Mars Exploration Program Analysis Group (MEPAG)

chartered by NASA HQ to assist in planning the scientific exploration of Mars

Mars: Current State of Knowledge and Why Mars Remains a Compelling Objective

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On behalf of the Mars Exploration Program Analysis Group

Sept. 9, 2009

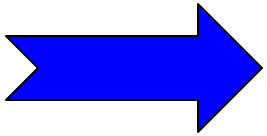
What Were Our Goals for the Past Decade?

MEPAG's Goals and Strategies, 2001-2011

I. Determine if life ever arose on Mars
II. Understand the processes and history of climate on Mars
III. Determine the evolution of the surface and interior of Mars
IV. Prepare for eventual human exploration

2001 Strategy

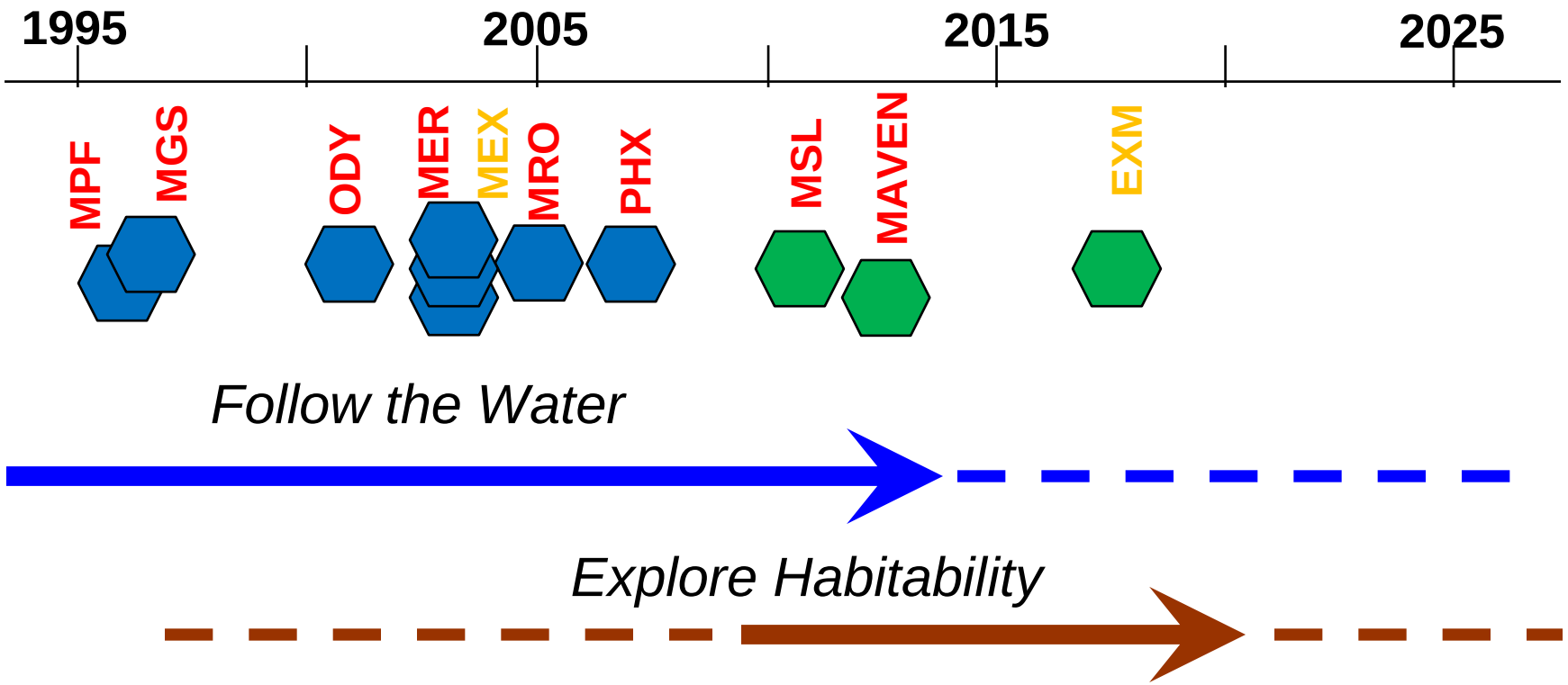
Follow the Water



2005 Strategy

Explore Habitability

Missions In Progress to Address Goals



Missions Legend

Successfully Flown

In Development

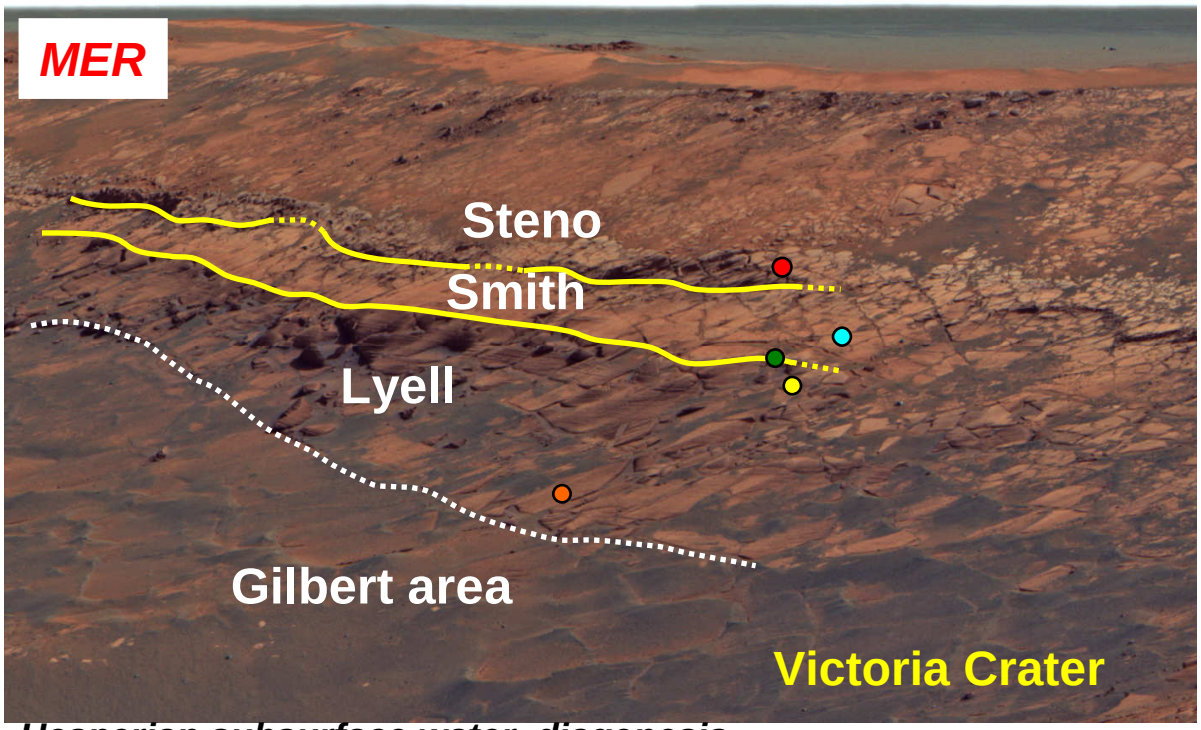
What Did We Learn?

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 (Goals II, III).**
  - **Mars has areas with diverse mineralogy, including alteration by water, with a change in mineralogy over time [MGS, ODY, MER, MEX, MRO]**
  - **In situ confirmation of Wet (Warm?) Climate in the past [MER]**
  - **Pervasive water ice in globally distributed, near-surface reservoirs [ODY, MRO, MEX, PHX]**
  - **Sources, phase changes, and transport of volatiles (H_2O, CO_2) are known & some are quantified [MGS, MEX, MRO, PHX]**
  - **Increasing evidence for geologically recent climate change: stratified layers in ice and in rock [MGS, ODY, MEX, MRO]**
  - **Dynamic change occurring even today: landslides, new gullies, new impact craters, changing CO_2 ice cover [MGS, ODY, MEX, MRO]**
  - **Presence of methane indicative of active chemical processes either biogenic or abiotic [MEX and ground-based]**
- **Based on much of the above, the perception of *Potential for past Life* has increased, and *Modern Life* may still be possible. (Goal I)**

Last Decade Discoveries: Diversity of Environments

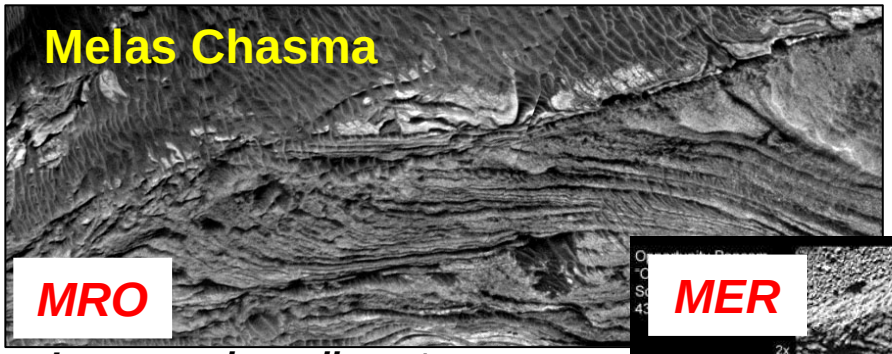
- **Chemistry and morphology indicate changing environments throughout geologic history**
  - Acidic waters at Meridiani
  - Basic waters at Phoenix landing site
  - Mineralogy: clays to sulfates to oxides



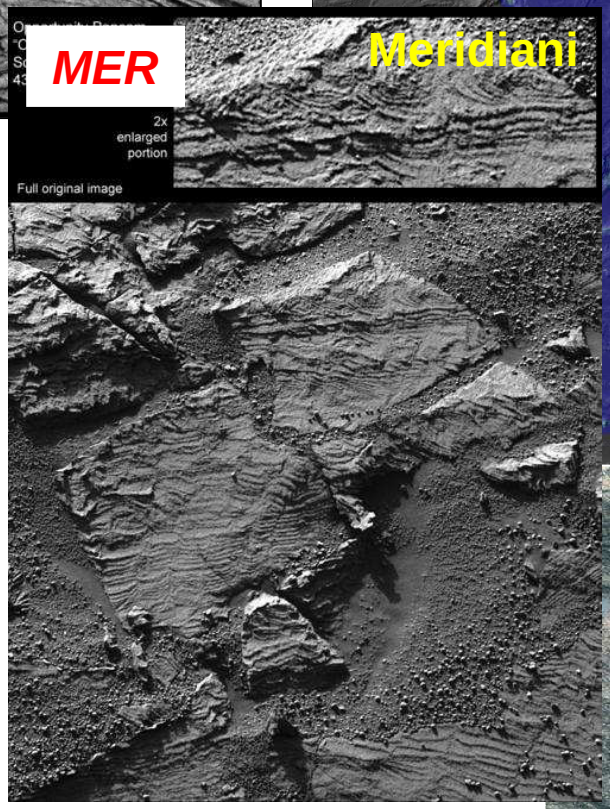
Hesperian subsurface water, diagenesis

Past Decadal Results:

Wide variety of sedimentary deposits

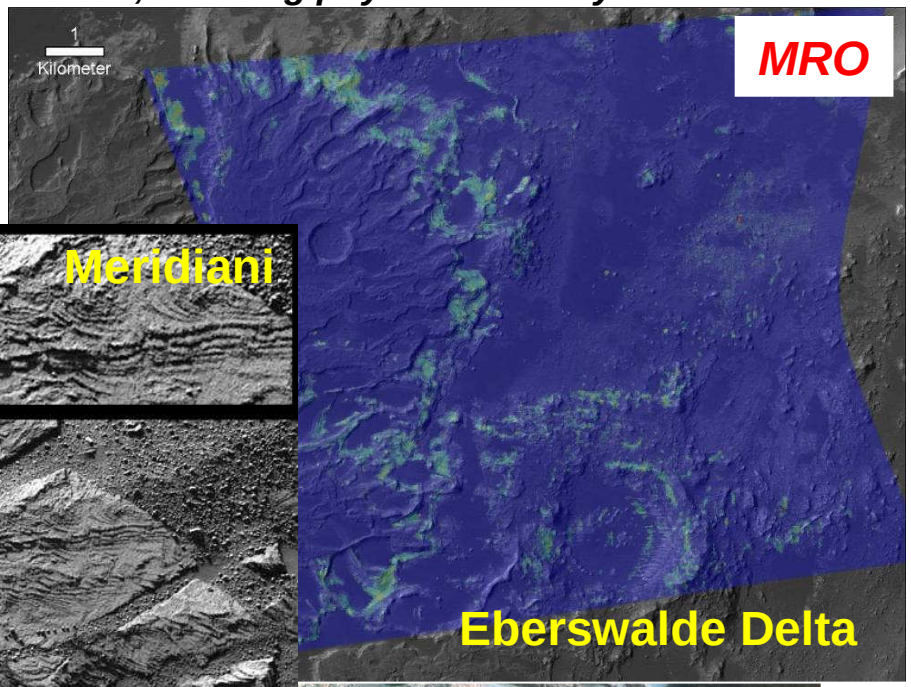


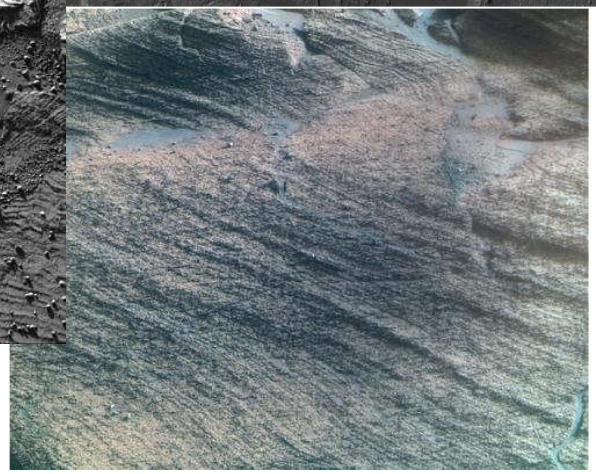
Large-scale sedimentary structures



Fine-scale sedimentary structures

Delta, showing phyllosilicate layers

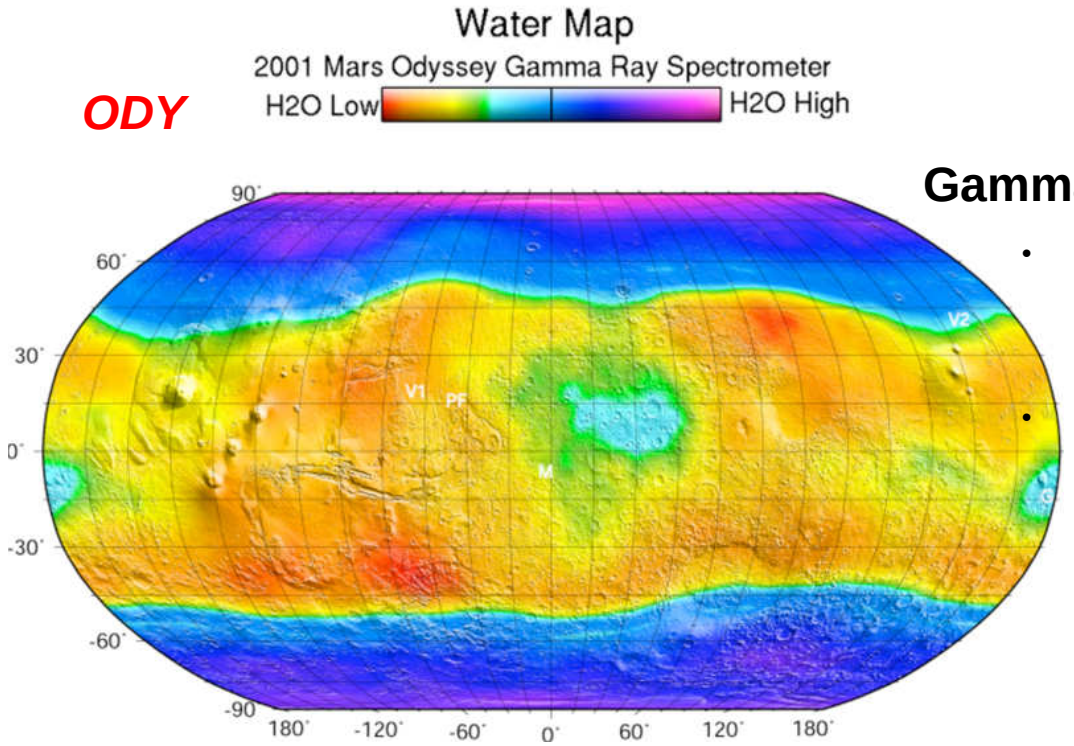




- **Depositional processes created a sedimentary record**
  - Developed in topographically low areas
  - Spectacular stratification at multiple scales
  - Evidence of persistent standing water, lakes
  - Sediments systematically change in character with time
  - Multiple facies recognized

Past Decadal Results:

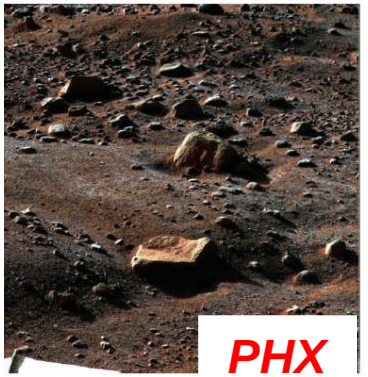
Distribution of Modern Water



Global Near-Surface Reservoirs of Water

Gamma Ray Spectrometer

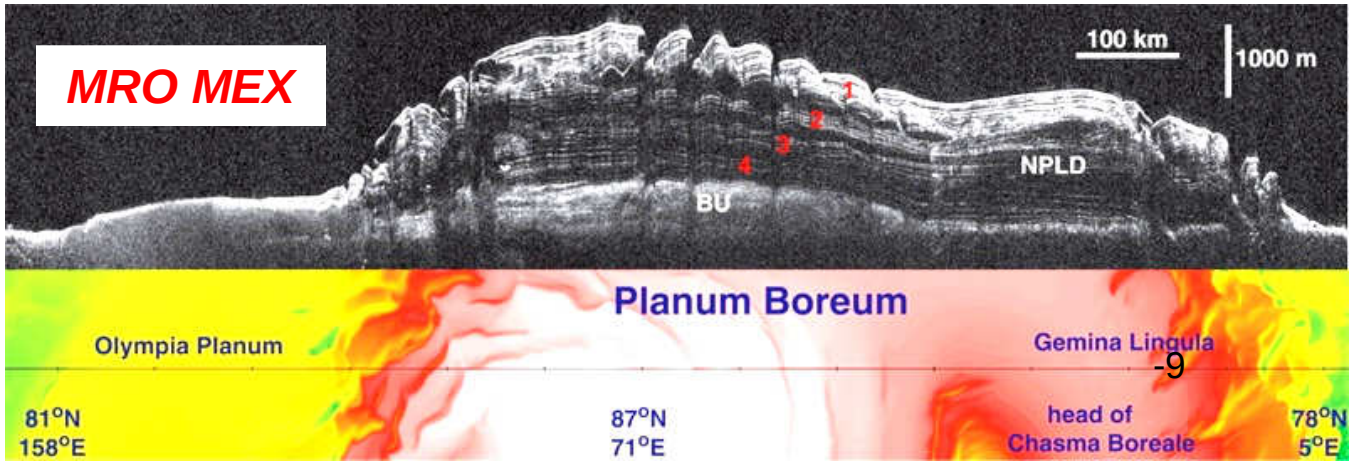
- Global hydrogen abundance and equivalent H_2O
- Ground ice to +/-60° in high abundance



Phoenix results

SHARAD and MARSIS

- Nearly pure water ice
- Distinct layering
- No deflection of crust
- Ice-cored lobate debris aprons in mid-latitudes

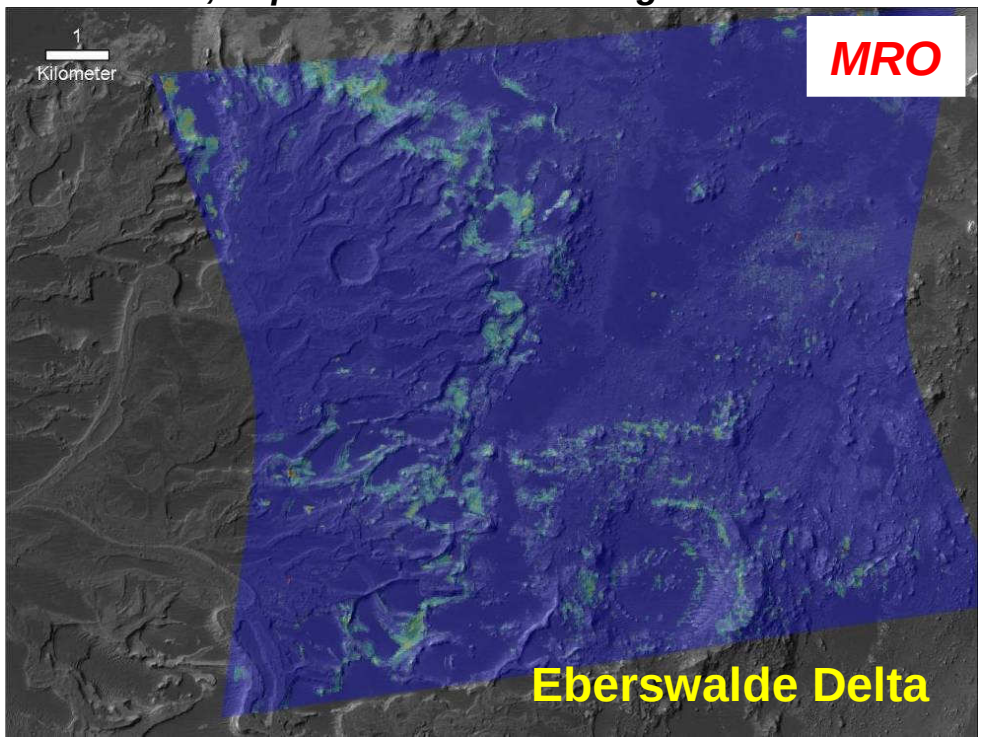


Past Decadal Results:

Ancient Mars Was Wet (Episodically?)

Channels formed by rainfall runoff

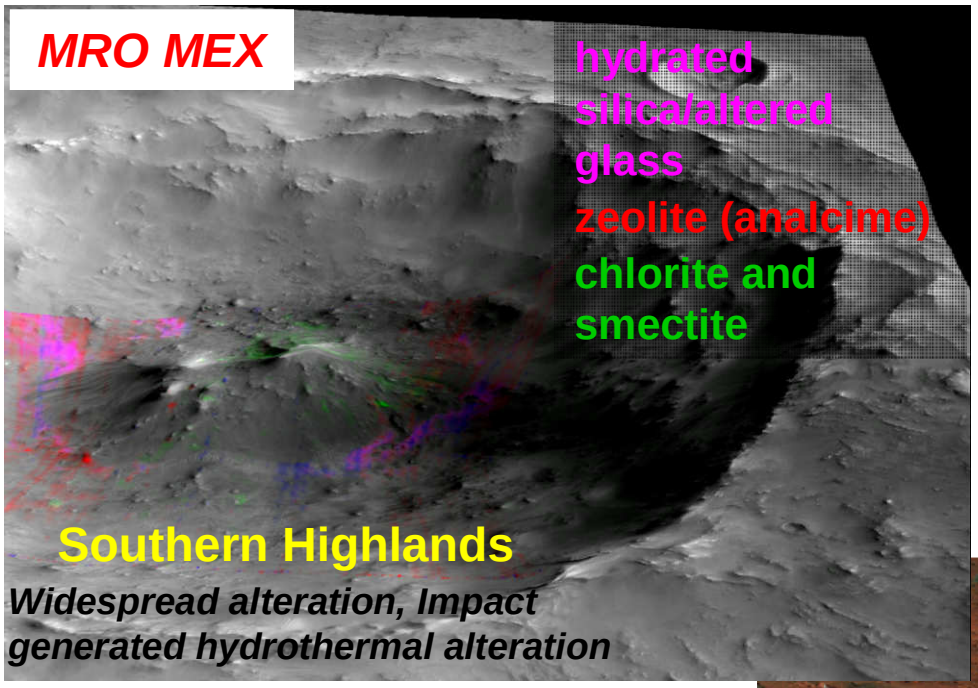
Delta, deposition into standing water

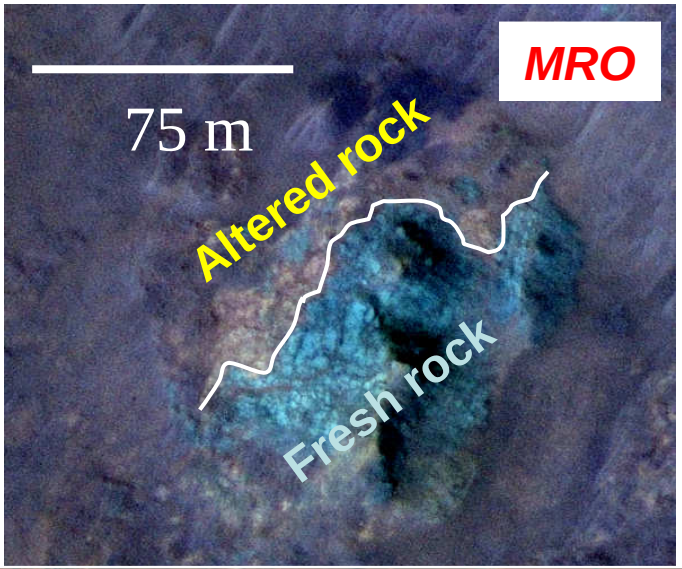


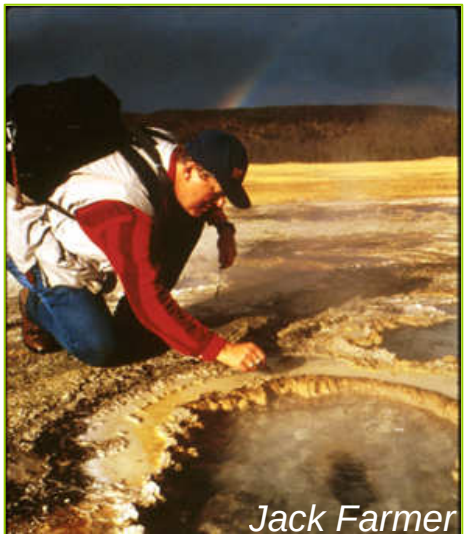
- **Ancient features indicate water present at the surface**
  - Evidence of persistent standing water, lakes
  - Evidence of rainfall, valley networks
  - Lake overflow features

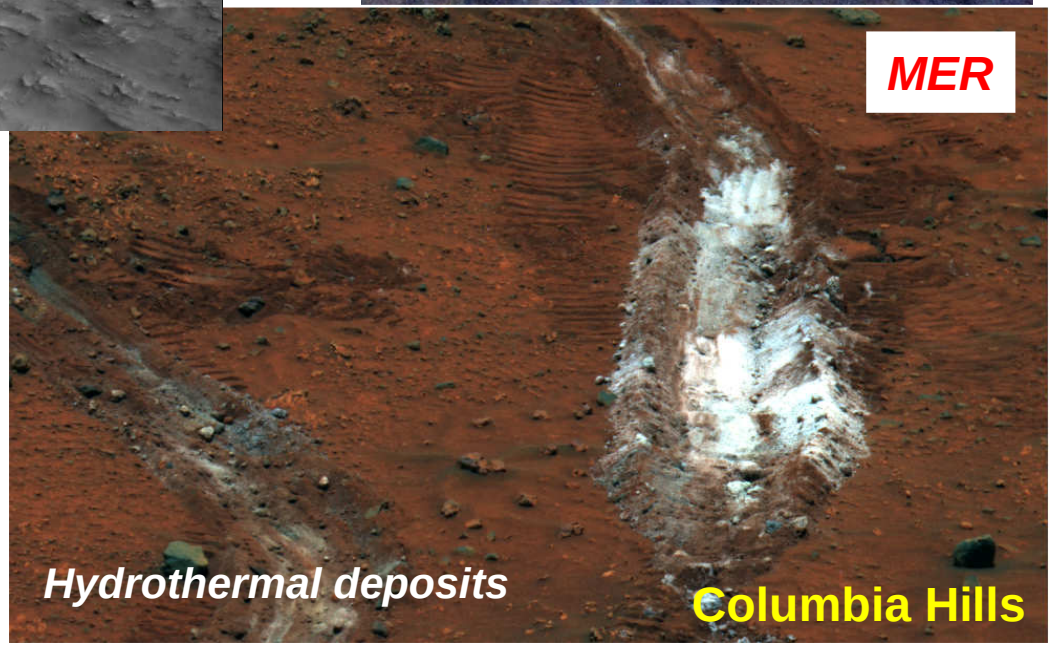
Past Decadal Results:

Evidence for Water/Rock Interaction



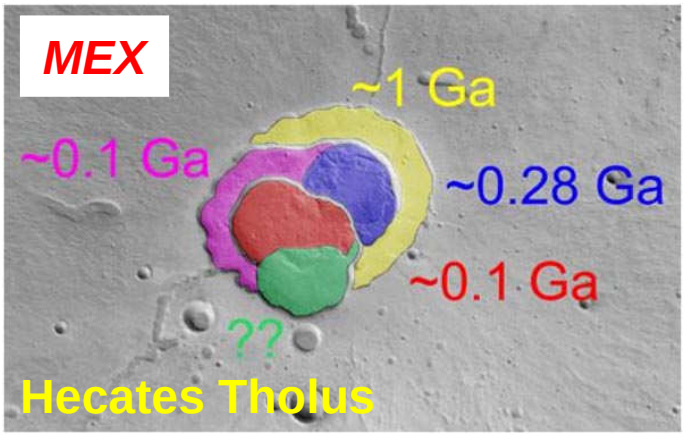


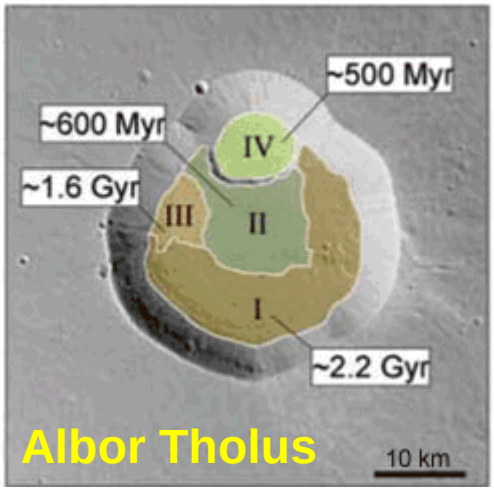




Past Decadal Results:

Mars Still Active Today

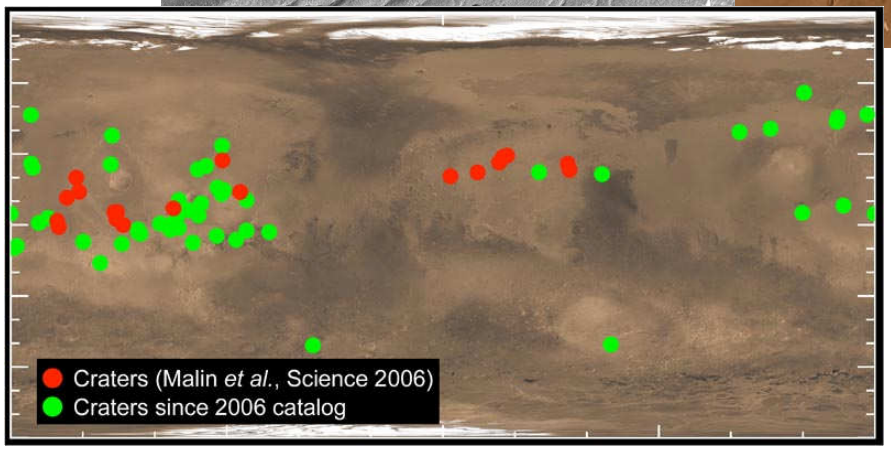




Lava Flows

Volcanic activity spans most or all of martian geologic history

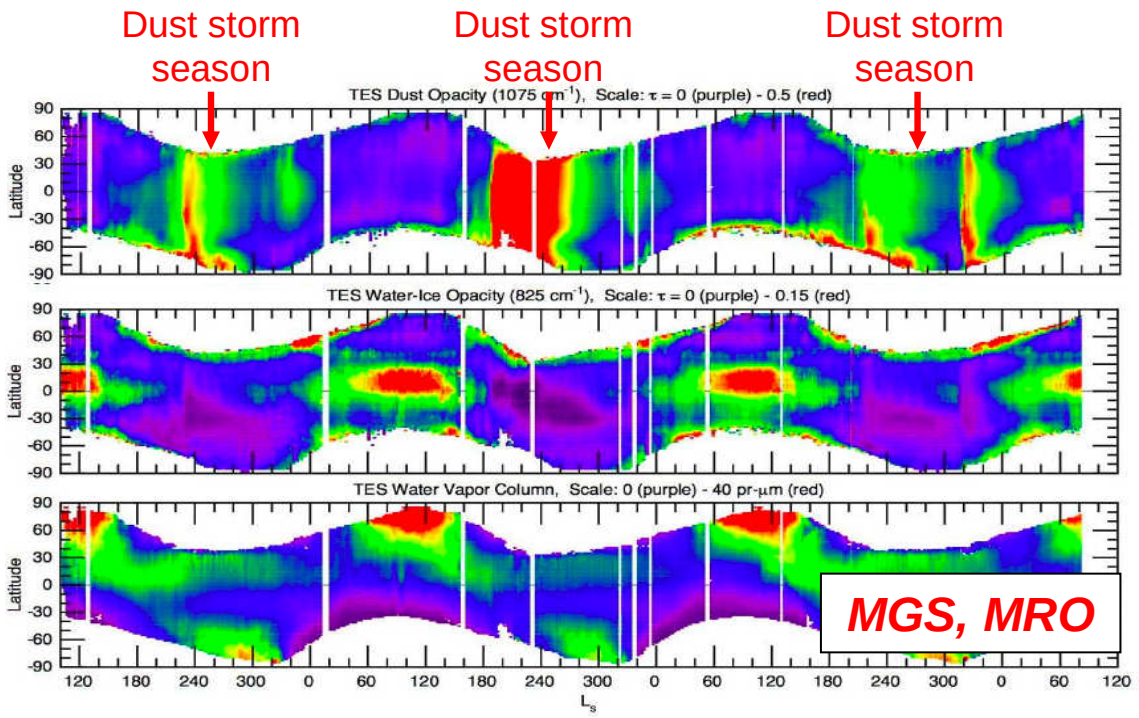
Mid-latitude mantes and gullies



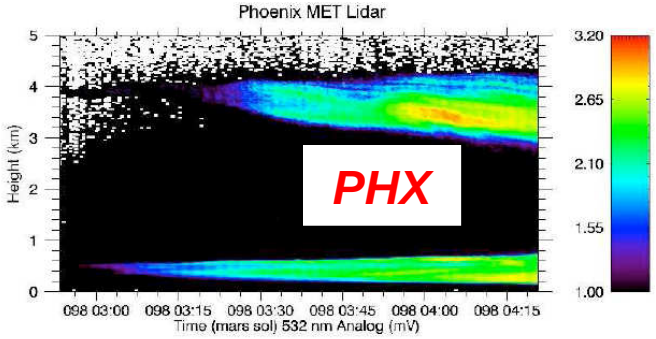
New Impact Craters

Past Decadal Results:

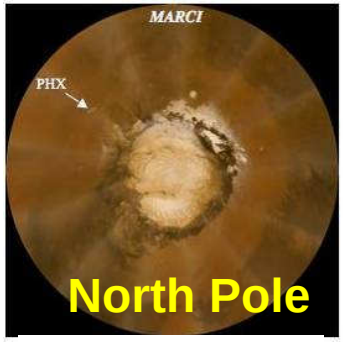
Atmosphere and Climate Results



Understand how the atmosphere works



Cloud, fog and storm dynamics

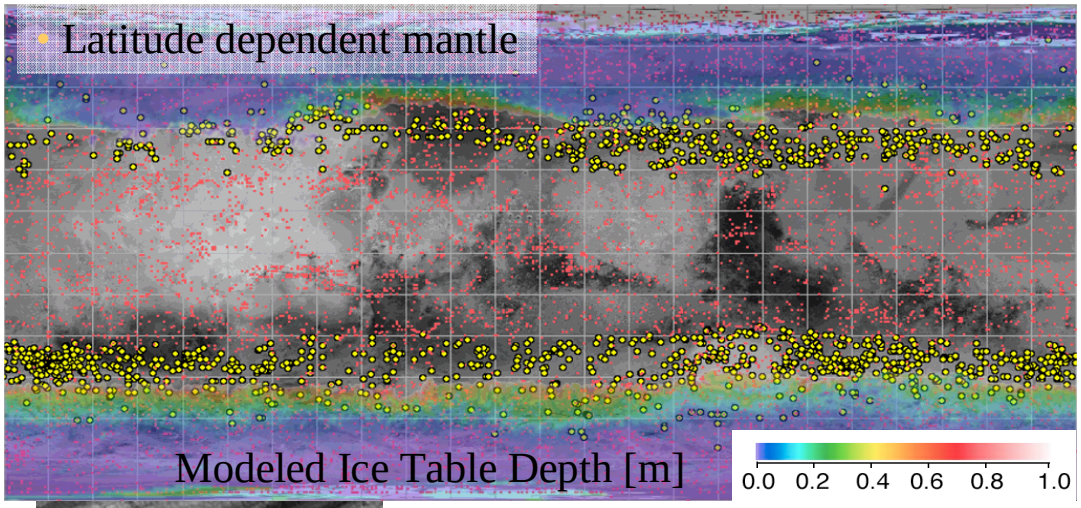


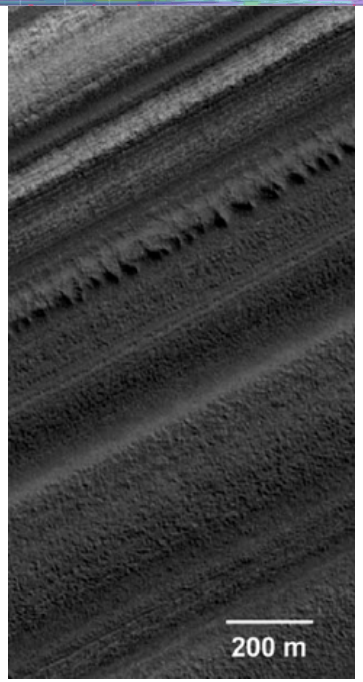
MEX, MRO

- **Climate change -- Past, recent and past: Understanding the process**
  - **Early wet (warm?) Mars (Noachian) has evolved to cold, dry Mars (Hesperian +)**
  - **Periodic change in last several million years**
- **Recent multi-year record of CO_2/water/dust; atmospheric dynamics [MGS, ODY, MEX, MRO]**
  - **Seasonal cycles and interannual variability**
- **SO_2, Argon, CH4, CO, etc.: Tracers of transport, chemistry, and surface-atmosphere interactions**

Past Decadal Results:

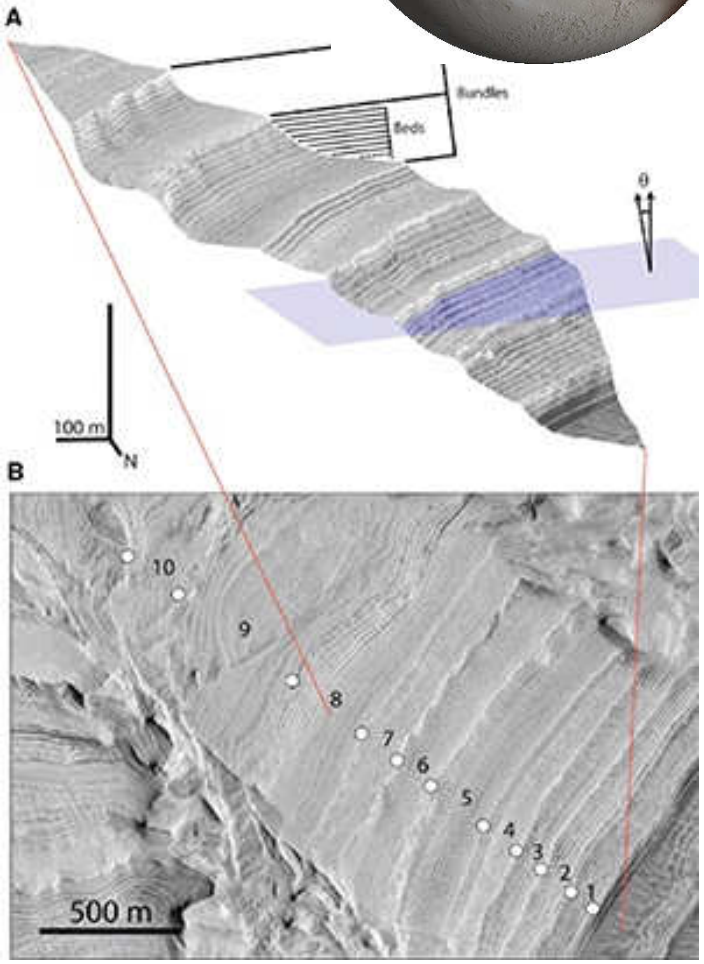
Periodic Climate Change



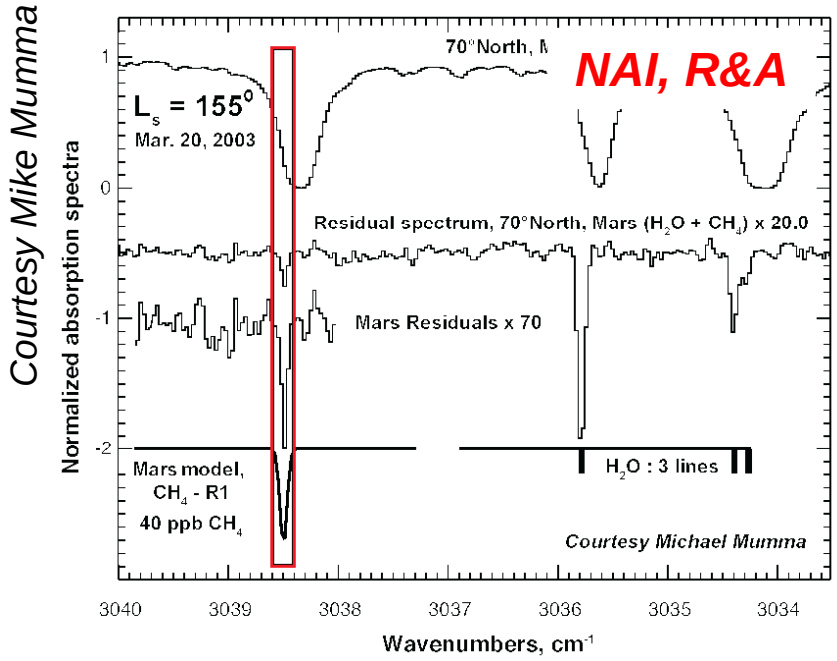


- **Volatile-rich, latitude dependent deposits (mantle, glaciers, gullies, viscous flow) coupled to orbitally-forced climate change**
- **Periodicity of layering in the north polar cap deposits as well as sedimentary deposits**

MGS, ODY, MEX MRO

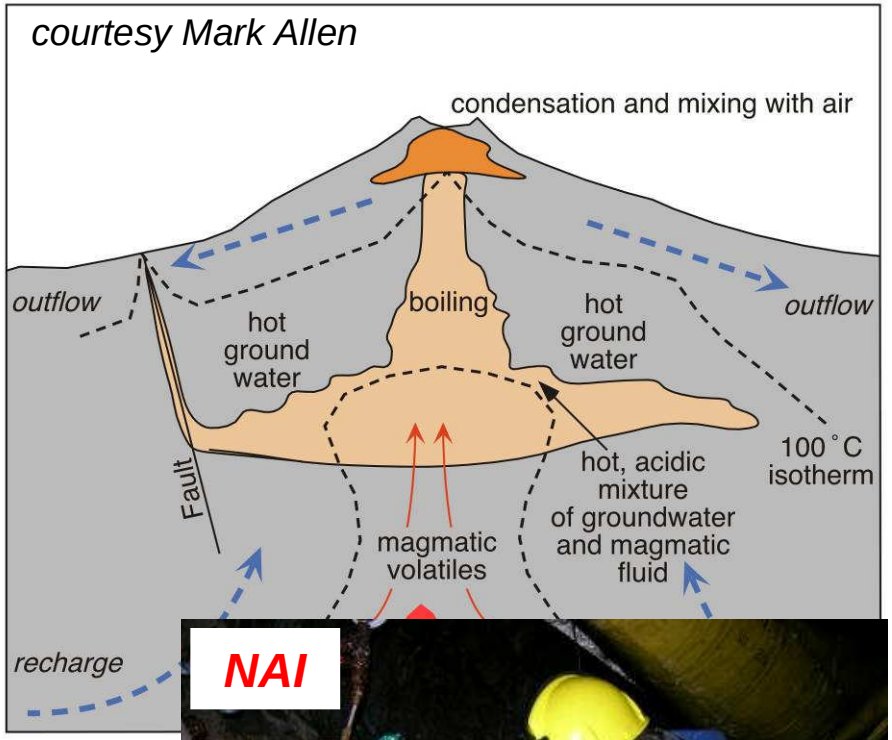


Past Decadal Results:
Modern Methane



Detection of Methane on Mars

MEX NAI R&A



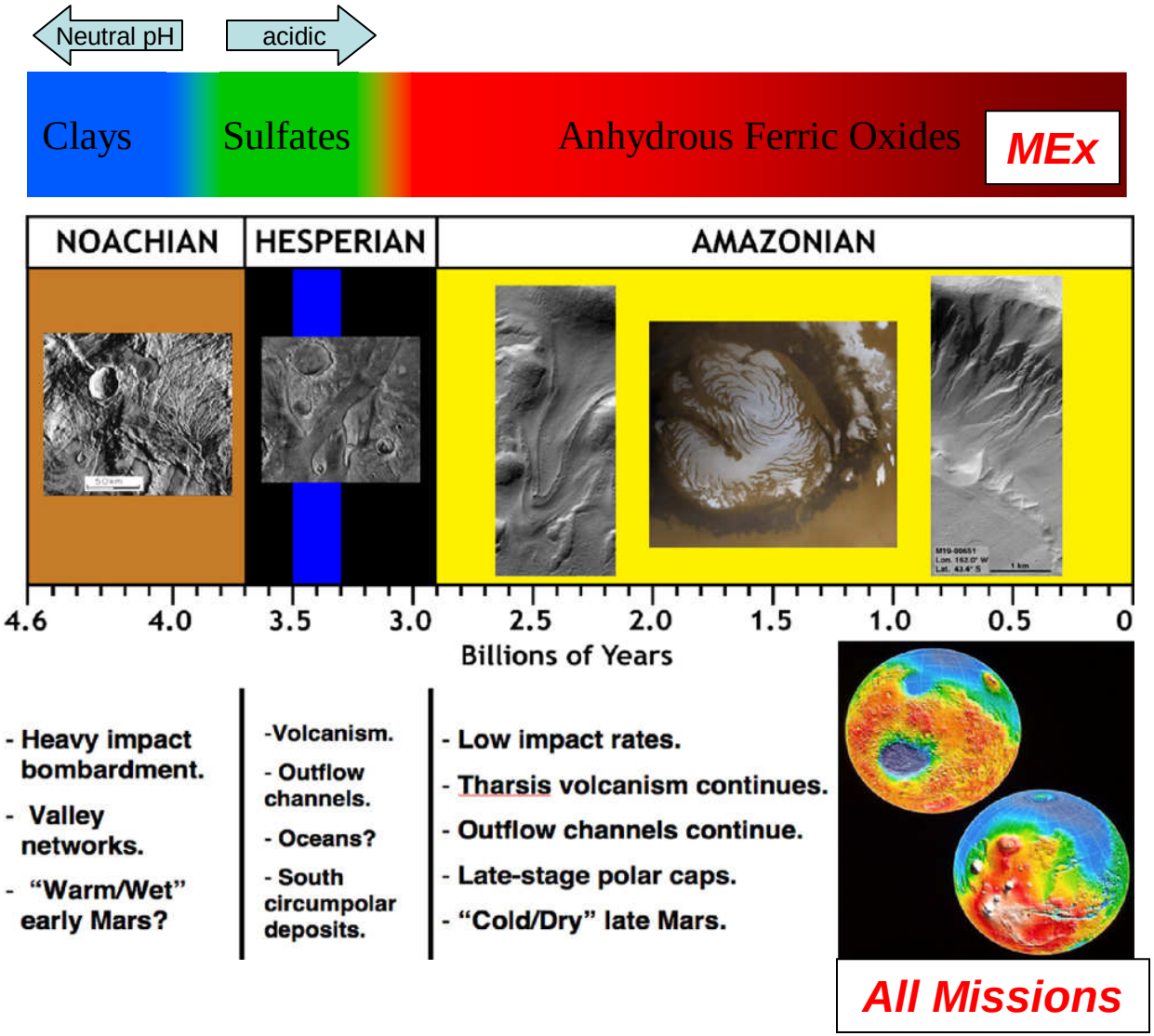
Evidence of an active subsurface?

Abiotic?

Biotic?

Past Decadal Results:

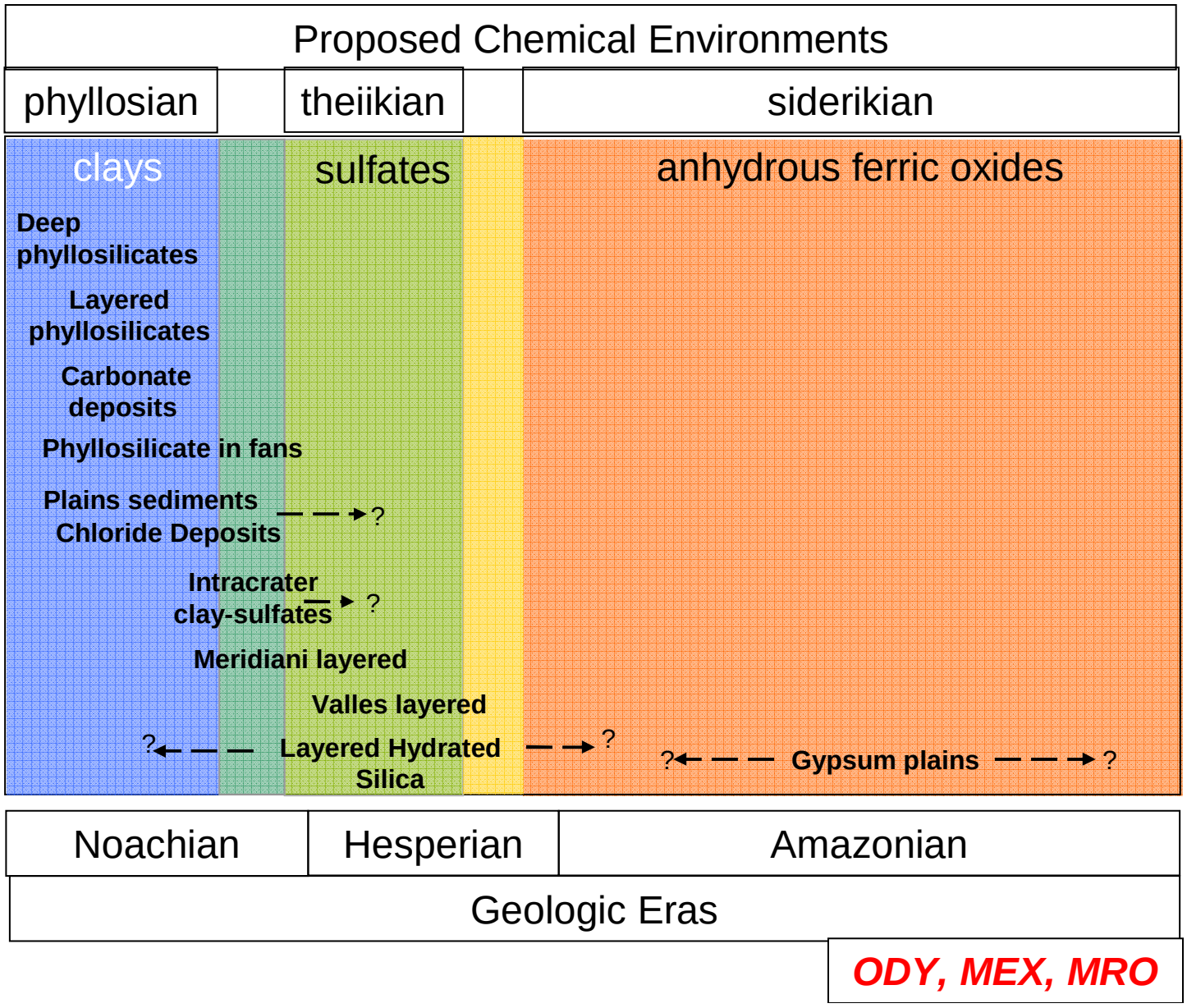
Mars Planetary Evolution



- **Hydrous Mineralogy Changed Over Time**
  - Phyllosilicate minerals (smectite clay, chlorite, kaolinite…) formed early
  - Evaporates dominated by sulfate formed later with opal/hydrated silica
  - Few hydrated mineral deposits since
- **Evolution of Aqueous, Fluvial and Glacial, Morphology with Time**
  - Valley networks, lake systems
  - Gullies
  - Viscous flow, glaciers, latitude dependant mantle

Past Decadal Results:

Mars Planetary Evolution



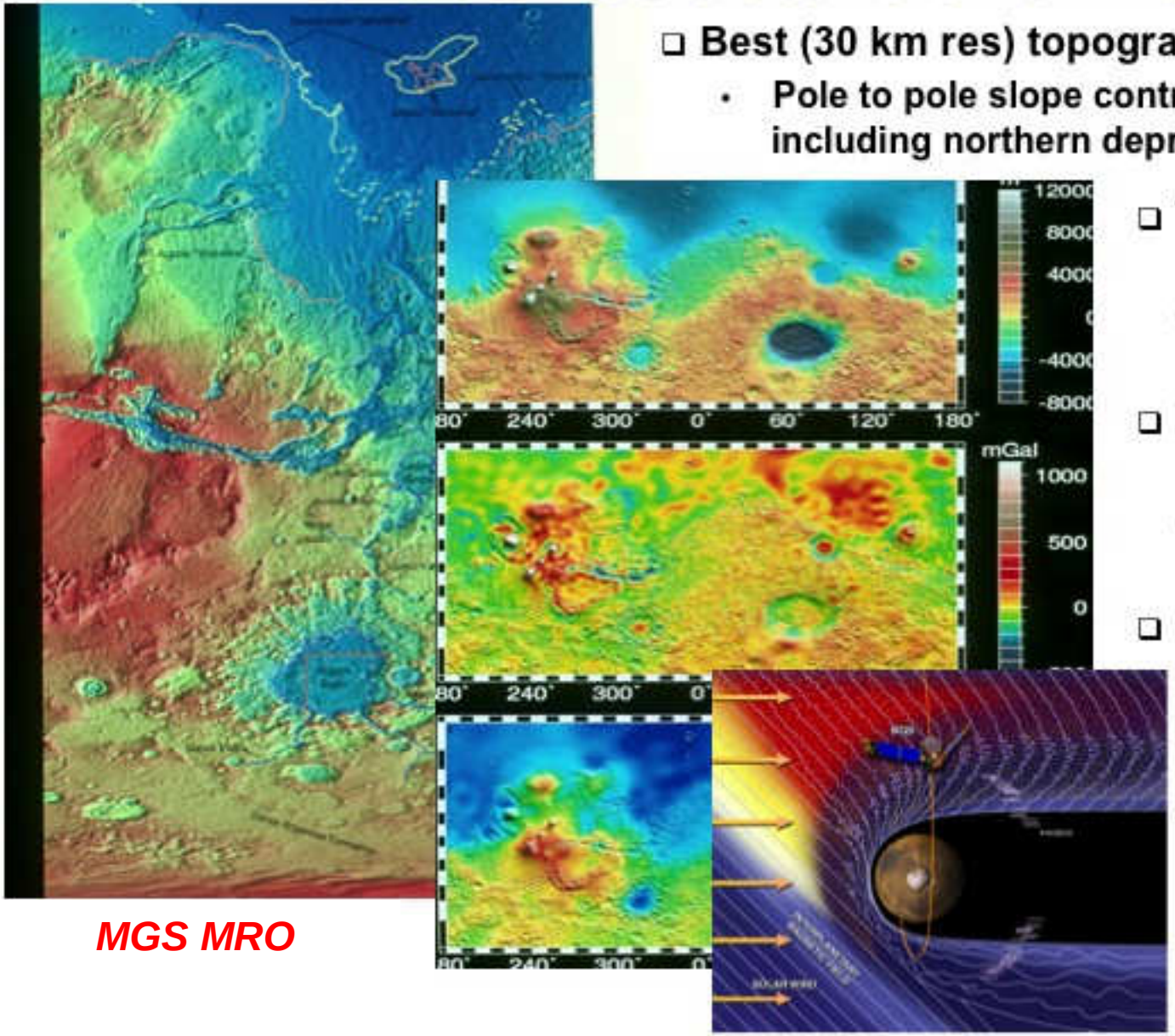
Coupled mineralogy and morphology define aqueous environments

Their character has evolved indicating changing environments

Data support the hypotheses but indicate greater complexity in local environments

Past Decadal Results:

Crustal Structure and History

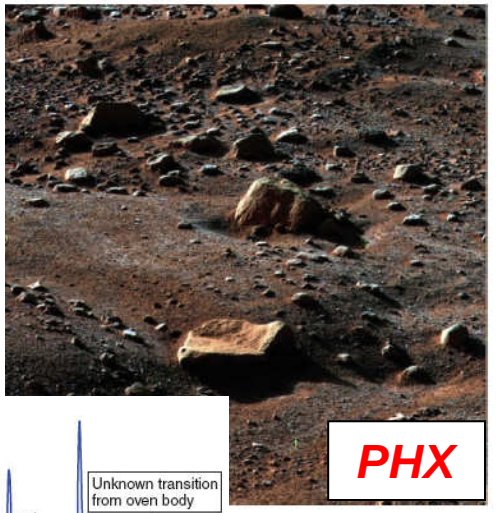


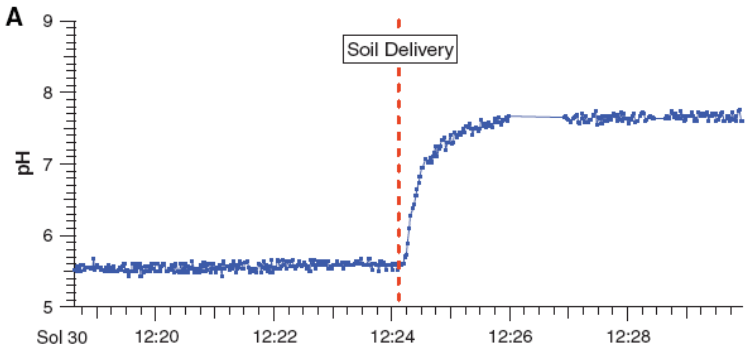
MGS MRO

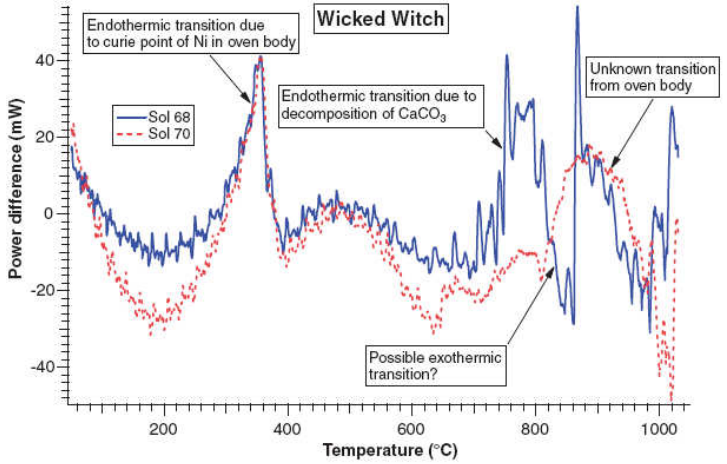
- Best (30 km res) topographic model
  - Pole to pole slope controlling water transport, including northern depression
- Thick crust with near-isostatic compensation in rougher south
- Range of uncompensated gravity anomalies in smoother north
- Center of figure offset by nearly 3 km, indicating north pole ~6 km lower than south pole
- Evidence of early molten interior

Past Decadal Results:
Goal IV Prepare for Eventual Human Exploration

- **Following the water is a key first step in the preparation for human presence on Mars**
  - Ice table at the depth, location, and concentration predicted by orbital data and theory
- **Phoenix instrumentation designed for environmental characterization**
  - Chemistry buffered by carbonate resulting in an alkaline soil pH







Given What We Have Learned, Mars is an Even More Compelling Exploration Target

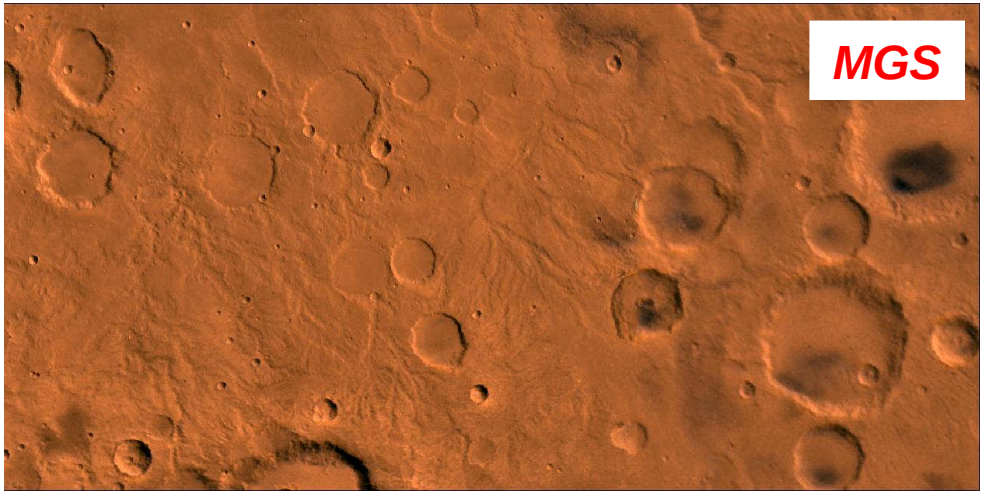
Why Mars?

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

Why Mars?

1. 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 and usually altered; Mars rocks exist at 4.5 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.*

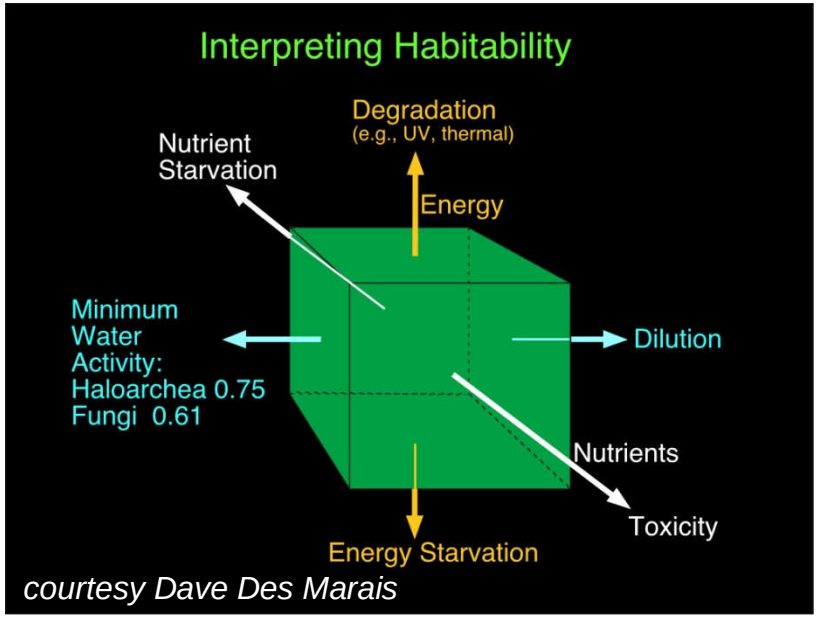


Ancient cratered surface of Mars (above)
and remaining Earth crust from same time period (below)

Why Mars?

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

- **Ancient life—interpreted potential has increased**
  - Lots of ancient liquid water in diverse environments
  - Past geological environments that have reasonable potential to have preserved the evidence of life, had it existed.
  - Understanding variations in habitability potential is proving to be an effective search strategy
  - **SUMMARY**: We have a means to prioritize candidate sites, and reason to believe that the evidence we are seeking is within reach of our exploration.
- **Modern life—interpreted potential still exists**
  - Evidence of modern liquid water at surface is equivocal—probable liquid water in deep subsurface
  - Methane may be a critically important clue to subsurface biosphere
  - **SUMMARY**: We have not yet identified high-potential surface sites, and the deep subsurface is not yet within our reach.



courtesy Dave Des Marais

Why Mars?

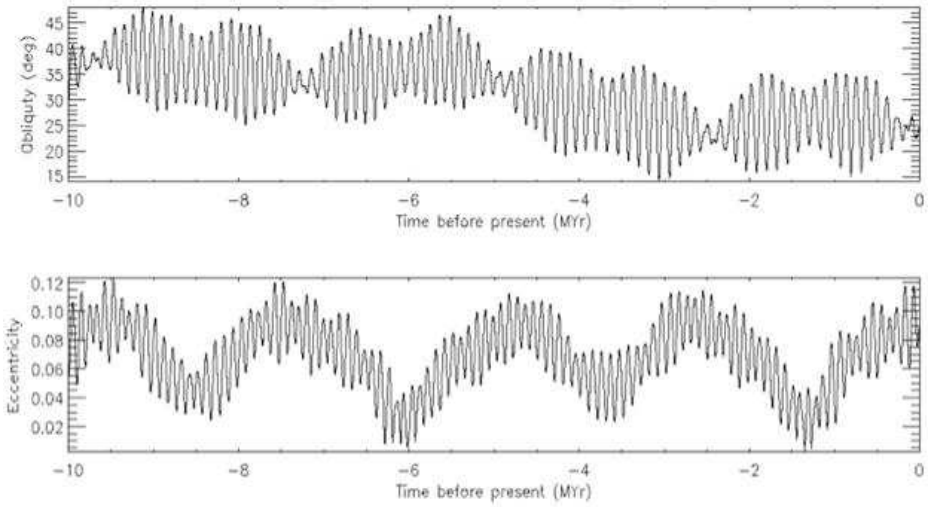
3. Excellent opportunity to investigate short- and long-term climate change

❑ 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

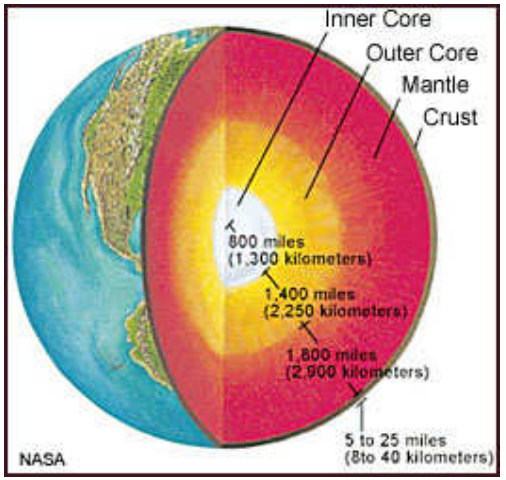
- We have observed a multi-year record of recent climate change
- The proposed MAVEN mission would establish the inventory of atmospheric trace gases to understand the internal and external processes that shaped Mars' atmosphere

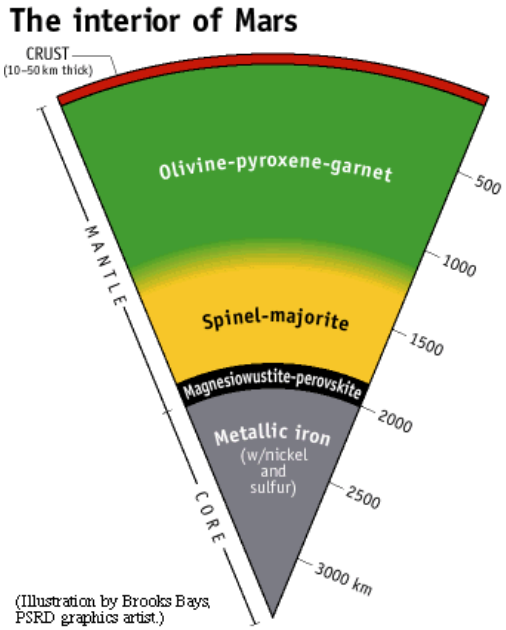


Why Mars?

4. Mars offers insight into the internal structure and origin of the terrestrial planets

- **The internal structure of a planet provides clues to its origin and evolution**
  - Can follow up clues from remnant magnetism discovered by MGS.
- **To date, we have data for the Earth and some data for the Moon**
- **Mars offers an opportunity to obtain results on another terrestrial planet**
  - Intermediate in size between the Earth and Moon
  - May provide clues to early differentiation that are not available from more active planets like Earth and Venus





Interior of Mars figure from http://www.psrd.hawaii.edu/June04/martianMantle.html. Used with permission.

Why Mars?
5. Strategic target for human exploration

- Closest to Earth in terms of surface environment
- Close enough that we can credibly discuss reaching it with astronauts.
- Public fascination fuels student interest in science and technololgy.