3. Ancient landforms: Understanding the early Mars environment

3.1 Erosional landforms

3.1.1 Outflow channels

3.1.2 Valley networks

3.1.3 Erosional processes on early Mars

3.2 Standing bodies of water

3.2.1 Ocean and shorelines

3.2.2 Crater lakes and deltas

3.2.3 Layered deposits

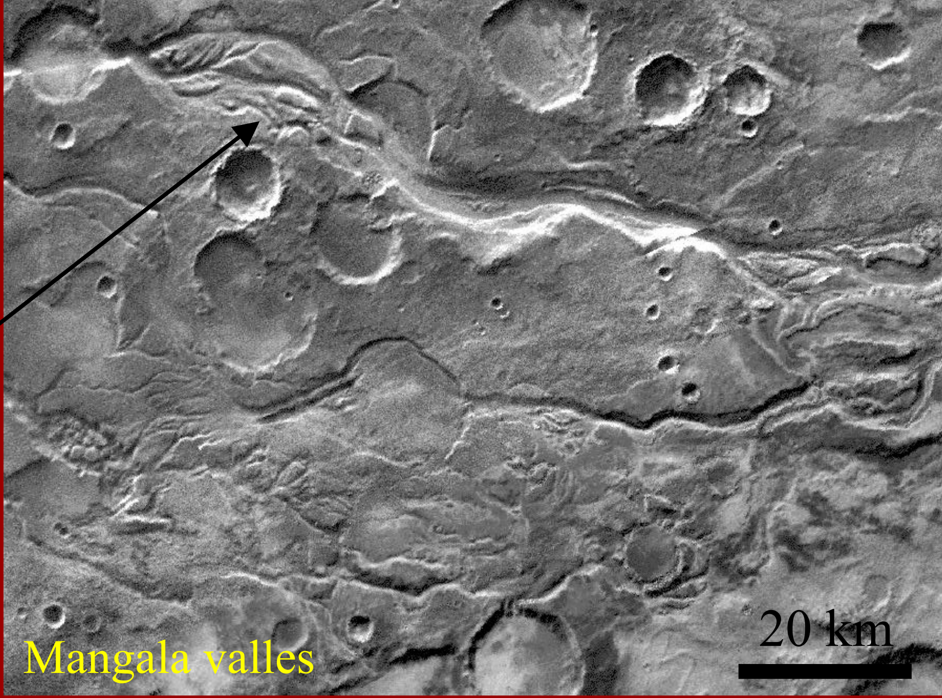
3.3 Composition of sediments: from geomorphology to geology

3.3.1 MER rover discoveries

3.3.2 Exobiological issues

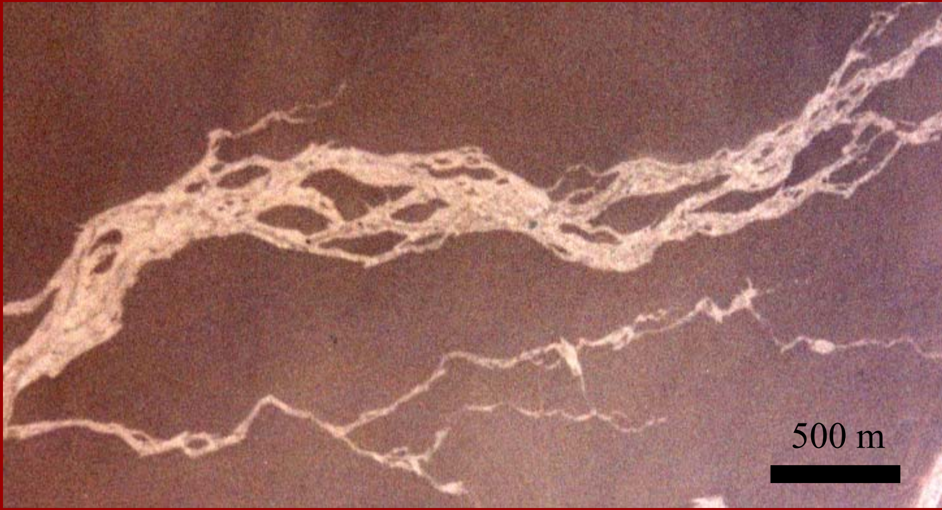
3.1.1 Outflow channels

Length: 100 to 1000 km
Width: 1 to 30 km
Low gradient (<0.1)
Anastomosing patterns, braided systems
Teardrop-shaped islands
Discharge rate : $10^7 - 10^9$ m^3 s^{-1}
(Baker, 1981; Komar, 1986)



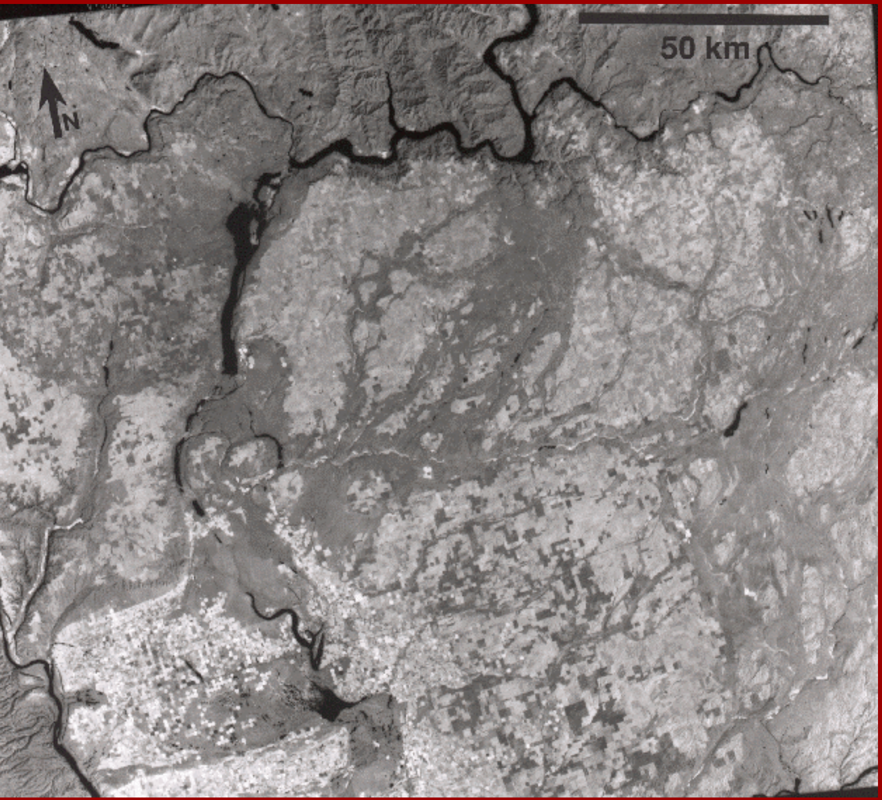
Mangala valles

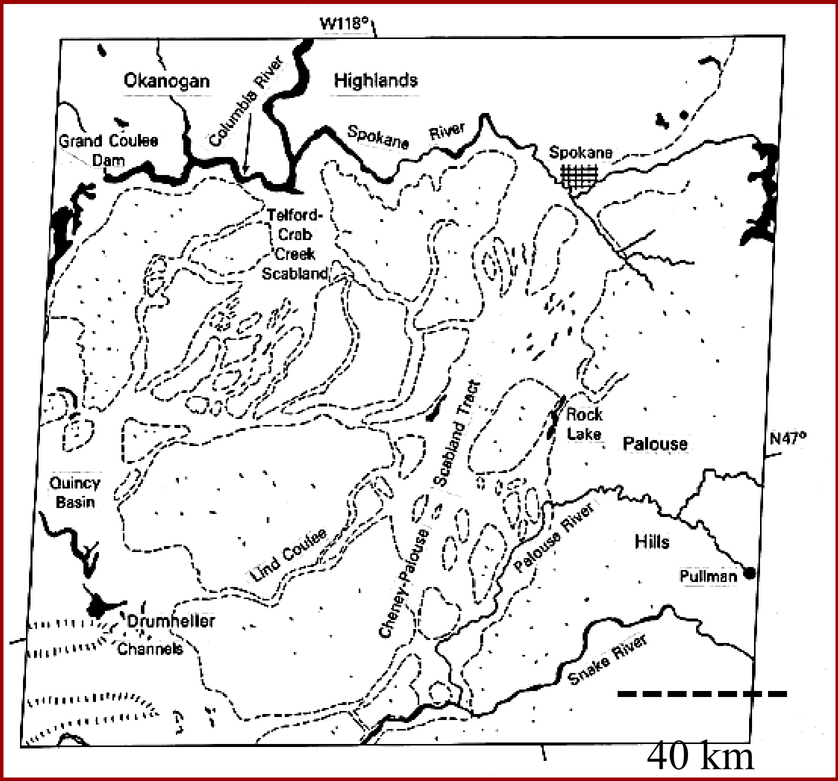
Ares Valles



Terrestrial floods: high discharge
(here due to a storm)

The Channeled Scabland analogy (Baker and Milton, 1974)



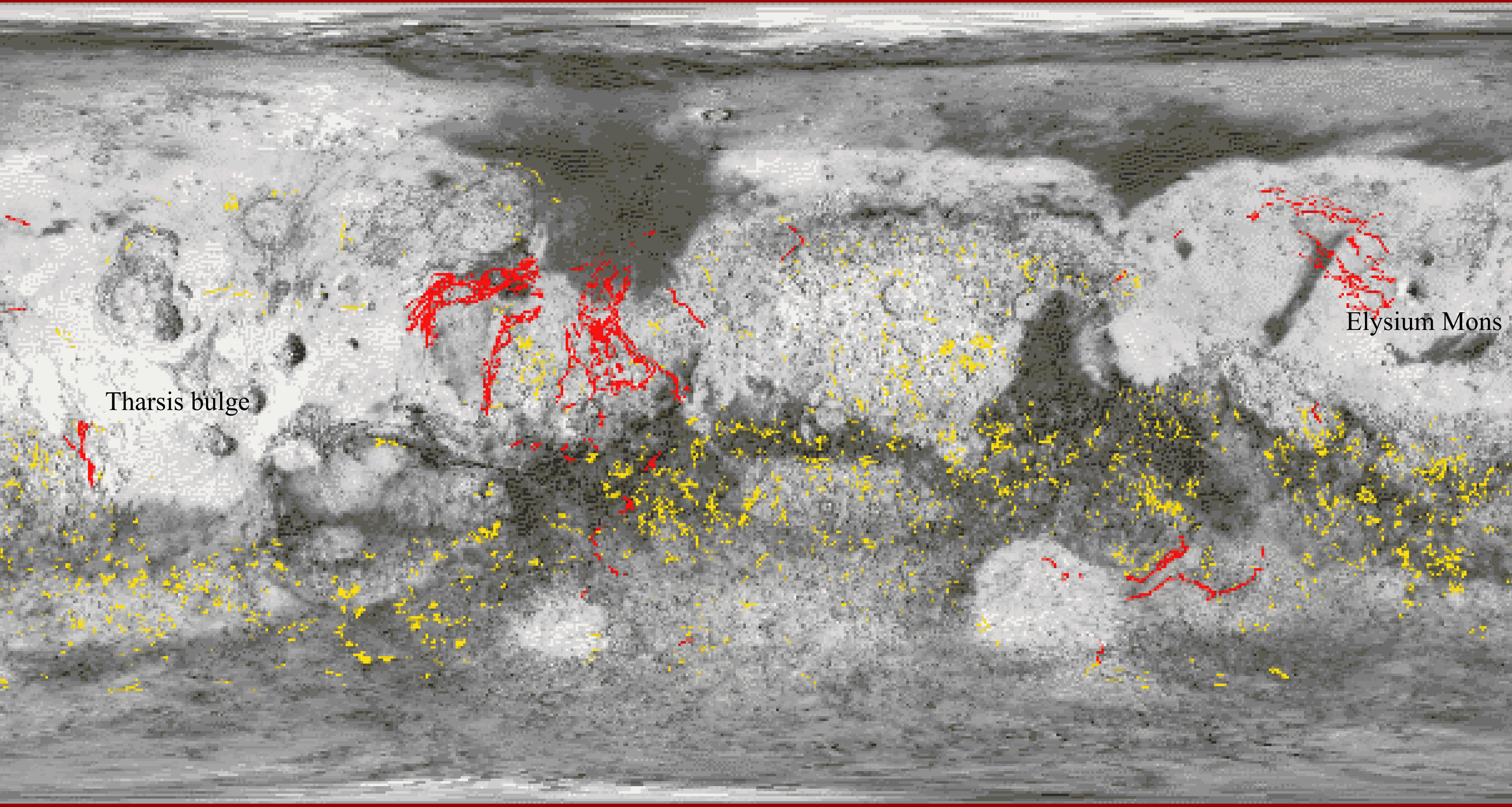


Columbia Basin (eastern Washington, USA)
A glacial dam releases the subglacial lake
Discharges of 2×10^7 m^3 s^{-1}

Geographic distribution: Correlation with volcanic regions

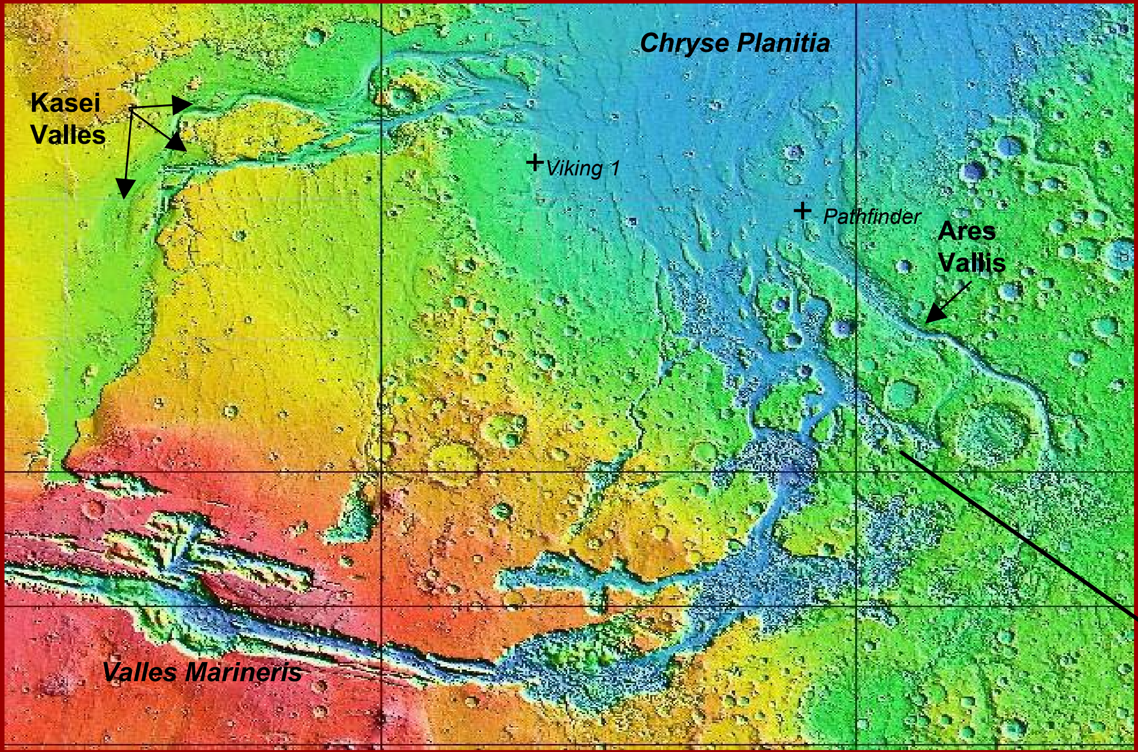
Role of geothermal activity

Outflow channels (red) and valley networks (yellow

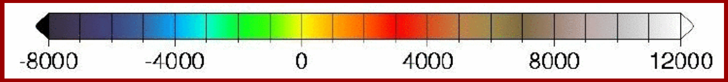


From Carr, 1979

Relationship between chaotic terrains and outflow channels



MOLA data



Altitude (m)

Disruption of the permafrost at the source

A recent outflow channel: Athabasca Vallis

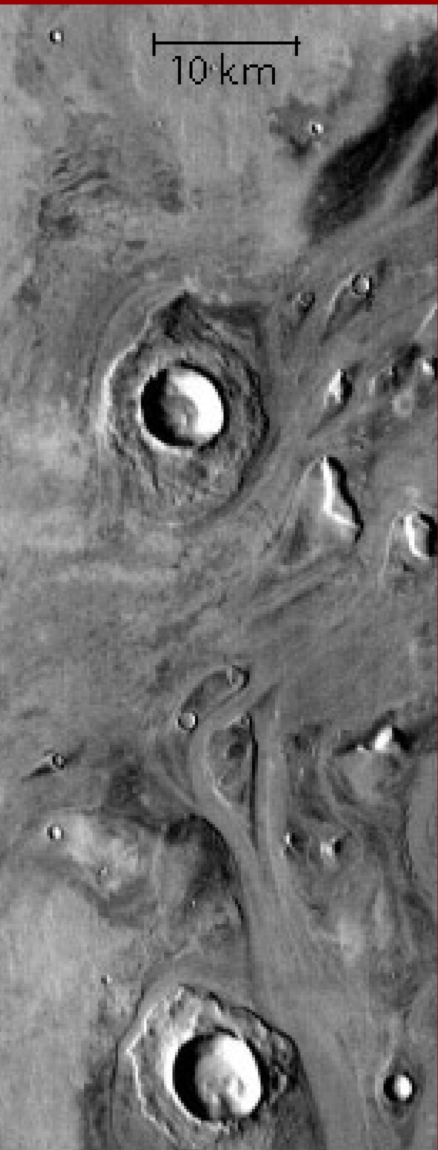
Outflow from fractures

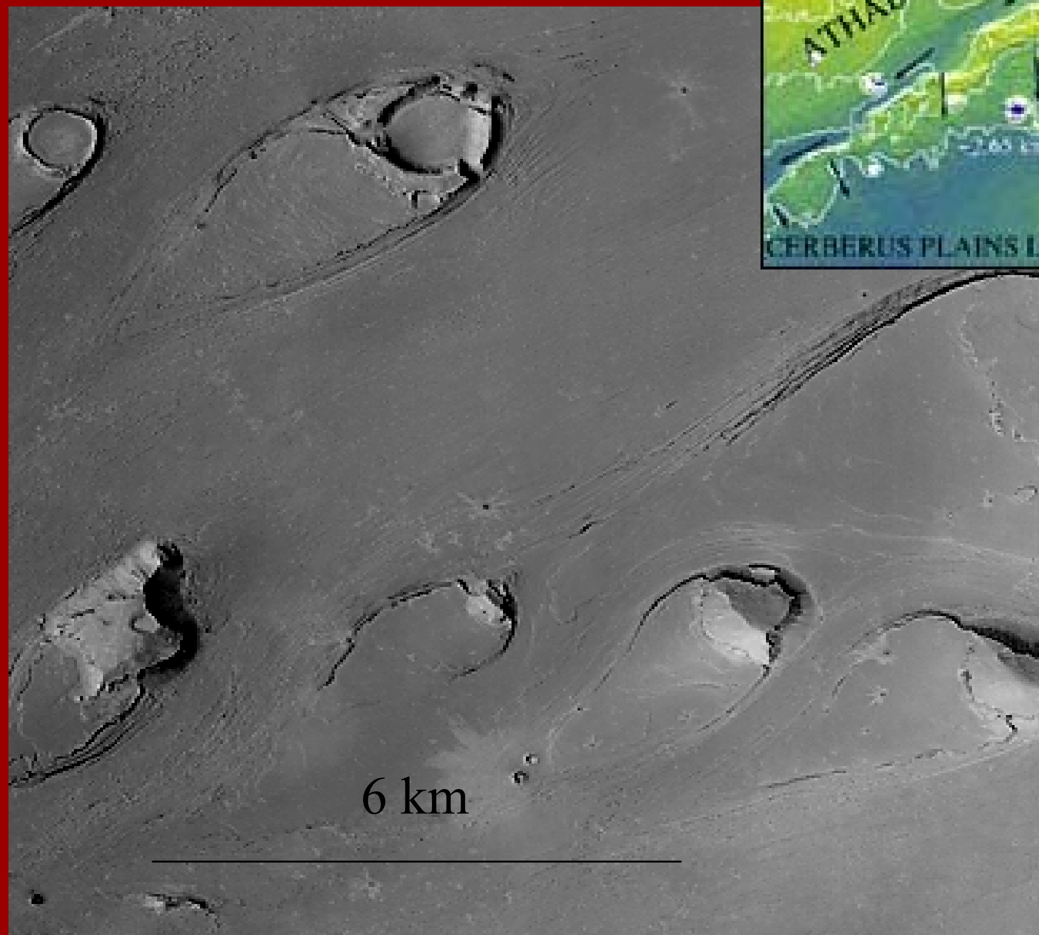
Very young:

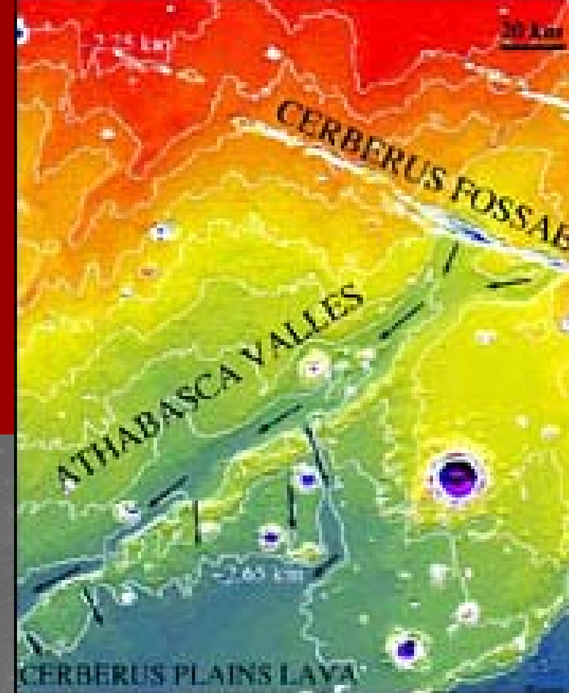
~10 million years ago

(Burr et al, 2002)

(Berman and Hartmann, 2003)







Origin of outflow channels

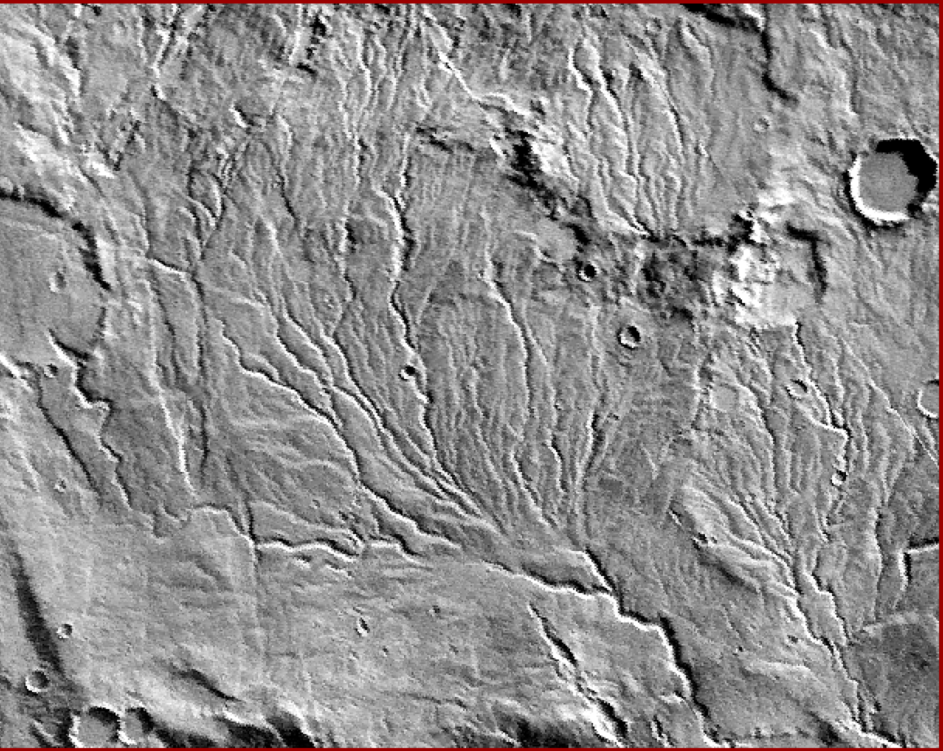
1 -Ground water under pressure confined within the permafrost (M. Carr, 1979)
(example: Xanthe Terra 10^4 km^3 of water)

2 – Scabland analogy (V. Baker, 1982), possible glaciers (Lucchita, 1982)
but few evidence for glaciers

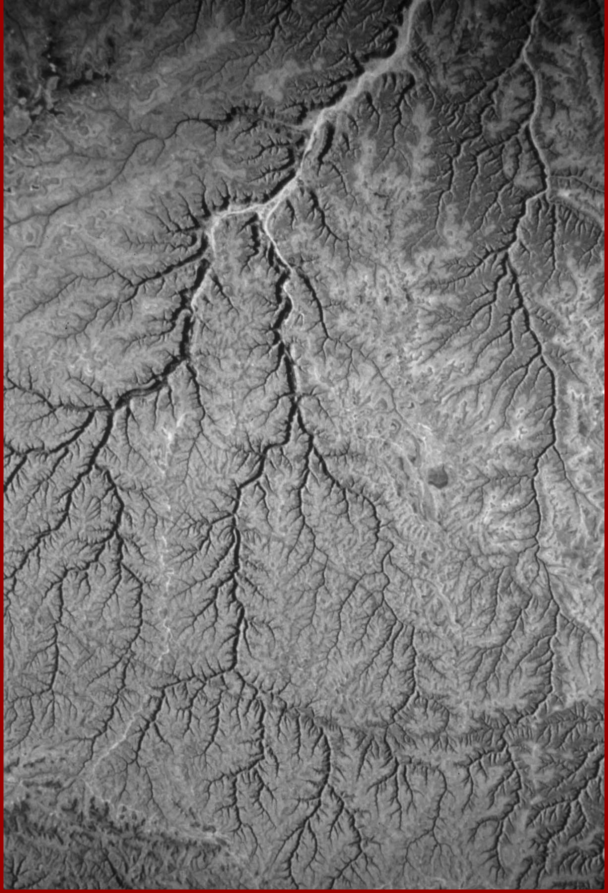
3 – Cold gas-supported density flow
Collapse due to liquefied slurry of regolith blocks,
Liquid CO2 as the lubricant. (N. Hoffman) or clathrates (CO2.H20)
but very speculative

Still enigmatic and poorly understood
=> More to know on the lecture this afternoon

3.1.2 Valley networks



Warrego Valles, Viking image



Yemen, Space Shuttle

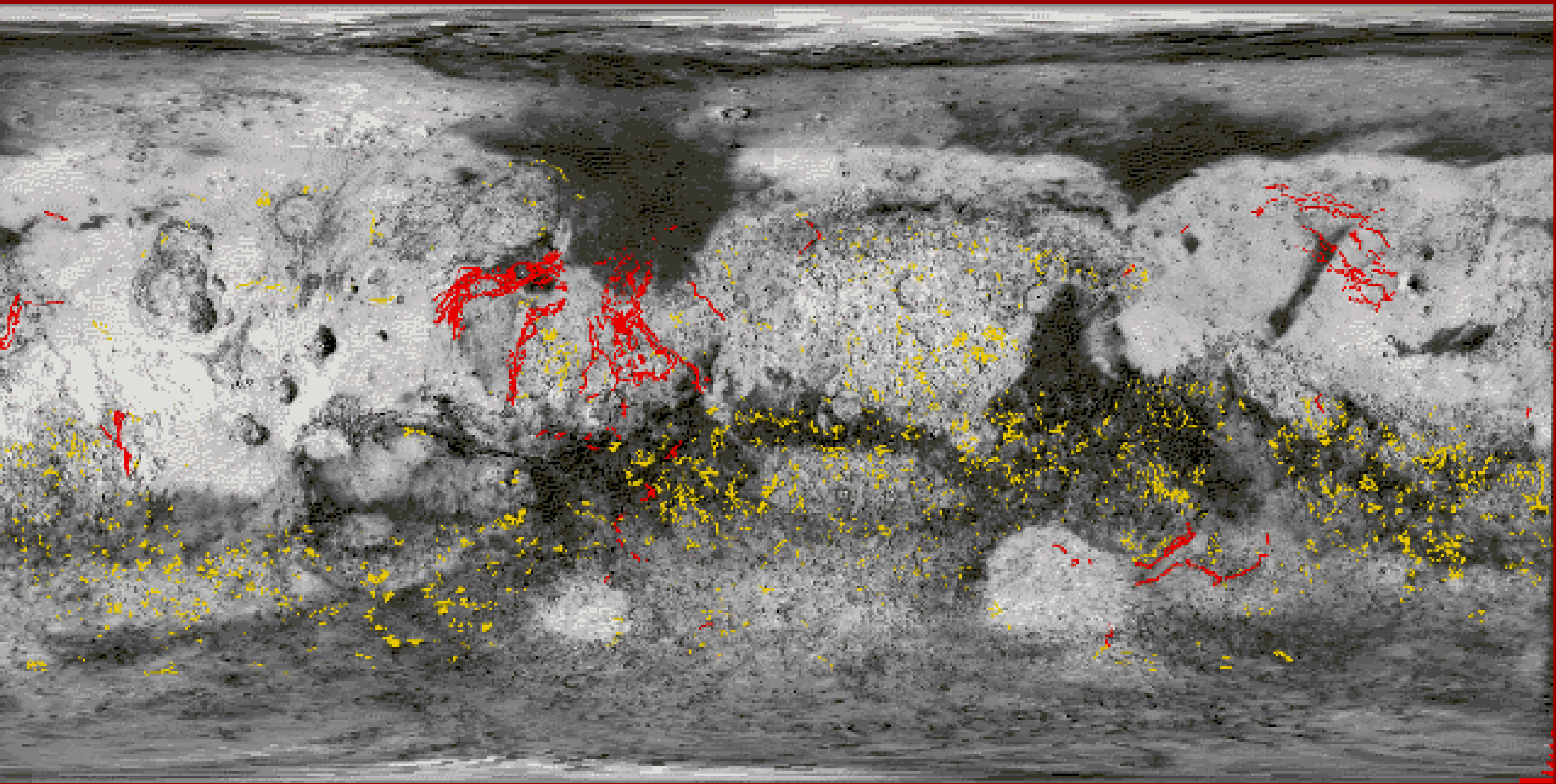
* Dendritic valleys with tributaries => different from outflow channels

* Suggest surface runoff analogous to fluvial rivers on Earth

* Liquid water is likely the fluid involved in the flow (much more stable than liquid CO_2)

3.1.2 Valley networks

Global distribution of valley networks (yellow)



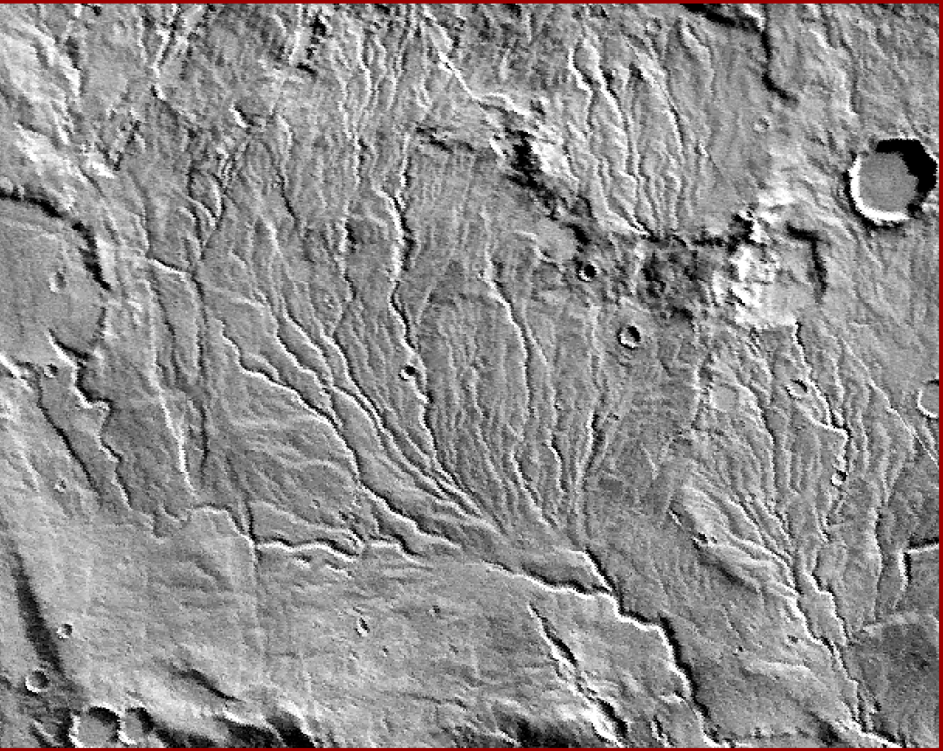
Location : Cratered highlands

Age : Noachian (80%) or Hesperian in some locations

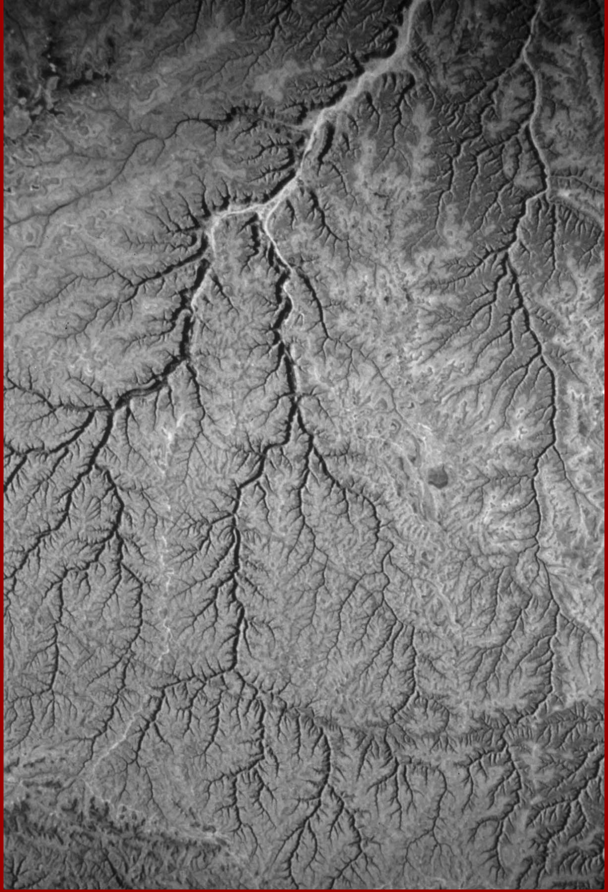
If related to surface run off

=> Indication of stable liquid water and thicker atmosphere during the early Mars

Valley networks



Warrego Valles, Viking image



Yemen, Space Shuttle

But: * Not so much dendritic (tree like organization)
* Not so dense than terrestrial networks
* Junction angles between valleys lower
* Widths of valleys seem not to increase

=> Other processes may be involved without runoff (80s)

Other processes involved:

* Mass wasting valleys (Carr, 1995)

* Sapping processes by geothermal heating (Squyres et al, 1990)

* Impact related heating (Segura et al., 2003)

* Hydrothermal heating and subsurface flow (Dohm et al., 1998)

* Glaciers melting (Carr and Head, 2003)

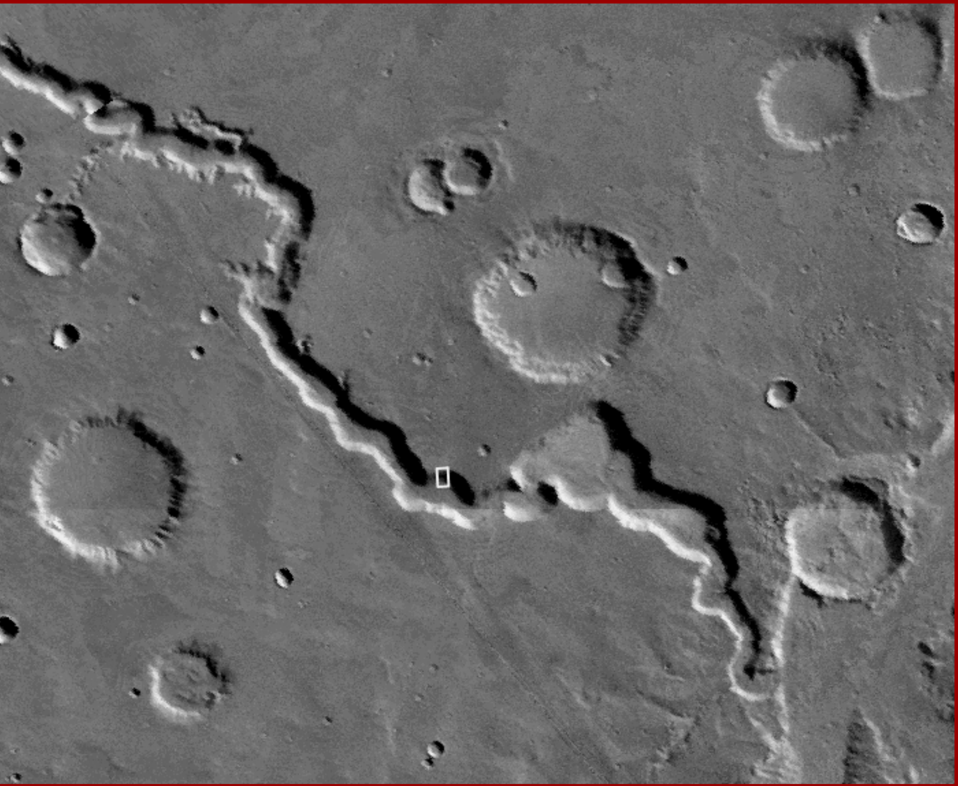
Most of them involve subsurface flow due to the higher geothermal gradient and volcanic activity, mainly by sapping.

What is sapping?

Sapping is the formation of valleys by subsurface flows that erode by backward recession of cliff:

It forms valley with constant width

With theater shape head



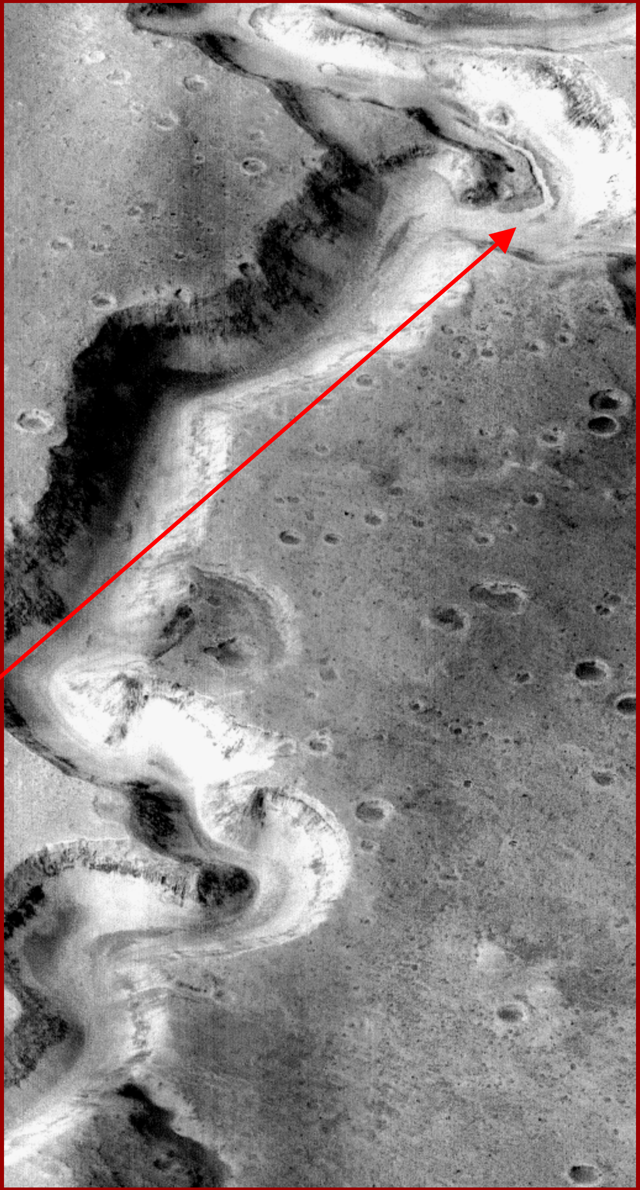
Nirgal valles: typical sapping valley on Mars

Figure 1. Aerial photograph of Box Canyon

From Lamb and Dietrich, 2004

Problem: On Earth, sapping is related to the permanent incoming flux of water from rainfalls, thus it involves atmospheric processes rather than pure subsurface

Nanedi Valles (3 km by 1000 km)



10 km x 28 km, MOC MGS

(Malin and Carr, 1999)

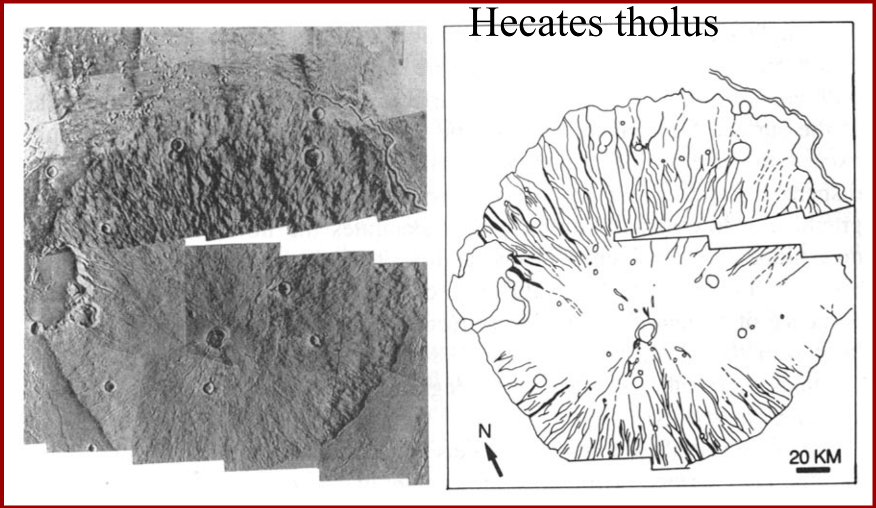
* In postulated sapping canyons, channels mean aerial flow of stable liquid water
=> thus different climate

* Groundwater sapping likely existed on Mars but in correlation with processes of recharge (rainfall, snowmelt?)

* Valleys on volcanoes
Effect of volcanic heating?

* Alba Patera: highest drainage density on Mars (2.3 km-1)

* Could be due to melting of ice caps over volcanoes (Gulick and Baker, 2001)



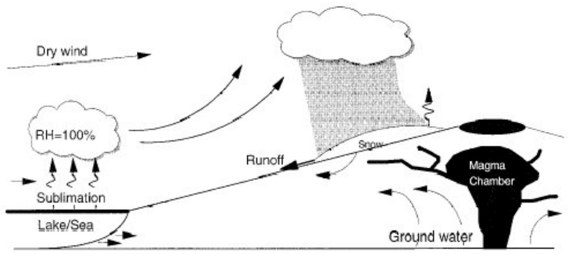
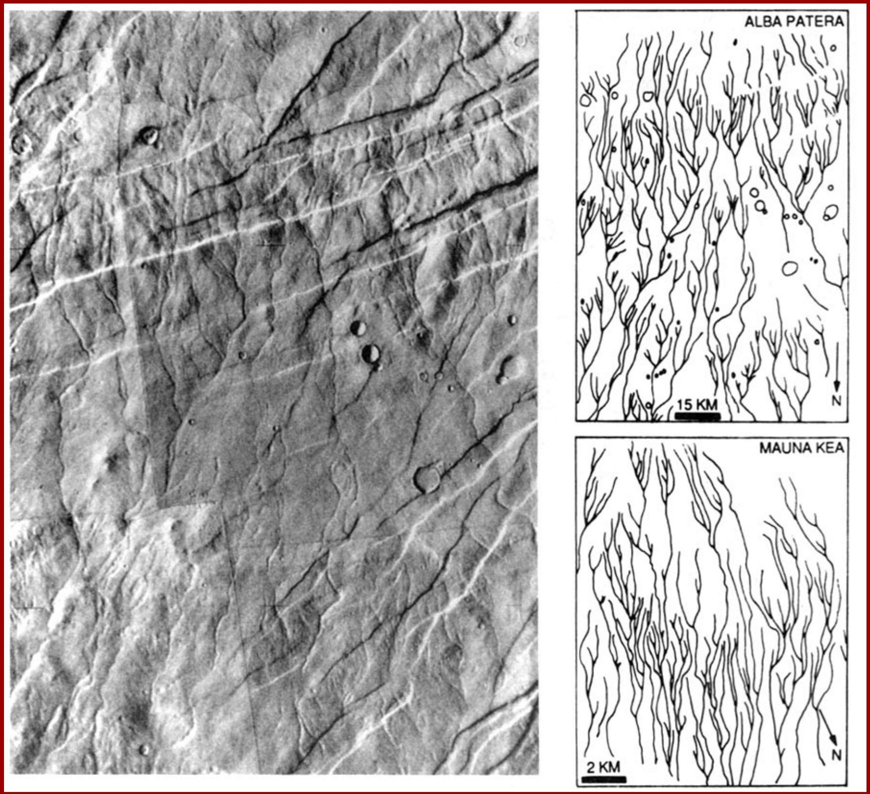


FIG. 13. Conceptual model of sublimating lake/sea/ocean mechanism. In this example, water vapor from a sublimating lake precipitates higher p on the flanks of a volcano where temperatures are cooler, forming a snowpack. Geothermal heating from an active volcano melts the base of he snowpack producing runoff and infiltration. Continued melting, runoff, and infiltration over time may result in the formation of fluvial valleys. he infiltrated water together with hydrothermally-driven upwardly moving groundwater may flow out to the surface farther down the flank and esult in sapping.



* But drainage density as large than Hawaii,
no evidence of glacier,
possibly due to rainfall too
(Craddock and Maxwell, JGR, 2002)

From Gulick, 1991

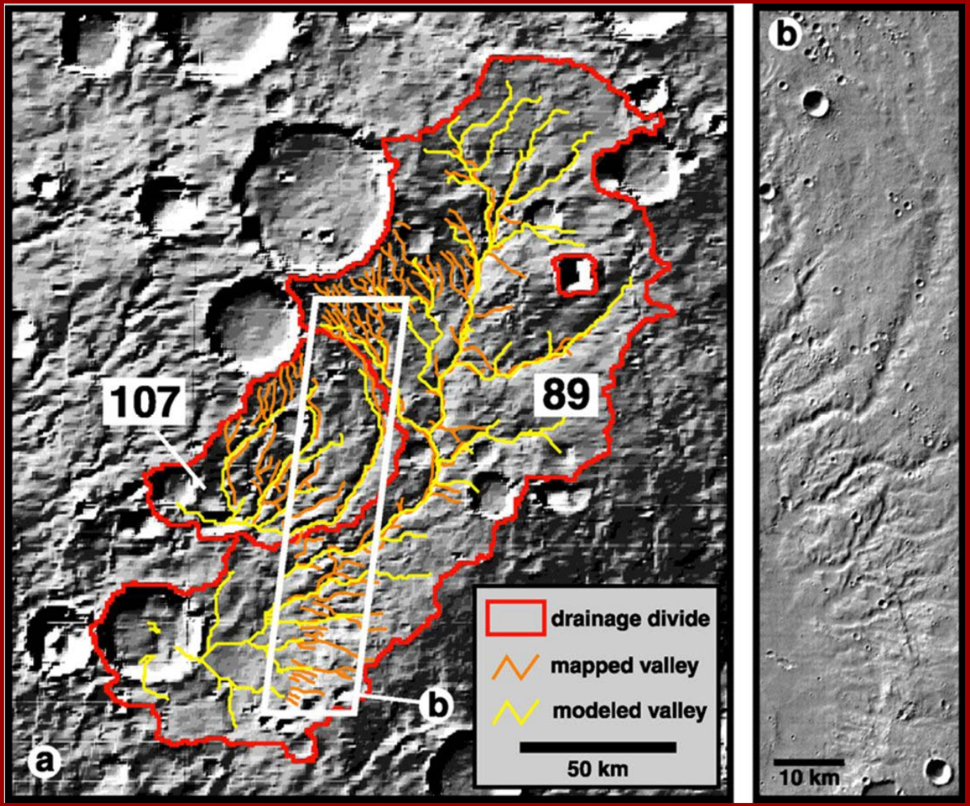
New studies using MOLA and THEMIS:

* Drainage basins typical of runoff and/or sapping

* Drainage densities larger than with Viking

* Strong modifications of 3 Gy of eolian processes explain their low depth

Example in Thyrrena region



MOLA

Mest and Crown, 2004

THEMIS IR

Detailed study of Warrego valles using THEMIS images:

* more numerous tributaries

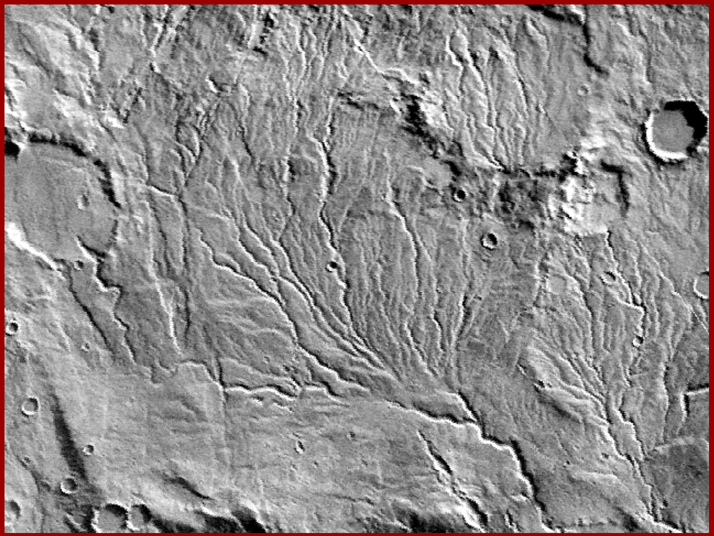
* drainage density : 0.27 → 0.53 km^{-1}

(like on Earth at this mapping scale)

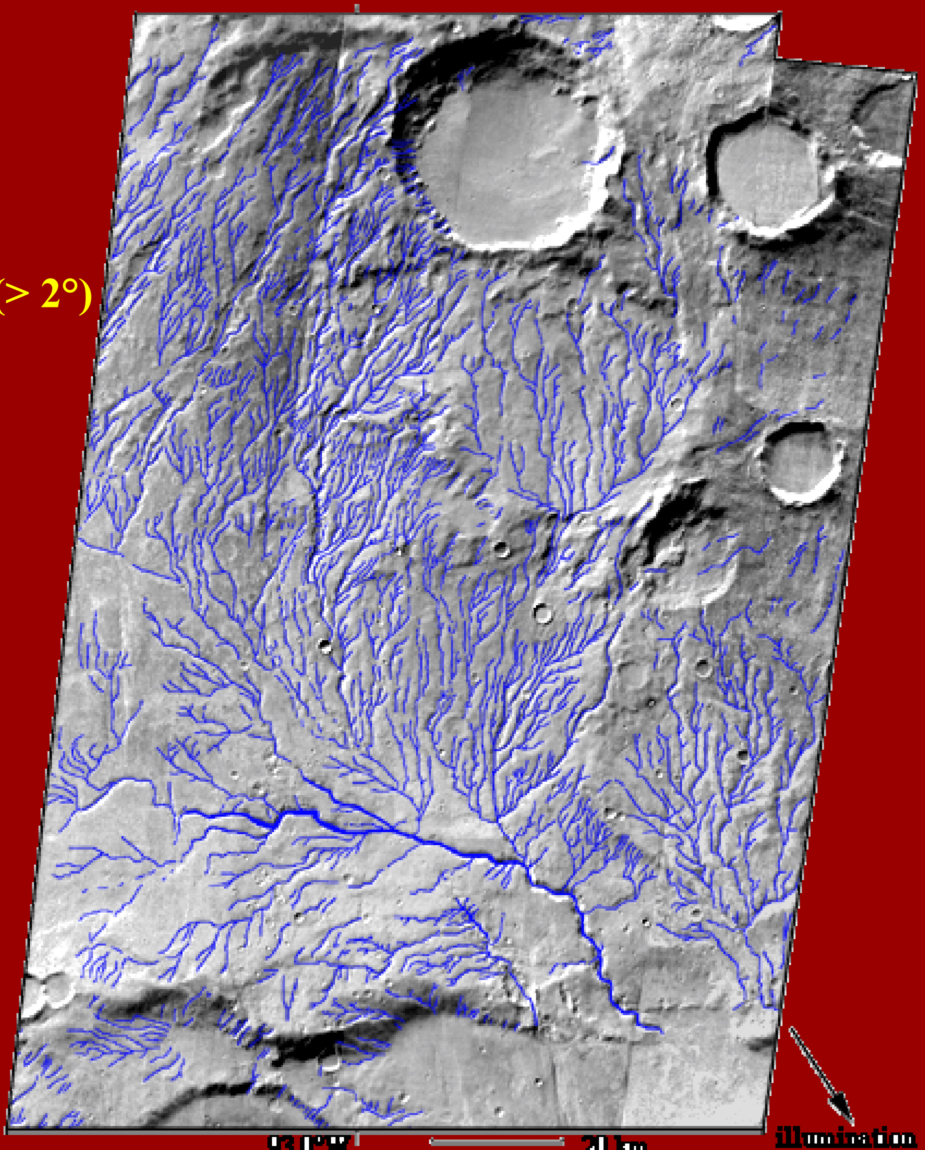
* junction angles explained by regional slopes (> 2°)

=> water atmospheric origin preferred

(Ansan and Mangold, 2003)



Viking



New dendritic valleys from THEMIS images

* Drainage density is ~ 0.7 to 1 km^{-1}

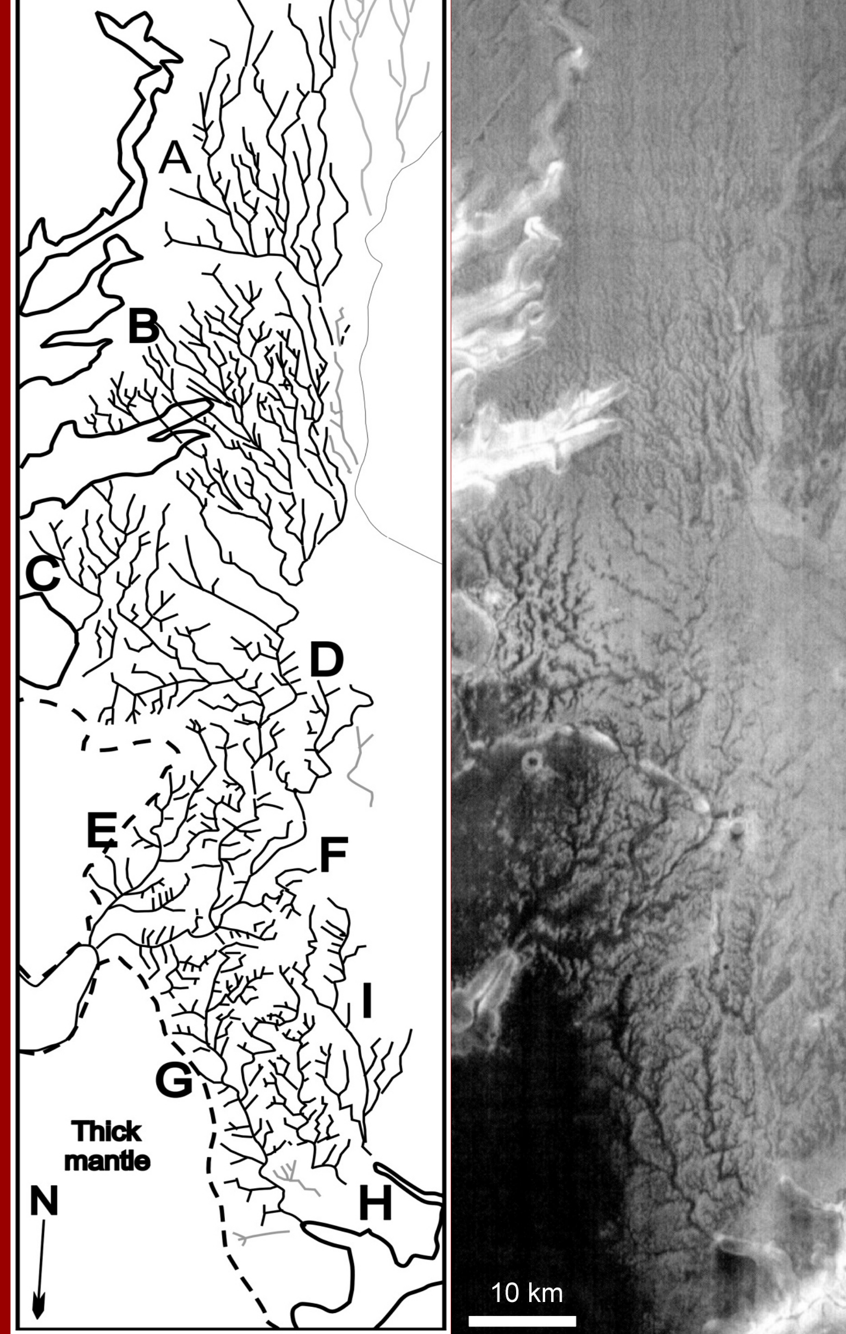
→ Terrestrial like value at such resolution of 100 m/pixel

(according to the study on scales by Carr and Chuang, 1997)

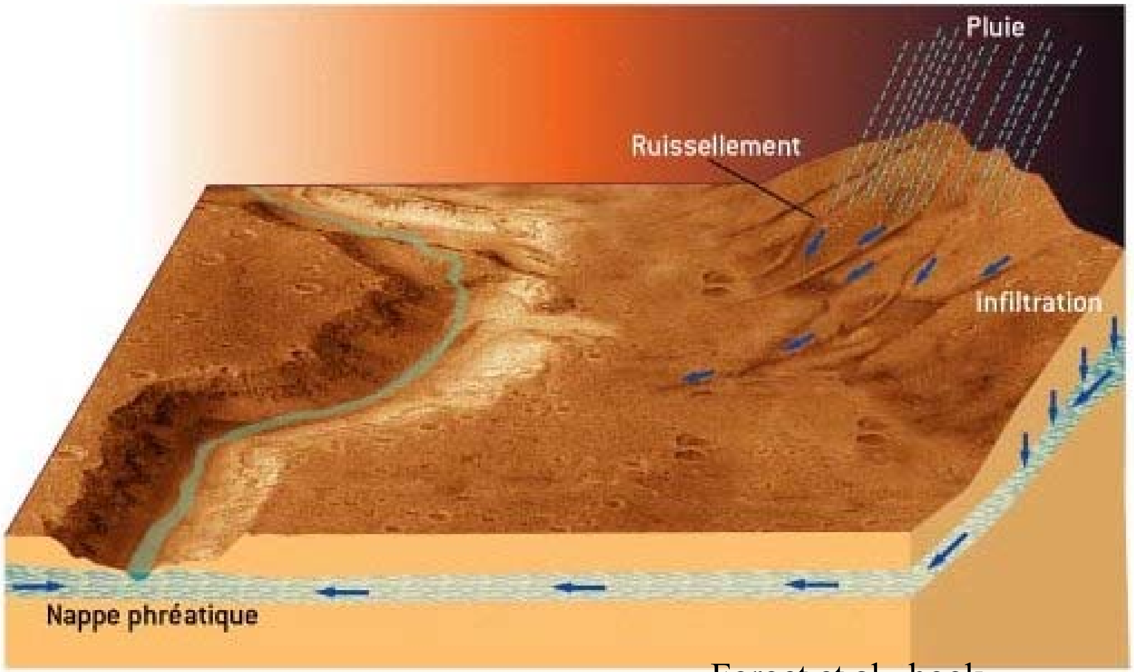
→ Strong organization
Long term action (> 10 ky)

=> Geometry similar to terrestrial river systems suggesting a formation by runoff from atmospheric precipitation

* Location on Tharsis plateau near Valles Marineris
=> formation during Hesperian epoch



Mangold et al., Science, 2004



Forget et al., book

In summary:

* Sapping or subsurface processes existed but they need recharge of water from the above surface

* Valleys likely involve surface runoff and a climate different than the current cold climate but this issue will be still debated

3.1.3 Erosional processes on early Mars

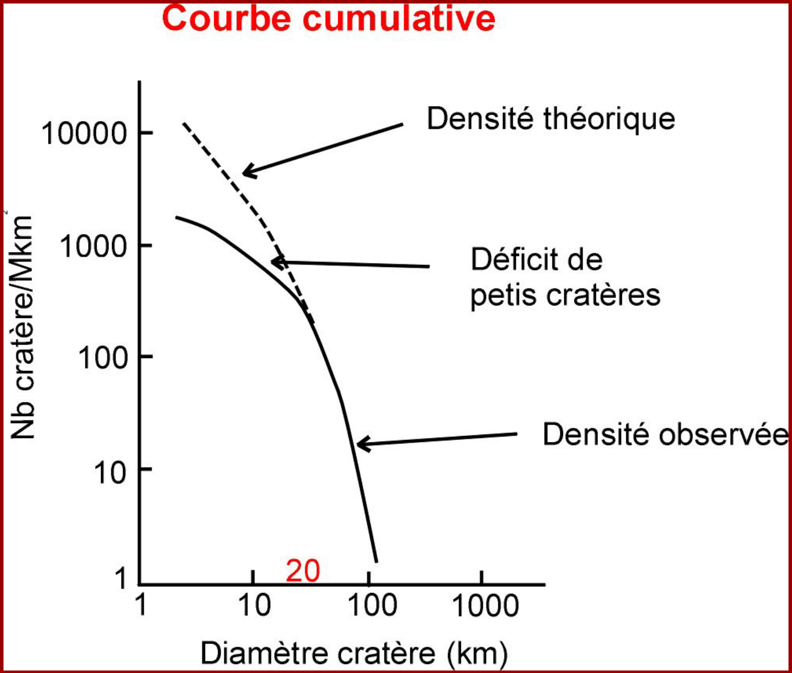
* Depletion of small craters (Craddock and Maxwell, 1993)

* Degradation of large craters (Howard et al.)

=> Best evidence of erosion stronger than at present time

=> Would not be possible with wind erosion and deposition

Highland terrains



Henry crater: filled to the top by layers

3 types of liquid flows on Mars:
Differences in the timing of their formation

I. Période ancienne (avant 3.5 Ga)

Réseaux de vallées
"Valley networks"

Précipitations? Eau liquide stable?
Climat très différent de l'actuel?

II. Période post 3.5 Gy

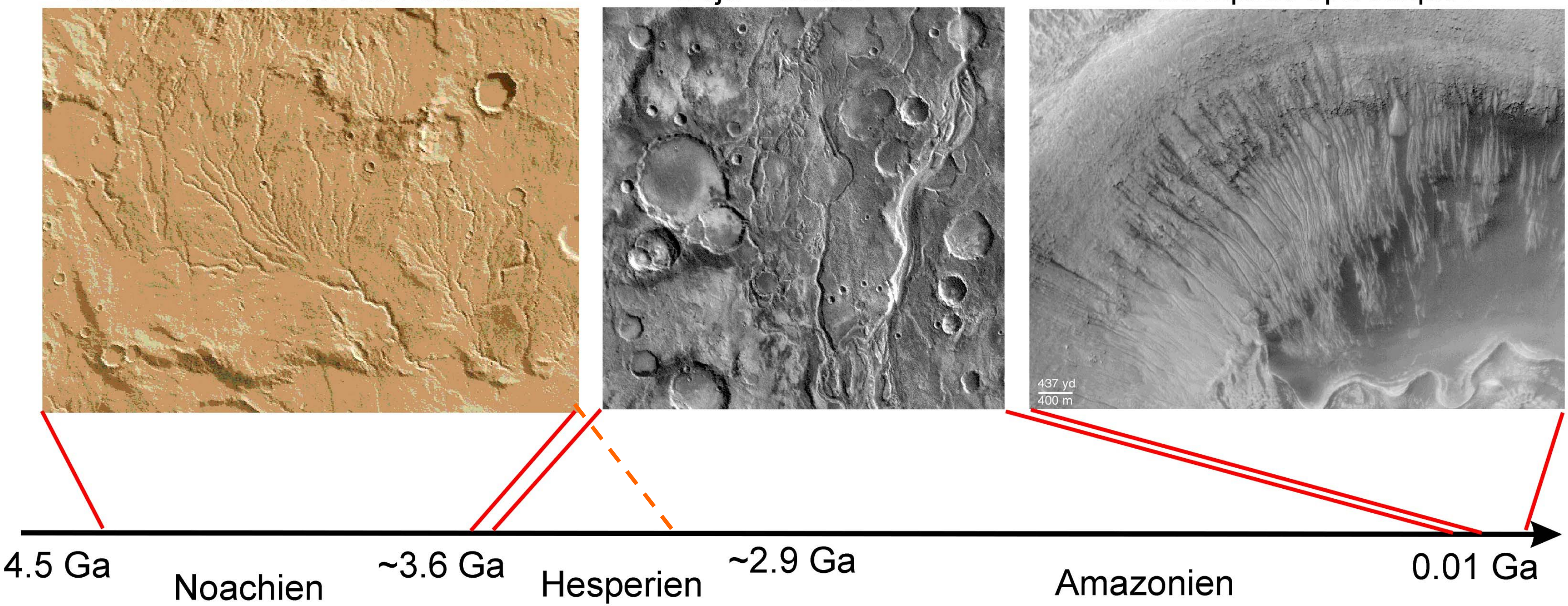
Chenaux
"Outflow channels"

Climat transitoire?
Déja ~ actuel

III. Période récente

Ecoulements sur les pentes
"Gullies"

Variations de l'obliquité
Eau liquide épisodique?

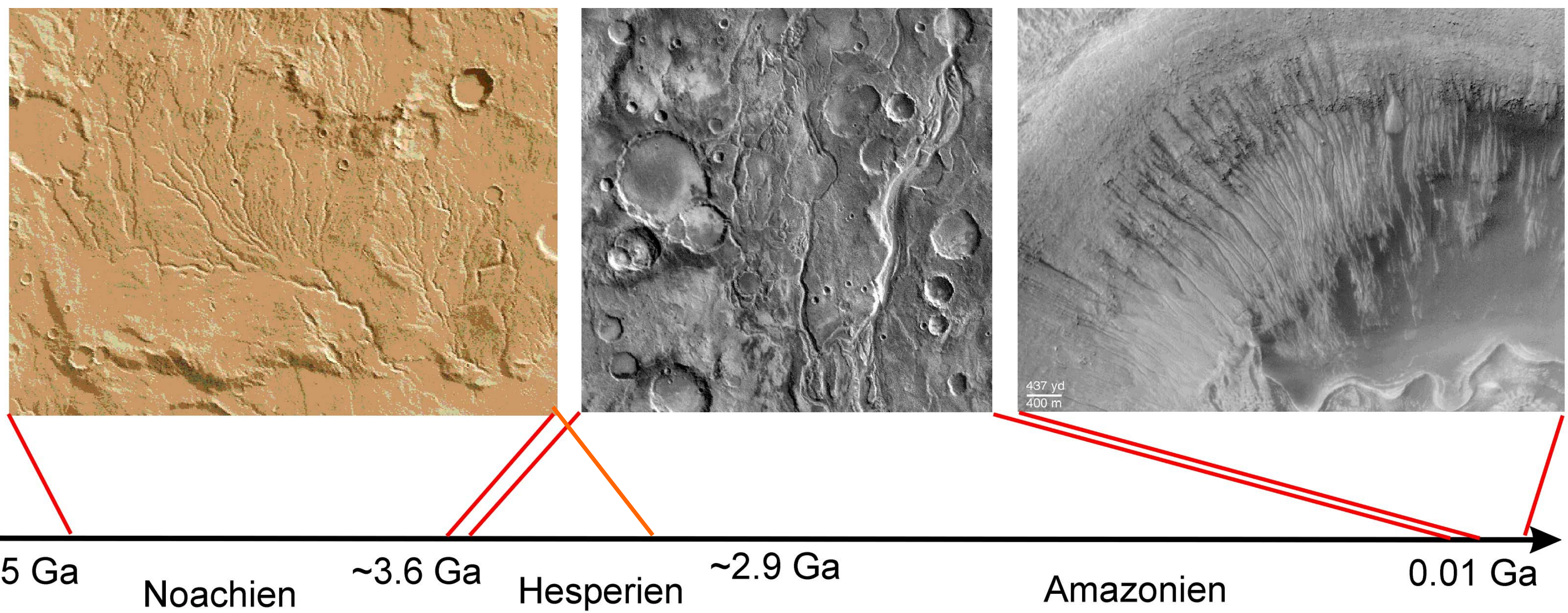


3 types of liquid flows on Mars:
Differences of morphology correspond to differences in processes

River stream (rock<10%)
High organization with tributaries
Length: 100s km
Duration: >1 My(bad constrained)

Concentrated liquid flows (rock 10-40%)
Catastrophic flood
Length: 1000 km
Duration: Days to weeks?

Viscous debris flows (rock>50%)
Strongly confined to hillslopes
Mass wasting more than aqueous flo
Length: 1 km
Duration: less than 1 hour
Episodic



3.2 Standing bodies of water

3.2.1 Ocean and shorelines

* Located in topographic lows (northern plains)

* Mud ocean (Jöns, 1985)

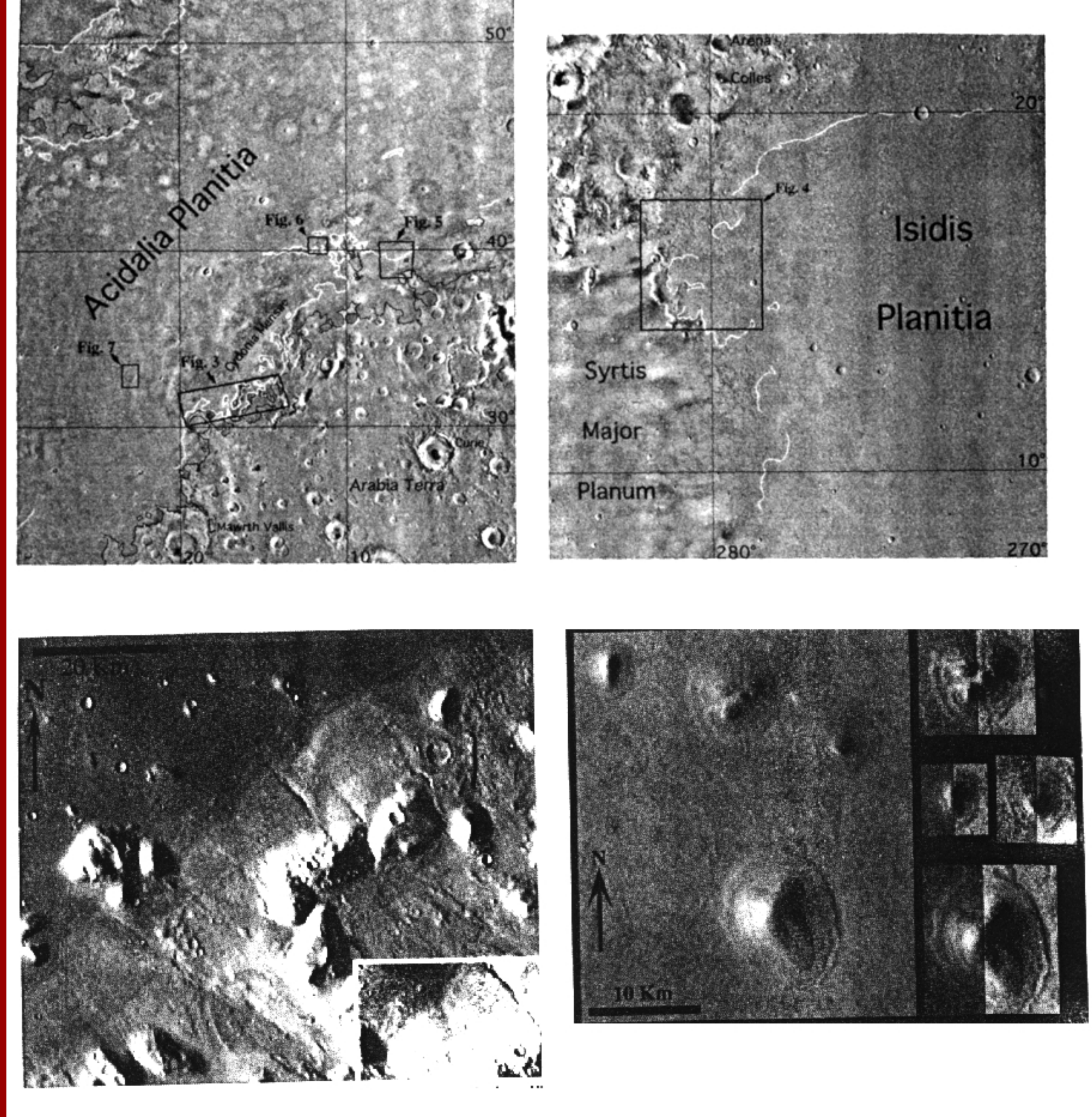
* Curvilinear features as possible fossil shorelines (Parker et al, 1993)

* Detection of shorelines with MOLA data (Head et al., 1999)

* But surface of northern plains of Hesperian age
=> episodic ocean feed by outflow channels?
(Head and Carr, 2003)

* Frozen ocean at surface (Clifford, 1993)

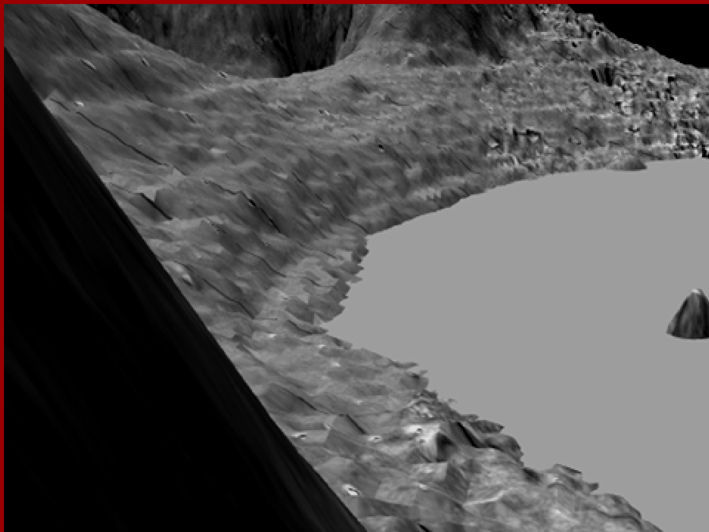
If existing:
Depth : 600 m to 2 km
Equivalent global water layer : 100 m to 400 m (Earth: 2.7 km)



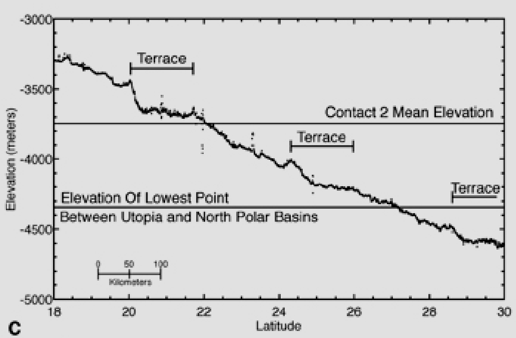
Linear features as possible fossil shorelines
(Parker et al, 1993)

Detection of shorelines by MOLA data

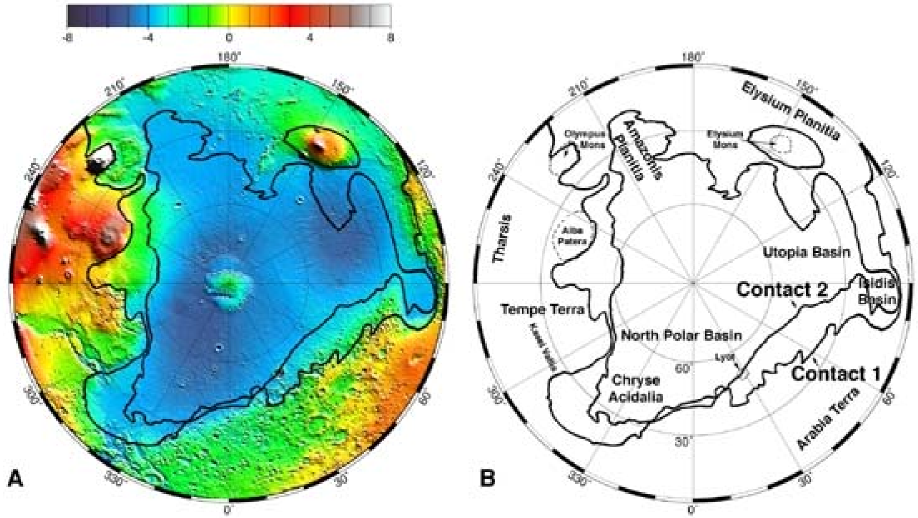
Two contact lines: only the contact 2 follows equipotential line



B
Figure 4



C
Figure 4



A B
Figure 1

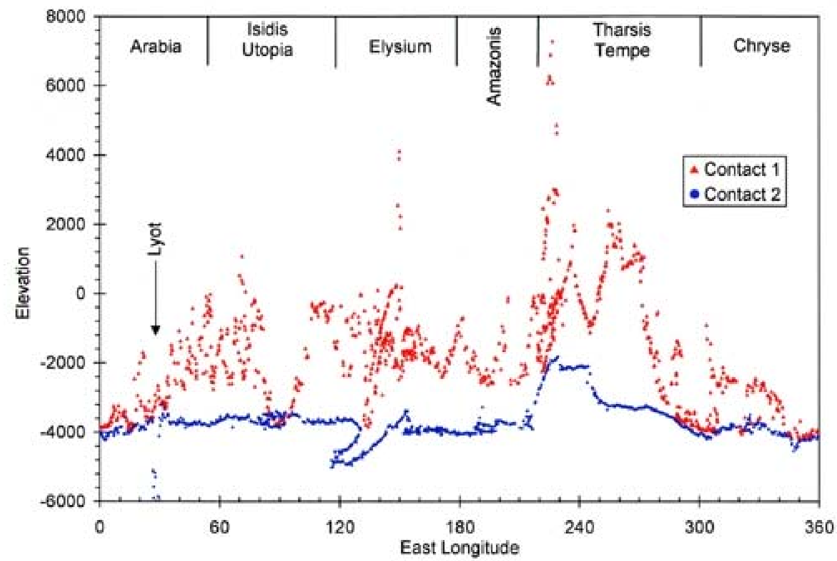
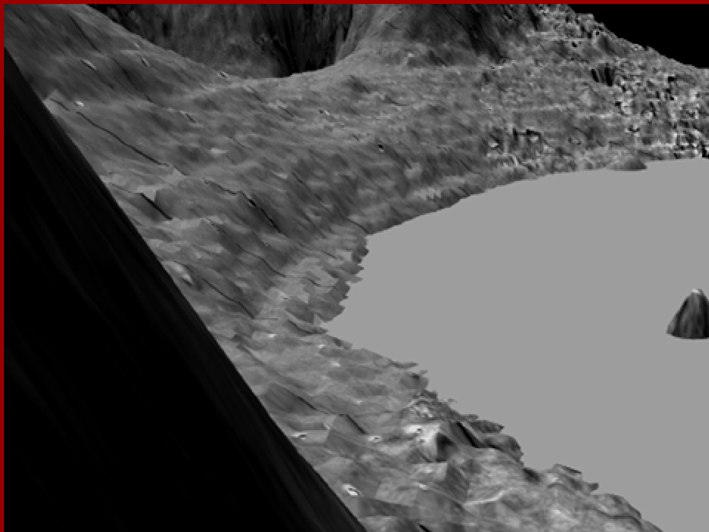


Figure 2

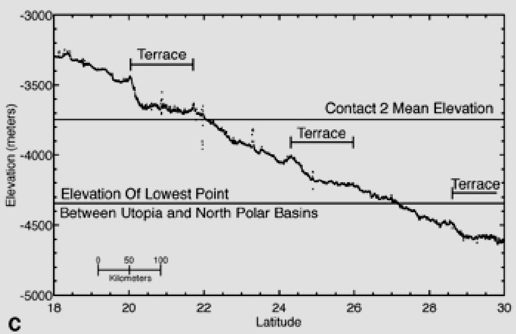
Head et al, 1999

From J. Head et al., 1999

Example of shorelines in the Nevada



B
Figure 4



C
Figure 4

Same topographic trend
but typical topography of 1-2 meters
rather than 100 m on Mars

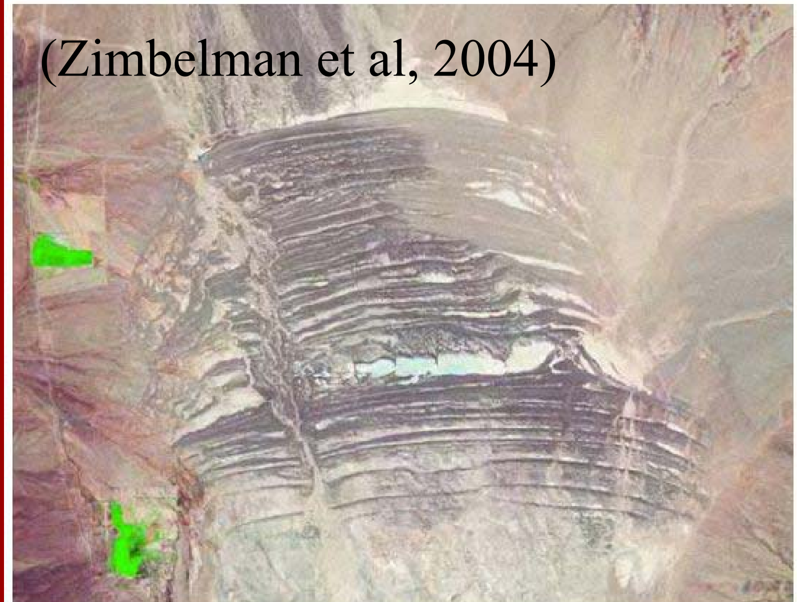


Figure 1. Portion of Landsat image of shorelines on the northern end of Spring Valley, Nevada.

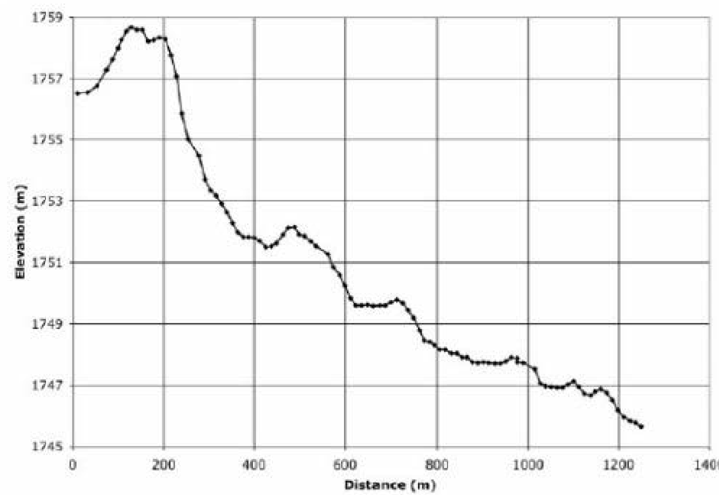


Figure 2. DGPS survey of uppermost shorelines in

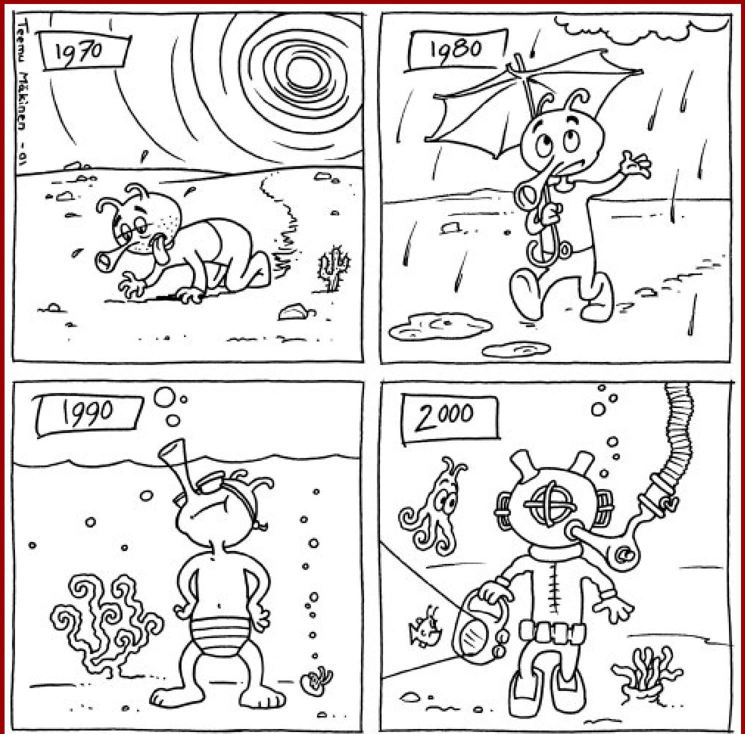
* Shorelines are strong topography (50-100 m)

Is this possible with a cold climate and frozen ocean? Or seasonal action of summer warmer temperatures

* Material composition of northern plains not fully understood

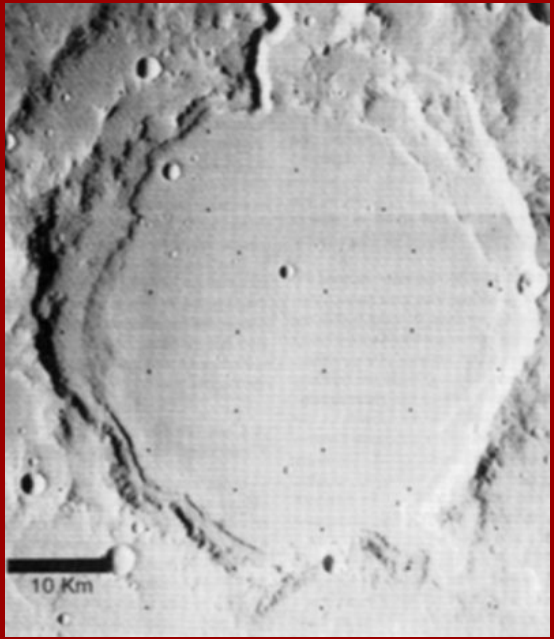
=> Sediments over 3 -4 km needed for explaining subdued impact basins

=> Volcanic filling can have filled 3/4 of the plains previously as sediments. Presence of buried wrinkle ridges could reveal volcanic rocks superimposed by several 100s of meters of sediments

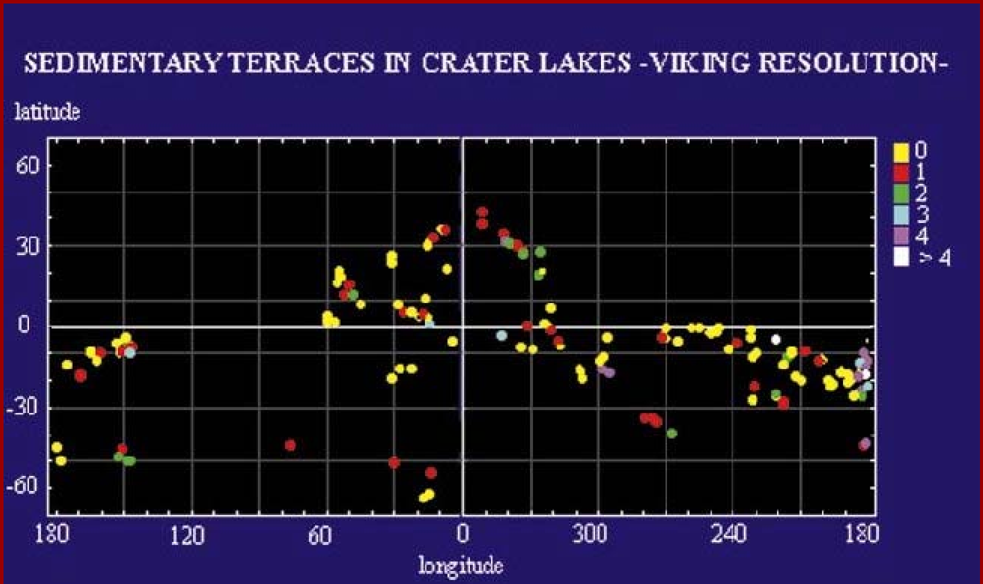


3.2.2 Crater lakes and deltas

Since Viking data, geologists find evidence for crater lakes from shorelines and delta fans



Forsythe and Zimbelman, 1994



Map from Cabrol and Grin, Icarus, 2000

Lakes exist especially in craters due to their lower topography

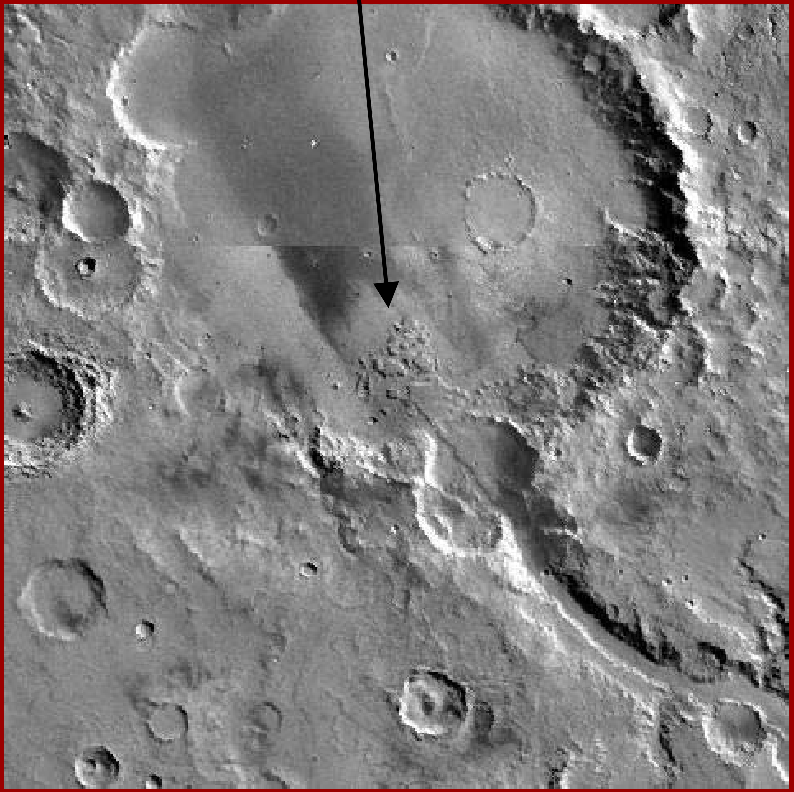
About 100 crater lakes identified mainly in highlands
(Noachian age but some can be Hesperian or even Amazonian)

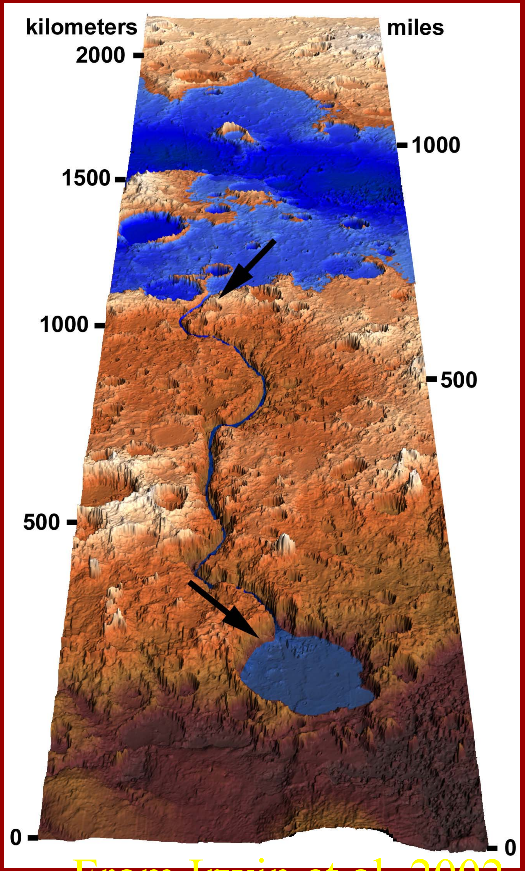
One specific crater lake: Gusev crater and Ma'adim Vallis

* Potential crater lake from identification of delta at the outlet of a large channel (Maadim valles) (e.g. Cabrol et al., 1994)

* Maadim valles formed by the rupture of lakes present in the highlands (Irwin et al., 2002)
=> does not mean that the lake was present over long duration in Gusev

Delta relics?



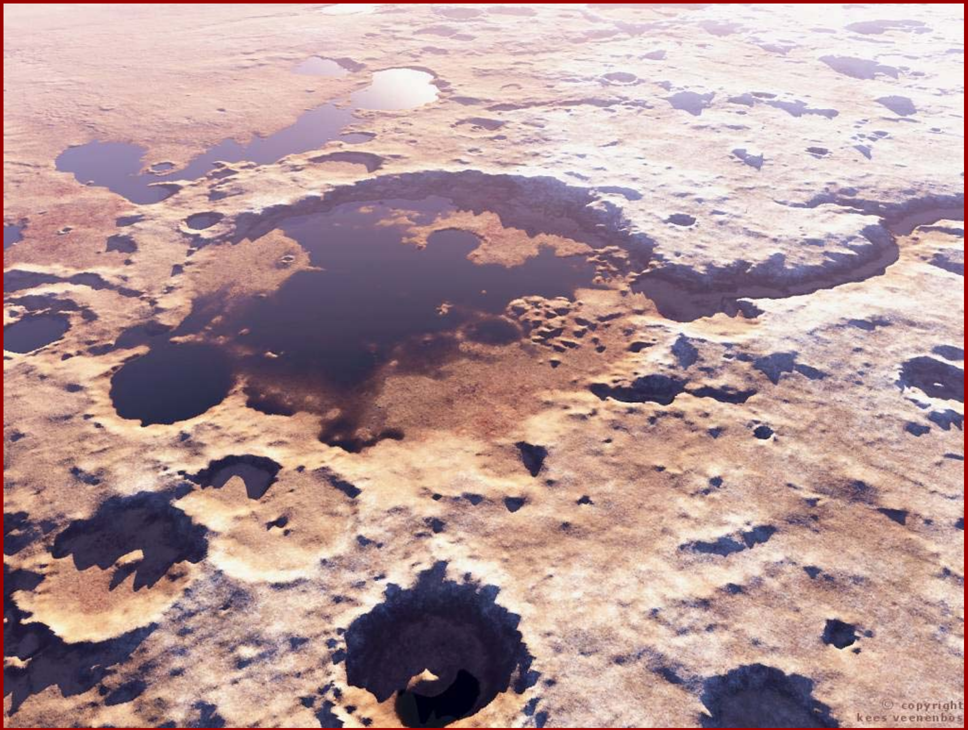


From Irwin et al, 2002

* Has been chosen for MER rover because of large size (> 100 km) of a potential crater lake

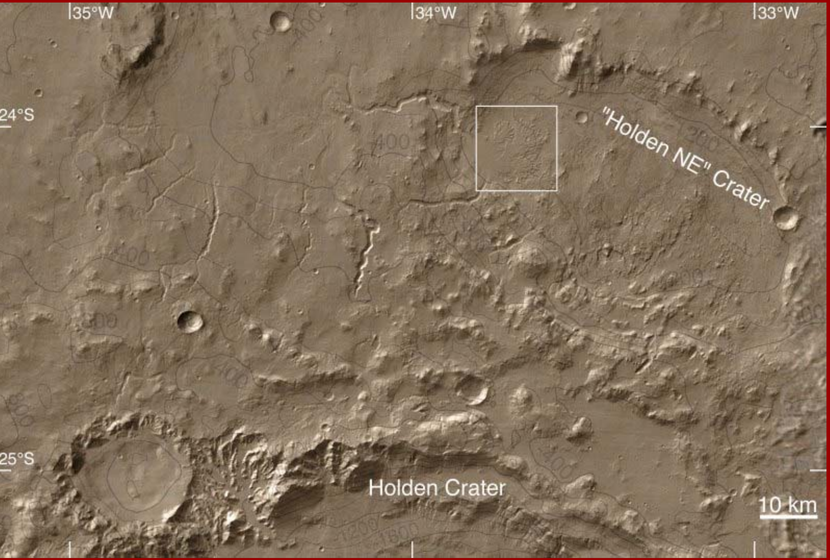
* But MOC images and now MER surface images suggest later volcanic activity

* Does not mean that crater lakes are not interesting



Interesting crater lakes with delta

NW Holden crater



Malin and Edgett (Science, 2003)

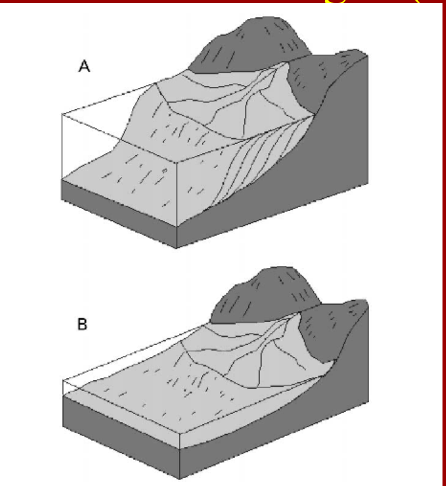
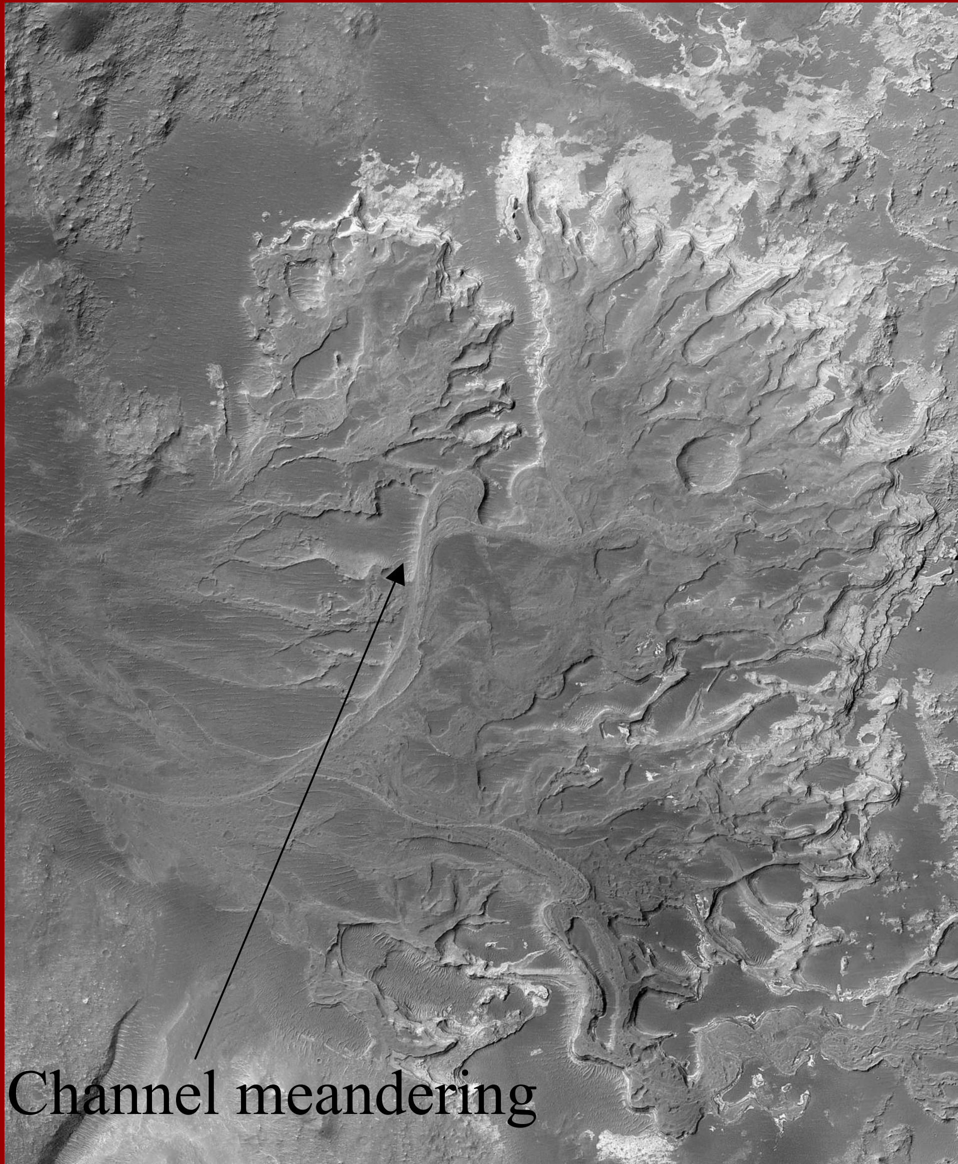


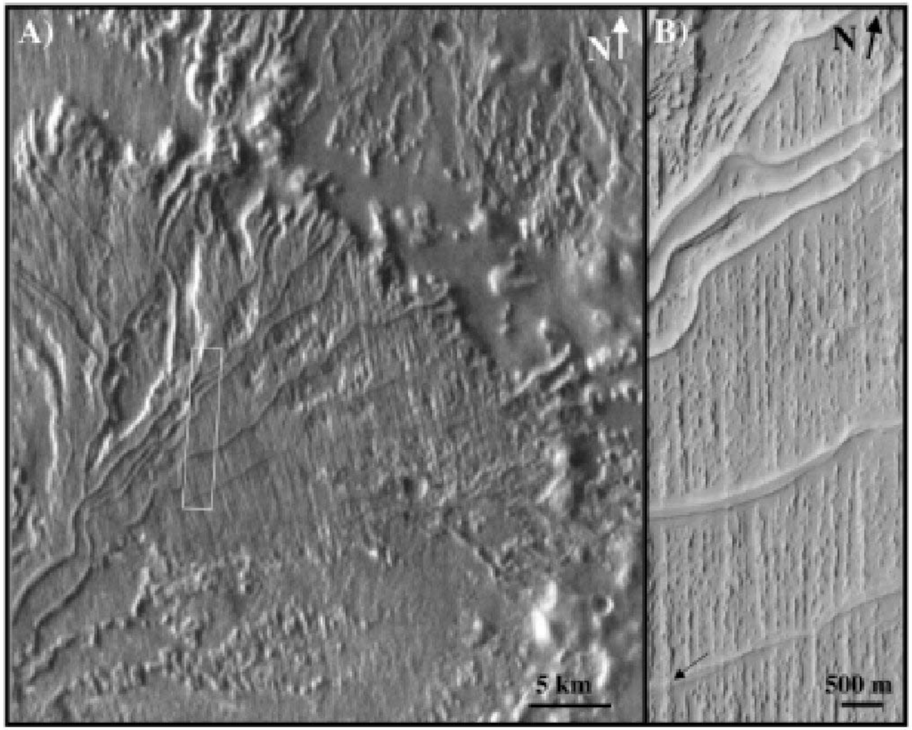
Fig. 2. Fan-like features with sedimentary body geometry in (A) deep-water and (B) shallow-water settings.

Ori et al., 2000

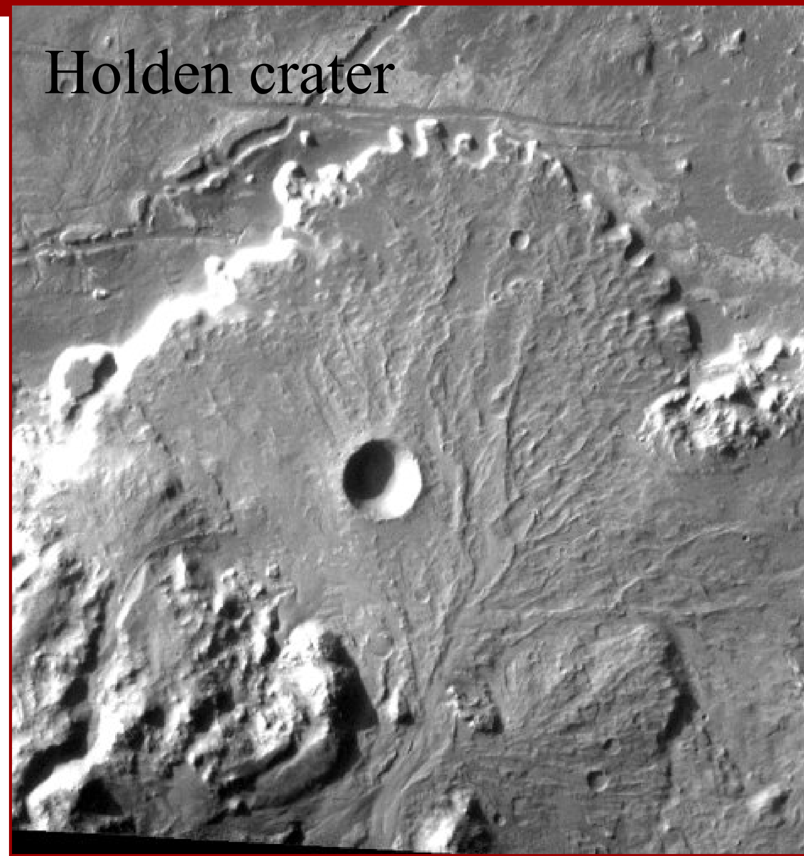
Delta with inverted channels



Other examples of delta will be found with new imagery



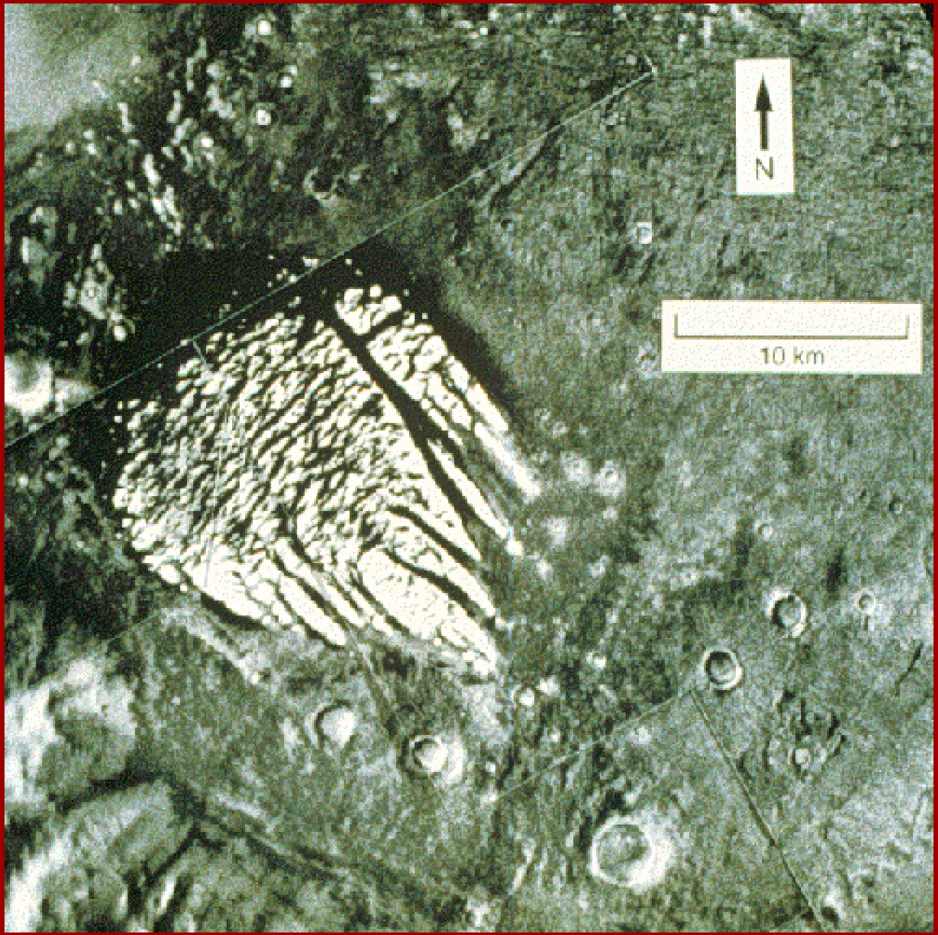
re 3: A) THEMIS IR image I05588001 of a fan-shape landform centered at 6.3° S 208° W in Aeolis Mensae on. A radiating pattern of bifurcating ridges is being exhumed from beneath a stratigraphically higher layer. te box is location of B). **B)** MOC NA E18-00307 illustrates the branching ridges are below strata that is eroding rm yardanges (arrow).



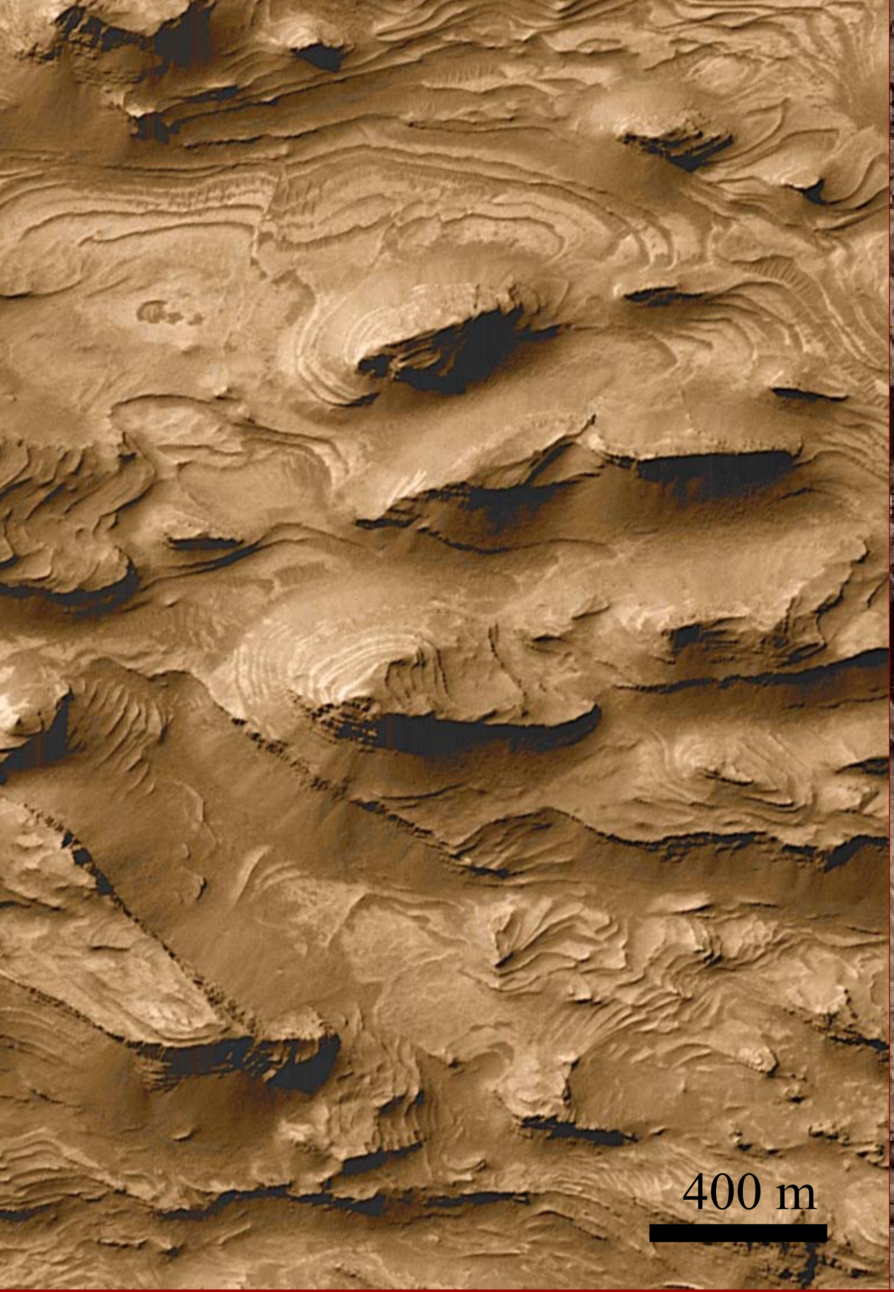
dgett and Williams, valley network workshop, 2004

Ansan and Mangold, Polar conf. 2003
Marinangelli et al., 5th Mars conf, 200

3.2.3 Layered deposits



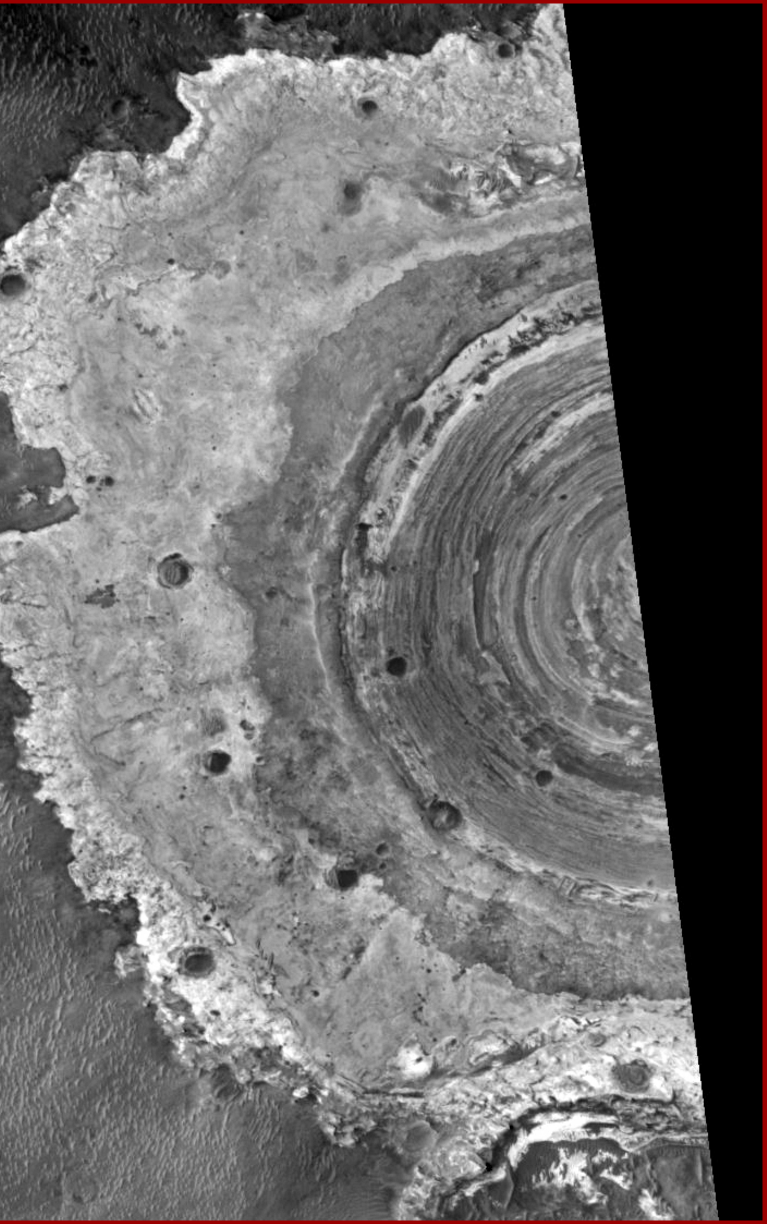
White rock: One of the first obvious crater interior deposit
Possible clay or evaporite deposits (e.g. Forsythe and Zimbelman, 1994)
Notice the wind erosion (yardangs)



ayered deposits in Candor Chasma
Valles Marineris region)

Inside crater of Xanthe Terra region

3.2.3 Layered deposits



* Deposits are widespread on Mars at MOC scale (Malin and Edgett, Science, 2001)

* Deposits can be exhumed by erosion like this circular crater fill (by wind)

* Deposits are ligth toned, almost always

* Color+weak resistance to wind erosion
=> sediments but 2 possibilities
1. Clays or evaporites from lacustrine deposits
2. Dust and sand deposed by wind

Strong debate about their origin

* New results by OMEGA spectrometer
(onboard Mars Express)
(unpublished, Bibring, COSPAR abstract)
300 m pix res , 0.5-5 micron spectral range

Observation of sulfates (kieserite, $MgSO_4$) on layered deposits that suggest evaporites
To be confirmed soon...

3.3 Composition of sediments: from geomorphology to geology

3.3.1 MER rover discoveries

* Viking and Pathfinder landers have found a dry and cold desert
* No evidence of past water lakes except rapid outflows over Ares valles on the Pathfinder site
* Rocks are volcanic, no sedimentary rocks
* But soil is rich in clay and sulfates and is strongly oxydized (red color)
* The nature of soil is uncertain: Only cold weathering over long time or material weathered in the past?

A completely new site:

Opportunity: site « Terra Meridiani » 25 january 2004

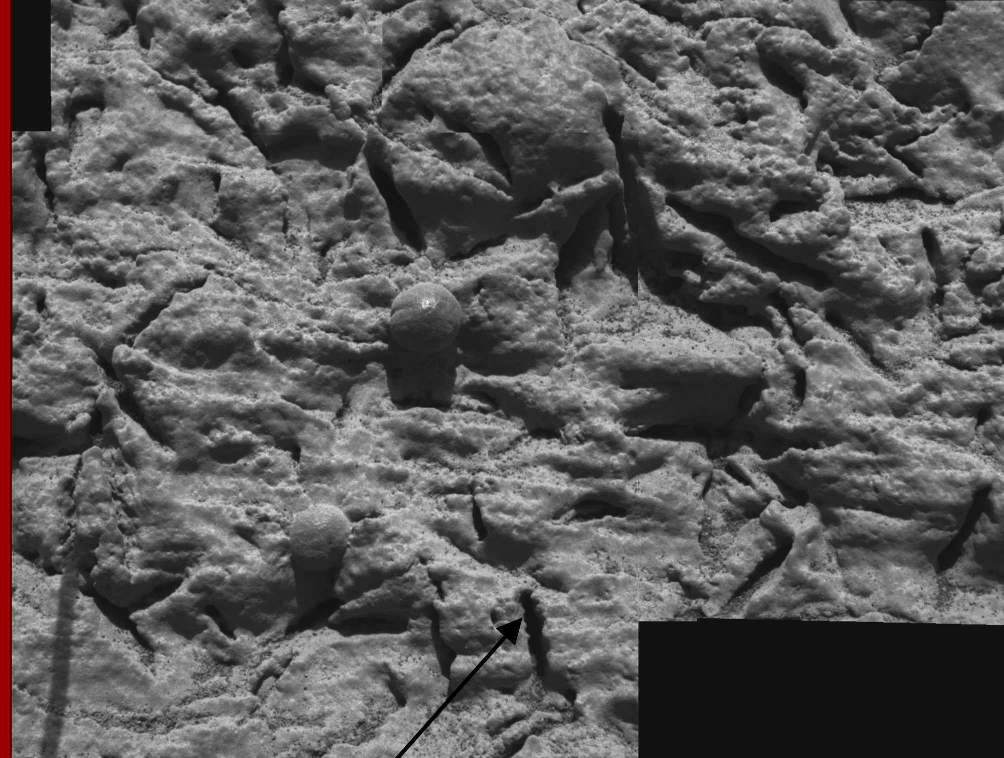
Identified by spectrometry (specular « gray » hematite).

First look to a sedimentary outcrop

[redacted] Terra Meridiani, Mars

Rover Opportunity

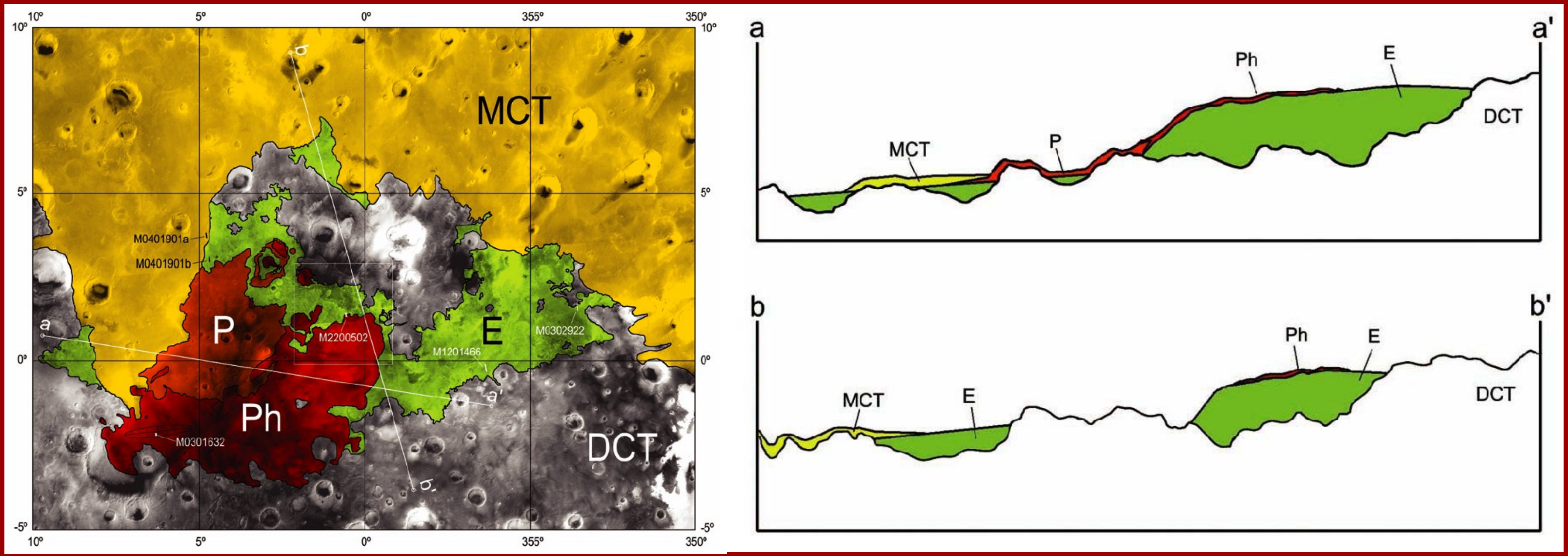
Likely sedimentary layers formed under water:
Cross bedding, ripples, « blueberries », gypsum mold...



Gypsum mold ($CaSO_4$)

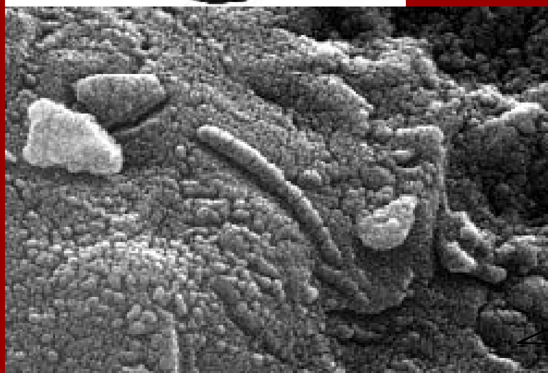
Fine layering + composition with high Cl, S, et Br content
=> subaqueous sediments most likely

Geologic cross section of the Hematite site (Arvidson et al., 2002)



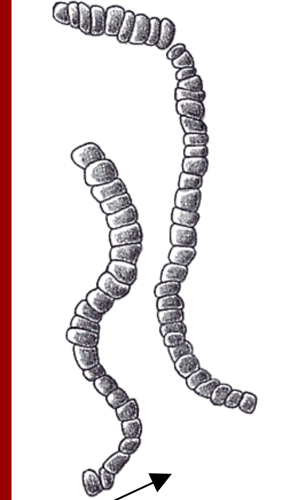
The crater outcrop may correspond to the top of the etched unit
=> >100 meters thick of layered deposits
which would mean a long time to form subaqueous sediments

3.3.2 Exobiological issues



Possible bugs found on ALH84001 meteorite
(D. MacKay et al., 1996)

Now, most people think this is not life, and can be terrestrial contamination or minerals but many studies have developed since this discovery

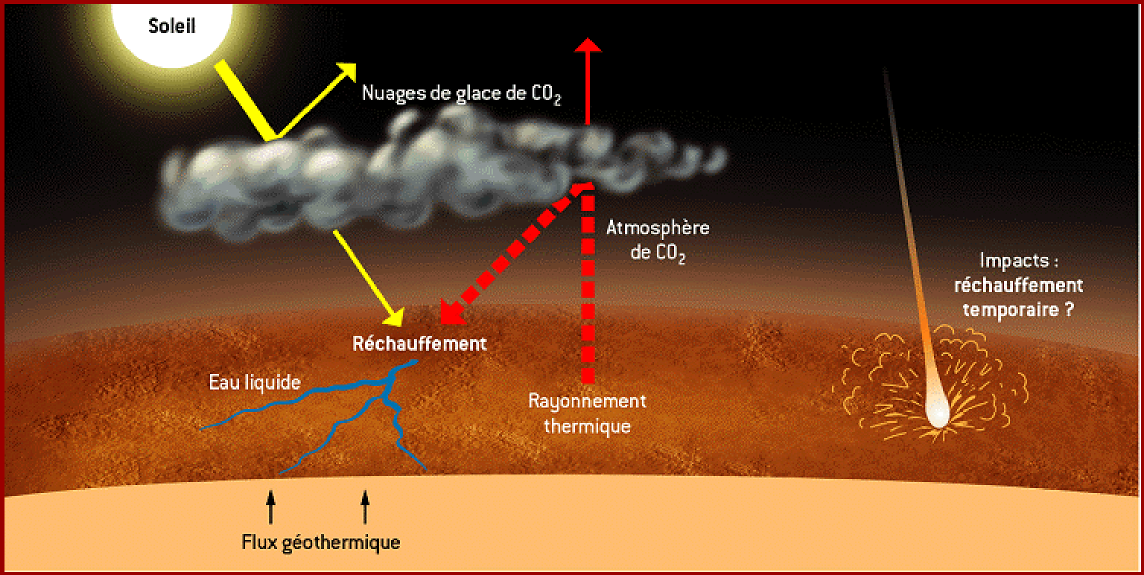


Oldest life form found on Earth 3.5 Ga in Australia has similar shape

But synthetic or mineral molecules can have same organization

A major interest of Mars is that its ancient climate could have been similar to Earth at the epoch at which life is supposed to have begin, and that we can found these evidences at the surface (no plate tectonics, moderate erosion)

Early Mars: complex history not yet fixed (influence of impact cratering, geothermal heating, volcanic flows, etc.)



* Many landforms (valleys, delta, lakes, sediments) in favour of warmer period with flowing liquid water at surface
=> require a thicker atmosphere, likely CO2

* Major problem against warm period: where is the CO2?
(atmospheric escape, weathering, carbonates, etc.)
but no carbonates currently observed
=>Problem of the « missing carbonates »