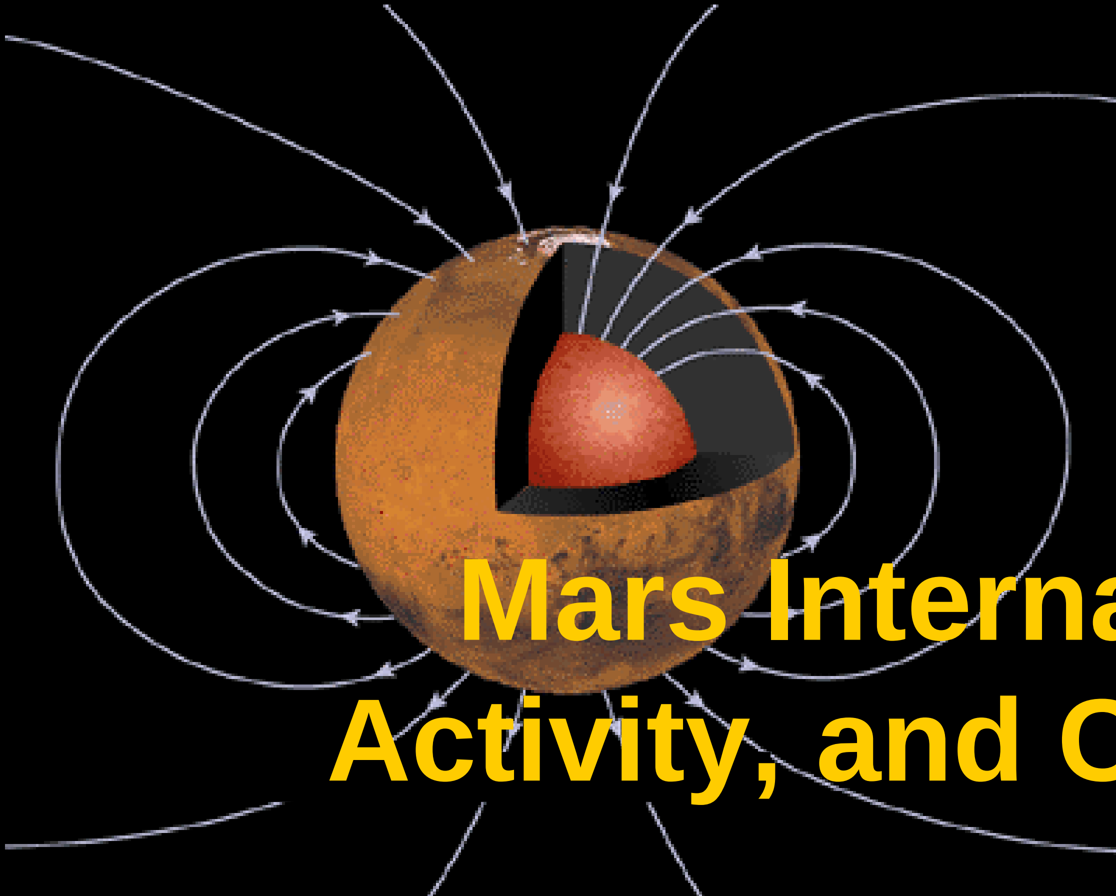


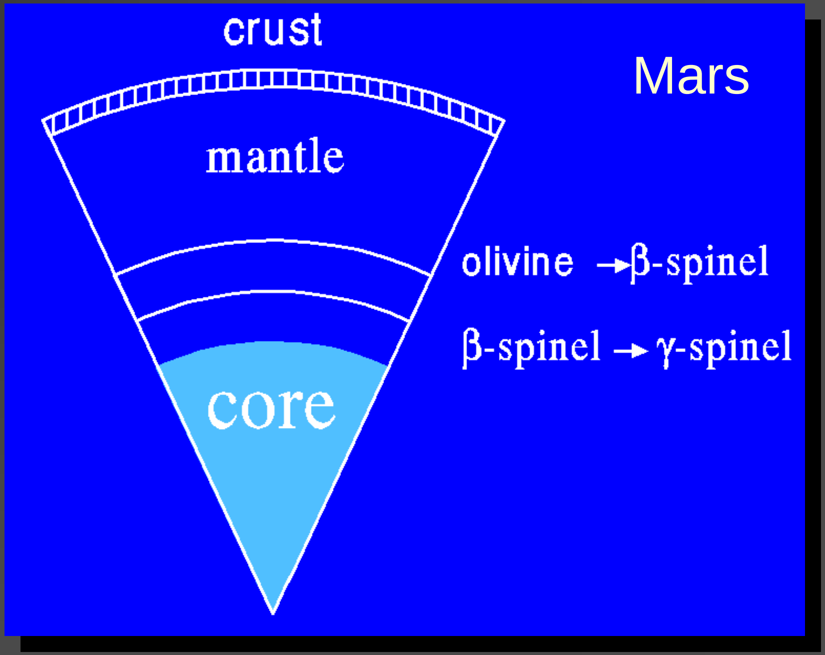
Mars Internal Structure, Activity, and Composition

Tilman Spohn

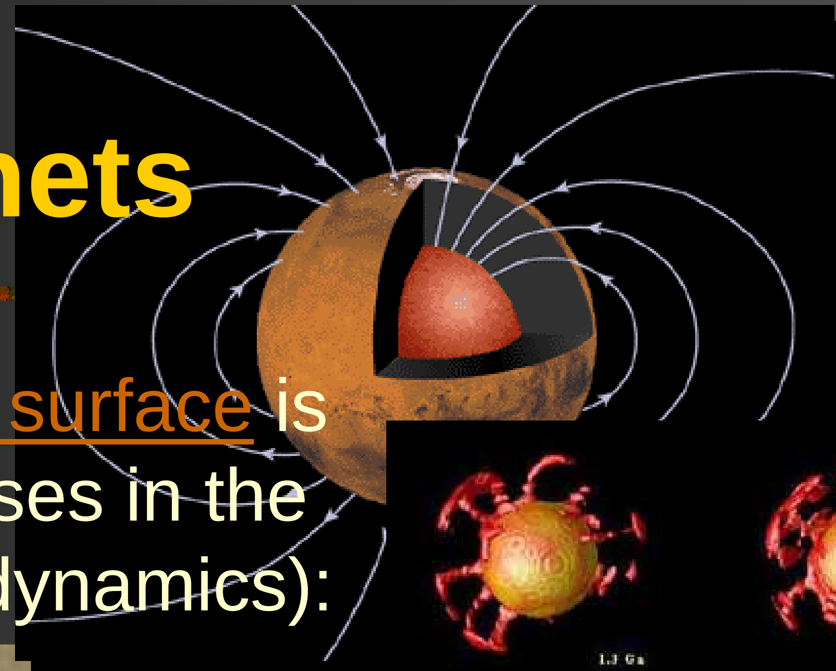
DLR Institute of Planetary Research, Berlin

Interior Structure

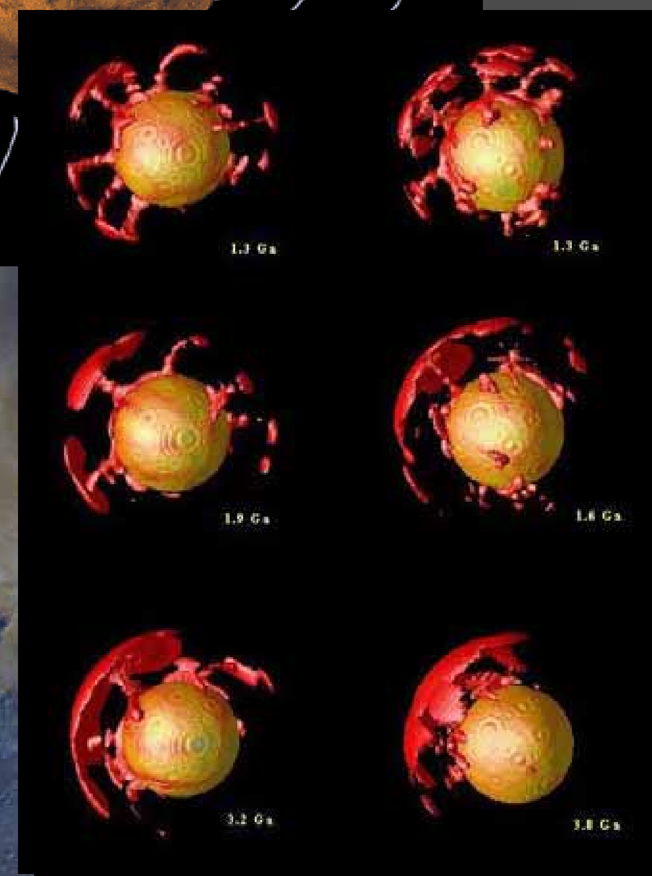
- Interior Structure models aim at
  - the bulk chemistry of the planet
  - the masses of major chemical reservoirs
  - the depths to chemical discontinuities and phase transition boundaries
  - the variation with depth of thermodynamic state variables (ρ, P, T)



Dynamic Planets



- The evolution of the surface is governed by processes in the interior (endogenic dynamics):
  - Tectonics, volcanism
  - Magnetic field
  - Evolution of atmosphere, hydrosphere

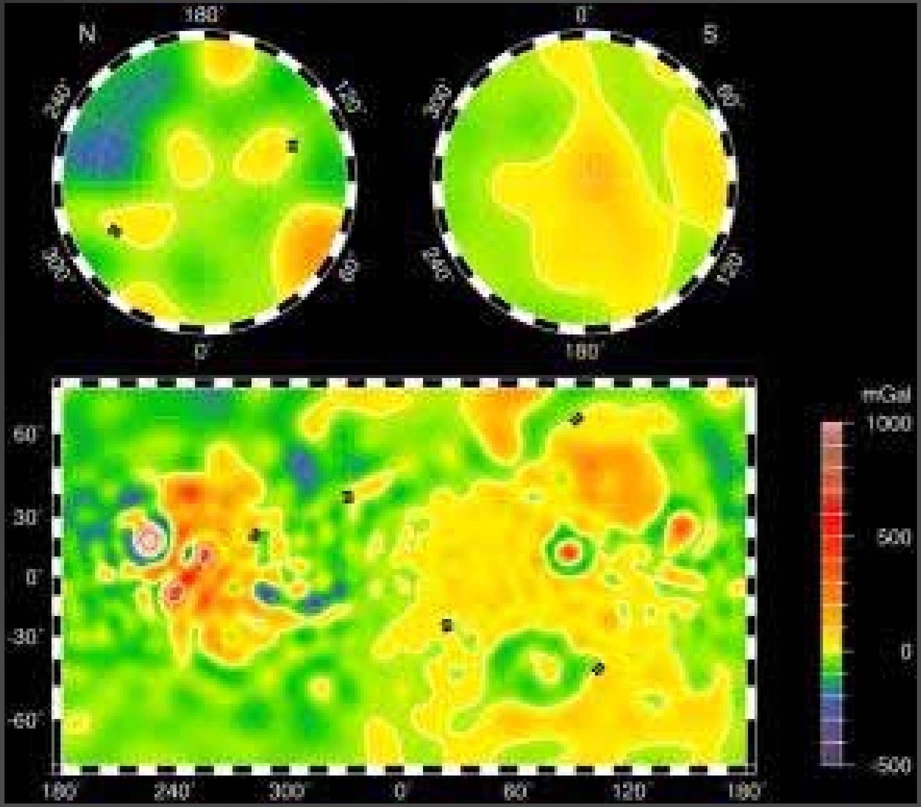


Relate observations to interior dynamics models

Interior Structure

- Constraints
  - Mass
  - Moment of inertia factor
  - Gravity field
  - Surface rock chemistry/ mineralogy/geology
  - Cosmochemical constraints
  - Laboratory data
- Future:
  - Seismology
  - Heat flow
  - Rotation, Nutation
  - Samples

MGS Gravity Field of Mars



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Interior Structure: The Data Set

- Mars: Mass, MoI-factor, Samples, Surface Chemistry, Geology
- Venus: Small rotation rate does not allow to calculate MoI-factor from J_2 under the assumption of hydrostatic equilibrium
- Mercury: MoI from Peale‘s experiment
- Galilean Satellites: J_2 and C_{22}

Mars: The MoI Debate

$$Pathfinder: \frac{C}{MR_P^2} = 0.3662 \pm 0.0017$$

$$Yoder\ et\ al\ 2003: \frac{C}{MR_P^2} = 0.353 \pm 0.0012$$

$$\frac{I}{MR_P^2} = \frac{C}{MR_P^2} - \frac{2}{3} J_2$$

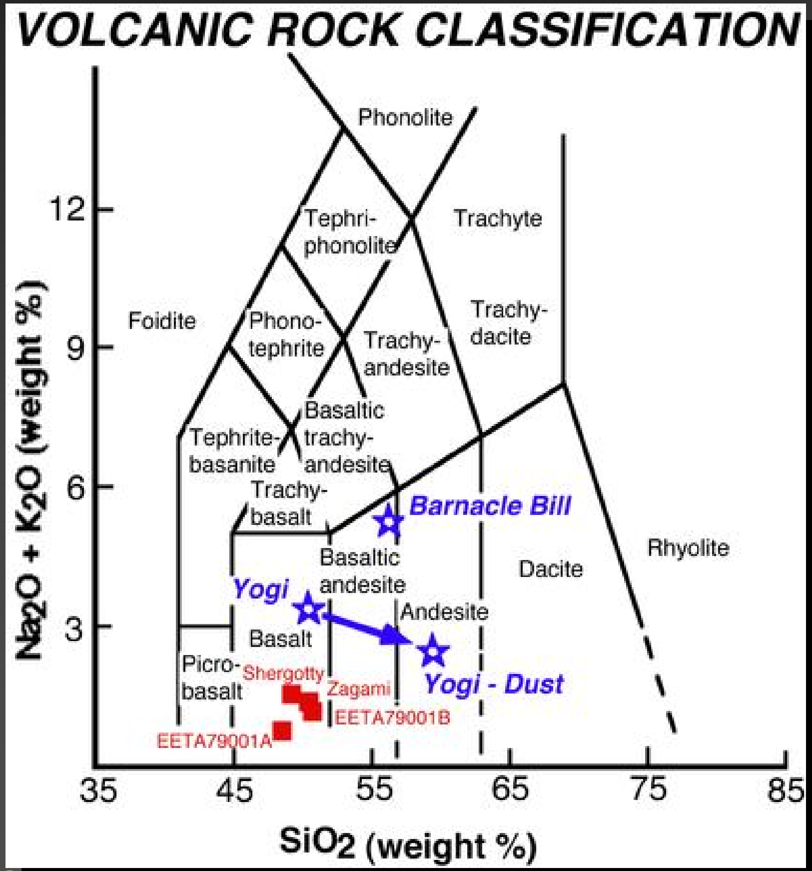
$$Sohl\ et\ al\ 2005: \frac{I}{MR_P^2} = 0.3635 \pm 0.0012$$

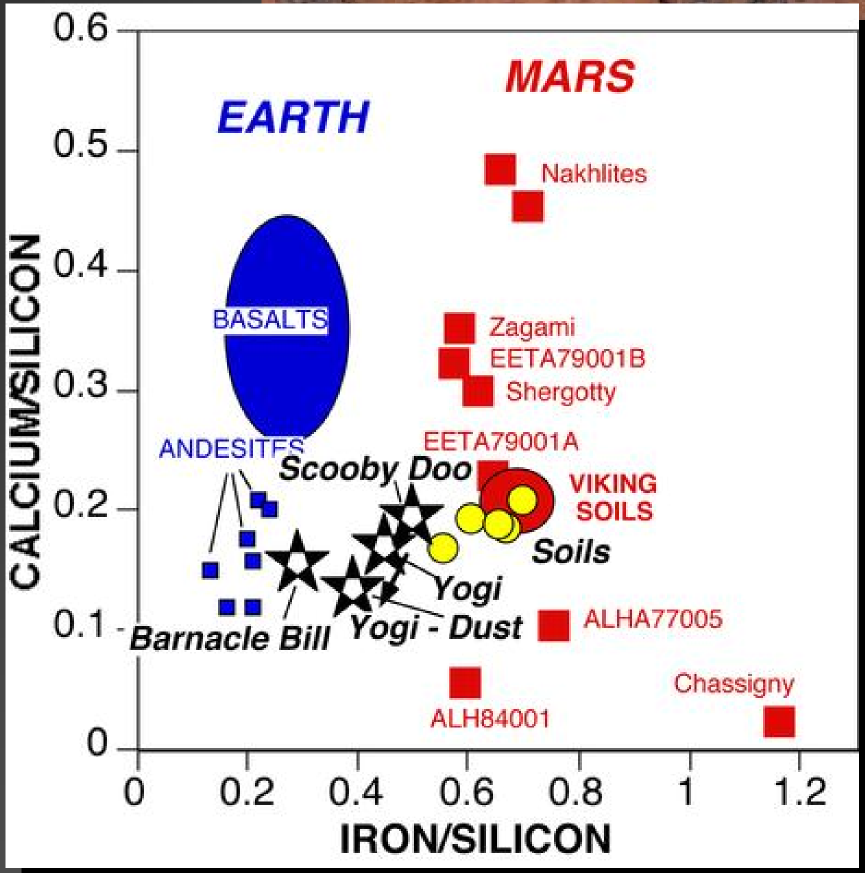
SNC Meteorites Samples from Mars?

SNC chemistry provides a model for planetary composition

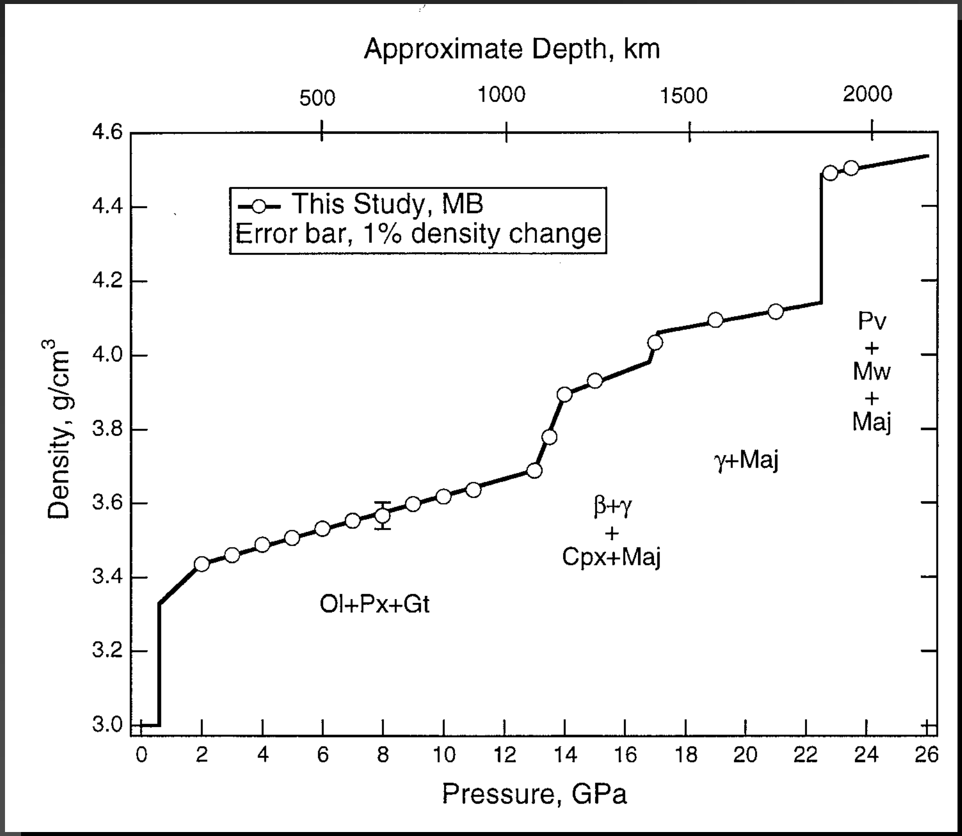
→ about 15 weight-% S in core

Surface Rock

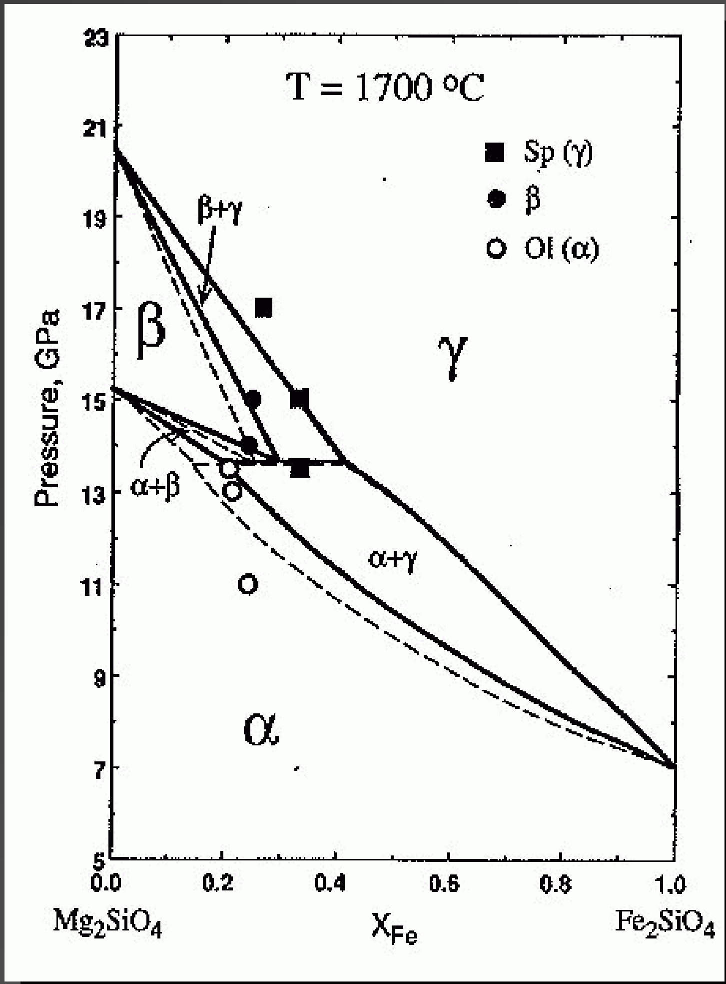




Laboratory Data



Bertka and Fei, 1997



Temperature

- Temperature requires some additional considerations
- Heat transfer model
- Model of interior chemistry, EOS
- Model of initial temperature

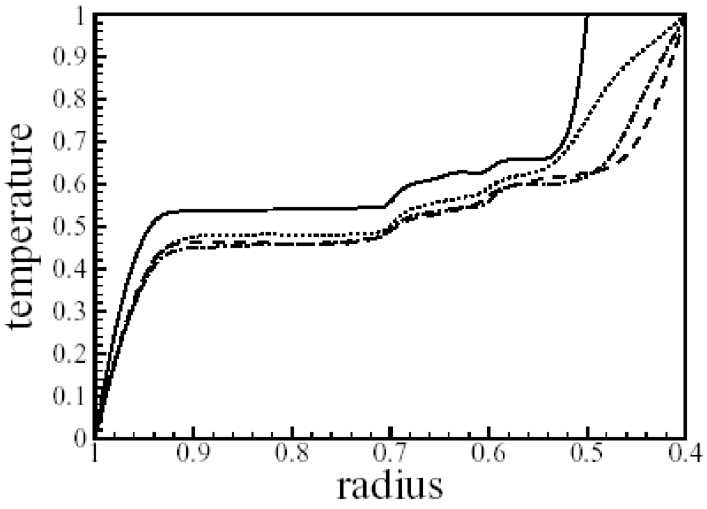
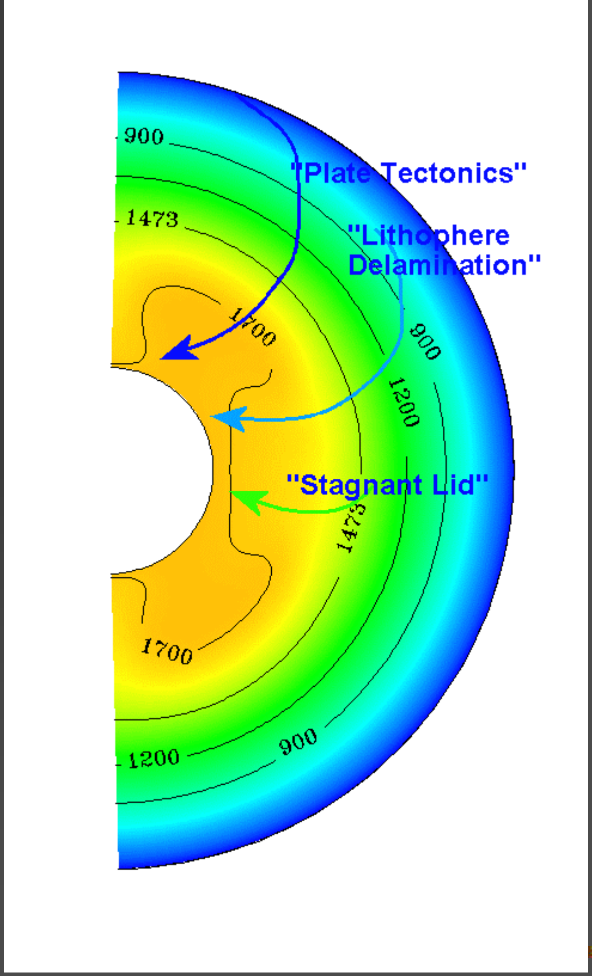


Fig. 22. Temperature profile for the model with two exothermic phase transitions (solid line) and for the model with the spinel–perovskite transition at varying depth and both exothermic phase transitions. The dotted line corresponds to $r_{sp/per} = 0.5 \times r_p$, the dash-dotted line to $r_{sp/per} = 0.45 \times r_p$, and the dashed line to $r_{sp/per} = 0.425 \times r_p$

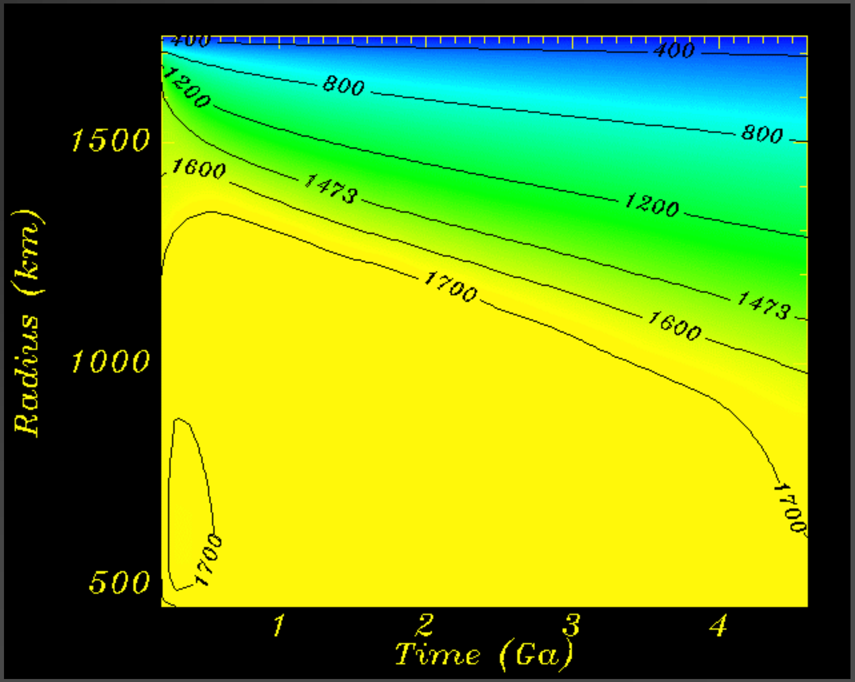
Heat Transfer: Stagnant Lid Convection

- Convection in a strongly temperature dependent viscosity „fluid“ tolerates an order of magnitude viscosity increase in convecting layer
- Therefore a stagnant lid forms on top through which the viscosity increases dramatically



Stagnant Lid Convection

- The figure shows a lunar thermal evolution model
- The planet cools by thickening its lithosphere while the deep interior stays warm
- Characteristic of SL convection



Thickness of the lid

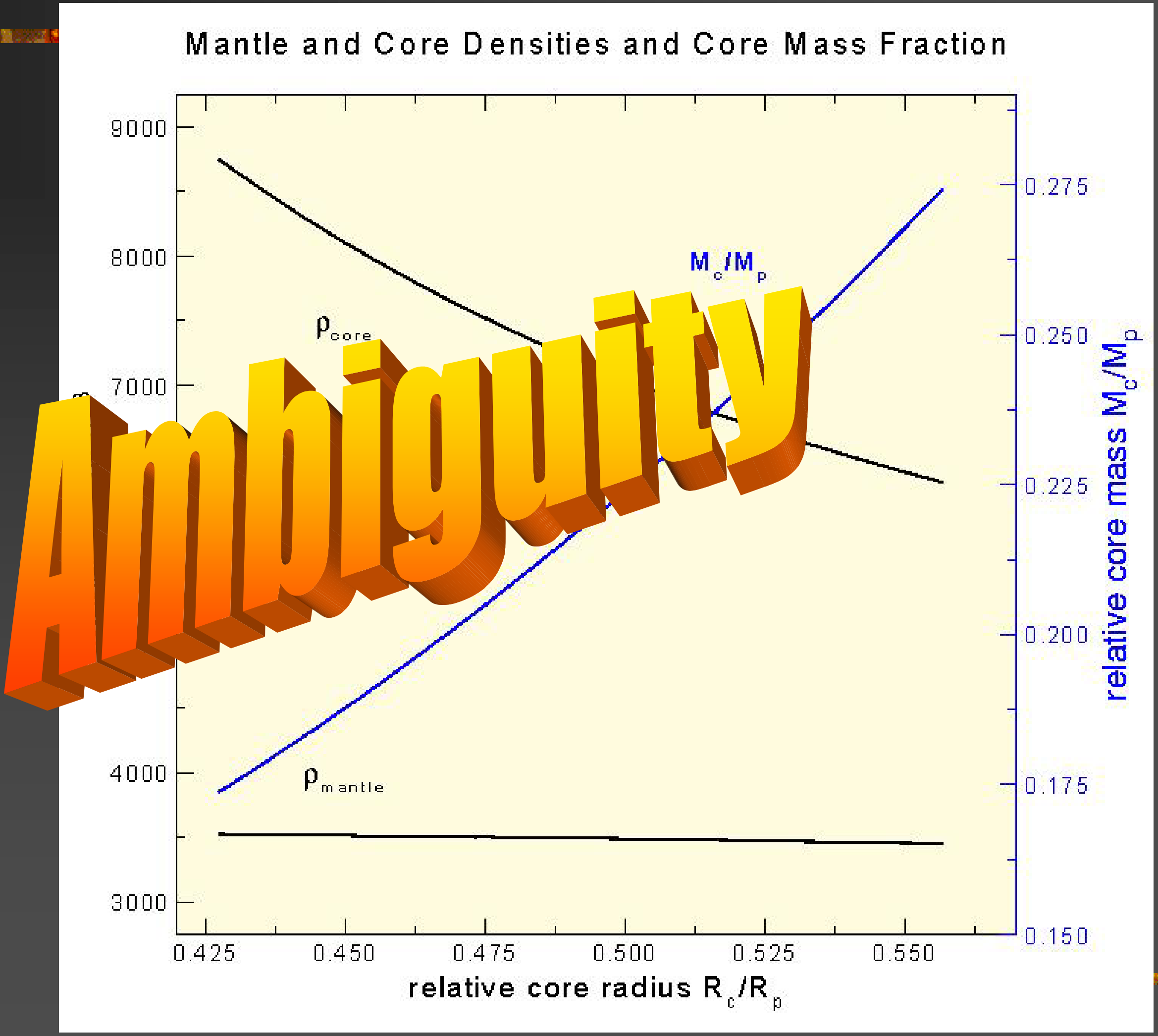
$$\nu = \nu_0 \exp A\left(\frac{T_m}{T} - 1\right)$$

$$T_m(P) = T_{m0} + \frac{dT_m}{dP} P$$

$$z_{stag} \approx \frac{T_{m0}\dfrac{A}{(A+\ln 10)} - T_S}{\dfrac{Q}{4\pi R_P^2 k} - \dfrac{dT_m}{dz}\dfrac{A}{(A+\ln 10)}}$$

Mars: Two-layer Model

- Just the MoI factor and mass
- Three unknowns (core, mantle density, core radius) two constraints
- Mantle density quite well constrained; trade off between core density and radius



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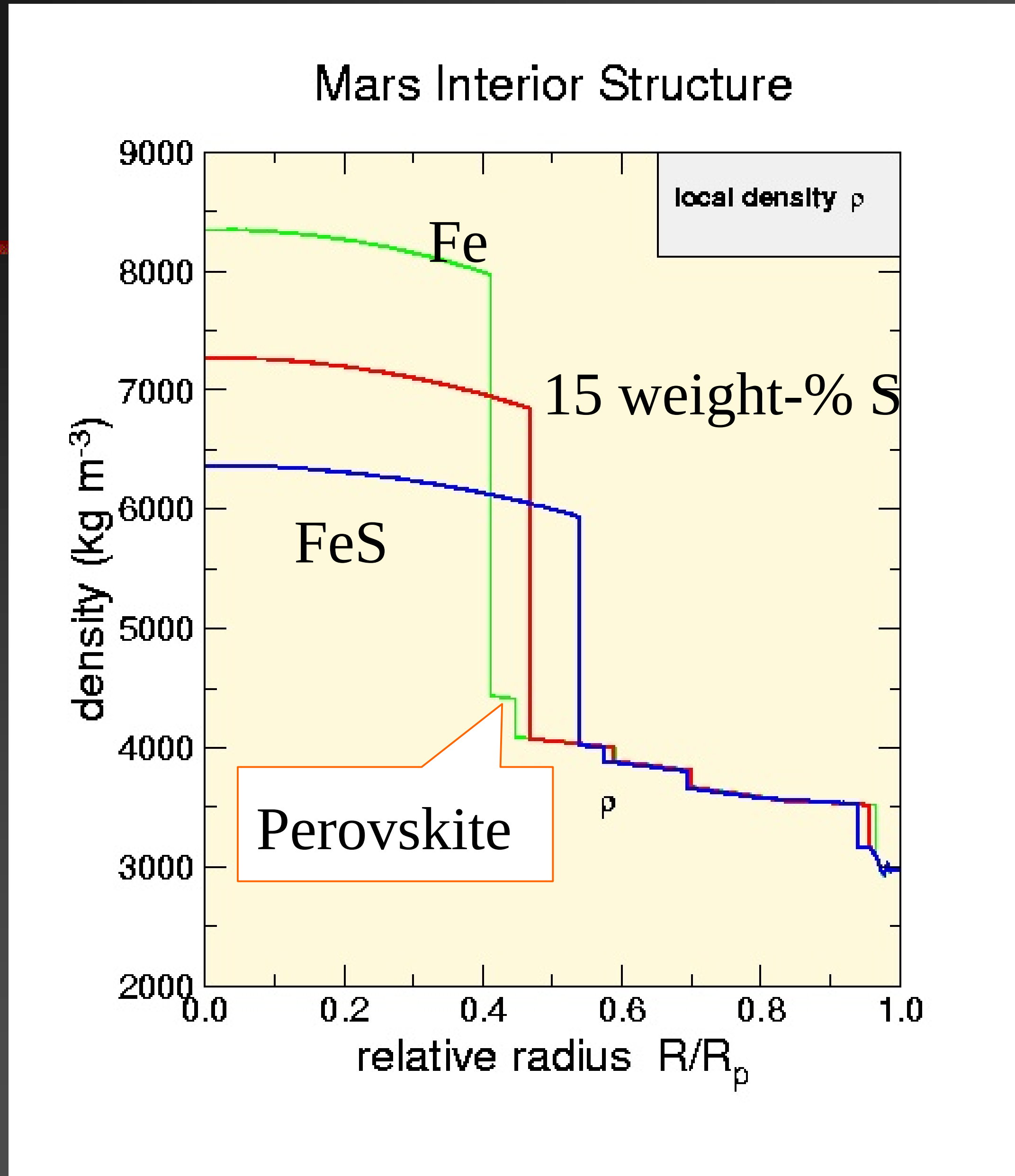
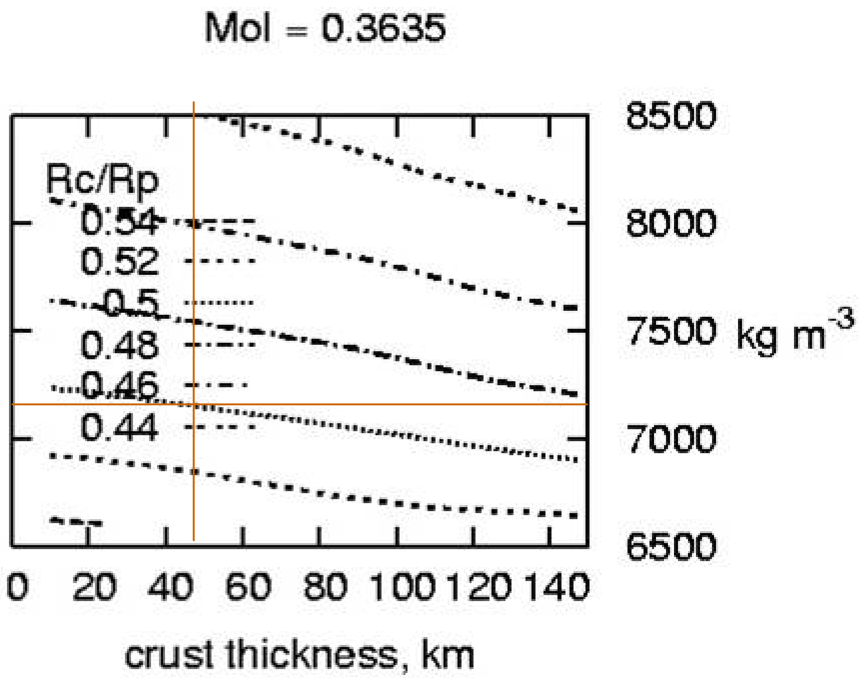
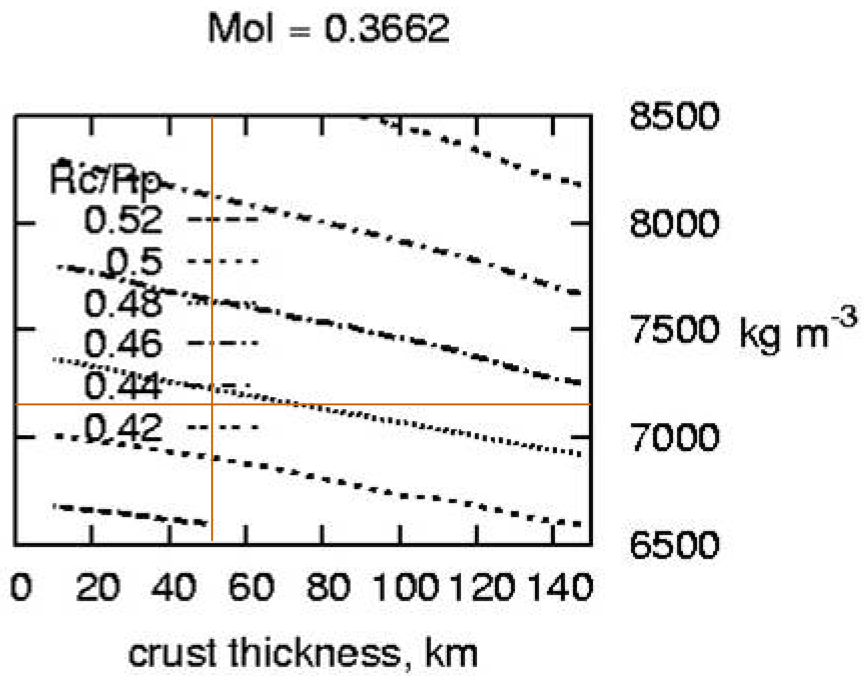

Mars Interior Structure
local density ρ
Fe
15 weight-% S
FeS
Perovskite
ρ
density (kg m⁻³)
9000
8000
7000
6000
5000
4000
3000
2000
0.0
0.2
0.4
0.6
0.8
1.0
relative radius R/Rp

Improved MoI: Core Size



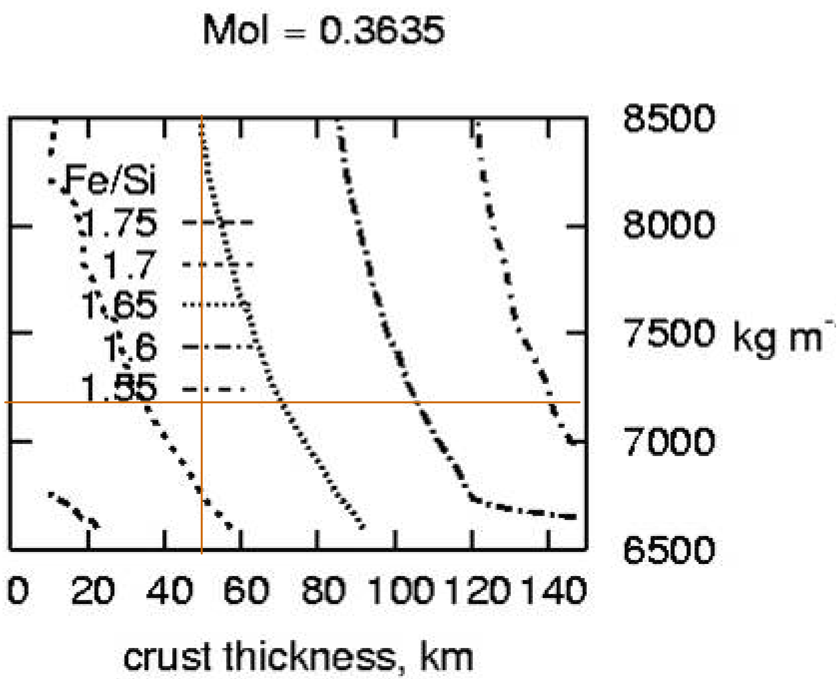


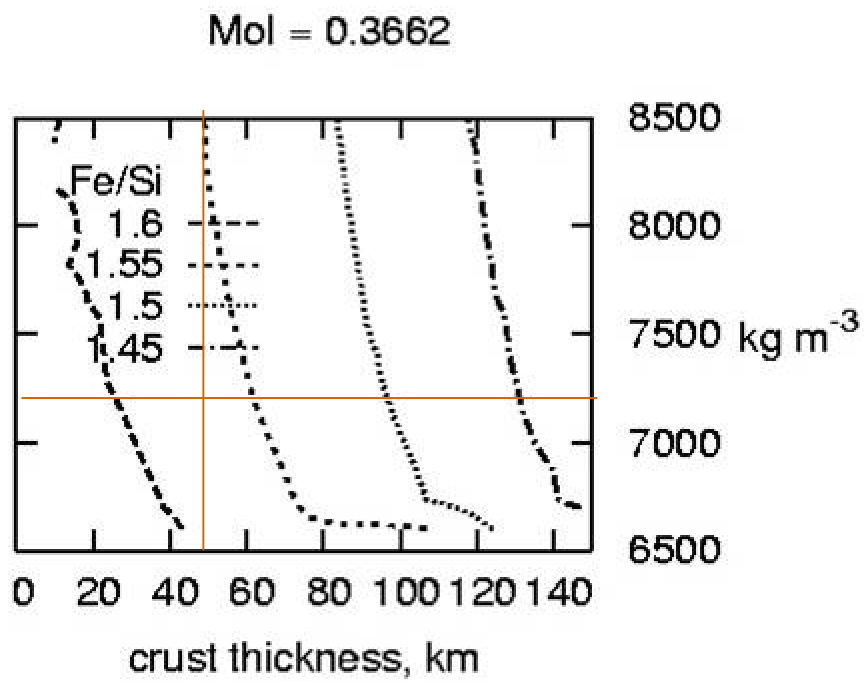
$$R_c / R_P \approx 0.510$$

$$R_c / R_P \approx 0.485$$

$$\Delta R_c \approx 50 km$$

Improved MoI: Fe/Si





$Fe / Si \approx 1.68$

$Fe / Si \approx 1.58$

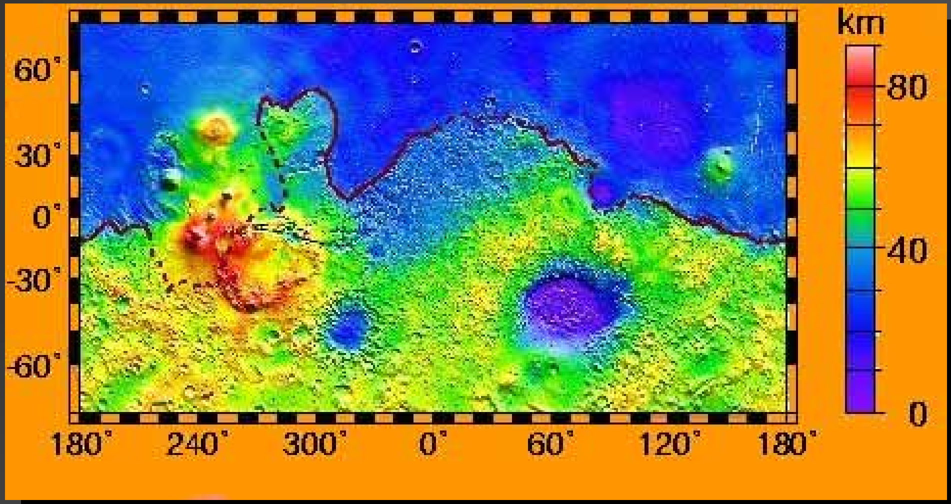
$chondritic : Fe / Si \approx 1.70 \pm 0.1$

Effects of smaller MoI

- Bigger core: less chance for perovskite mantle layer
- Larger Fe/Si: more chondritic
- Smaller mantle density (by about 100kg/m³): more Earth like mantle

The Crust: MGS

- **Average thickness ~ 50 km, but ambiguous**
- **Crust thickness variations from gravity**
  - **Minimum underneath hellas**
  - **Maximum underneath Tharsis**
- **Crust production rate peaked in the Noachian and extended into the Hesperian**

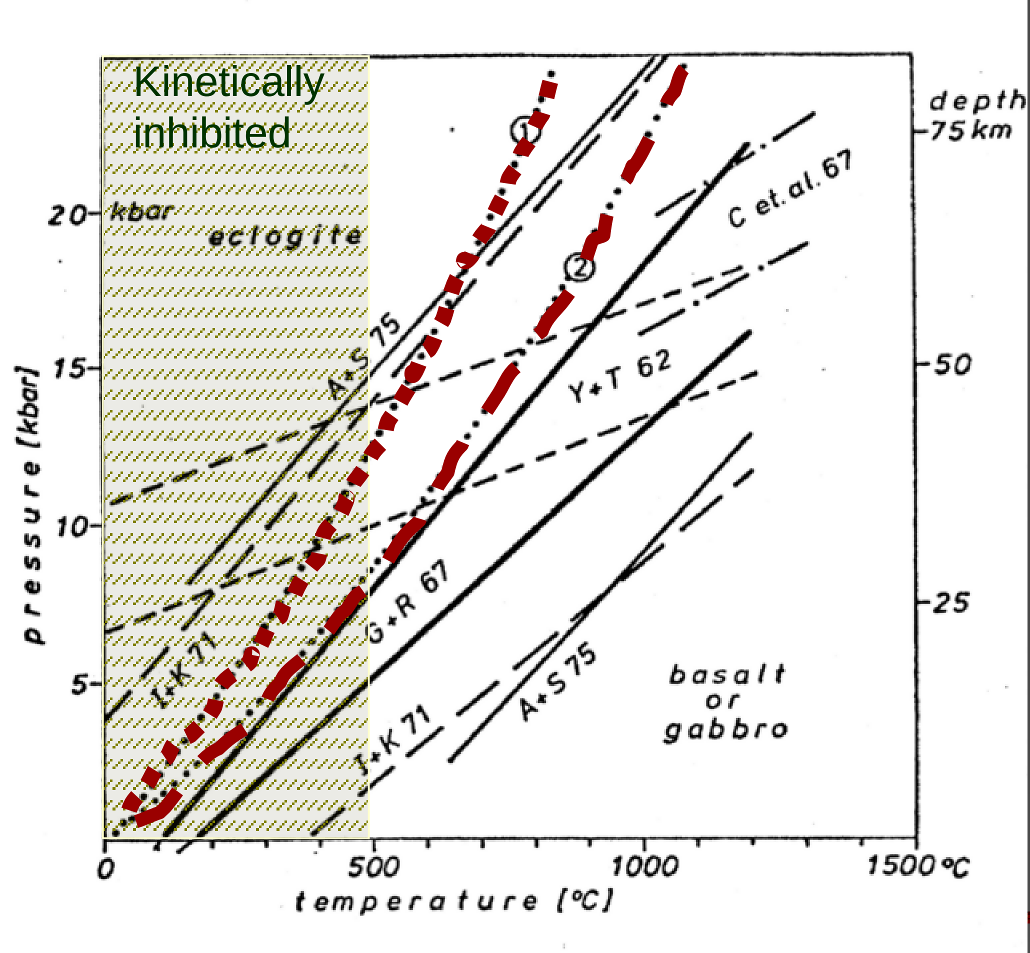


Period	ends Gyr b.p.
Noachian	3.5 – 3.7
Hesperian	2.9 – 3.2
Amazonian	today

Garnet Granulite – Eclogite Lower Crust?

0.2 *GPa*

0.1 *GPa*



40 *km*

25 *km*

10 *km*

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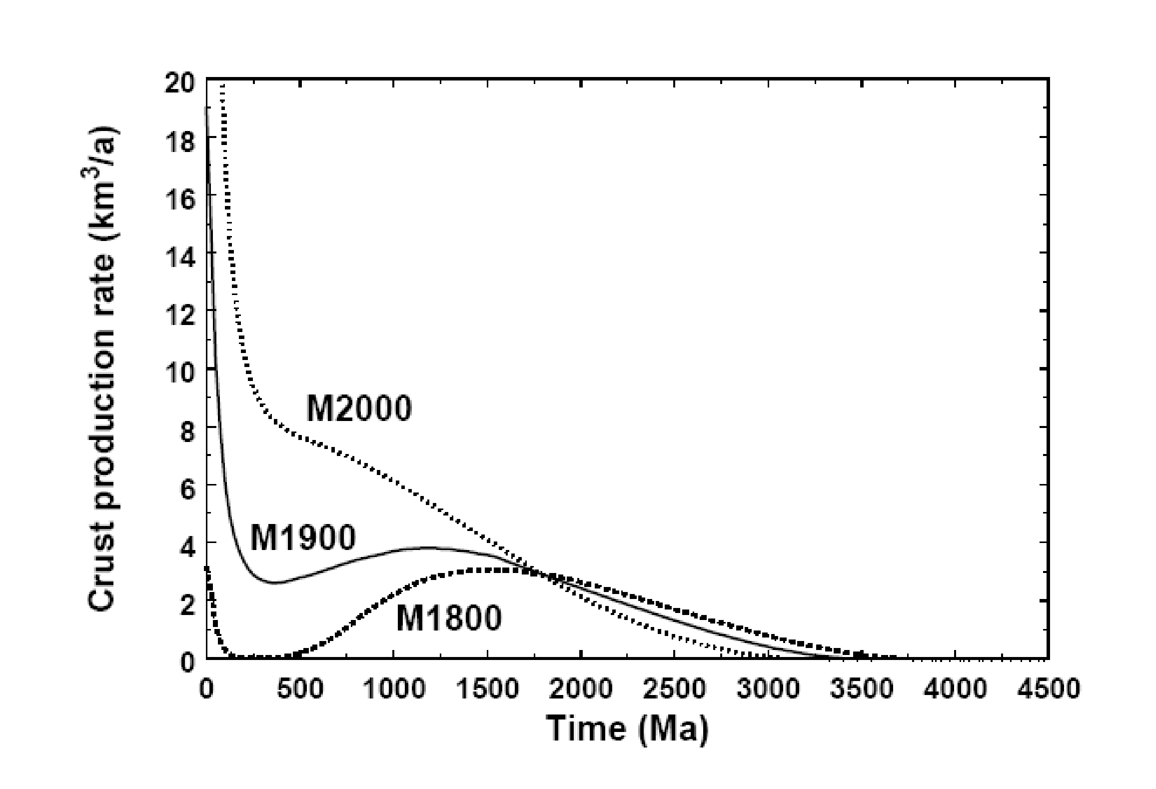
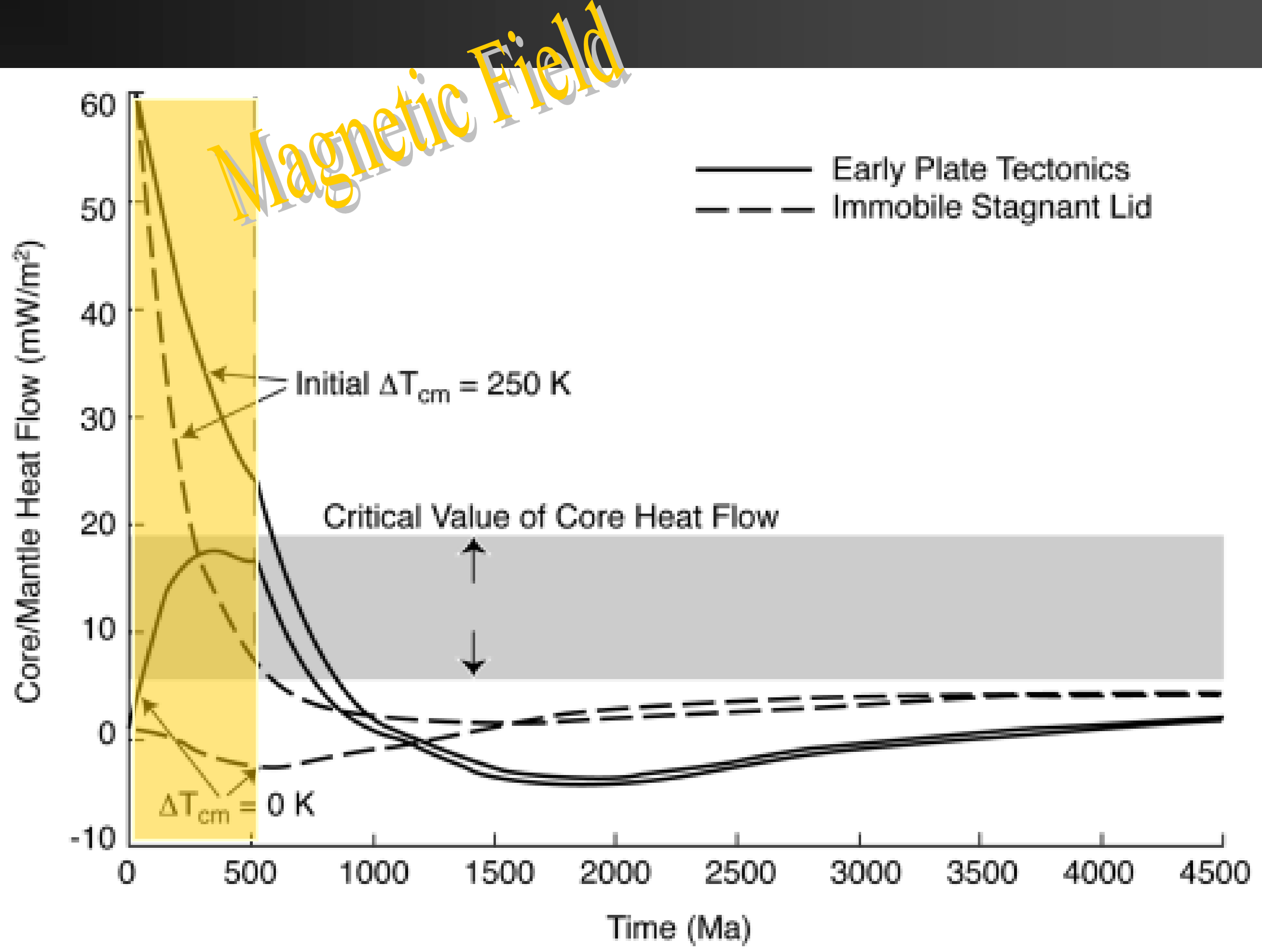
Crust Growth

Growth models have the crust form early (e.g., Breuer and Spohn, 2003;2005)

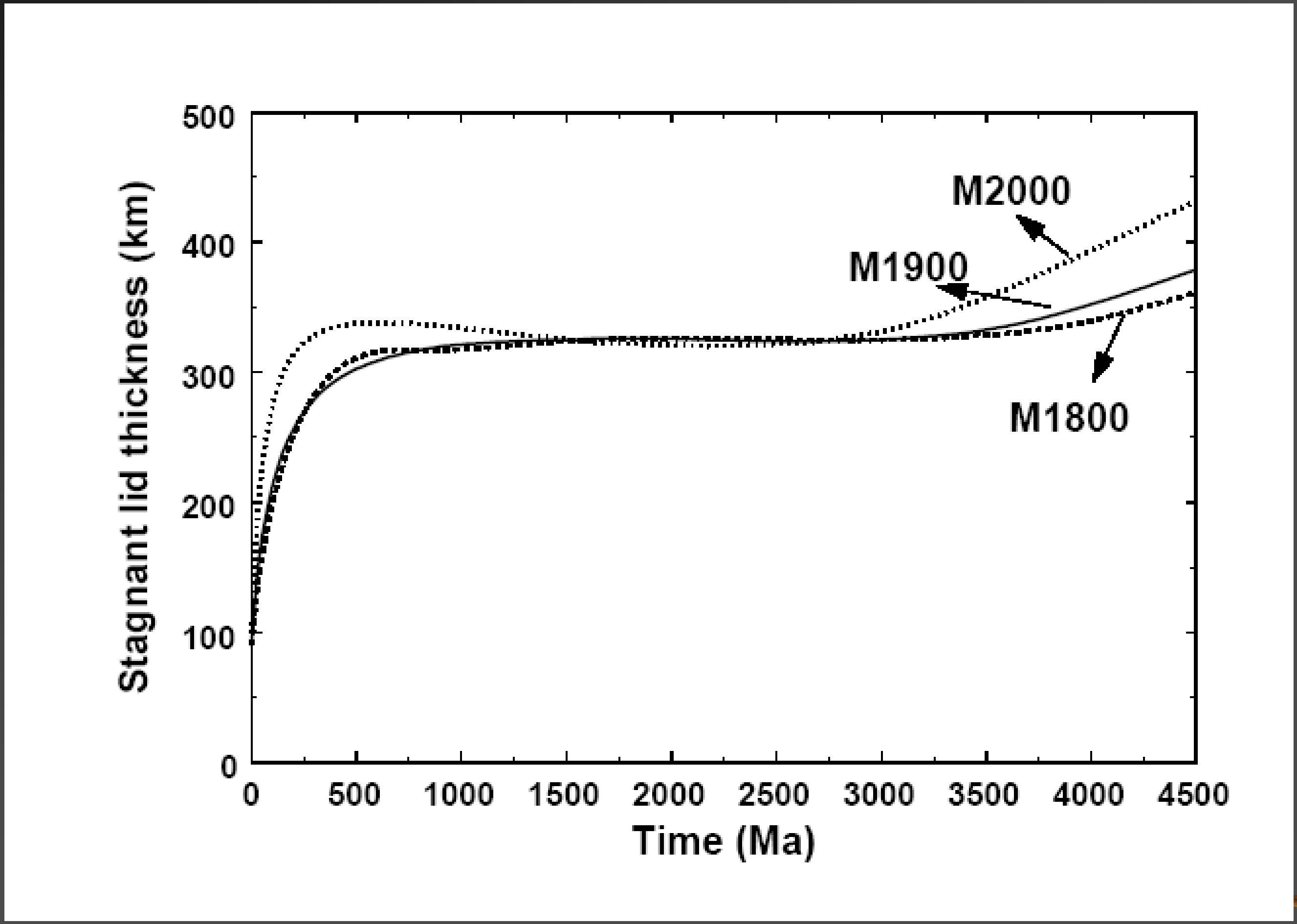


Thermal Evolution of the Core



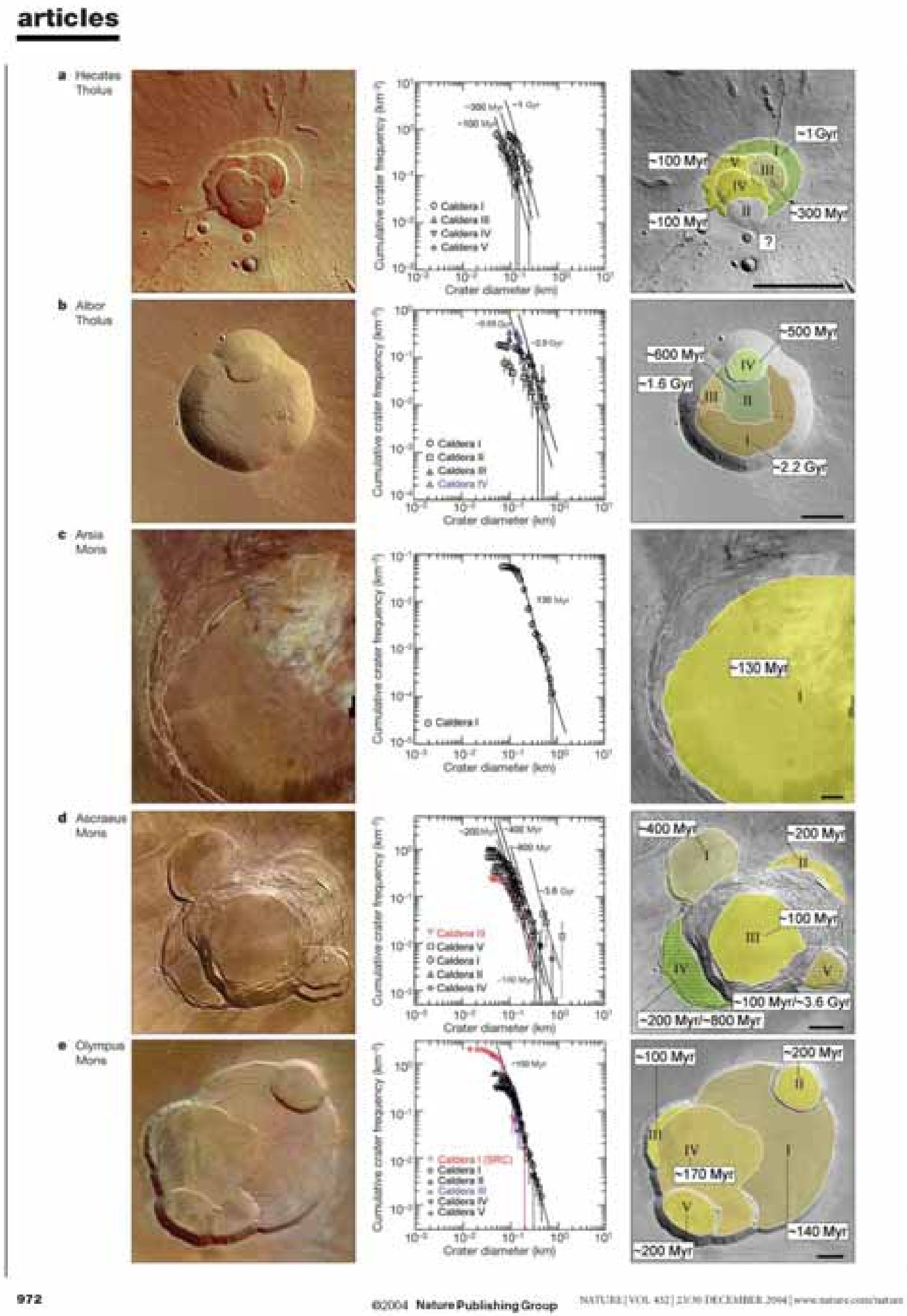
Breuer und Spohn, 2003

Stagnant Lid (Thermal Lithosphere



Chemical Reservoirs

- The chemistry of the SNC meteorites suggests that there are 3 reservoirs in the silicate portion of Mars: one enriched, one depleted, and one primordial
- These reservoirs formed early, together with the core (within 10 Ma since formation) and remained basically unmixed
- The lid may help to keep the reservoirs seperate



Recent volcanism

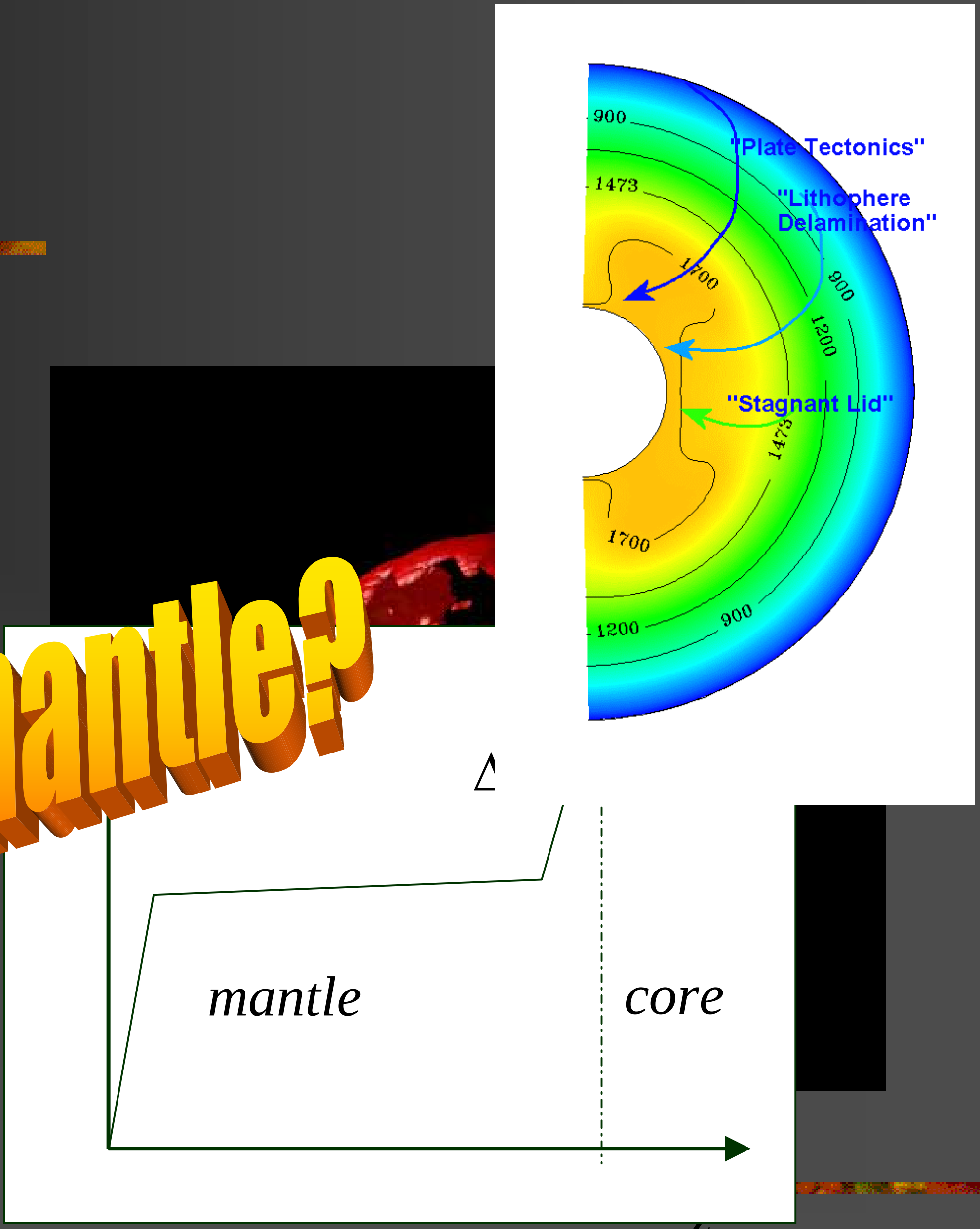
How can we reconcile recent volcanism with present interior structure and evolution models?

A thick lid may frustrate volcanic activity!

Either….

- A big mantle plume
- Requires substantial core superheat
  - Difficult to explain
- Thin lid (locally?)
- Efficient mechani… p… interior c… …genics in the core

Water in mantle?



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Or…

- Find a way to transport the magma through the thick lithosphere…that is not necessarily too big a problem, viz. terrestrial volcanism