A two-stage evolution model of Venus' mantle and its implications for the Earth

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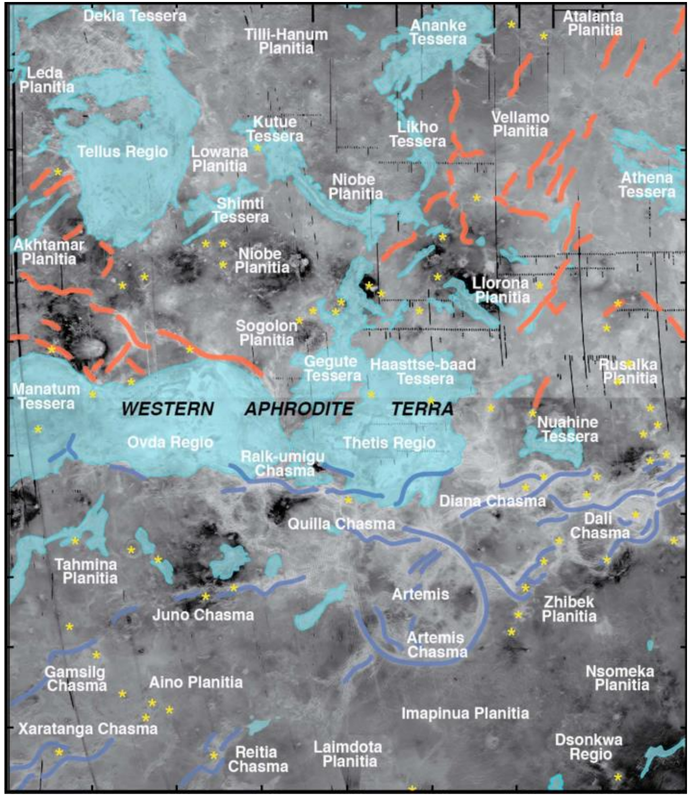
A 2D numerical model of magmatism in the convecting mantle

Resurfacing of Venus by a widespread magmatism

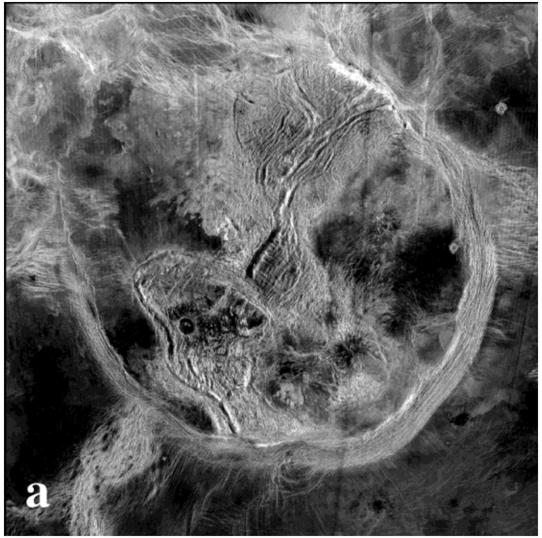


(Hansen & Lopez., 2018)

tessera terrain → volcanic plain

Ovda; no lithosphere

Artemis; thicker lithosphere



(Brown & Grimm, 1999)

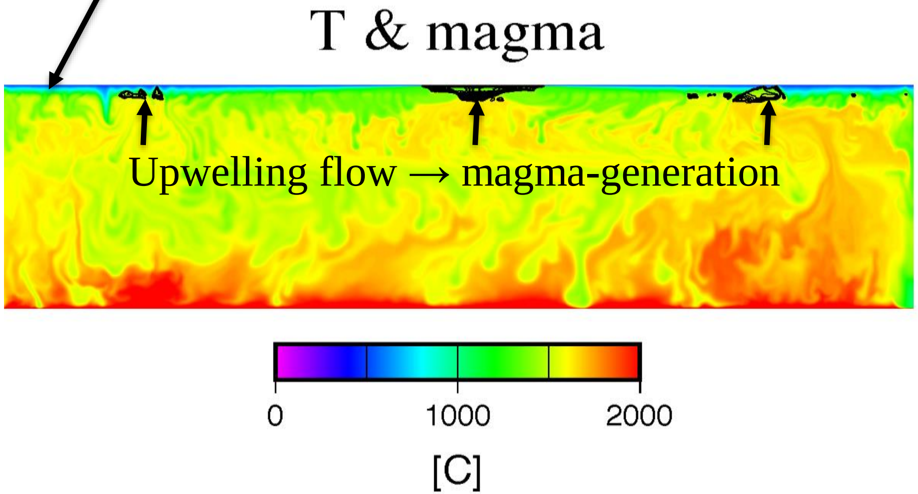
Various models of resurfacing

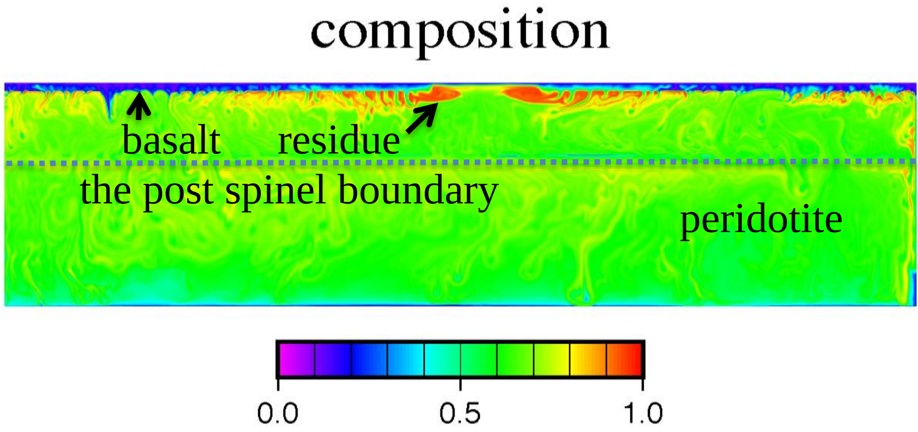
1. Widespread melting is caused by a transition from layered to whole mantle convection (Steinbach and Yuen, 1992). As Venus is cooling, the tendency for mantle layering that is caused by the endothermic spinel-to-perovskite phase transition decreases until the layered structure breaks up with a single catastrophic event.
2. Periodic instabilities of a depleted layer beneath the crust (Herrick and Parmentier, 1994; Parmentier and Hess, 1992) result in the global melting event. In that scenario, the competition between compositional stratification due to crustal formation and thermal buoyancy may cause episodic overturn of the mantle.
3. The resurfacing is associated with a transition from oscillatory to steady convection due to planetary cooling and thus a decreasing Rayleigh number (Arkani-Hamed et al., 1993).
4. The global resurfacing has been related to some kind of episodic plate tectonics. After a resurfacing event, the cold lithosphere has been subducted, and a new lid grows conductively. As this lid thickens, its negative buoyancy increases, until at some critical thickness, it is able to subduct again and thereby instigates a new resurfacing event (Armann and Tackley, 2012; Fowler and O'Brien, 1996; Moresi and Solomatov, 1998; Turcotte, 1993; Weinstein, 1996). Herrick (1994) concluded that a change in surface boundary condition could lead to a rapid rise in mantle temperature and catastrophic resurfacing in the form of plate subduction.
5. Solomatov and Moresi (1996) assumed that the resurfacing event is caused by the cessation of plate tectonics. The reduction in convective stresses with time might cause deformation in the stagnant lid to change from brittle (plate tectonics) to ductile (little surface movement).

(Breuer & Moore, 2015)

A model of magmatism in the convecting mantle

T-dependent viscosity → the stagnant lithosphere





two elementary processes that exert control over mantle evolution:
(1) the magmatism-mantle upwelling feedback, (2) mantle burst

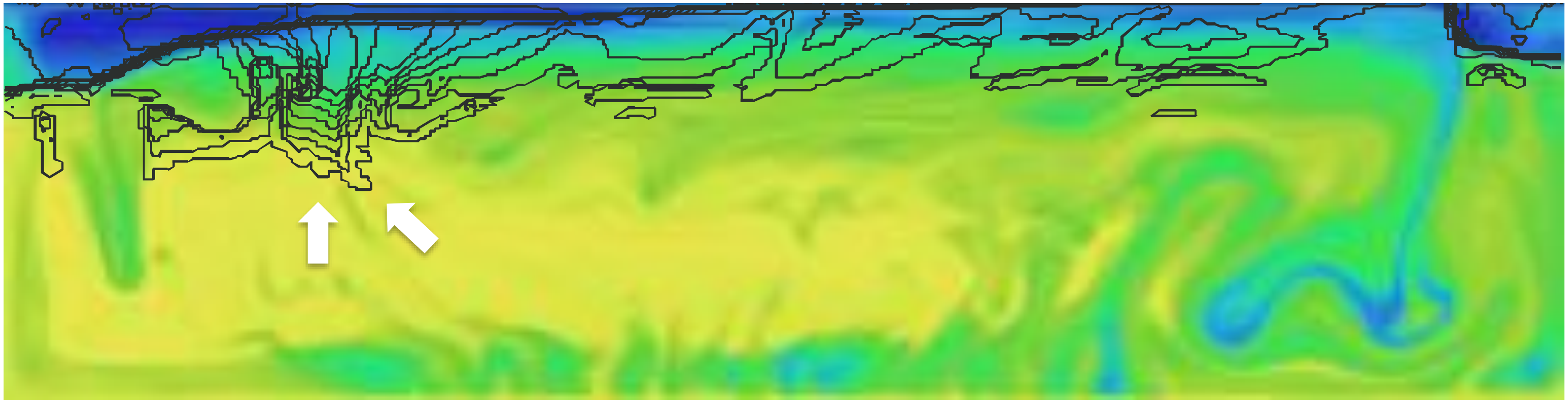
(1) The Magmatism-Mantle Upwelling feedback

decompression melting

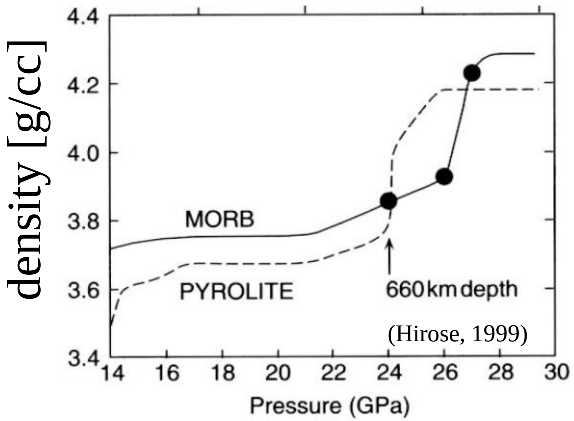
upwelling flow

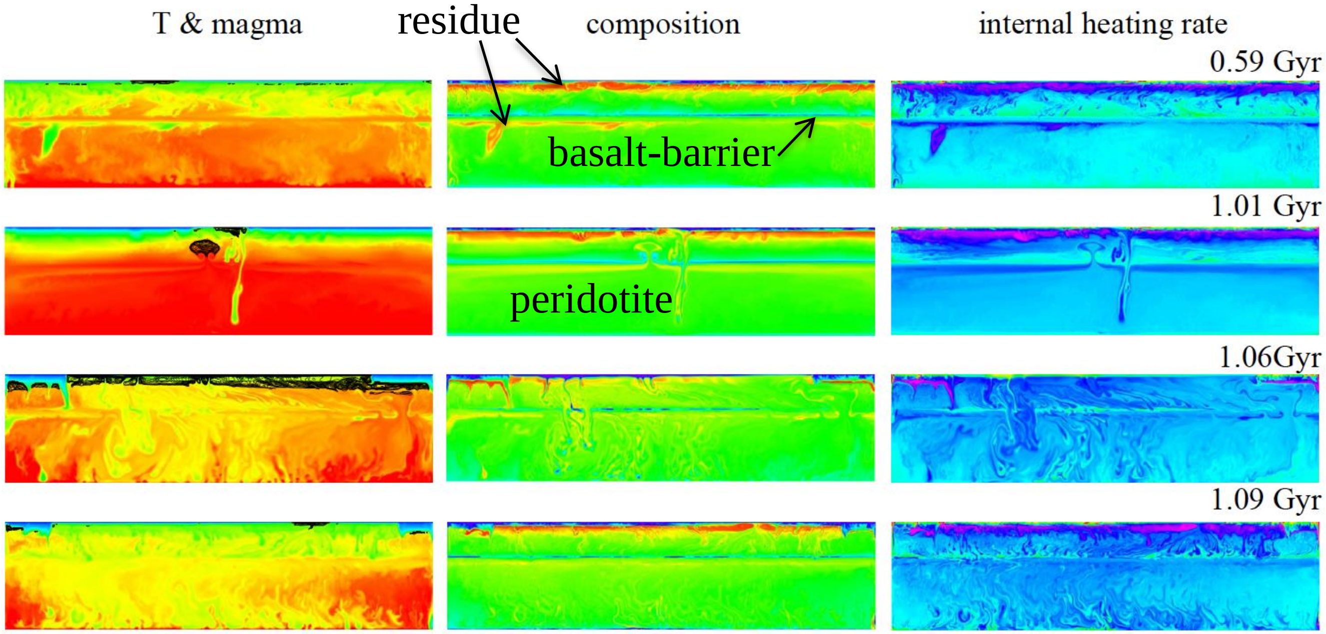
magmatism

Melt-buoyancy + volume change of matrix from magma-migration

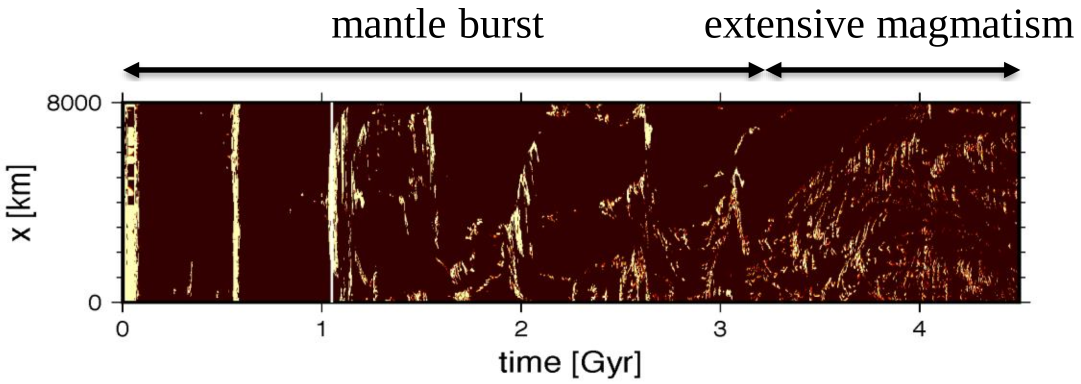


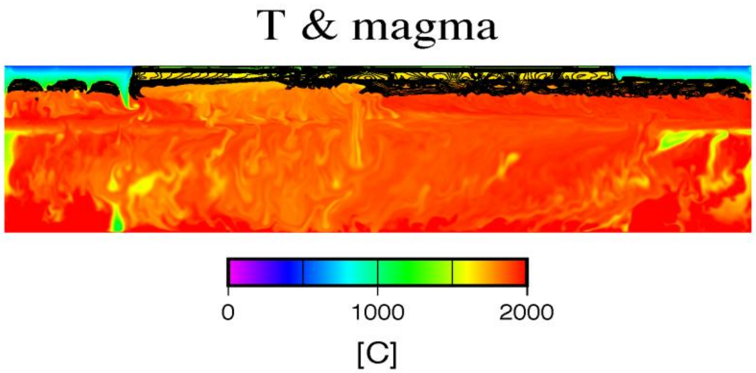
(2) Mantle burst

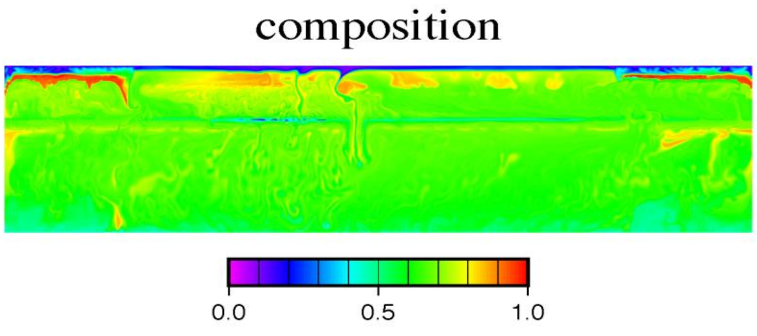




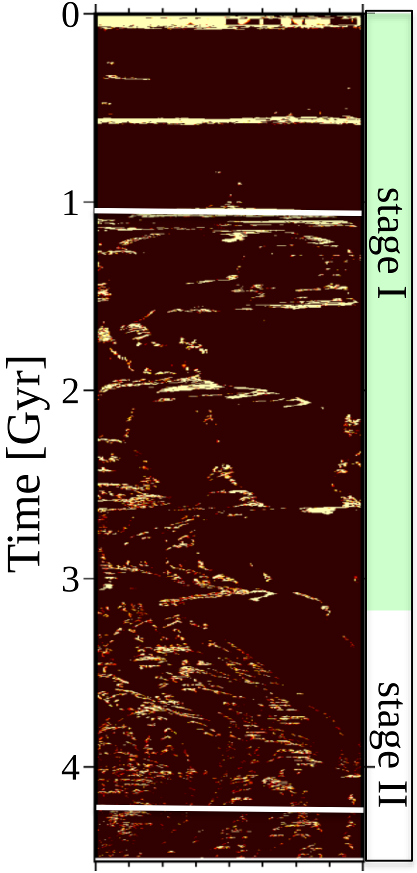
A two-stage evolution model of the Venus' mantle heated by radioactive elements that decay with time



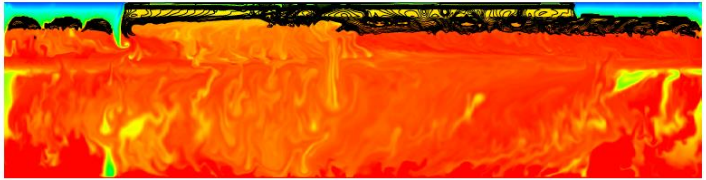




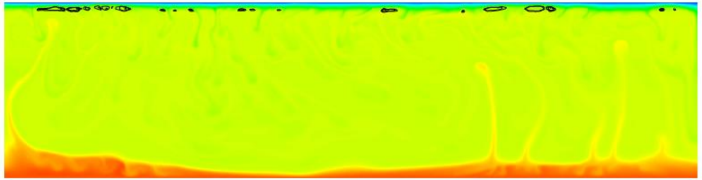
Two stages of magmatism: burst vs. shallow magmatism

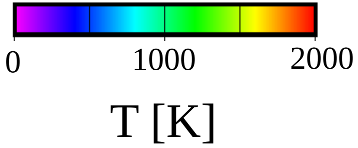


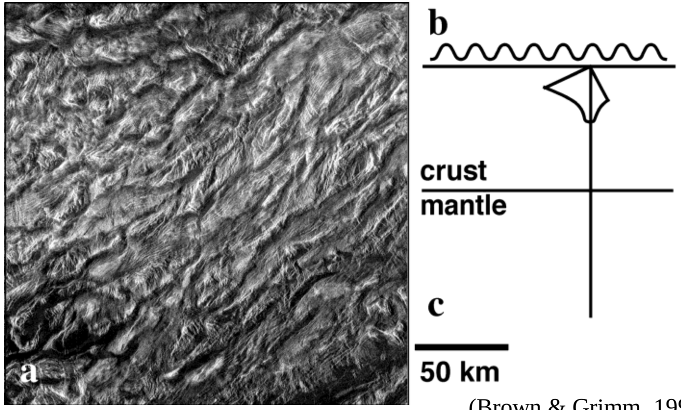
surface deformation → tessera?



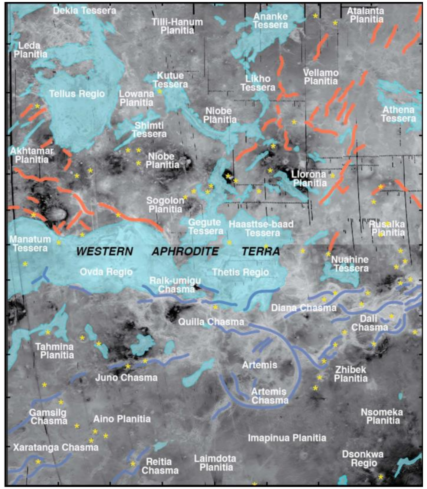
Small-scale magmatism
→ resurfacing?

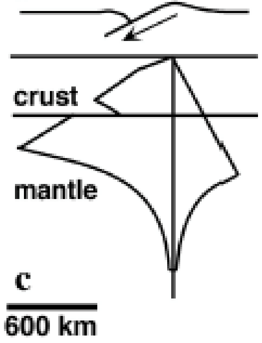






(Brown & Grimm, 1999)

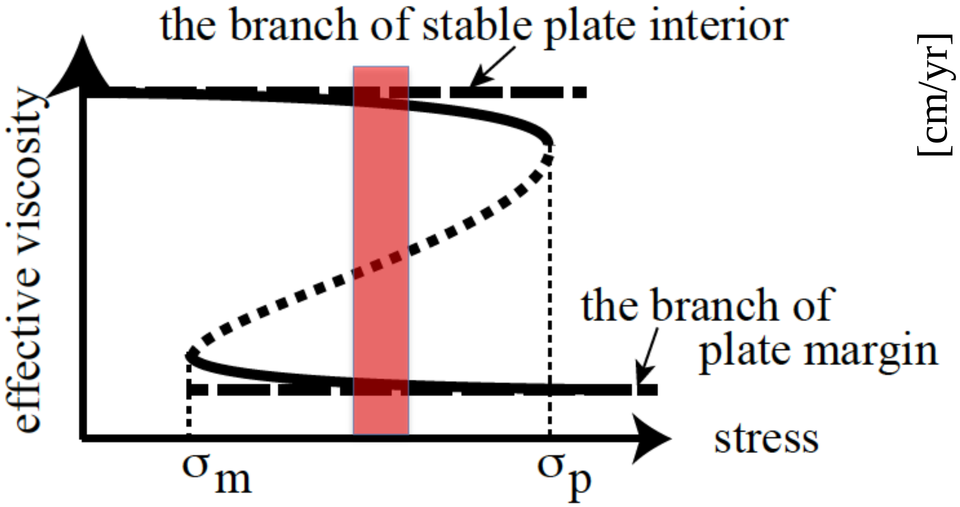


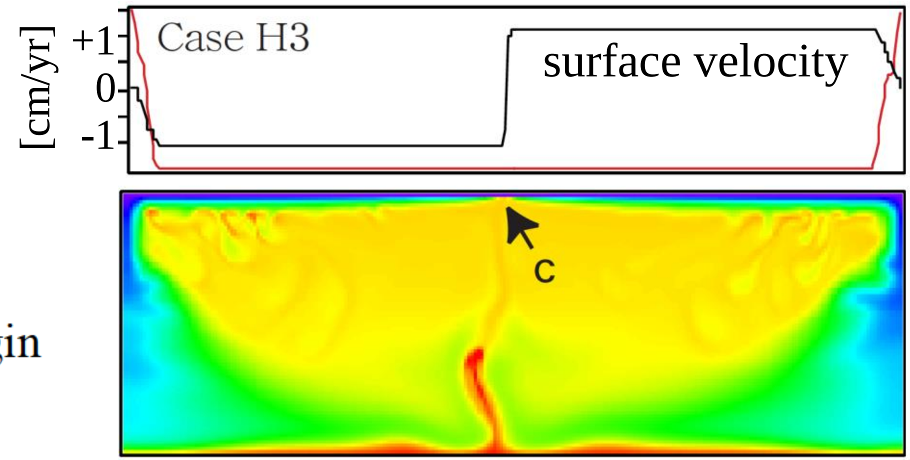


(Hansen & Lopez., 2018)

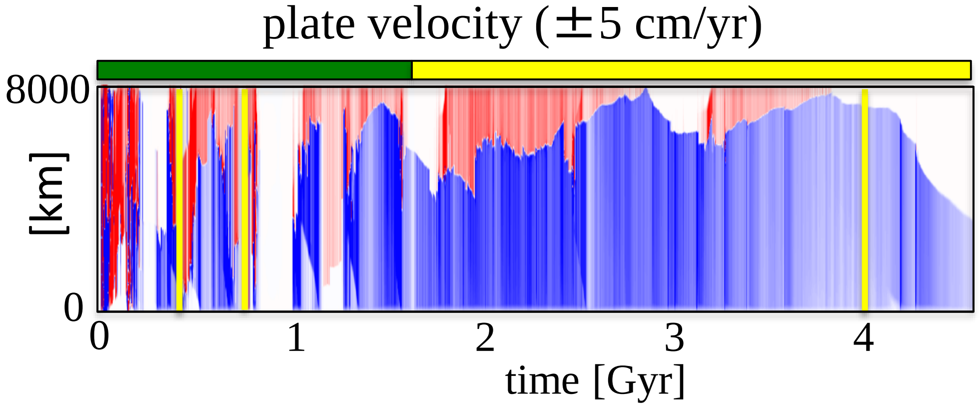
Venus + plate tectonics = a two-stage evolution model of the Earth

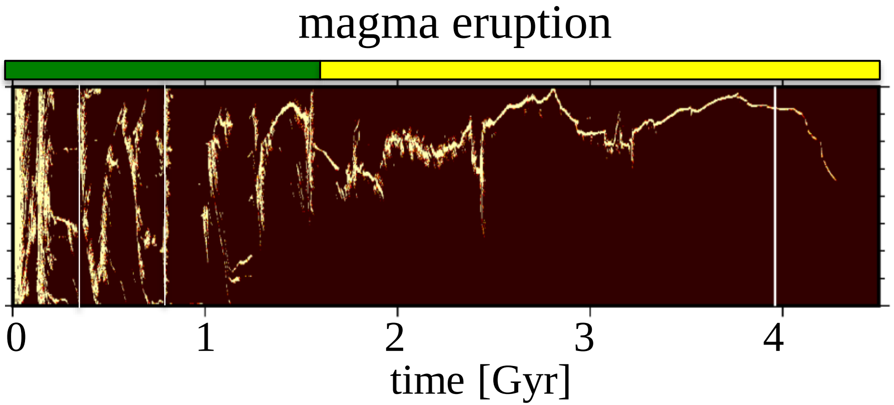
tectonic plates reproduced by a stress-history dependent viscosity

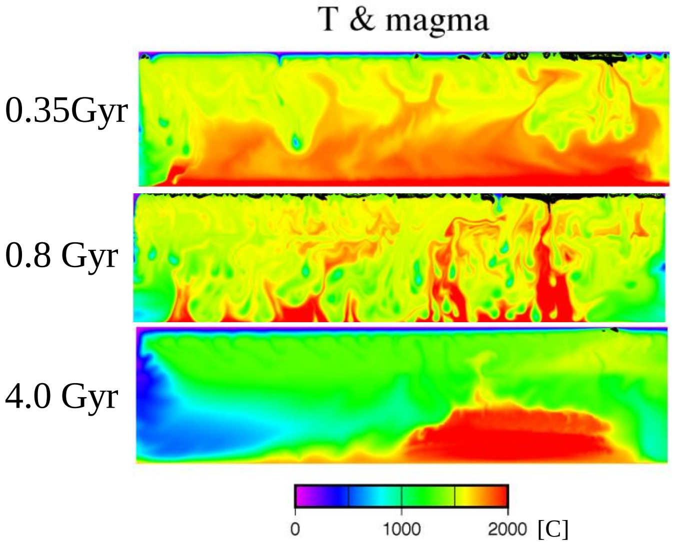


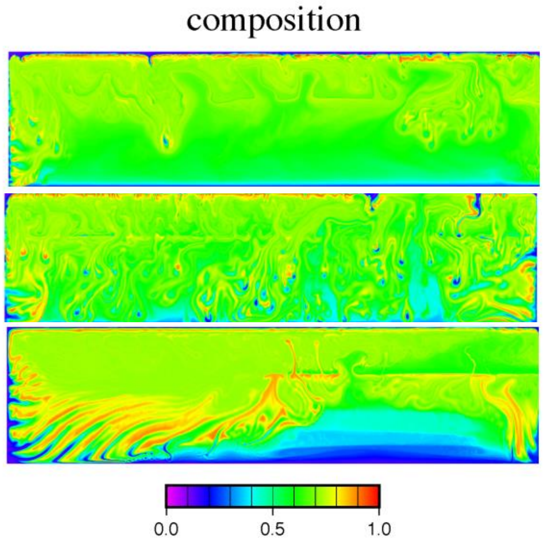


Two stages of plate tectonics and magmatism



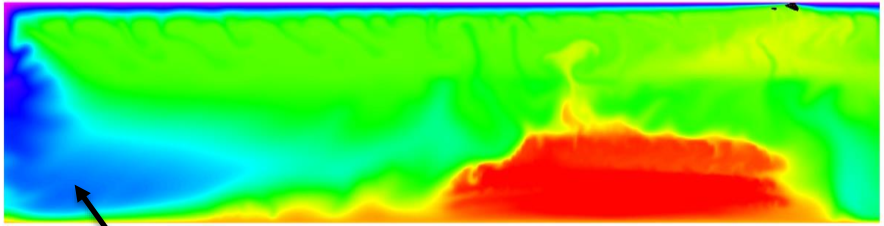






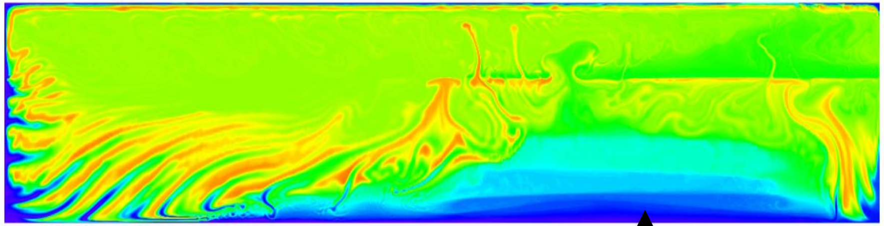
A thermo-chemical pile in the deep mantle ↔ LLSVP

Temperature & magma

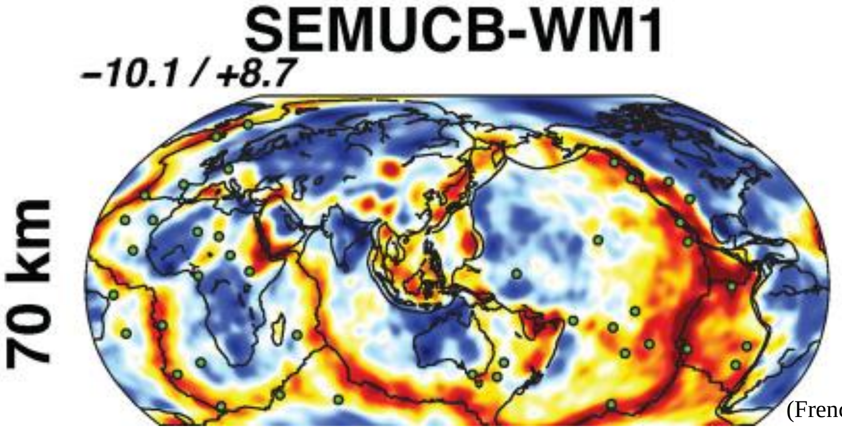


Slab graveyard

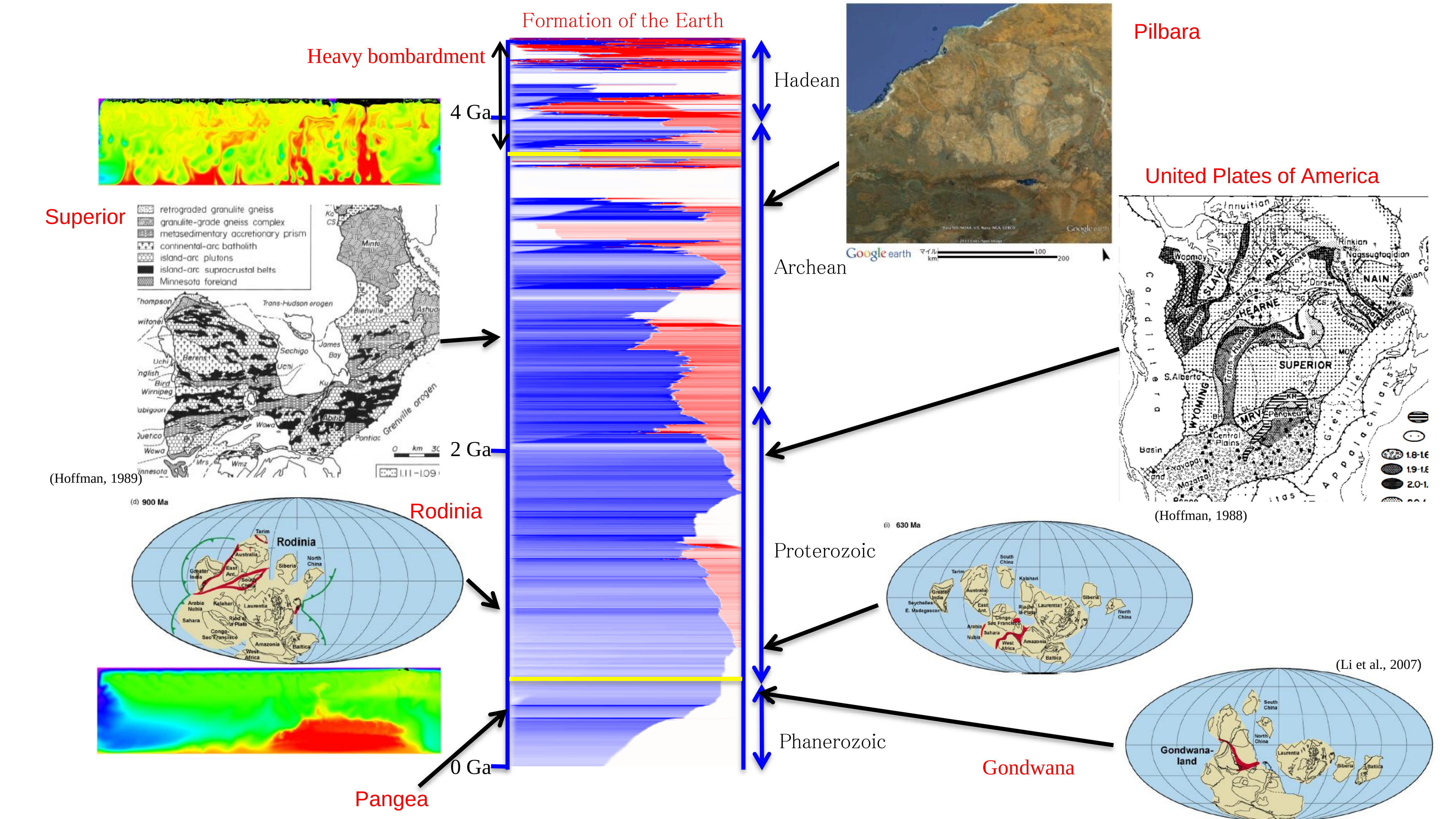
composition



Recycled basaltic crust



(French & Romanowicz, 2014)



Formation of the Earth
Heavy bombardment
4 Ga
2 Ga
0 Ga
Hadean
Archean
Proterozoic
Phanerozoic
Pilbara
Superior
retrograded granulite gneiss
granulite-grade gneiss complex
metasedimentary accretionary prism
continental-arc batholith
island-arc plutons
island-arc supracrustal belts
Minnesota foreland
Trans-Hudson orogen
Grenville orogen
James Bay
(Hoffman, 1989)
United Plates of America
SUPERIOR
SLAVE
HEARNE
RAE
NAIN
WYOMING
(Hoffman, 1988)
(d) 900 Ma
Rodinia
(i) 630 Ma
(Li et al., 2007)
Gondwana
Gondwana-land
Pangea

Summary

The mantle has evolved in two stages in Venus & the Earth:

the earlier stage: repeated mantle bursts

tessera terrain (Venus)

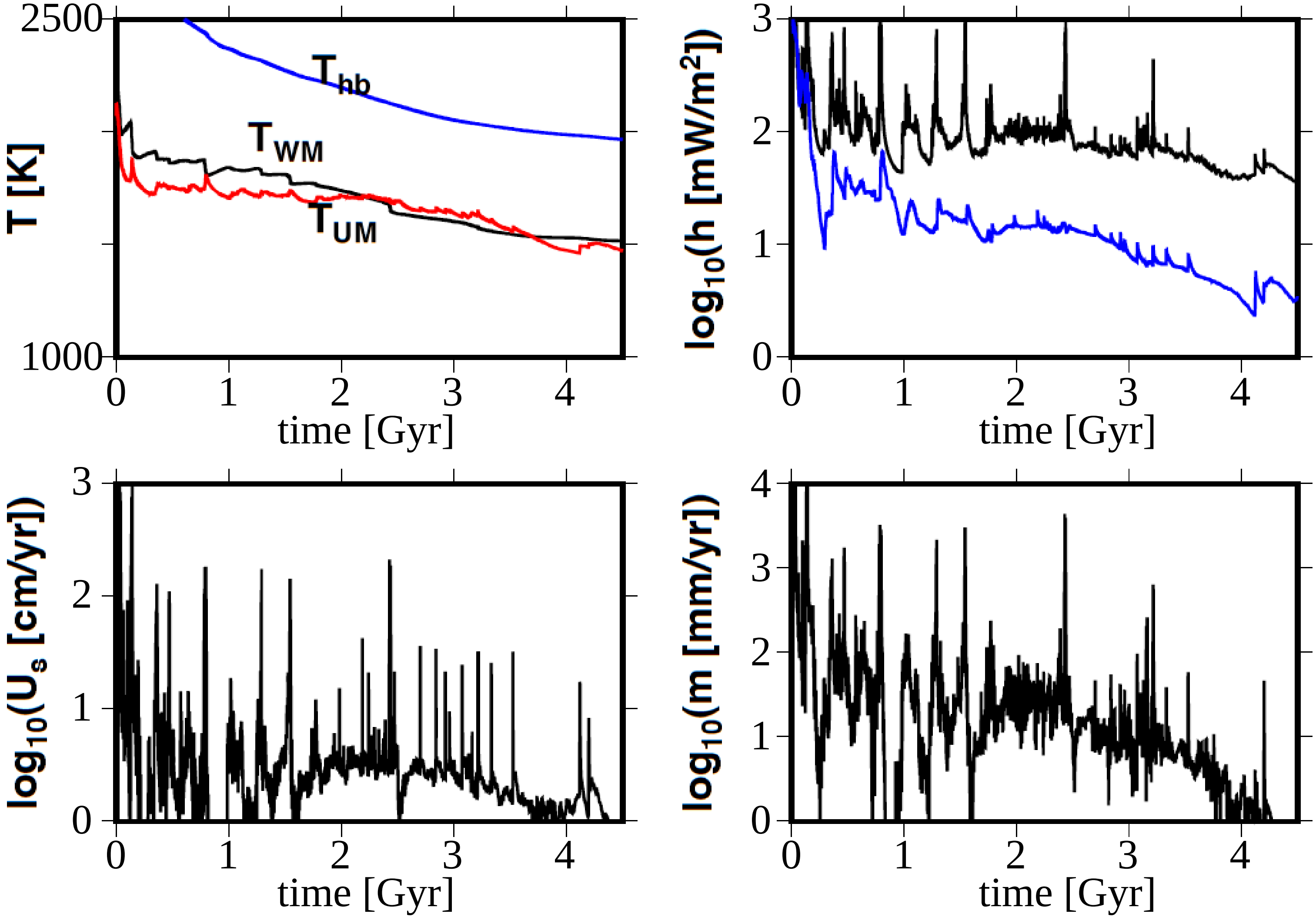
chaotic plate tectonics (the Earth)

the later stage: steady mantle convection

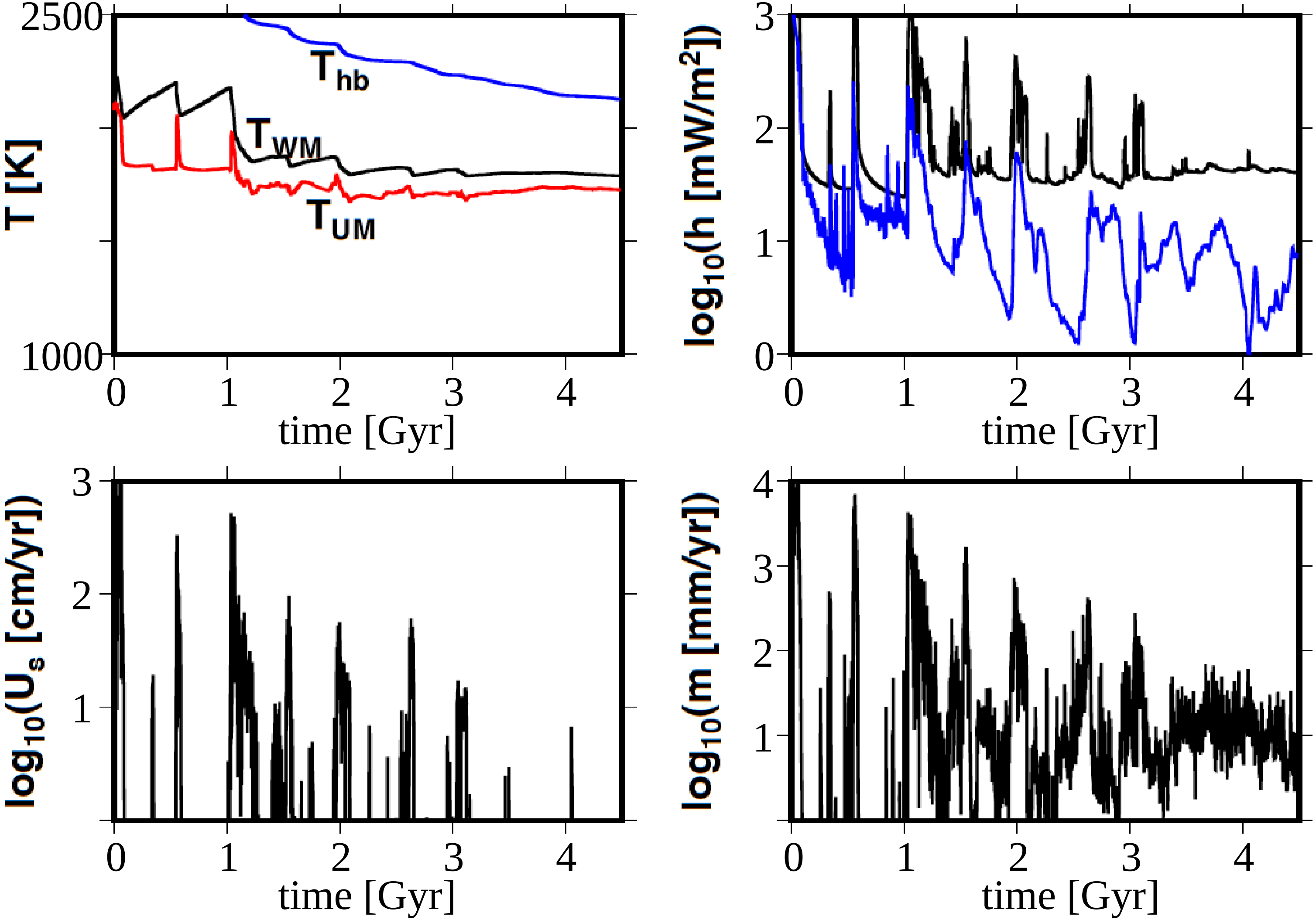
resurfacing by a mild but widespread magmatism (Venus)

stable plate tectonics

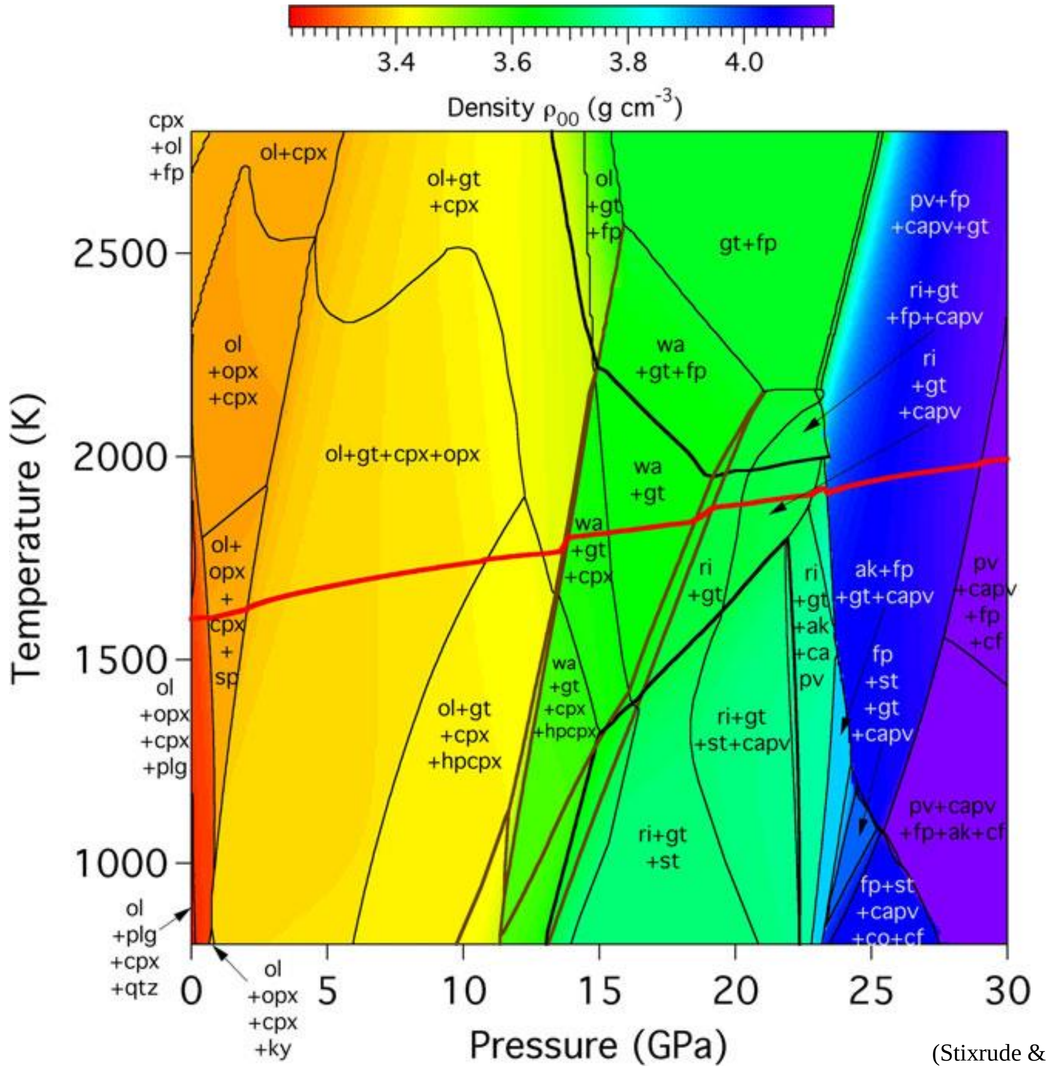
& thermo-chemical piles on the CMB (the Earth)



2500
1000
T [K]
T_hb
T_WM
T_UM
0
1
2
3
4
time [Gyr]
log10(h [mW/m2])
log10(Us [cm/yr])
log10(m [mm/yr])



2500
1000
T [K]
T_{hb}
T_{WM}
T_{UM}
0 1 2 3 4
time [Gyr]
$\log_{10}(h\ [mW/m^2])$
3 2 1 0
0 1 2 3 4
time [Gyr]
$\log_{10}(U_s\ [cm/yr])$
3 2 1
0 1 2 3 4
time [Gyr]
$\log_{10}(m\ [mm/yr])$
4 3 2 1
0 1 2 3 4
time [Gyr]

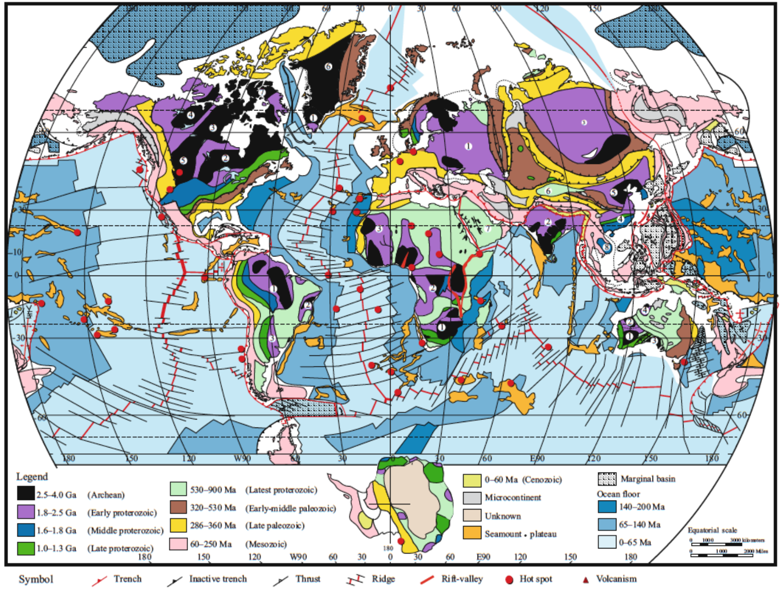


(Stixrude & Lithgow-Bertelloni, 2011)

Venus model + plate tectonics = the Earth's two-stage evolution model

Hadean | Archean | Proterozoic

4.5 Ga　4 Ga　2.5 Ga



(Utsunomiya et al., 2007)