Searching for Evidence of Past Oceans on Venus

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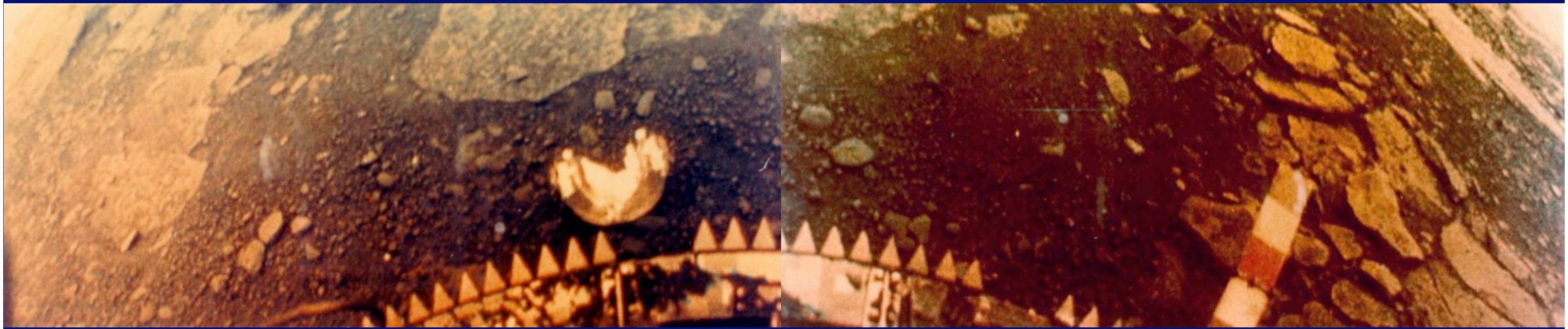
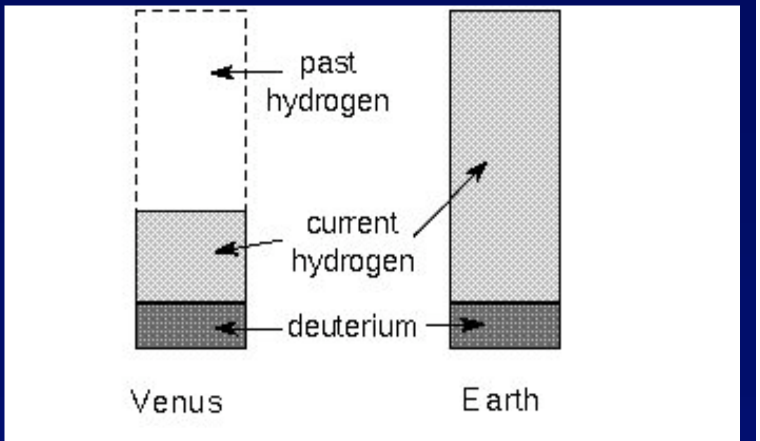


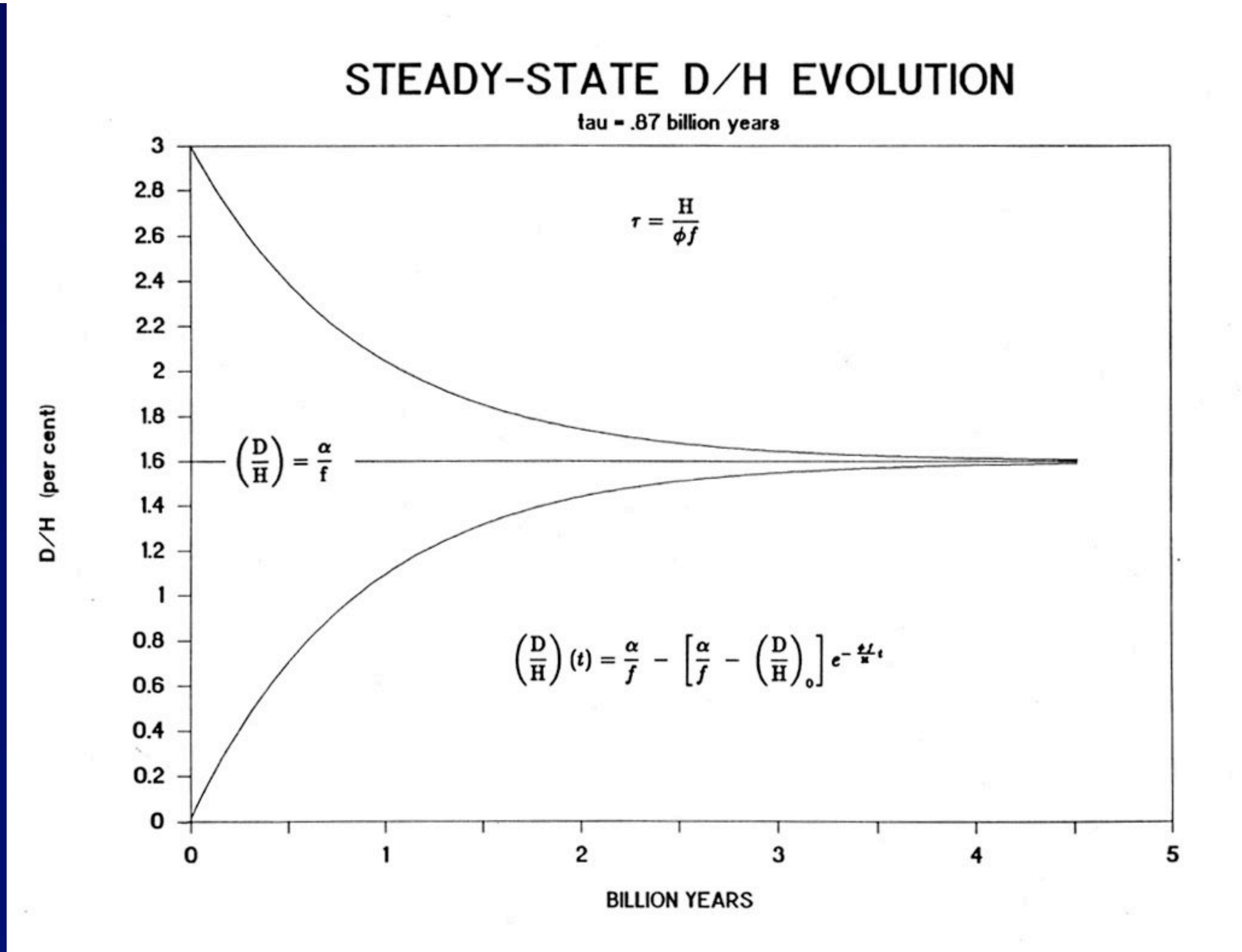

R. GROSSMAN

Possible Approaches

- Atmospheric isotopes
- Atmospheric escape rates
- Better constrained models
- Surface mineralogies
- Evidence for sediments
- Zircons?



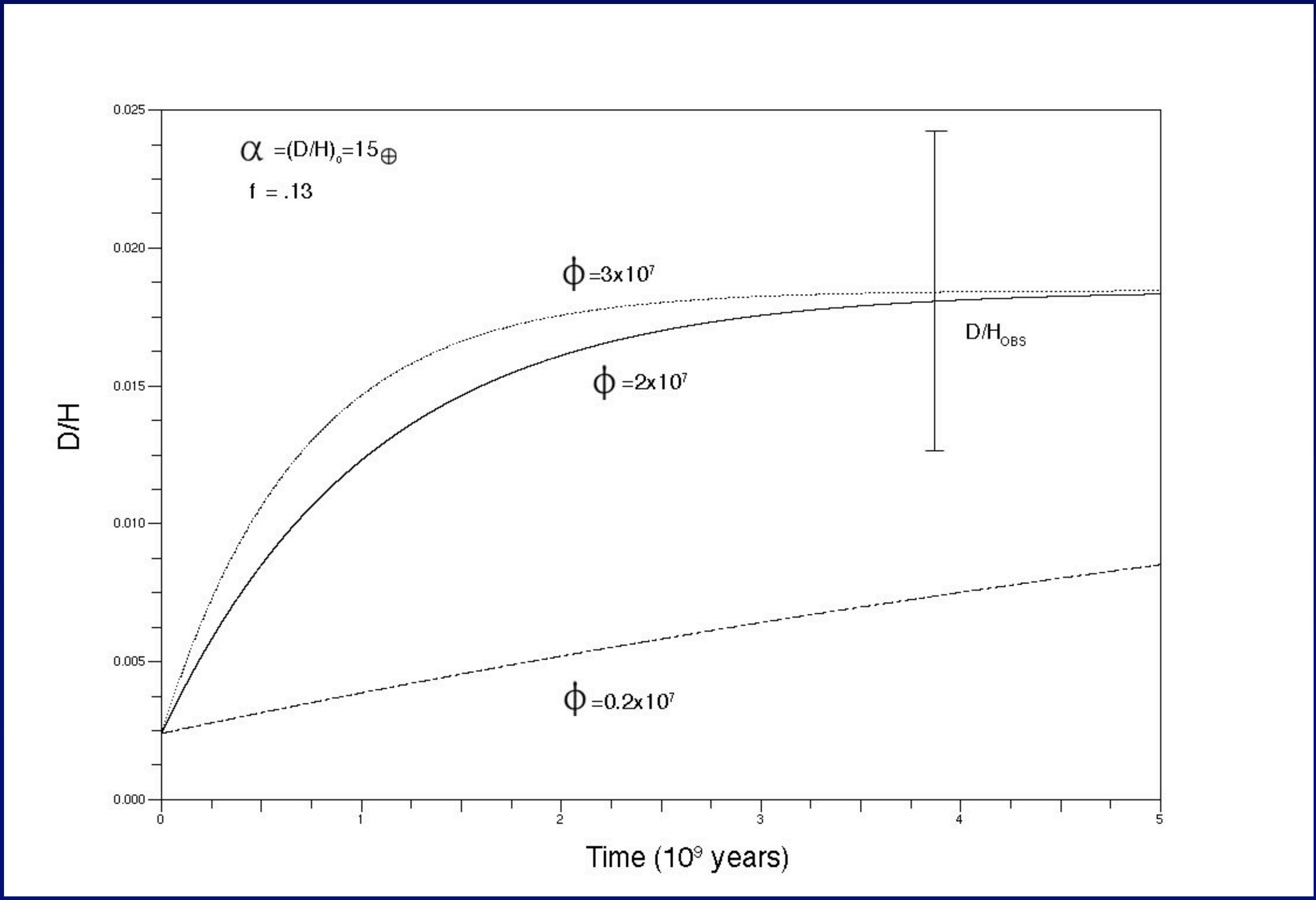
Proportions of hydrogen to deuterium on Venus and Earth are very different—ordinary hydrogen isotope was preferentially removed on Venus.



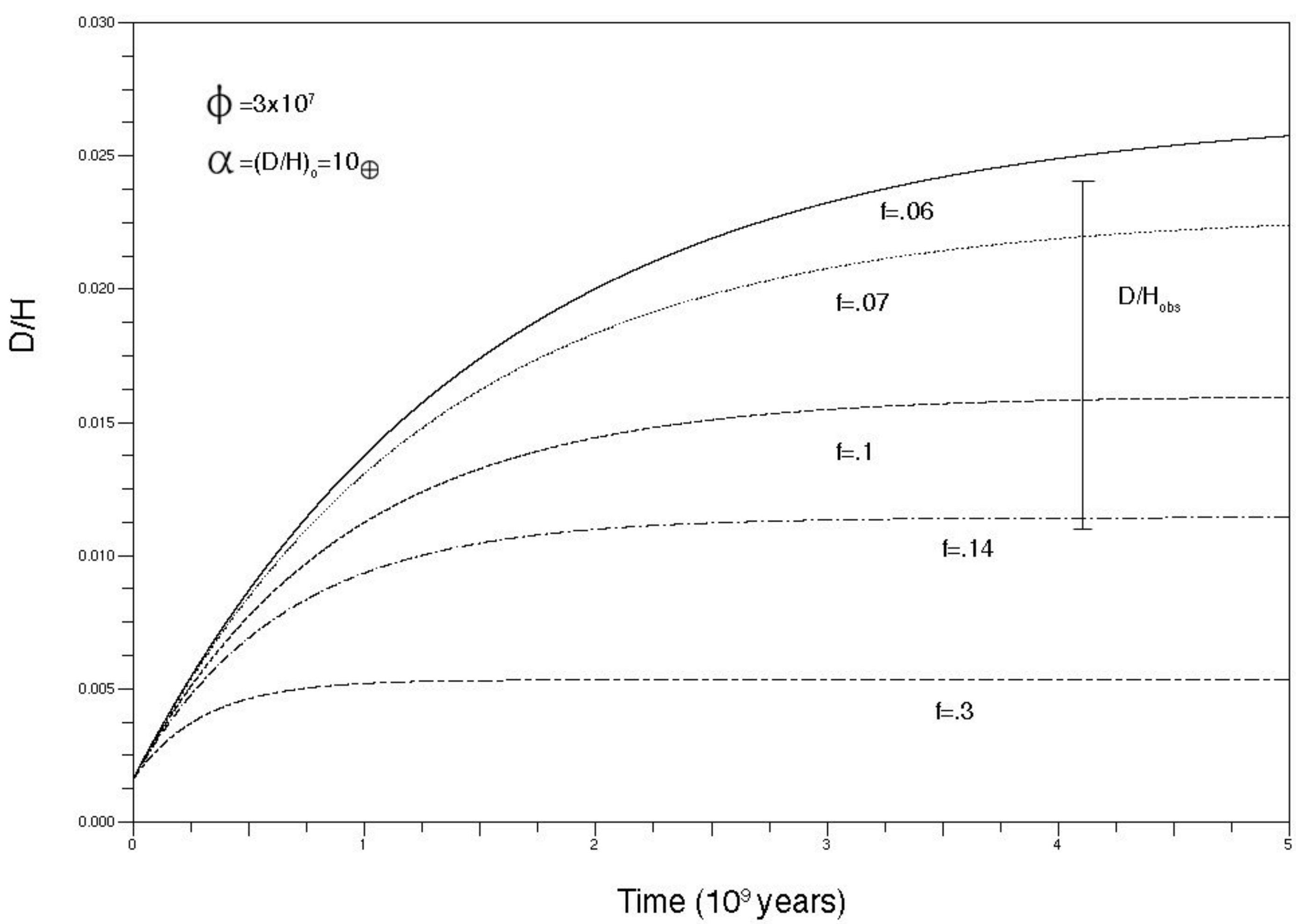
Observed D/H not "primordial residue"; reflects fractionation in the last 1 G.Y. (Grinspoon, 1993, Donahue 1999)

Escape flux of H, combined with post-Magellan estimates of resurfacing rate allows estimate of magma water content ≈ 50 ppm H_2O. (Grinspoon, 1993)

Varying hydrogen flux (ϕ):



Varying fractionation factor (f):



Presently, the problem is underdetermined.

Improved measurements of D/H, constraints on escape flux and fractionation factor will allow us to rule out many interpretations of D/H and allow more definitive derivations of history of water.

Especially when combined with models of ^{40}Ar

(reflects integrated degassing and magmatism over the planet's history)

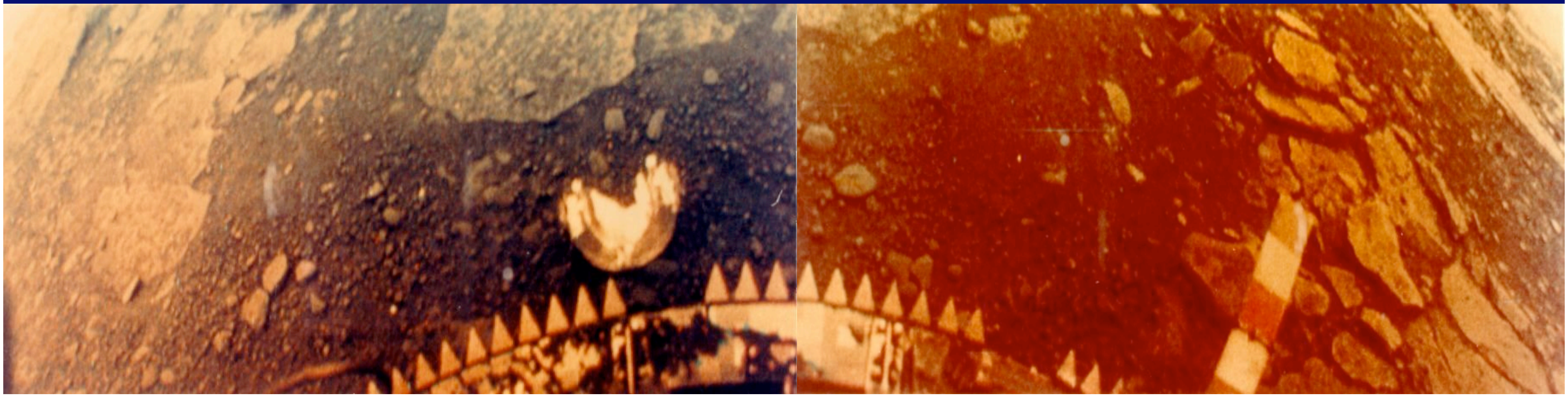
and ^{4}He.

residence time of 200Myr - 1.8Gyr
records the volume of magma produced during the "last global resurfacing event".

The First Great Transition:

Venus lost its ocean after perhaps 600 m.y.

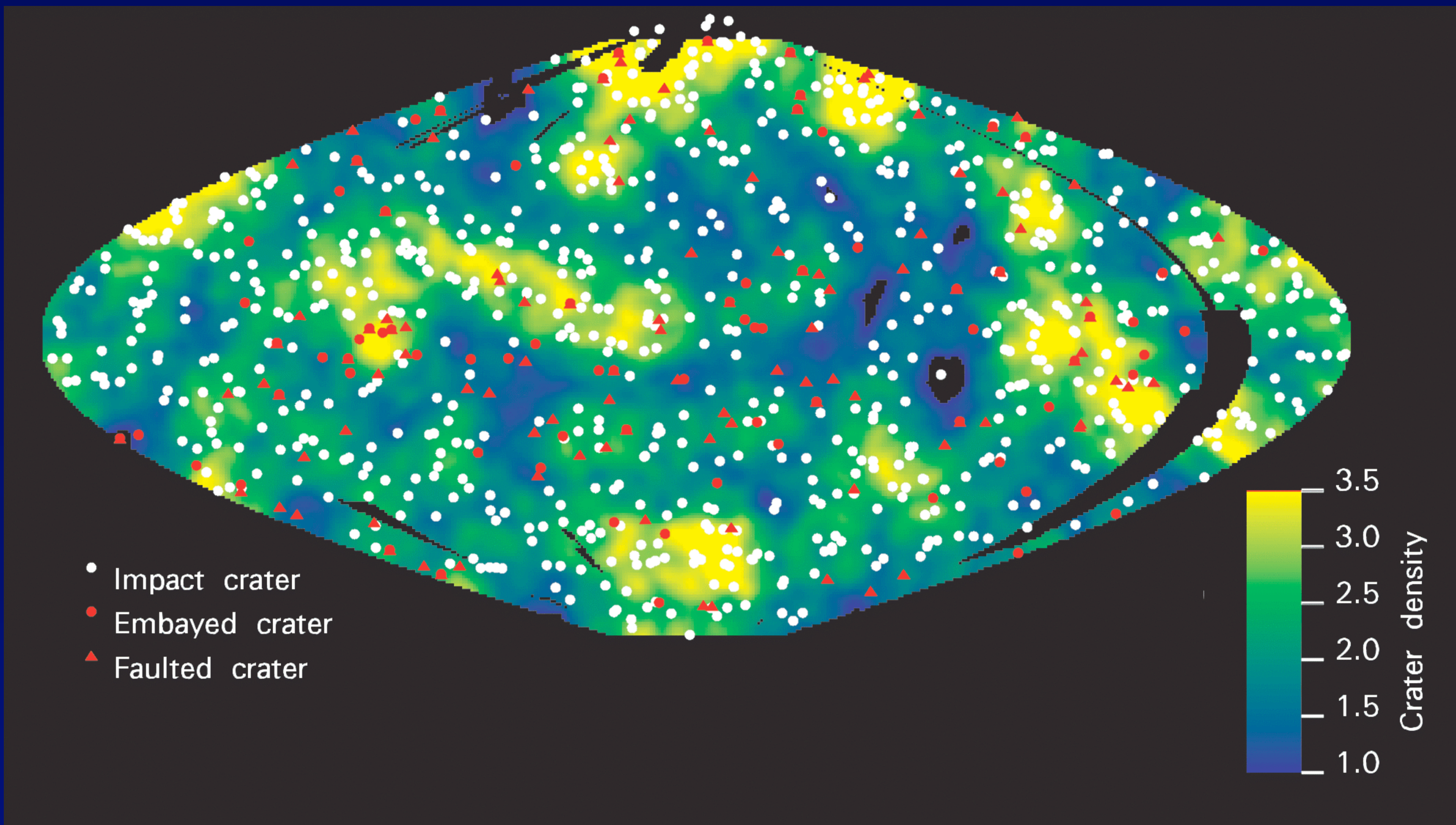
(Kasting, 1988)



Moist Runaway greenhouse

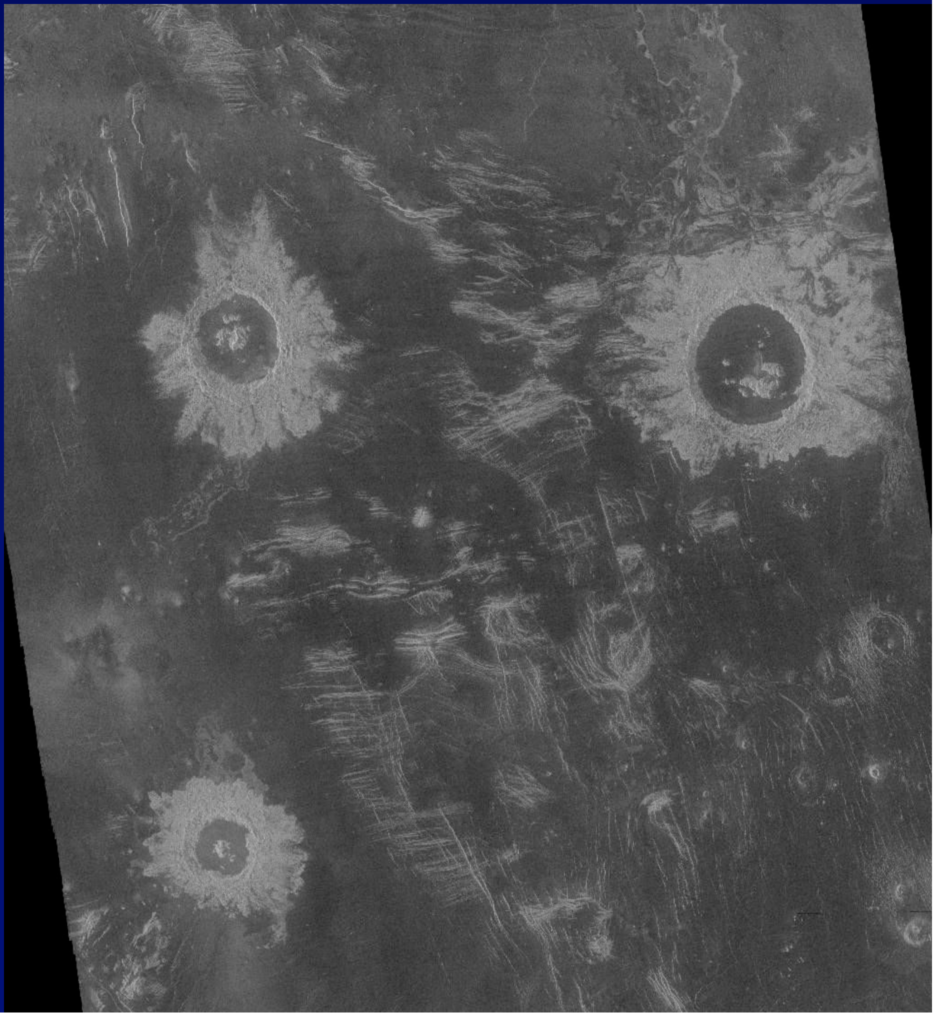
- Warm oceans persisted for a few 100 My while the atmosphere had > 10% H_2O and hydrodynamic escape.
- When atmospheric H_2O became low enough, D/H fractionation began. Carbonation of the surface.
- As Venus lost its surface water, carbonates decomposed and volcanism returned most of the CO_2 to the atmosphere.

The Venus Impact Cratering Record



The Second Great Transition:

Most of the present surface was created in a brief resurfacing epoch 700±200 m.y. ago.



What happened?

A) Venus died tectonically 700 m.y. ago; plate tectonics ceased as radioactive heat production decreased.

B) Venus experiences episodic global subduction events.

Longevity of an Early Venus Ocean

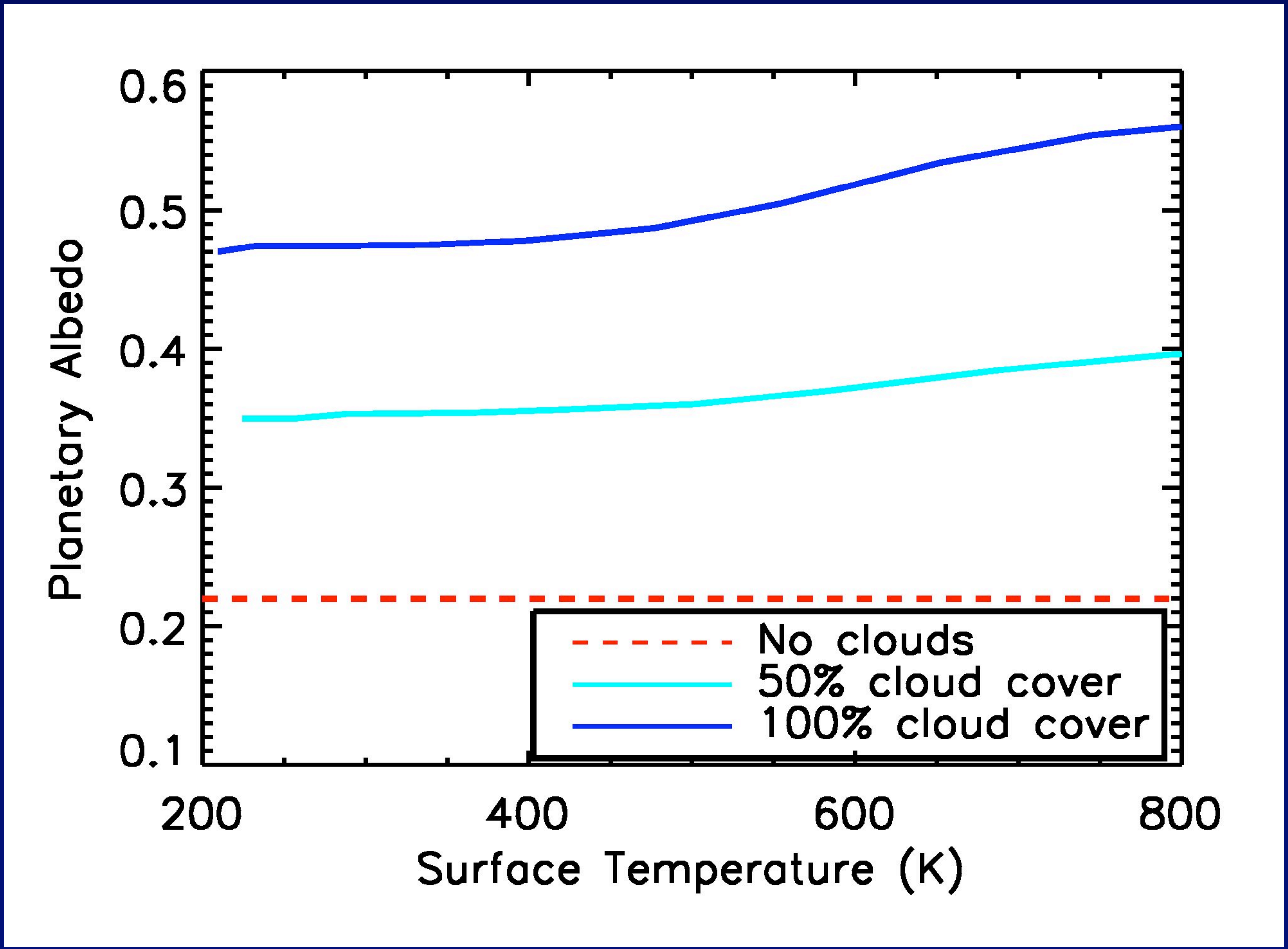
Kasting (1988) in many ways optimized to get rid of ocean quickly:

- Calculations produce **upper limit** on surface temperatures (and therefore upper limit on escape fluxes, and lower limit on lifetime of ocean).
- **Clouds excluded** No cloud feedback which, qualitatively, is expected to stabilize surface temperatures with rising solar flux, and therefore extend the lifetime of the moist greenhouse.
- Preliminary new results suggest that the oceans of Venus may have persisted for ≈ 2 Gy.

Radiative-Convective Equilibrium Calculations for High H_2O Atmospheres

- Gray 2-component, 2-stream model
- Wet adiabat with H_2O cloud formation
- Absorption of sunlight within the clouds
- Calculations for 1 AU, present-day solar luminosity
- 1 bar N_2, 350 ppm CO_2, H_2O from 0.6 mbar to 60 bars
- 0, 50% and 100% cloud cover

Radiative-Convective Equilibrium Calculations for High H_2O Atmospheres:

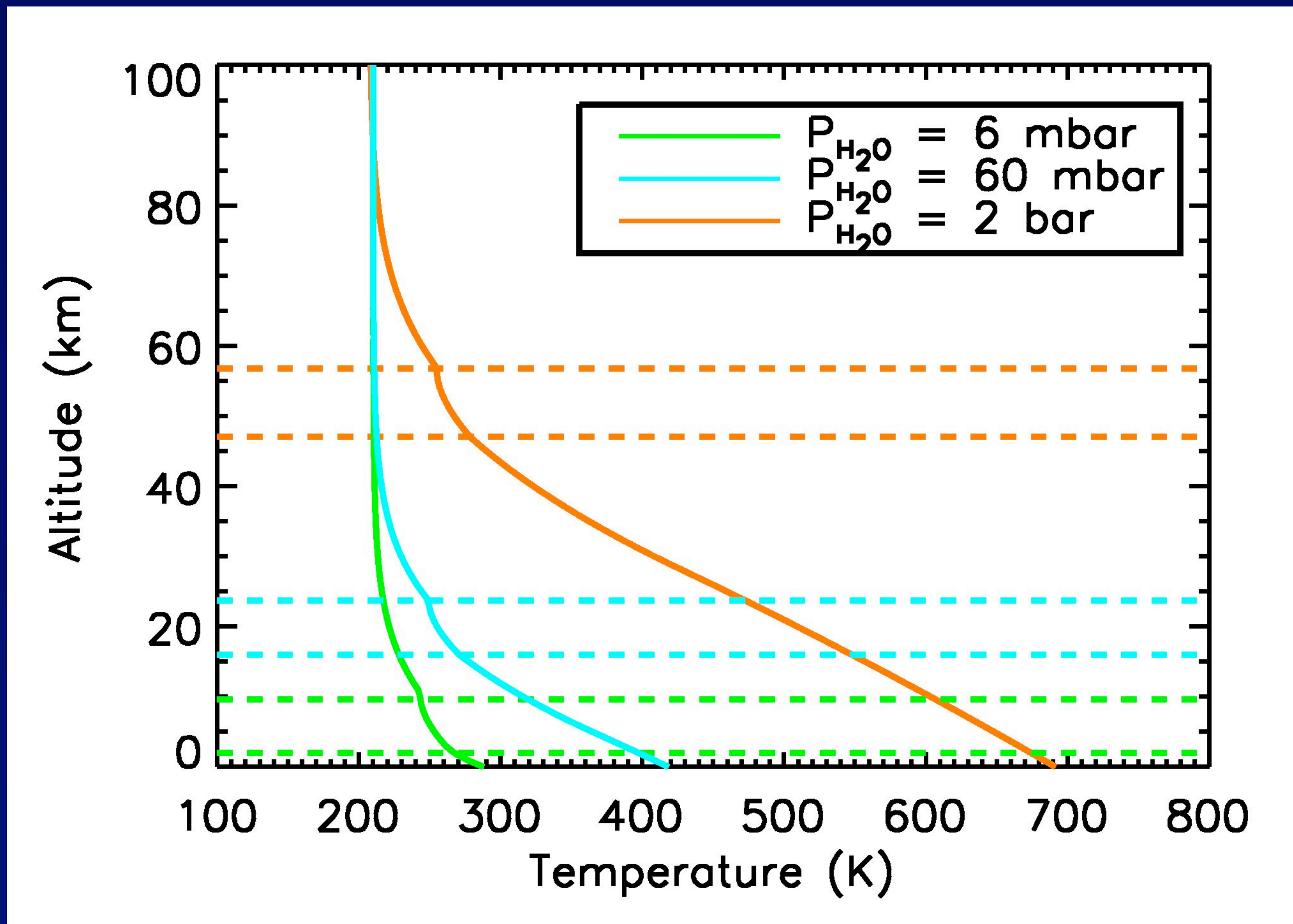


More cloud cover:

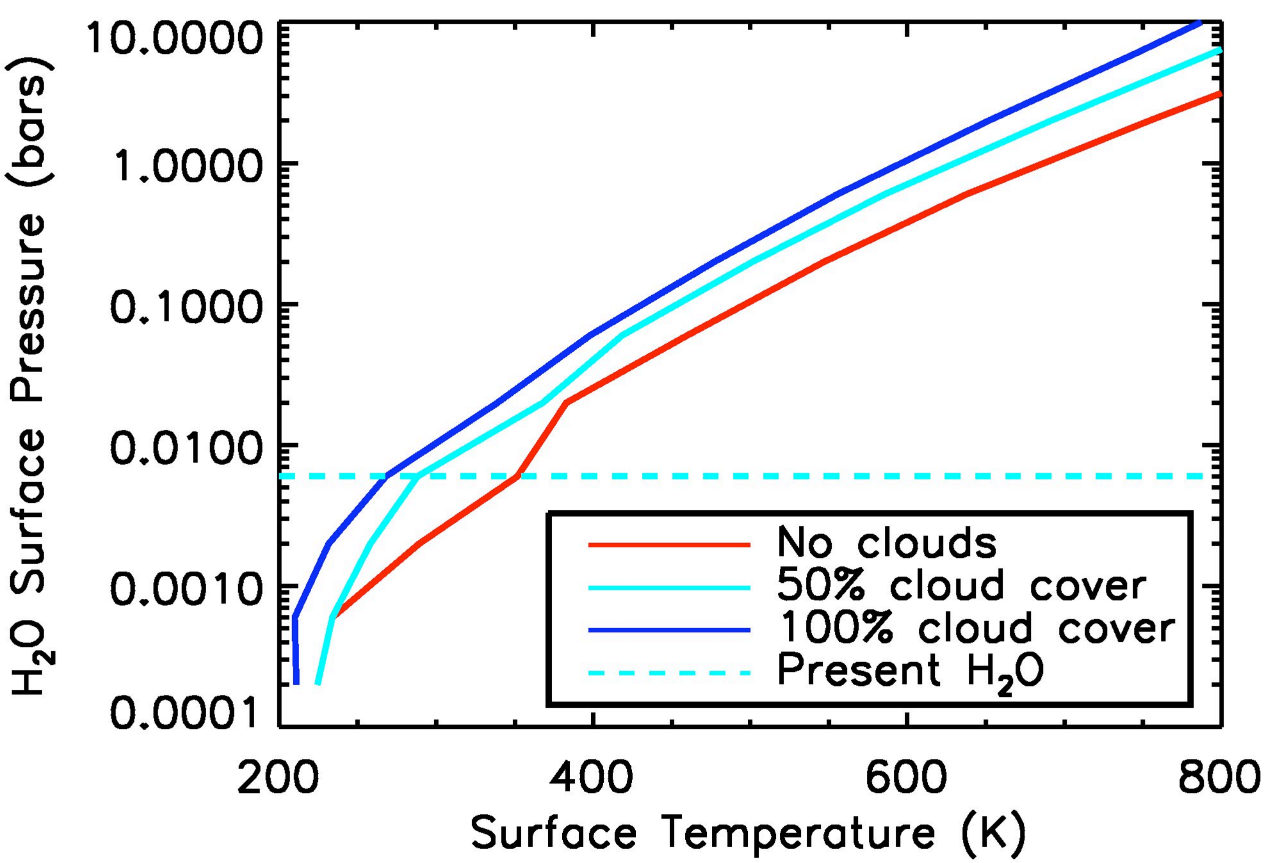
Higher reflectivity,

Cooler surface.

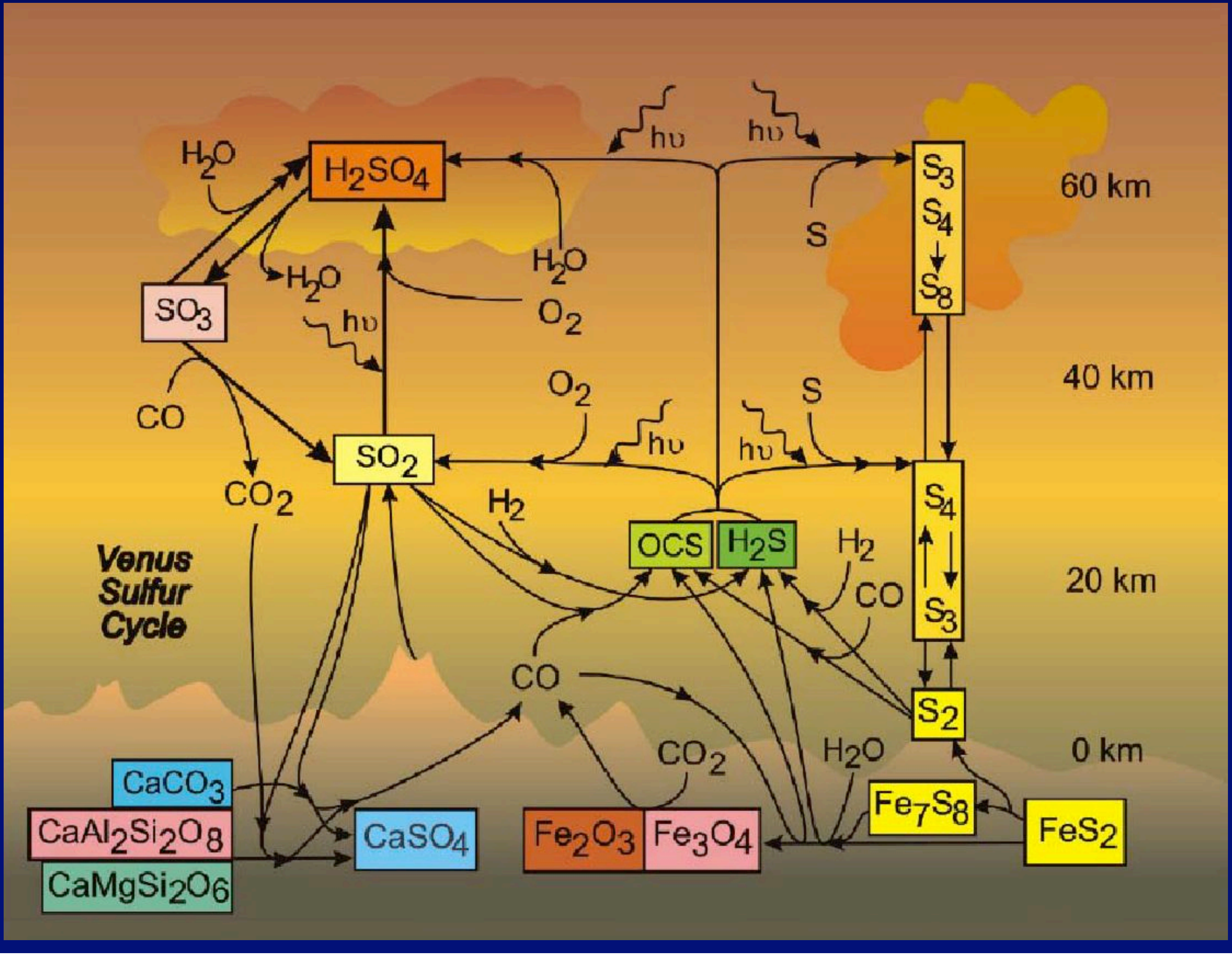
Oceans more stable!



Altitude (km)
100
80
60
40
20
0
P_{H_2O} = 6 mbar
P_{H_2O} = 60 mbar
P_{H_2O} = 2 bar
100 200 300 400 500 600 700 800
Temperature (K)


10.0000
1.0000
0.1000
0.0100
0.0010
0.0001
H2O Surface Pressure (bars)
200
400
600
800
Surface Temperature (K)
No clouds
50% cloud cover
100% cloud cover
Present H2O

Surface and Atmosphere S



Temperature-Dependent Geochronometers

- Most amphiboles and micas are not thermodynamically stable on Venus (Zolotov *et al.* 1997).
- However, tremolite is metastable, decaying over timescale of ~1 By (Johnson and Fegley 2000).
- Large temperature difference between highlands and lowlands of Venus means that differential decay of amphiboles will occur.

Differential Tremolite Abundance

Rate Law for Decomposition

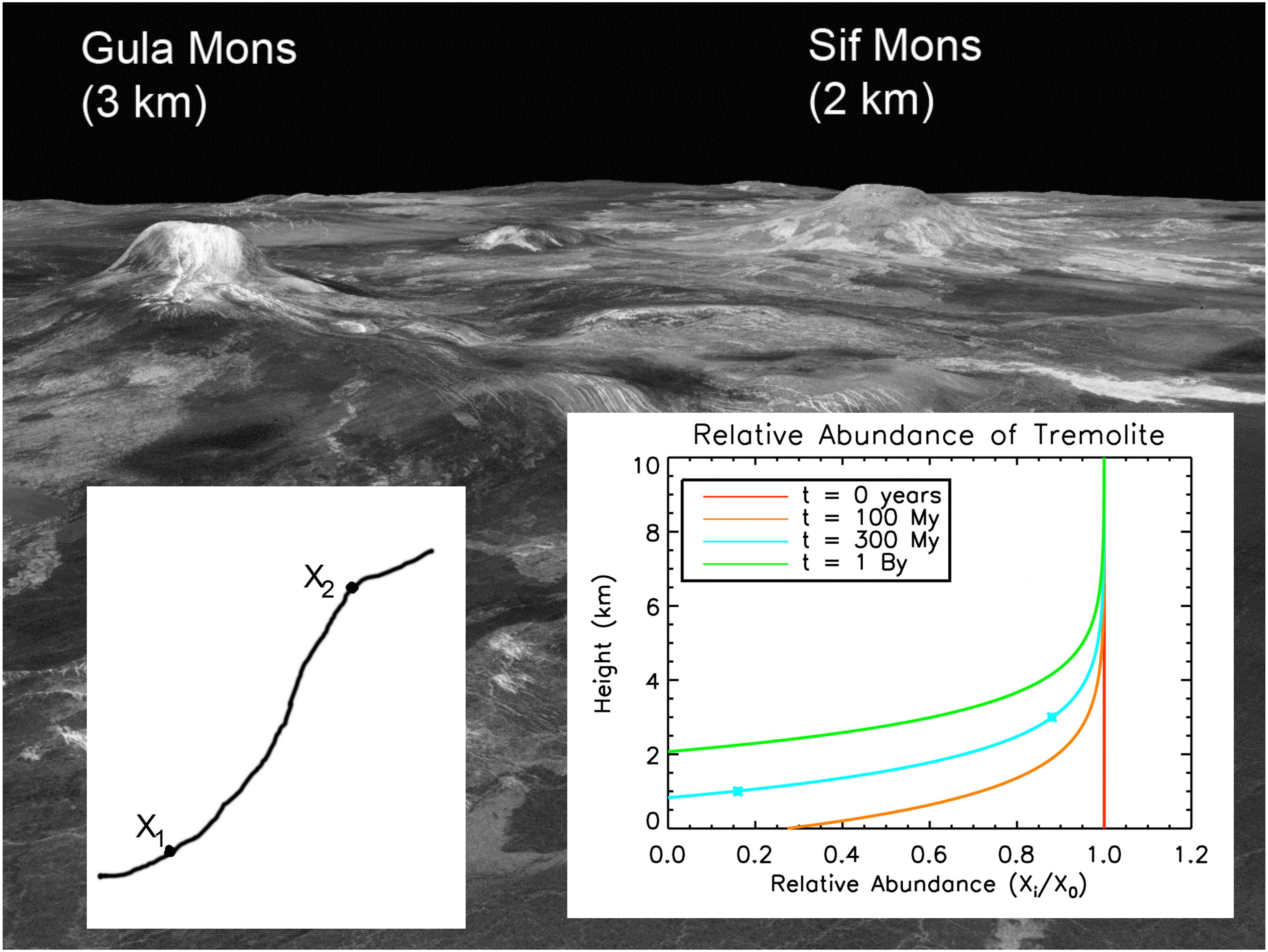
Adiabatic Atmospheric Lapse Rate

Rate of Change of Concentration

Surface Age Determination

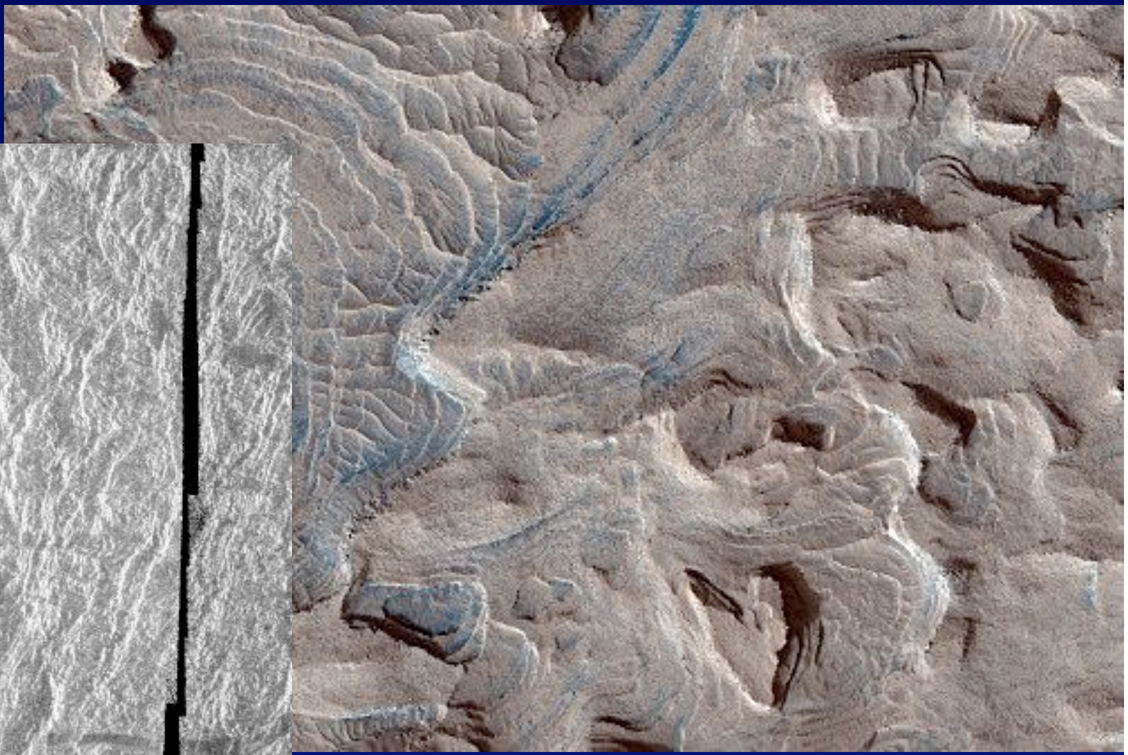
Integrate

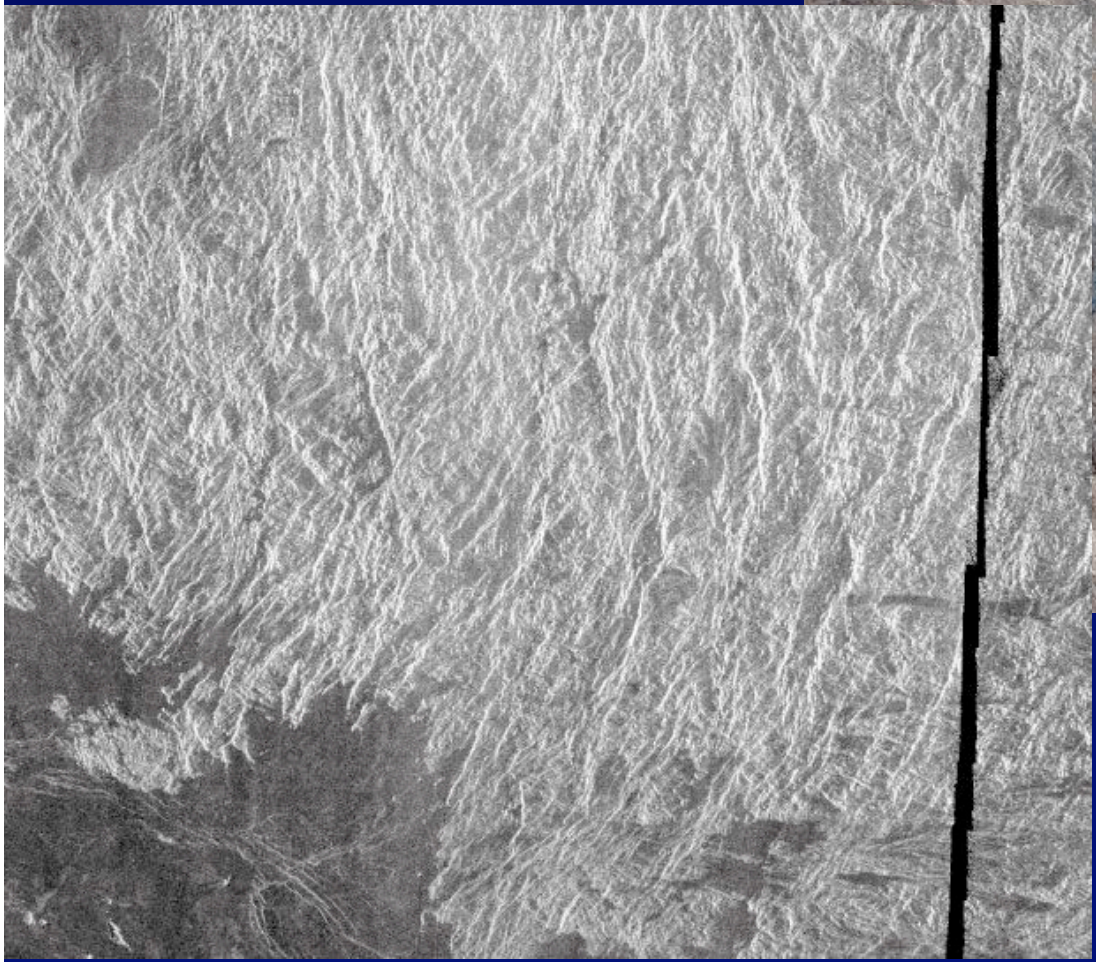
Average Age



Gula Mons
(3 km)
Sif Mons
(2 km)
X1
X2
Relative Abundance of Tremolite
t = 0 years
t = 100 My
t = 300 My
t = 1 By
Height (km)
Relative Abundance (Xi/X0)
0
2
4
6
8
10
0.0
0.2
0.4
0.6
0.8
1.0
1.2

Look for Sediments





Role of Water in Plate Tectonics

•"Hydrolytic weakening"

Lack of water -> greater creep resistance ->thicker lithosphere.

•Hydrated silicates -> asthenosphere

Without water, strong coupling of mantle to lithosphere.

•Water is an essential ingredient for silicic volcanism.

No water, no granites, no continents, no plate tectonics

•Variable viscosity convection models

desicated mantle -> more sluggish convection

So, terrestrial-style plate tectonics is, in many ways, facilitated by water.

No water, -> no plate tectonics?

HISTORY OF VENUS: a unified Scenario

- ≈ 2 G.Y. Loss of surface water, Subduction of hydrated sediments ceases.
- Mantle becomes desiccated
- Lack of water makes lithosphere thicker and more difficult to break
- Loss of asthenosphere -> lithosphere is tightly coupled to mantle.
- Crustal recycling is inhibited
- ≈ 1G.Y. Plate tectonics ceases, Venus becomes a "one plate planet"
- Heat builds up in interior
- ≈ 700 M.Y. Episode of global subduction, global resurfacing
- 700 M.Y. to present: localized volcanism and tectonism, conductive Heat release, production population of craters.

  - Tessera are remnants of more vigorous past tectonics. (continents?)
  - Plains record global resurfacing.

OVERALL GOAL:

Push at the chronology of water loss from both ends:

- Back from the present, through models of escape, isotopic, evolution. (H, D, Ar, He…)
- Forward from planetary origin, through models of the early steam atmosphere, thermal balance, and cloud evolution.

Arrive at a consistent, better constrained story for the evolution of Venus.

Apply toward generalized models of terrestrial planet evolution.

Improve definition of habitable zones.

Make useful predictions for extrasolar terrestrial planets.

How Can Exploring Venus Help Us Here on Earth?

- Is Venus too difficult to explore?
- Stability of climate
- Relevance of Venus exploration technologies to society
- Is there an end to time?
- What is the value of contemplating the habitability of other worlds?