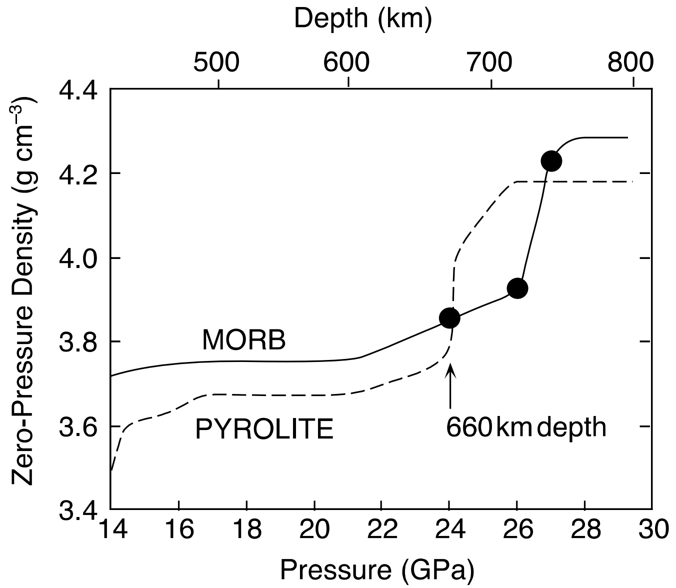
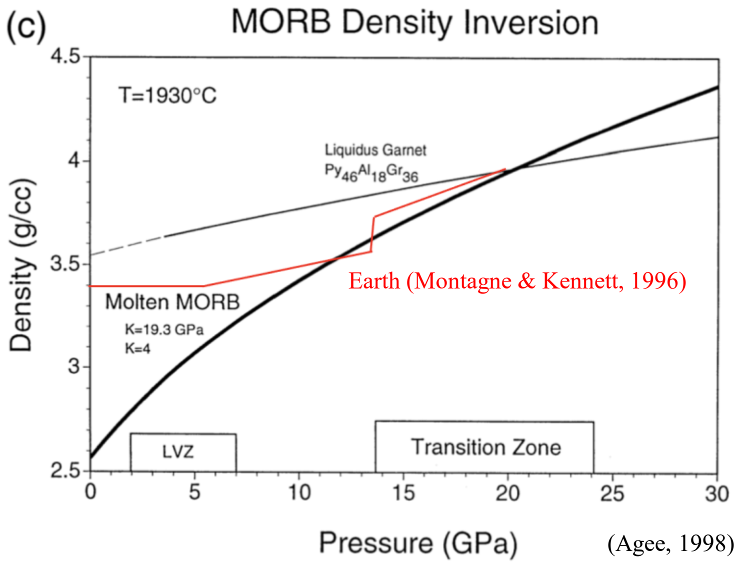
第6章 金星と地球:より大きな惑星

火星からの外挿:サイズ効果

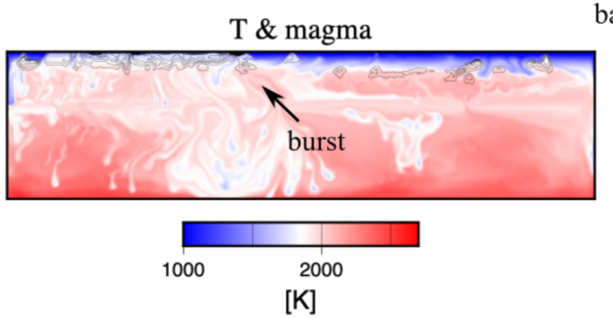
(1) 大きな熱容量と地表単位面積あたりの内部発熱量
(2) より低い粘性抵抗 → 余裕で熱対流、より強いMMUb
(3) 岩石物性の効果:the basalt-barrier と melt-buyoancy

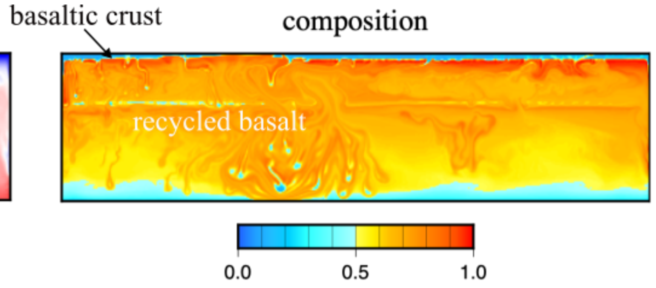


(Hirose et al., 1999)

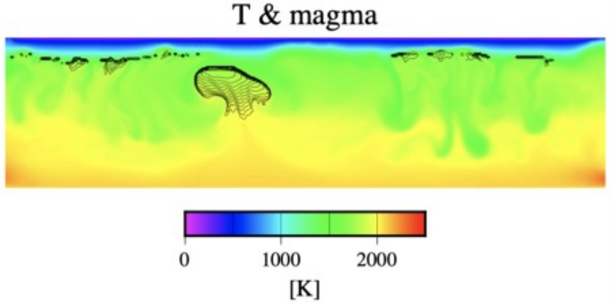


(Agee, 1998)

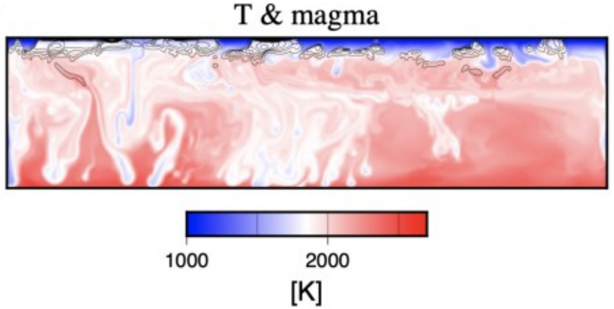




火星:プルームの浮上



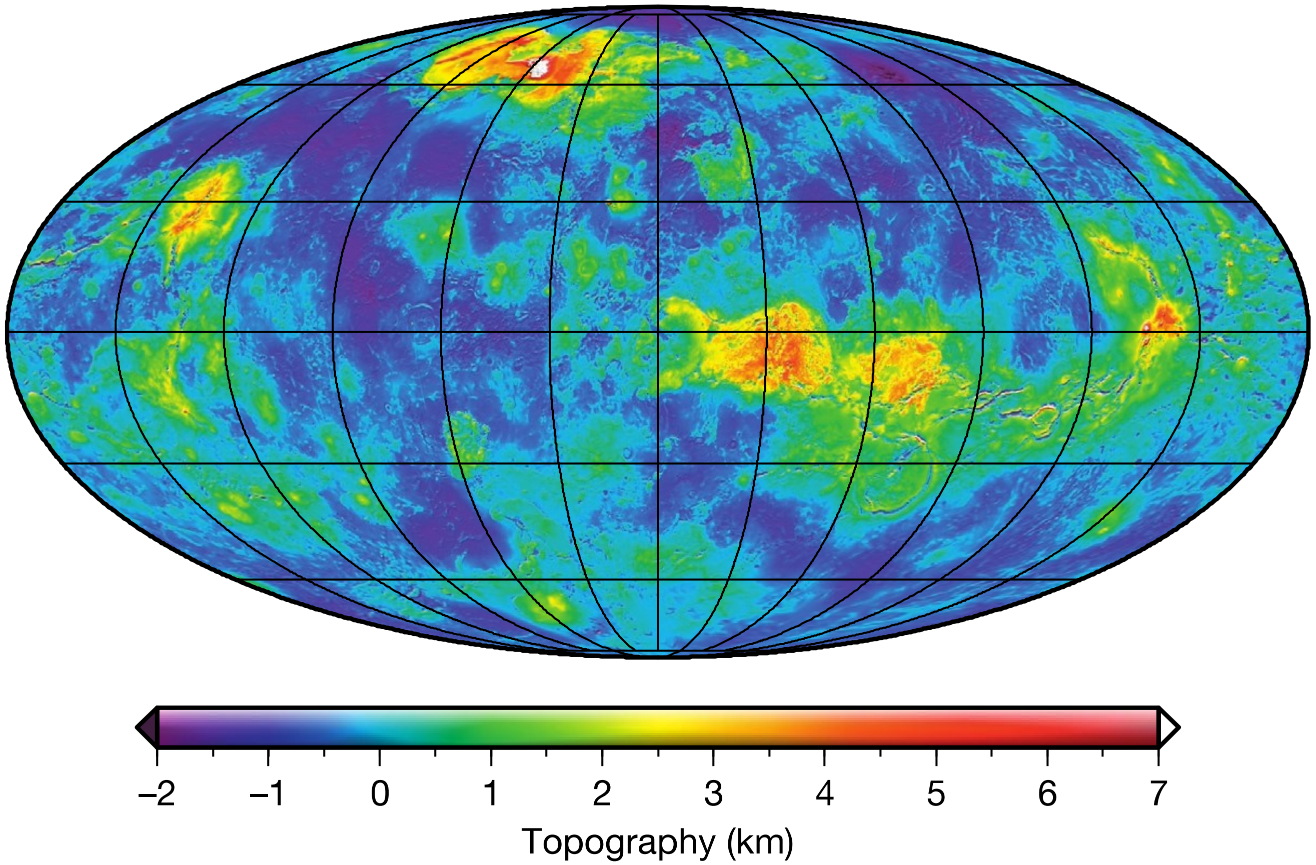
金星:上から吊り上げる湧昇流



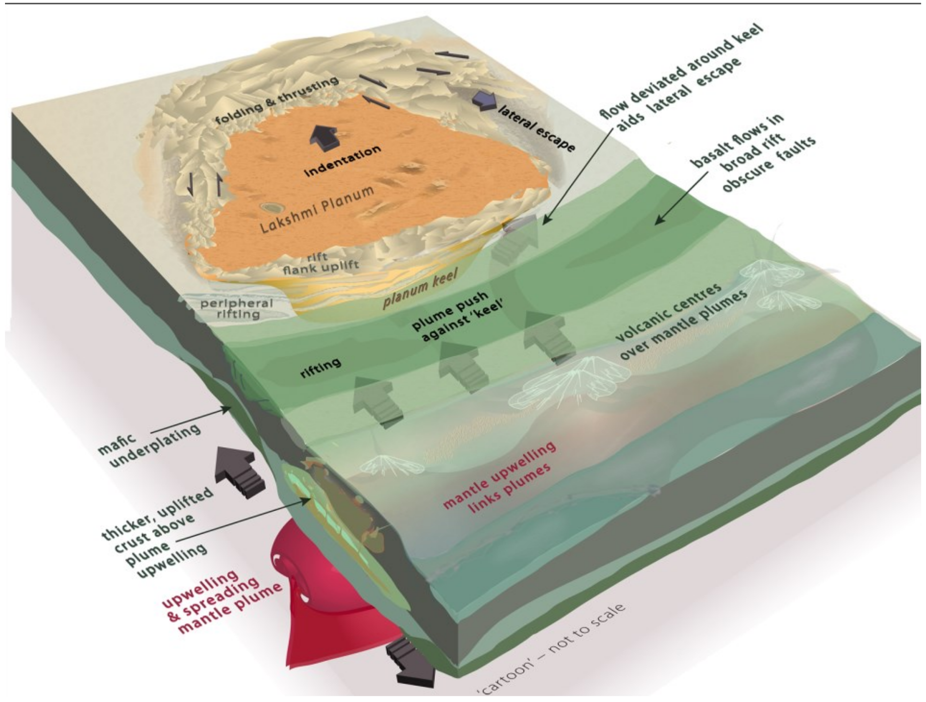
6-1 金星のテクトニクスと火山活動

海嶺・海溝なし→プレート・テクトニクスなし

沈み込み損ないの地形：原因＝水（プレート境界での潤滑剤）がない



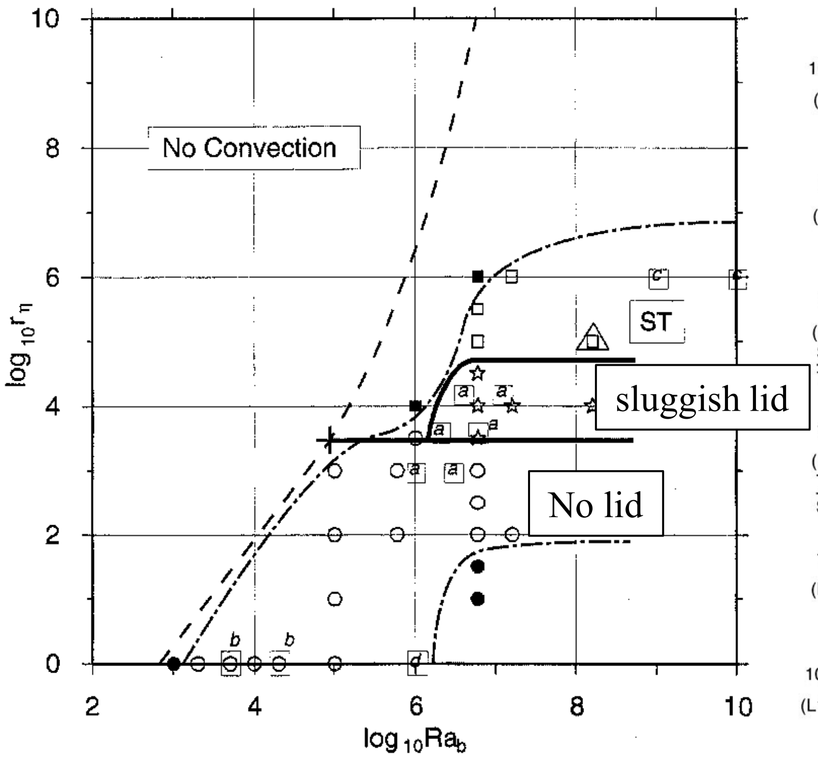
(Wieczorek, 2015)

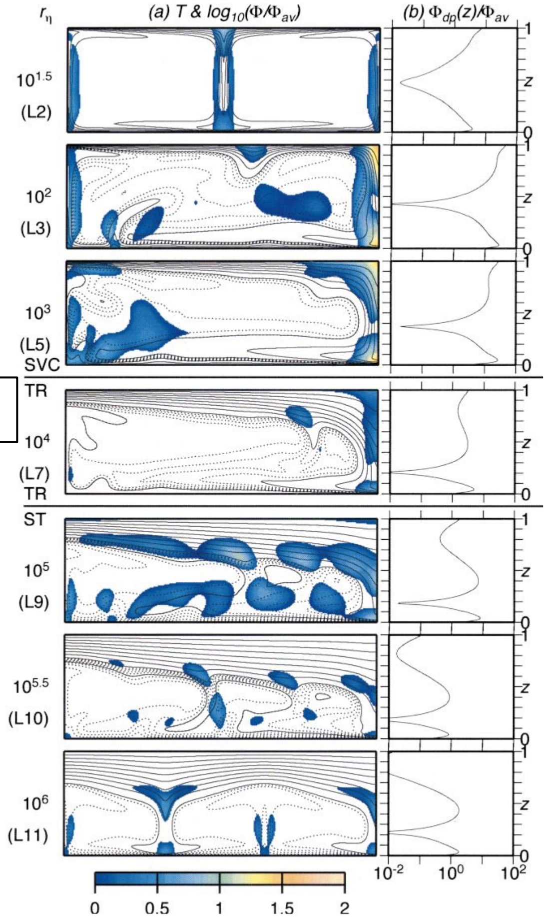


(Harris & Bedard, 2014)

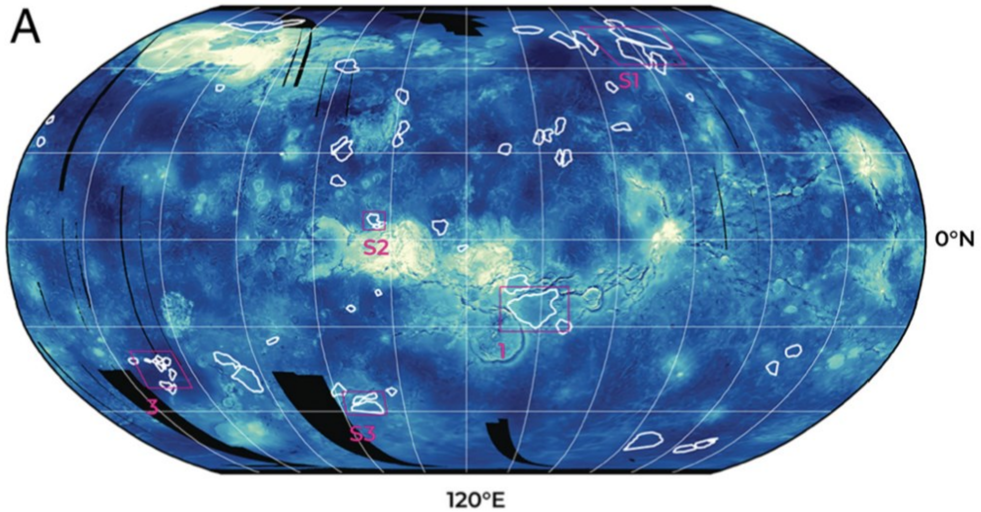
現在の金星　sluggish or stagnant lid regime

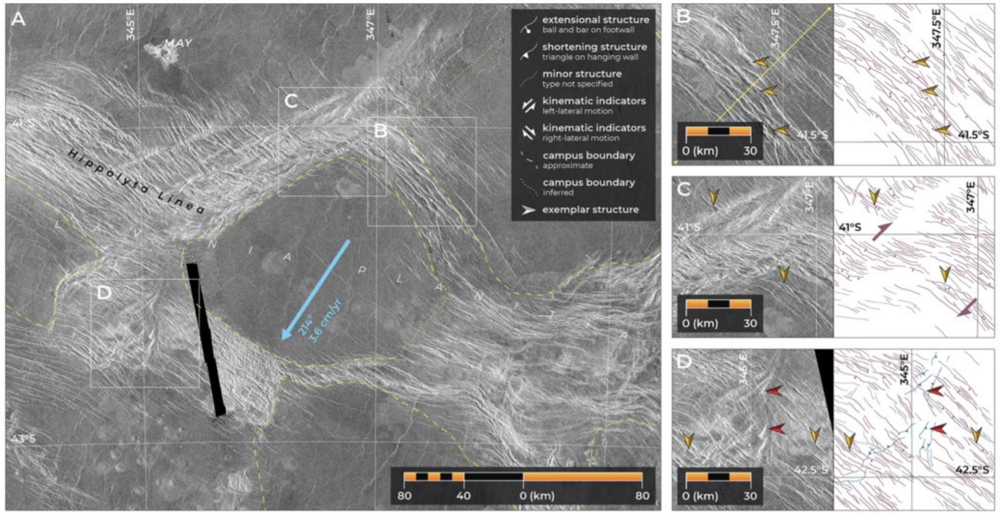
地表面温度≒450℃ → 小さな粘性率コントラスト





(Kameyama & Ogawa, 2000)

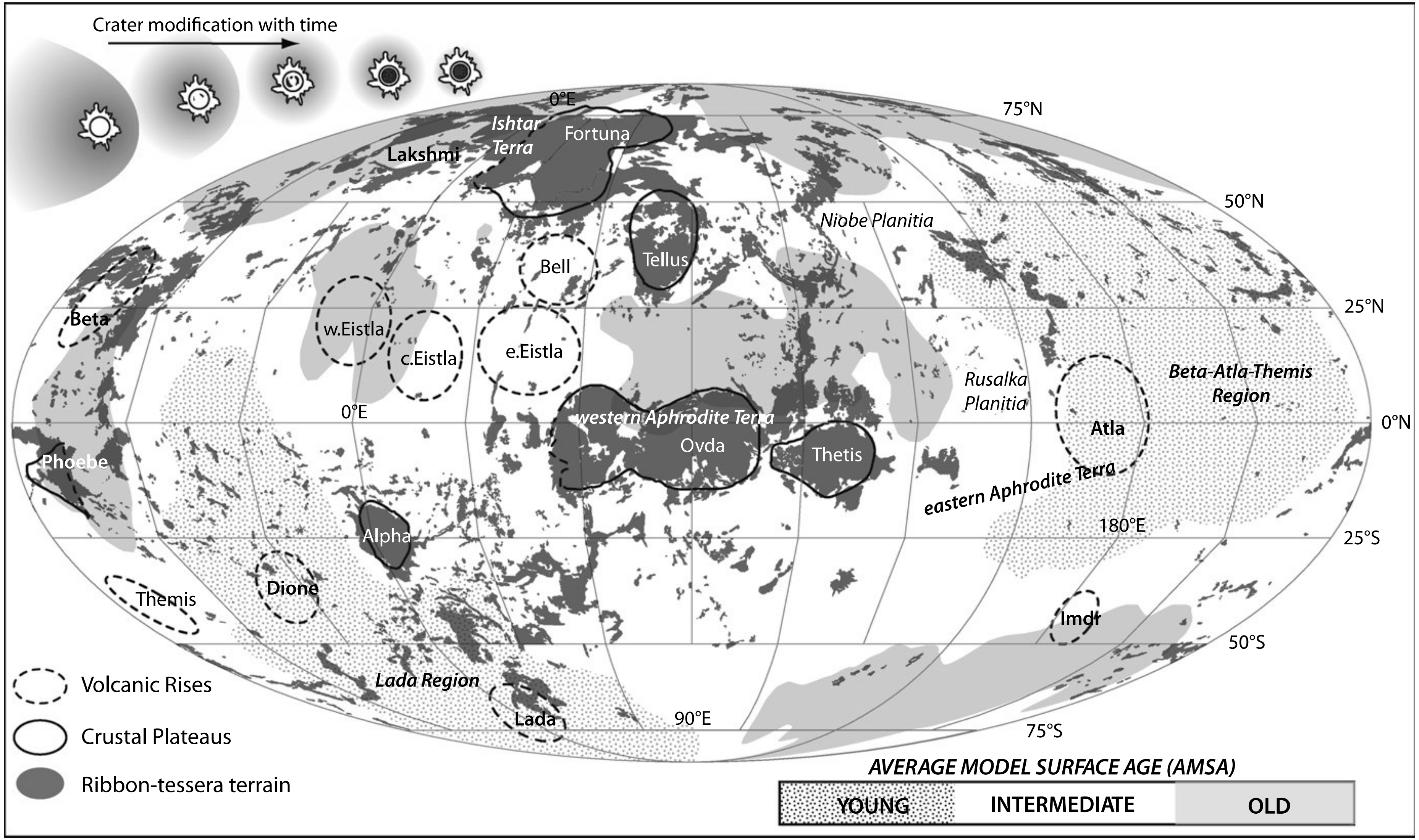




(Byrne et al., 2021)

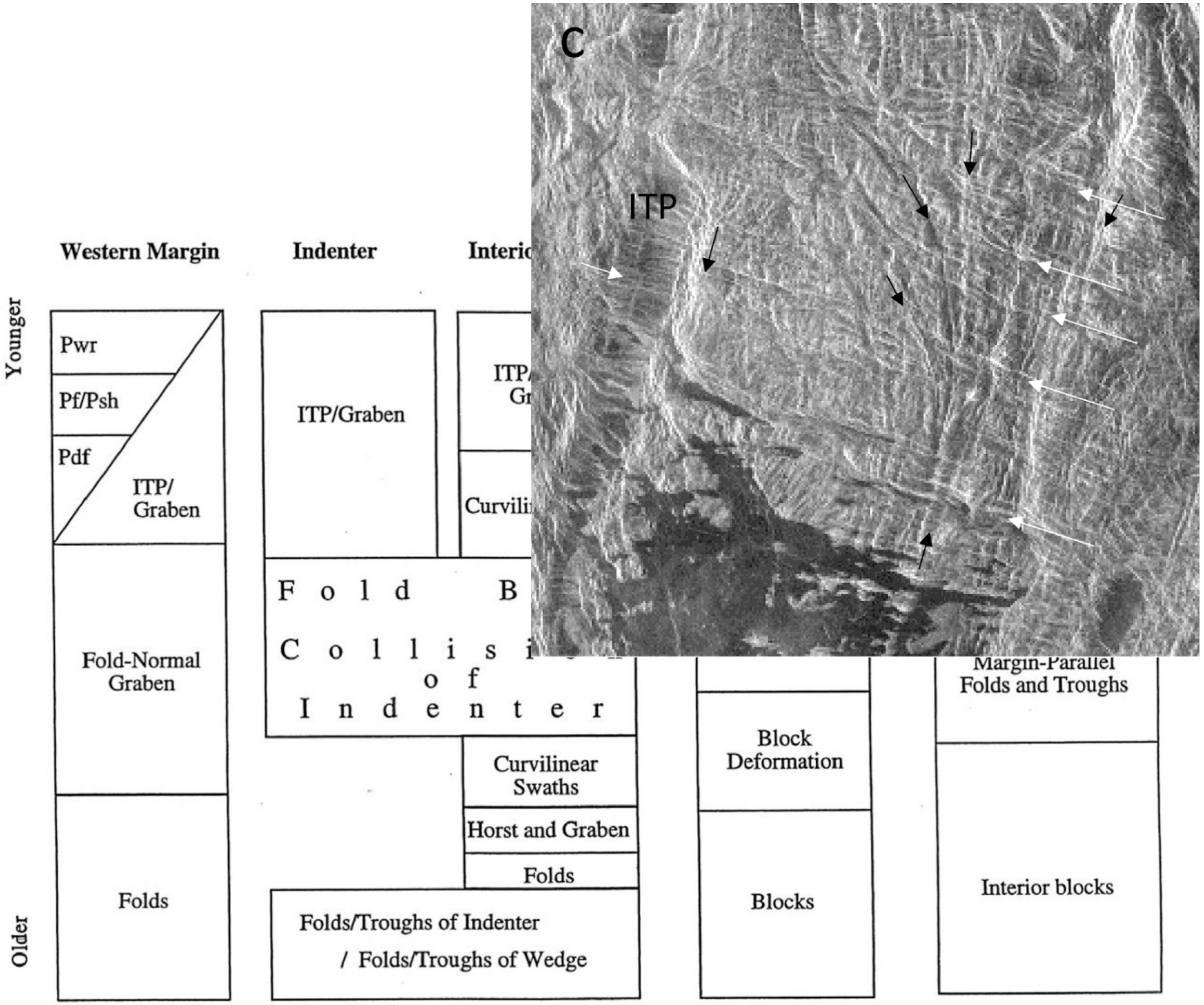
テセラ・テレンから火山平原へ

火山平原の平均年齢 = 150−750Myr

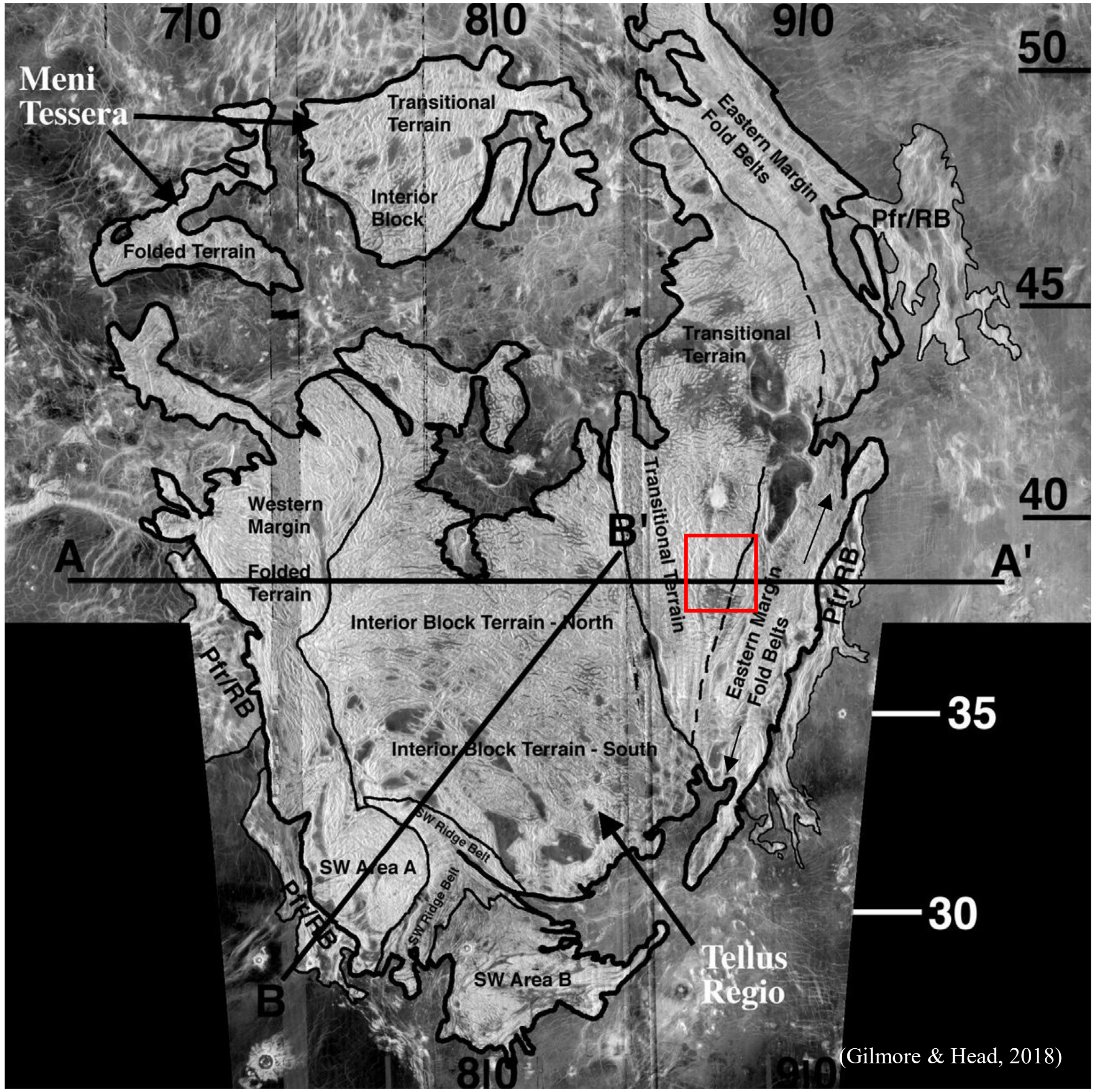


(Bjonnes et al., 2012)

テセラ (Tellus)



Western Margin
Indenter
Interic
Younger
Older
Pwr
Pf/Psh
Pdf
ITP/ Graben
Fold-Normal Graben
Folds
ITP/Graben
F o l d B
C o l l i s i
o f
I n d e n t e r
Curvilinear Swaths
Horst and Graben
Folds
Folds/Troughs of Indenter / Folds/Troughs of Wedge
ITP/ Gr
Curvili
Block Deformation
Blocks
Margin-Parallel Folds and Troughs
Interior blocks
C
ITP

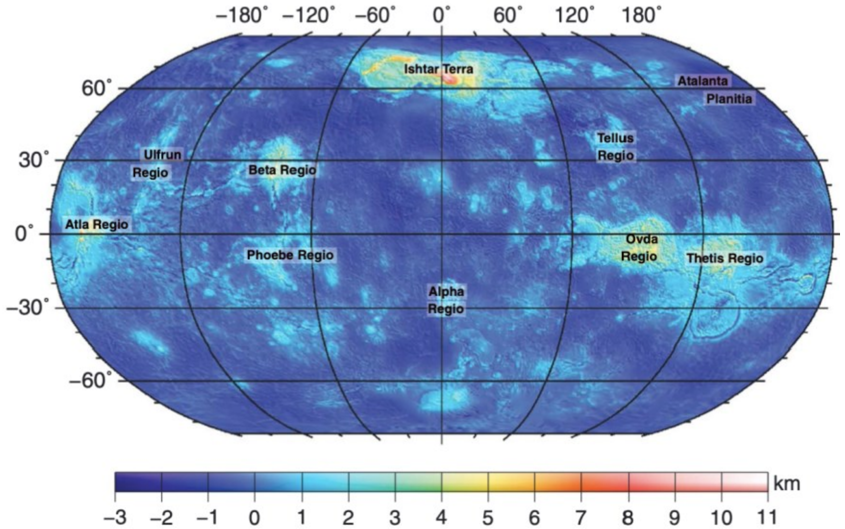


70
80
90
50
45
40
35
30
Meni Tessera
Transitional Terrain
Interior Block
Folded Terrain
Eastern Margin Fold Belts
Pfr/RB
Transitional Terrain
Western Margin
Folded Terrain
B'
A
A'
Transitional Terrain
Interior Block Terrain - North
Eastern Margin Fold Belts
Pfr/RB
Interior Block Terrain - South
SW Ridge Belt
SW Area A
SW Area B
B
Tellus Regio
(Gilmore & Head, 2018)

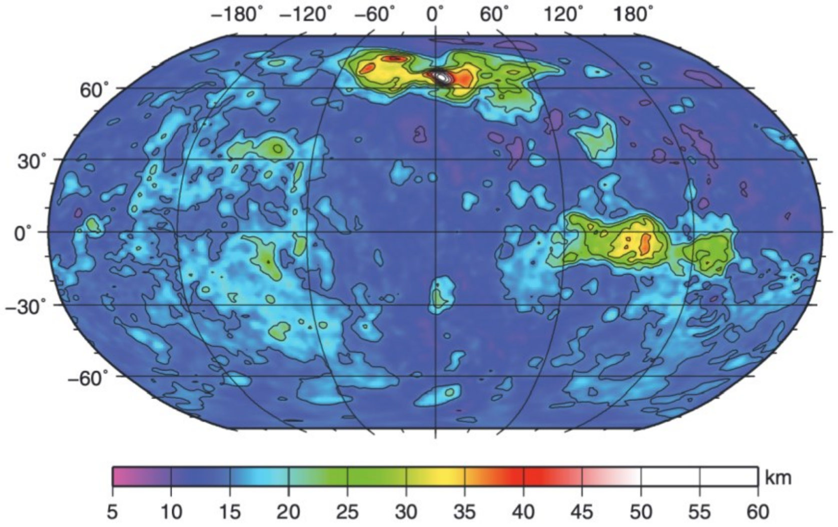
火山平原

プルーム火山

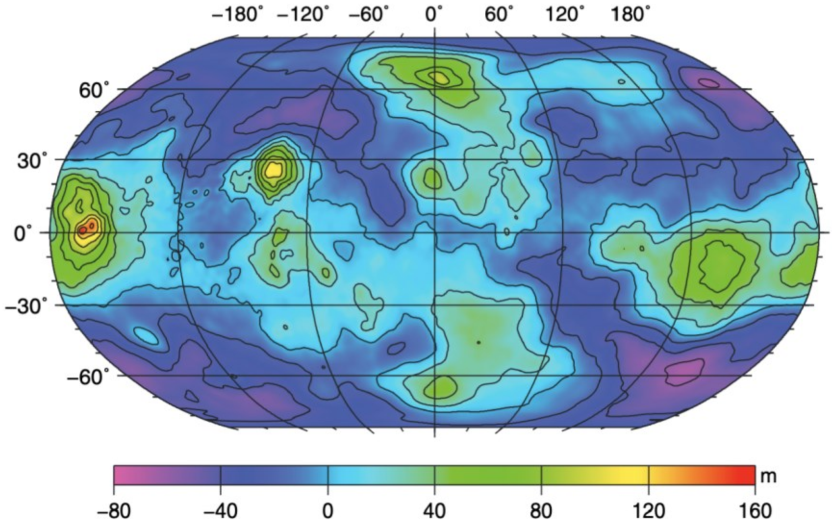
地形



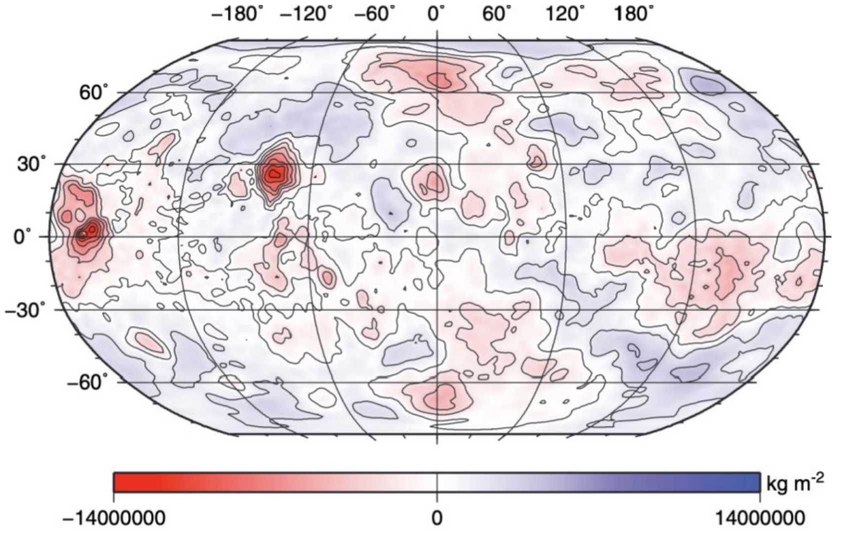
地殻厚



ジオイド



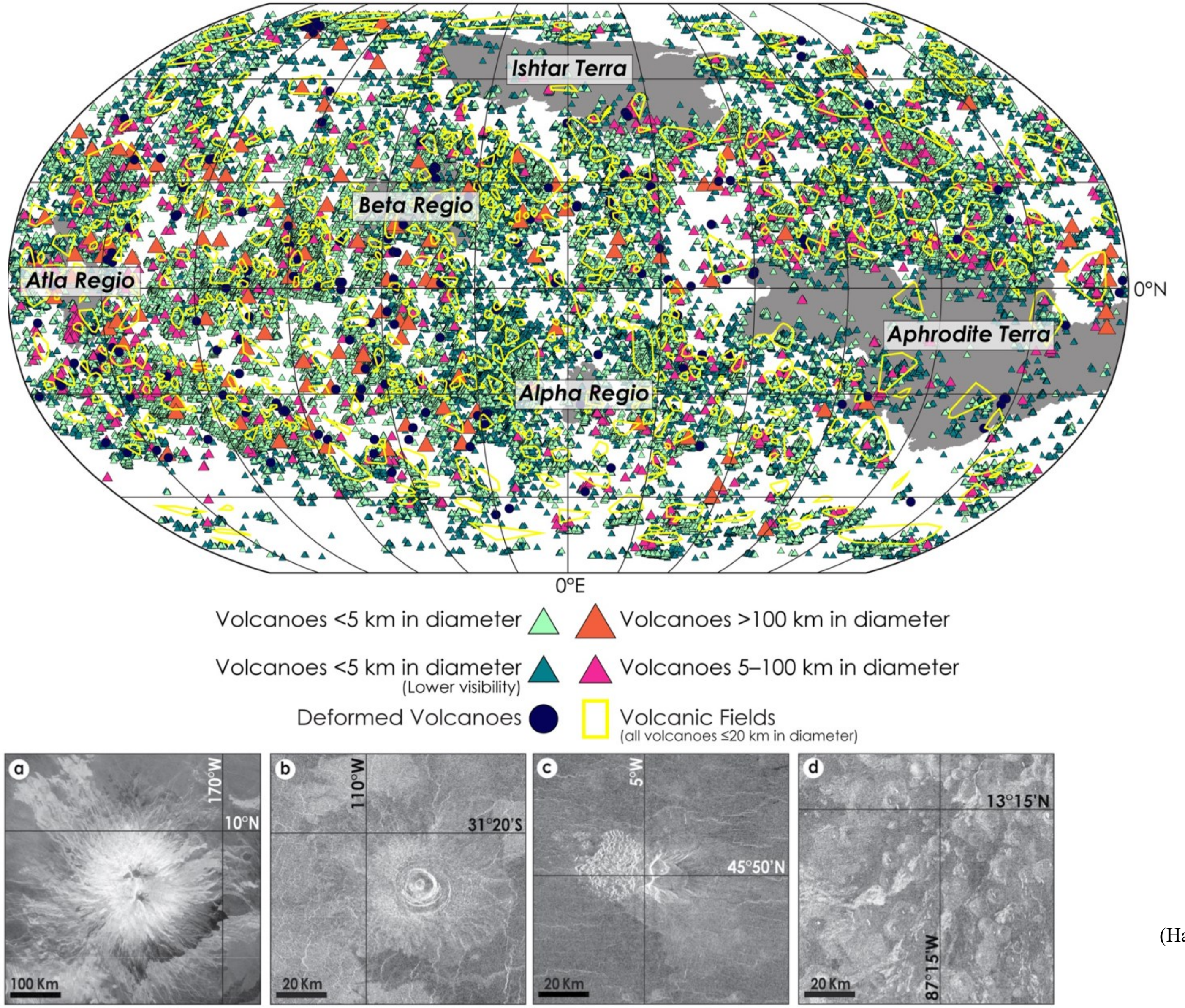
マントルからの荷重



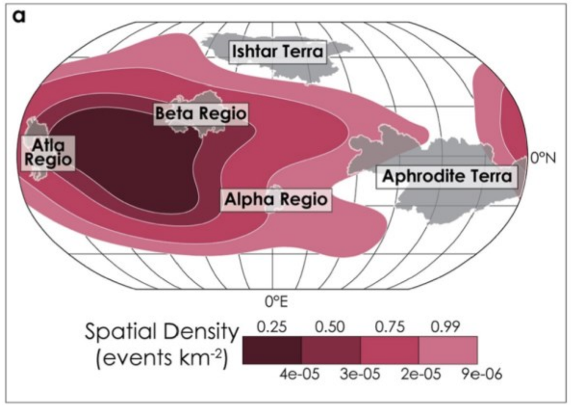
James et al. (2013)

より小さな無数の火山による火山平原（厚さ400 m程度？）

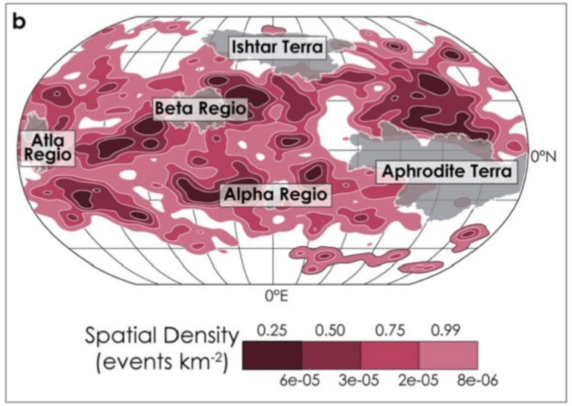
(Ivanov & Head, 2013)



サイズ＞65 km



サイズ<65 km

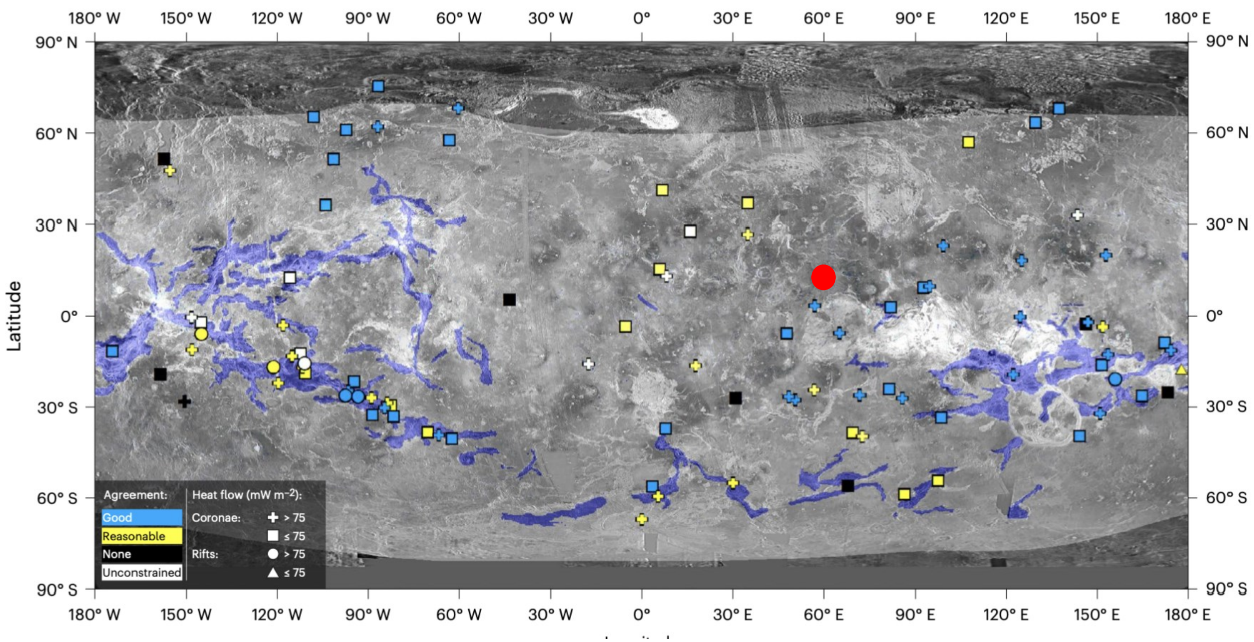


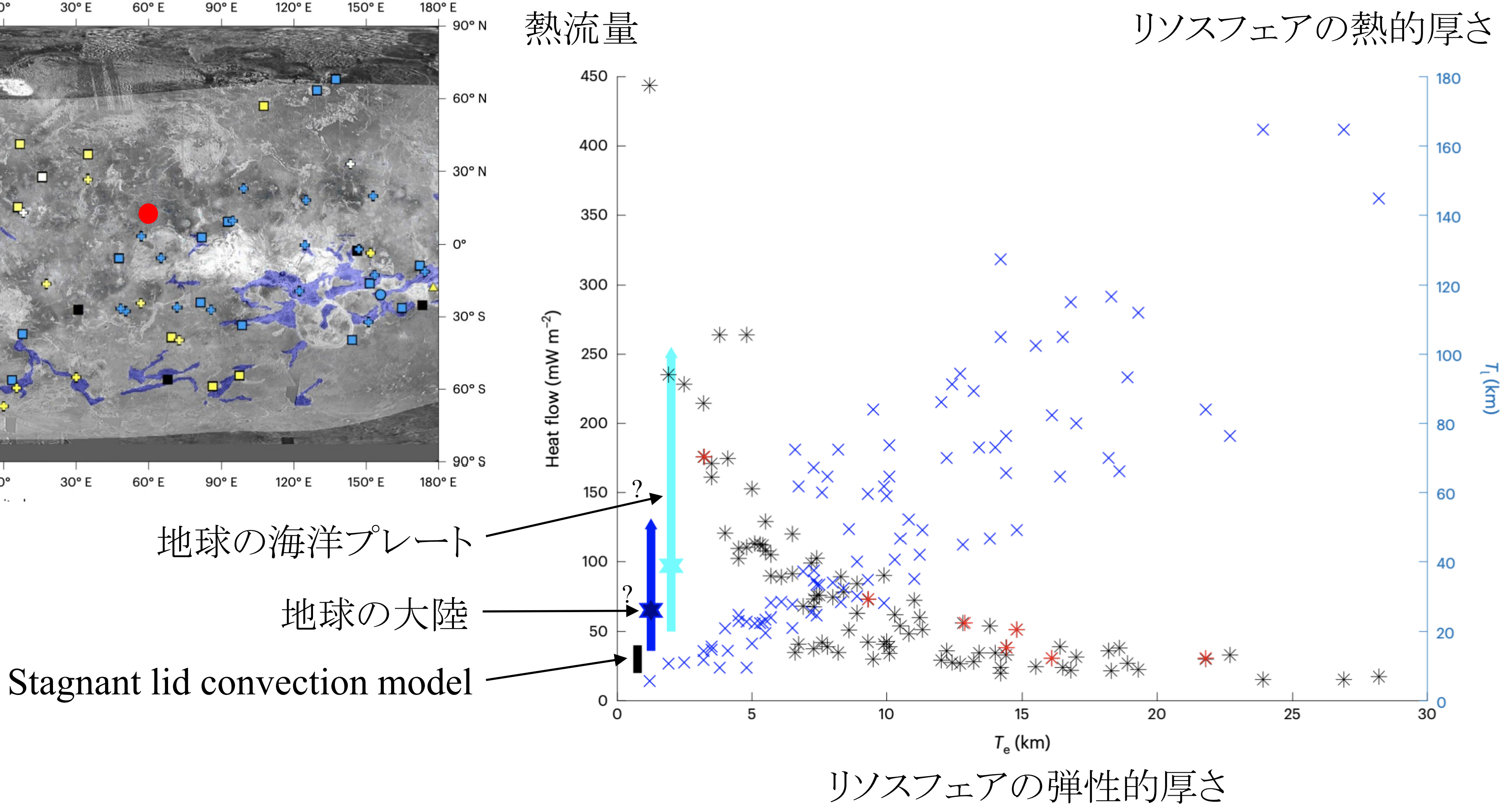
(Hahn & Byrne., 2023)

金星の地殻熱流量

(1) 盆地の地形より ＜ 28 mW/m^2 (Bjonnes et al. 2021)

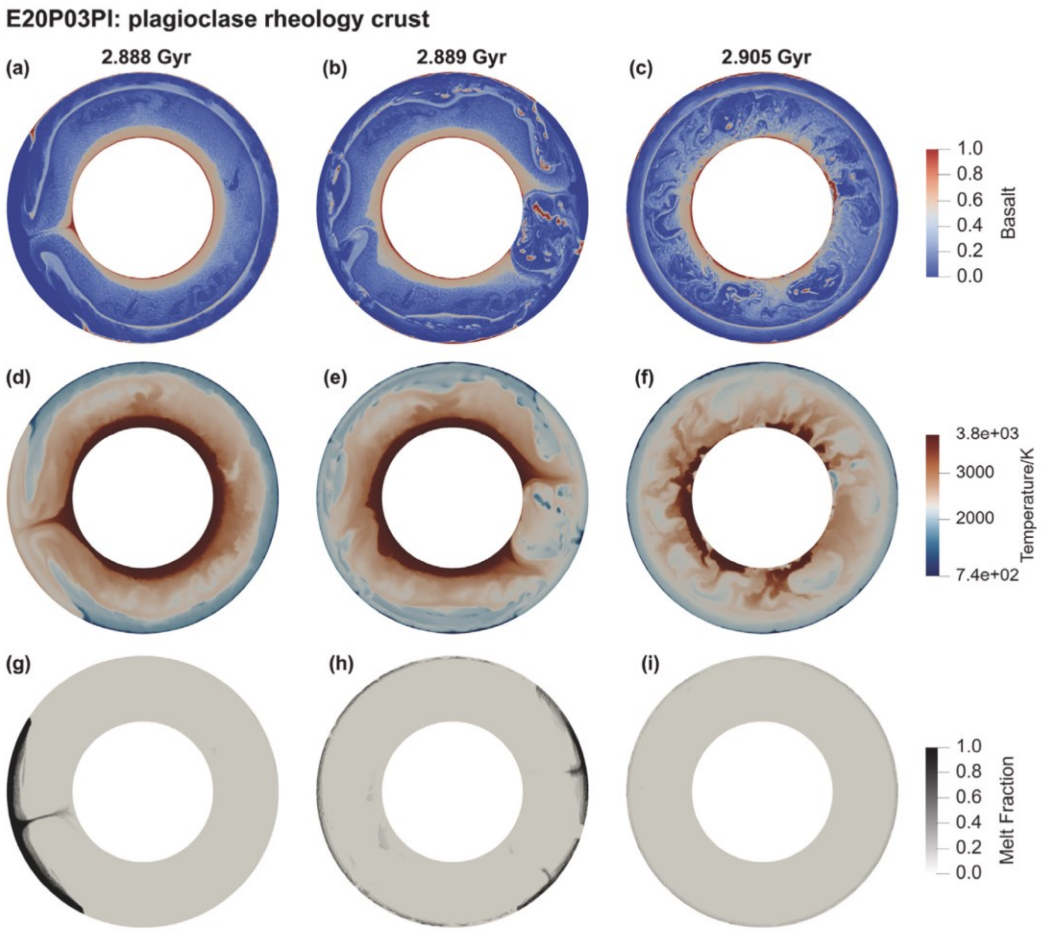
(2) 荷重によるリソスフェアの撓みより (Smrekar et al., 2023)：火山活動による放熱？

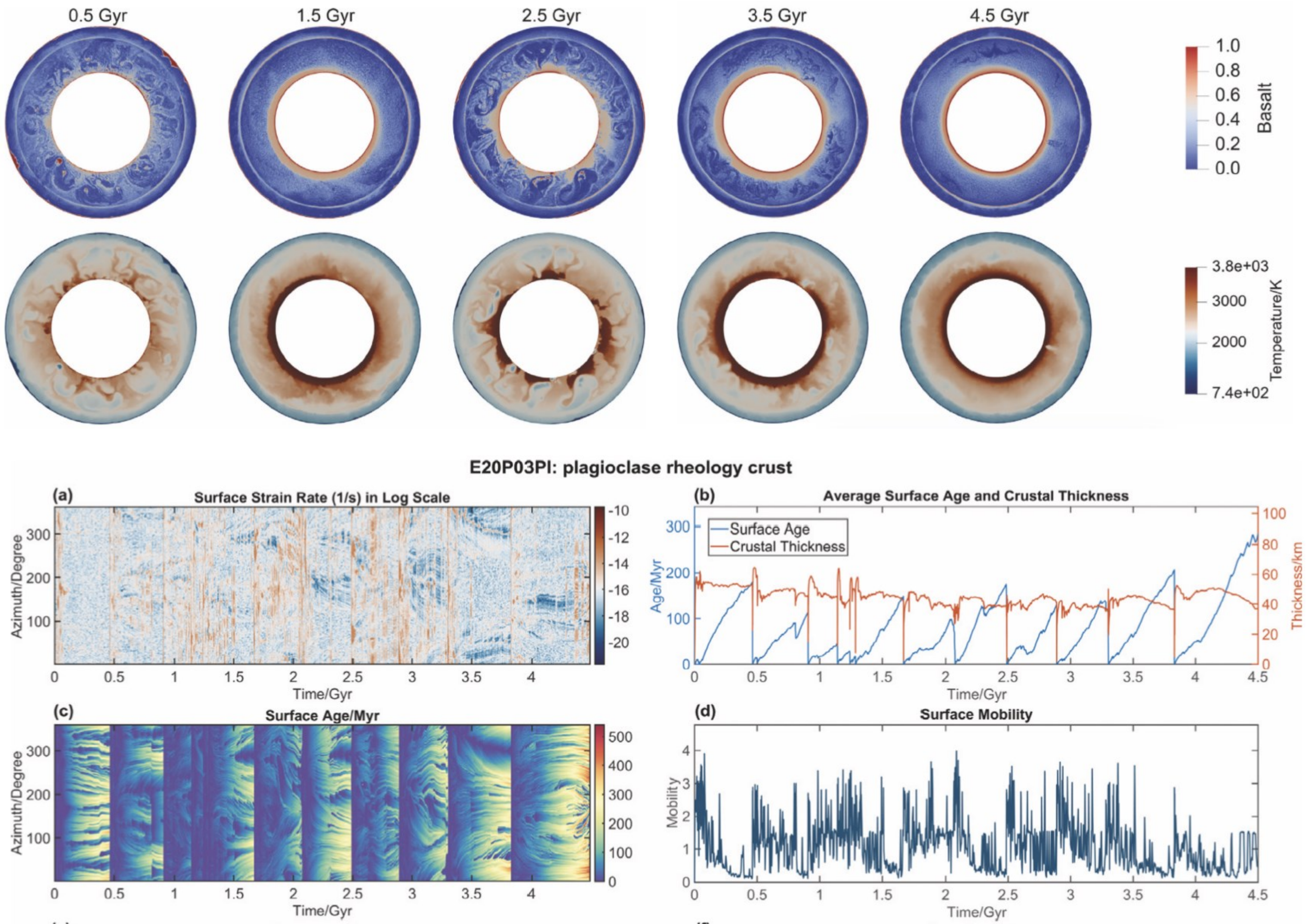




テセラ ⇔ 火山平原　directional or cyclic?

Cyclic evolutionの例：Yieldingによるリソスフェアの崩落





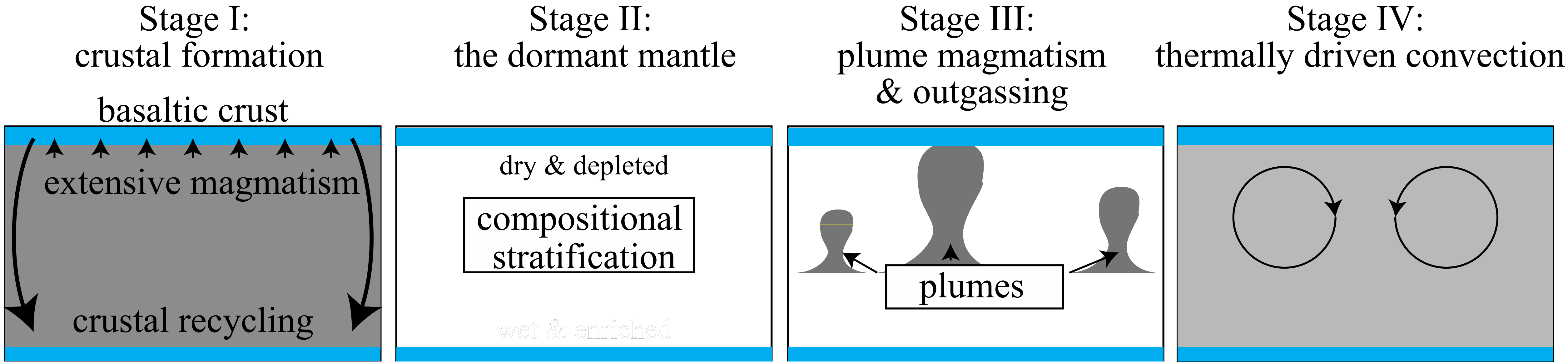
(Tian et al., 2023)

崩落の痕跡？地球のプレート・テクトニクスと両立？

6-2. 火星から金星へ: a directional evolution

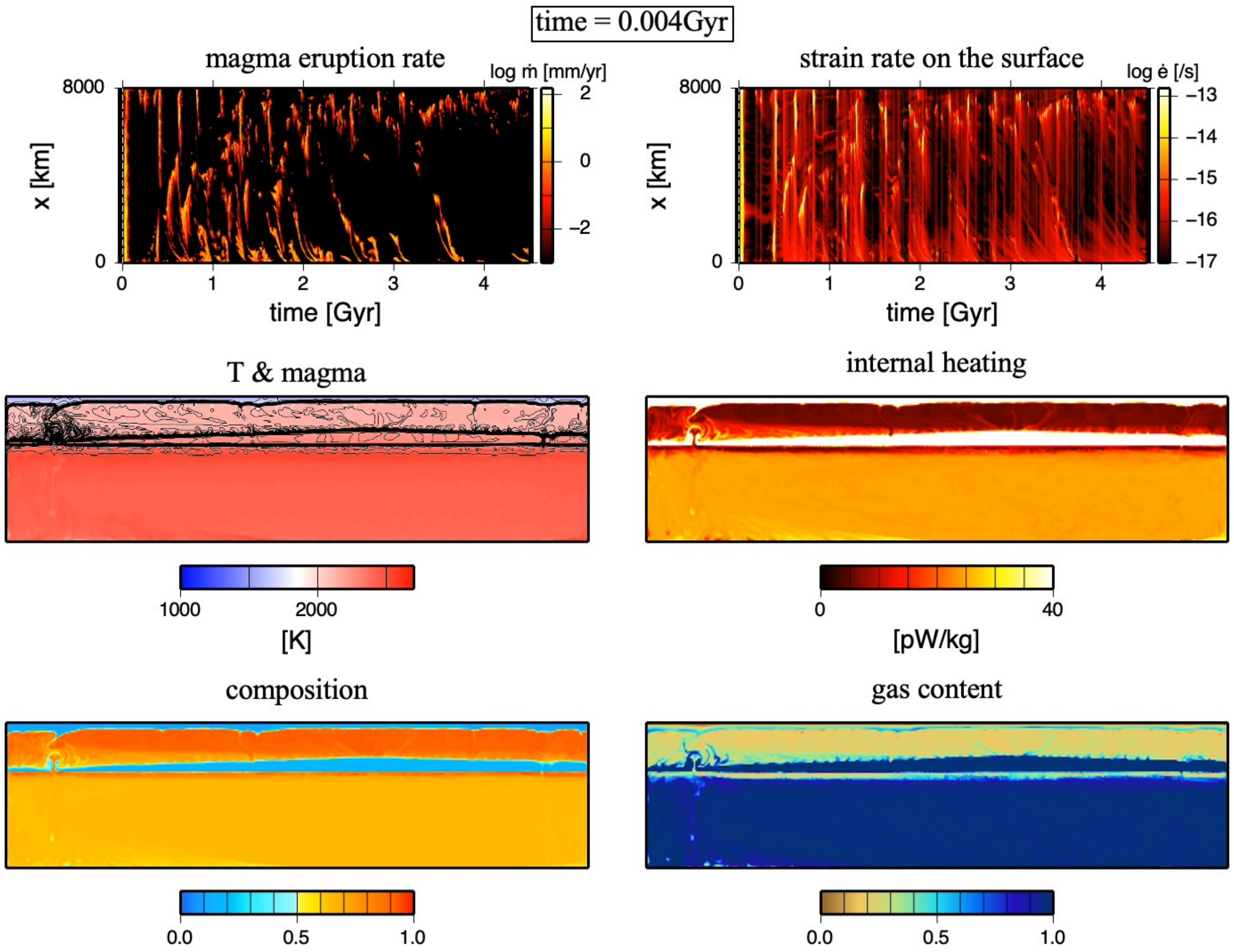
(cf. Ogawa & Yanaisawa, 2014)

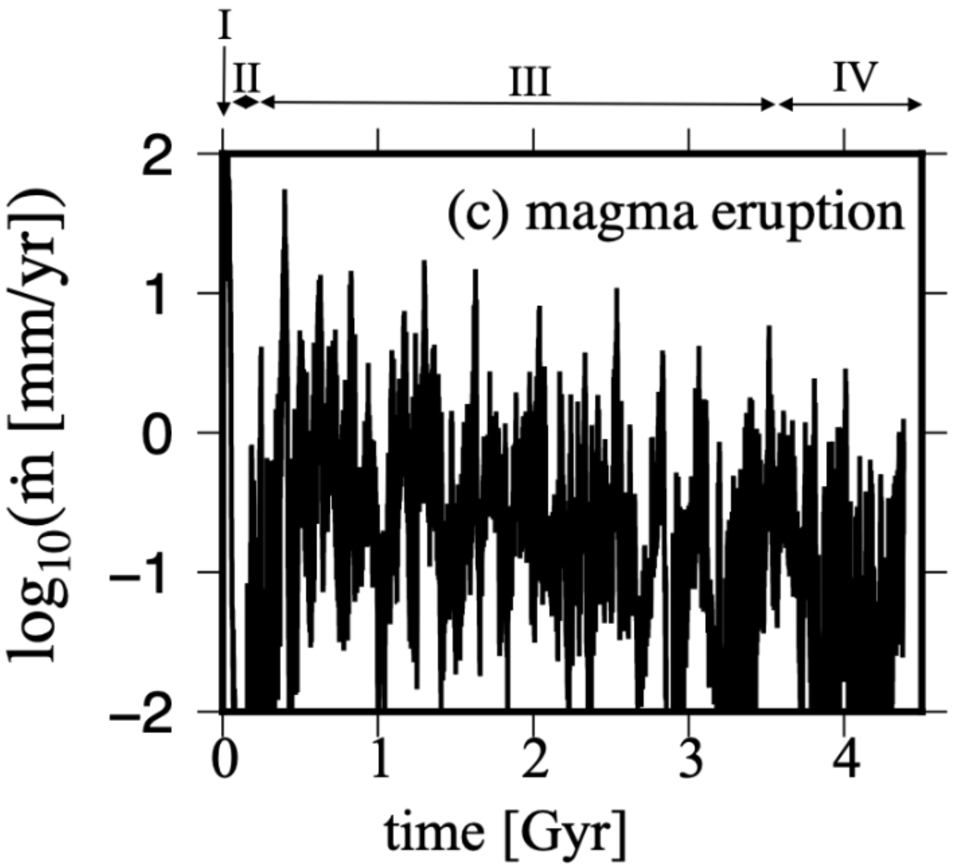
The four-stage evolution (FSE) model of Mars

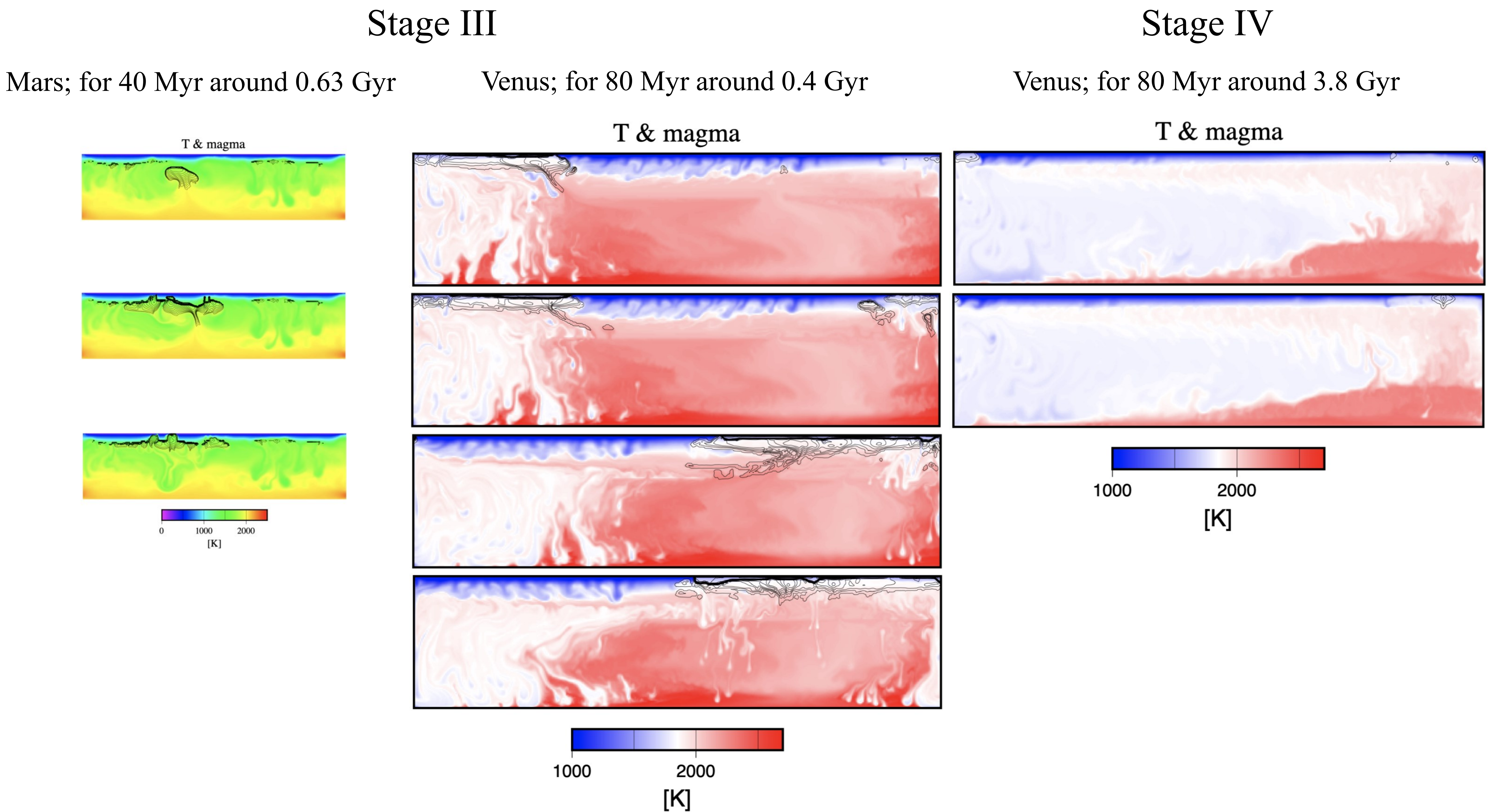


Larger planetary size ⇒ more extensive MMUb & longer Stage III

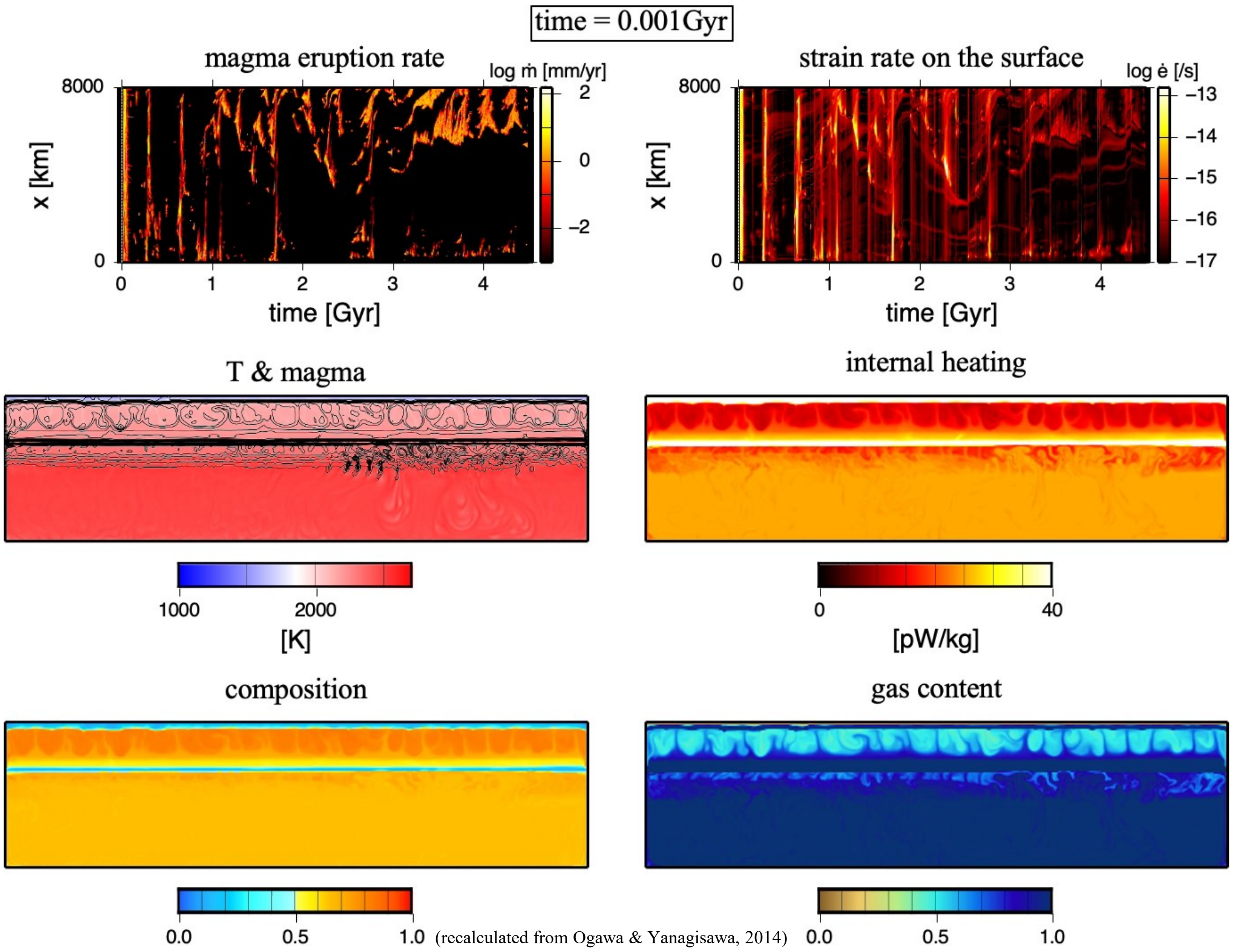
because of (1) lower viscous resistance, (2) the larger heat capacity and (3) stronger heating per unit surface area



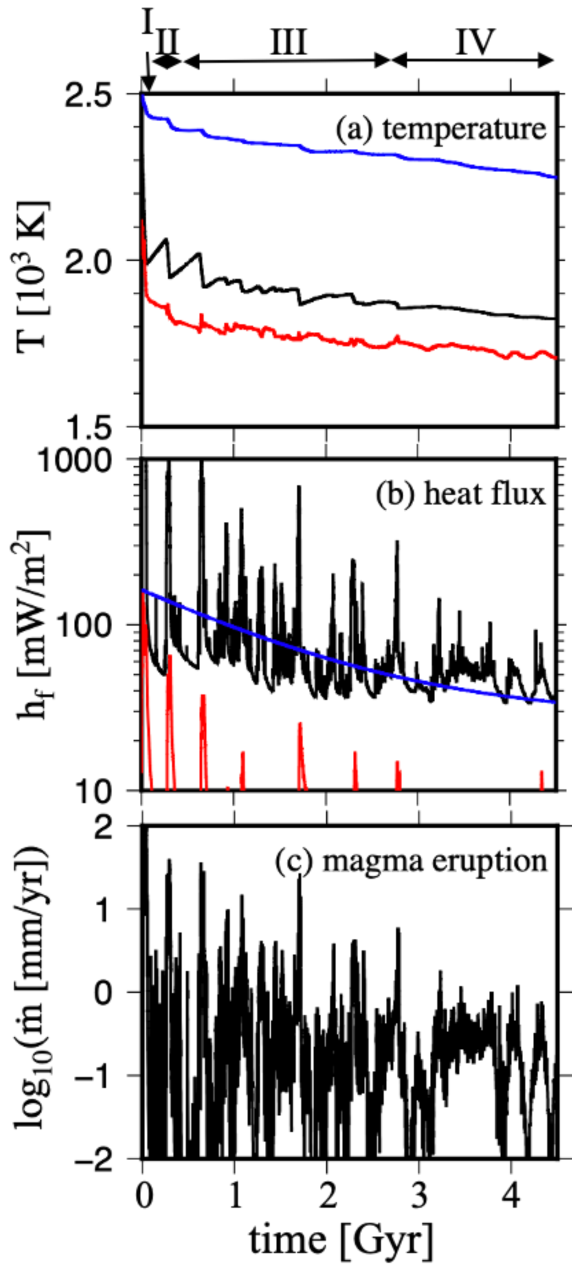



Stage III
Stage IV
Mars; for 40 Myr around 0.63 Gyr
Venus; for 80 Myr around 0.4 Gyr
Venus; for 80 Myr around 3.8 Gyr
T & magma
T & magma
T & magma
0
1000
2000
[K]
1000
2000
[K]
1000
2000
[K]

Evolution of the mantle with basalt-barrier



(recalculated from Ogawa & Yanagisawa, 2014)



A directional change in the style of volcanism

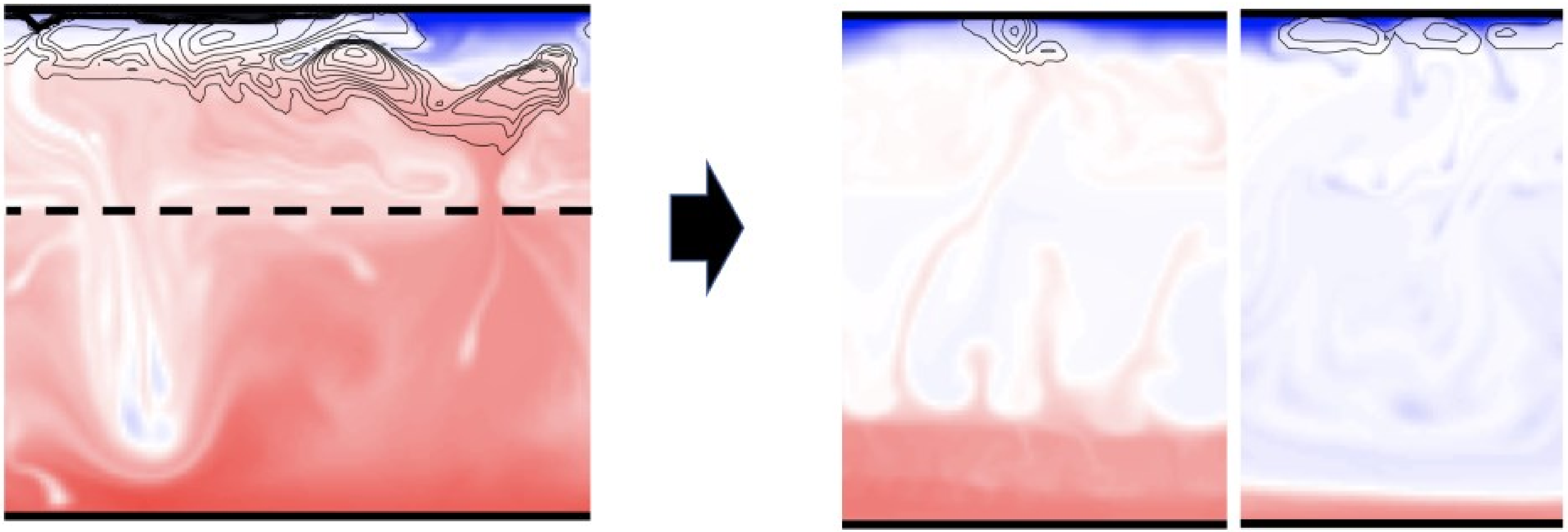
Stage III: mantle burst by the MMUb

Stage IV: stable lithosphere & localized magmatism

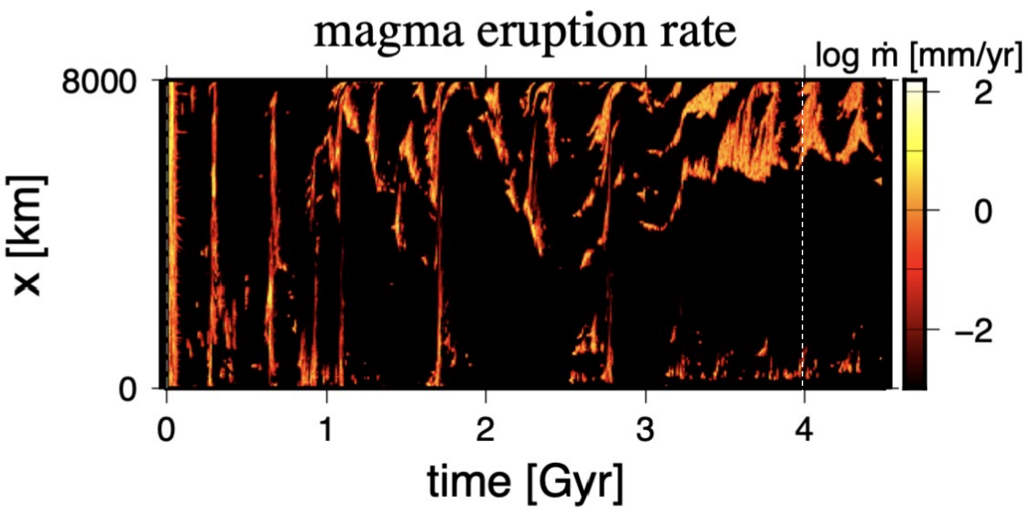
severe deformation of the lithosphere

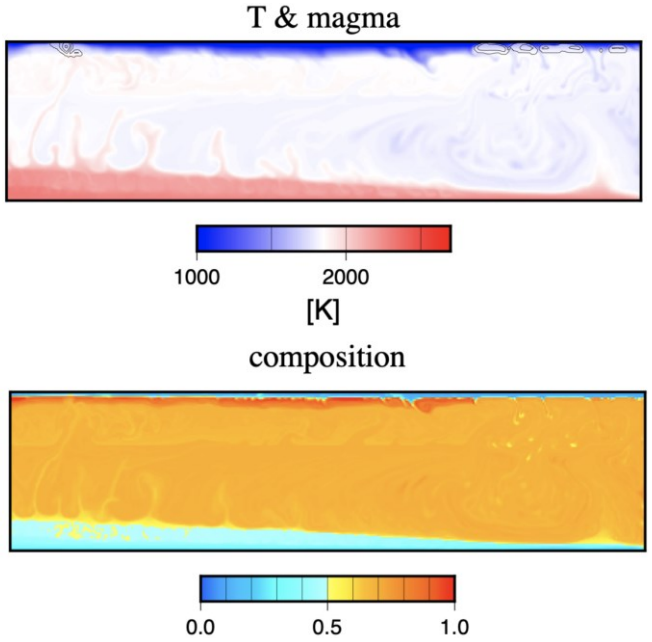
Plume magmatism

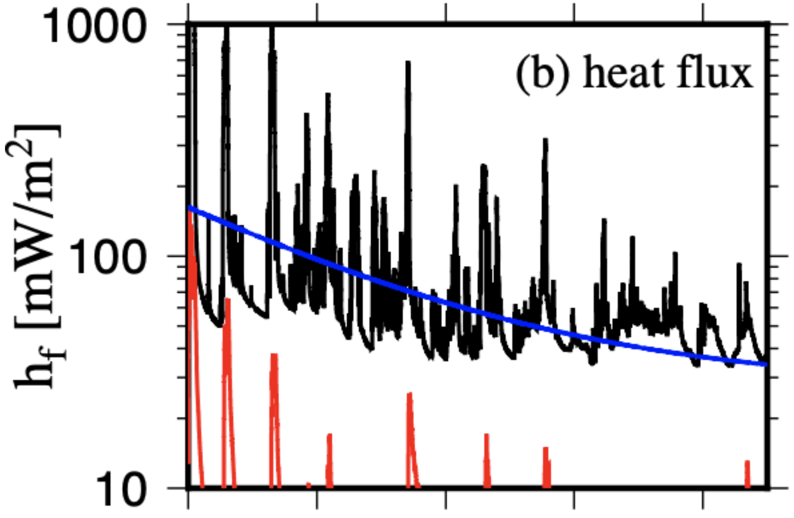
Magmatism induced by the secondary convection

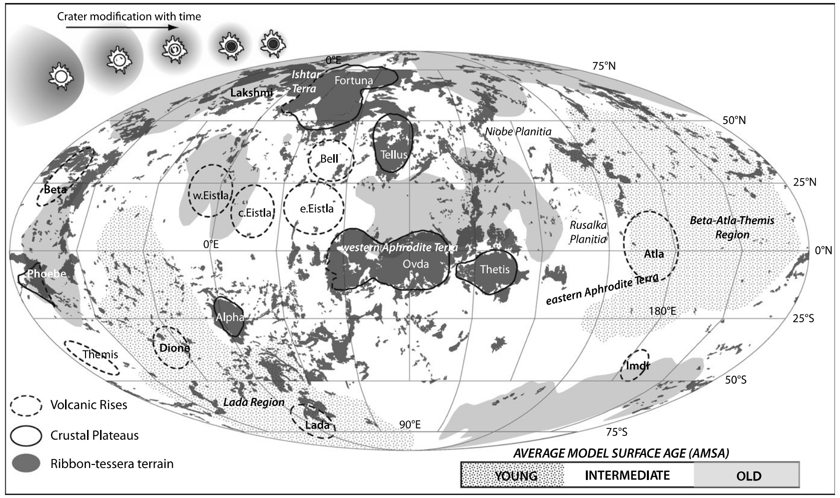


マントルの構造と火山活動

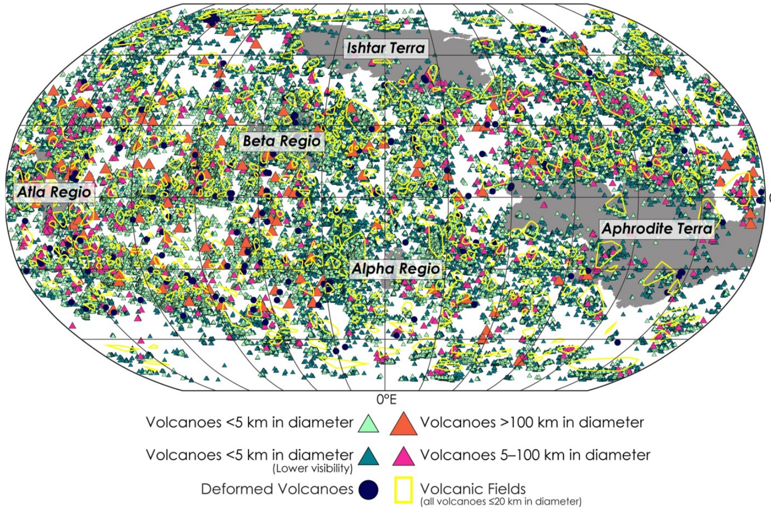






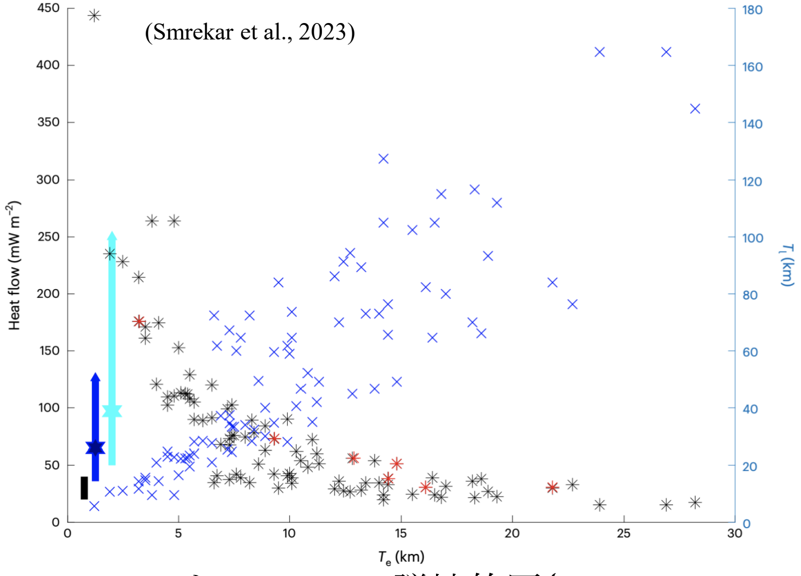


(Bjonnes et al., 2012)



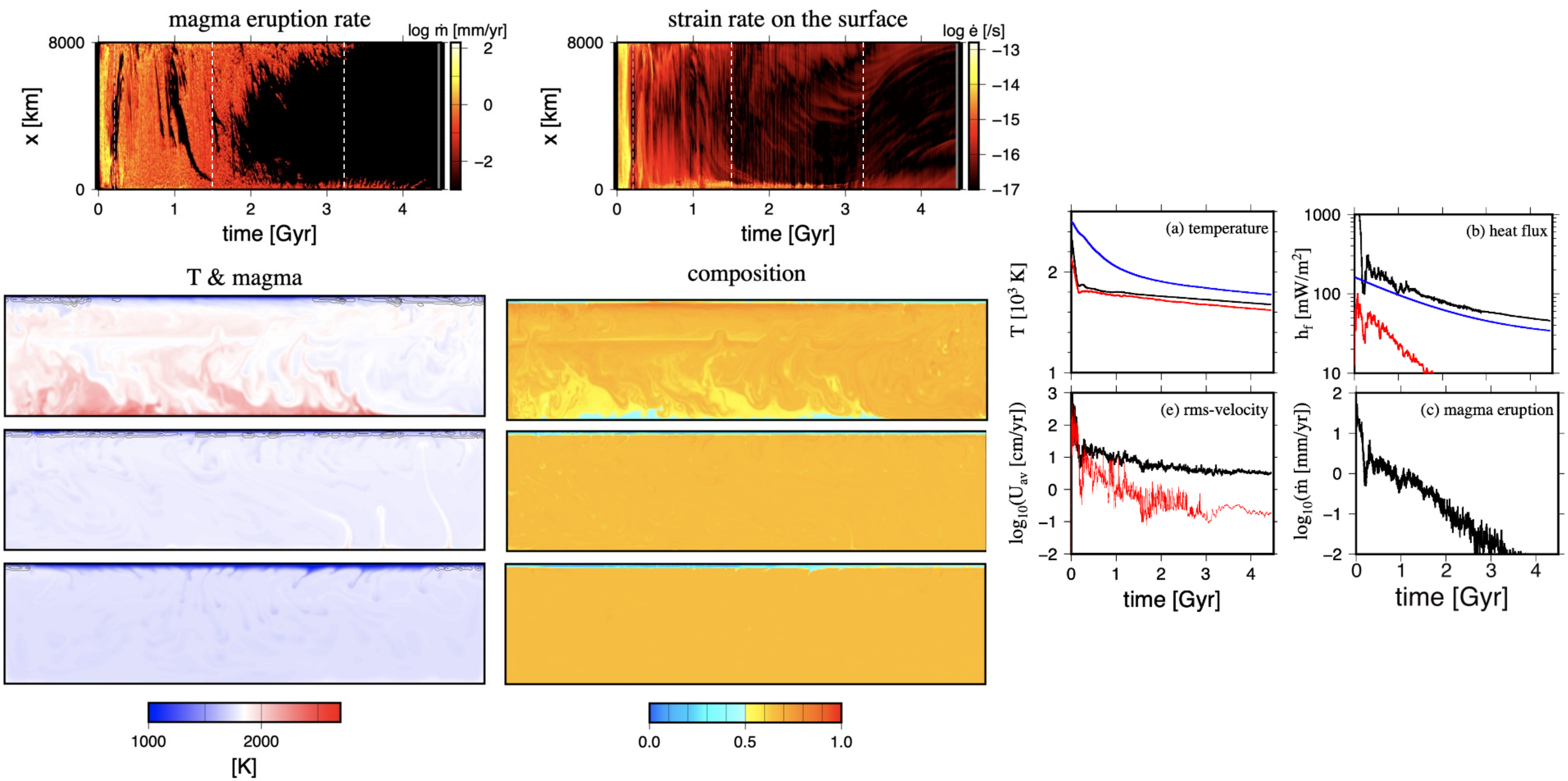
(Hahn & Byrne., 2023)

熱流量



リソスフェアの弾性的厚さ

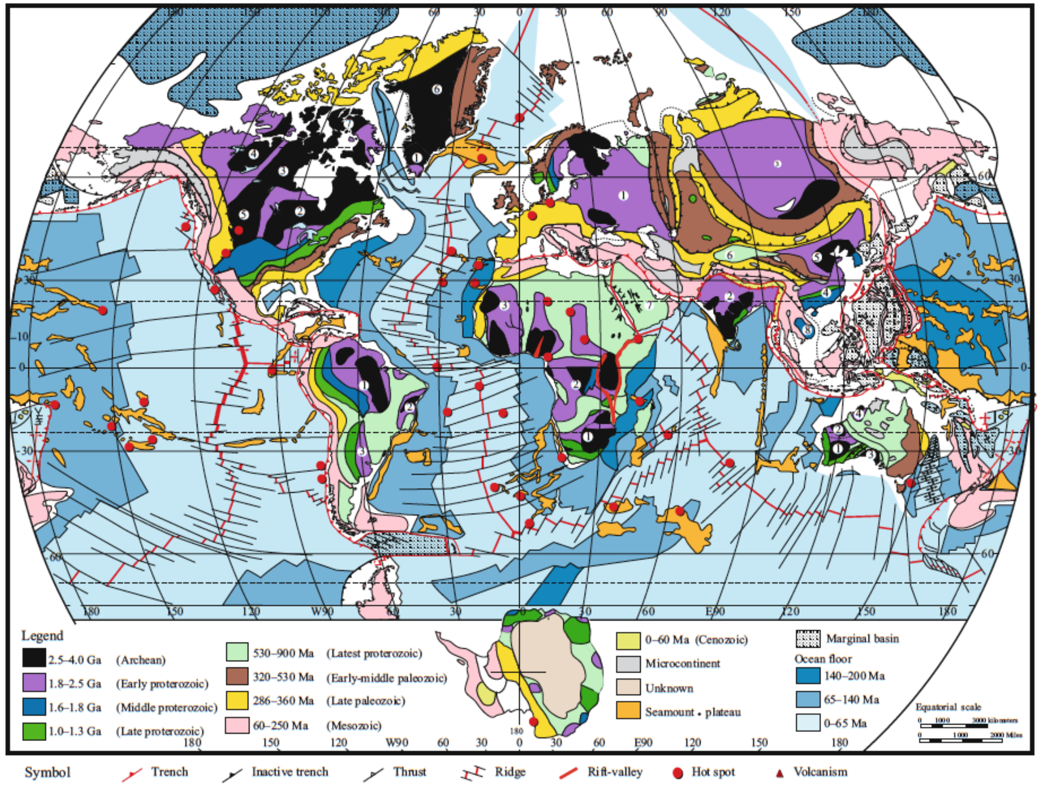
マントルの構造進化が本質：4.5 Gyrを通して均質な時（浸透率1/10）



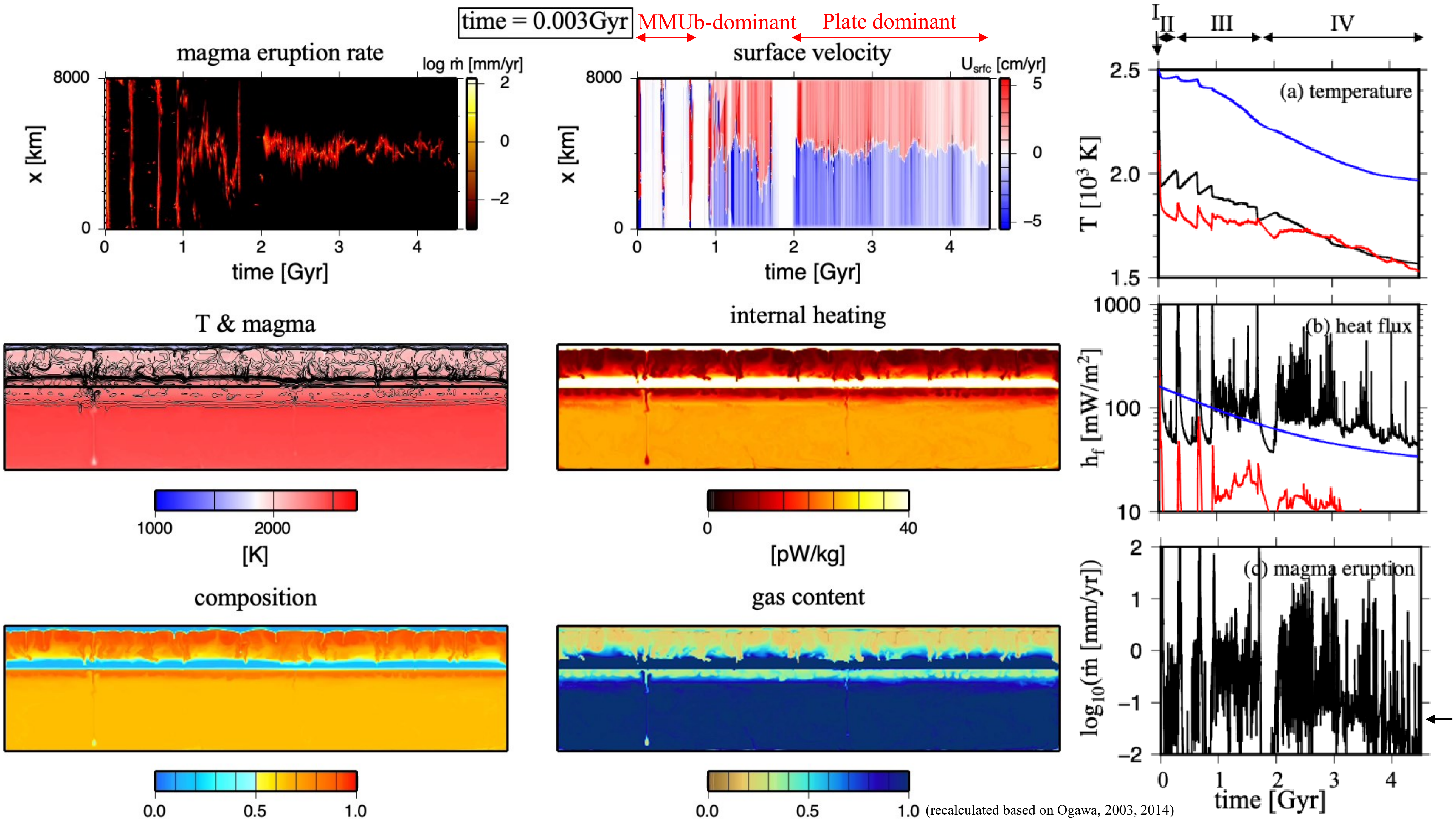
6-3. 地球=金星＋プレート・テクトニクス　(cf. Ogawa, 2014)

Hadean	Archean	Proterozoic

4.5 Ga　　4 Ga　　2.5 Ga

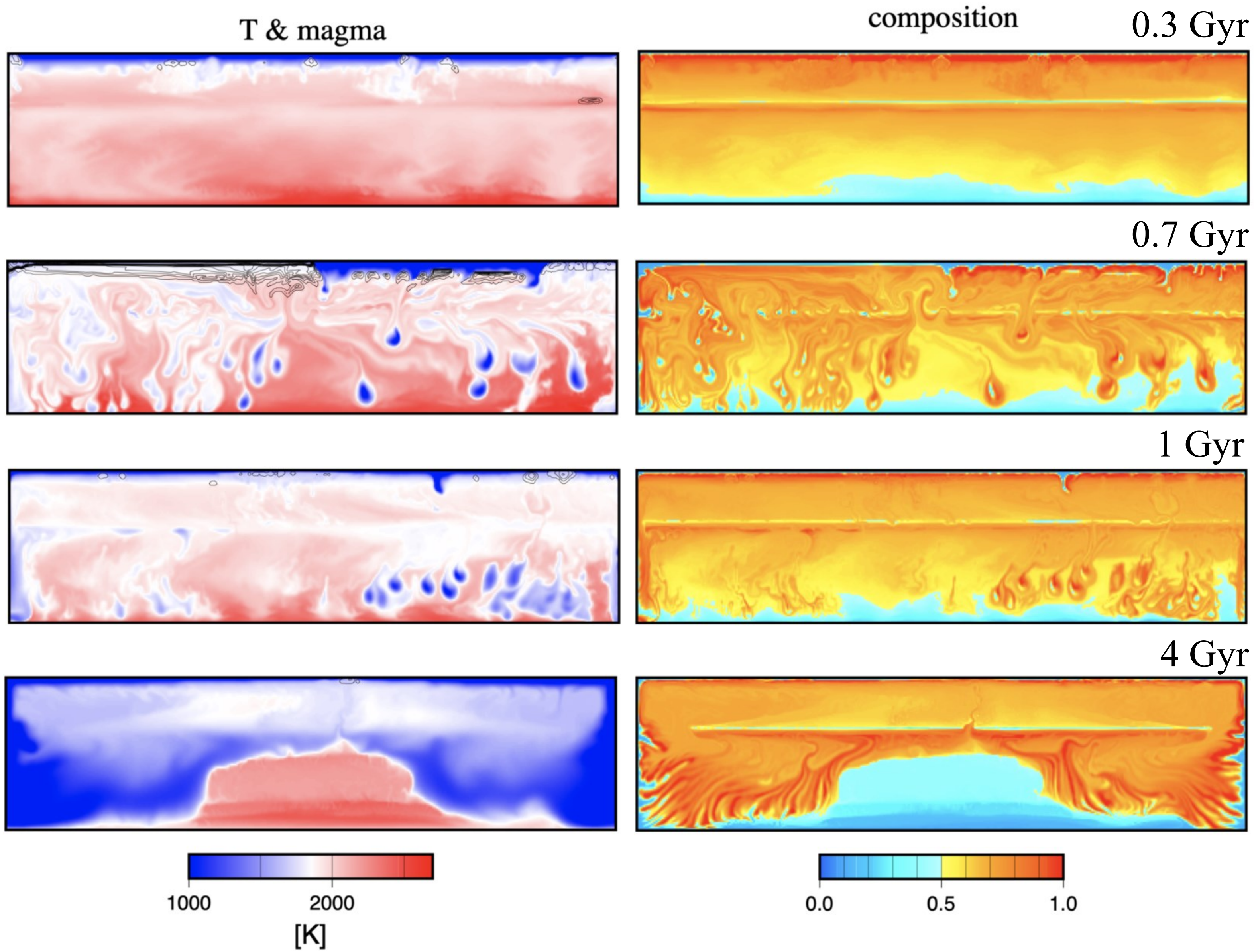


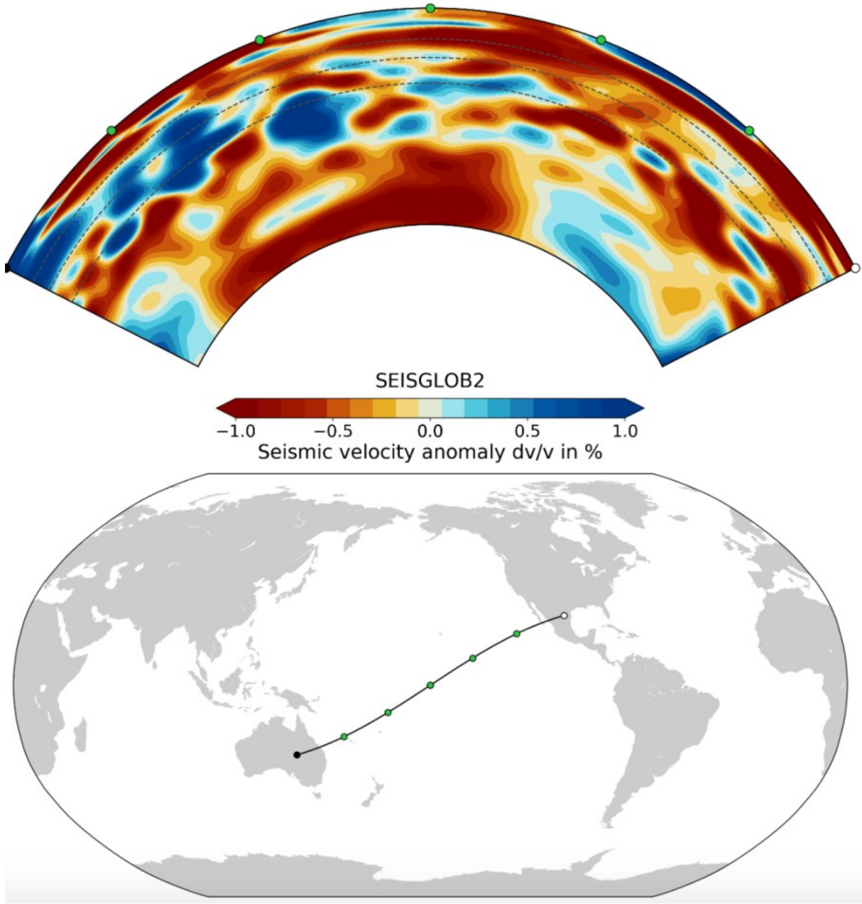
(Utsunomiya et al., 2007)



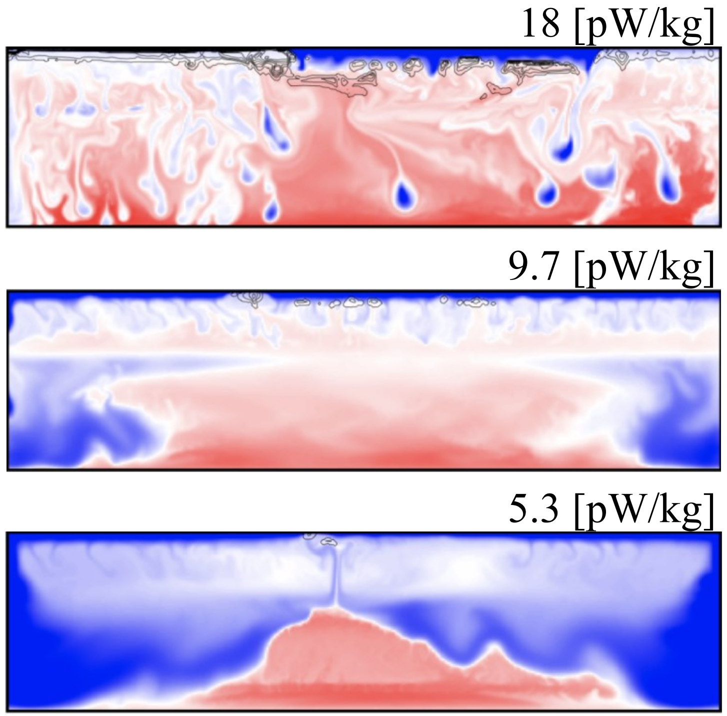
(recalculated based on Ogawa, 2003, 2014)

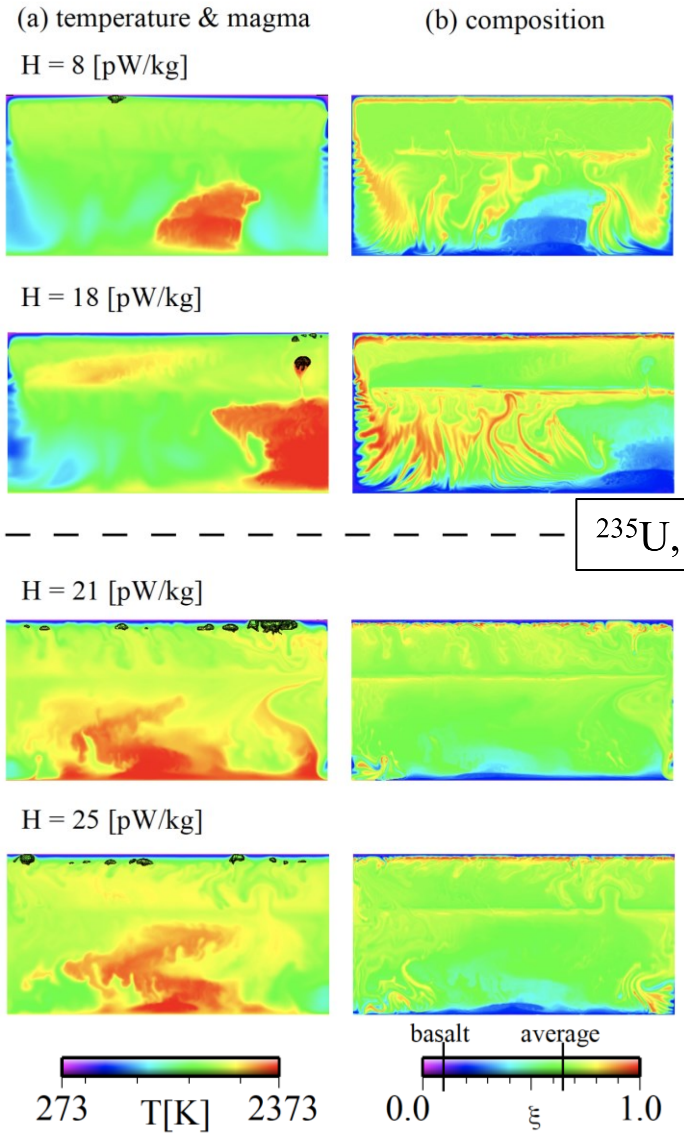
マントルの構造進化
初期マントル分化 → MMUbによる分化・均質化 → 海嶺火山による分化 (LLSVP)



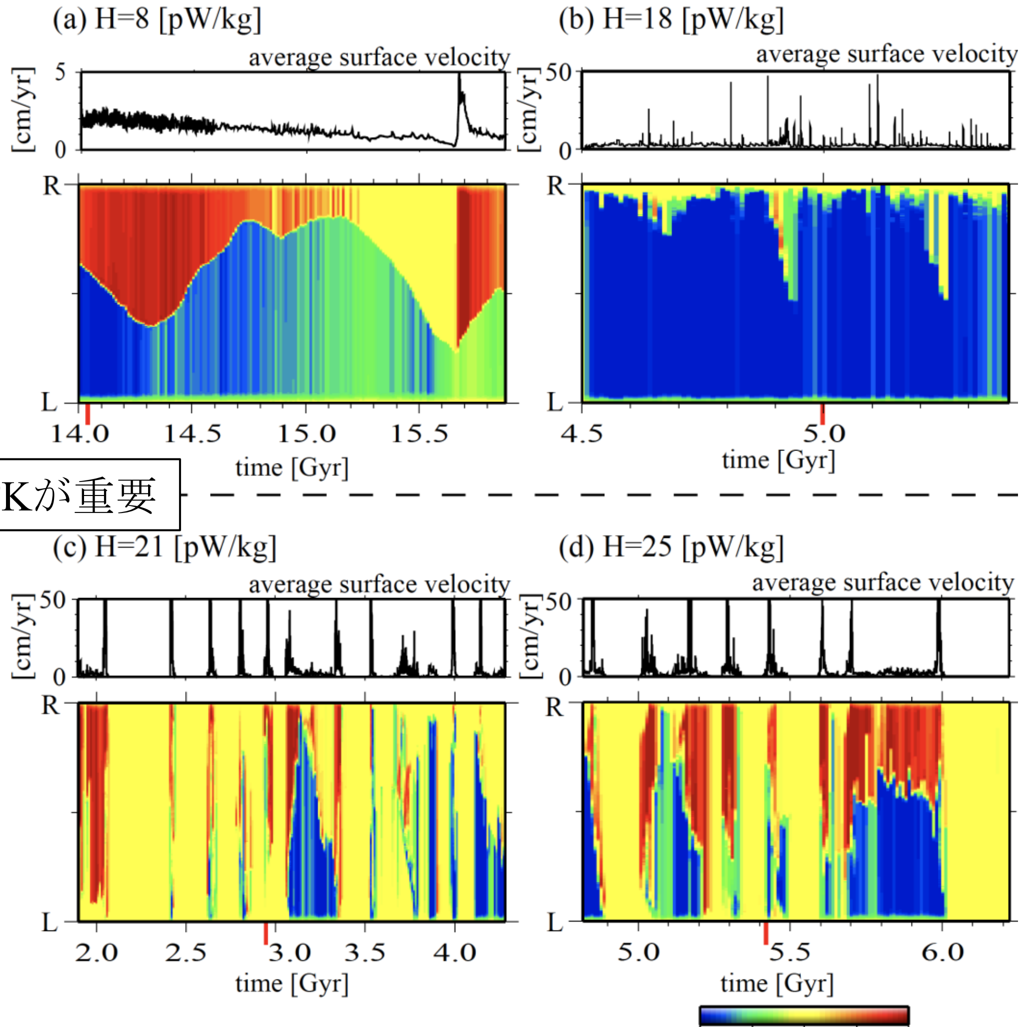


玄武岩パイルの安定性が支配するマントルの構造進化

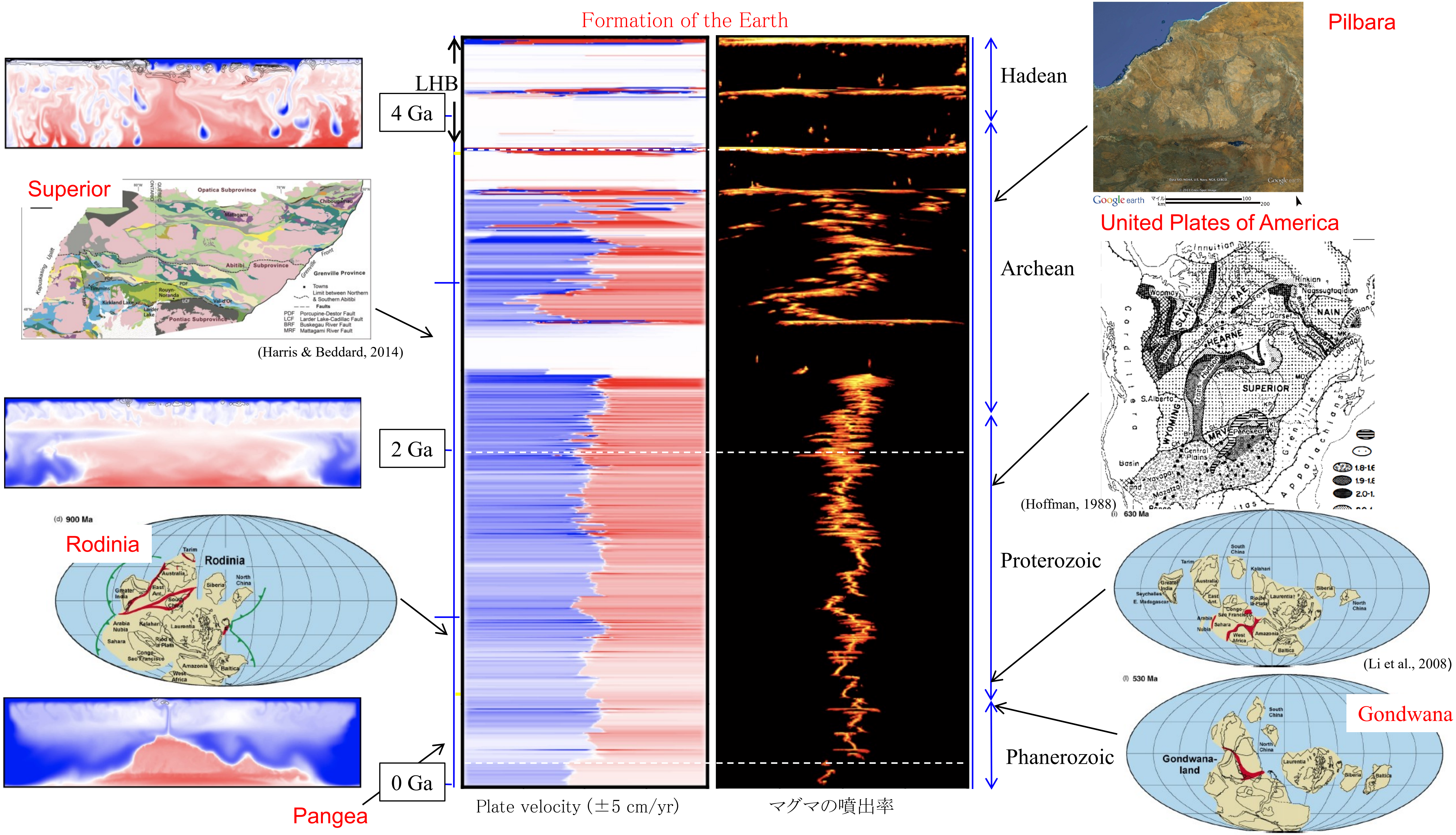




^{235}U, ^{40}Kが重要

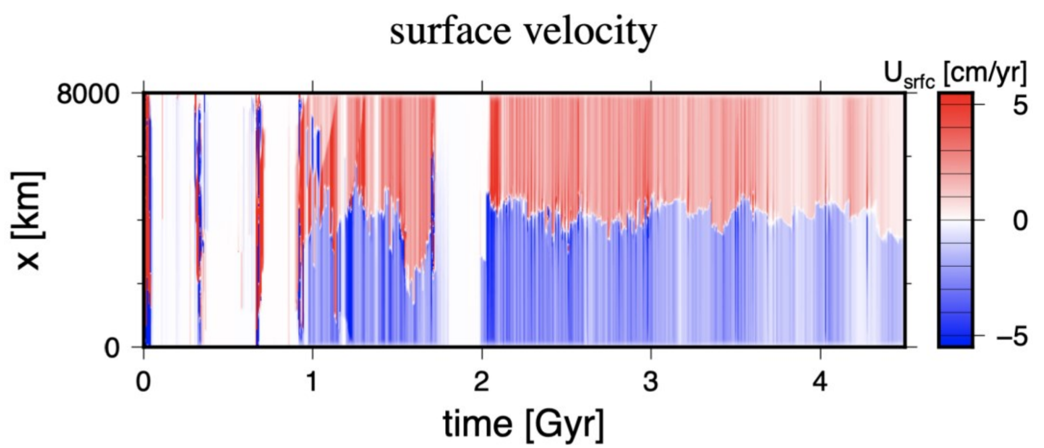


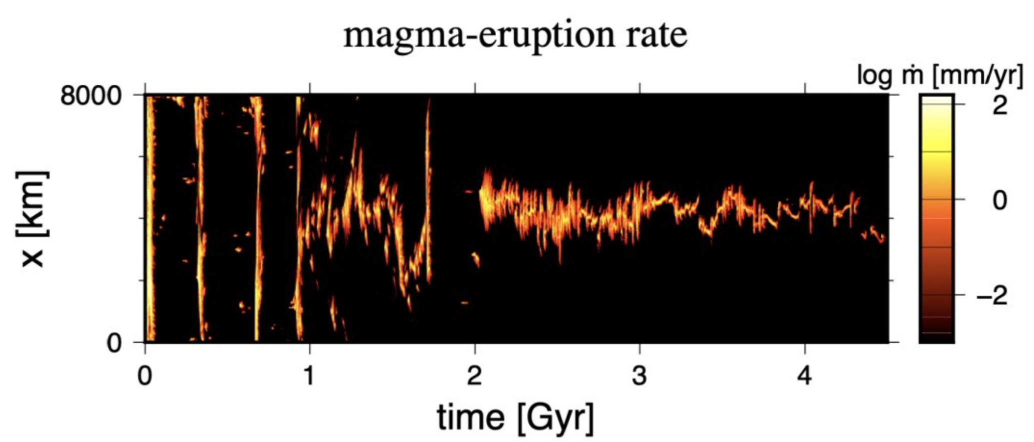
(Fujita & Ogawa, 2009)

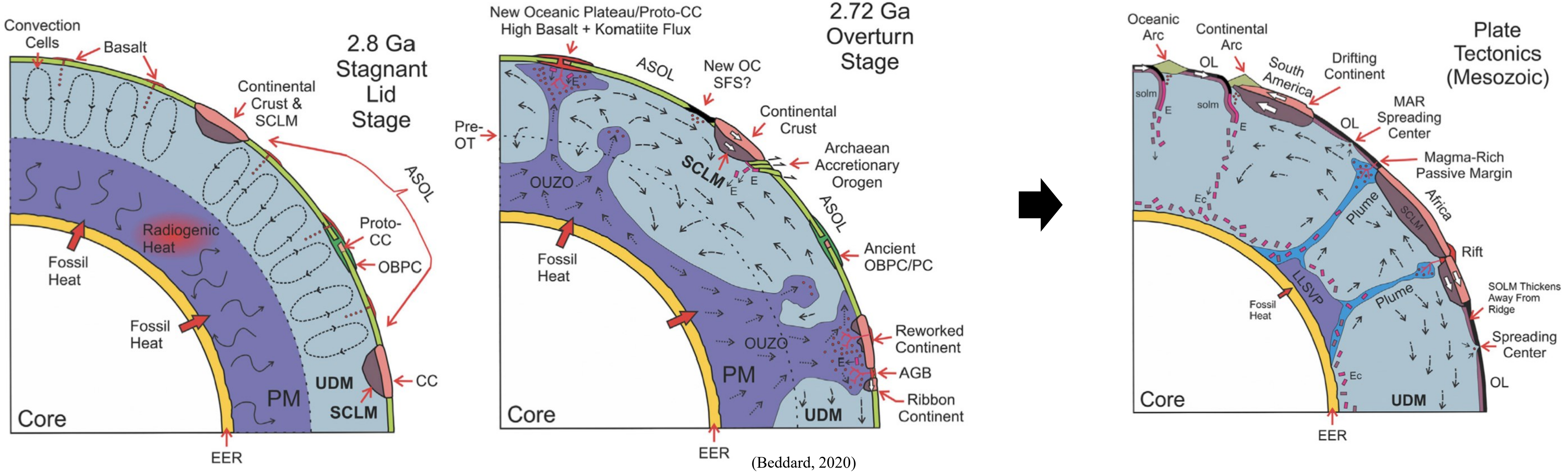


Formation of the Earth
LHB
4 Ga
2 Ga
0 Ga
Hadean
Archean
Proterozoic
Phanerozoic
Superior
(Harris & Beddard, 2014)
Rodinia
(d) 900 Ma
Pangea
Pilbara
United Plates of America
(Hoffman, 1988)
(i) 630 Ma
(Li et al., 2008)
(l) 530 Ma
Gondwana
Gondwana-land
Plate velocity (±5 cm/yr)
マグマの噴出率

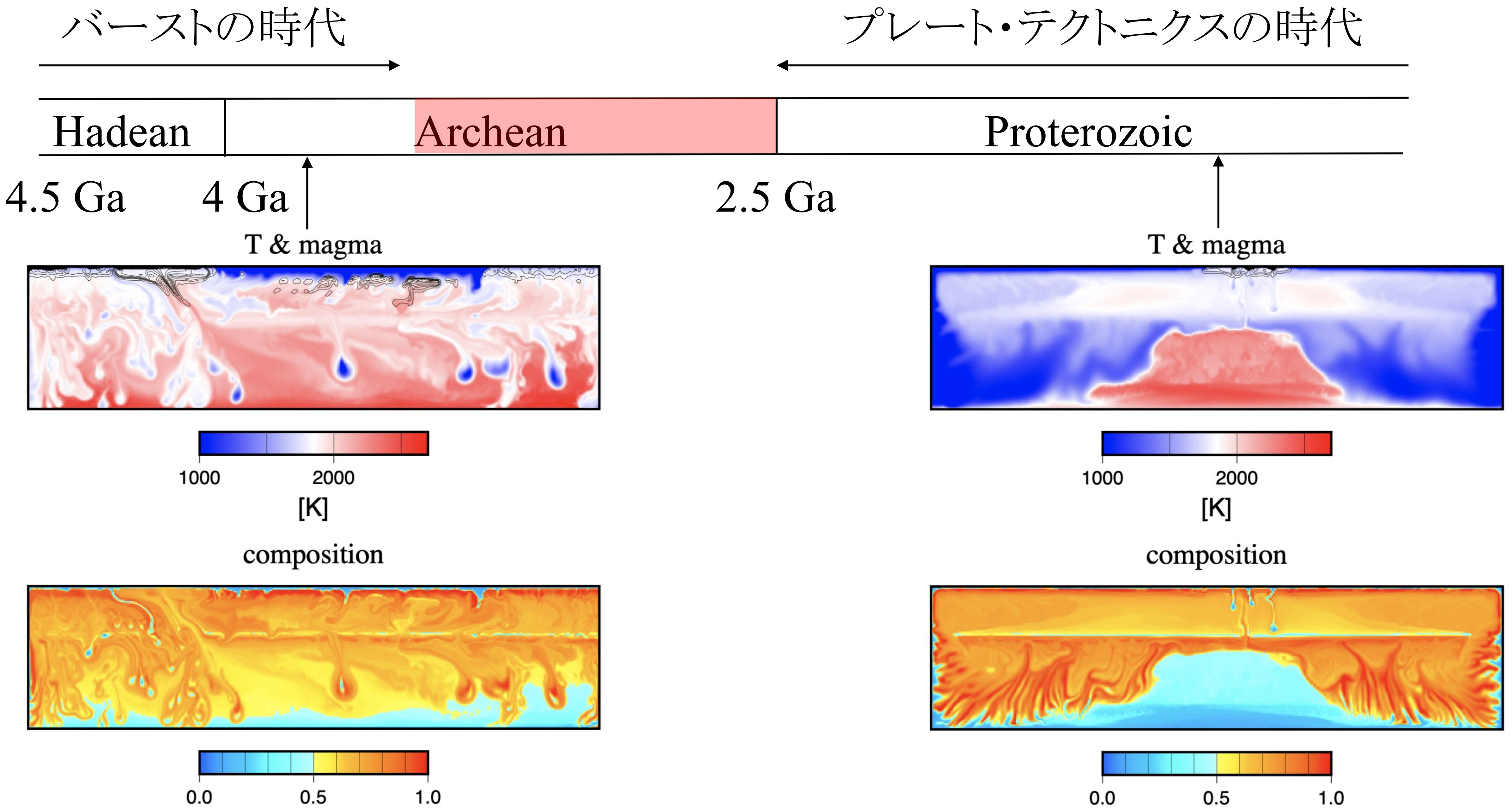
数値モデルとよく似た地質モデルの存在







(Beddard, 2020)



MMUの活動 → マントルは均質
(火星のStage III)

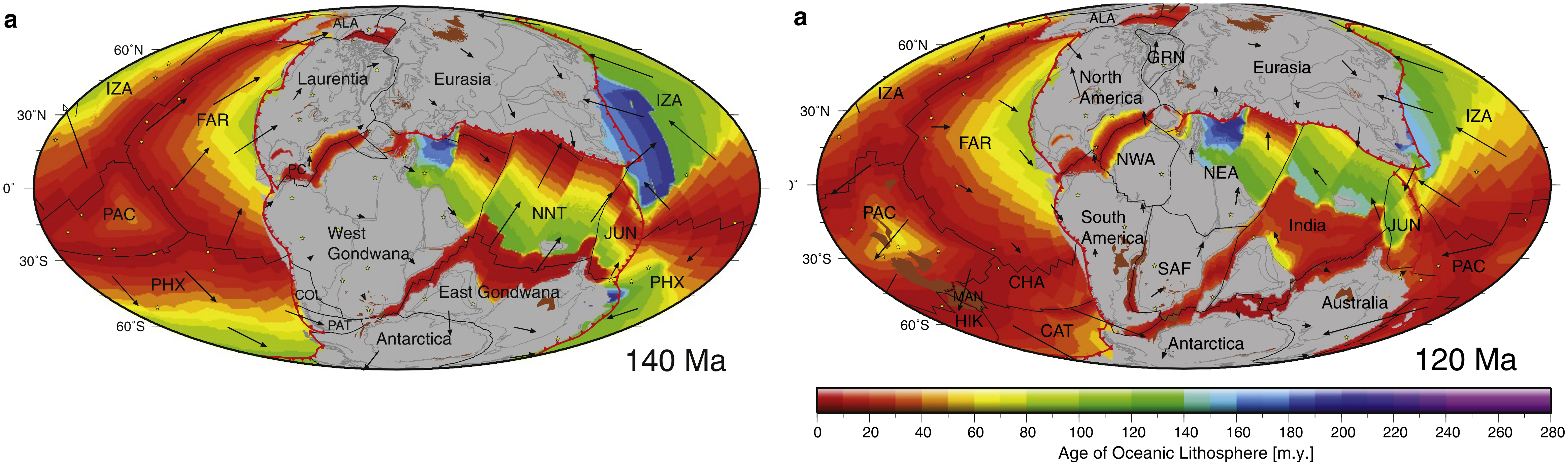
プレート → マントルを不均質化
(火星のStage IV)

Supplement: parameter search

パラメター依存性はあまりない

（1）玄武岩バリアーがない時
　　LLSVPが上部マントルまで成長
（2）permeabilityが低い時(Pm = 100)
　　ある程度の地殻のリサイクリングによるマントル分化；LLSVPは未成熟

初期地球の姿：MMU feedbackにより、現在より大規模なLIPがより頻繁にあった。マントルは今と比べてより均質だった。



(Seton et al., 2012)