Follow the Water on Mars

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Water On Mars: Some Key Questions

- Key ingredient for life.
  - Follow the water!
- How much is there?
- Where does it occur today on Mars?
  - What are the states?
  - What are the reservoirs?
- How do the reservoirs change with time?
  - Over seasons, millennia, eons.
- How has the water budget and partitioning changed with time?
- Does water become permanently sequestered with time?
  - Where and in what state?
Climate History of Mars

- What are the present climate conditions on Mars?
- How do they compare to Earth?
- Is the current Mars climate typical or anomalous?
- What controls climate history on Mars?
- Are there Milankovitch cycles on Mars?
Lessons For Life

- Do habitable environments currently exist on Mars?
  - Where and in what form?
- Have they existed in the past?
  - Where and in what form?
- How does knowledge of water (budget and reservoirs) inform us?
- How does knowledge of climate change inform us?
- Where should we go to search for extant and extinct life on Mars?
- Where on Earth should we go to look for analogs?
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   7. Tropical mountain glaciers: The Tharsis volcanoes.
You Are Here
Current conditions at the surface:

- Mean atmospheric pressure is ~ 6 mbar (Earth: 1000 mbar).
- Mean temperature is ~ -40°C (Earth: +17°C).
- Under present conditions, liquid water cannot exist on the surface of Mars.
- Mars currently a very cold polar desert.
Surface water reservoirs: Atmosphere & polar caps

- Total volume of $H_2O$ in atmosphere is $\sim 1-2 \text{ km}^3$ (Earth: $13,000 \text{ km}^3$).
- Equivalent to a global water layer $\sim 10 \mu \text{m}$ thick.
- Total volume of polar caps $\sim 4x10^6 \text{ km}^3$.
- Equivalent to global water layer $\sim 30 \text{ m}$ thick.
Hidden water reservoir: Megaregololith.

- Abundant evidence for water erosion on the surface.
- Impact craters with lobate ejecta provide evidence for the presence of water in the ground.
- Requires substantial amount of water.
- This water must be hidden in the ground.
Structure of megaregolith:

- Megaregolith is a porous media.
- Porosity decreases with depth due to self-compaction.
- Estimated depth of self-compaction is about 10 km.
- Global layer of water 540 m thick could be stored in megaregolith if its porosity = 20%.
- Global layer of water 1400 m thick could be stored in megaregolith if its porosity = 50%.
- Megaregolith is the principal reservoir for water on Mars.
Ground Ice: Cryosphere and global aquifer system

- Cryosphere is the primary reservoir for water on Mars.
- Thickness of cryosphere is limited by internal heat flux.
- Liquid water is stable below the cryosphere.
- A global aquifer system should exist on Mars; upper boundary is bottom of cryosphere; lower boundary is depth of self compaction (~10 km).
Martian Volatile Reservoirs

Average $P_{\text{atmos}} = 6$ mbar
Average $T_{\text{equator}} = 215$ K
Minimum $T_{\text{pole}} = 150$ K
Climate

- Mars has a climate system that has many direct comparisons to the Earth.
- Postulated mechanisms of change (Milankovitch) similar.
- Yet differences are extreme (no biosphere, much larger orbital variations, no oceans, different atmosphere).
<table>
<thead>
<tr>
<th><strong>NOACHIAN</strong></th>
<th><strong>HESPERIAN</strong></th>
<th><strong>AMAZONIAN</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavy impact bombardment.</td>
<td>Volcanism.</td>
<td>Low impact rates.</td>
</tr>
<tr>
<td></td>
<td>South circumpolar deposits.</td>
<td>Late-stage polar caps.</td>
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<td></td>
<td>“Cold/Dry” late Mars.</td>
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Understanding Climate Dynamics and the Climate Record

(Imbrie, 1982)
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(Imbrie, 1982)
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1914: On the attenuation of the transmission of heat by the atmosphere of Mars.
1916: Investigation of the climate of the planet Mars.
1930: Mathematical climatology and the astronomical theory of climatic changes.
1936: Through far-off worlds and times: Letters from a wayfarer in the Universe.

- The obliquity of Mars is strongly chaotic.
- Therefore, impossible to solve for its evolution over > a few Ma.

1) Precise solution of evolution of Mars' spin over 10-20 Ma.
   - Most recent data on the rotational state of Mars.
   - New numerical integration of the Solar System.

2) Statistical study of its possible evolution over 250 Ma.
   - Using the uncertainties in the present rotational state.

3) Over much longer time periods, 5 Ga.
   - Chaotic diffusion prevails; performed extensive statistical analysis.
   - Density function of eccentricity, obliquity specified analytically.
   - Eccentricity: Averages 0.0690; SD 0.0299.
   - Obliquity: Averages 37.62°; SD 13.82°.
   - Maximum Obliquity: 82.035°.
   - Probability of obliquity >60° in past 1 Ga is 63.0%; 89% in past 3 Ga.
Last 20 Myr.
Last 250 Myr.
Implications of Orbit/Spin Axis Variations on Climate History:

1) Control the global distribution and seasonal intensity of solar insolation.
2) Astronomical variations could have a profound effect on climate history.
3) Changes characterized by:
   - Redistribution of major volatiles: \( \text{CO}_2, \text{H}_2\text{O} \).
   - Redistribution of dust (no stabilizing vegetation).
   - Variations in reservoir partitioning: Atmosphere, surface, subsurface.
4) Permanent \( \text{CO}_2 \) in polar cap is in equilibrium with the atmosphere.
   - Climate models predict large variations in atmospheric pressure.
   - Depending on amount of \( \text{CO}_2 \), could produce warmer, wetter climates.
5) Similarly, \( \text{H}_2\text{O} \) behavior is very sensitive to changes in orbital parameters:
   - Reservoir redistribution between ground ice, surface ice, atmosphere.
   - During periods of high obliquity (>40°), polar ice migrates to tropics.
(Imbrie, 1982)
(Imbrie, 1982)
Ingredients to Decipher Mars Climate History:

1) The Cause: External Forcing Function:
   -Very strong orbital parameter signals relative to Earth.
   -Precise solution of evolution of Mars' spin over 10-20 Ma.
   -Statistical study of its possible evolution over 250 Ma, 5 Ga.

2) The Climate System: The Internal Response Mechanism:
   -Know how input signals linked to insolation.
   -Increasingly sophisticated general circulation models.
   -Full 3-D simulations, include water vapor behavior.

3) The Effect: The Geological Record:
   -Polar caps: 3 km thick, layered, CO₂, H₂O, dust.
   -International Mars Exploration Program.
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Mars Global Surveyor (MGS) Roughness Data

Kreslavsky and Head (2000, 2002)

http://www.planetary.brown.edu/planetary/rough/
Recognition and Properties of Degraded Mantle Layer in MOC Images

- Intact surface present in the local region.
- Blankets the surface covering highs and lows equally.
- Impact craters > 300 m in diameter rare or not present: age ~100s kyrs.
- No relation to geologic units, elevation.
- Strength similar to duricrust.
  - Mustard, Cooper, Rifkin, Nature 412 (2001)

Portion of FHA01450, 1.5 km across
• Degraded mantle (formerly ice-rich) observed in MOC image
• No dissected mantle observed
Portion of M0304950, 1.5 km across
• Modeling of ice stability in near surface soils overlain with MOC dissected mantle observations

Ice Table Depth [m]
Mellon, LPSC 34
CAUSE

EXTERNAL FORCING FUNCTION

INTERNAL RESPONSE MECHANISM

EFFECT

INPUT

OUTPUT

SYSTEM

\( y \)

0 \quad t

\( x \)

0 \quad t

\( \sigma_y^2 \)

0 \quad f

\( \sigma_x^2 \)

0 \quad f

(Imbrie, 1982)
Ice Ages

- Geologic evidence indicates surface deposition
- Last 350 Kyr period of dessication/degradation of mid-latitude deposits
- High obliquity periods 0.35-2.1 Myr result in deposition
- Low obliquity periods result in some degradation, but too short and inefficient to remove (retarding lags and atmospheric density)
- In contrast to Earth’s Ice Ages, Mars “glacials” are warm polar periods, interglacials are cold poles
Human genetics
HapMap opens the next chapter

Mars in an ice age
The red planet before the present interglacial

Organic chemistry
Aromatics with a Möbius twist

2003 in context
Science on the front line

Events directory 2004
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Troughs and Layers
Goals of Polar Analysis

• **Quantitatively characterize layers.**
  – Patterns in vertical stratigraphy.
  – Variations in layer continuity locally, regionally.

• **Update thinking on polar history.**
  – Recent climate change is recorded in the layers.
  – Understand layer signal and its relation to climate change.
Images Used in this Analysis
Analysis Techniques

- Paleoceanography: deep sea core data (e.g. $\delta^{18}O$ vs depth)
  - Study changes in accumulation rates, climate signals
- Mars PLD: MOC and MOLA data (brightness vs depth)
Summary of North Polar Stratigraphy

(Milkovich and Head, 2005, JGR Planets)
Climate History

  - Recent climate history from orbital calculations, geology
- If 30 m = insolation (51 kyr)
  - Upper 350 m = 0.5 Myr
    - End of last ice age
  - “No Signal” layer = lag from end of last ice age
  - Older signal (35 m) must predate this

From Head et al, 2003.
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Lobate debris aprons: Evidence for ground ice

- Occur primarily in the 30-60° latitude bands.
- Aprons are formed at the base of escarpments.
- Preferentially appear to form where steep slopes are present in the cratered uplands.
- Formation of aprons requires at least a few tens of percent of ice.
1. Debris aprons and lobate debris flows apparently involve some combination of water ice and debris. 
   - Ice-assisted rock creep, ice-rich landslides, rock glaciers, debris-covered glaciers)
2. How much water is there, where does it come from? 
   - Groundwater or ground ice? 
   - Diffusive exchange with the atmosphere? 
   - Precipitation?
3. When do these features form?
4. HRSC examples inform us about these questions: 
   - Debris fans in massifs east of Hellas. 
   - Hourglass feature in massifs east of Hellas.
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MOLA Topography/Gradient Map:
Deuteronilus Mensae Region
• Major Morphology.
• Topographic Shape.
• Planform.
• Surface Features.
Conclusions: Lineated Valley Fill

- Numerous elements are consistent with glacial-like flow. Therefore, we conclude that for this example of Lineated Valley Fill:
  - Climate change led to conditions favorable for deposition of snow/ice.
  - Local topographic conditions (craters, theater-headed valleys) favored accumulation and preservation of snow and ice.
  - Accumulation led to glacial-like flow down slopes and into surrounding areas for distances approaching 70 km.
  - Accumulated ice may be preserved today beneath sublimation till.
  - Evidence suggests that other examples of lineated valley fill may be related to glacial-like activity.
High-latitude dichotomy boundary during Amazonian ice ages?
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Ridged Facies
Knobby Facies
Smooth Facies

Drop Moraines
Sublimation Till
Rock Glaciers
Mars - Western Olympus Mons

Earth - Malaspina Glacier (Alaska)
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- Heavy impact bombardment.
- Valley networks.
- "Warm/Wet" early Mars?

- Volcanism.
- Outflow channels.
- Oceans?
- South circumpolar deposits.

- Low impact rates.
- Tharsis volcanism continues.
- Early outflow channels.
- Late-stage polar caps.
- "Cold/Dry" late Mars.
The Amazonian Period of Mars History (Present to ~3 Ga)

1. Hydrological cycle: Reservoirs dominantly layered:
   -Atmosphere, cryosphere (surface and subsurface), groundwater.

2. Astronomical cycles are the dominant forcing function in climate change.

3. Present not typical; higher obliquity common.
   -Mars polar caps may be transient features.

4. More typical conditions might be:
   -Small to no polar caps, mid-latitude glaciation and ice sheets, tropical mountain glaciation.

5. Biological implications:
   -Large-scale, short term migration of microenvironments.
   -Local transient melting possible.
   -Transport mechanisms: dust/ice transport linked.
   -Look to Antarctic Dry Valleys for analogs.
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