Geophysics & Meteorology on the surface of Mars

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Geophysics on the Martian surface

Why a geophysical exploration of Mars?

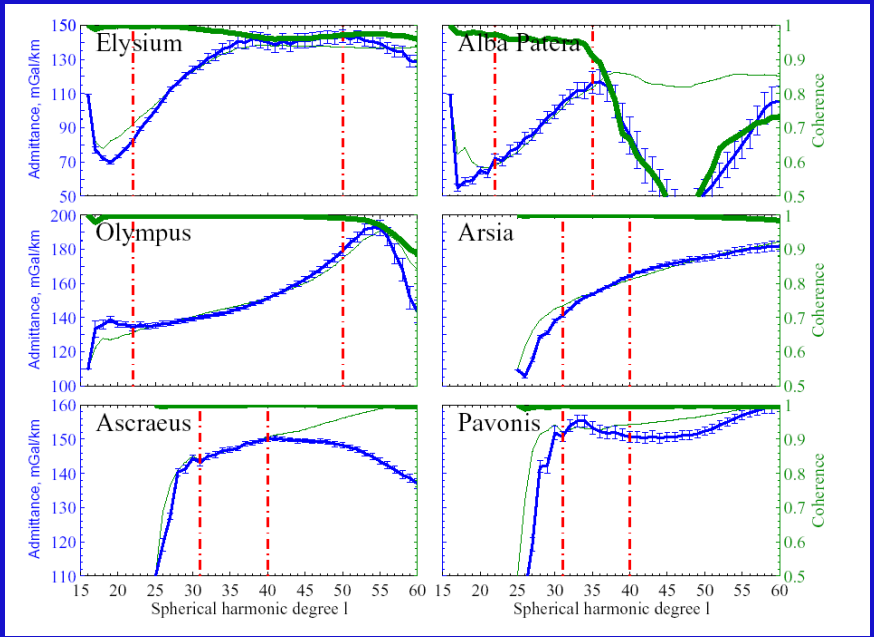
- Many strong geophysical differences between Earth and Mars:
  - Active Earth Magnetic field/ Extinct on Mars ... shielding of atmosphere
  - Active Plate Tectonics/no clear evidence on Ancient Mars... green house regulation and convection regulation
  - Large scale convection/past plume convection possibly extinct ... cooling rate
  - Big Moon/small moons ... rotation stabilisation
- Geophysics and geochemistry are the only way to constrain the key parameters of the “living” planet
- Main Objectives:
  - comparative planetology between Earth and Mars
  - to understand why Earth has evolved differently from Mars
  - to understand the link between planetary evolution, habitability evolution and life survival
  - demonstrated links may change the probability for life survival in the univers and the probability for present evolved life forms in other solar systems

News in Martian geophysic/geochemistry

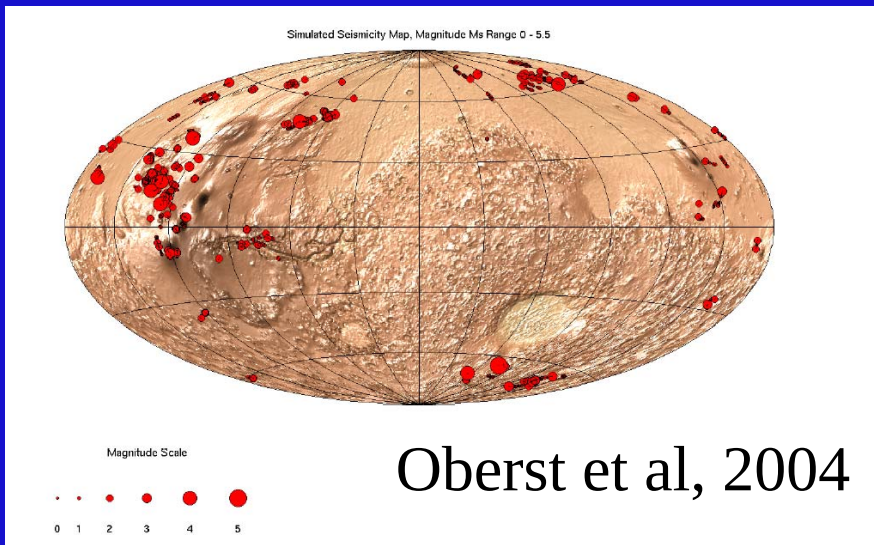
- **The first billion of year was the most active period**
  - Global core/mantle differentiation occurred very early, at least before the complete decay of ^{182}Hf (9 My)
  - Crustal/mantle differentiation occurred also very early, at least before the complete decay of ^{146}Sm (103My)
  - Isotopic analysis of Pb, Sr, Os are consistent with little or no crust remixing
  - No magnetic anomalies are found in the youngest major impact basins (Utopia, Hellas, Isidis, Argyre) showing that the core dynamo had ceased by late Noachian or early Hesperian
- **Interior/atmosphere interaction is crucial for understanding the ancient habitability of Mars**
  - Most of the Tharsis bulge was produced during the Noachian and Tharsis formation could has released a global layer of 120m of water and 1.5 bar of CO_2
  - Atmospheric escape and liquid water stability suffered from the early cessation of the dynamo
- **and… Mars is possibly still geologically significantly active!**

Present Mars

- Atmospheric methane has been detected by PFS, suggesting a continuous production (volcanic or volcanic/biogenic)
- Admittance analysis of MGS topo/gravi data suggest a possible signature of still active mantle plumes beneath Elysium and Arsia
- Young lava flow are found in Tharsis and near Elysium by HRSC data
- Fault analysis suggest a localized tectonic activity in the last 100 My



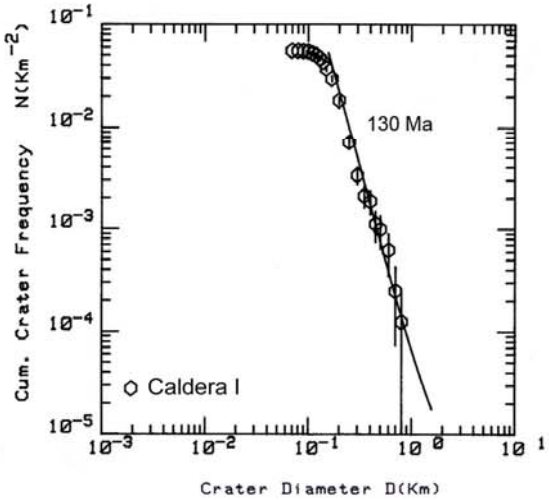
Belleguic et al., 2005

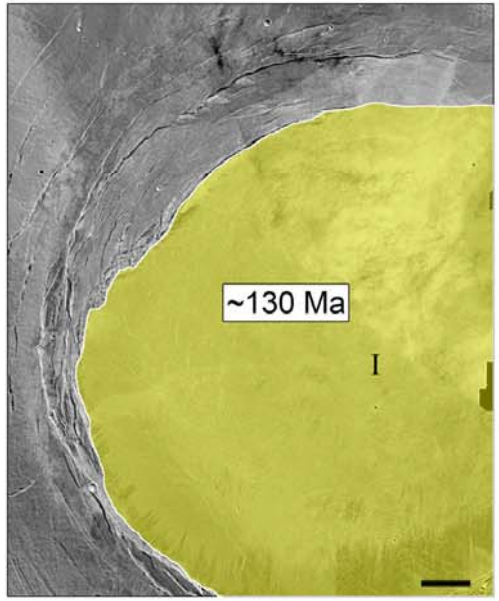


Oberst et al, 2004

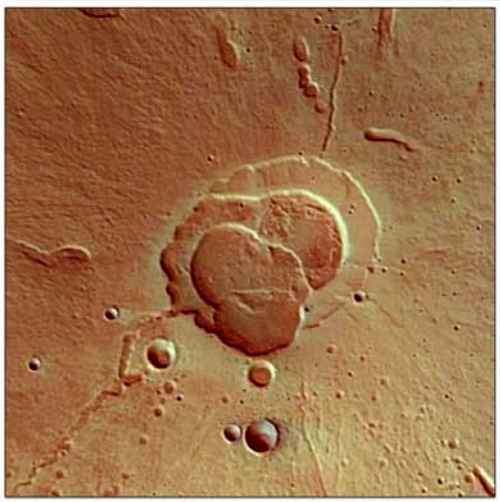
Arsia Mons and near-Elysium Hecates Tholus

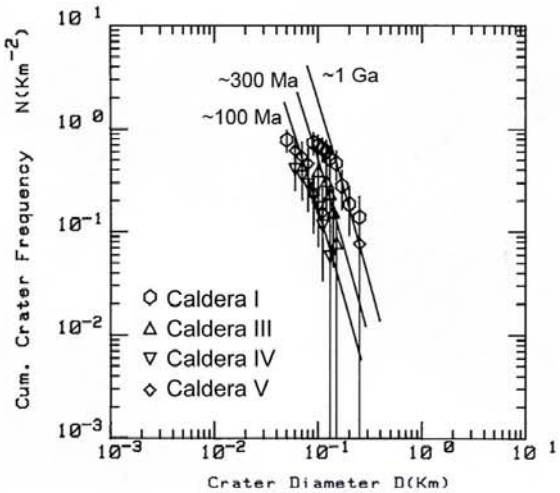
Arsia Mons

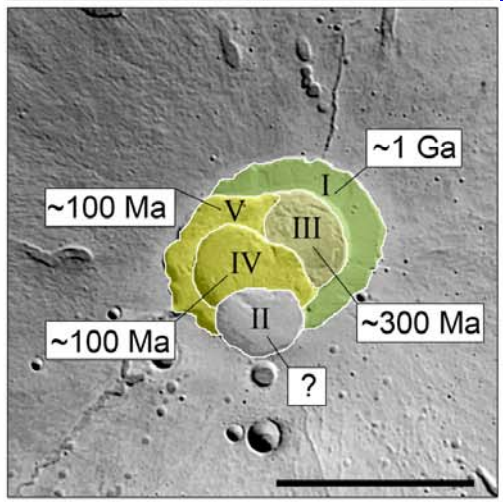




Hecates Tholus

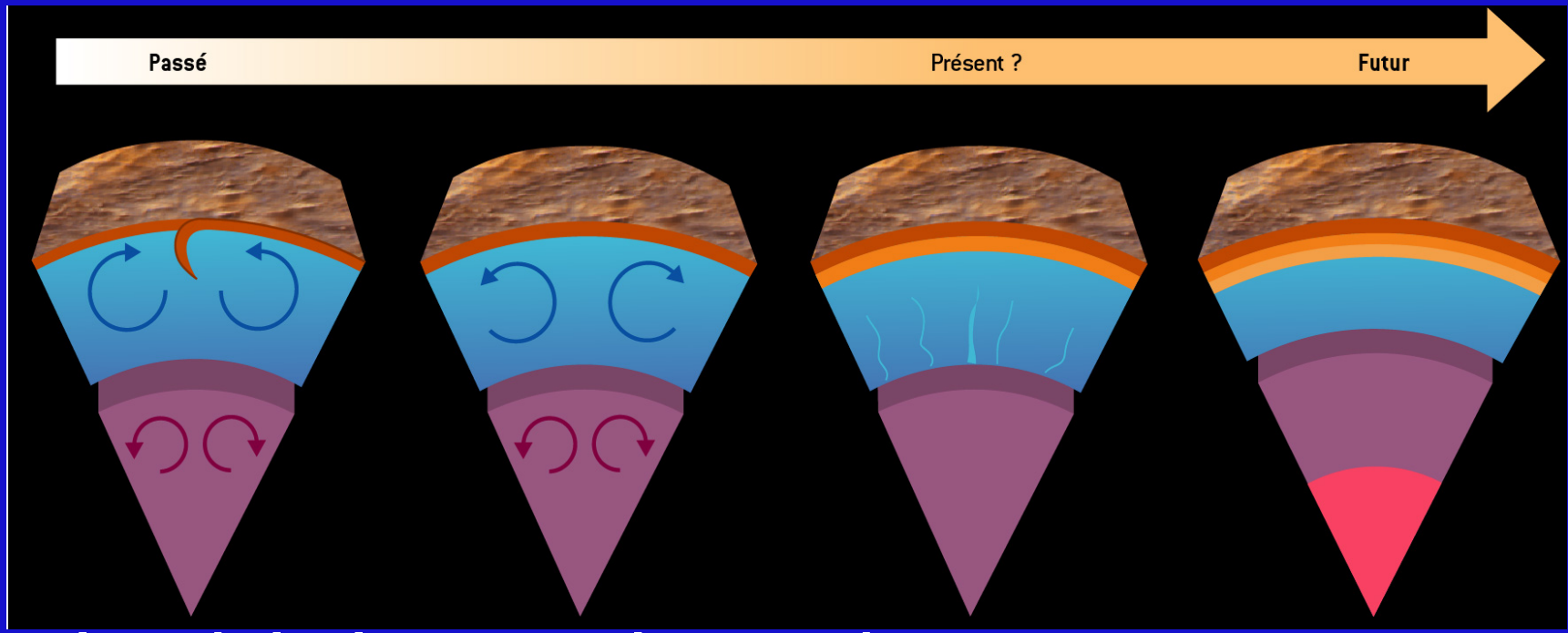






Neukum et al., 2004

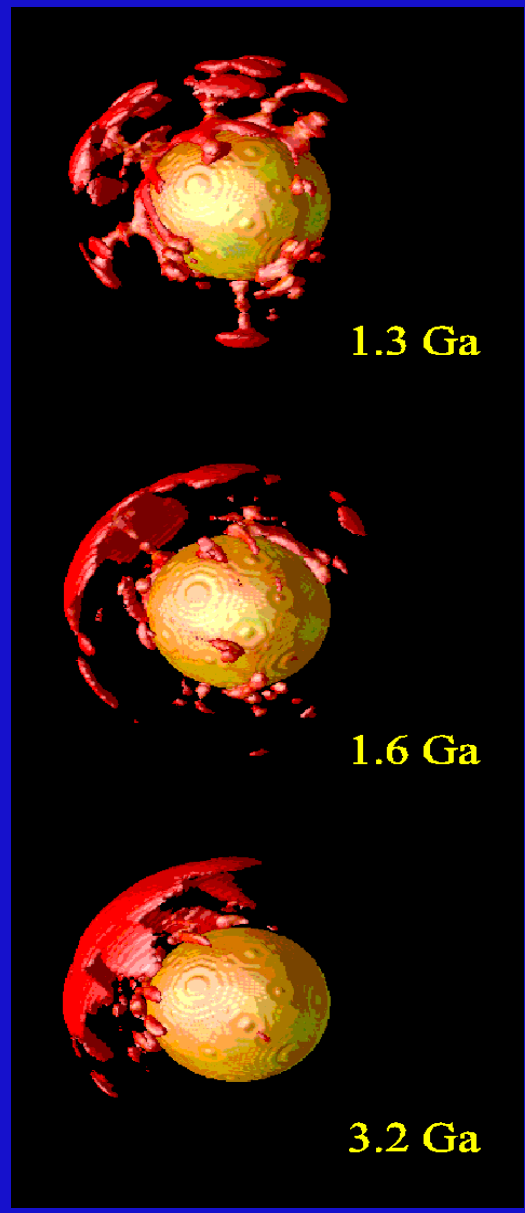
and….many open questions!



- Did Mars had a plate tectonics during Noachian?
- What is the water/volatile content of the Martian mantle and its outgazing history?
- Does the lack of magnetization of the Northern hemisphere results from a post-dynamo formation or from hydrothermal alteration in the upper-crust associated to a major water reservoir in the northern plains?
- What is the present heat flux? What is the present volcanic and tectonic activity?
- Did Mars started an inner-core formation?
- What is the timing of the geological evolution?
- How does such evolution impact on the habitability of the planet?

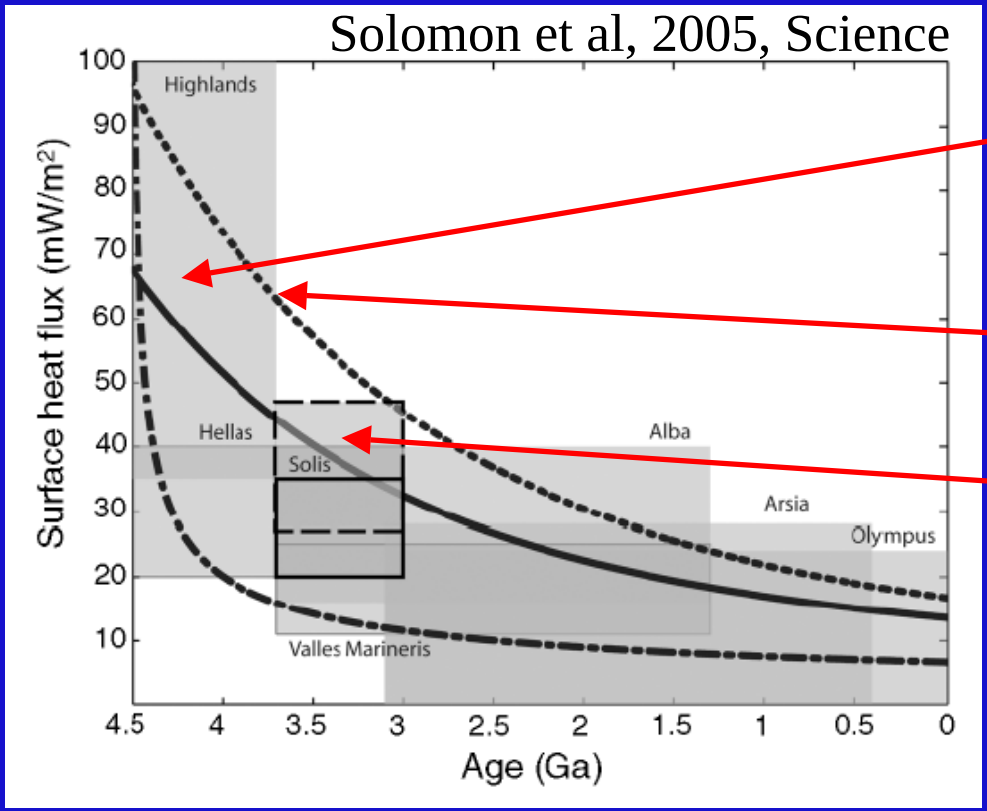
One example : Tharsis formation

- Understanding of Tharsis formation (including its impact on the past climate, water cycle and planetary habitability) need the knowledge of the mantle convection processes
- Key parameters:
  - Martian heat flux and mantle viscosity
  - Mantle layering and effect of exothermic/endothermic phase transitions
  - Crustal heating and crustal insulation



Spohn, Breuer et al., 1997

Constraints on the heat flux



Gravimetry/topography studies

Theoretical studies

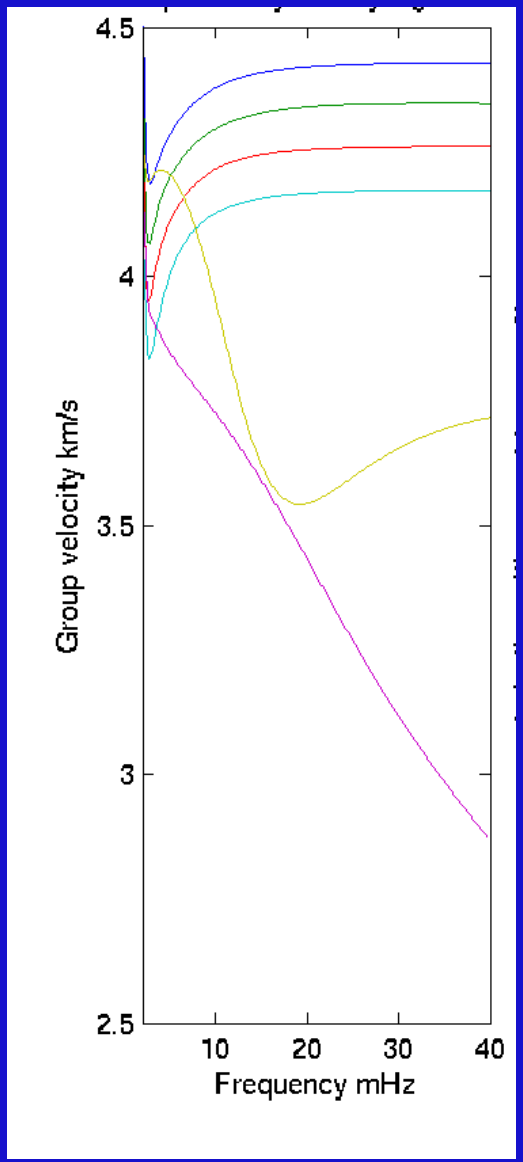
Wrinkle ridges modeling

- Other parameters are also not constrained:
  - The mean crust is ranging from 30 to 80 km and no constrain on the chemical heterogeneities of the crust are existing
  - The core radius is ranging from 1450 to 1750 km and a spinel-perokskite layer is possible only for the smallest core models
- Existing models of the Tharsis evolution are NOT strongly constrained!

How to solve these questions…

- Did Mars had a plate tectonics during Noachian?
- What is the water/volatile content of the Martian mantle and outgazing history?
  - Determine the crustal thickness and density
  - Search for low seismic velocity zone or partial melting in the mantle
  - Determine the seismic and conductivity mantle profiles
- Does the lack of magnetization of the Northern hemisphere results from a post-dynamo formation or from hydrothermal alteration in the upper-crust associated to a major water reservoir in the northern plains?
  - Determine and detect liquid water in the subsurface near major drainage basins
  - Measure the surface magnetic field near or at the Martian surface
- Did Mars started an inner-core formation?
  - Detect a possible inner core through its seismic and geodetical signature
- What is the present heat flux? What is the present volcanic and tectonic activity?
  - Measure the surface heat flux, detect and locate marsquakes
- What is the timing of the geological evolution?
- How does such evolution impact on the habitability of the planet?
  - Model planetary convection with constrained models of the Martian Interior
  - Return samples and determine an absolute timing of Martian geology

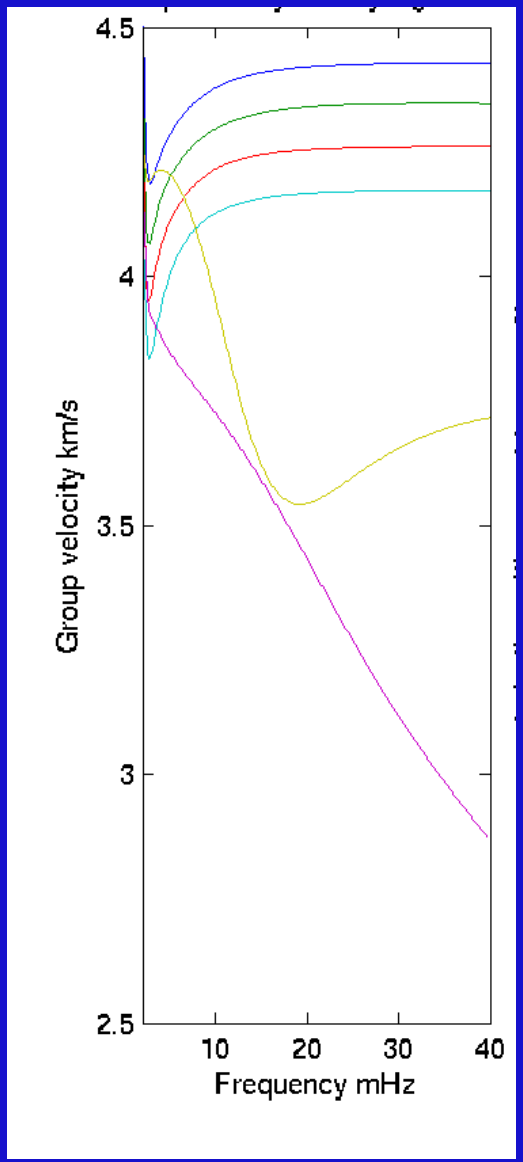
Can we reach these objectives with limited efforts?



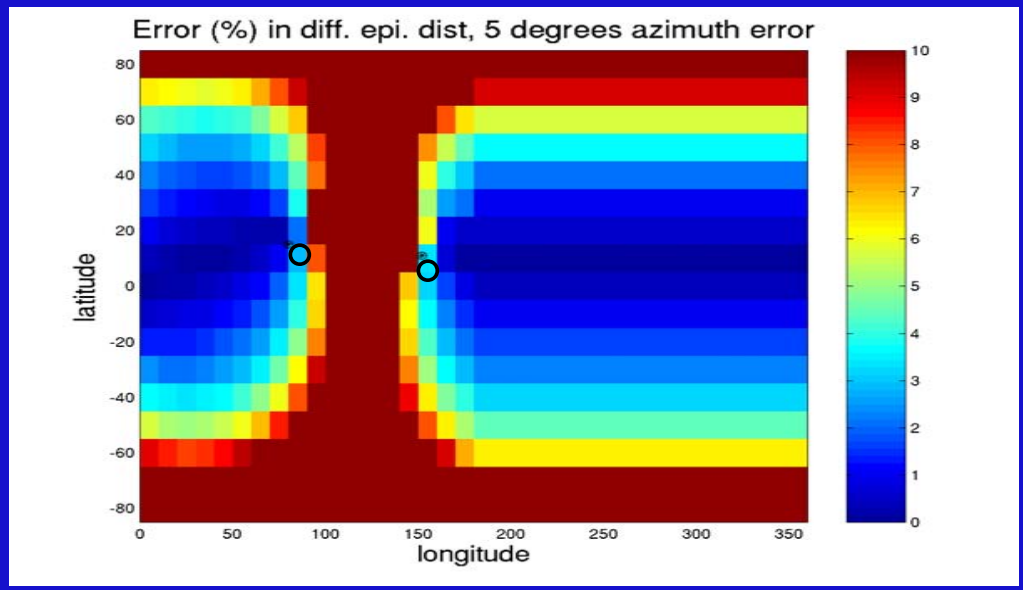
- Internal structure is so poorly known than major differences are found between published models
  - >20 % difference associated to the crustal structure and mantle structure

Velocities of Surface waves

2 lander mission

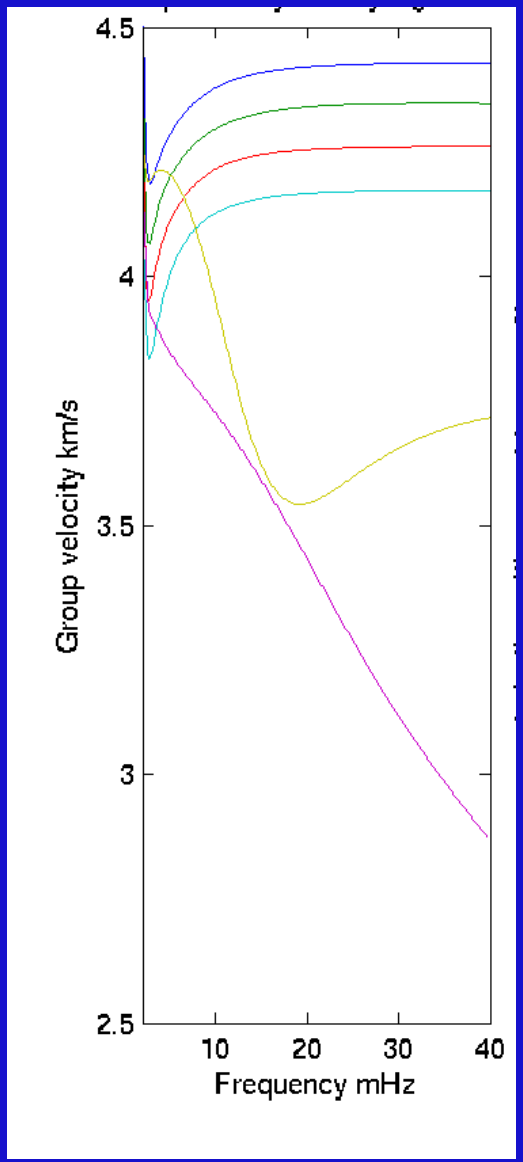


- Internal structure is so poorly known than major differences are found between models
  - Can be achieved by a 2 lander mission

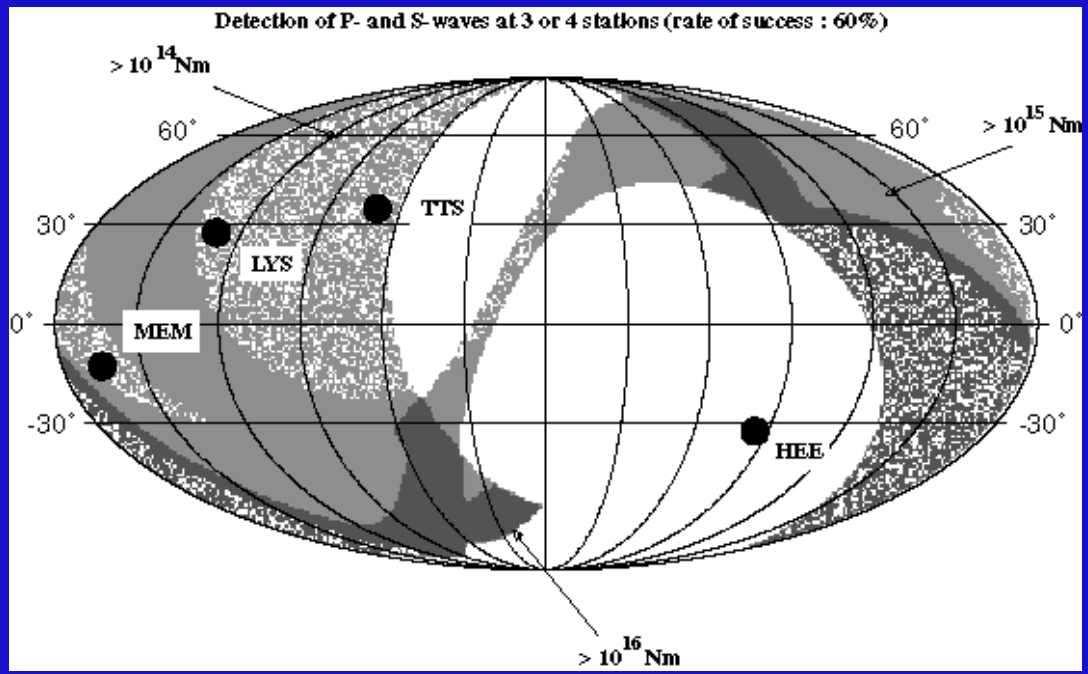


Velocities of Surface waves

4 landers mission



- Smaller differences are constraining better the mantle mineralogy (e.g. FeO content)
  - Can be achieved by a 3+ lander mission



Velocities of Surface waves

Meteorology on the Martian surface

Environment and meteorological observations

- Understanding the complex Mars Climate system: (circulation, dust, water, CO2 cycle)

  ⇨*Study the present to understand the past*

- Learn meteorology from another atmosphere: *Comparative meteorology*
- Prepare future missions : precise landing, aero-assistance, human exploration

In situ Investigation of the Martian environment

- Winds : « new », key measurements to understand circulation and surface atmosphere exchange (boundary layer, dust lifting).
- Water vapor: new measurement (never measured in situ). Understand exchange with the subsurface
- Pressure : monitoring of Mars global circulation and comparative meteorology. After VL1 and VL2
- Temperature: energy balance, turbulence.
- Electric field : new. Major surprise can be expected from a dusty atmosphere. Application for human exploration.
- Aeorosol sensor
- Gaz / isotope sensor
- Remote sensing from surface : Spectrometers, Lidar

Exploration of a diverse Mars environment : multi-site mission

- Like in geology, each site corresponds to a new environment that can be as diverse as the geological setting can be.
- We can explore : new latitude, dust storm initiation site, large dust devils site, cloudy region etc…
- “Network science” :
  - Planetary wave characterization,
  - Dust storms monitoring
  - Geodesy: global measurements of the atmospheric mass variation (CO_2 cycle) and the global momentum of the moving atmosphere

Conclusions

- Fundamental, new Martian science remains to be done in the field of geophysics and Mars environmental science with in situ investigations.
- This research is of primary importance for understanding the evolution of hability of Mars as well as for comparative planetology
- Most major objectives can be achieved with relatively light instruments using available technologies
- Most major objectives would not require mobility.