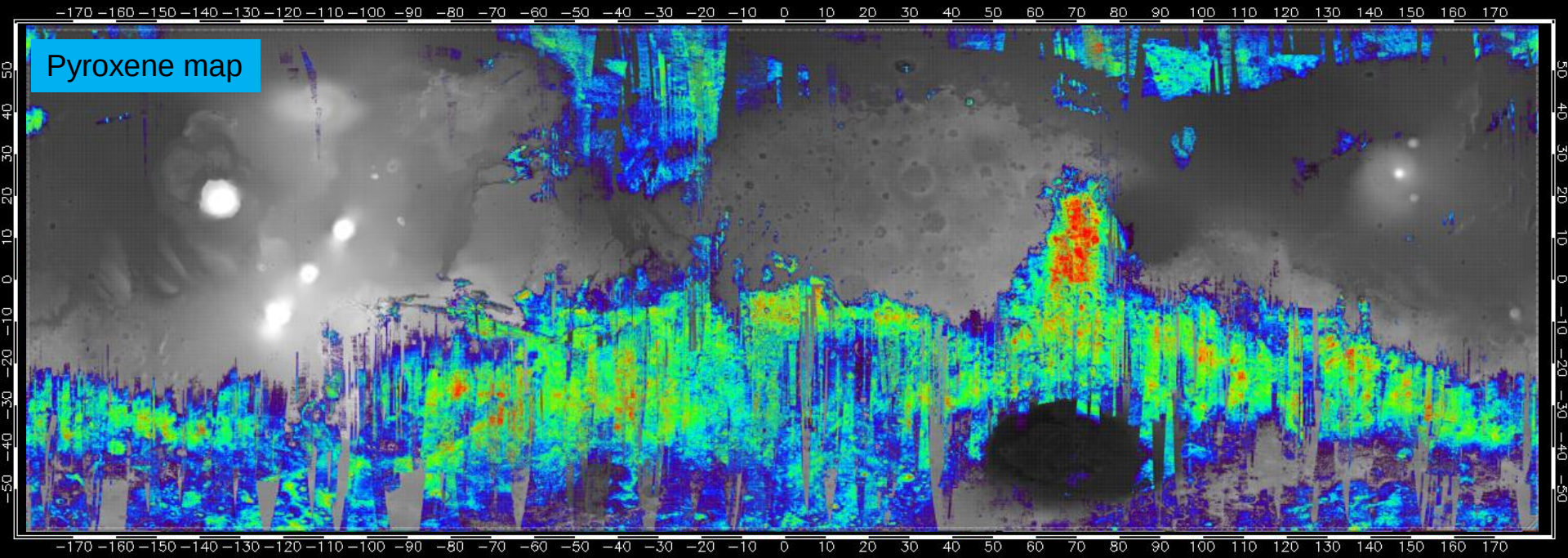
HRSC

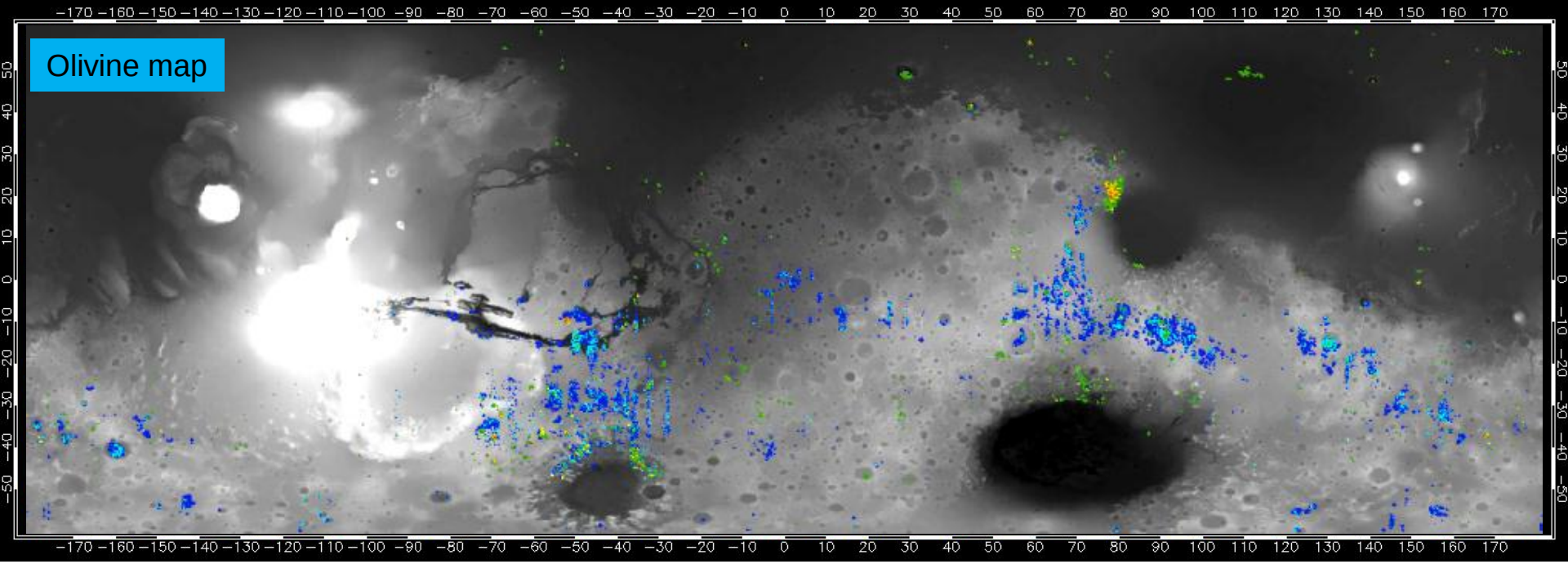
caldera age


src OLYMPUS CALDERA 1
HRSC OLYMPUS CALDERA 1
Cum. Crater Frequency N(Km^{-2})
Crater Diameter D(Km)
10^{2}
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}

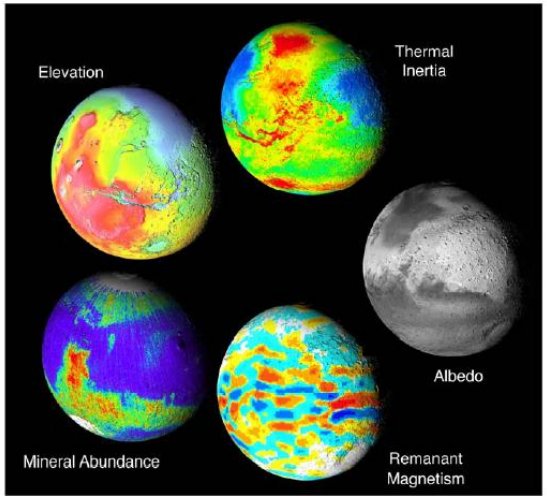



~0.2 Ga
~0.1 Ga
~0.17 Ga
(SRC:~0.14 Ga)
~0.17 Ga
~0.2 Ga
10 km


Pyroxene map


Olivine map

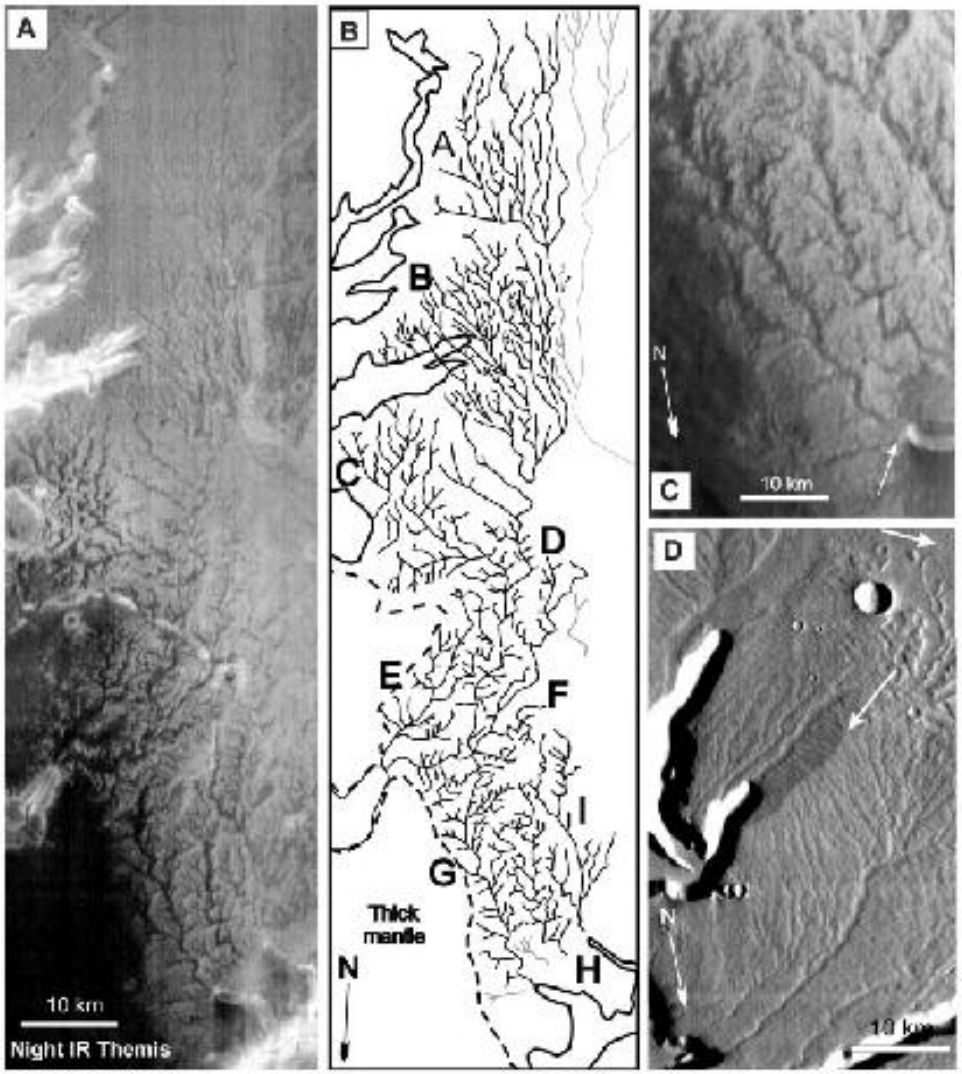
Mars: the starting point



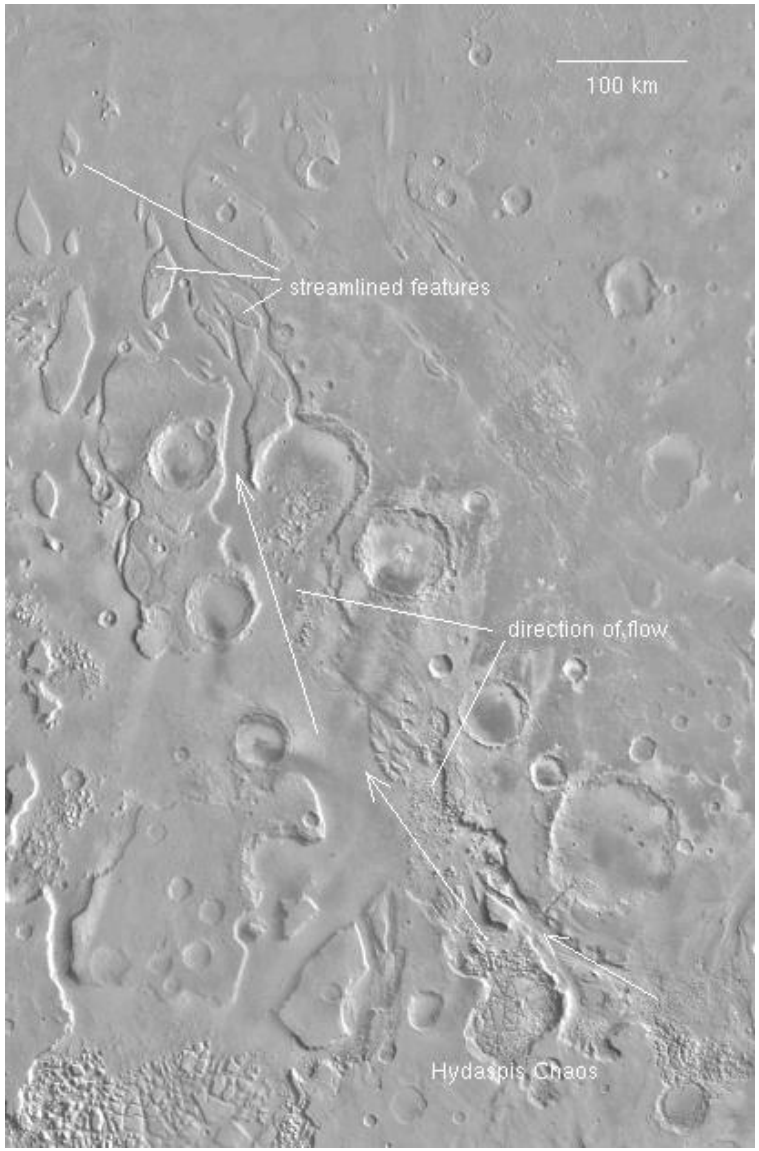
The starting point

- Mars has marked seasons
- Mars has icy polar caps
- Mars present atmosphere is very tenuous and CO_2 rich (96 %)
- Mars has kept the record of its ancient bombardment
- Mars underwent massive volcanic episodes
- Mars exhibits a variety of flooding/fluvial structures

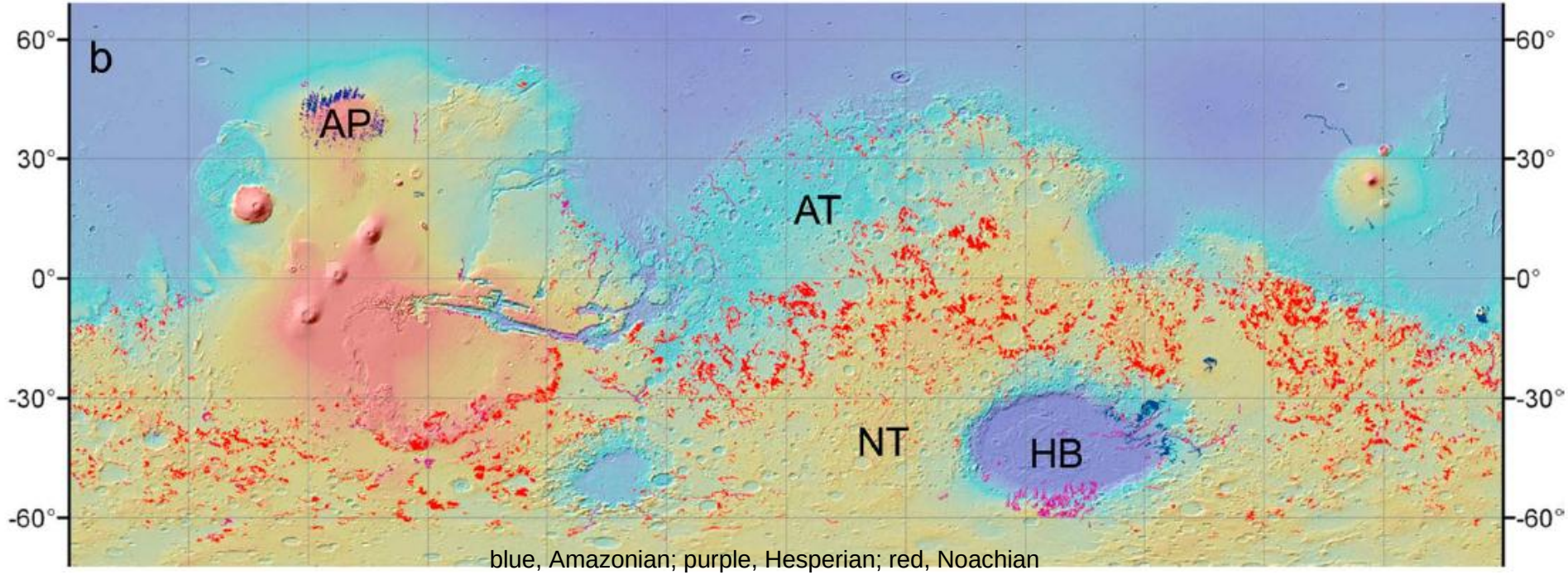
Valley networks



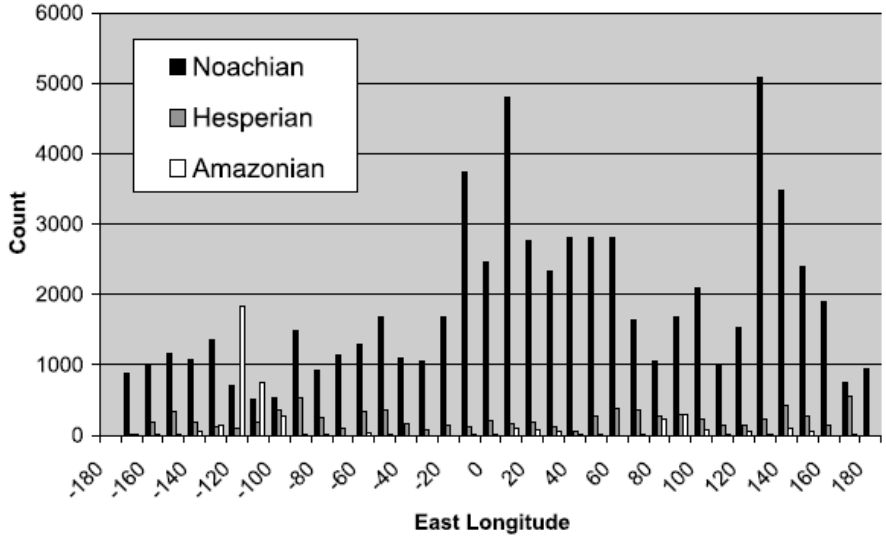
Outflow channels



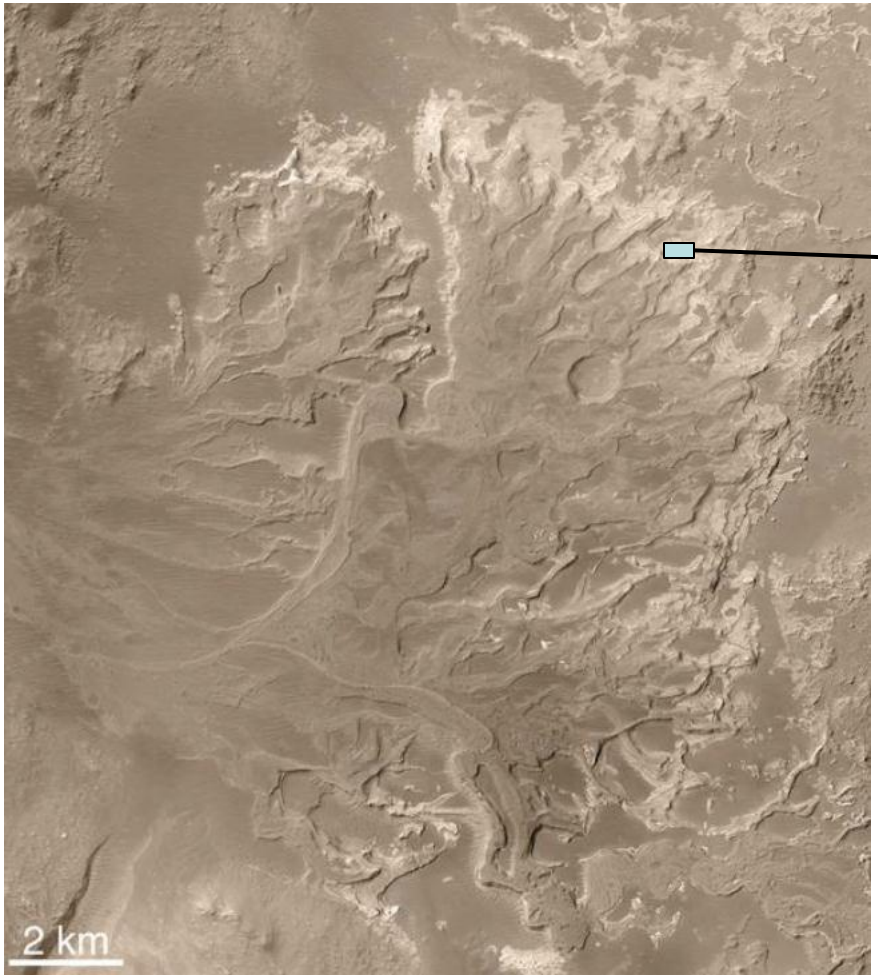
Global map of valley networks

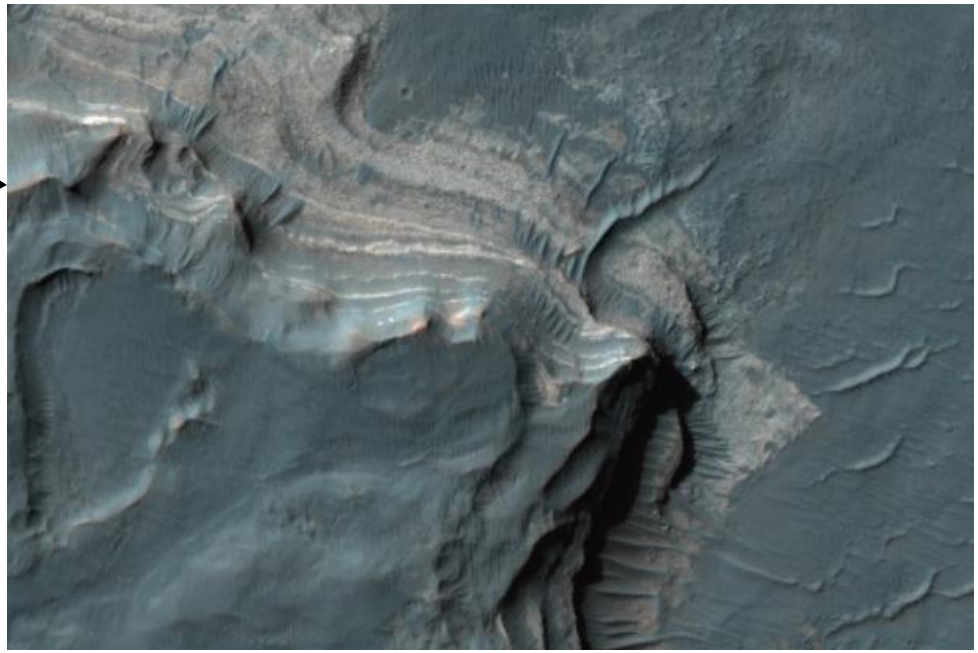


blue, Amazonian; purple, Hesperian; red, Noachian

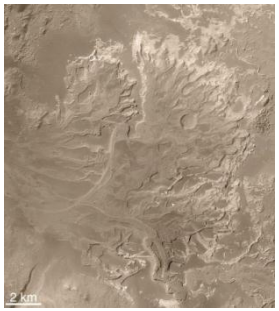


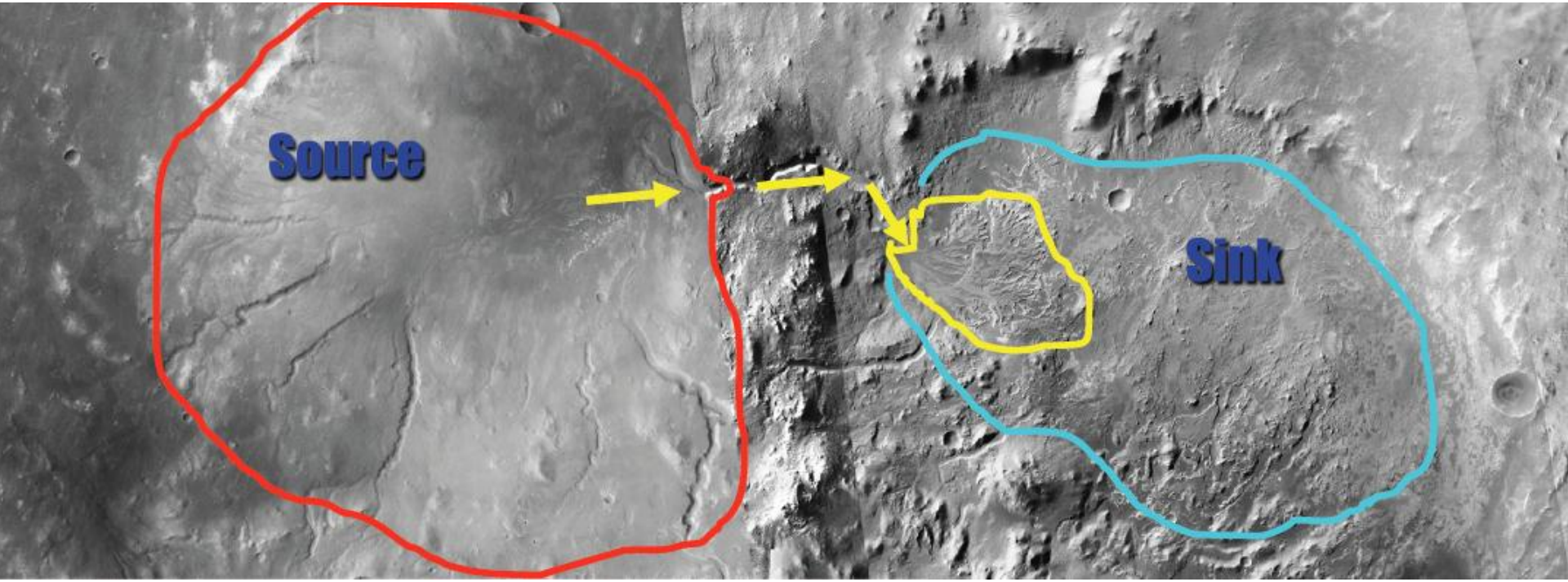
Open basin-lakes and deltas





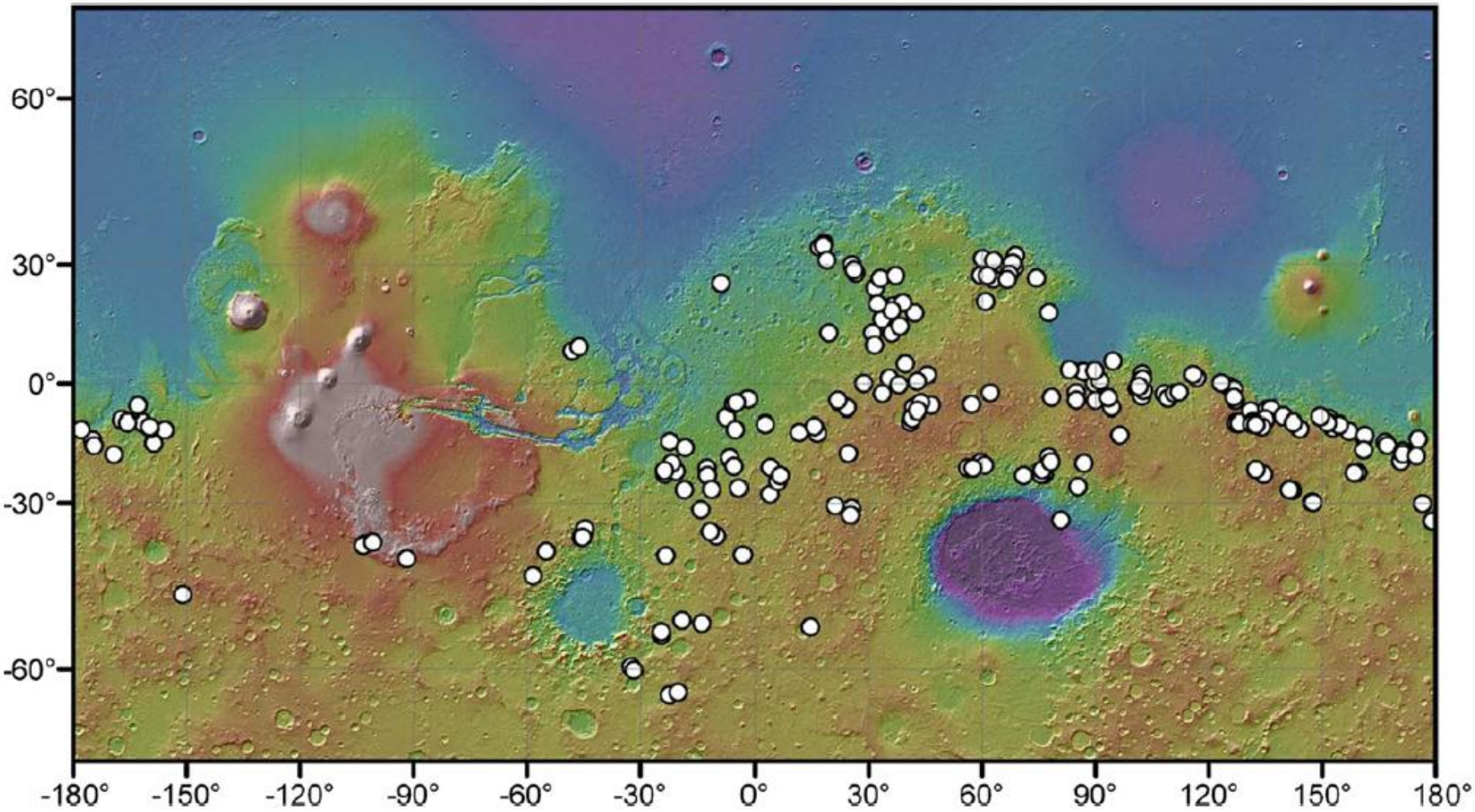
Lakes delta



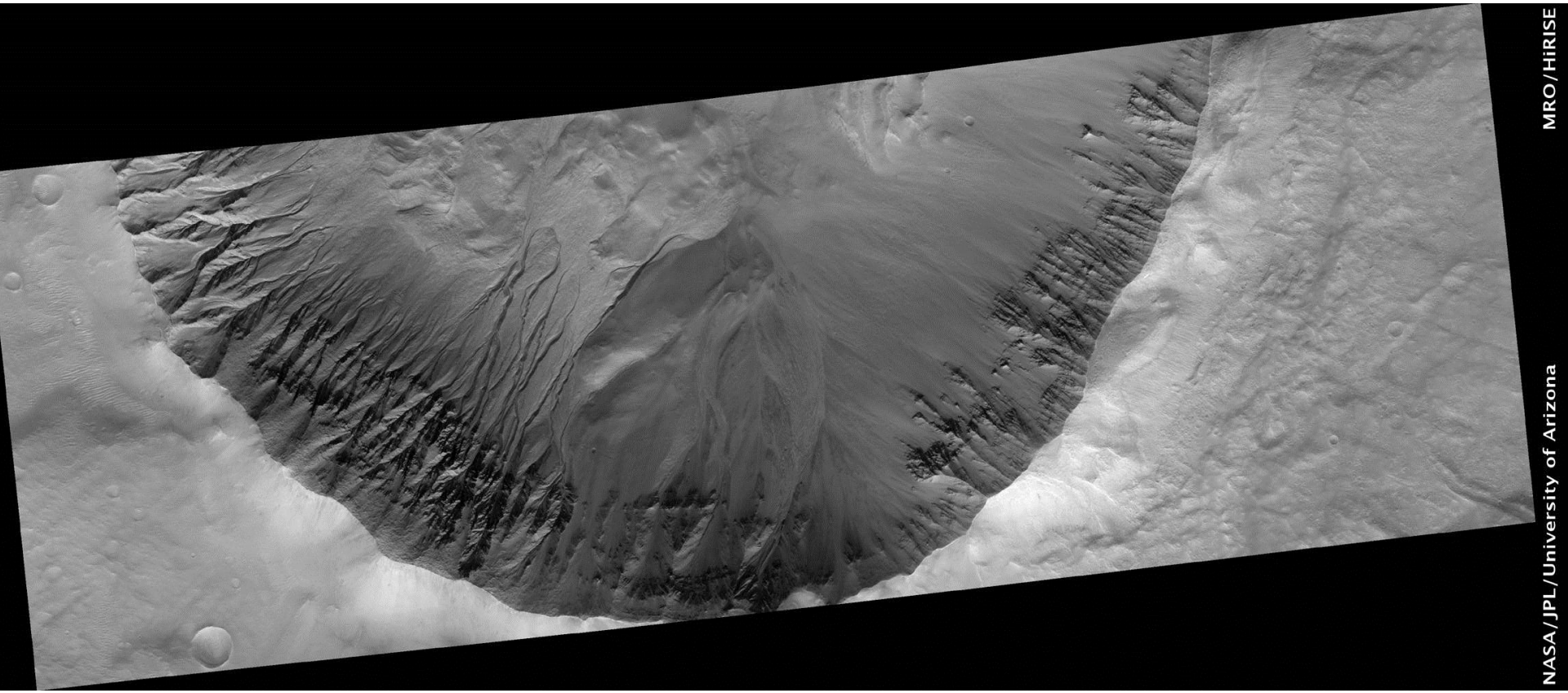


Delta could have a lacustrine origin

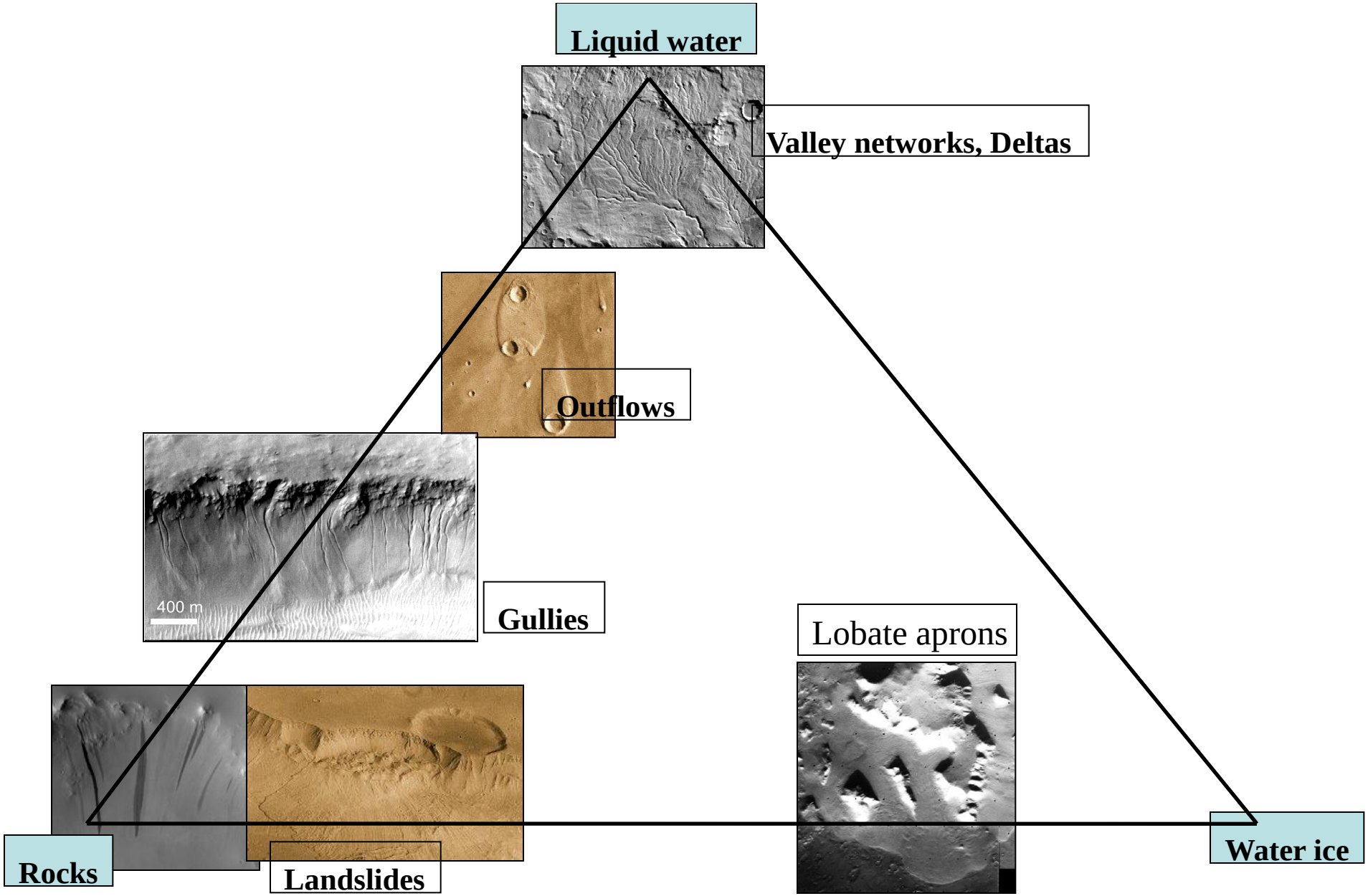
Global map of open basin-lakes



Gullies

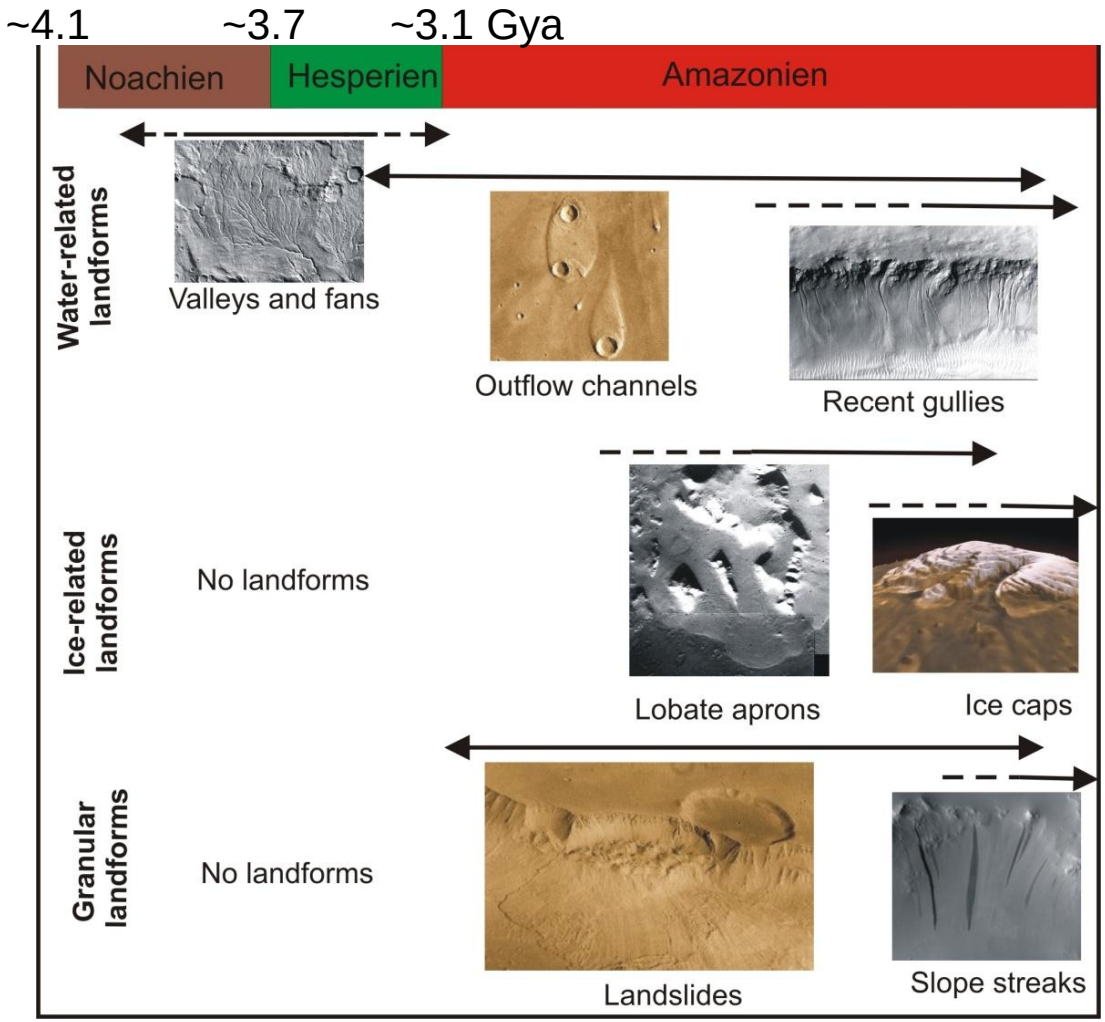


Classification of Surface structures

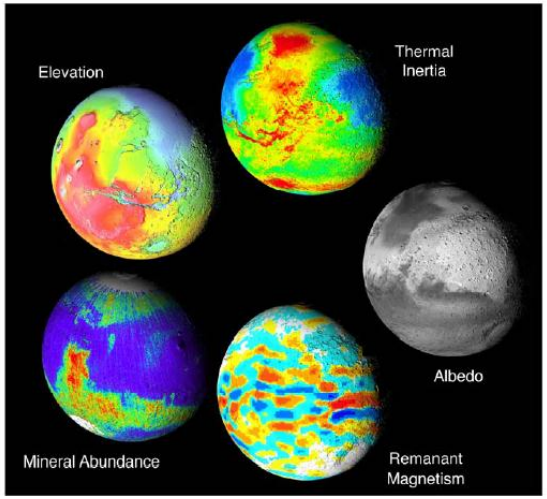


=> Mars history derived from structure surfaces

Mars history derived from surface structures



Mars: the starting point

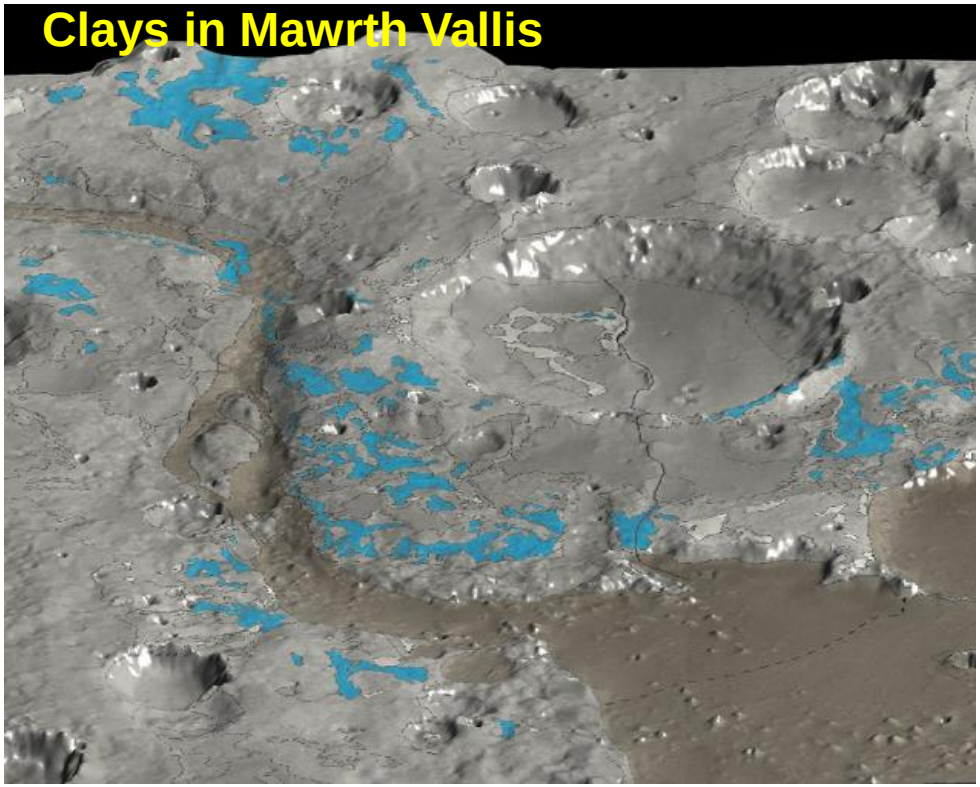


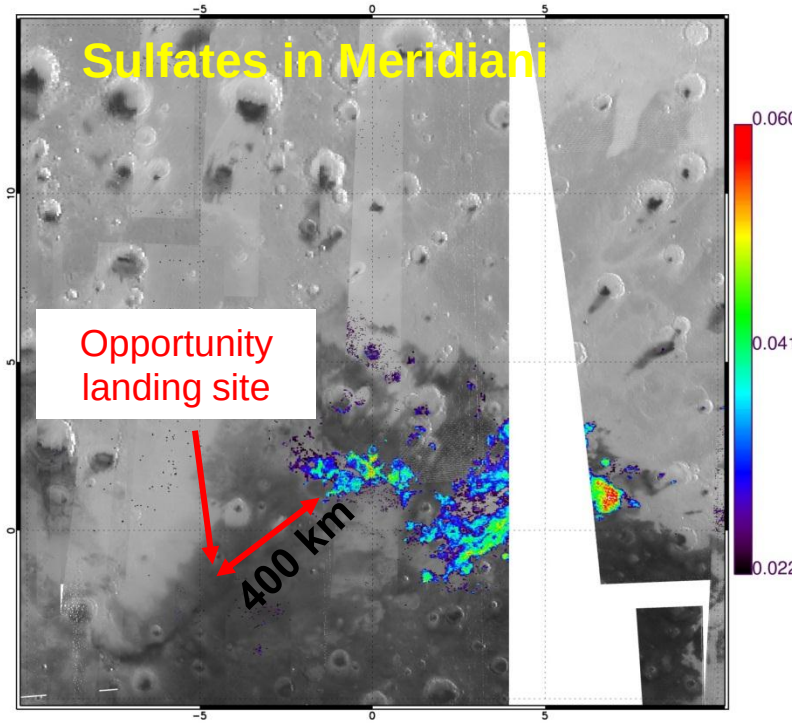
The starting point

- Mars has marked seasons
- Mars has icy polar caps
- Mars present atmosphere is very tenuous and CO_2 rich (96 %)
- Mars has kept the record of its ancient bombardment
- Mars underwent massive volcanic episodes
- Mars exhibits a variety of flooding/fluvial structures
  => Mars history derived from structure surfaces
- Mars has areas with diverse mineralogy, including alteration by liquid water

Hydrated Minerals

- Phyllosilicates widespread in ancient terrains: Alkaline water
- Sulfates in more localized and younger terrains: Acidic waters
- Carbonates and hydrated silica found in very localized terrains



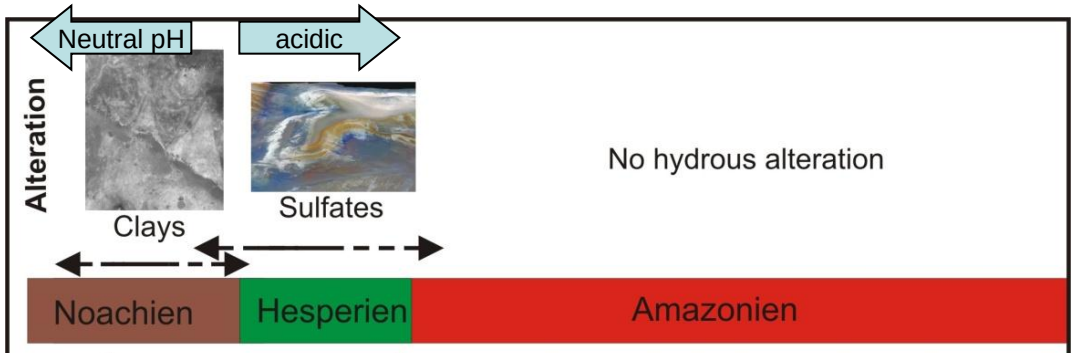


Mineralogy indicates changing environments throughout geologic history

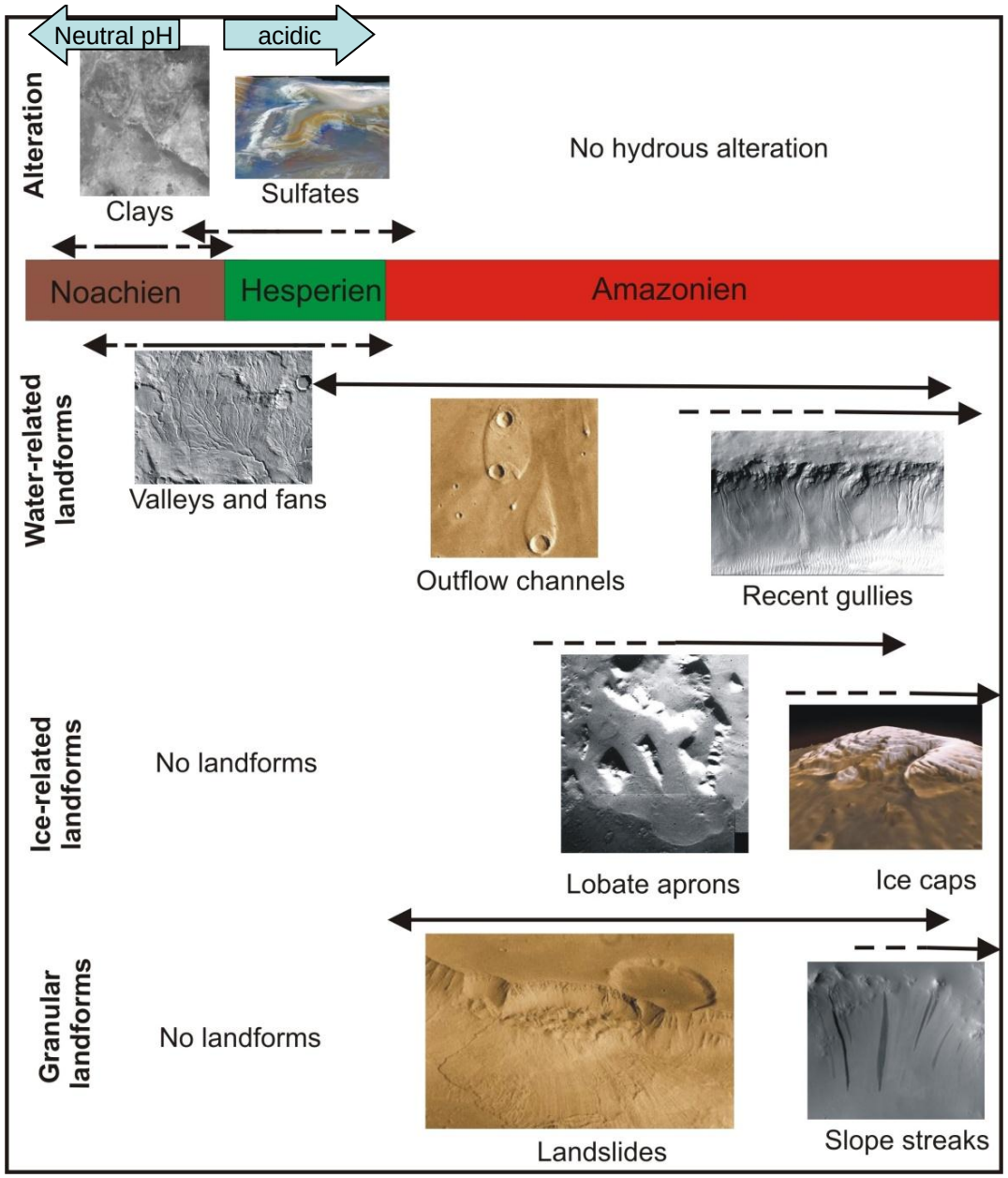
Global map of Hydrated minerals

=> Mars history derived from structure composition

Mars history derived from surface composition



Mars history derived from surface composition and surface structures



Coupled mineralogy and morphology define aqueous environments

Their character has evolved indicating changing environments

Data support liquid water during Early Mars but also indicate greater complexity in local environments and with time

Outline

- The starting point (a short review of the surface characteristics of Mars)
- Study of planetary surfaces (methods and observations)
- Forming planetary surface (crust)
- Mars surface : a planetary surface with very high astrobiological interests

Study of planetary surfaces

Objective: Constrain the formation and the evolution of the planetary body

Physical processes:

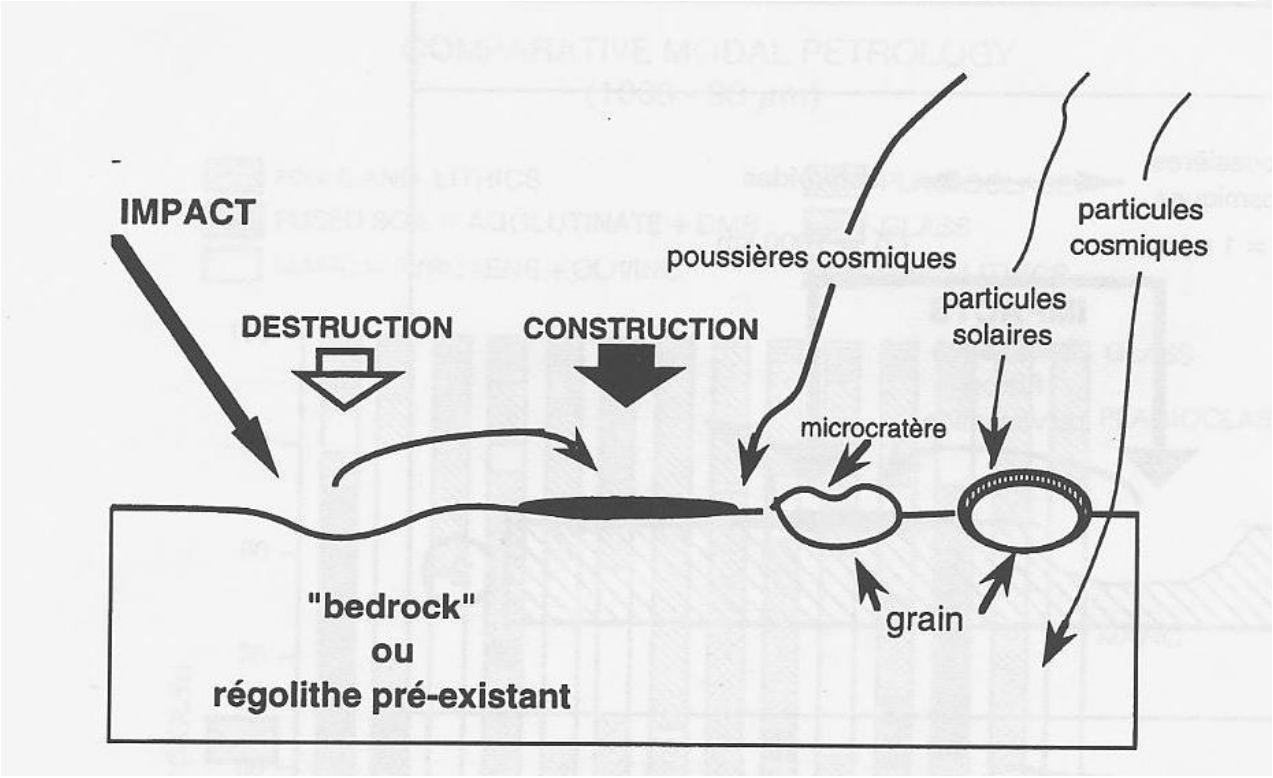
1- Exogenous:

- Impact
- Micro-meteoritic impact
- Charges particles (cosmic rays, solar wind, magnetosphere)
- Solar radiation

2- Endogenous:

- Volcanism
- Tectonics
- Mass motion, viscous relaxation
- Thermal conduction
- Chemical alteration

Study of planetary surfaces: atmosphereless body

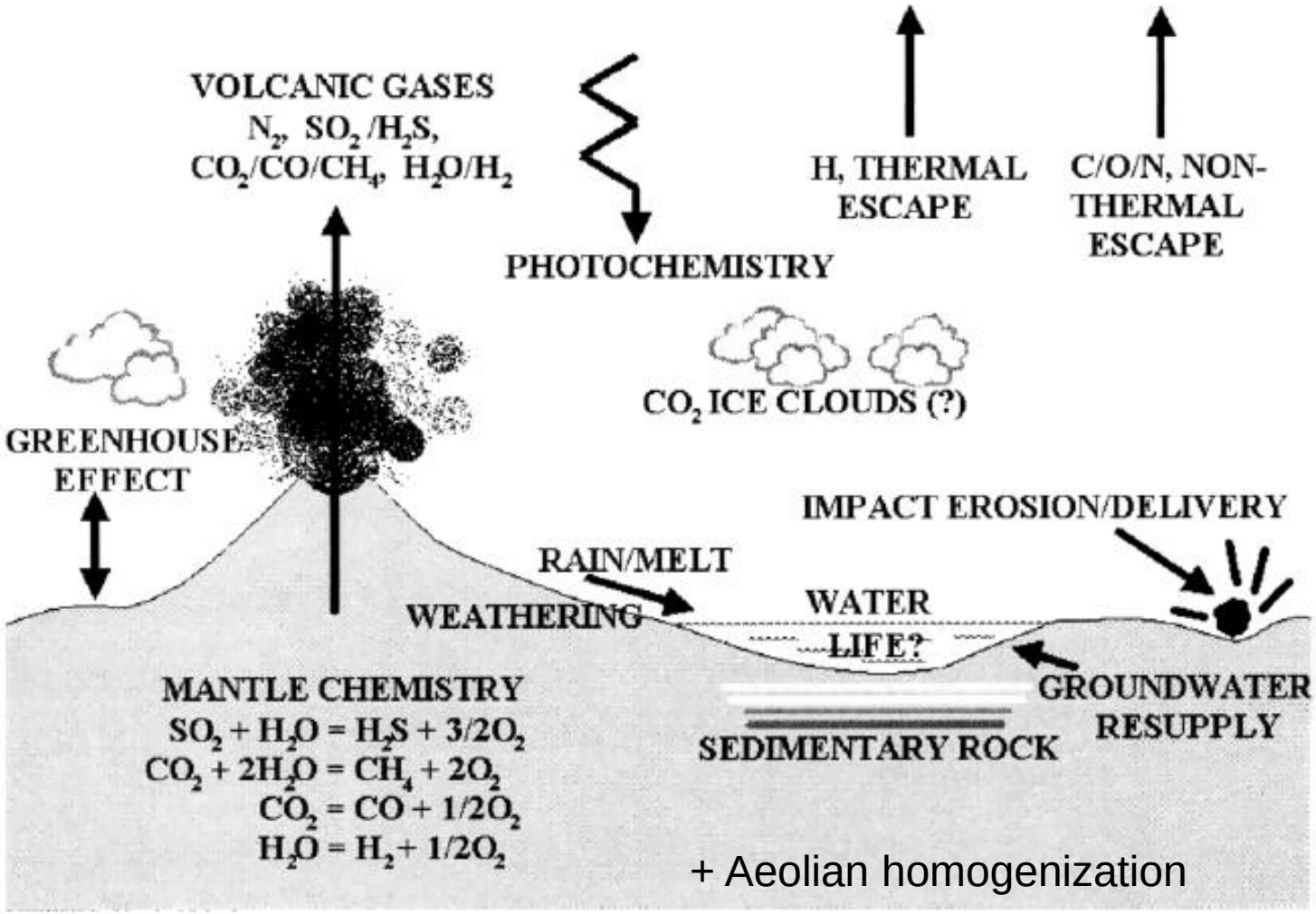


Bedrock → Excavation and exposure → Modify the physical petrographic chemical properties

↑

Impact
Meteorite
Solar Wind
Cosmic Ray (space weathering)

Study of planetary surfaces: Mars



Endogenous processes vary with time

Study of planetary surfaces: Methods

Goal: Characterize and classify the types of surface and material

$\Rightarrow$ Geological unit

Map: Define the spatial extension of geological units and determine their properties:

- Geomorphology
- Thermophysical properties
- Mineralogical composition
- Elemental composition
- Chemical composition

$\Rightarrow$ Each unit is mapable

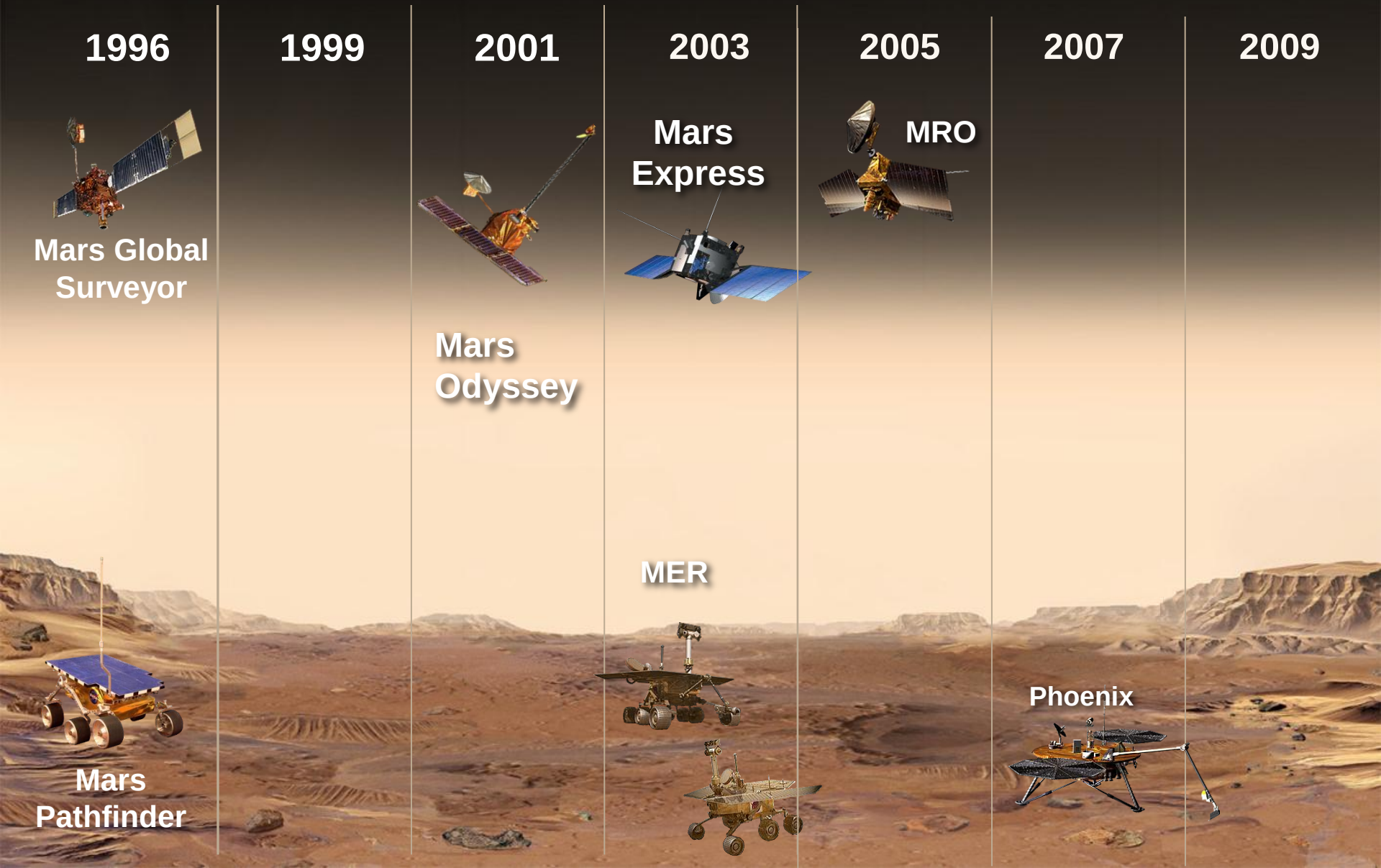
Methods:

1- Remote sensing observations
2- In situ observations (ground-truth)
3- Sample return (next phase)

Remote sensing Observations

METHOD	EM Spectrum	INFORMATION	INTERPRETATION
Gamma-Ray Spectroscopy	Gamma rays	Gamma spectrum	K, U, Th, O, Si, Fe, Mg, Ti (relative) abundances
X-ray Fluorescence spectrometry	X-rays	Characteristic Wavelengths	Surface mineral/ chemical composition
Photometry	UV, Visible	Albedo	Nature of Surface
Multispectral Imagers	UV, Visible, IR	Spectral and Spatial	Surface Features; Composition
Reflectance Spectrometers	Visible, IR	Spectral intensities of reflected solar radiation	Surface Chemistry; Mineralogy
Infrared Radiometer	Infrared	Thermal radiant intensities	Surface composition
Laser Altimeter	Visible/IR	Time delay between emitted and reflected pulses	Surface Relief
Polarimeter	Visible	Surface Polarization	Surface Texture and Composition
Bistatic Radar	Microwave	Surface reflection profiles	Surface Heights; roughness
Imaging Radar	Microwave	Reflections from swath	Topography and roughness
Sounder Radar	Microwave	Multifrequency Doppler Shifts	Surface Profiling and imaging; conductivity

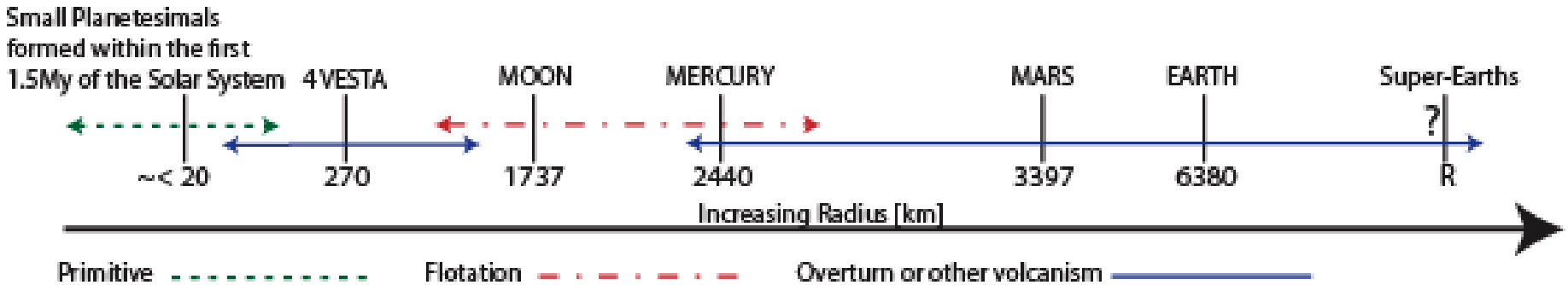
Space exploration after Viking



Outline

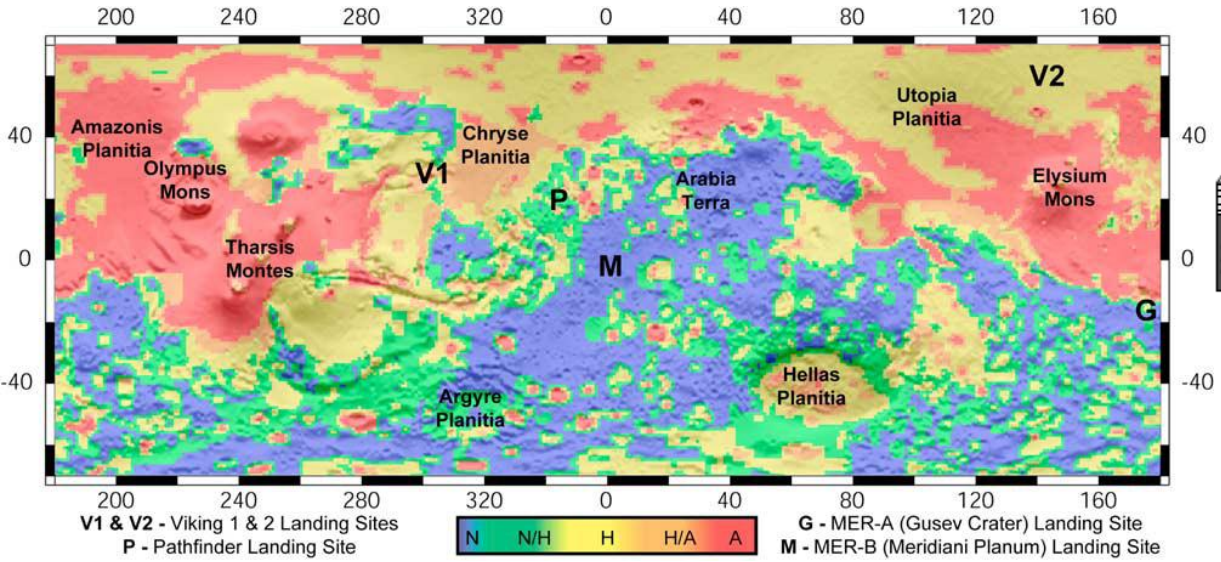
- The starting point (a short review of the surface characteristics of Mars)
- Study of planetary surfaces (methods and observations)
- Forming planetary surface/crust
- Mars surface : a planetary surface with very high astrobiological interests

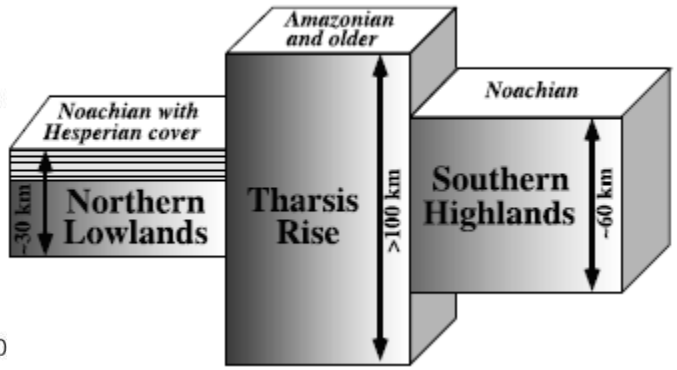
The crust/surface formed on young, rocky planets in three ways, depending on the radius of the body



- Undifferentiated bulk composition
- Flotation of buoyant minerals in a magma ocean (primary crust)
- Production of a volcanic crust through mantle melting (secondary crust)
- Partial melting and differentiation of secondary crustal materials and sediments (tertiary crust)

Constraints on the petrogenesis of the martian crust/surface





Crust >4% of the planetary volume (compared to 1% on the Earth)

- Geomorphology
- Petrology of Martian Meteorites
- In Situ Chemical Analysis of Martian Crustal Rocks
- Surface composition from remote sensing observations

AND

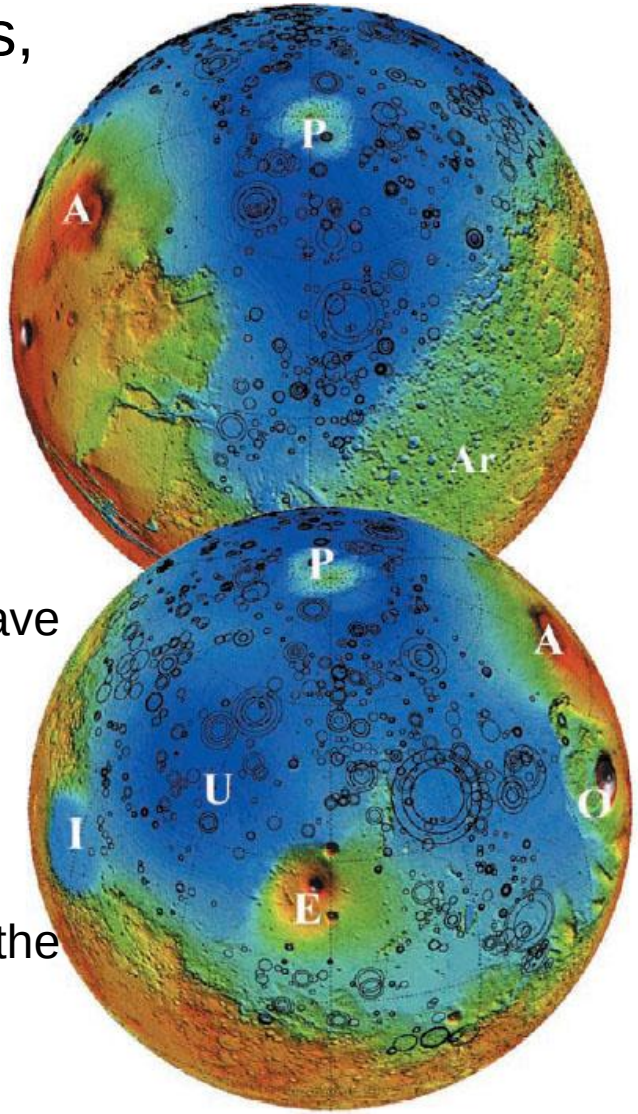
- Petrologic modeling

The first 10^8 years: core formation and differentiation

- T_0 = 4567.2 ± 0.6 Myr
- Rapid formation of planetesimals < 1Myr
- Formation of Chondrules and Chrondrites a few Myr later
- Gas disk dissipates
- Accretion
- Mars :
  - Core formation at 11Myr after T_0
  - Silicate differentiation (crust) at ~40 Myr
- Earth takes longer (~30-100Myr), accretes more embryos
  - Ends with the moon-forming impact, 50-150Myr
  - Earth has a solid surface 4.4 Gya (oldest terrestrial rocks)
- Water delivered

The first 10^8 years: giant impact

- ~50-100 Myr period involves giant impacts, the leading theory for explainning…
  - Stripping of Mercury's silicate mantle
  - Formation of Earth's moon
  - Formation of Mars topographic dichotomy



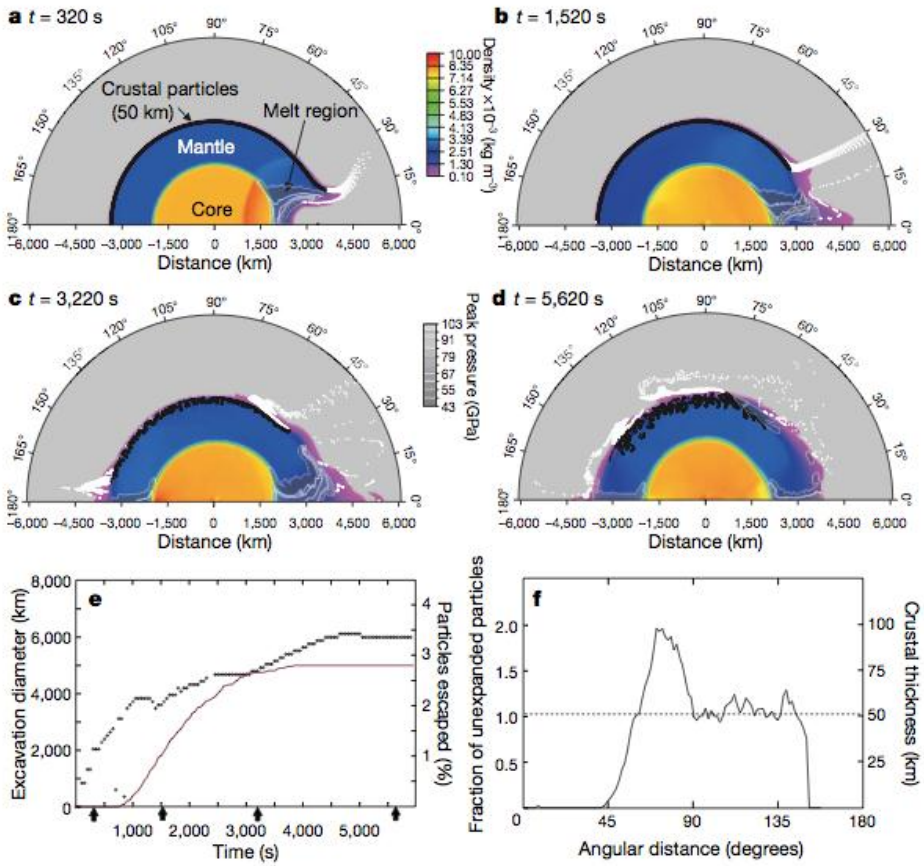
- Mars dichotomy

  Despite all the differences, this is only skin deep
  - Buried impact basins in the northern hemisphere have been mapped
  - Before this burial the northern and southern hemispheres were indistinguishable in age
  - Rules out Earth-style plate tectonics
  - Northern hemisphere is a thinly covered version of the southern hemisphere, just mantled by 1-2 km of material (sediments and volcanic flows)

The first 10^8 years: giant impact

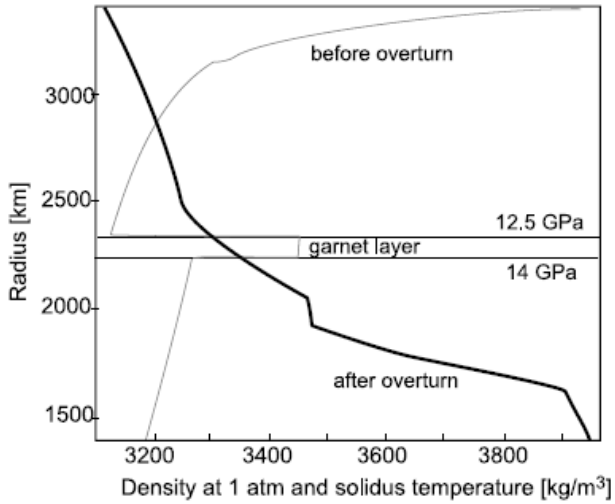
Hydrocode modeling of a vertical and oblique impacts:

- 6-10 km/sec at 30-60°, diameter 1600–2700 km, 3x1029 J impact
- No global melting – melt layer 10s of km thick within basin



The first few 10^8 years : Primary crust

- Formation of a magma ocean with anorthosite (plagioclase feldspar) floating
  - Floats in an anhydrous melt – moon, mercury?
  - Sinks in a hydrated melt – Earth, Mars, Venus
- Olivine and Pyroxene:
  - Sink faster in the shallow magma ocean
- Overturn:



=> A basaltic primary crust/mantle (initial volatile contents, silica content)

Geochemical conditions and outgassing of atmosphere during early Mars

Crustal evolution: Heat and heat transport sources

- Primary energy (~20%)
  - Accretion
  - Gravitational energy due to core formation

- Decay of radioactive elements (~80%)
  - Uranium
  - Thorium
  - Potassium

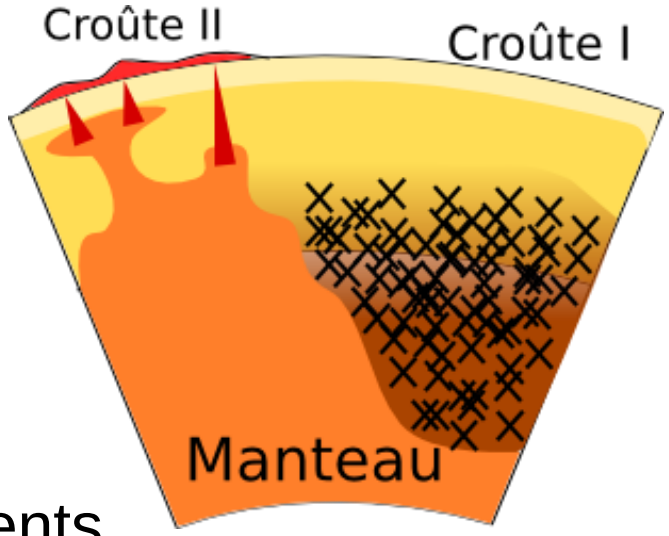
+ Heat Transport Mechanisms

=> Magma transport (volcanism)

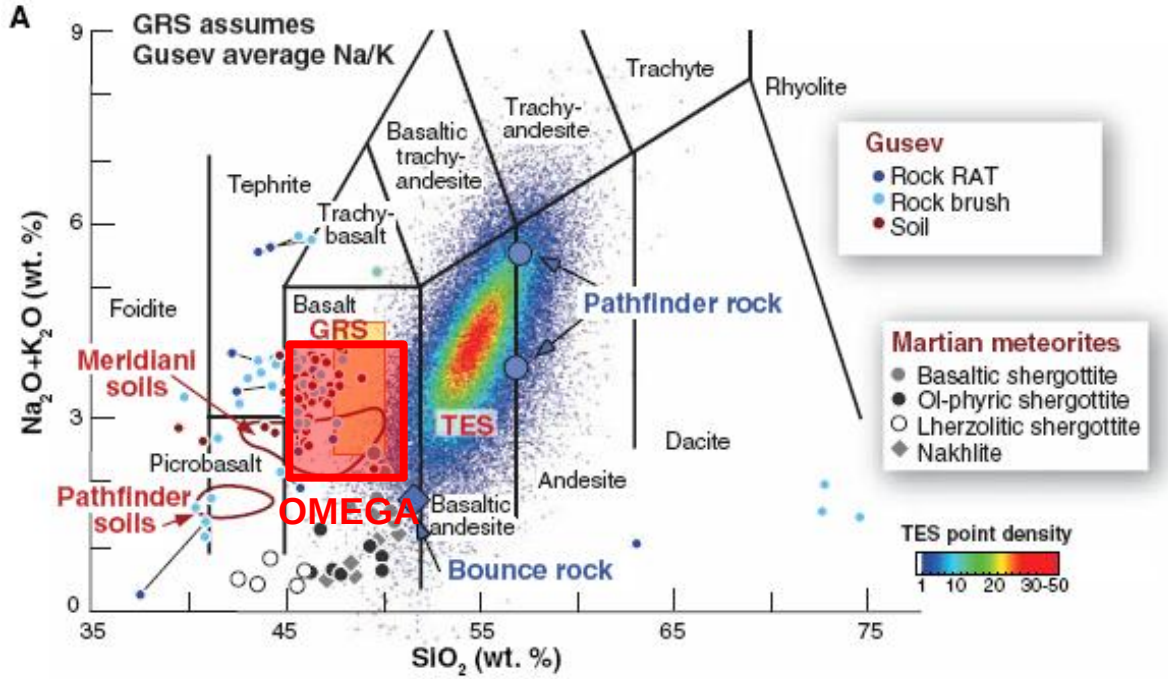
Crustal evolution: Secondary basaltic crust

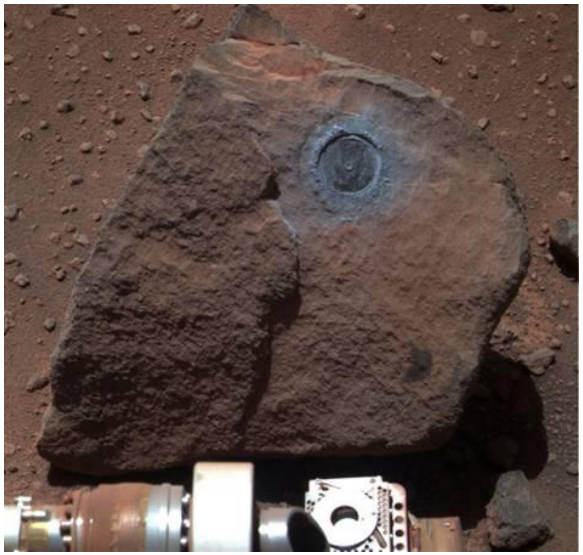
- Volcanism => Volatile content and atmospheric evolution

Need to sample very old rocks!!!



- Martian in-situ and orbital measurements



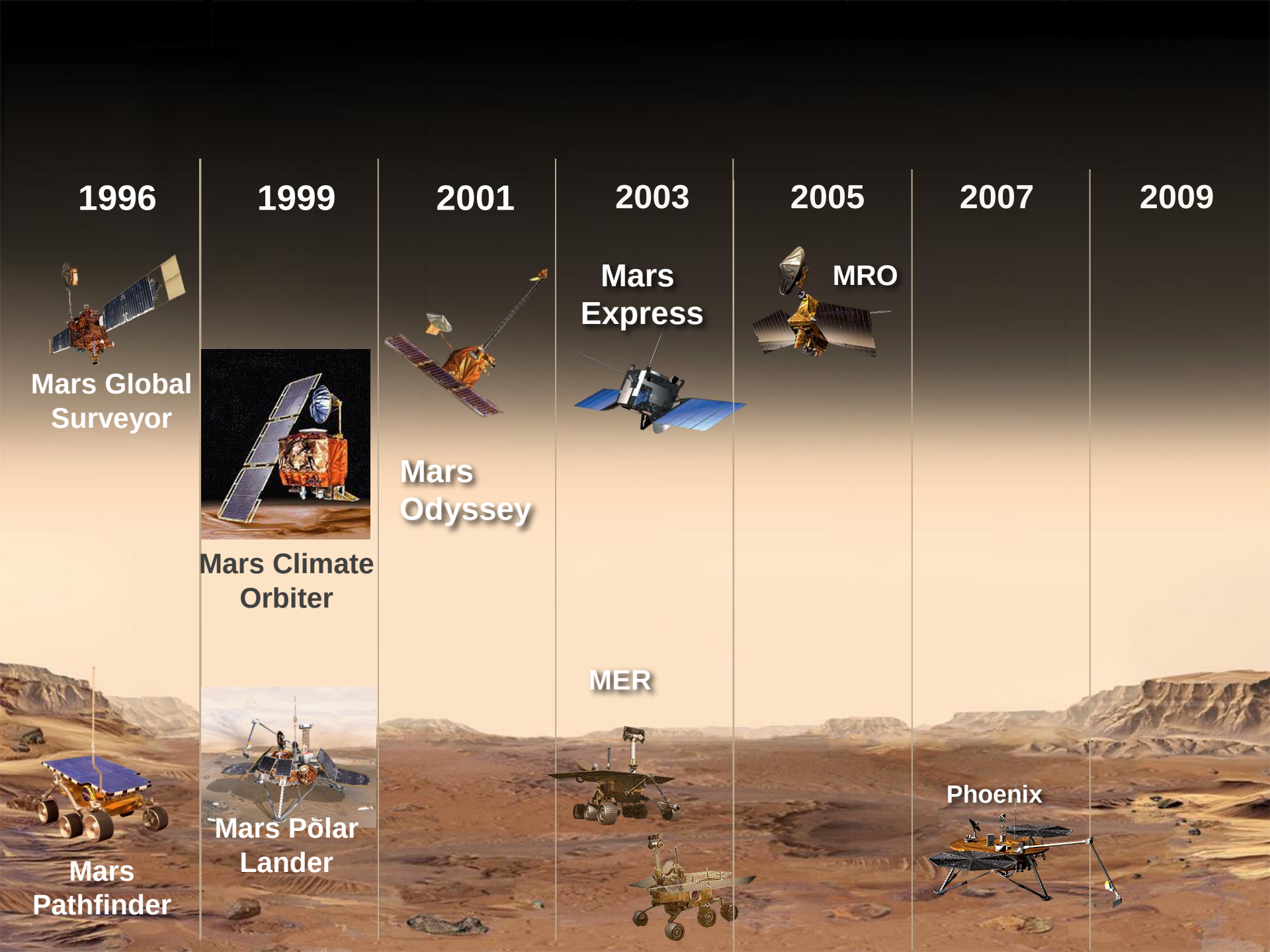


Outline

- The starting point (a short review of the surface characteristics of Mars)
- Study of planetary surfaces (methods and observations)
- Forming planetary surface/crust
- Mars surface : a planetary surface with very high astrobiological interests

Outline

- The starting point (a short review of the surface characteristics of Mars)
- Study of planetary surfaces (methods and observations)
- Forming planetary surface/crust
- Mars surface : a planetary surface with very high astrobiological interests
  - Major results from the last decade
  - Clay minerals: high habitability and biosignatures preservation potential


1996
1999
2001
2003
2005
2007
2009
Mars Global Surveyor
Mars Climate Orbiter
Mars Odyssey
Mars Express
MRO
MER
Mars Pathfinder
Mars Polar Lander
Phoenix

Last Decade Discoveries: Diverse Planet with Complex History

We have made significant advances in understanding the processes and history of climate, as well as understanding the evolution of the surface.

→ 1. Mars has areas with diverse mineralogy, including alteration by water, with a change in mineralogy and deposition settings over time

→ 2. Water ice in globally distributed, near-surface reservoirs

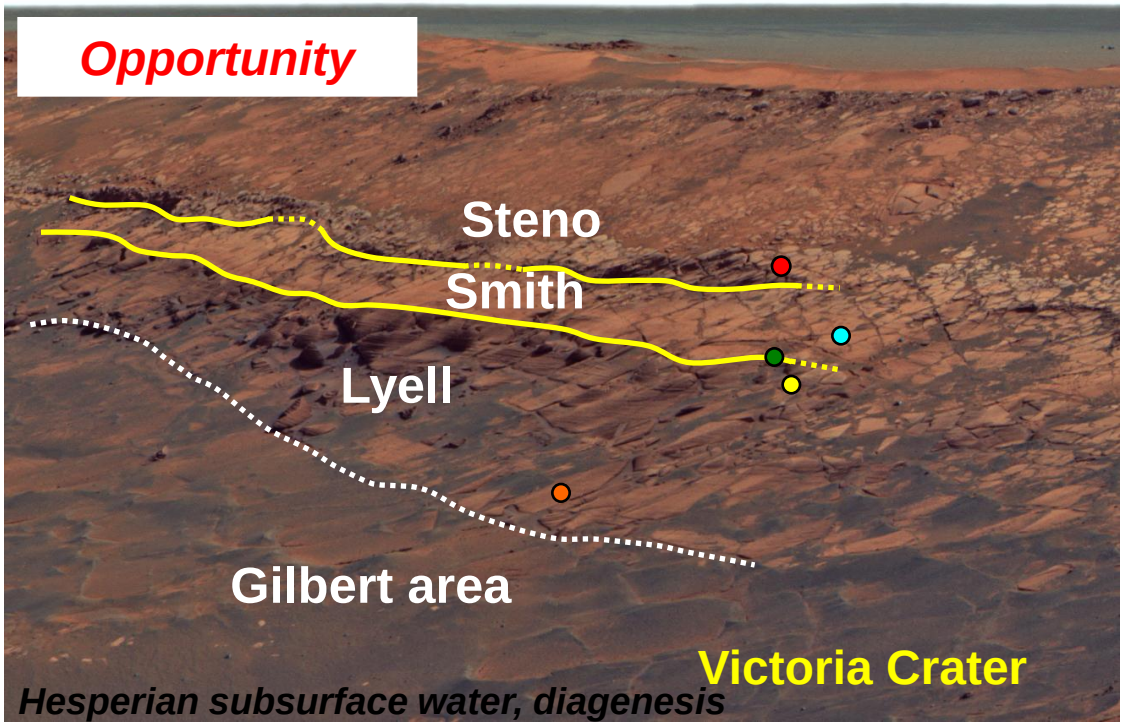
3. Increasing evidence for geologically recent climate change (stratified layers in ice and in rock) and volcanism

4. Dynamic change occurring even today: landslides, new gullies, new impact craters, changing CO_2 ice cover

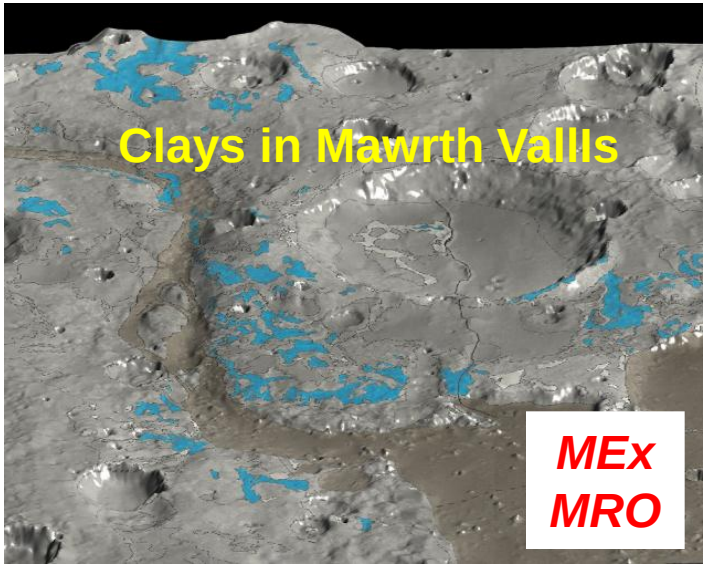
- Based on much of the above, the perception of *Potential for past Life* has increased, and *Modern Life* may still be possible.

Last Decade Discoveries:
1a. Diversity of water-related environments

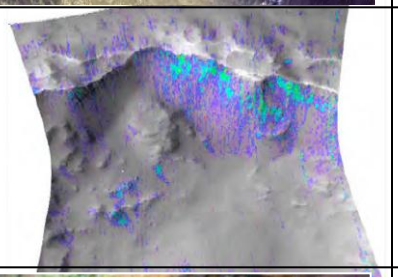
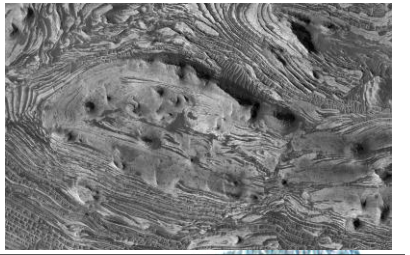
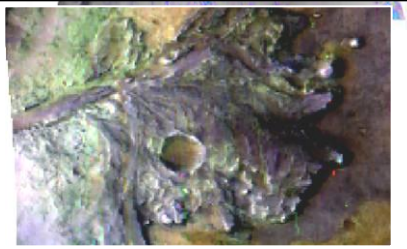
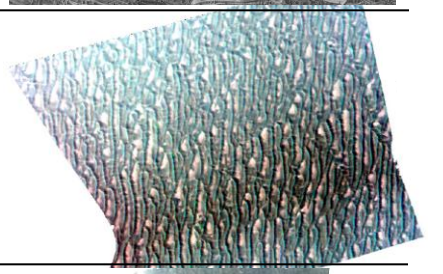
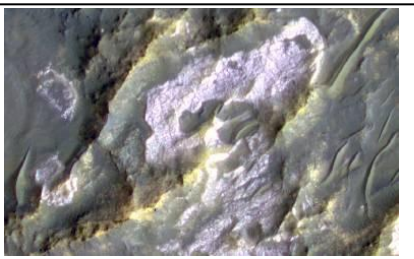
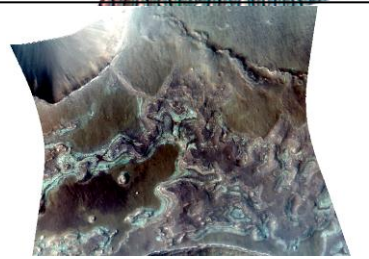
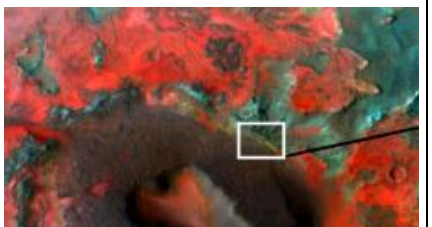
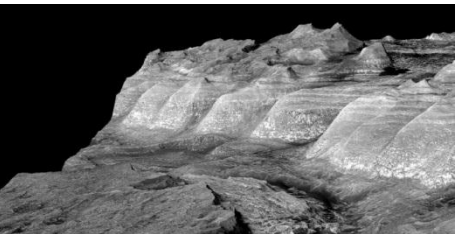
- **Chemistry indicates changing environments throughout geologic history**
  - Acidic waters at Meridiani
  - Basic waters at Phoenix landing site
  - Evolution with time: clays to sulfates to oxides



Hesperian subsurface water, diagenesis



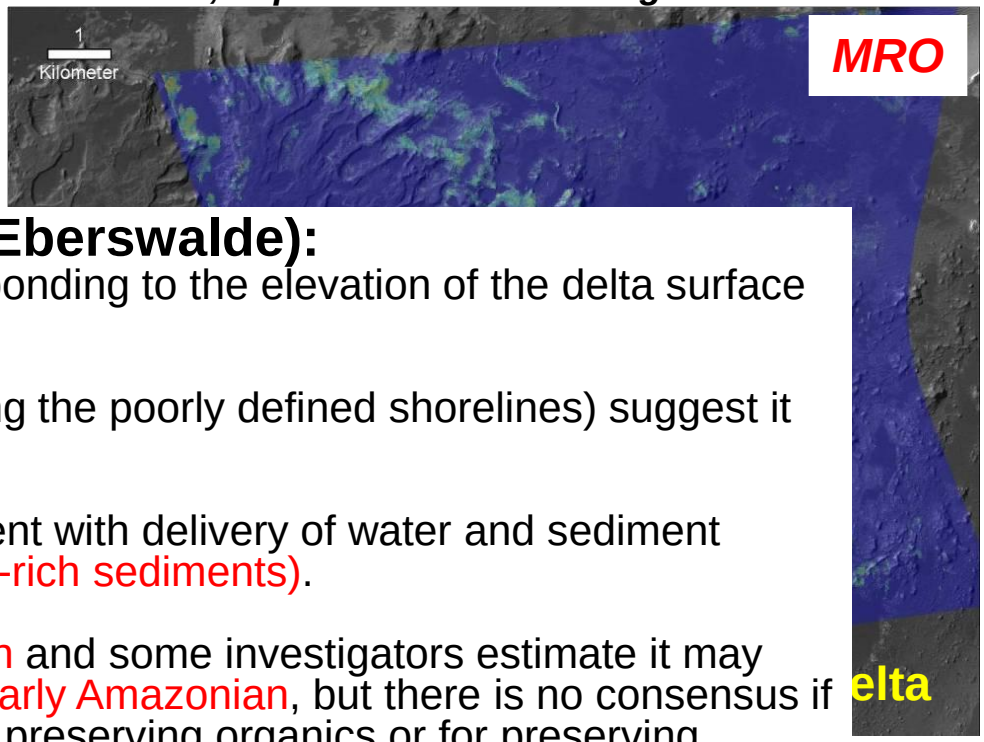
Last Decade Discoveries:
1b. Diverse Hydrous Mineral Deposits

Noachian layered clays (type: Mawrth Vallis)		Early Hesperian Sulfate-rich layered deposits (type: Terra Meridiani)	
Deep Noachian phyllosilicates exposed in highland craters, chasma walls (type: Tyrrhena Terra)		Hesperian Sulfate-rich Valles-type layered deposits (type: Candor Chasma)	
Fans with phyllosilicate-rich layers (type: Jezero, Eberswalde)		Amazonian gypsum deposits (type: Olympia Undae)	
Noachian "glowing terrain" Chloride deposits (type: Terra Sirenum)		Hesperian hydrated silica (type: Ophir Planum, Gusev)	
Mg-Carbonate/olivine assemblages (type: Nili Fossae, Gusev)		Interbedded sulfates and clays (type: Gale Crater)	

Last Decade Results:
1c. Water-related structure (Episodically wet?)

Channels formed by rainfall runoff

Delta, deposition into standing water

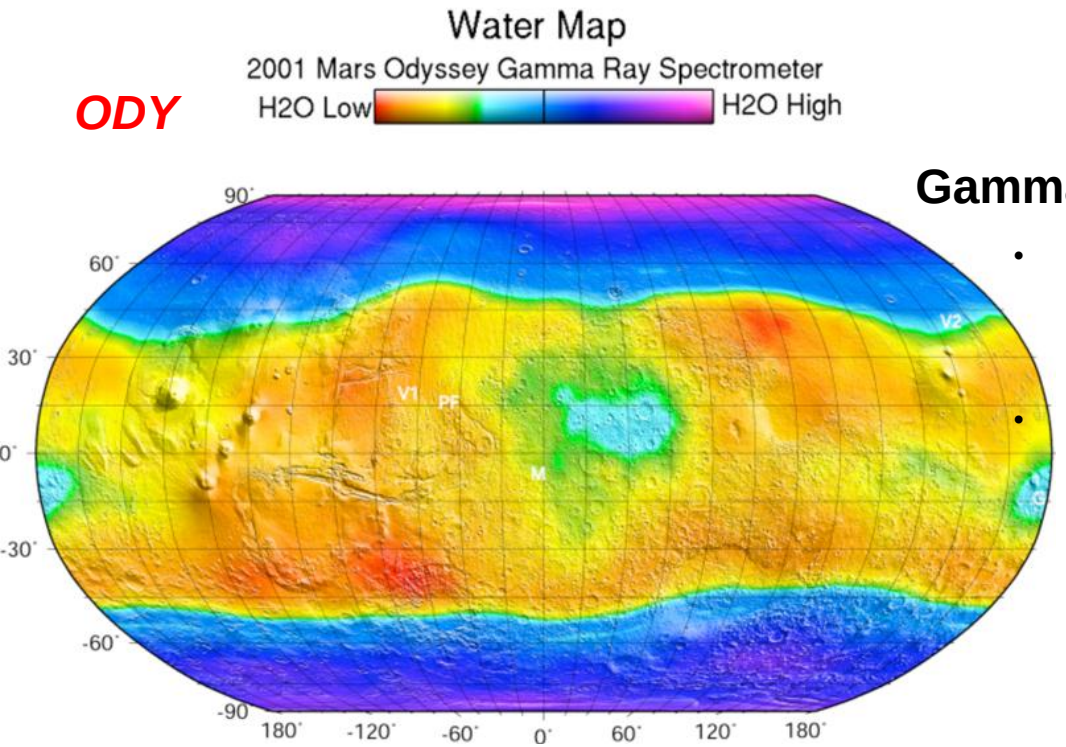


Remaining Uncertainties (e.g. Eberswalde):

- Little evidence for shorelines corresponding to the elevation of the delta surface and the spillway to the eastern basin
- Some aspects of the system (including the poorly defined shorelines) suggest it may have been ice-covered.
- Delta emplacement might be consistent with delivery of water and sediment shortly after the Holden impact (in icy-rich sediments).
- Delta is no older than Early Hesperian and some investigators estimate it may have been deposited as late as the Early Amazonian, but there is no consensus if a post-Noachian age is a concern for preserving organics or for preserving evidence for past habitability or life on Mars.

(adapted from masoweb)

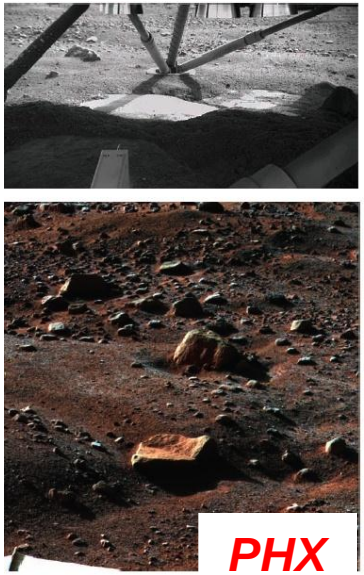
Last Decade Results:
2. Distribution of Modern Water



Global Near-Surface Reservoirs of Water

Gamma Ray Spectrometer

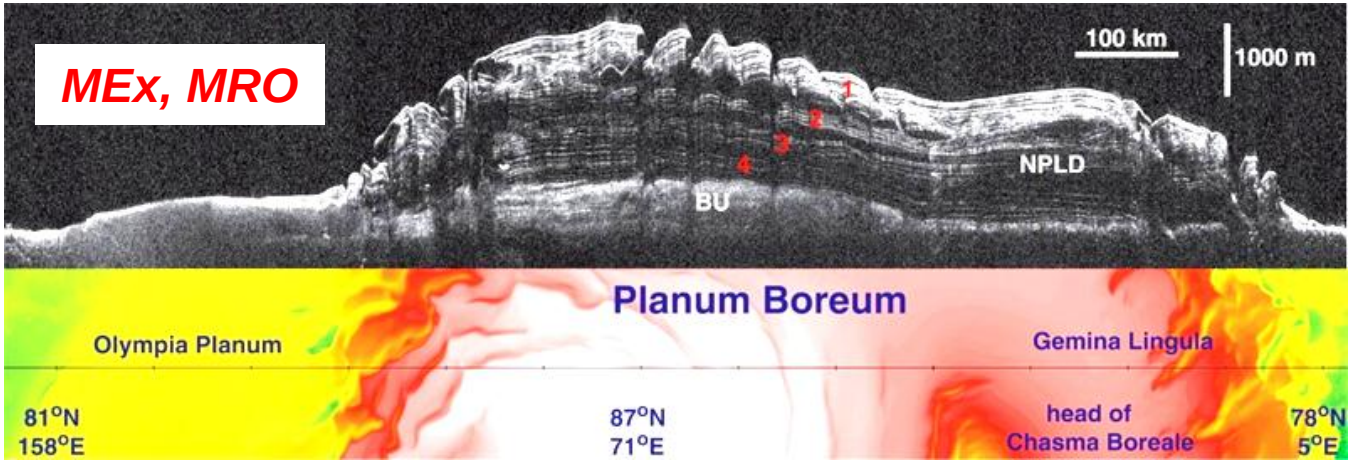
- Global hydrogen abundance and equivalent H_2O
- Ground ice to +/-60° in high abundance



Phoenix results

SHARAD and MARSIS

- Nearly pure water ice
- Distinct layering
- Ice-cored lobate debris aprons in mid-latitudes



Mars: a planetary surface with very high astrobiological interests

→ 1. Mars provides a means to approach, and possibly answer, origin and evolution of life questions

1. Mars provides a means to approach, and possibly answer, origin and evolution of life questions

❑ Potential for past life has increased

- Lots of ancient liquid water in diverse environments
- Past geological environments, which have reasonable potential to have preserved the evidence of life, had existed.
- Understanding variations in habitability potential is proving to be an effective search strategy

=> We have a means to prioritize candidate sites (Let's explore them!)

❑ Potential for modern life still exists

- Evidence of modern liquid water at surface is unlikely
- Liquid water in deep subsurface
- What about methane? It may be a critically important clue to subsurface biosphere

=> We have not yet identified high-potential surface sites, and the deep subsurface is not yet accessible by space exploration

Mars: a planetary surface with very high astrobiological interests

1. Mars provides a means to approach, and possibly answer, origin and evolution of life questions
2. → Mars offers crucial information about the early evolution of the terrestrial planets, including Earth

2. Mars offers crucial information about the early evolution of the terrestrial planets, including Earth

- Mars retains history that has been completely erased from Earth (and Venus)
  - Earth's oldest rocks >3.5 billion years old are rare (<<1%) and usually altered; Mars rocks exist at >4.0 billion years (determined from dating Mars meteorites)
- This is the period of time when life evolved on Earth
  - *As interpreted from chemical signatures in rock at 3.8 billion years (earliest microfossils are 3.0 billion years old)*

Mars: a planetary surface with very high astrobiological interests

1. Mars provides a means to approach, and possibly answer, origin and evolution of life questions
2. Mars offers crucial information about the early evolution of the terrestrial planets, including Earth
3. → Mars provides excellent opportunity to investigate short- and long-term climate change

3. Excellent opportunity to investigate short- and long-term climate change

- Preserved records of global environmental change
  - Layered terrains in high- and low- latitudes indicative of cyclic changes related to orbital and axial variations
  - Evidence of hydrous mineralogy changing from clays to sulfates to oxides. Mars morphology indicates water evolution over time in cooling environment.
- Modern climate may provide clues regarding solar forcing or internal process drivers of atmospheric escape
- The internal structure of a planet provides clues to the atmospheric origin and evolution

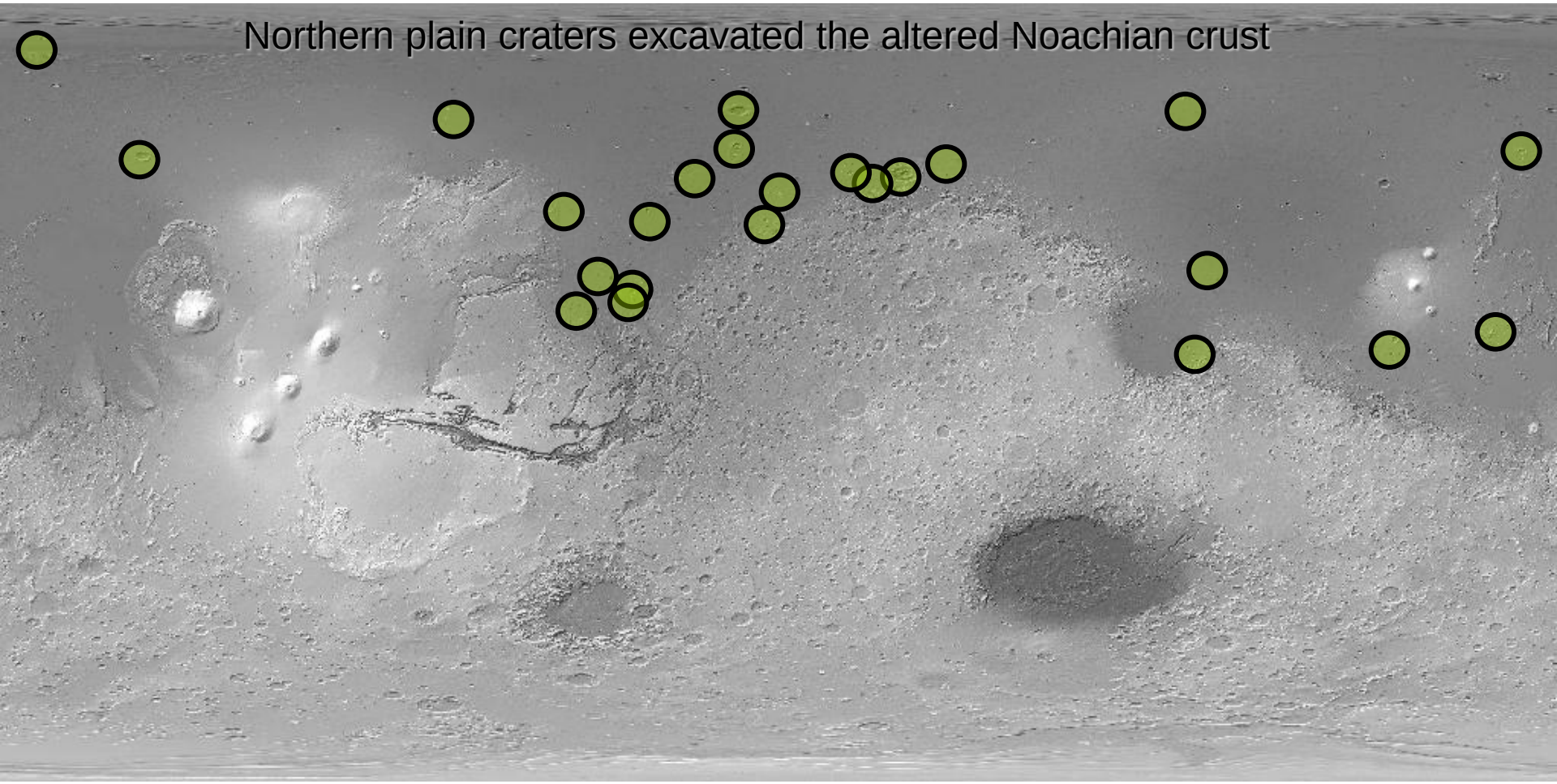
Outline

- The starting point (a short review of the surface characteristics of Mars)
- Study of planetary surfaces (methods and observations)
- Forming planetary surface (crust)
- Mars surface: a planetary surface with very high astrobiological interests
  - Major results from the last decades
  - Clay minerals: high habitability and biosignatures preservation potential

Global mapping of hydrated minerals on Mars

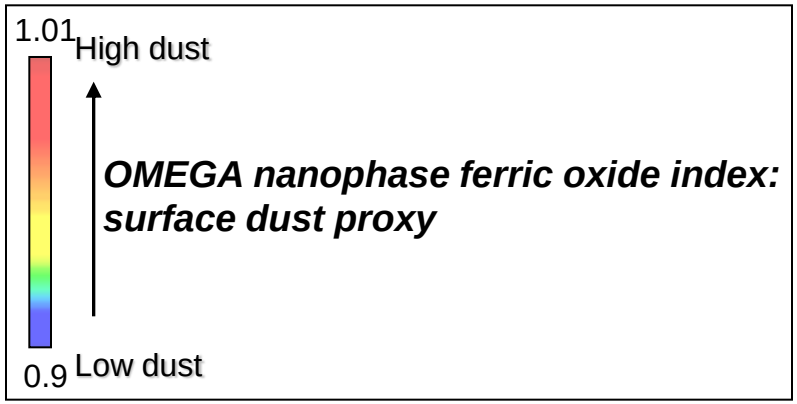
OMEGA/CRISM-based map

The Northern plains of Mars: a pre-Noachian basement and surviving Noachian structures



10s northern plain craters with hydrated minerals

Global map – physical biases



→ Most of the detections are found in dusty-free regions

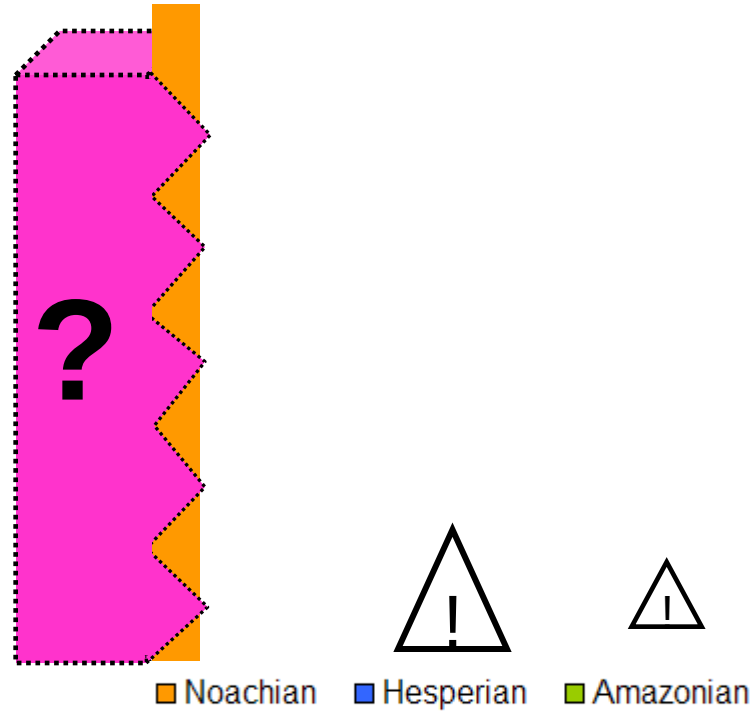
Mineral exposure ages

Mostly Noachian material exposed and/or remobilized in younger terrains

Northern craters

Deltas

Mineral exposure ages



Pre/Early-Noachian

What deposits are actually pre-LHB ?

Geological context

Various landforms: Outcrops,
scraps, fans, deltas, mesas, knobs

Craters

79%

→ **Associated with impact craters**

Mineral composition

Mineral occurrence in deposits

Spectral classes

and salts

+ *Fe/Mg carbonates, K-rich, serpentines < 1 %*

Major trend ➔ Dominated by phyllosilicates

What can clay minerals tell us?

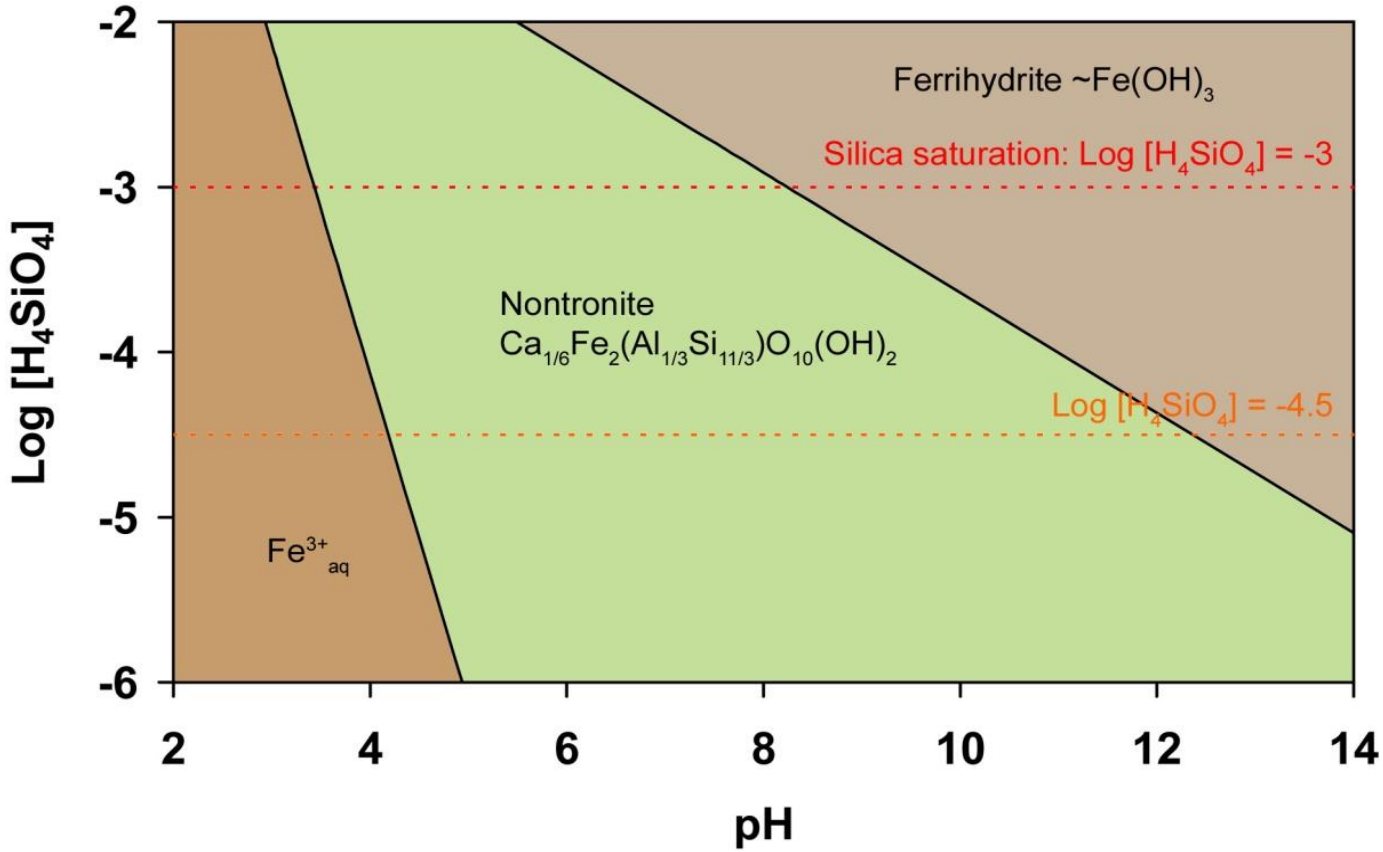
- That liquid water was present!

- That alteration took place at (relatively) low temperatures (e.g., weathering)

- Water compositions
– open vs. closed hydrologic systems

- Whether any post-formation alteration took place
– diagenesis, metamorphism

What can clay minerals tell us?



Silica activity often controls the formation of clay minerals

Mineral composition

Mineral occurrence in deposits

Spectral classes

Low T, Low P

Neutral/alkaline pH

and salts

+ *Fe/Mg carbonates, K-rich, serpentines < 1 %*

Formation processes of clays

Three principle pathways for formation:

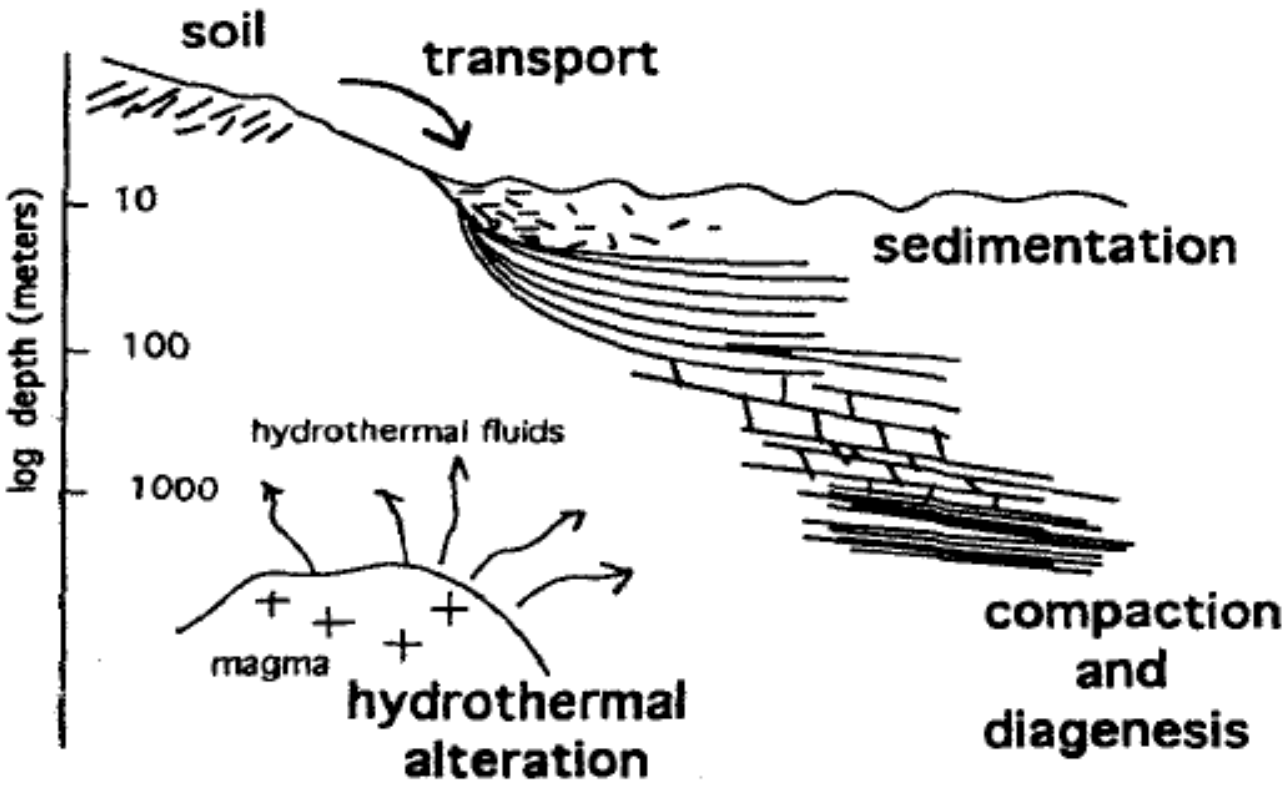
1. Neoformation
   - Precipitate directly from soil or matrix solutions
   - Low temperature

2. Weathering transformation of other phyllosilicates
   e.g., mica weathering to smectite

3. Hydrothermal alteration
   - Heat source, e.g., volcanic or impact events
   - Burial metamorphism or diagenetic conditions

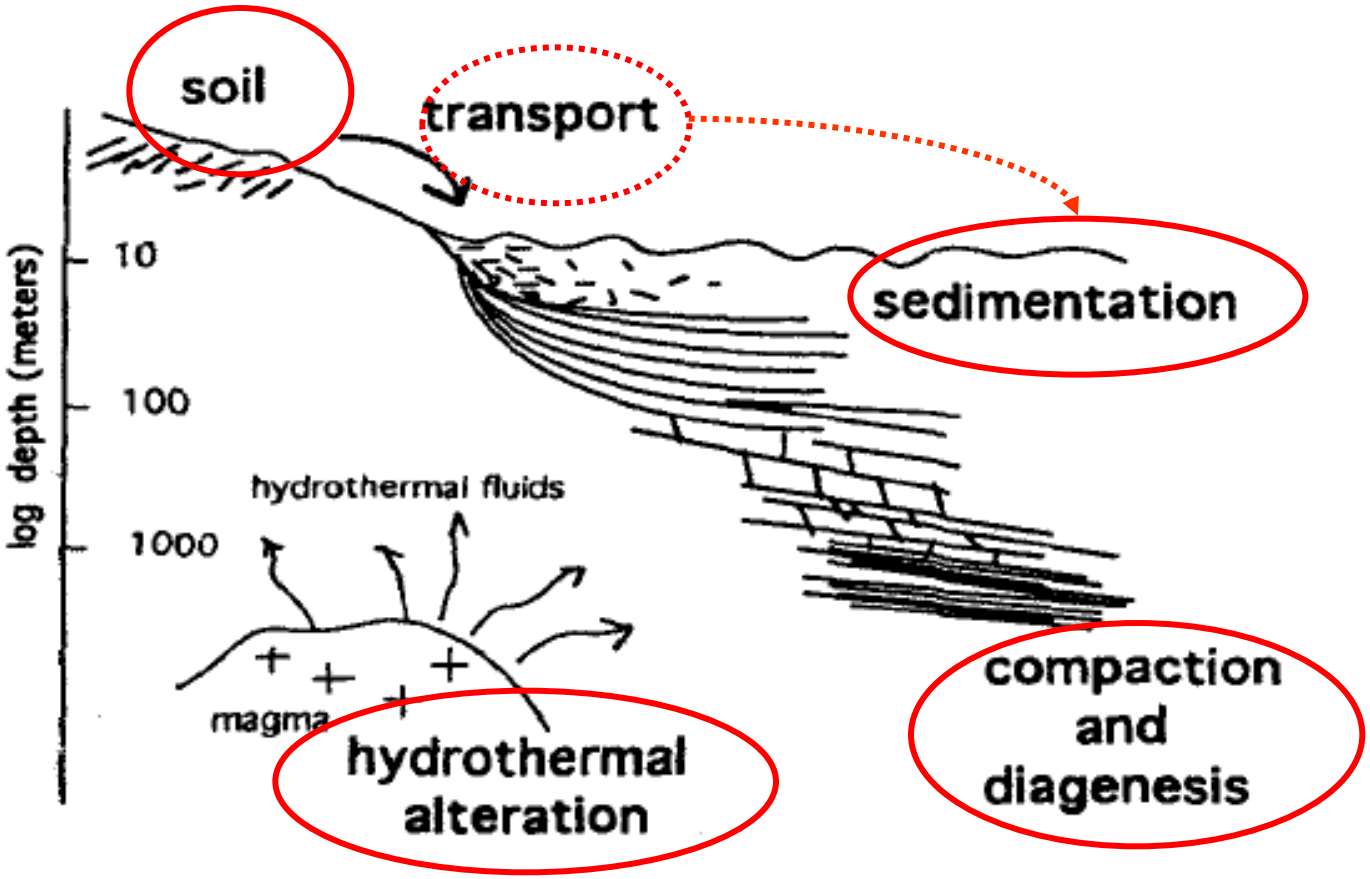
Formation processes : clay cycle on Mars?

Earth clay mineral formation and life cycles (Velde 1995)



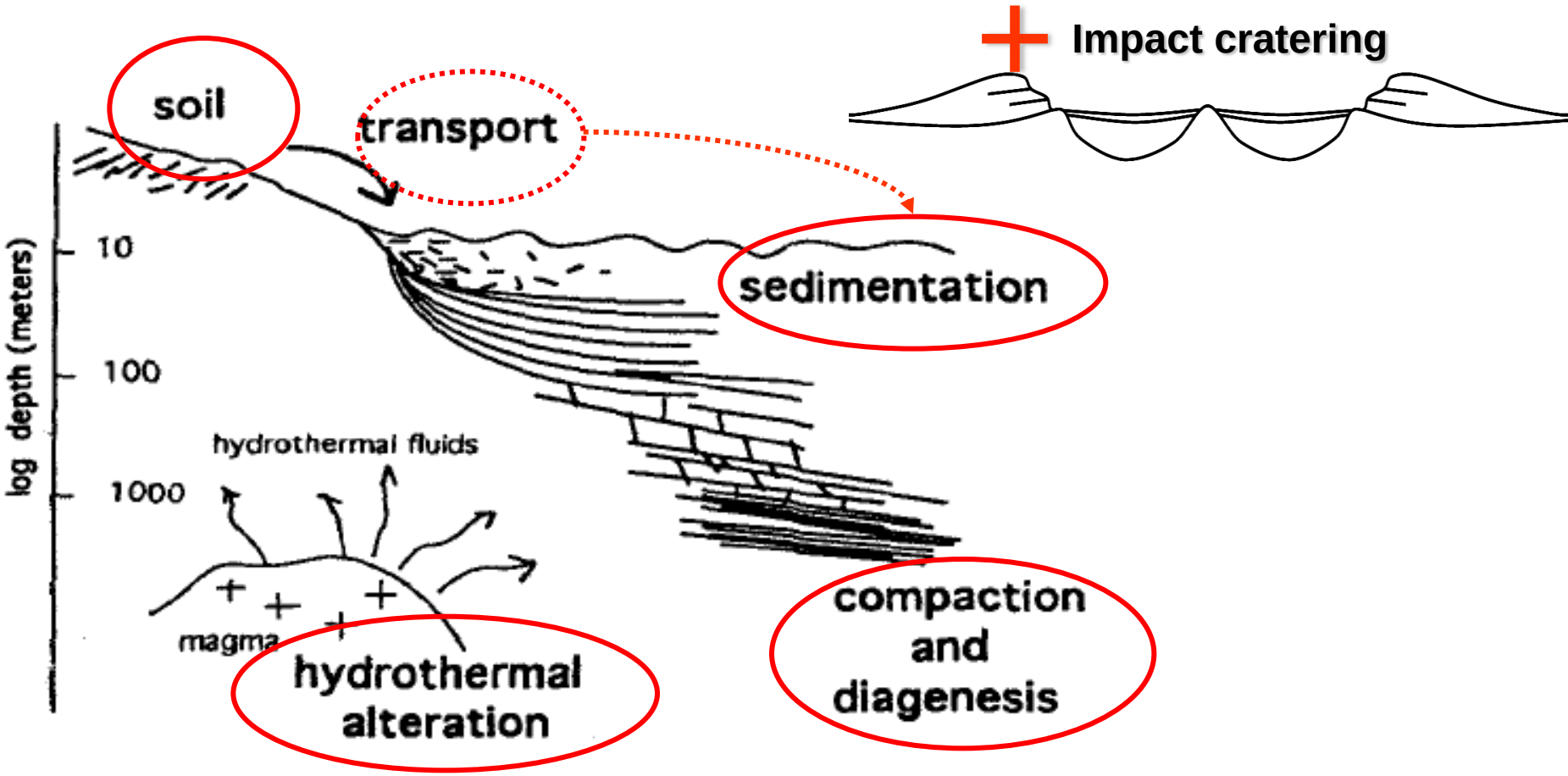
Formation processes : clay cycle on Mars

Earth clay mineral formation and life cycles (Velde 1995)



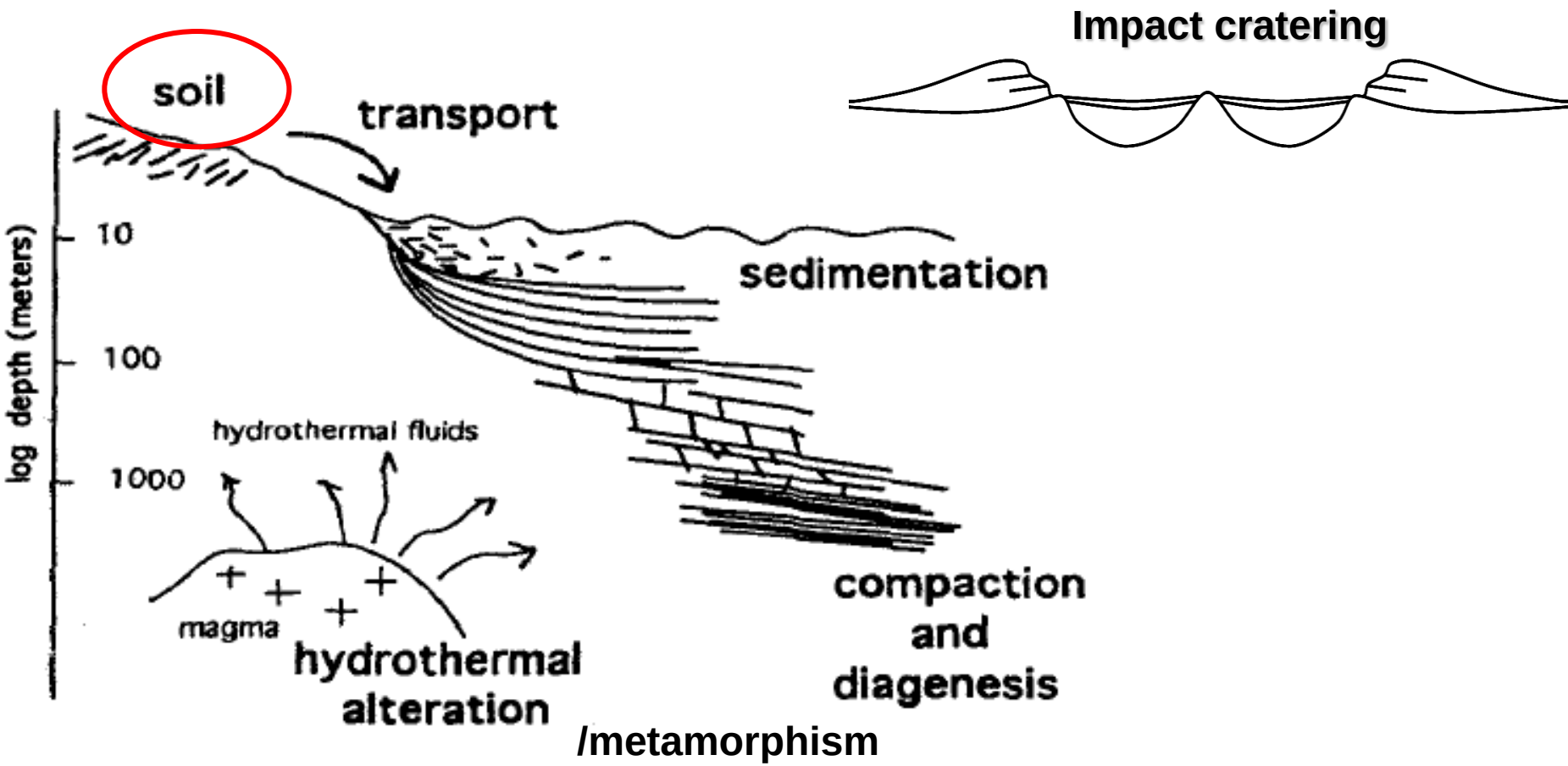
Formation processes : clay cycle on Mars

Earth clay mineral formation and life cycles (Velde 1995)

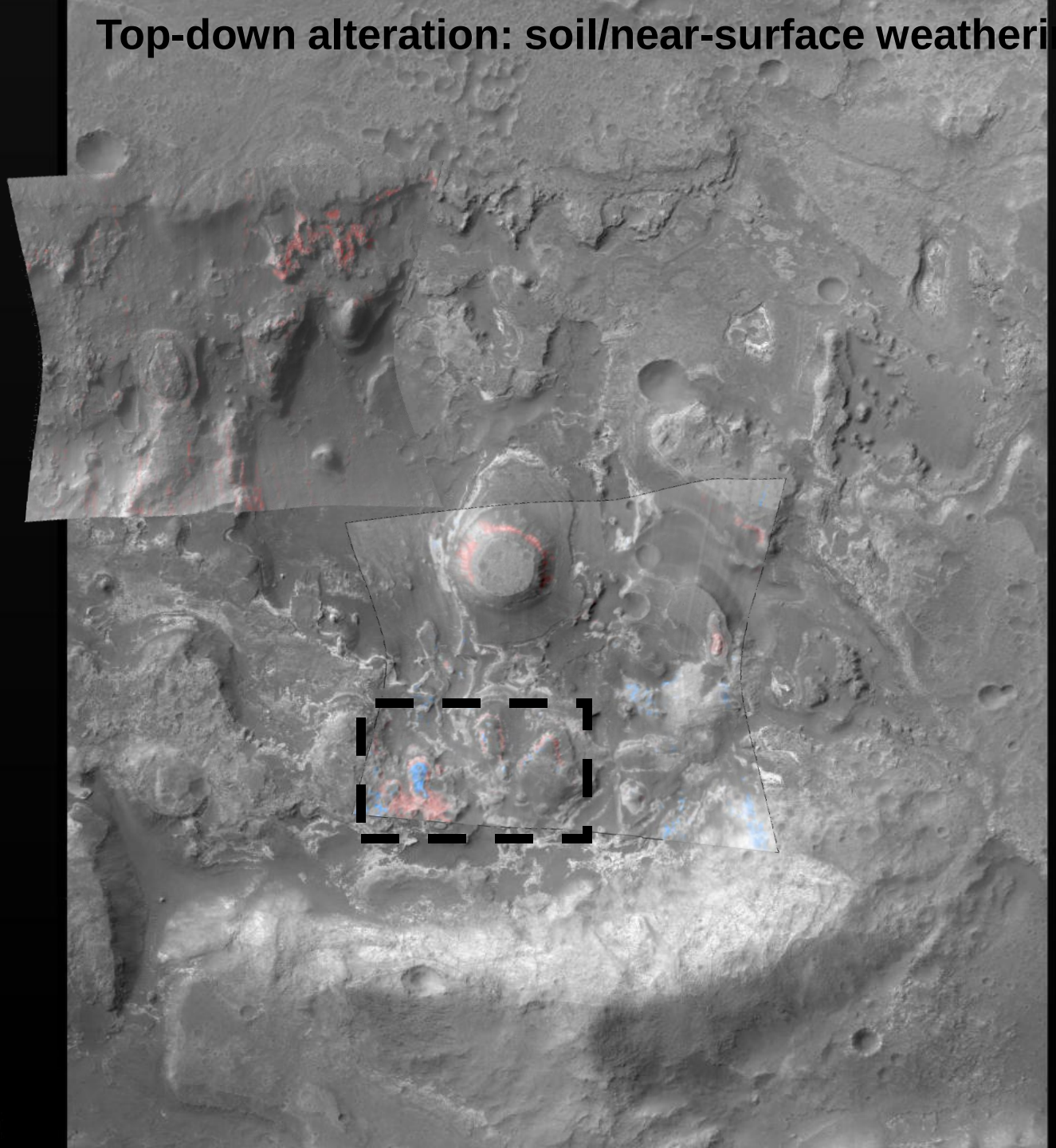


Formation processes : Soil/Near-surface Weathering

Earth clay mineral formation and life cycles (Velde 1995)



Top-down alteration: soil/near-surface weathering

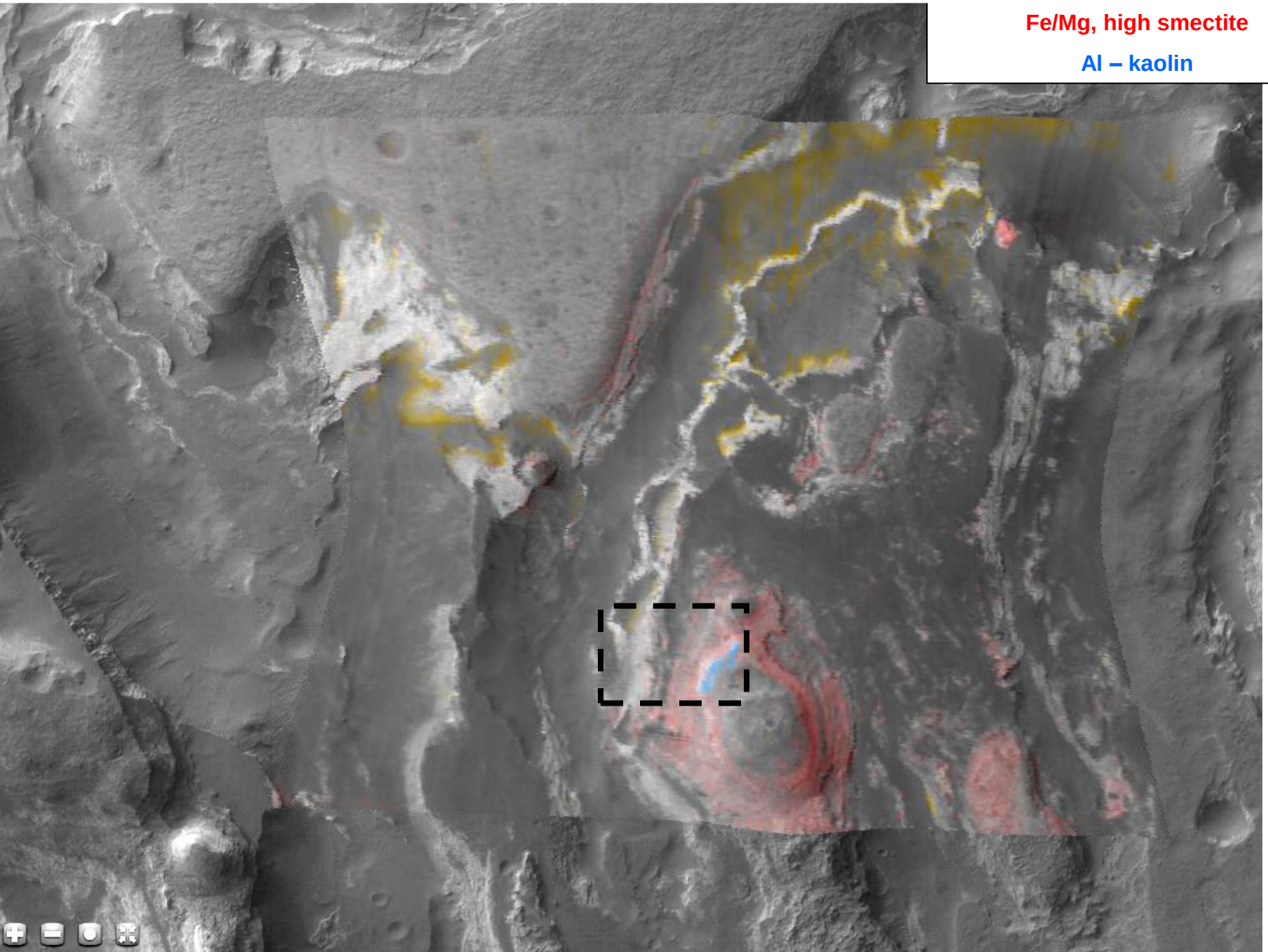


Top-down alteration: soil/near-surface weathering

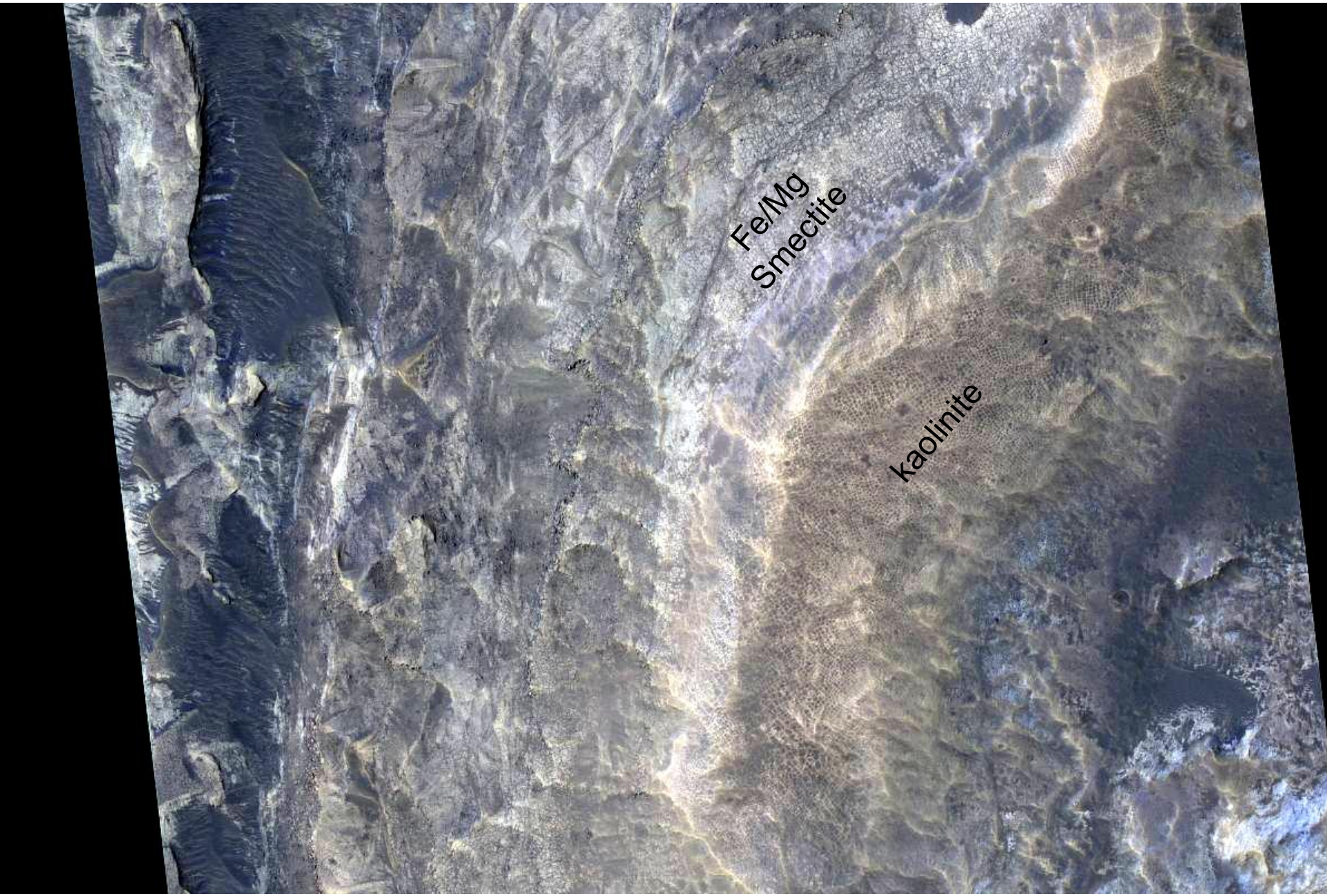
Fe/Mg- smectite

Montmorillonite + Fe/Mg

Top-down alteration: soil/near-surface weathering

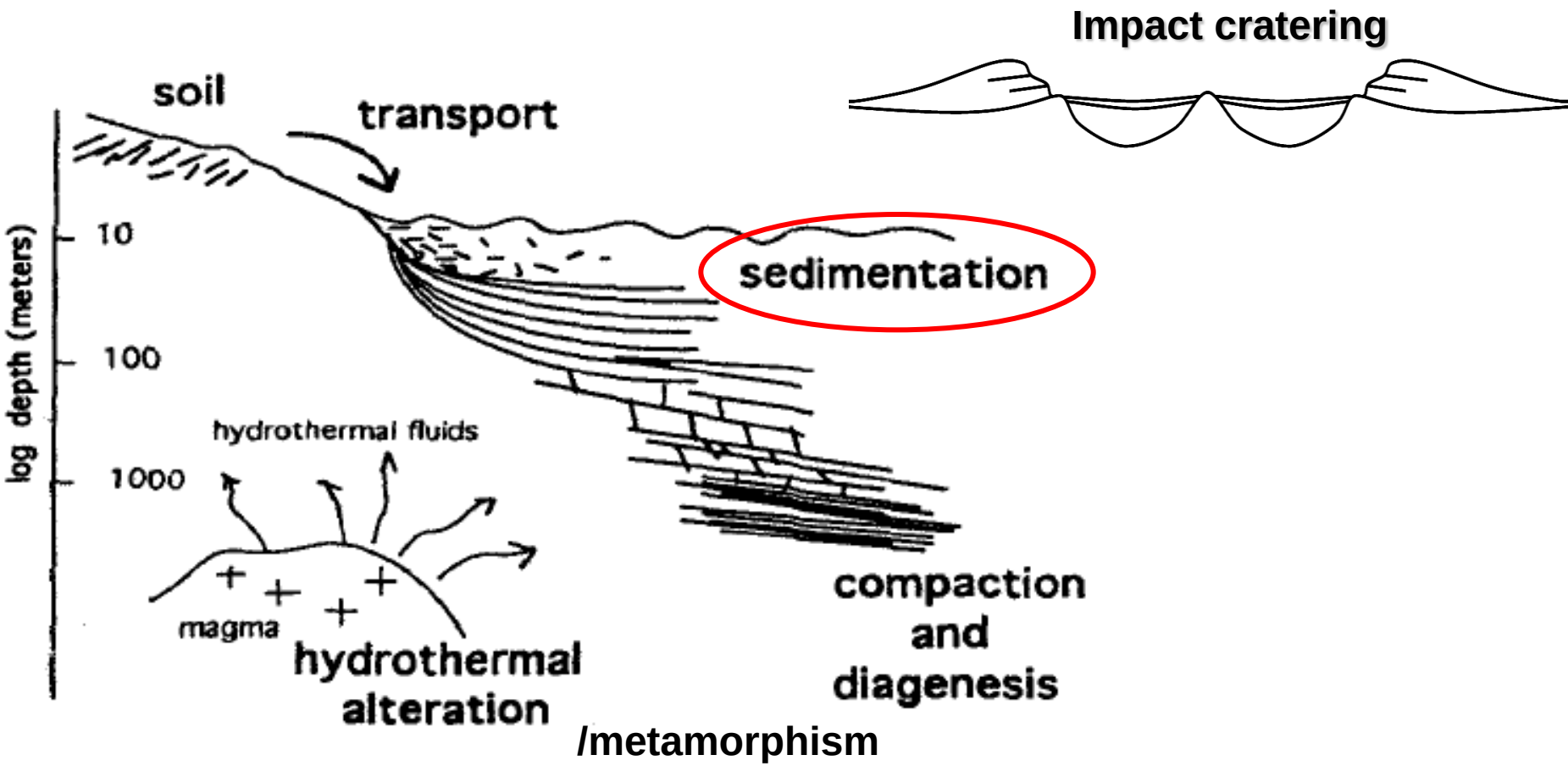


Top-down alteration: soil/near-surface weathering

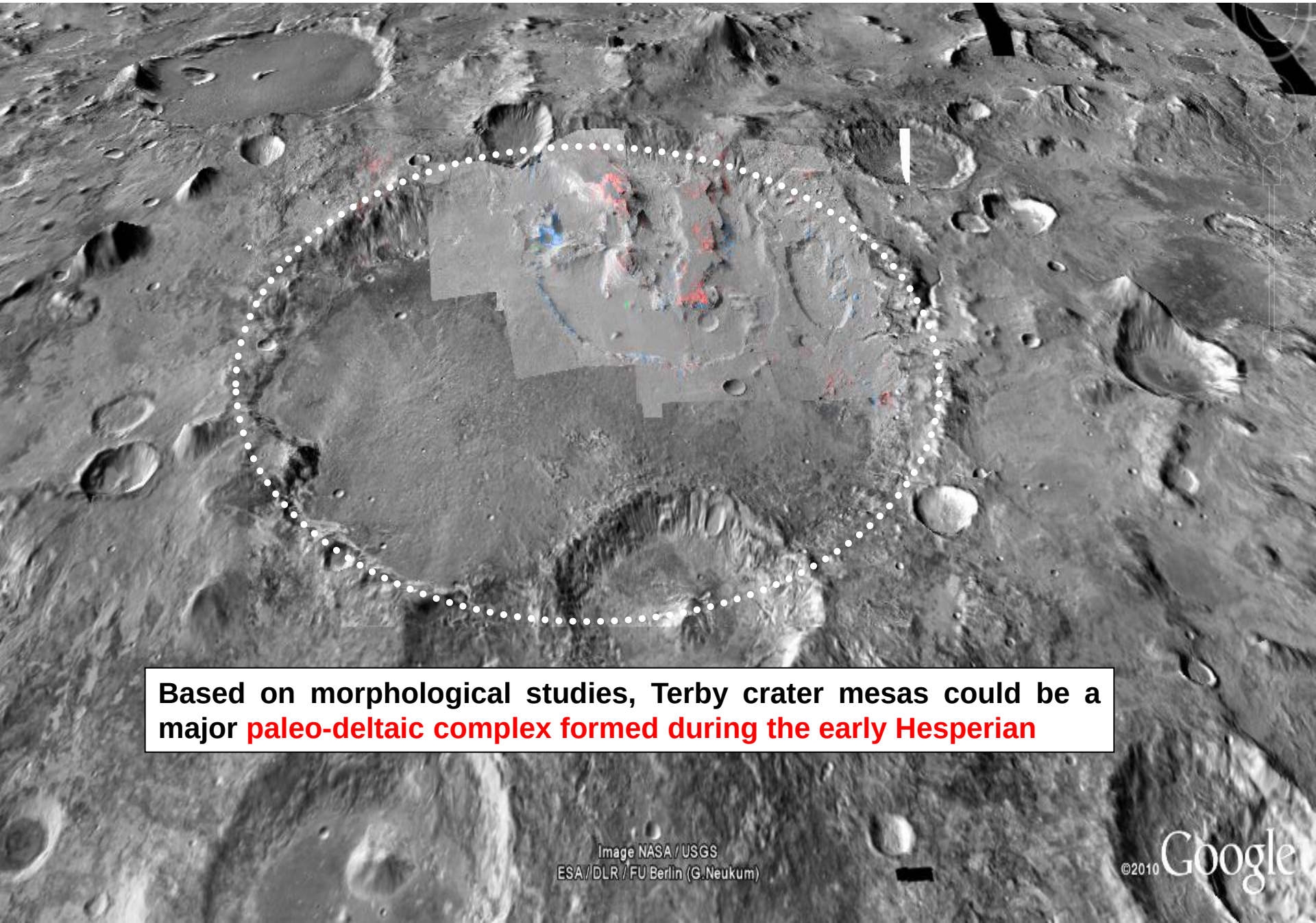


Formation processes : Sedimentation

Earth clay mineral formation and life cycles (Velde 1995)



Formation processes : Sedimentation



Based on morphological studies, Terby crater mesas could be a major paleo-deltaic complex formed during the early Hesperian

Formation processes : Sedimentation

Fe/Mg smectite

Zeolite

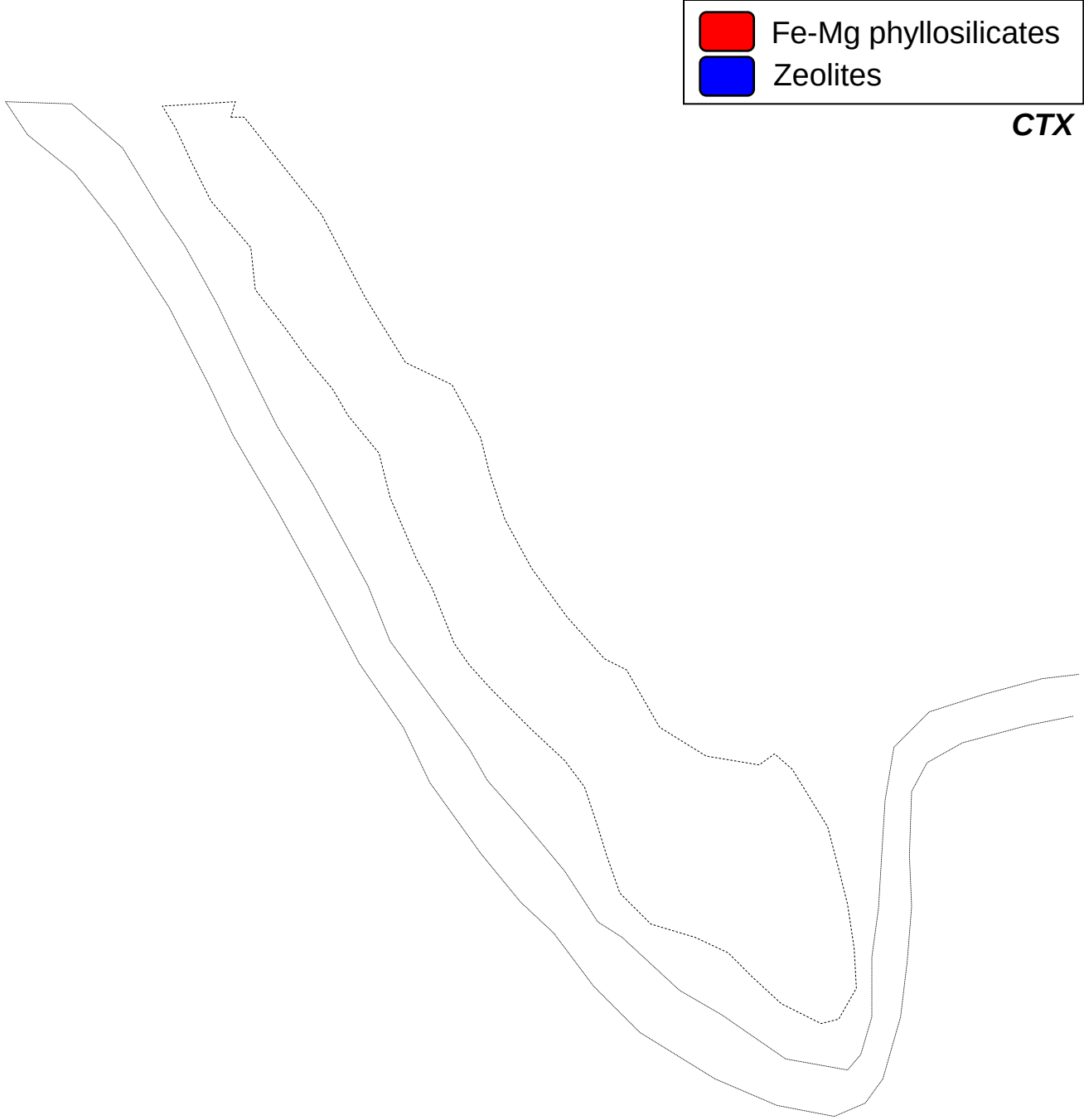
Opaline silica/hydrated glass

Terby layered mesas

Fe-Mg phyllosilicates

Zeolites

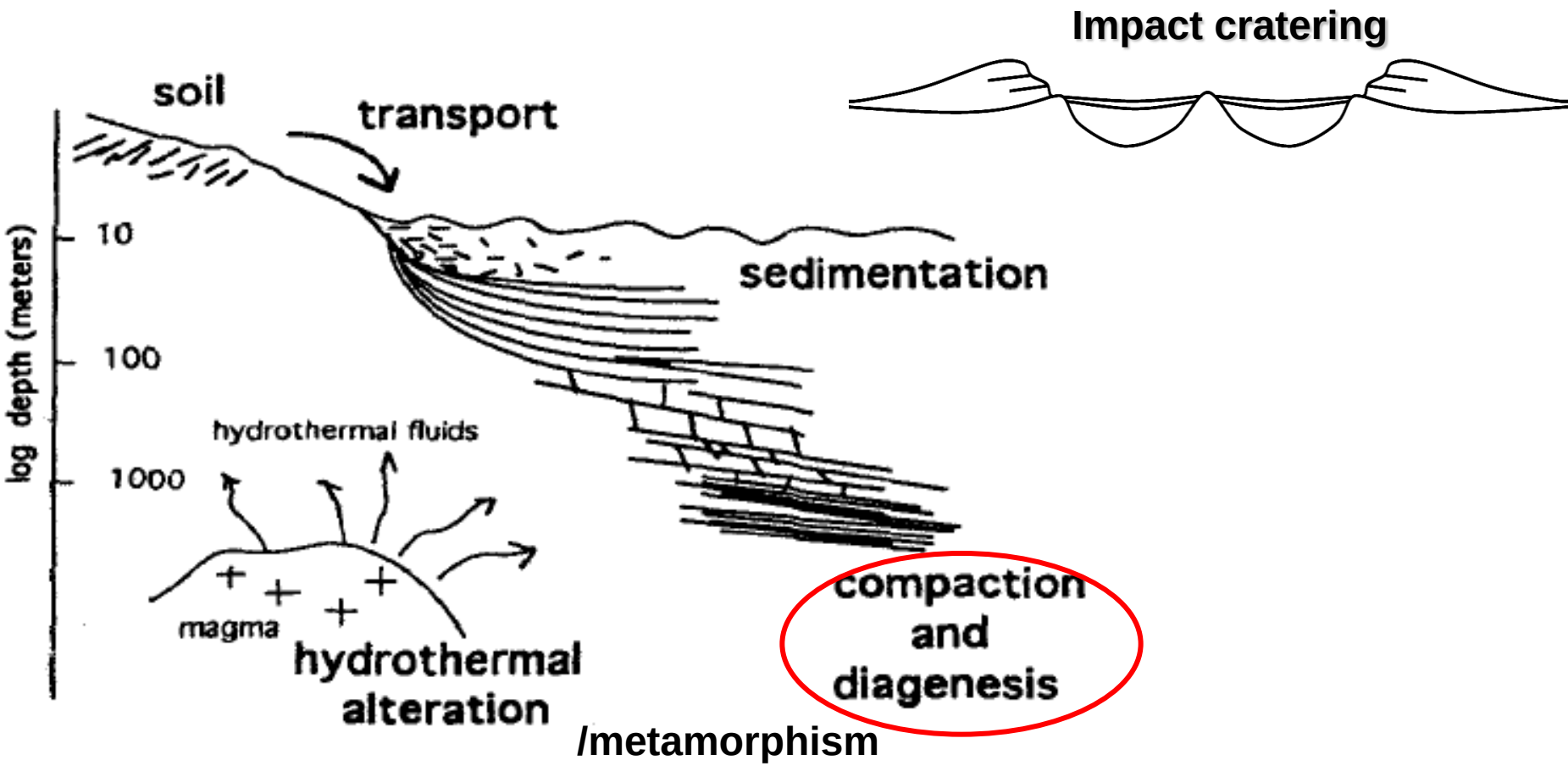
Terby layered mesas

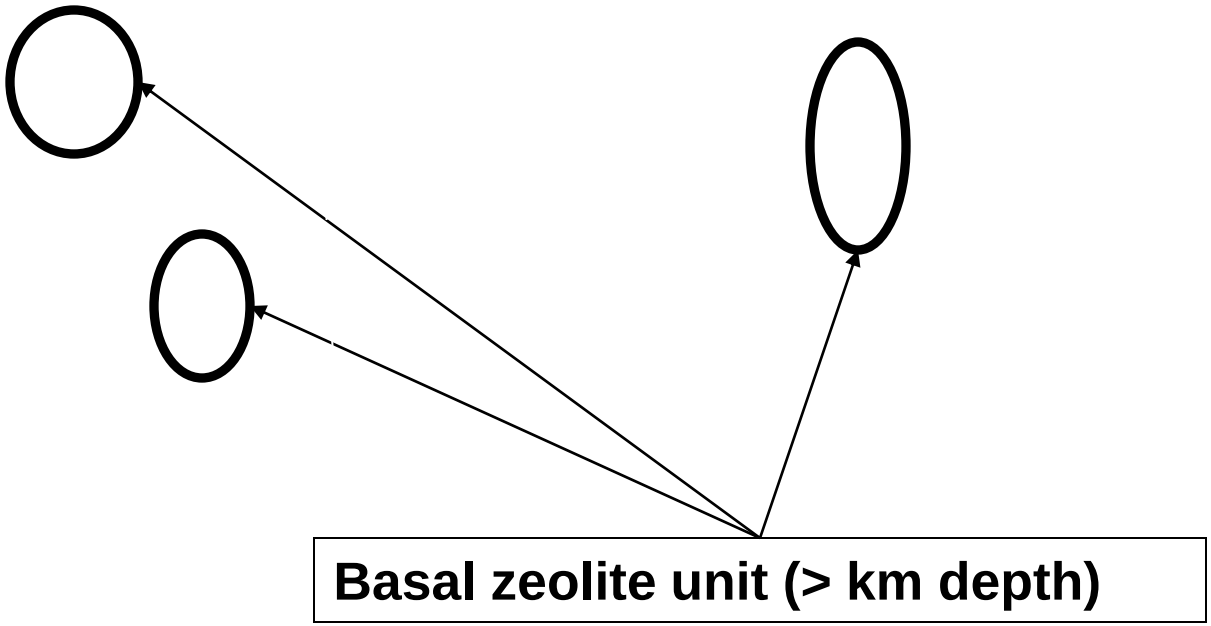


Terby layered mesas

Formation processes : Compaction and diagenesis

Earth clay mineral formation and life cycles (Velde 1995)

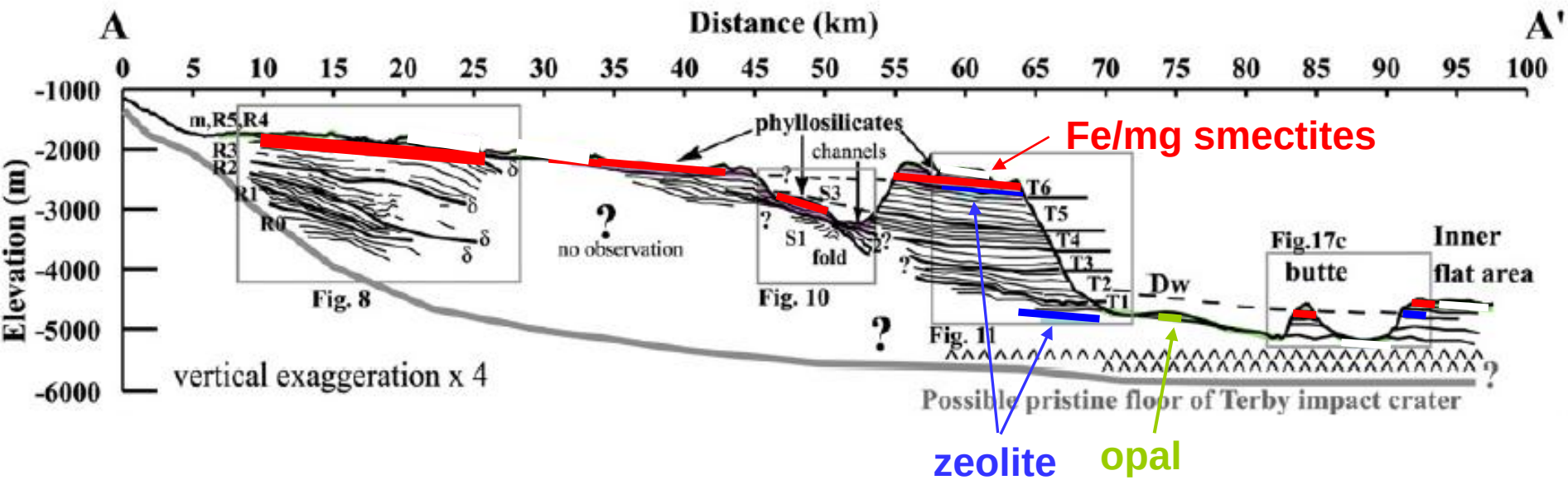


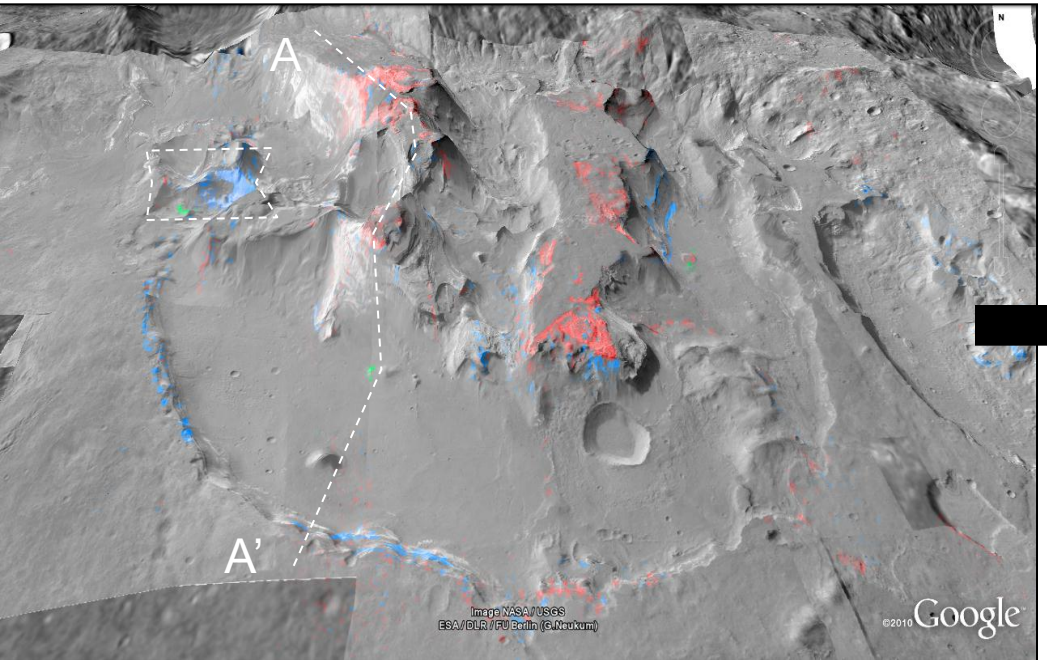


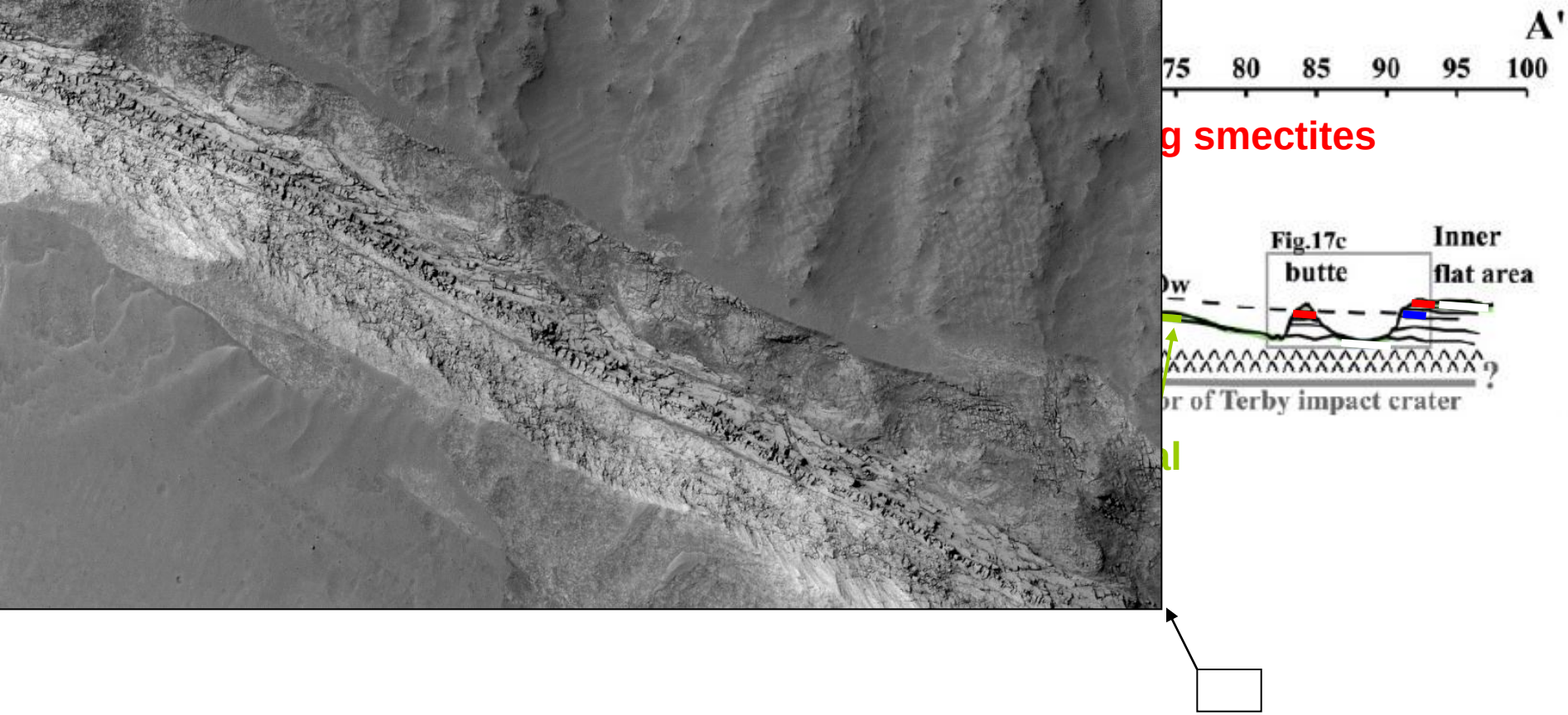
Fe/Mg smectite

Zeolite

Opaline silica/hydrated glass


A
A'
Distance (km)
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100
Elevation (m)
-1000
-2000
-3000
-4000
-5000
-6000
m,R5,R4
R3
R2
R1
R0
Fig. 8
phyllosilicates
channels
S3
S1
fold
Fig. 10
no observation
Fe/mg smectites
T6
T5
T4
T3
T2
T1
Fig. 11
Dw
Fig.17c
butte
Inner
flat area
vertical exaggeration x 4
Possible pristine floor of Terby impact crater
zeolite
opal

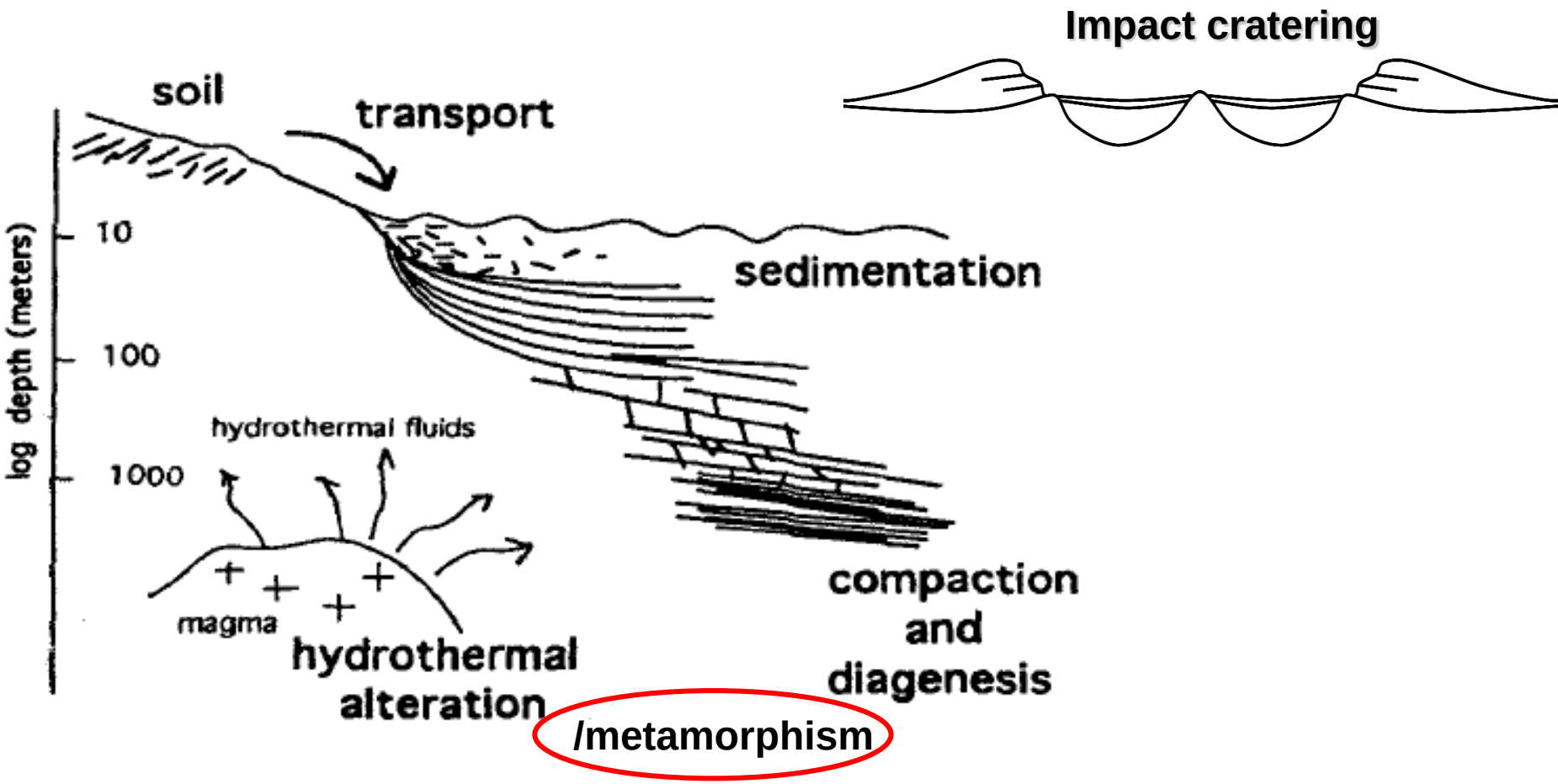

A
A'
Google



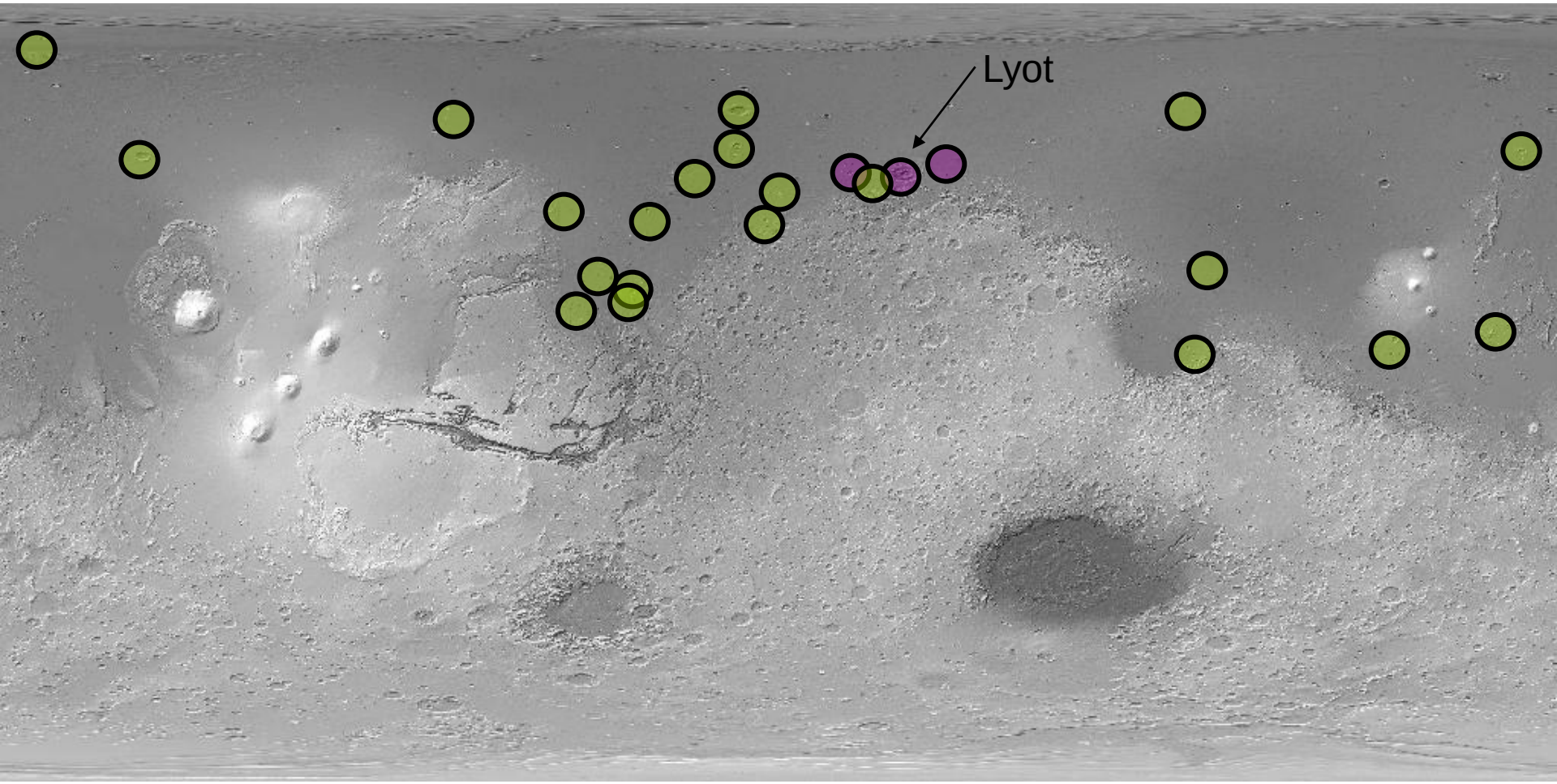
zeolite facies resulting from diagenetic processes of sedimentary rocks

Formation processes : Metamorphism

Earth clay mineral formation and life cycles (Velde 1995)



Formation processes : Metamorphism

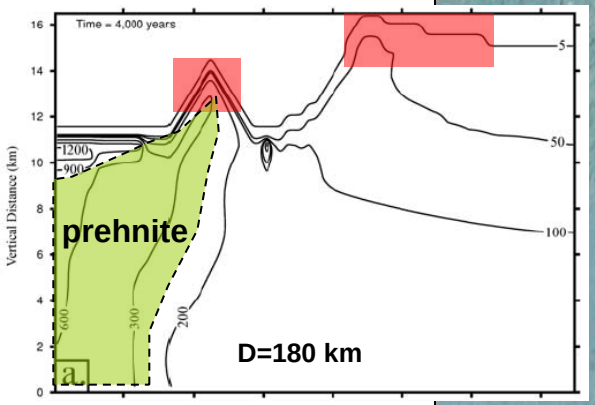


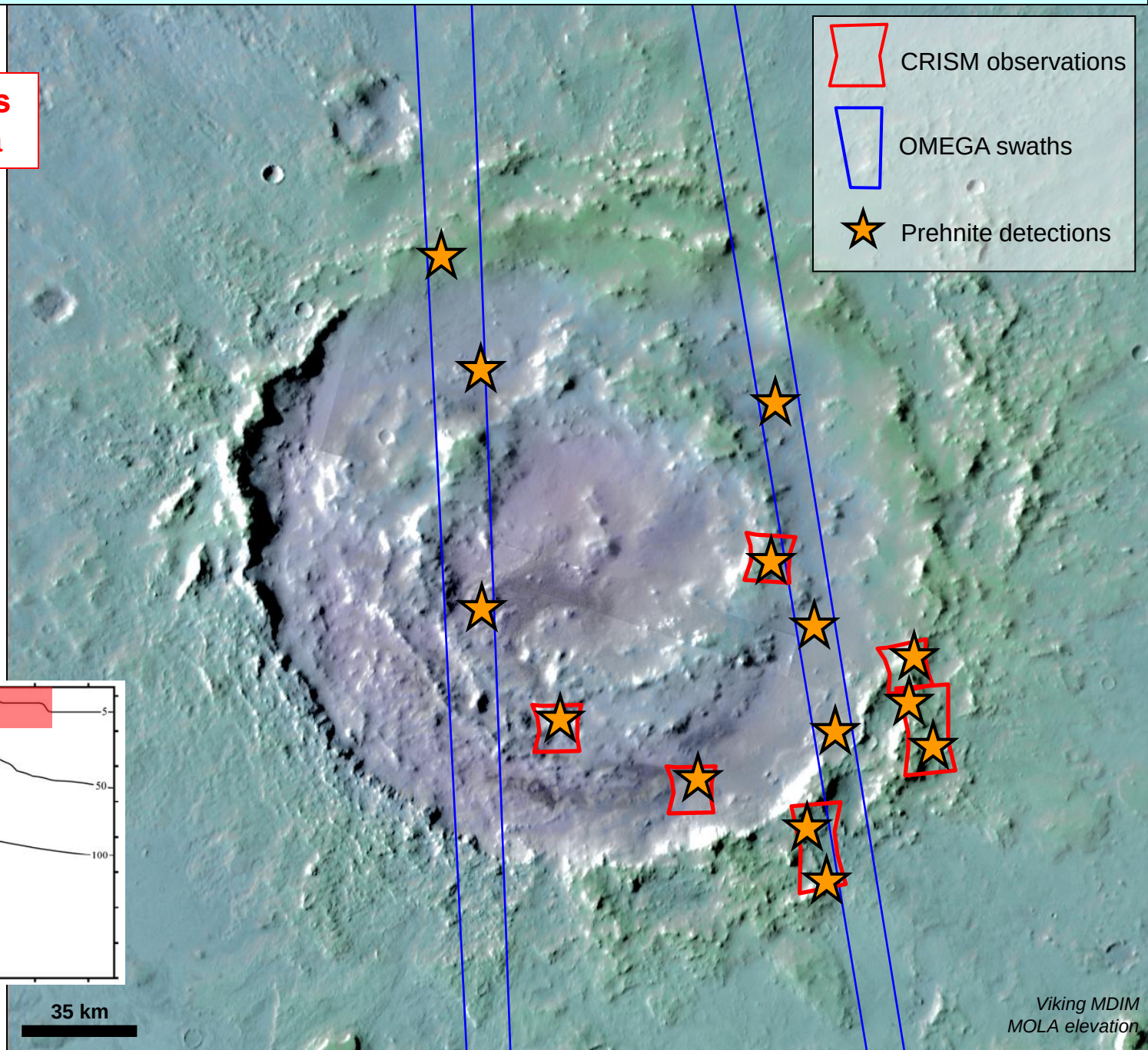
10s of northern plain craters with hydrated minerals

With low-grade metamorphic prehnite+chlorite

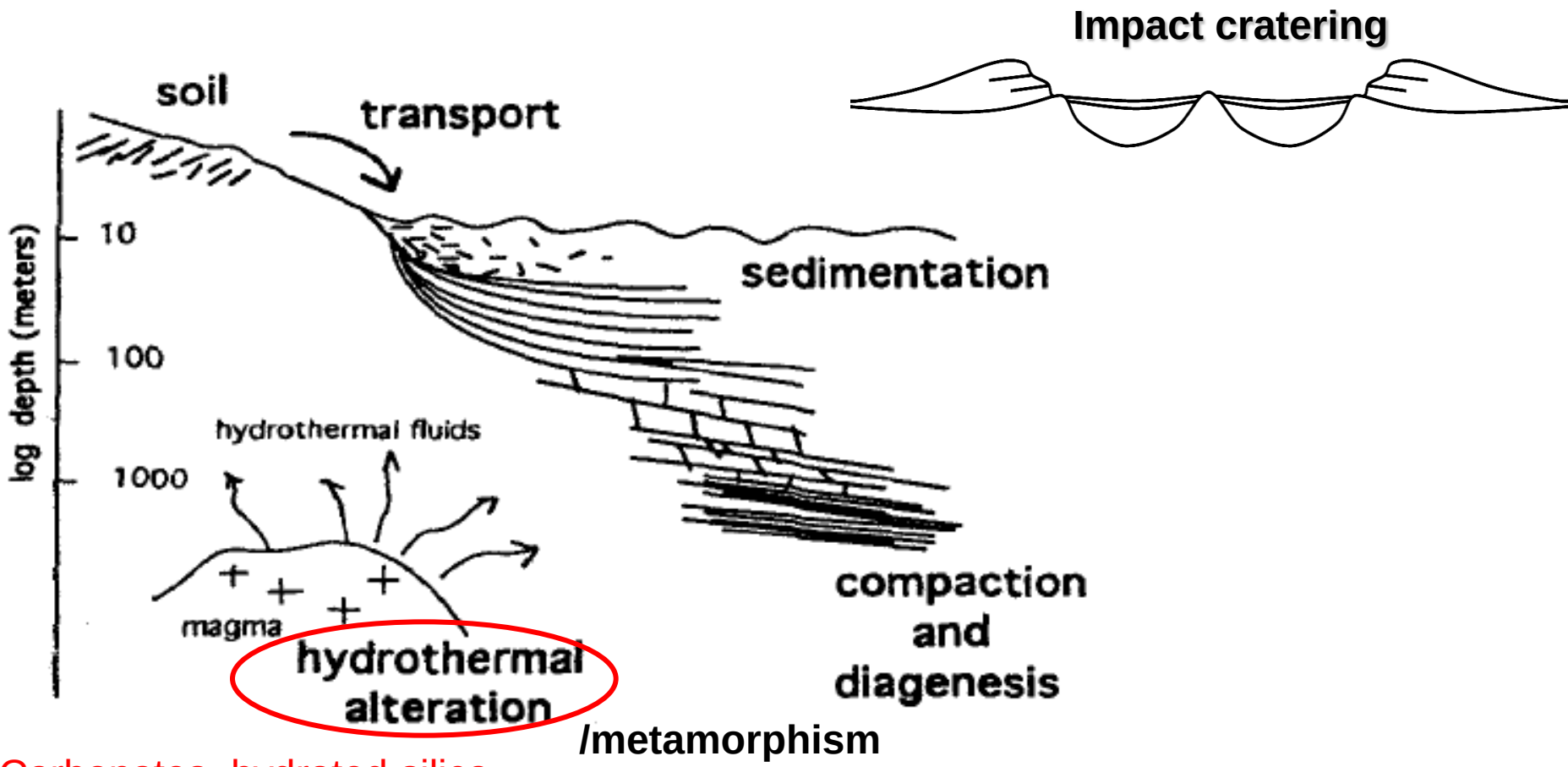
Excavation of metamorphic minerals from the buried northern crust

Prehnite in Lyot's outer rim / ejecta



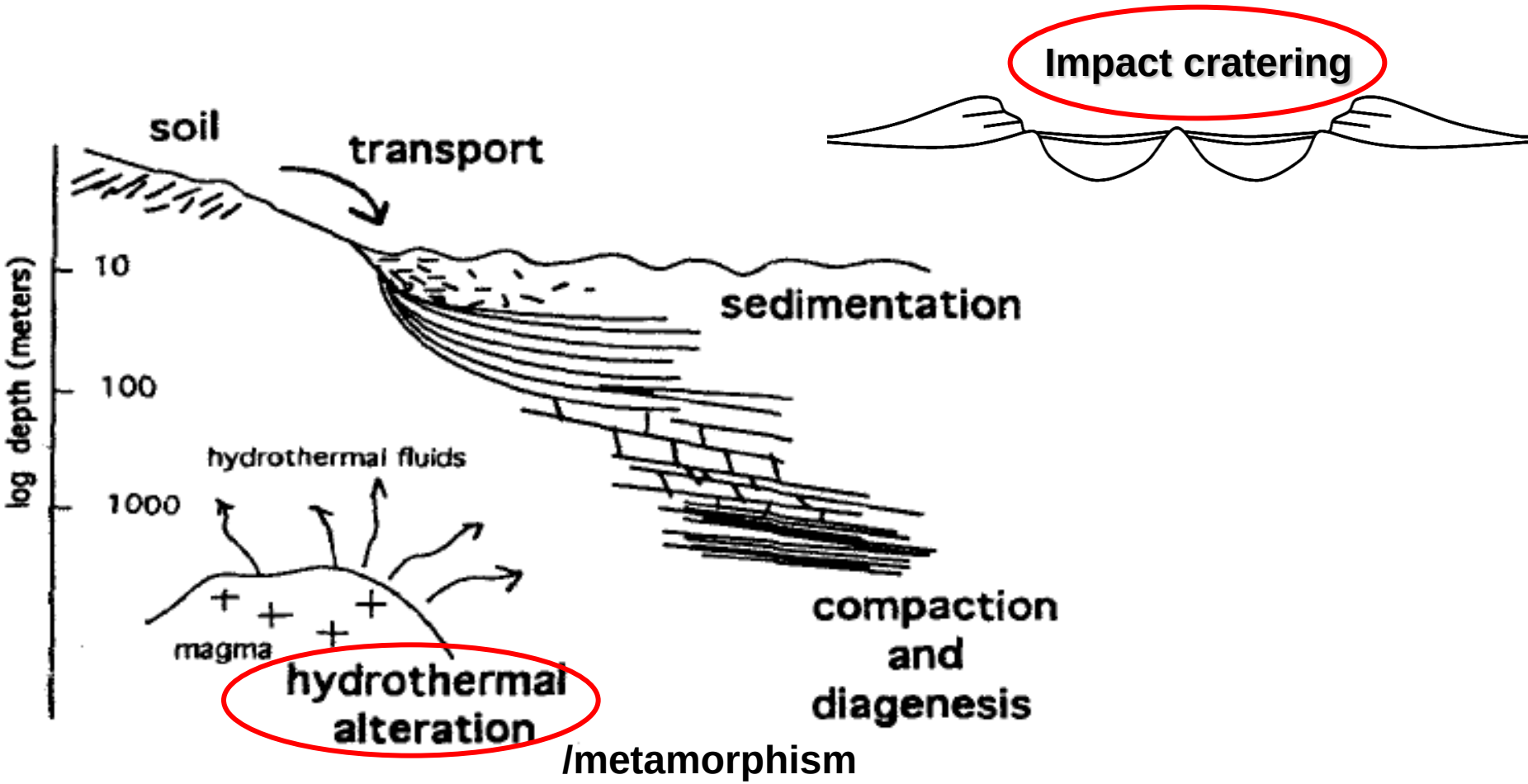


Formation processes by impact: Hydrothermal vs Excavation



Carbonates, hydrated silica

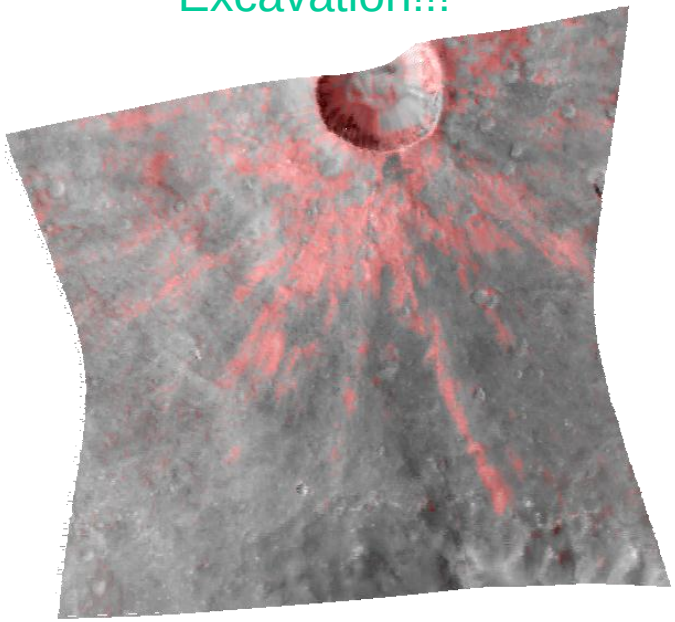
Formation processes by impact: Hydrothermal vs Excavation



Formation processes by impact: Hydrothermal vs Excavation

Terra Tyrrhena region

Excavation!!!



79 craters ranging [~0.2 – 81] km in diameter

Fe-Mg smectites

Chlorites

Prehnite

Zeolite

Al-smectite

Formation processes by impact: Hydrothermal vs Excavation

Terra Tyrrhena region

Excavation or hydrothermal?

79 craters ranging [~0.2 – 81] km in diameter

Fe-Mg smectites

Chlorites

Prehnite

Zeolite

Al-smectite

Formation processes by impact: Hydrothermal vs Excavation

➔Central uplift poor indicators of excavation vs hydrothermal alteration

➔Bright, superficial opal deposits in >20 km craters consistent with impact induced hydrothermal systems

Central uplift

Prehnite

Zeolite

Hydrated silica

Chlorite

Fe-Mg smectite

Formation processes by impact: Hydrothermal vs Excavation

➔Larger craters excavate higher grade temperature (and deeper) minerals => could be an indication of hydrothermal alteration

➔Prehnite at all scales is puzzling !

Crater ejecta

Higher grade minerals

Prehnite

Zeolite

Hydrated silica

Chlorite

Fe-Mg smectite

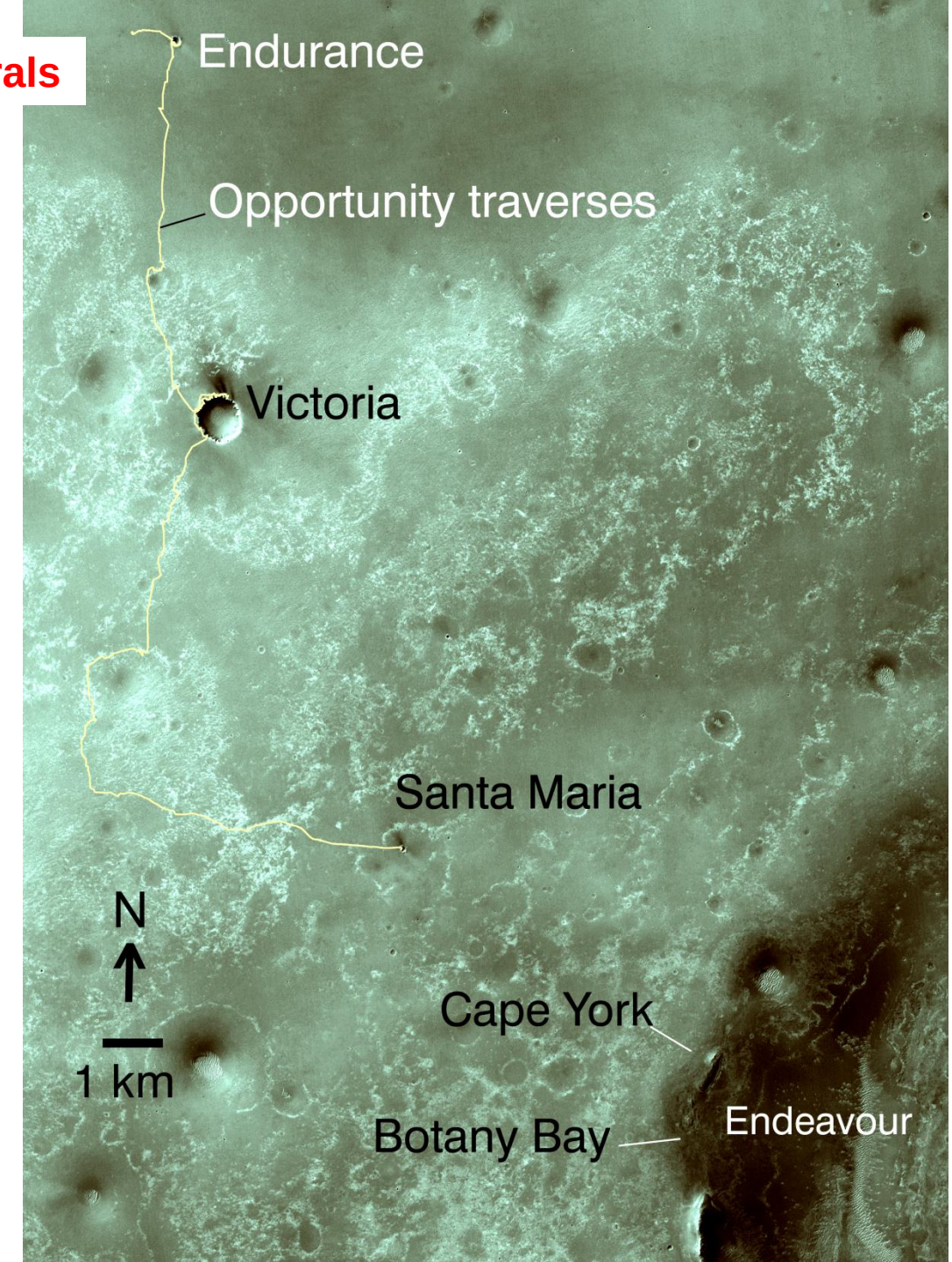
$$H_{ex} = \frac{0.109 D^{0.872}}{2}$$

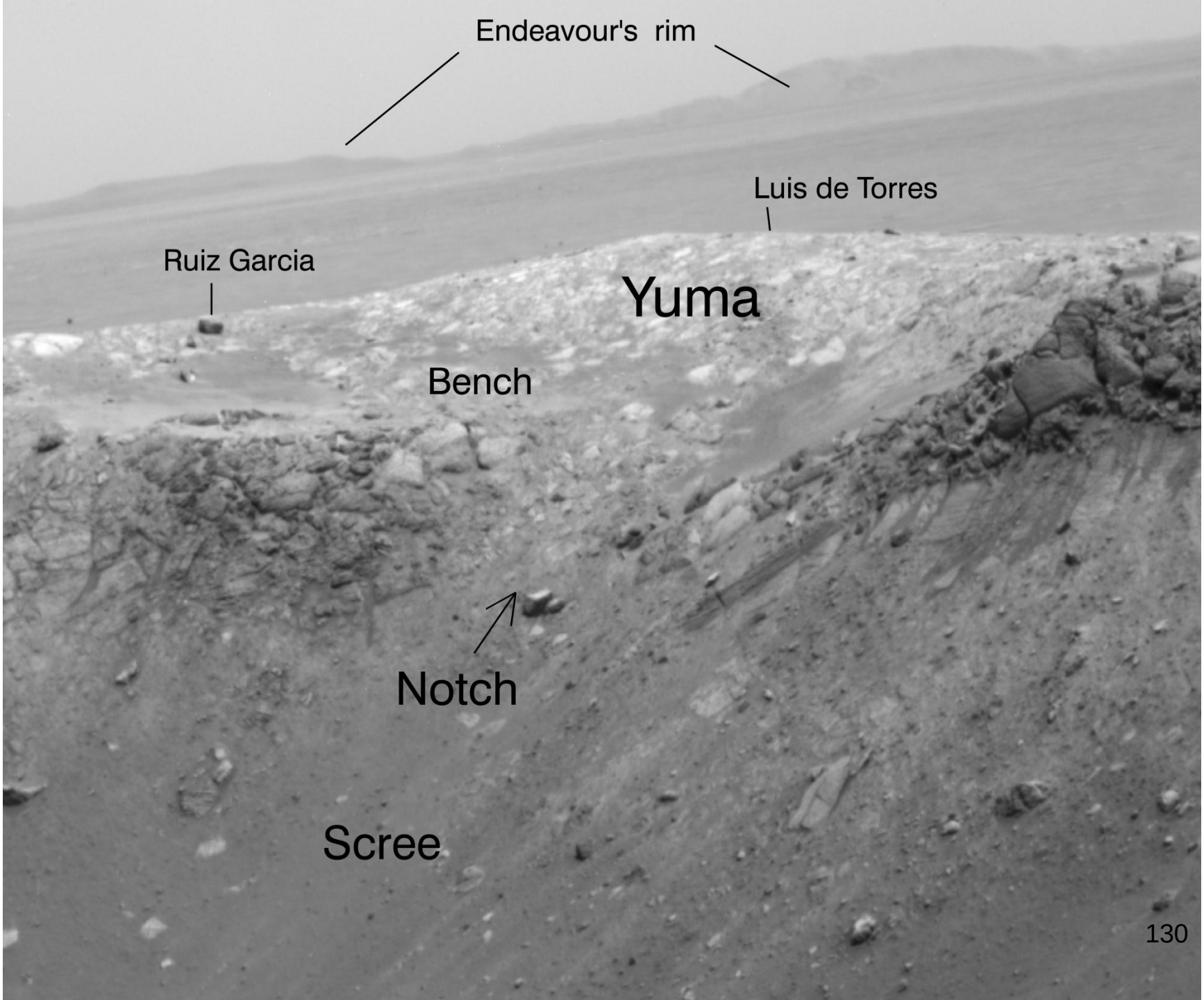
Mean excavation depth

<200 m	< 400m	< 740m	[740 – 2500] m

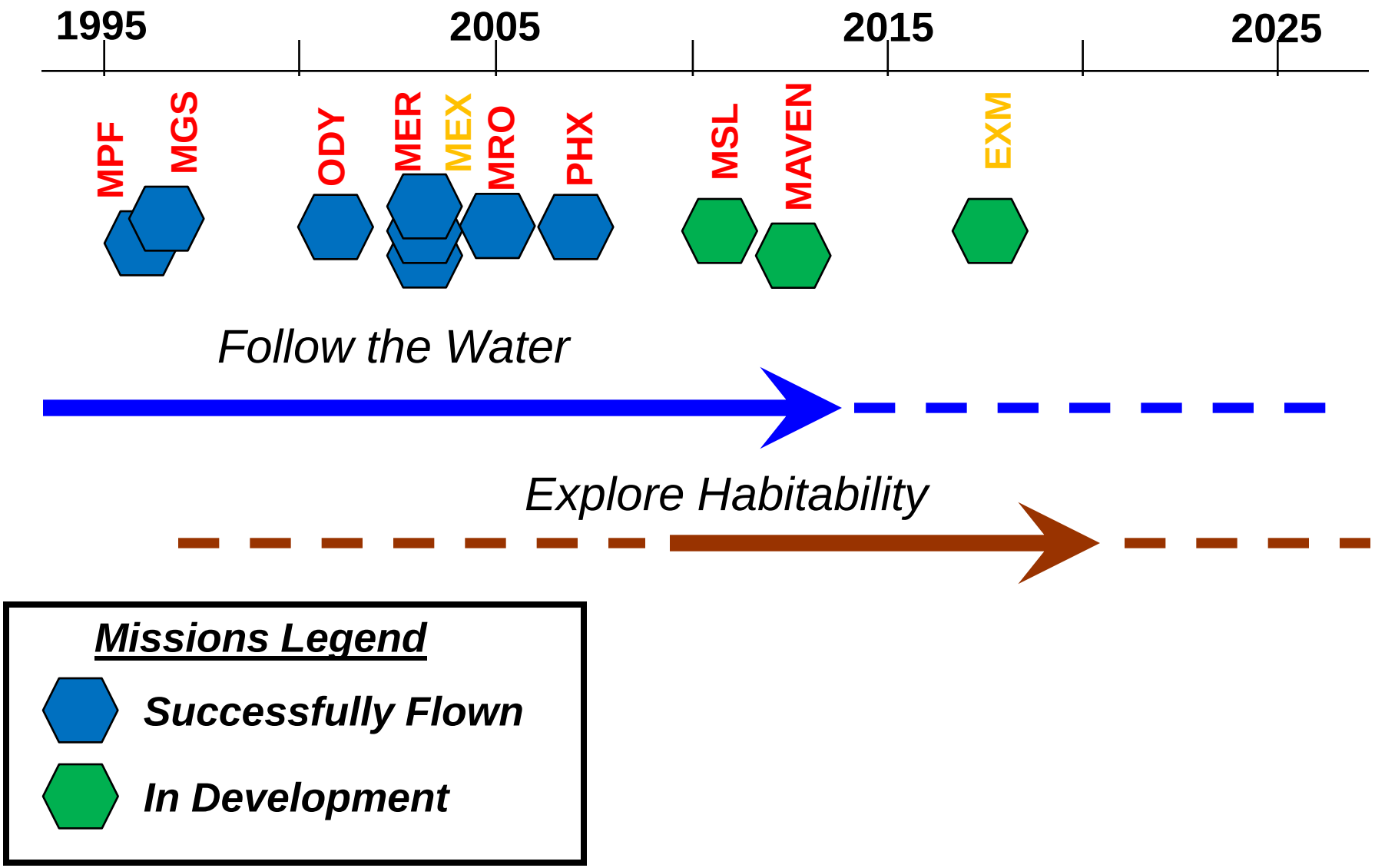
In situ observations of clay minerals

On the way to Endeavour's rim (a few kms) and its Noachian-aged outcrops (Fe/Mg phyllosilicates likely)




Endeavour's rim
Luis de Torres
Ruiz Garcia
Yuma
Bench
Notch
Scree

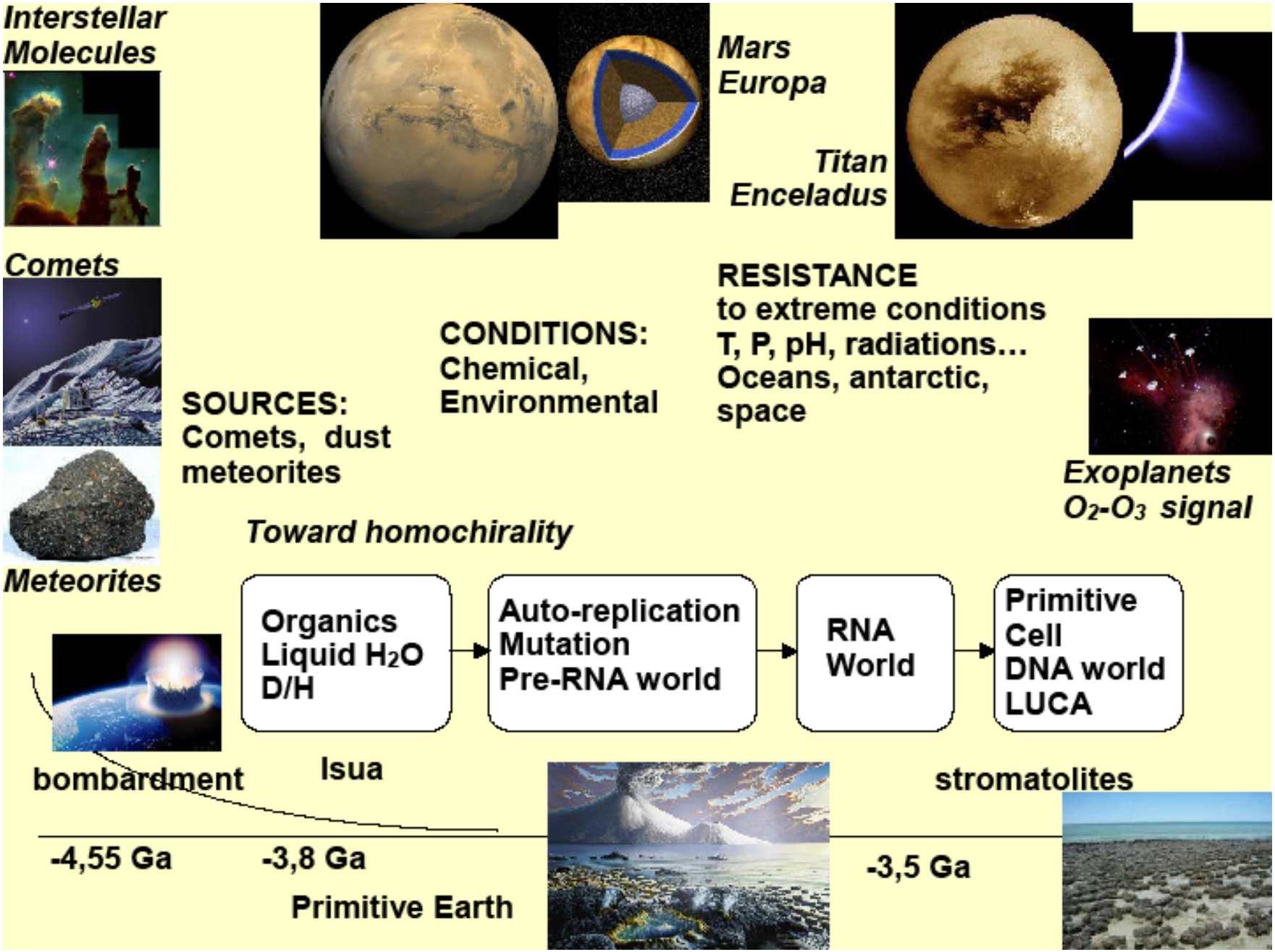
Missions in Progress to Address Goals



Courtesy Zurek

Astrobiology and Mars

1. Did life exist?
2. Do life exist (possible developments)?



Courtesy J. Carter, J.-P. Bibring, J. Mustard, F. Raulin, S. Murchie, R. Arvidson