Coupled Fluid Flow, Deformation, Heat Transport & Mineral Reactions in Hydrothermal Mineralising Systems

热液成矿系统中流体流动，变形，热传递&矿物反应的耦合过程

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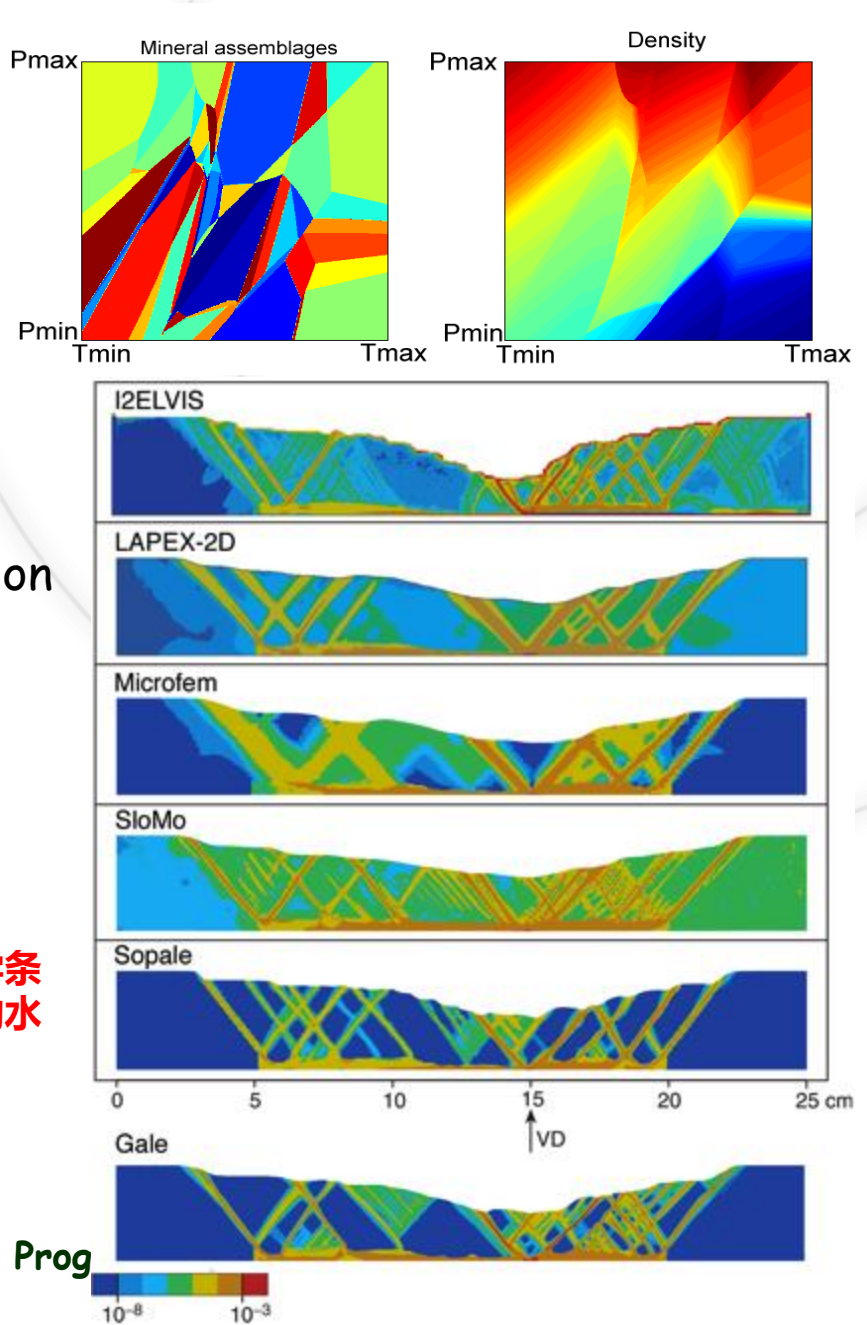
One Hour Presentations

1. A Systems Approach: The 5 Questions
2. Folding & Boudinage
3. Shear Zones, Fractures, Breccias and Veins.
4. The Regional Scale – Fundamentals
5. **The Regional Scale – Applications**
6. Synthesis – The Way Ahead

Numerical technique:

- **Rheological model:**
  VISCO-EELASTO-PLASTIC
  流变模型：粘弹塑性
- **Stable mineral assemblages** are computed based o thermodynamic data and Gibbs free energy minimization (Connolly & Petrini, 2007) as a function of P and T
  稳定的矿物组合：可根据热力学数据和最小吉布斯自由能（比如P和T的的函数）计算得到。
- **Hydration and water migration:** Dehydration reactions and associated water release are computed based on the physico-chemical conditions and the assumption of thermodynamic equilibrium. Expelled water is stored in a newly generated water marker that moves independently
  水合作用和水迁移：脱水反应和相关水的释放可基于物理化学条件和热力学平衡假设计算得到，释放的水储存在一个新生成的水环境中，并且能够独立移动
- **Changes in topography** - account for the effects of erosion and sedimentation
  地形改变：考虑侵蚀和沉积的影响



- **Partial melting** – For a given pressure and rock composition the volumetric degree of melting M_0 is:

部分熔融 - 对于给定的压力和 岩石组成，熔融的M0体积度是:

$$M_0 = 0 \quad \text{when } T < T_{solidus},$$

$$M_0 = (T - T_{solidus}) / (T_{liquidus} - T_{solidus}) \text{ when } T_{solidus} < T < T_{liquidus},$$

$$M_0 = 1 \quad \text{when } T > T_{liquidus},$$

- effective viscosity is calculated using:

$$\eta = \eta_0 \exp[2.5 + (1-M)(\frac{1-M}{M})^{0.48}]$$

$\eta_0 = 10^{13}$ Pa·s - molten mafic rocks,

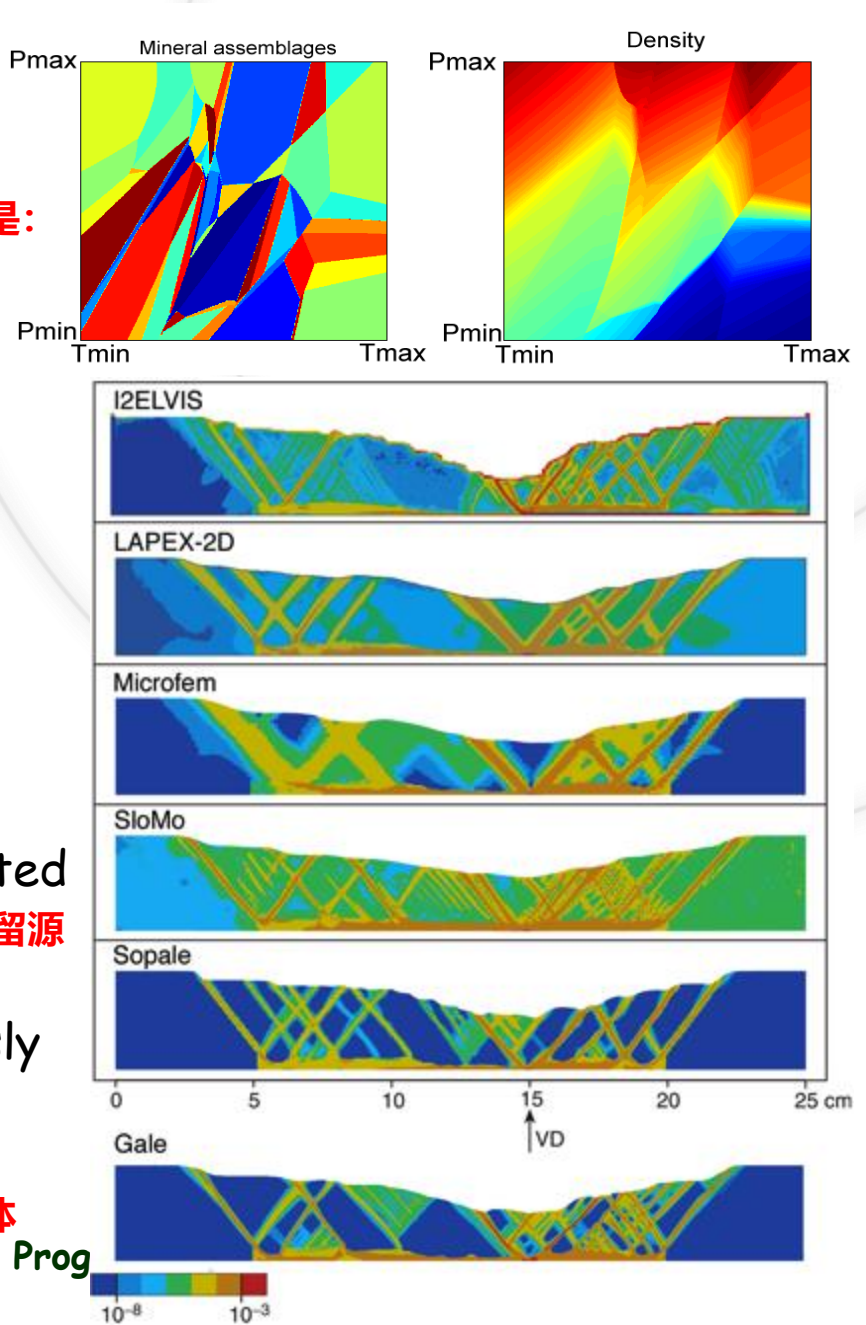
$\eta_0 = 5 \times 10^{14}$ Pa·s - molten felsic rocks

- **Melt extraction and intrusion** – when melt fraction exceeds 4%, only 4% remain in the source, markers track the amount of extracted melt. 熔体萃取和侵入- 当熔体超过4%，只有4%的熔体保留源中，标记能够对萃取的数量进行追踪。

Extracted melt is transmitted instantaneously to emplacement areas: 萃取的熔体即时侵位

intrusive rocks 80% of melt 侵入岩80%熔体

extrusive rocks – 20 % of melt 喷出岩 – 20%熔体



erosion/sedimentation

free slip, T = 0

Initial setup:

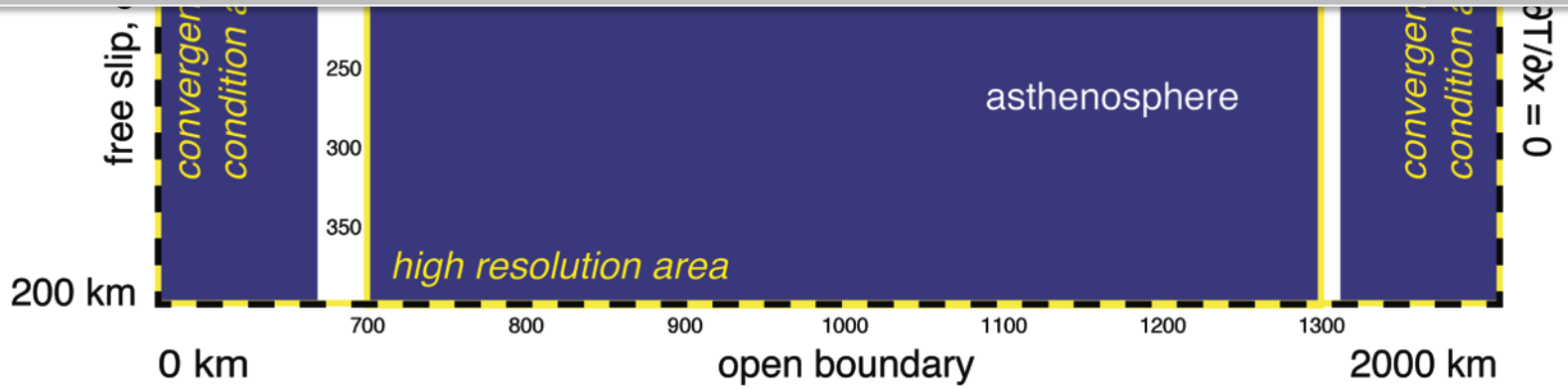
Compression for 6Ma at rates: 0.5, 1, 2, 3 cm/a

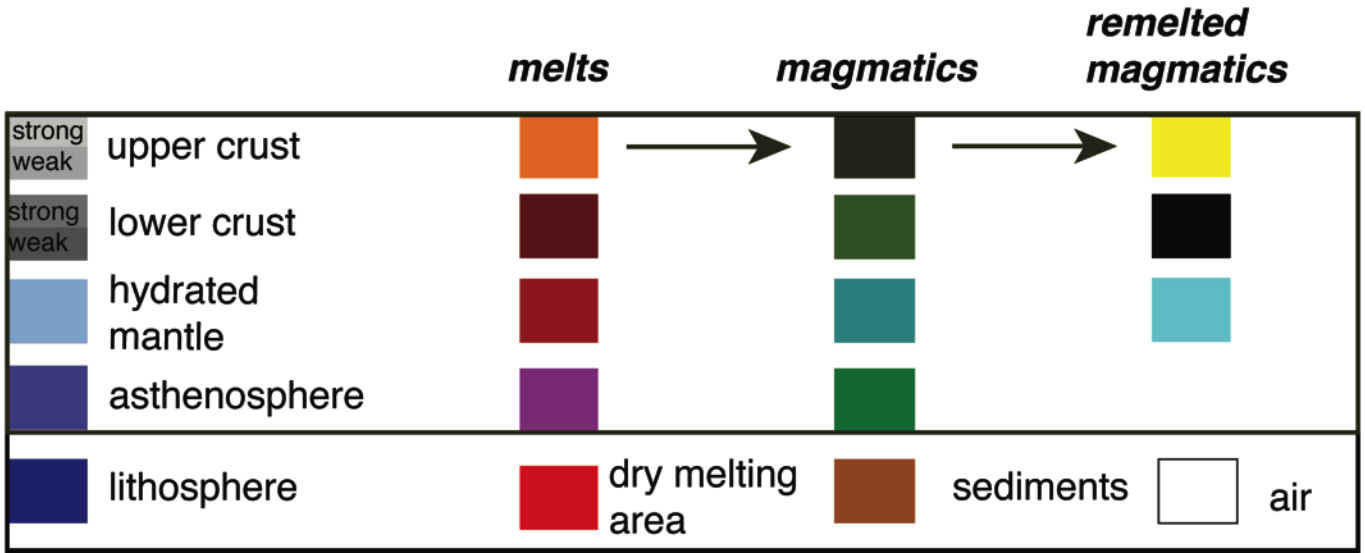
Lithospheric thickness: 60, 80, 100, 200, 300 km

初始设置

6Ma压缩:

岩石圈厚度:





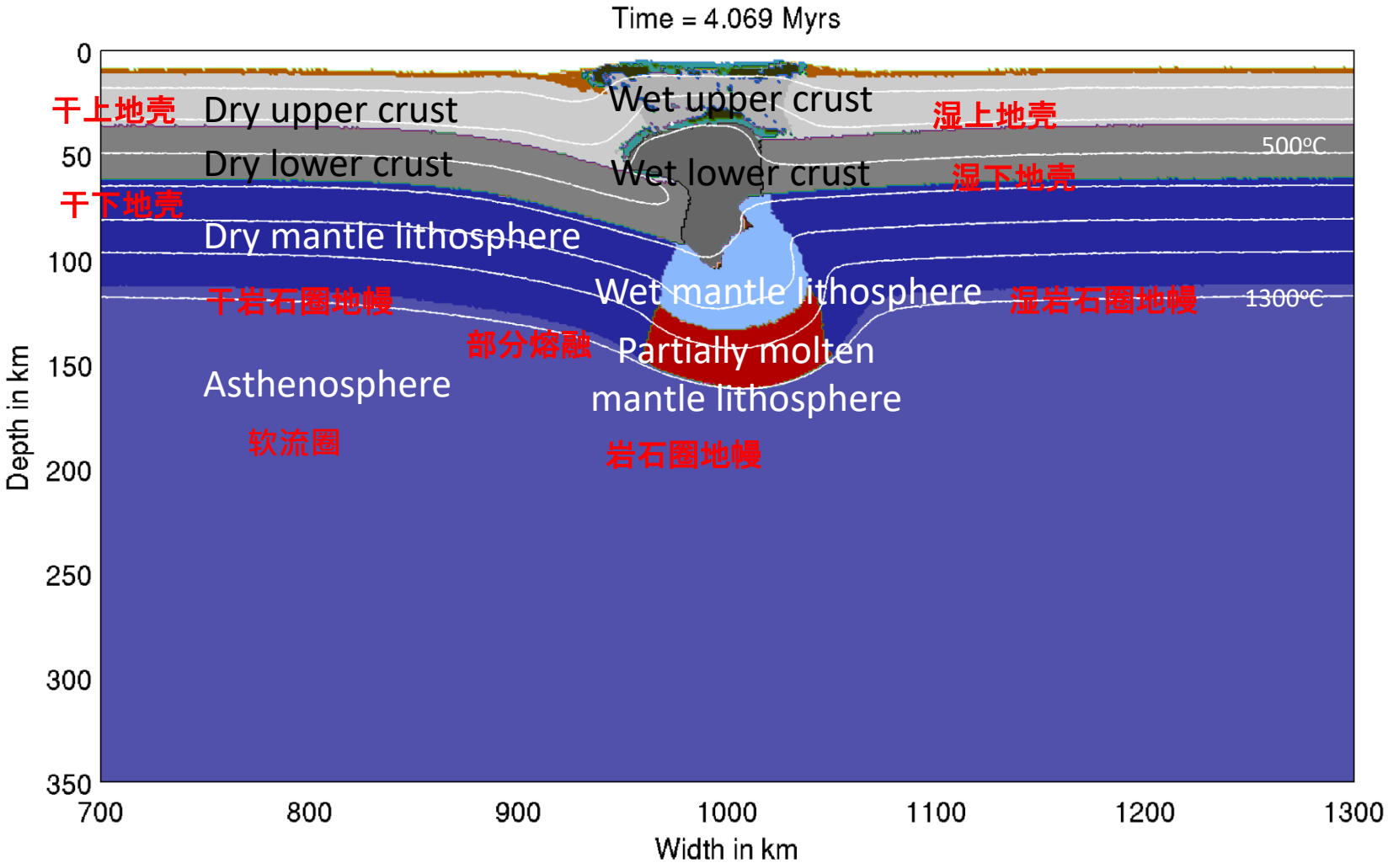
Intra-plate tectonics and magmatisim associated with it

板内构造与相关岩浆活动

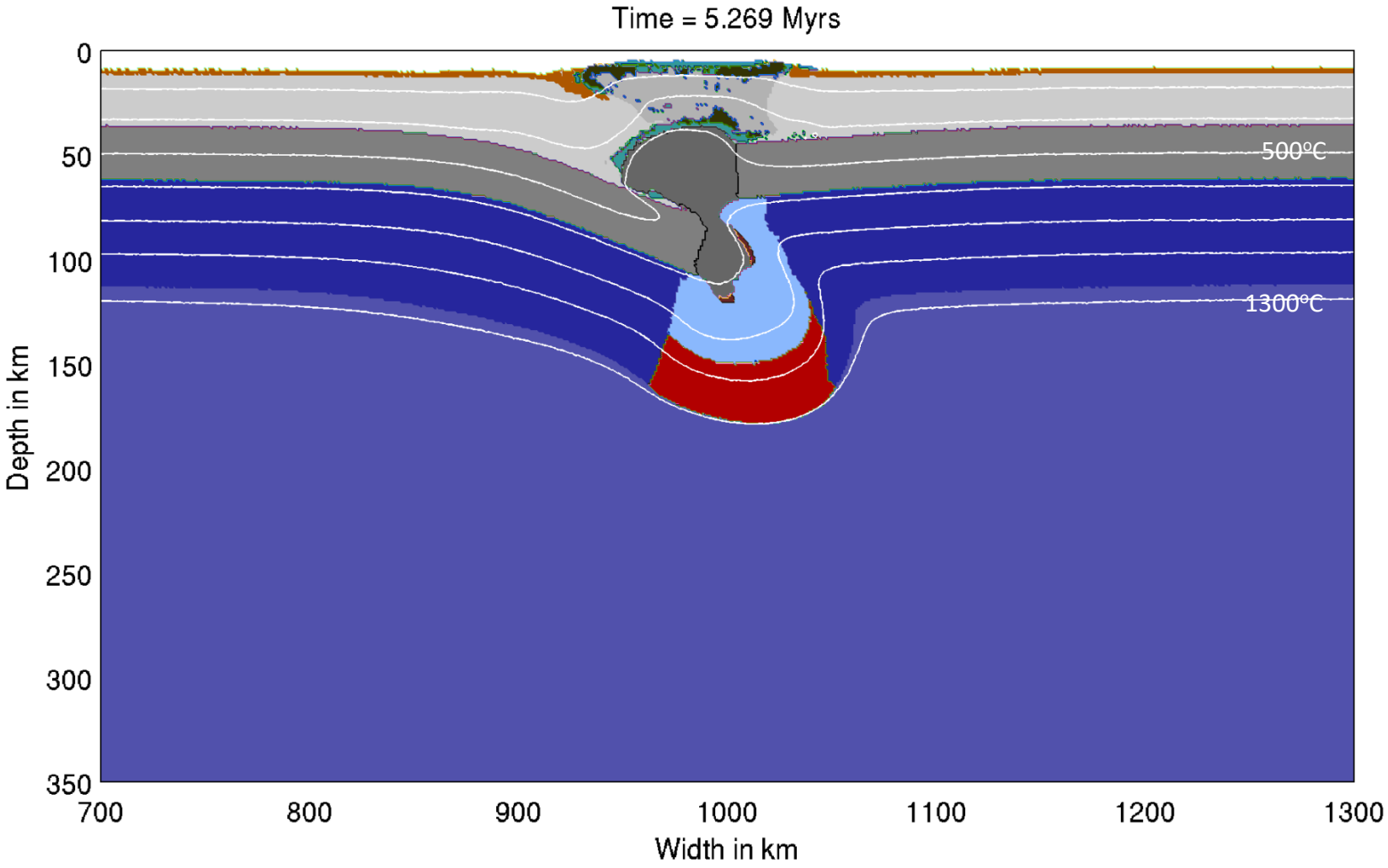
Weronika Gorczyk

Rayleigh-Taylor Instability

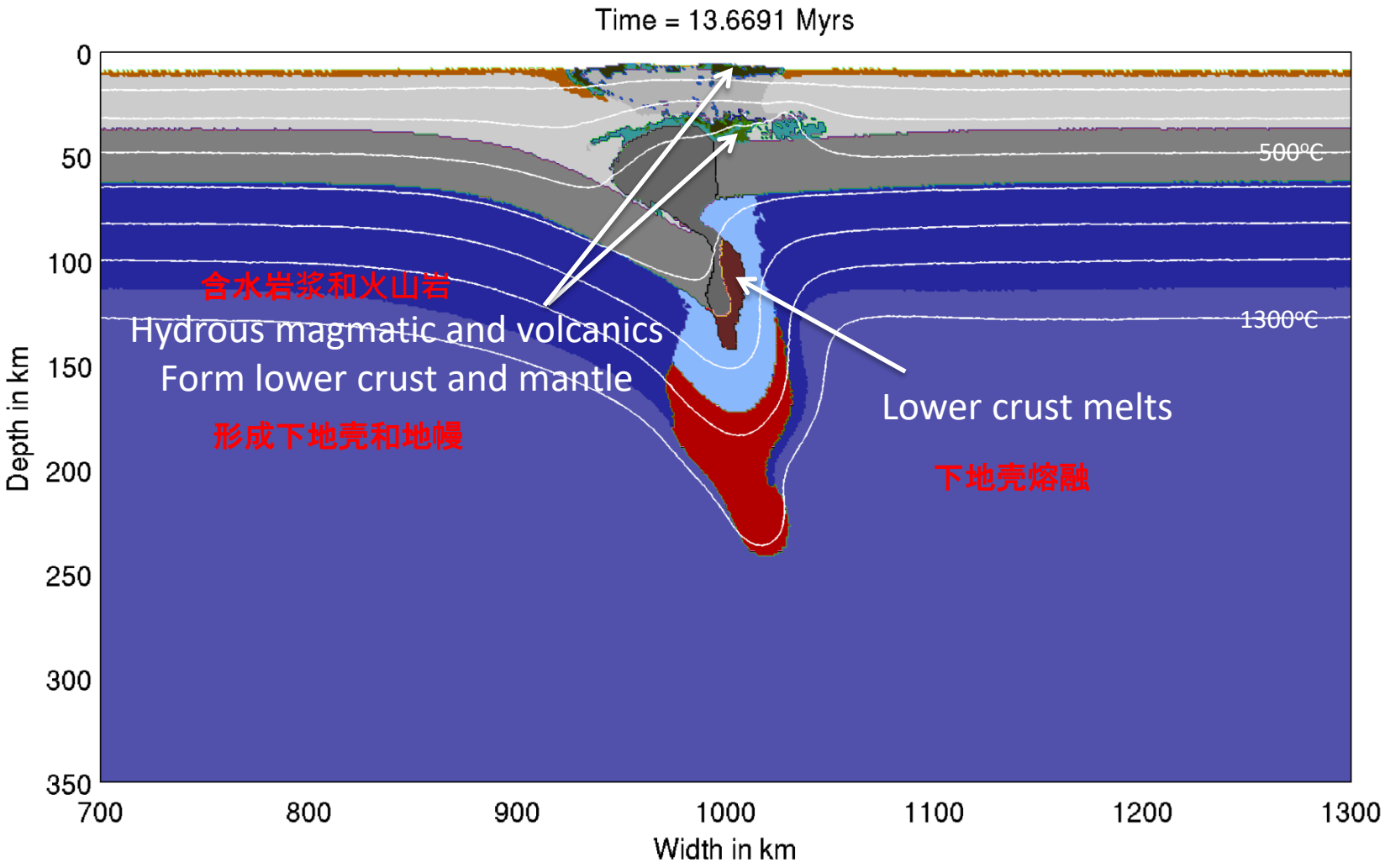
瑞丽-泰勒不稳定



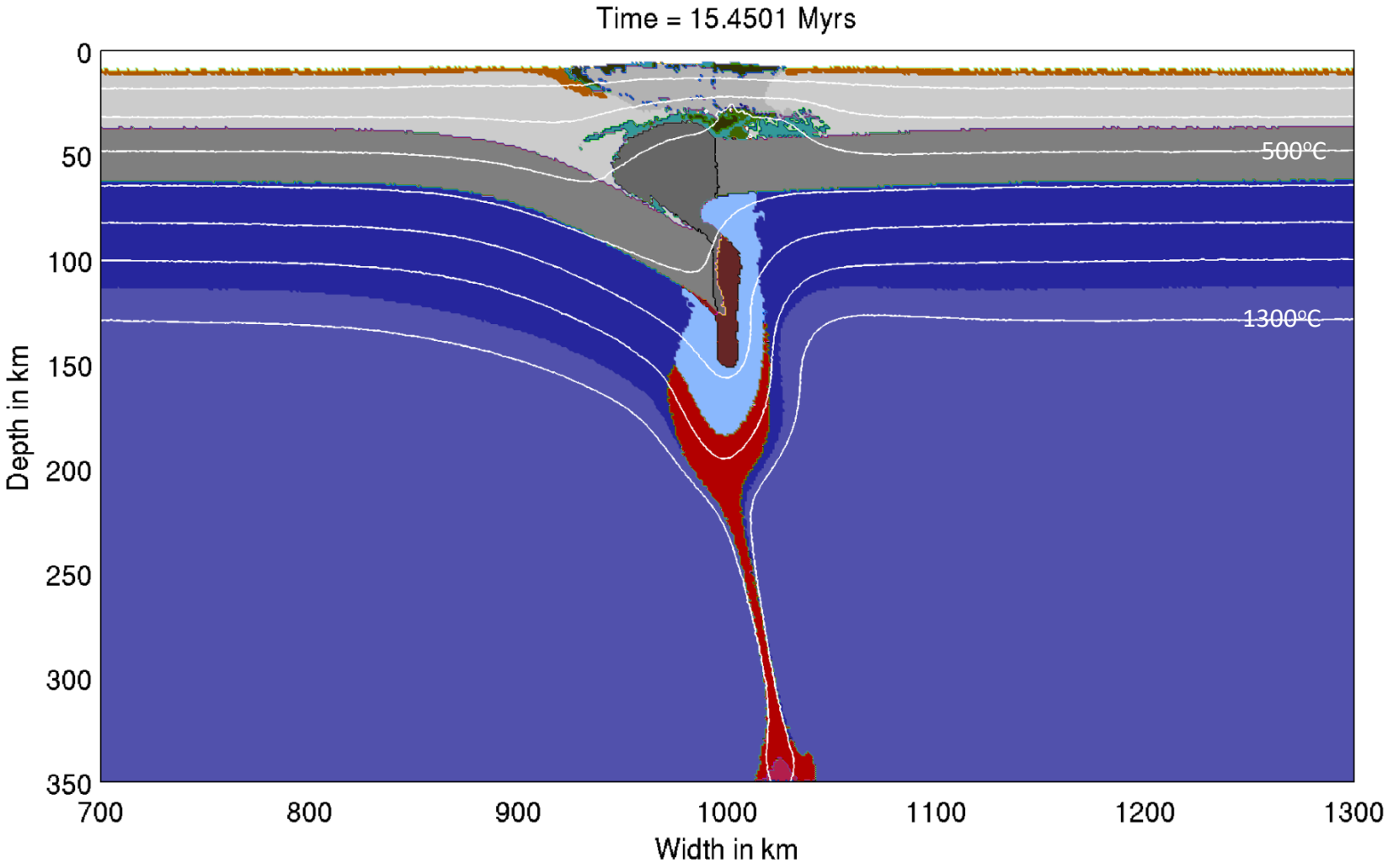
Rayleigh-Taylor Instability



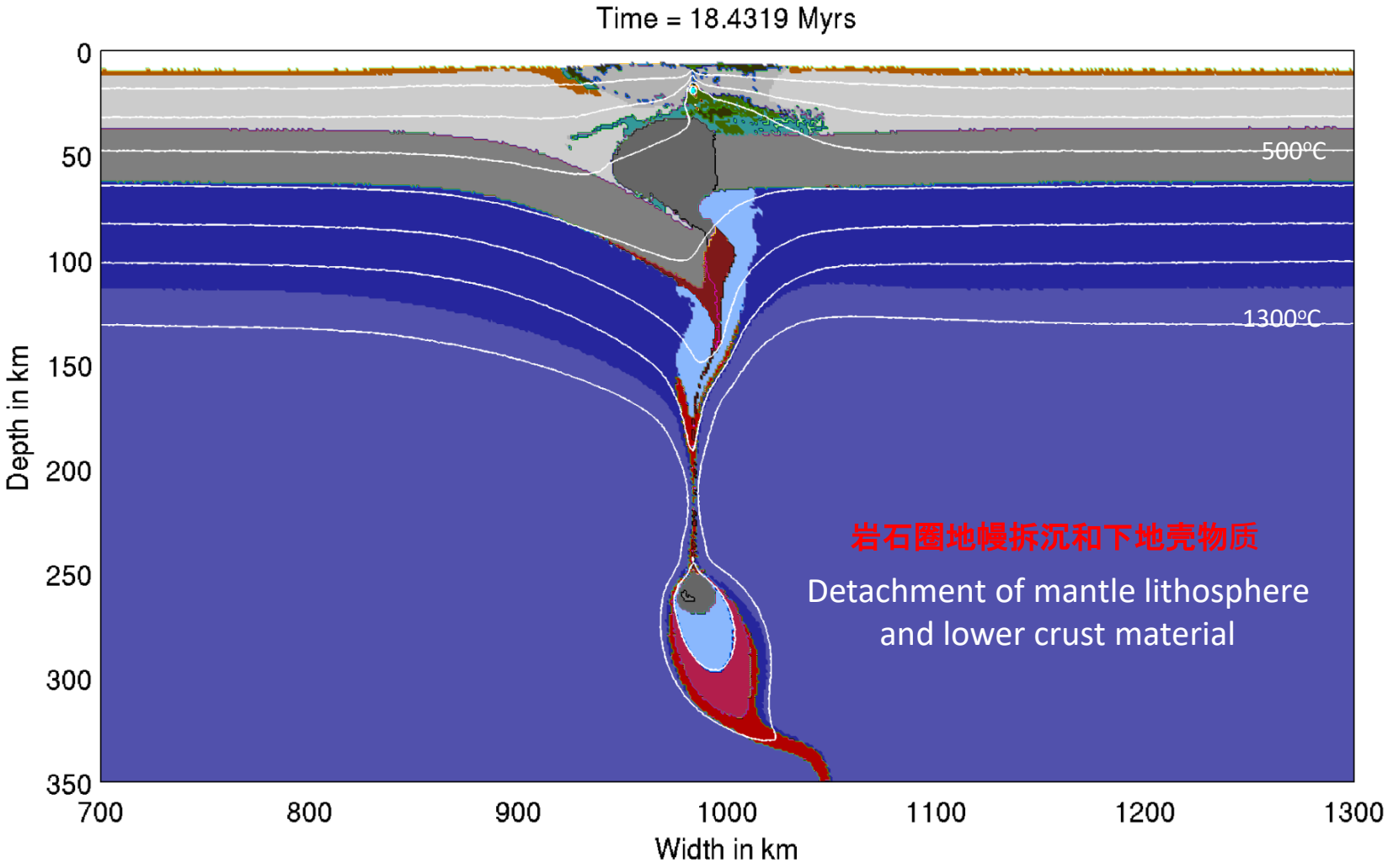
Rayleigh-Taylor Instability



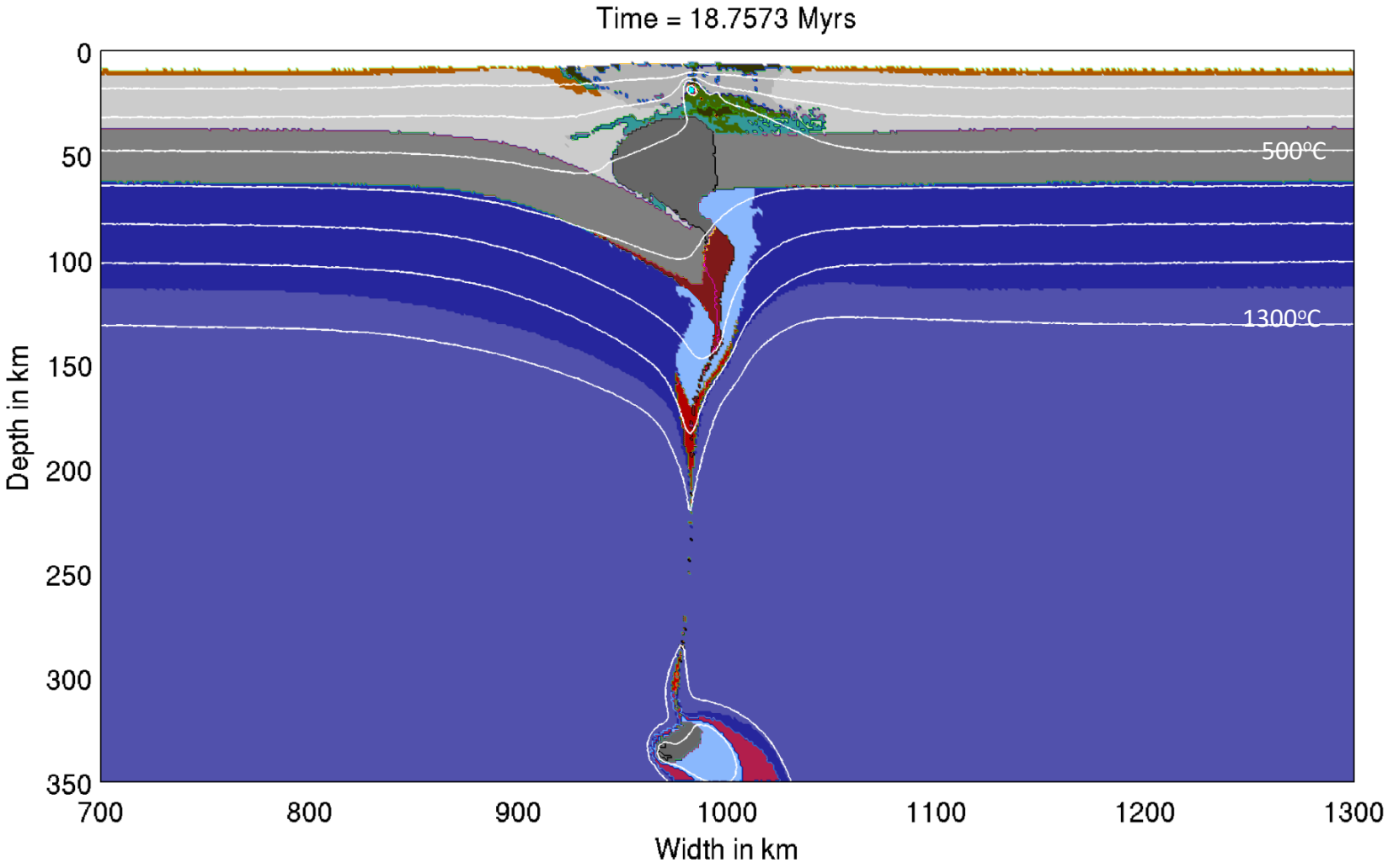
Rayleigh-Taylor Instability



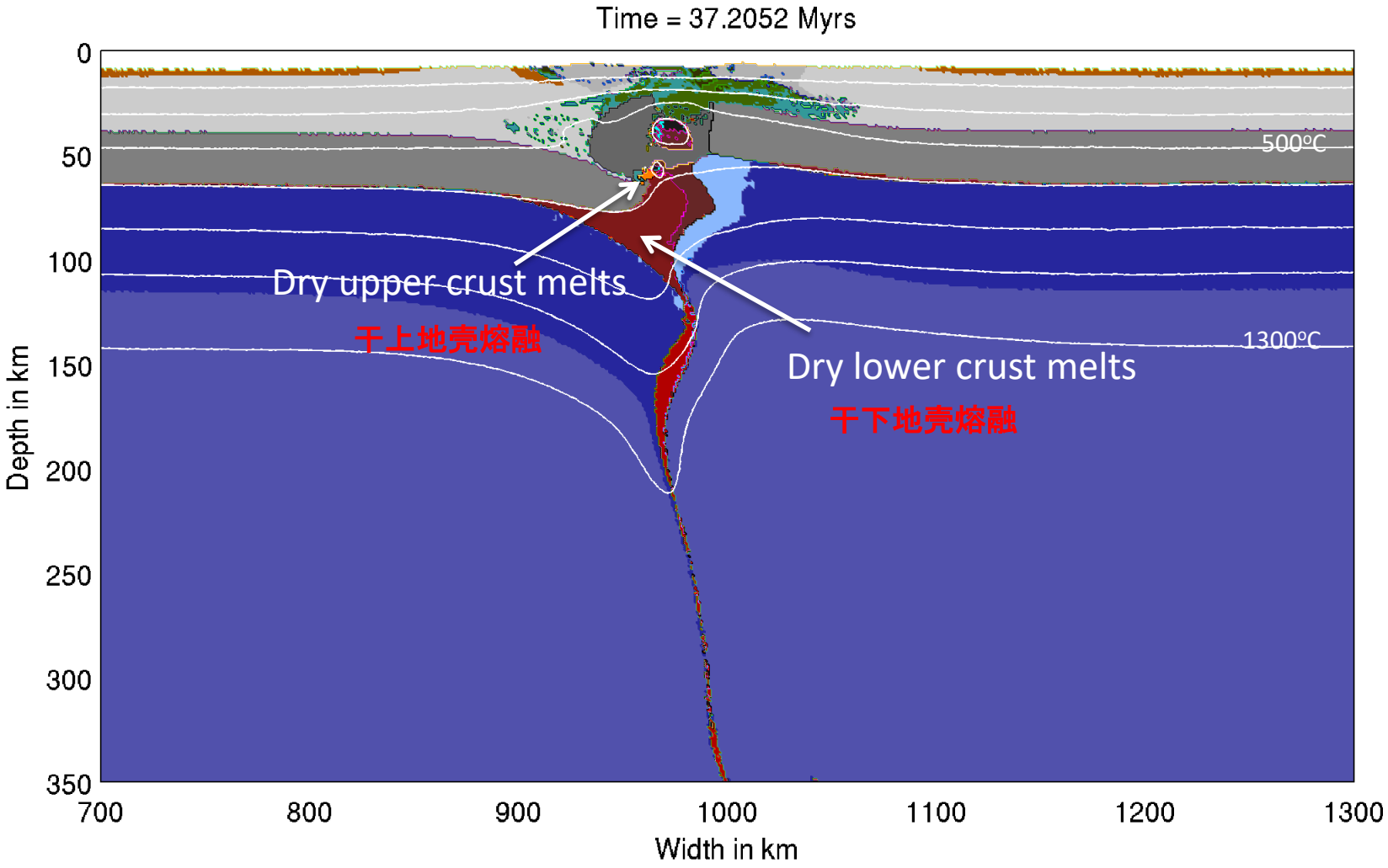
Rayleigh-Taylor Instability



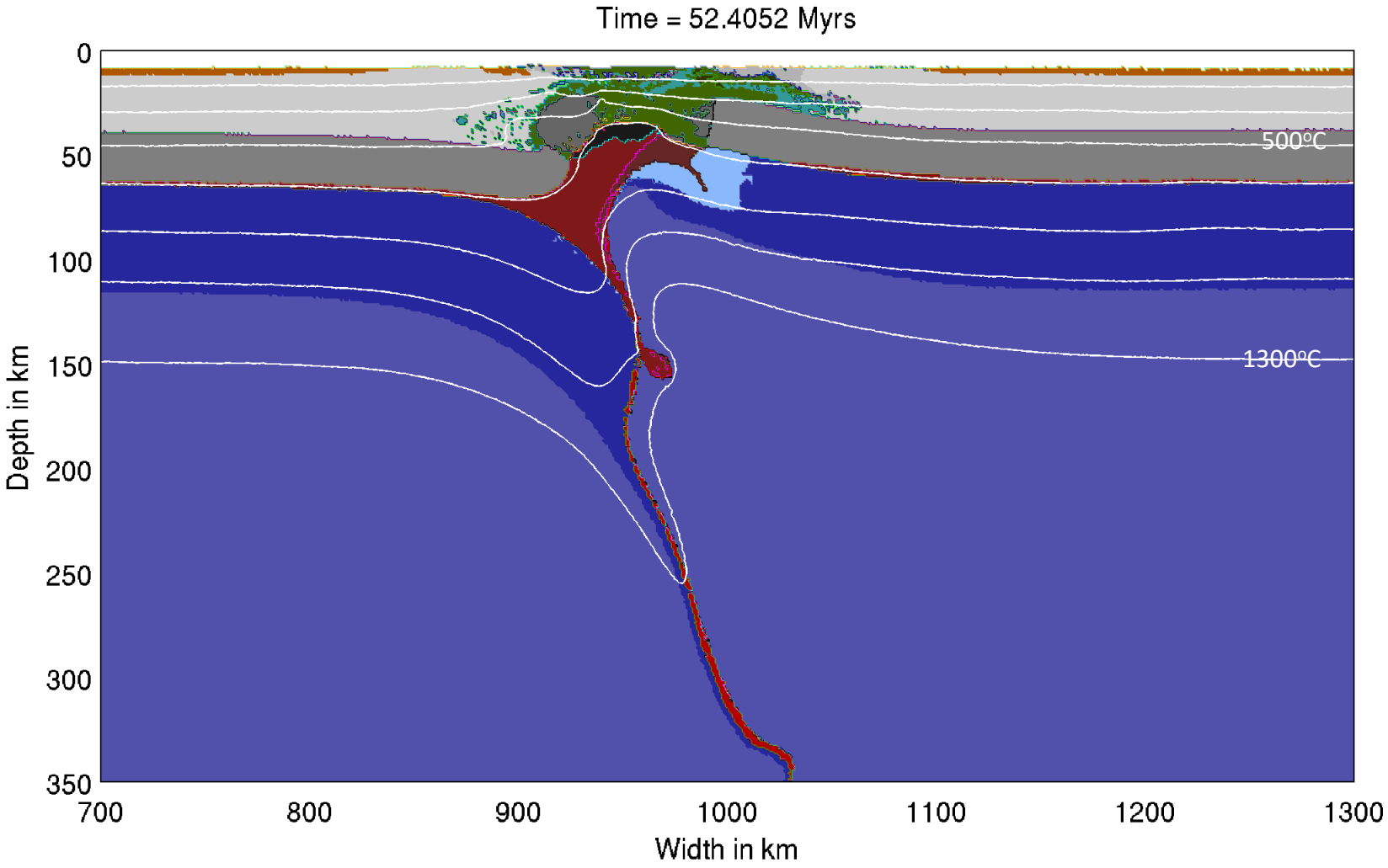
Rayleigh-Taylor Instability

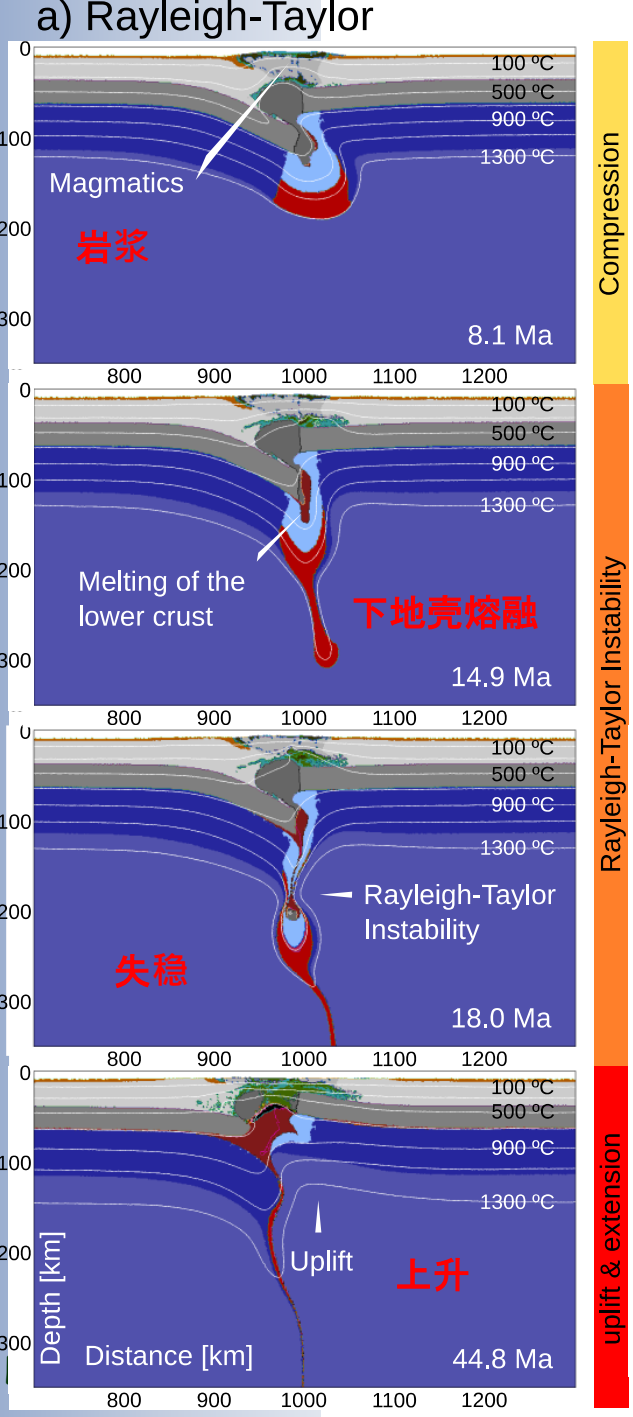


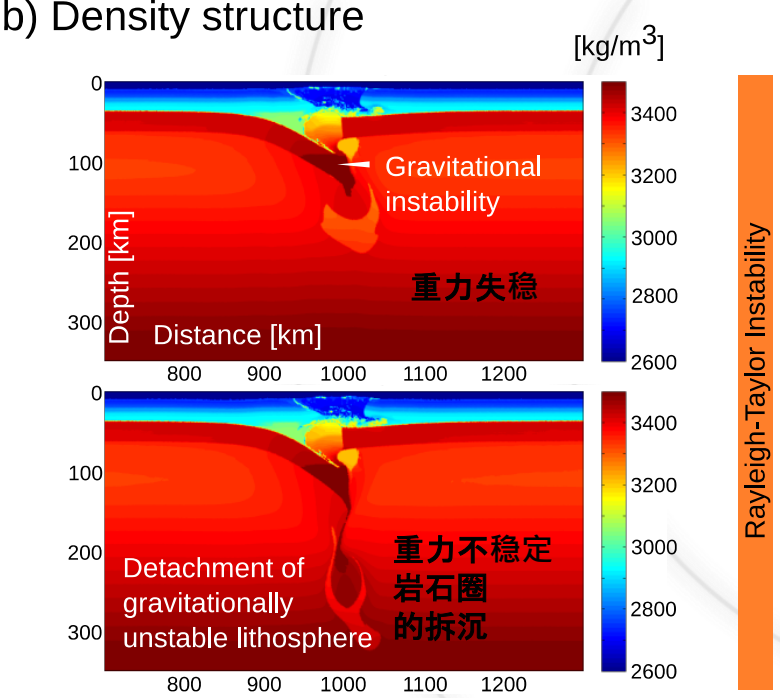
Rayleigh-Taylor Instability

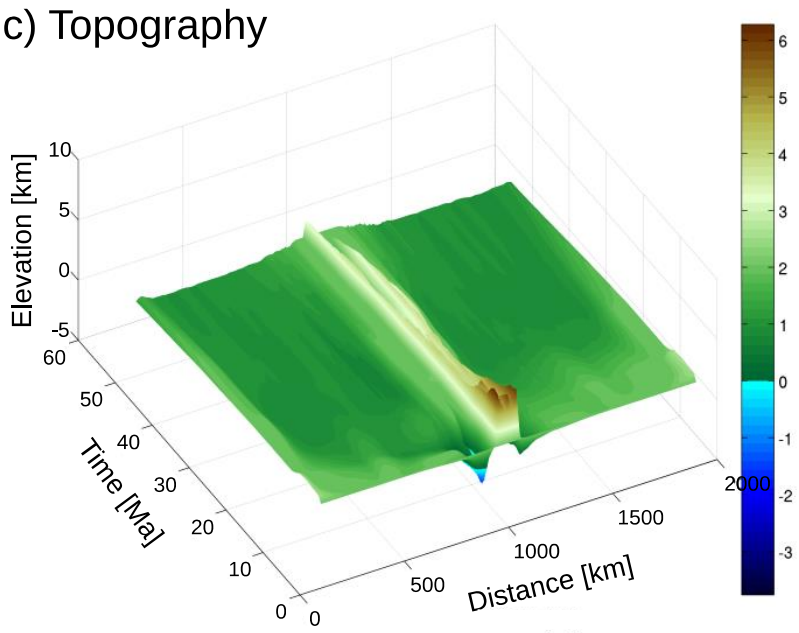


Rayleigh-Taylor Instability

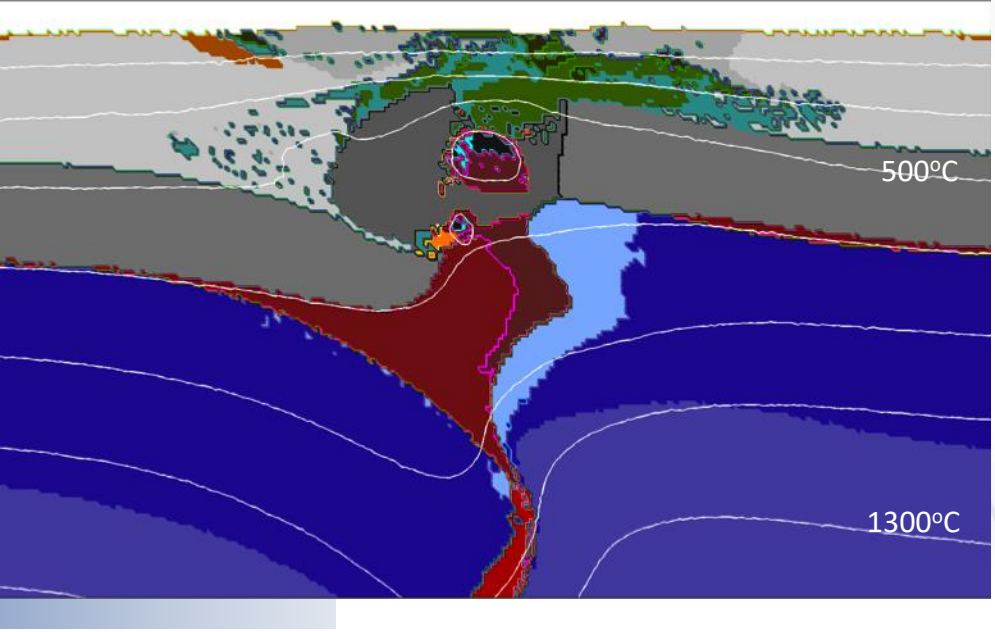



a) Rayleigh-Taylor
100 °C
500 °C
900 °C
1300 °C
Magmatics
岩浆
8.1 Ma
Melting of the lower crust
下地壳熔融
14.9 Ma
Rayleigh-Taylor Instability
失稳
18.0 Ma
Uplift
上升
Depth [km]
Distance [km]
44.8 Ma
0
100
200
300
800
900
1000
1100
1200
Compression
Rayleigh-Taylor Instability
uplift & extension


b) Density structure
[kg/m3]
Gravitational instability
重力失稳
Depth [km]
Distance [km]
Detachment of gravitationally unstable lithosphere
重力不稳定岩石圈的拆沉
3400
3200
3000
2800
2600
Rayleigh-Taylor Instability


c) Topography
Elevation [km]
Time [Ma]
Distance [km]

2015

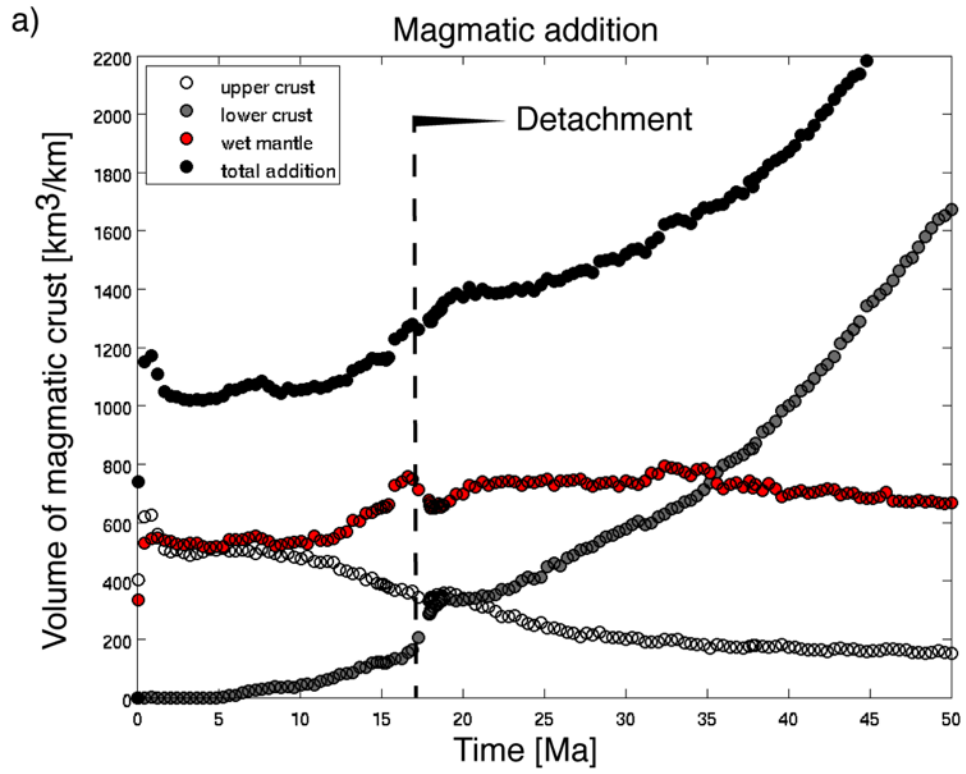


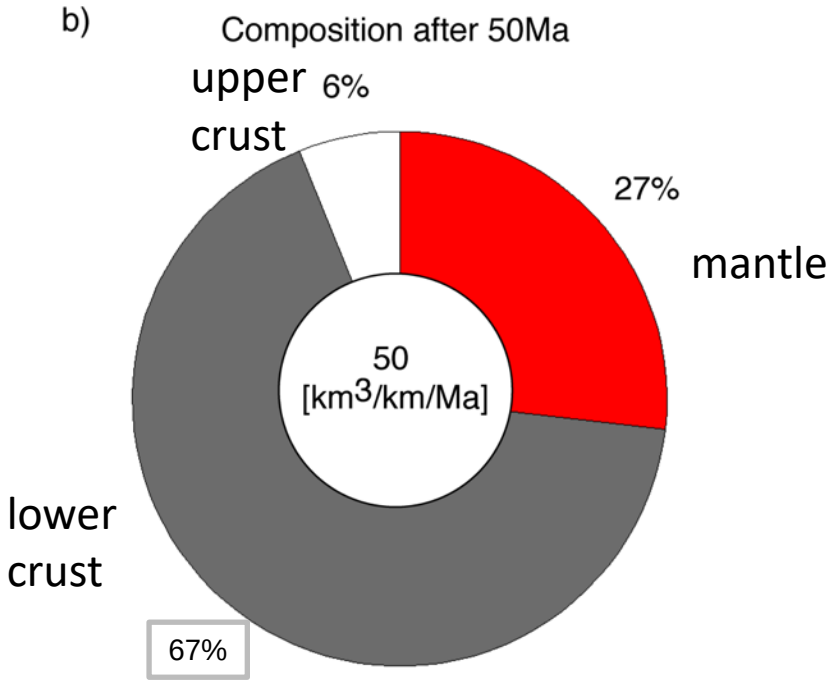
新生地壳多在拆沉后生成-下地壳熔融主导过程

Generation of new crust happens mostly after detachment – dominated my melting of the lower crust

新地壳

New crust





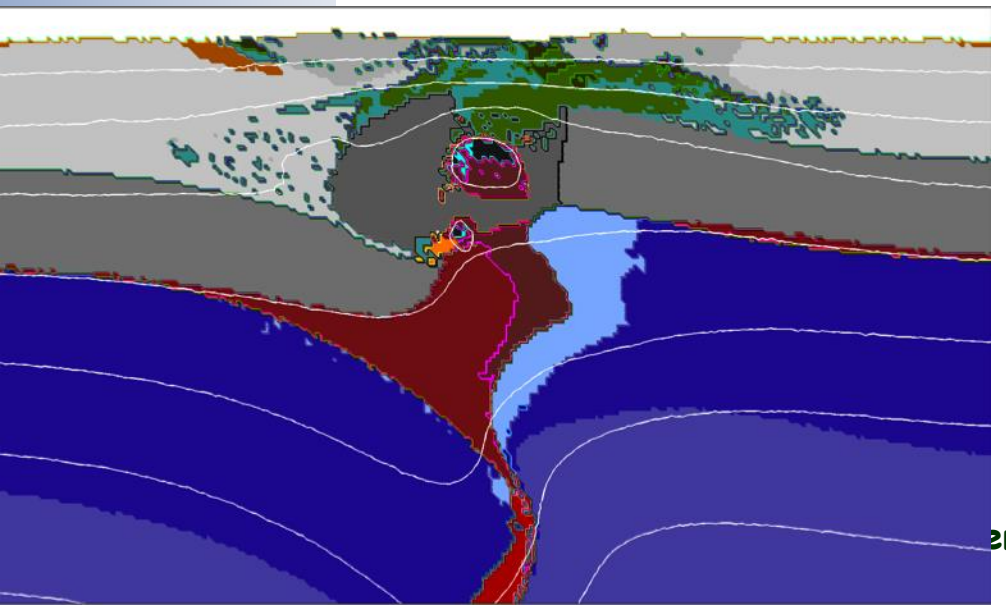
Modeling vs geology 建模VS地质

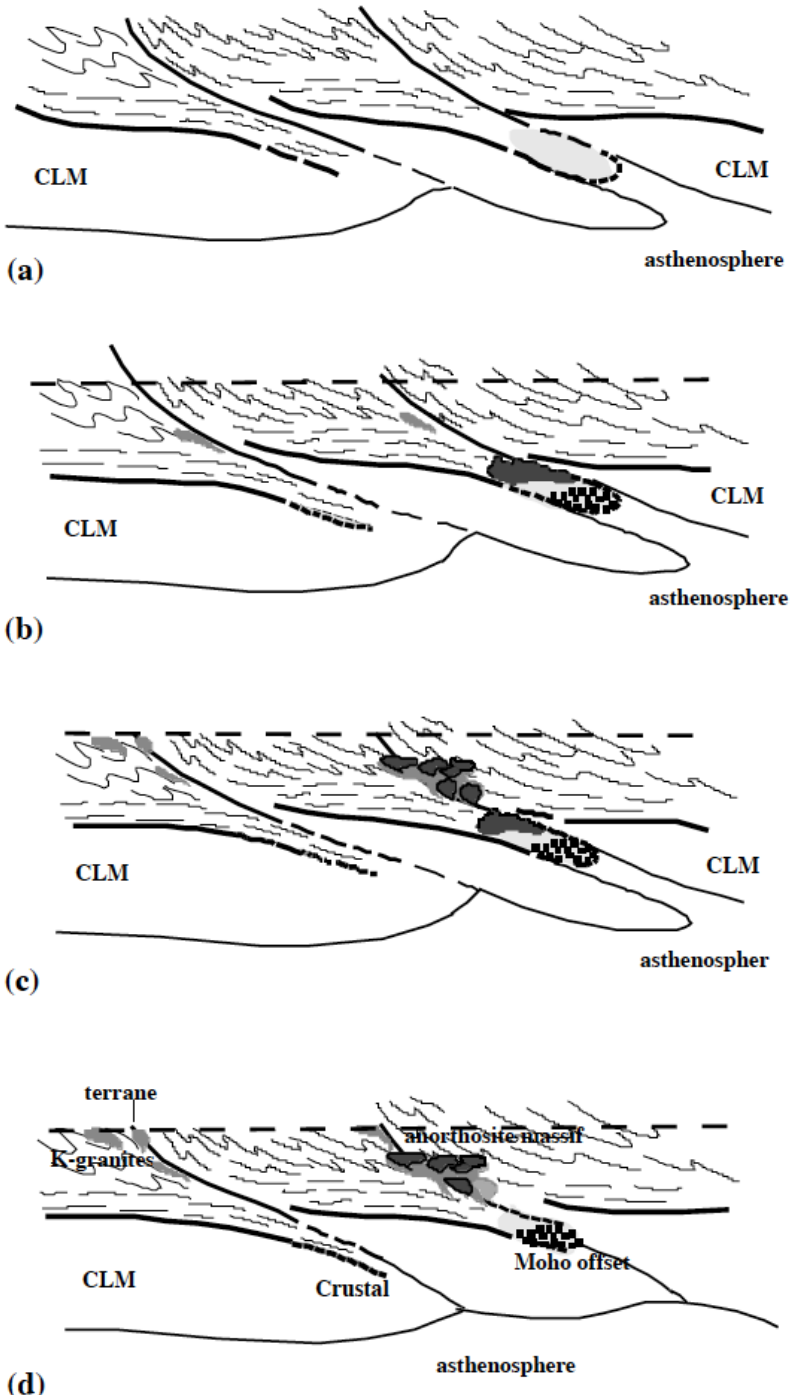
与地壳特征相关的厚大斜长岩省

Masive **anorthosite provinces** associated long crustal lineaments :

- the Lac St Jean and Havre-St. Pierre anorthosite complexes 斜长杂岩体
- Laramie anorthosite complex拉勒米斜长岩杂岩体
- Suwalki anorthosite苏瓦乌基斜长岩
- AMCG Grenville province (anorthosite, mangerite, charnockite, granite,)

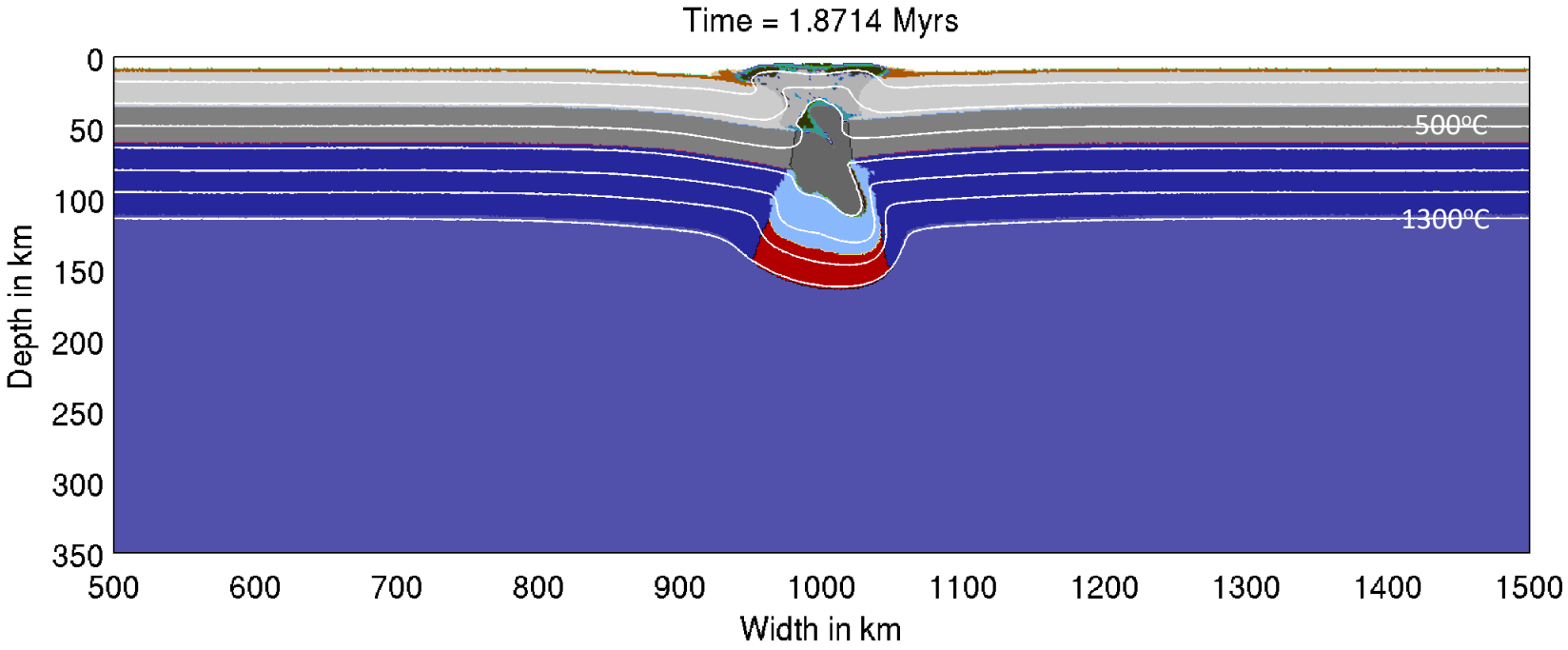
…AMCG格伦维尔省（斜长岩，紫苏花岗岩，花岗岩）





The crustal tongue melting model (after Duchesne et al, Terra Nova, 1999)

Delamination



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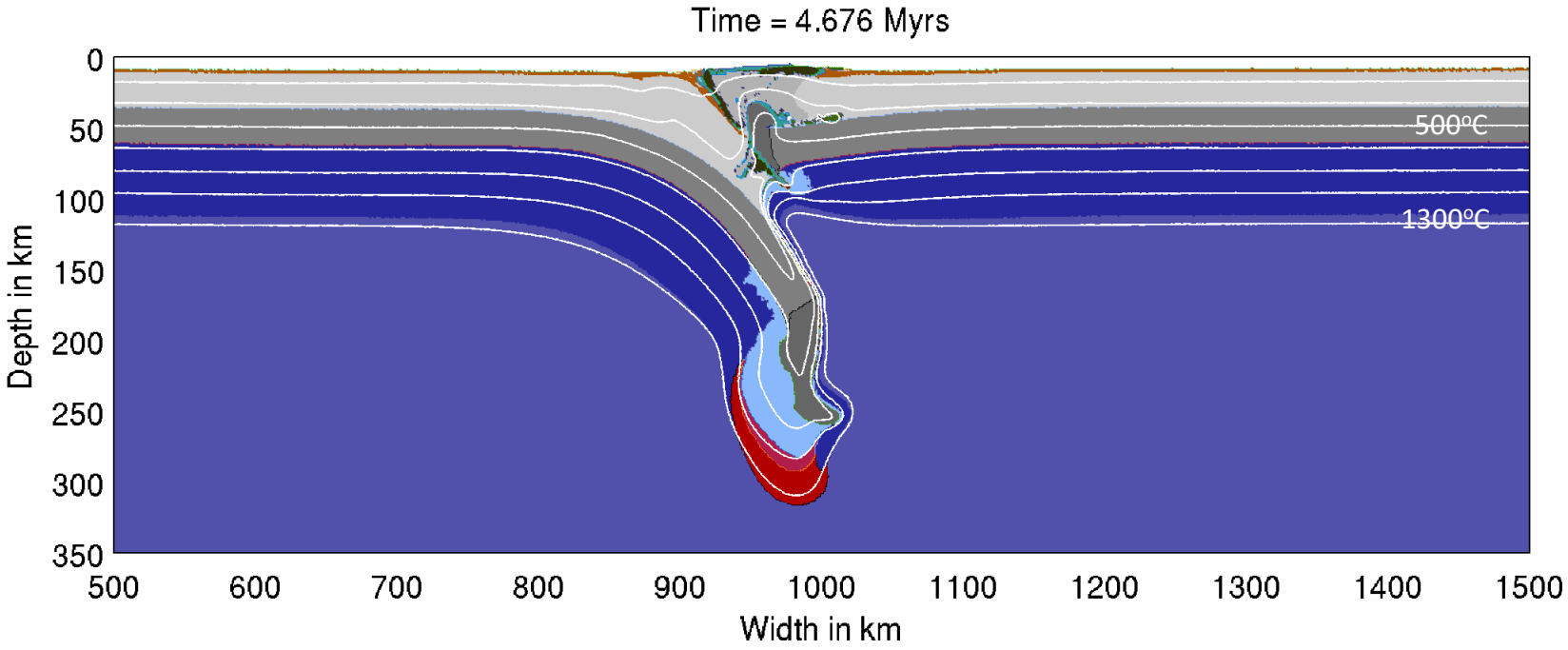
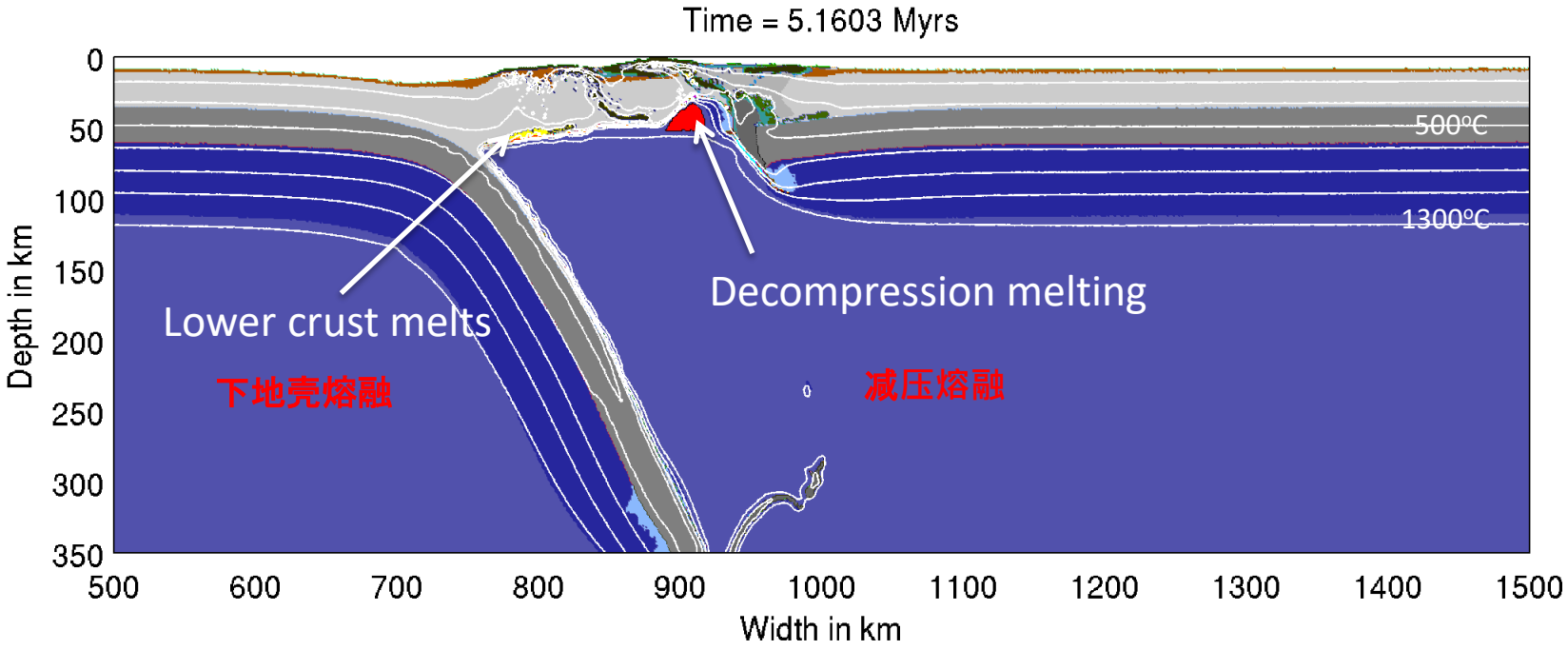


Delamination



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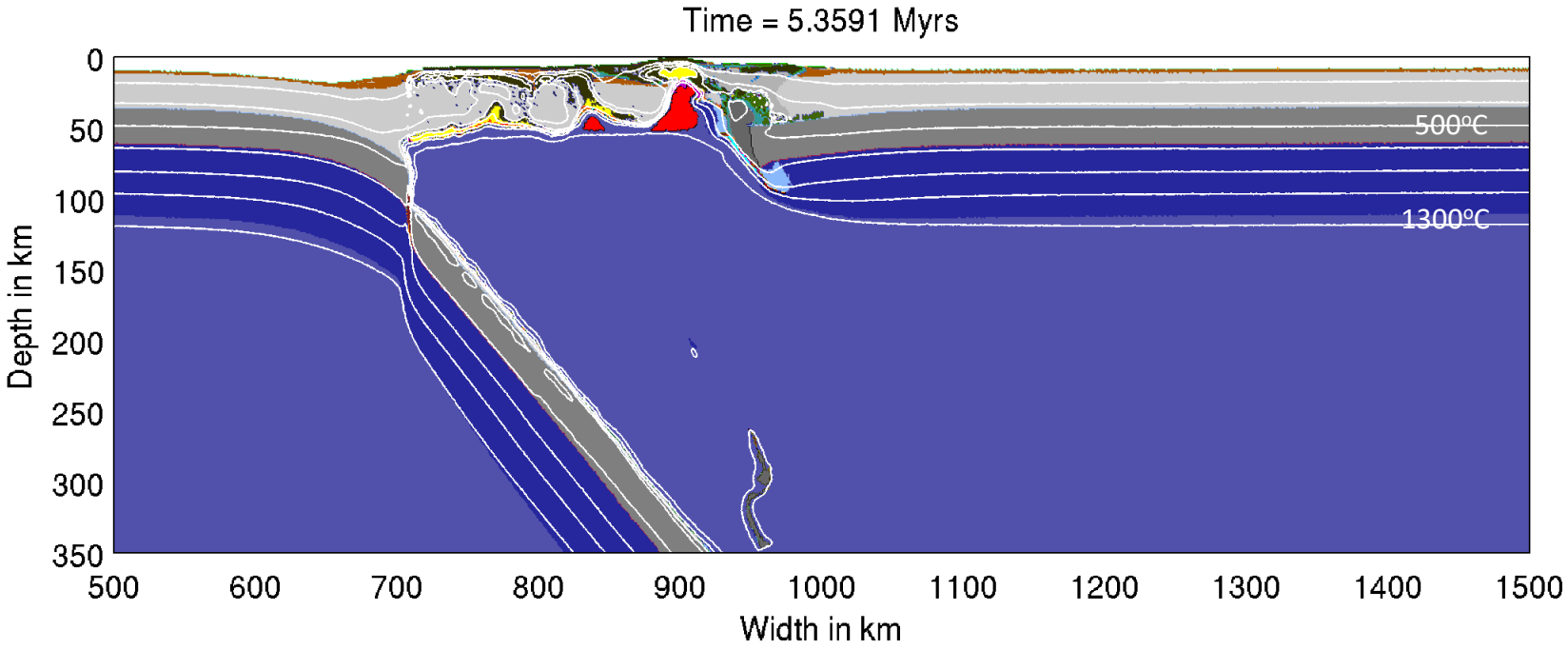
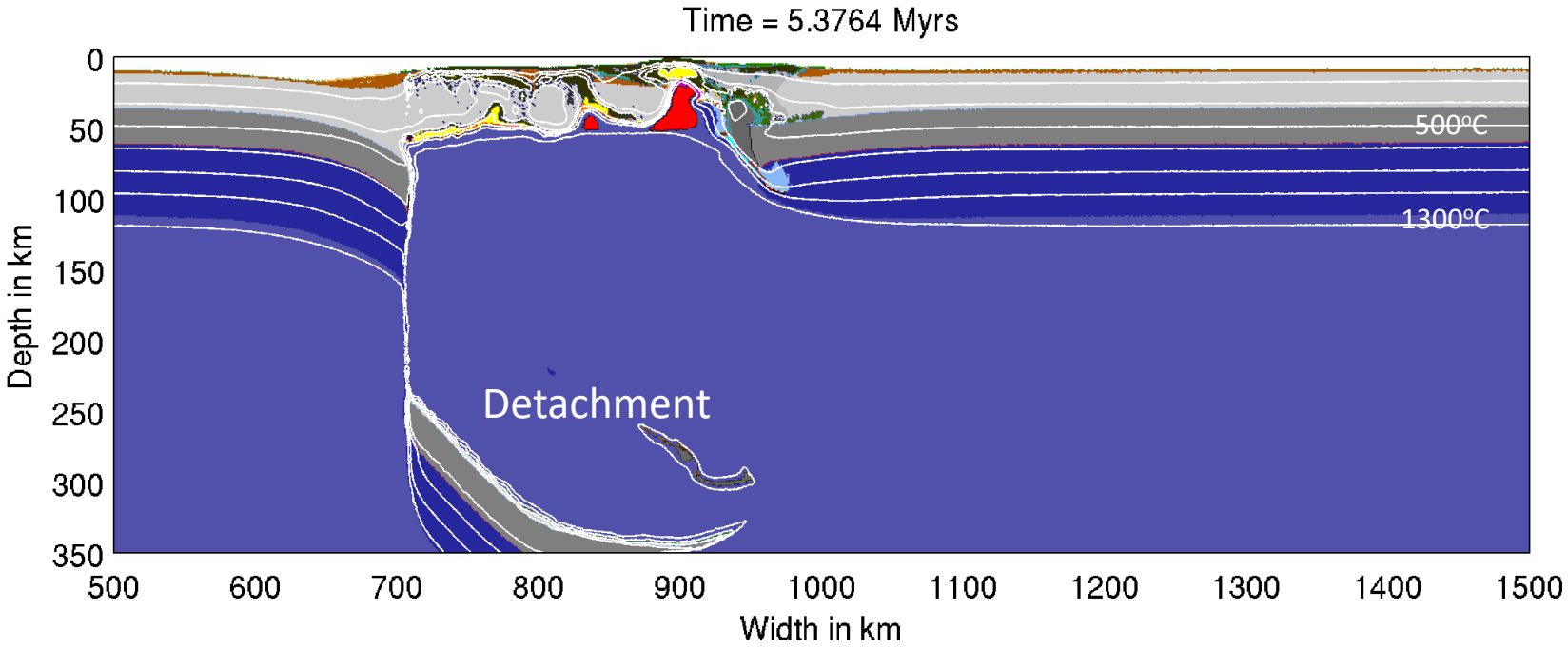


Delamination



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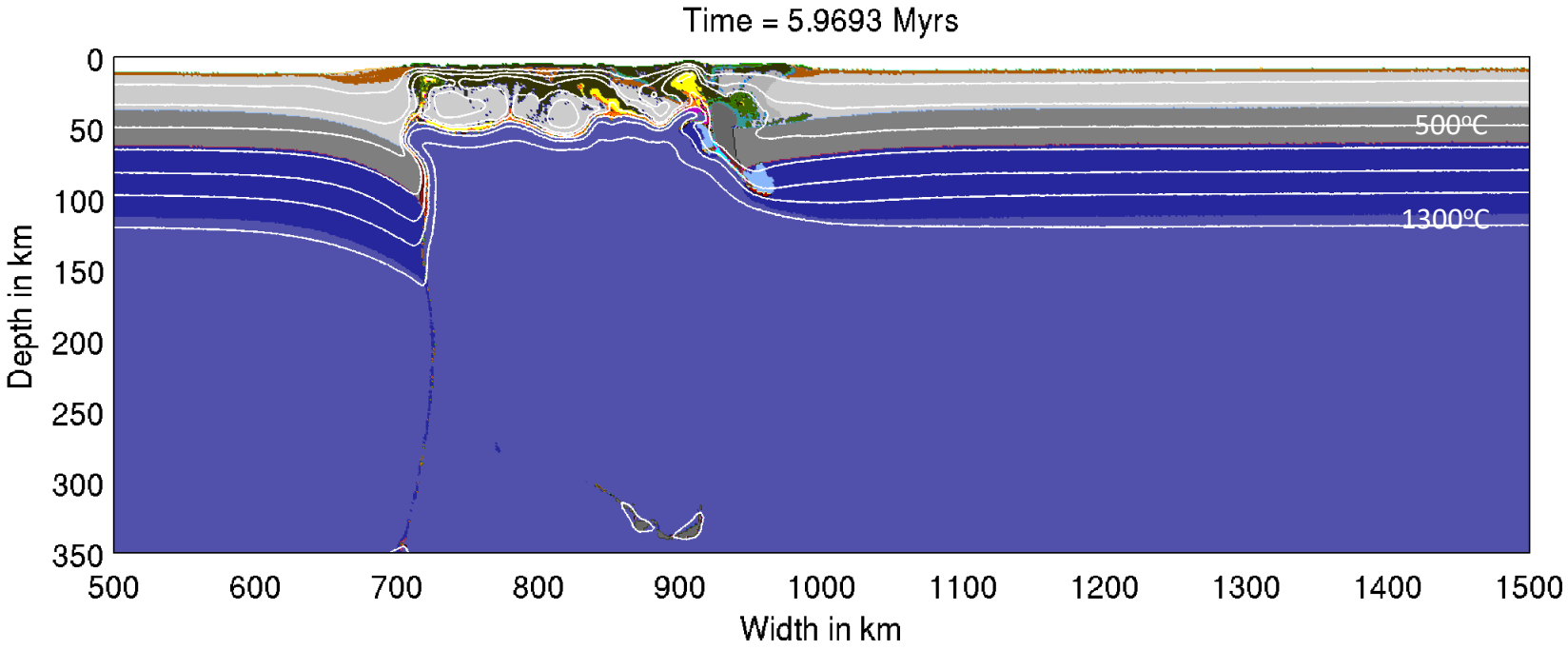

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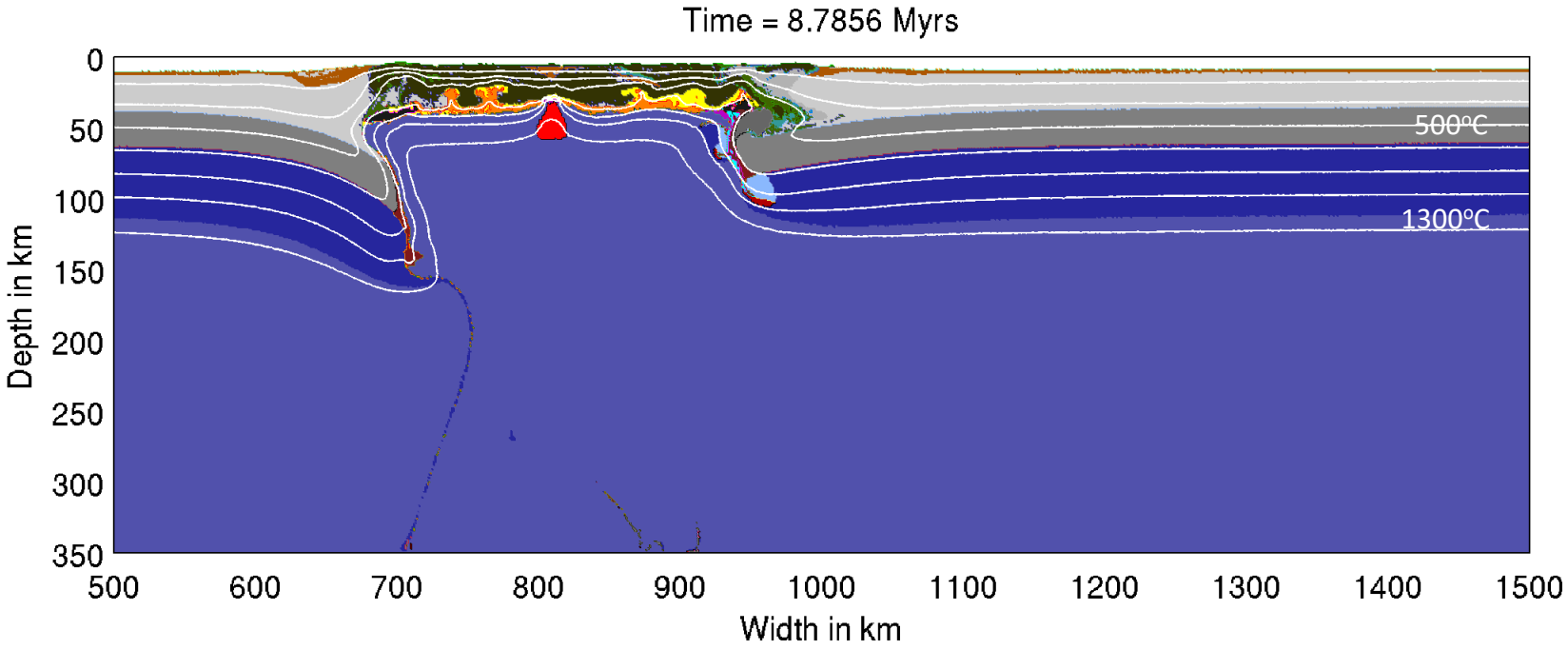

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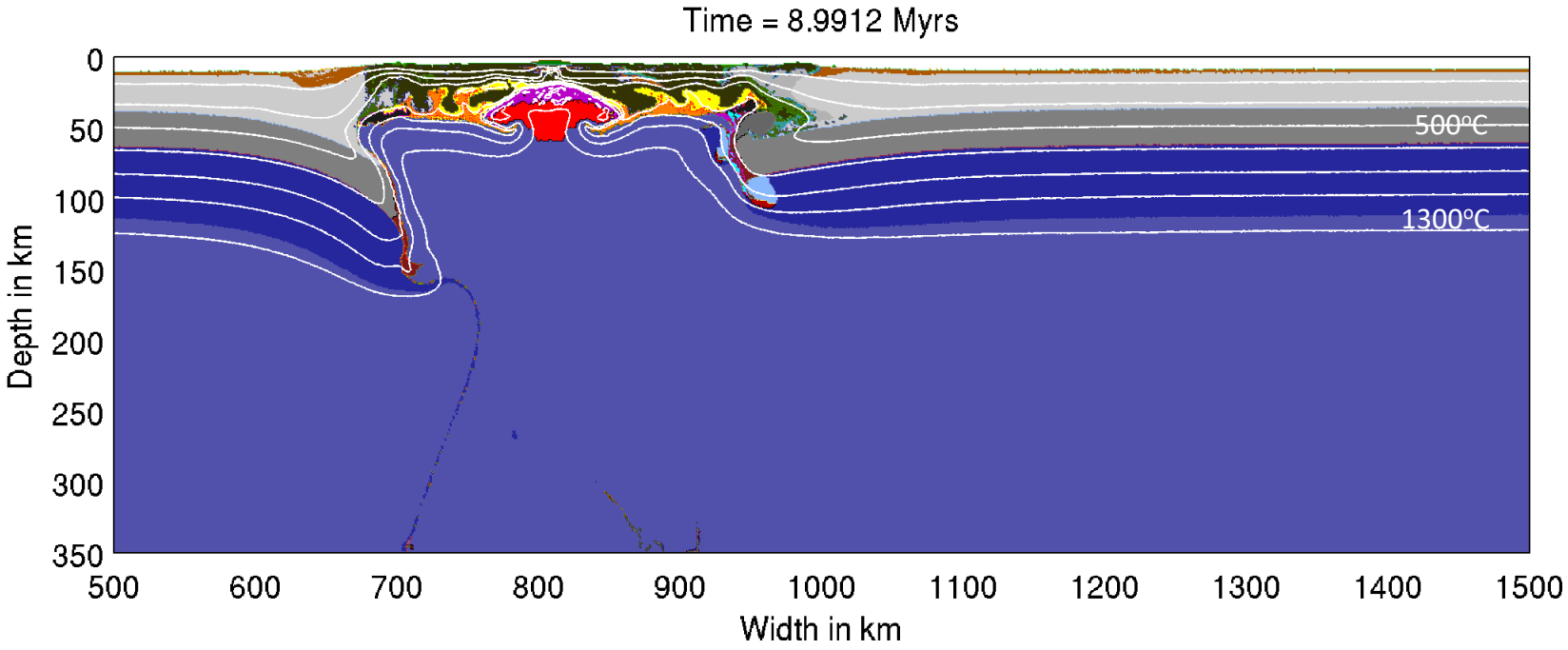

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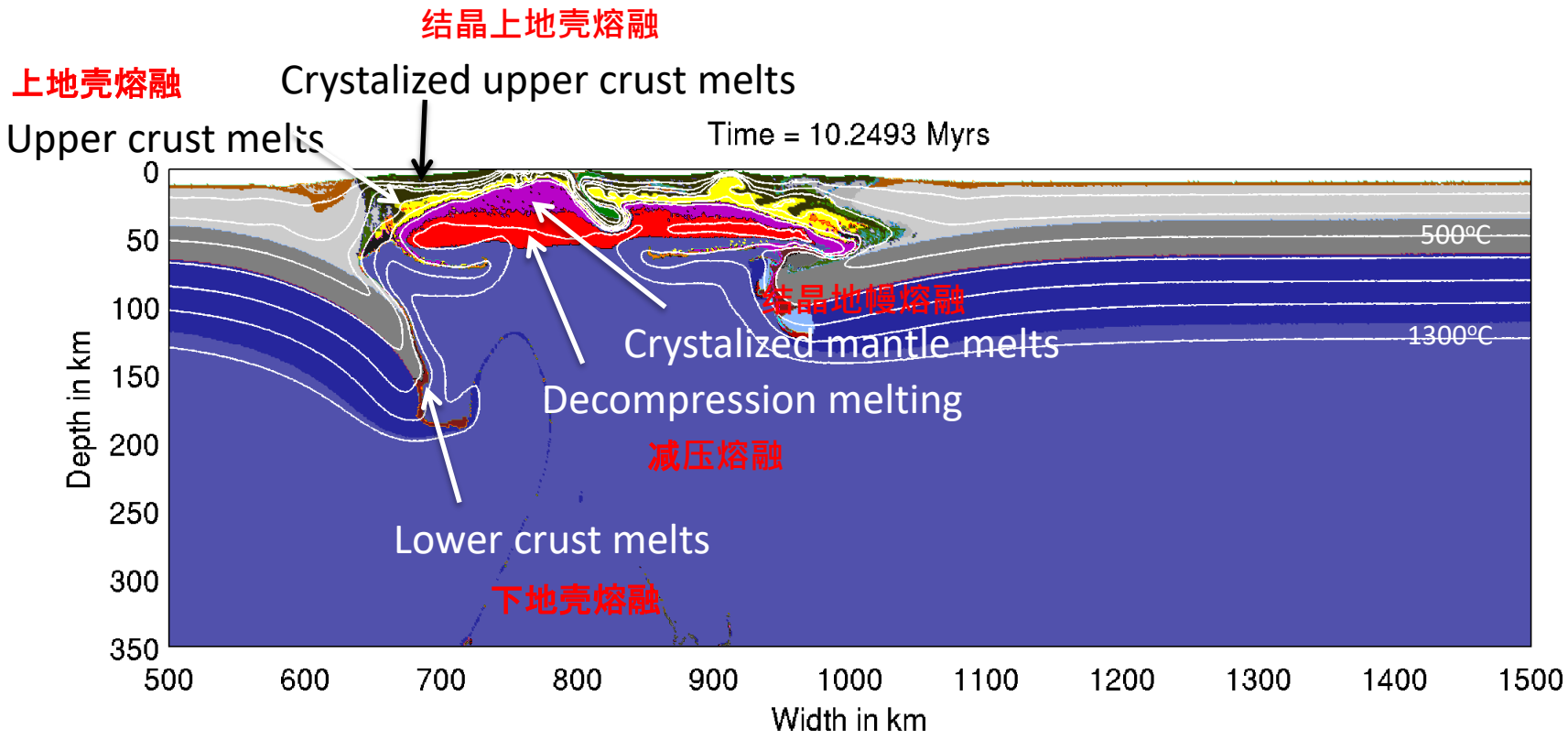

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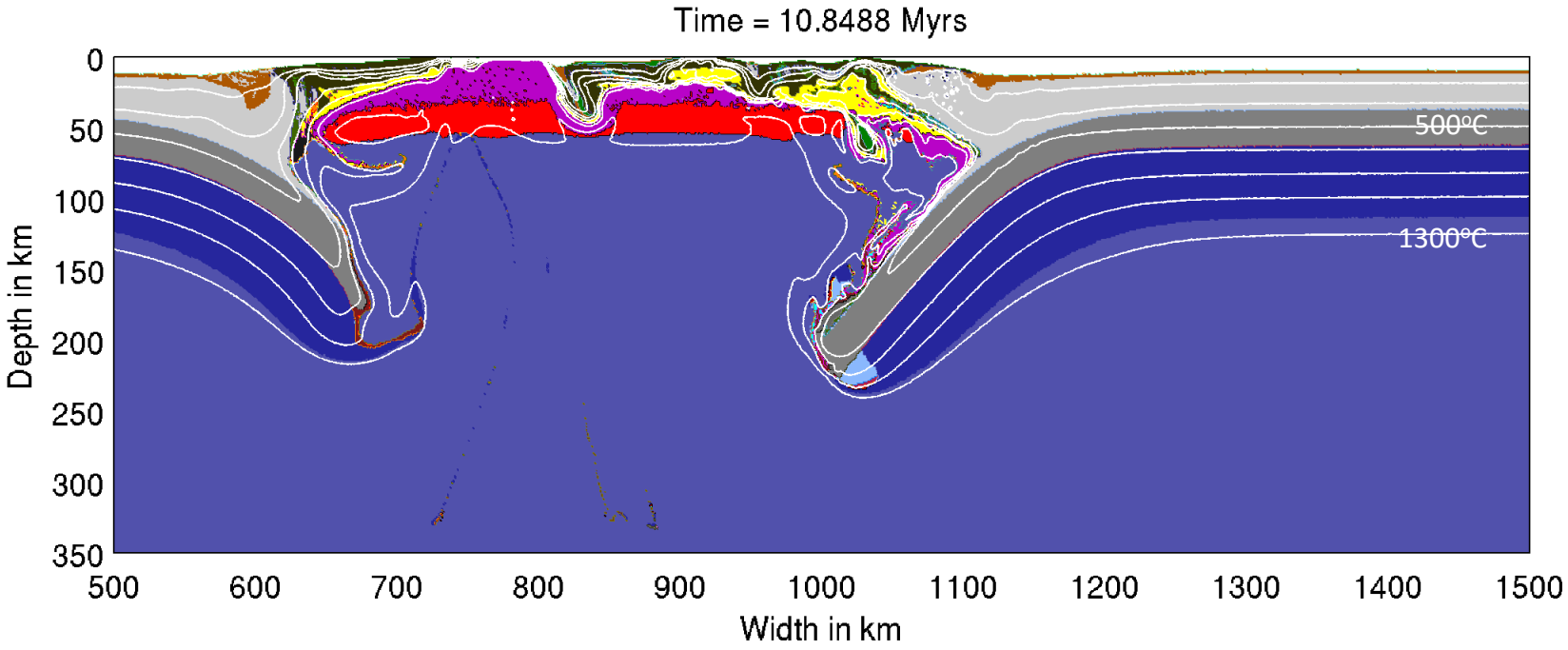

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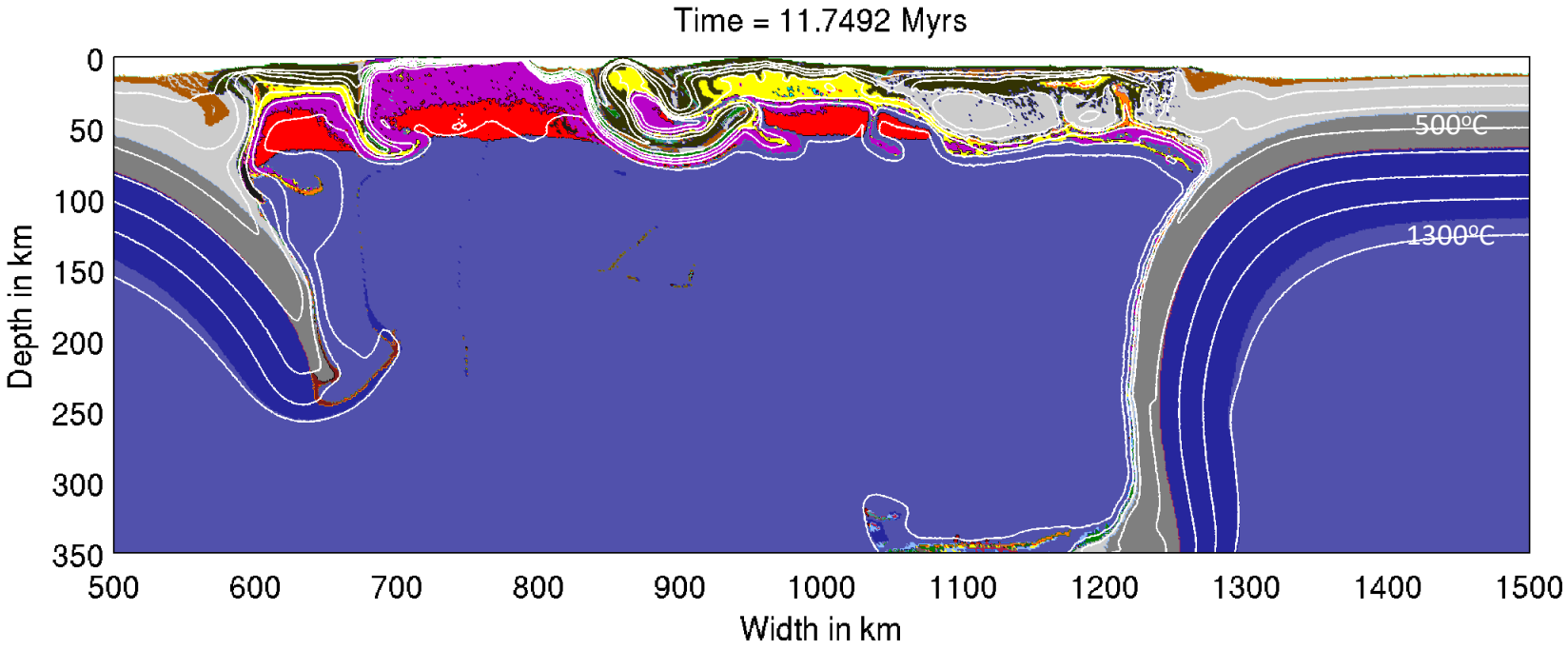

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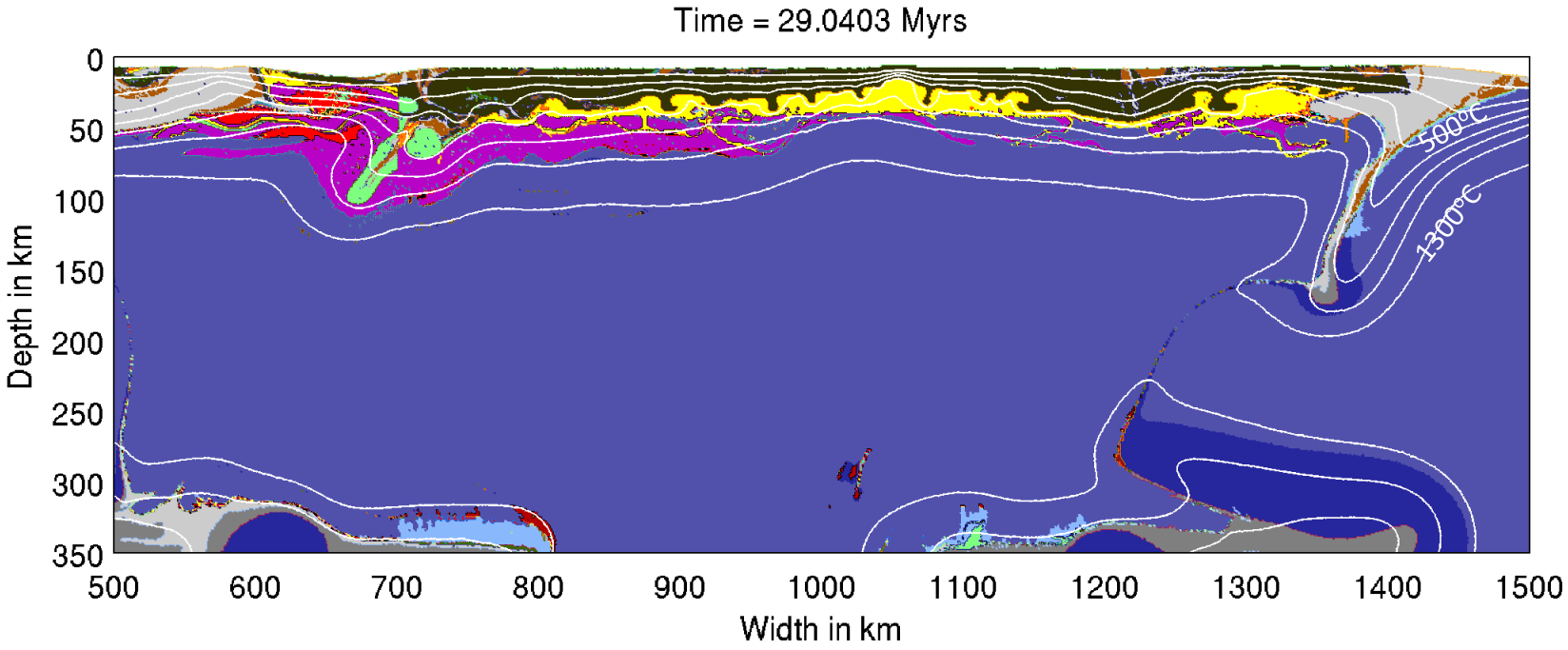
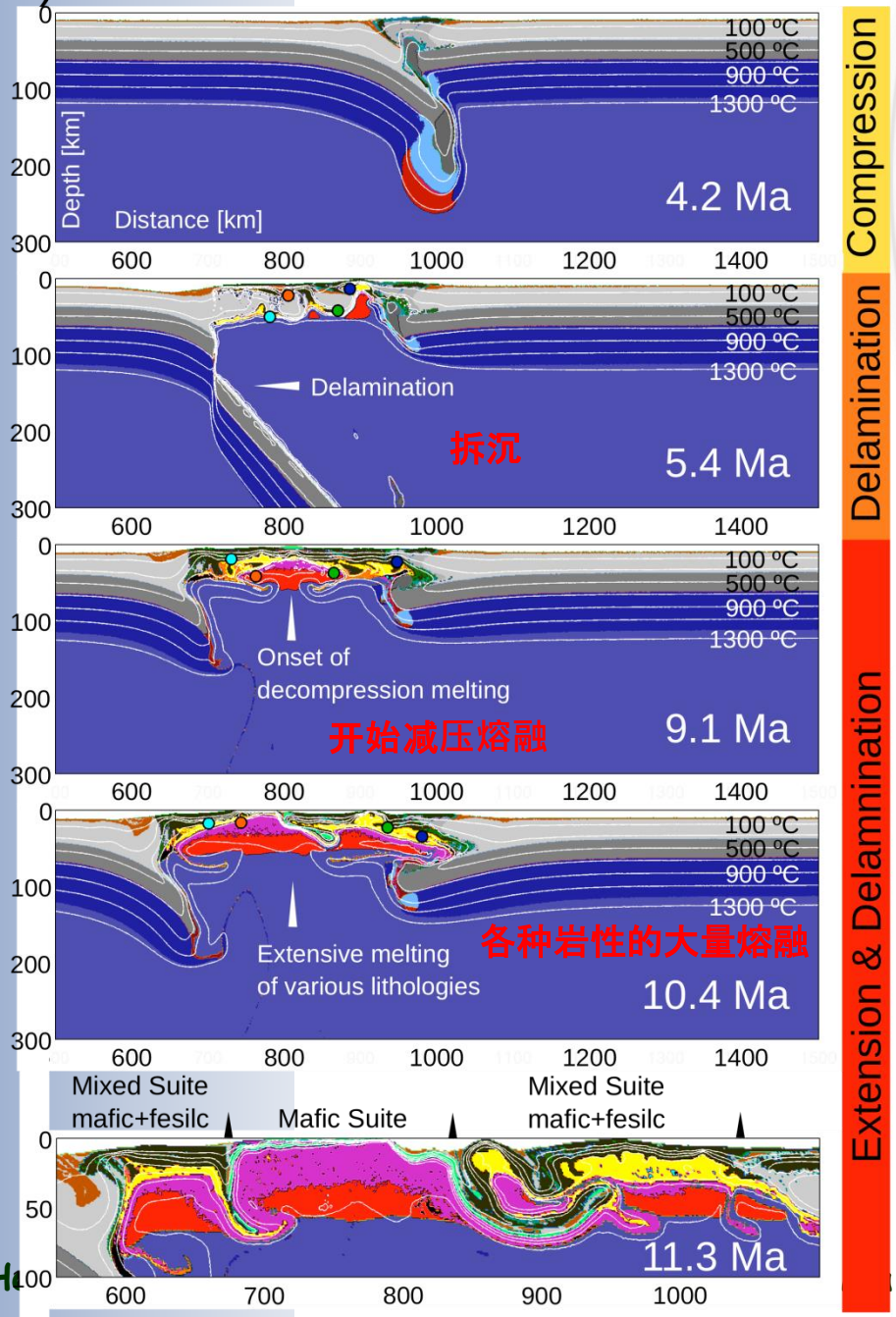
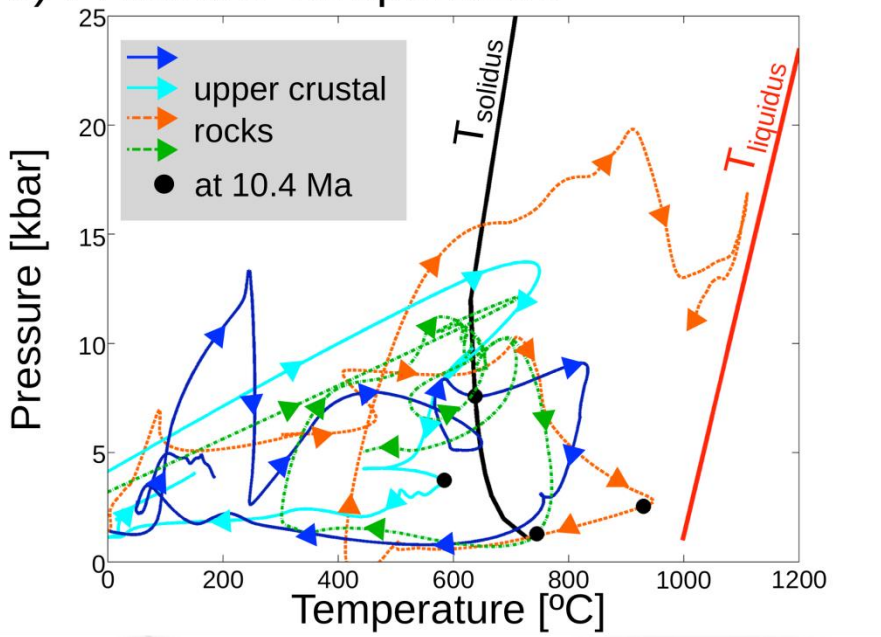
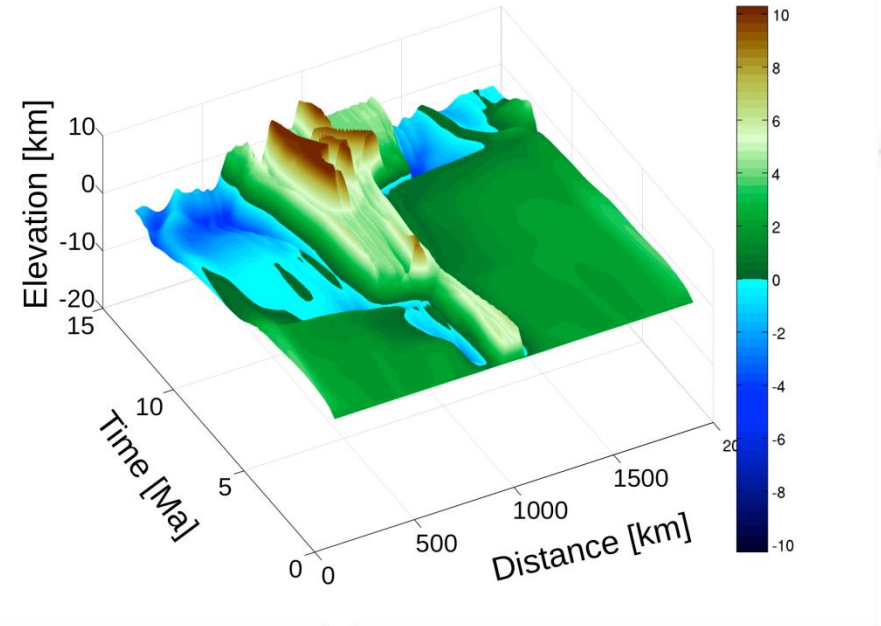



a) Delamination
100 ºC
500 ºC
900 ºC
1300 ºC
Depth [km]
Distance [km]
4.2 Ma
Delamination
拆沉
5.4 Ma
Onset of
decompression melting
开始减压熔融
9.1 Ma
Extensive melting
of various lithologies
各种岩性的大量熔融
10.4 Ma
Mixed Suite
mafic+fesilc
Mafic Suite
Mixed Suite
mafic+fesilc
11.3 Ma
Compression
Delamination
Extension & Delamnination


b) Pressure-Temperature
upper crustal
rocks
at 10.4 Ma
T solidus
T liquidus
Pressure [kbar]
Temperature [ºC]


c) Topography
Elevation [km]
Time [Ma]
Distance [km]

High T metamorphism

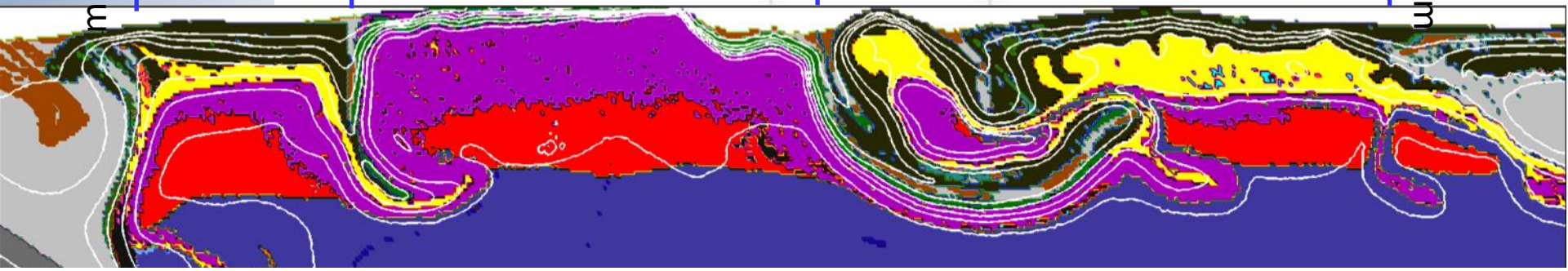
混合系列
镁铁质+长英质
Mixed suite
mafic + felsic

镁铁质系列
Mafic suite

混合系列
镁铁质+长英质
Mixed suite
mafic + felsic

High T metamorphism

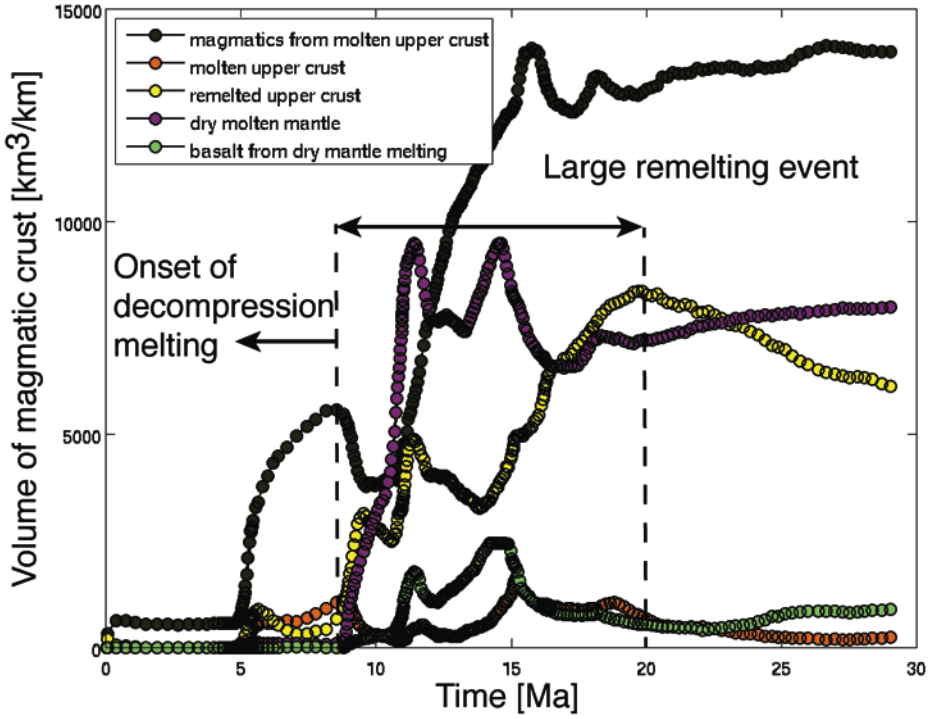
高温变质



600 650 700 750 800 850 900 950 1000 1050

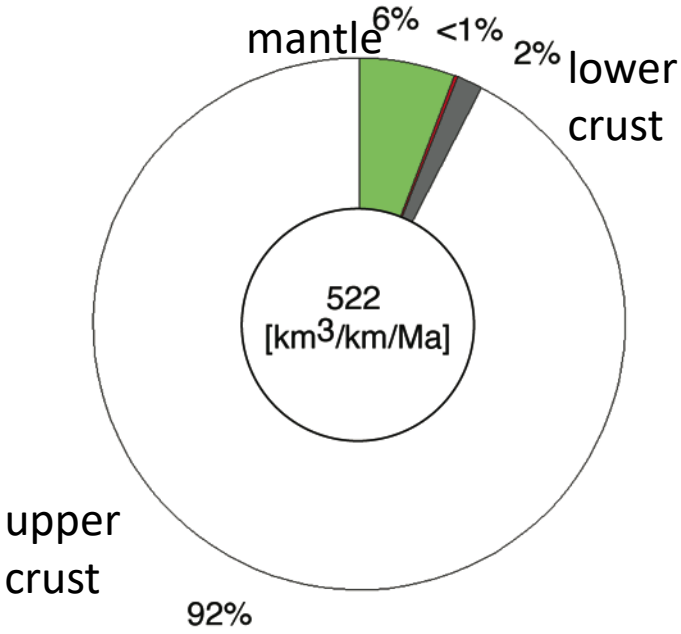
Magmatic addition

a)

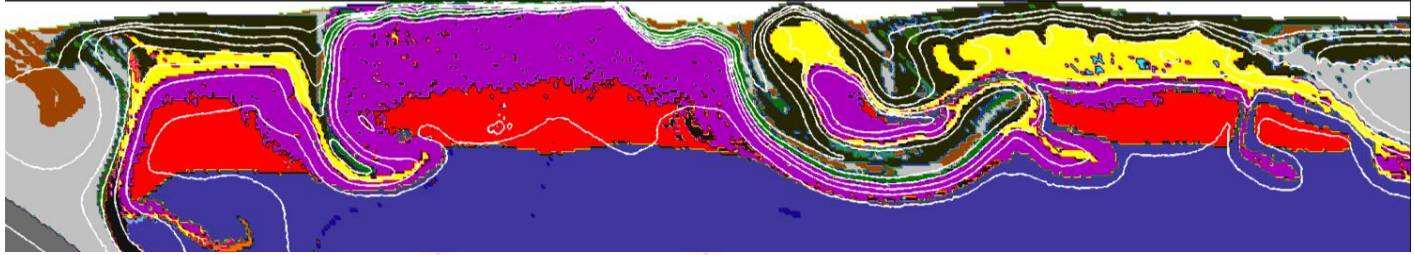


b)

Composition after 50Ma

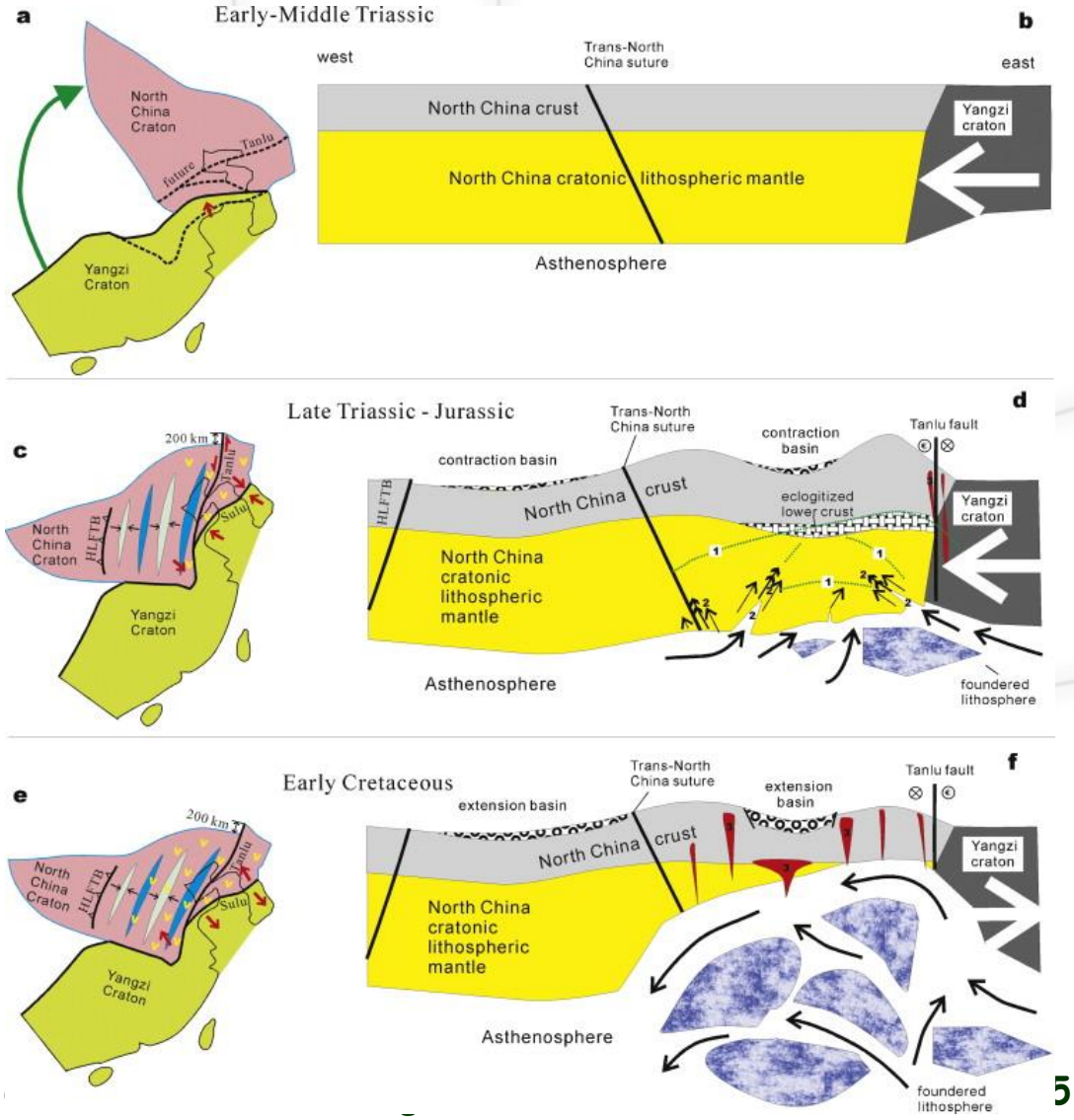


Modeling vs geology

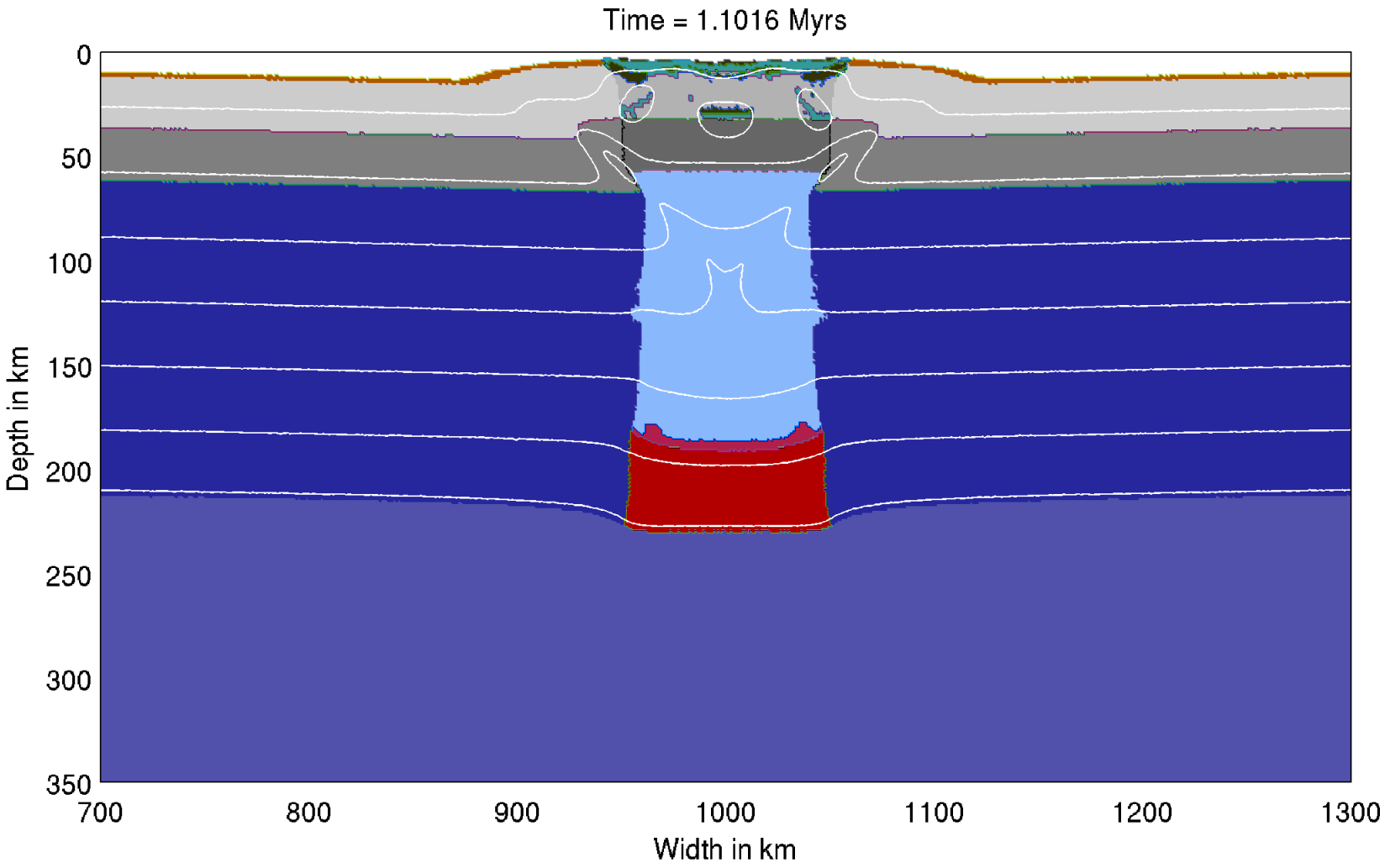


三叠纪晚期到中侏罗世
华北克拉通破坏

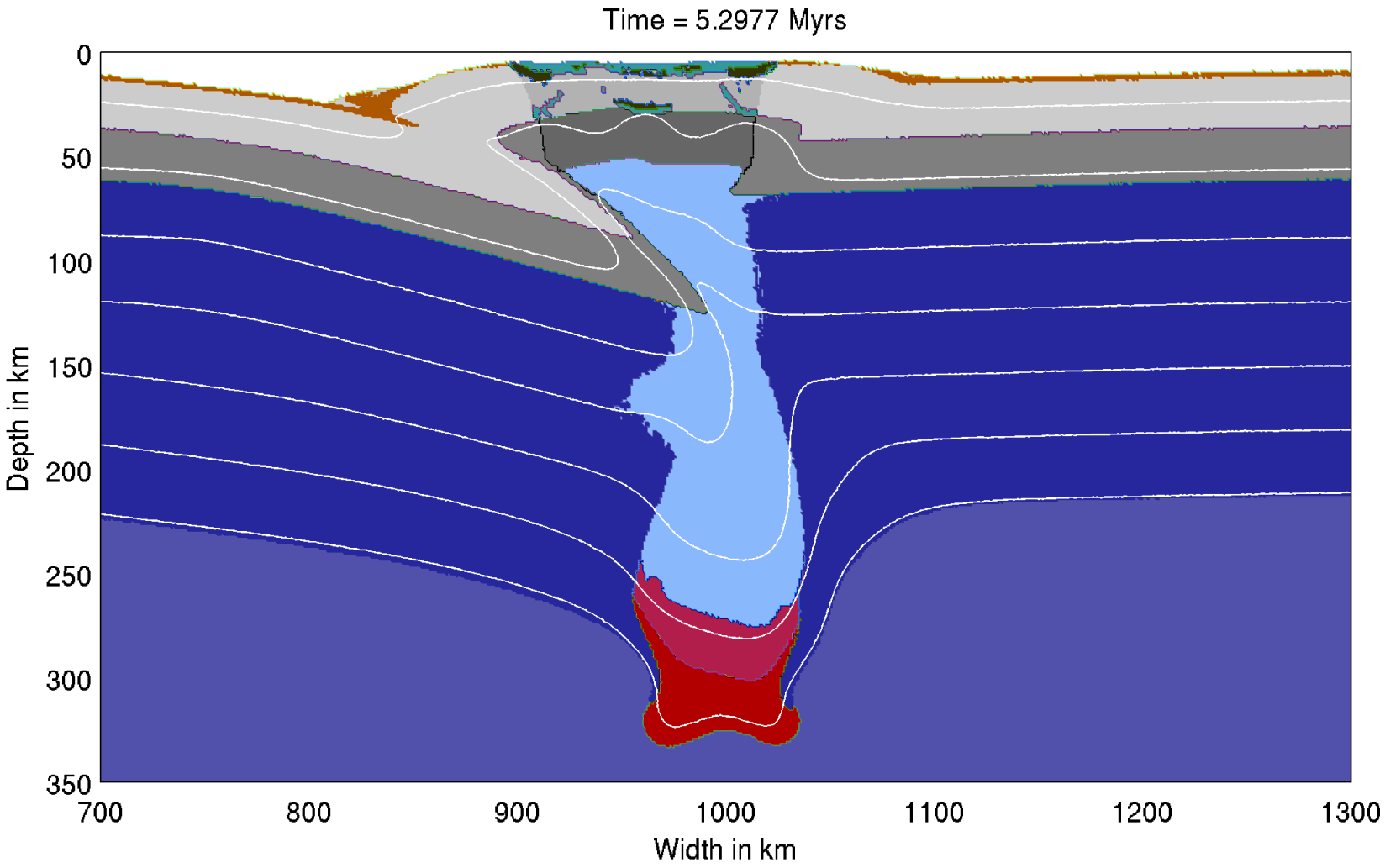
Possible scenario for destruction of the **North China Craton** During late Triasic to middle Jurassic



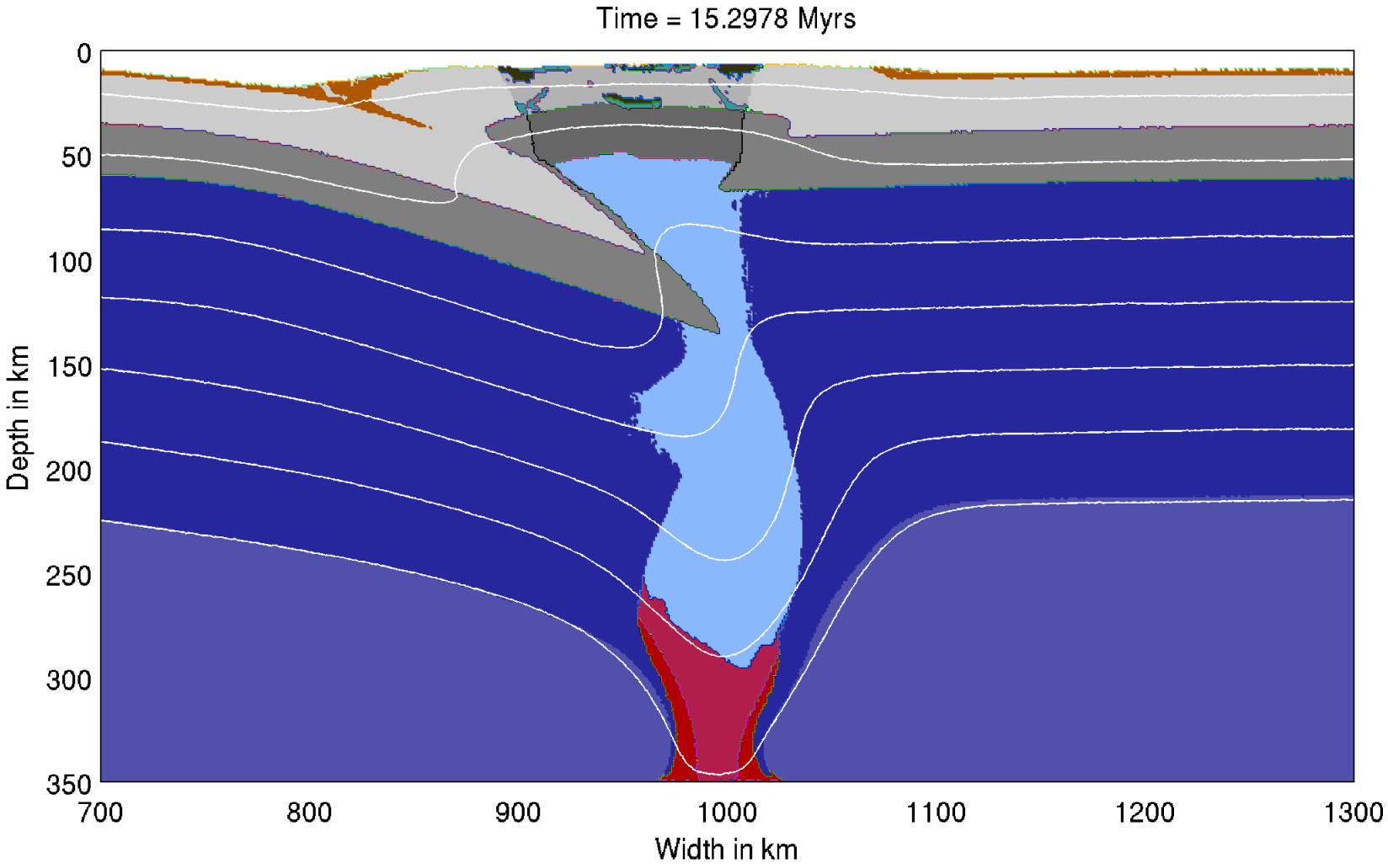
Thrusting


Time = 1.1016 Myrs
0
50
100
150
200
250
300
350
Depth in km
700
800
900
1000
1100
1200
1300
Width in km

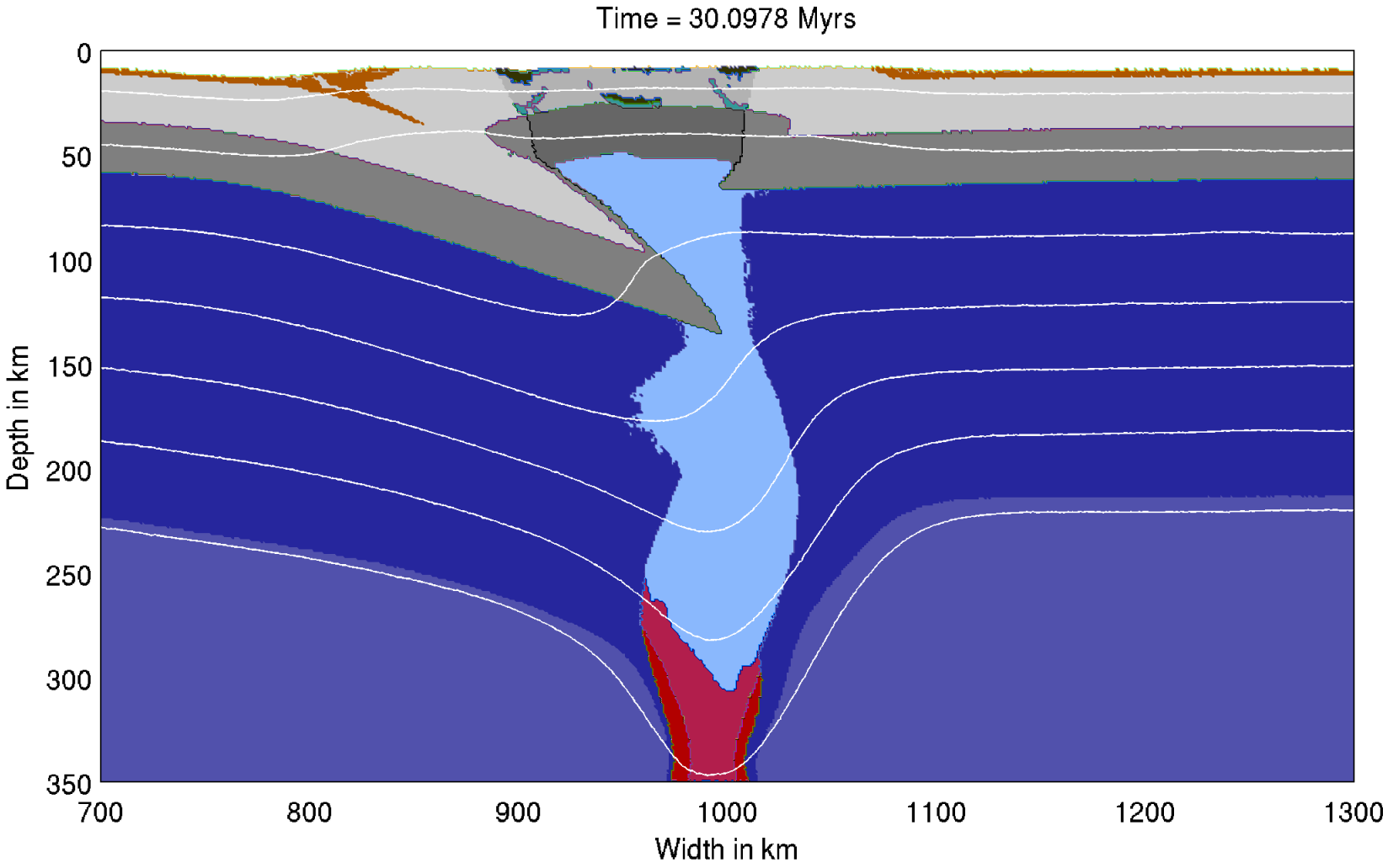
Thrusting


Time = 5.2977 Myrs
0
50
100
150
200
250
300
350
Depth in km
700
800
900
1000
1100
1200
1300
Width in km

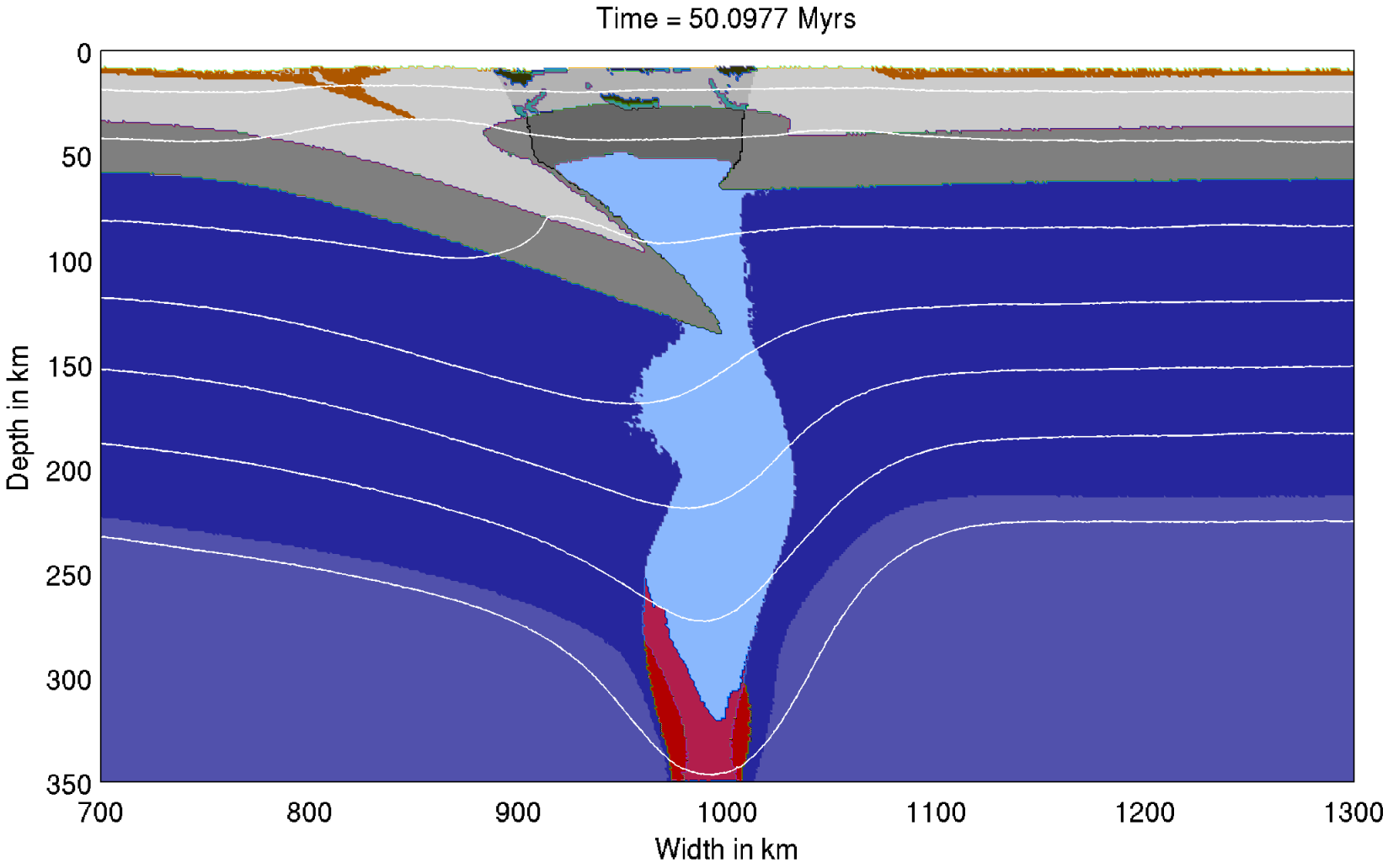
Thrusting


Time = 15.2978 Myrs
Depth in km
0
50
100
150
200
250
300
350
700
800
900
1000
1100
1200
1300
Width in km

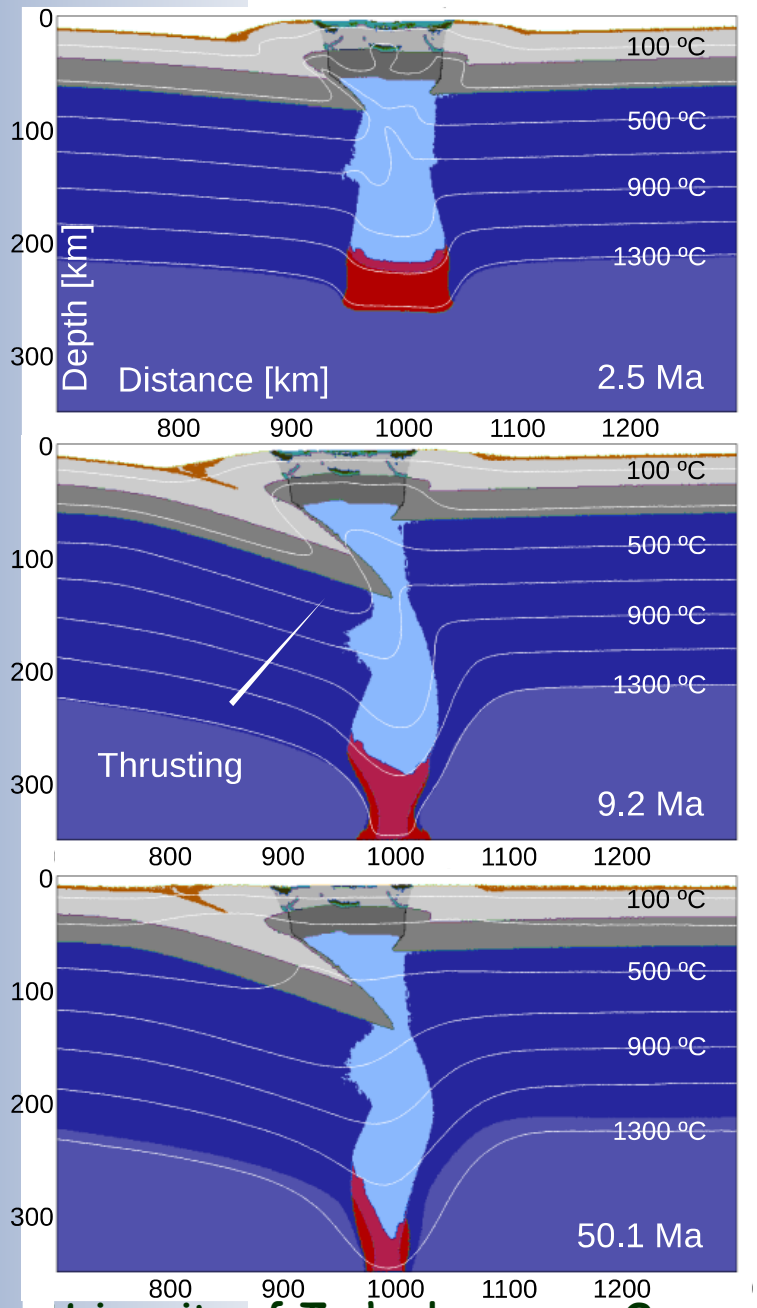
Thrusting


Time = 30.0978 Myrs
0
50
100
150
200
250
300
350
Depth in km
700
800
900
1000
1100
1200
1300
Width in km

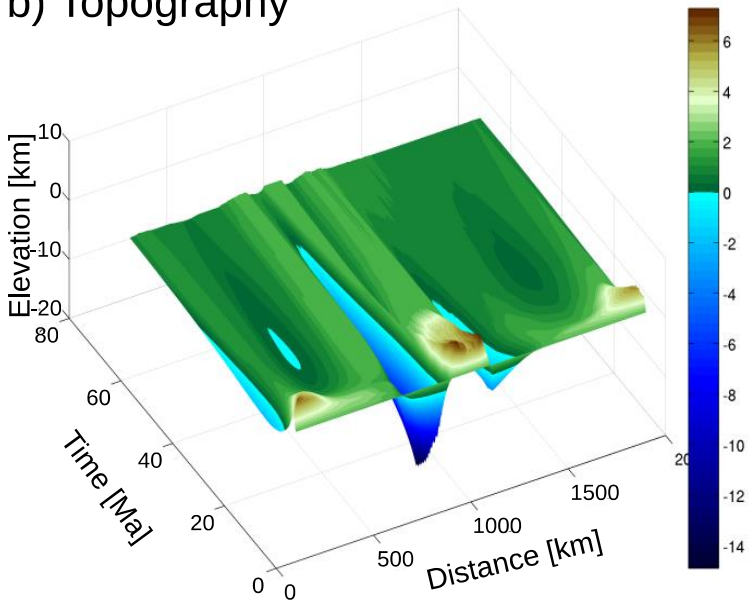
Thrusting

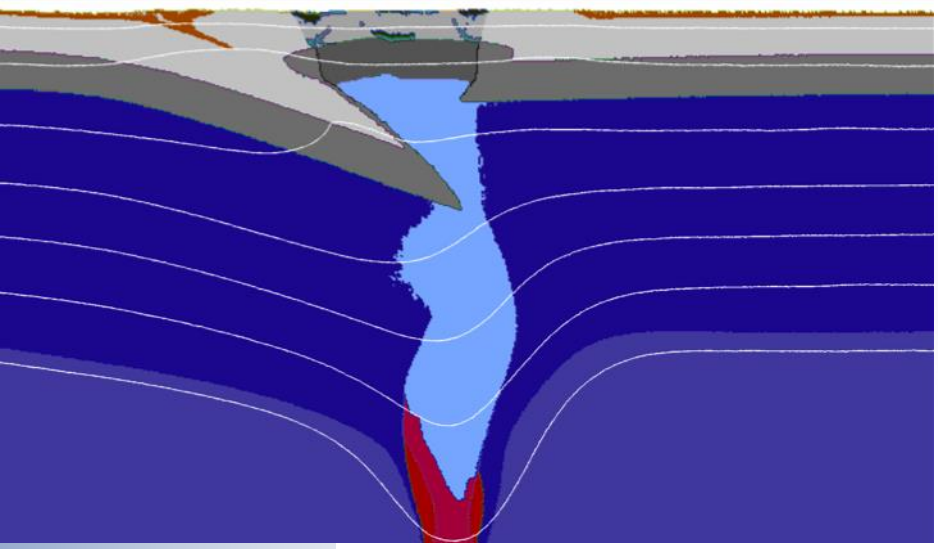

Time = 50.0977 Myrs
Depth in km
0
50
100
150
200
250
300
350
700
800
900
1000
1100
1200
1300
Width in km

a) Thrusting



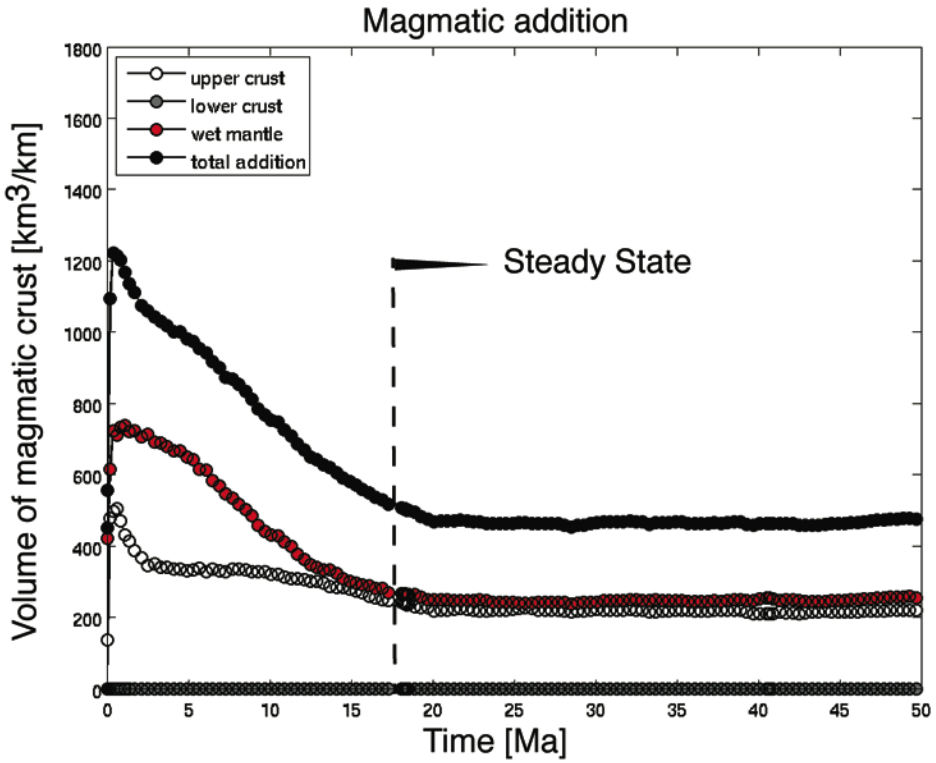
b) Topography

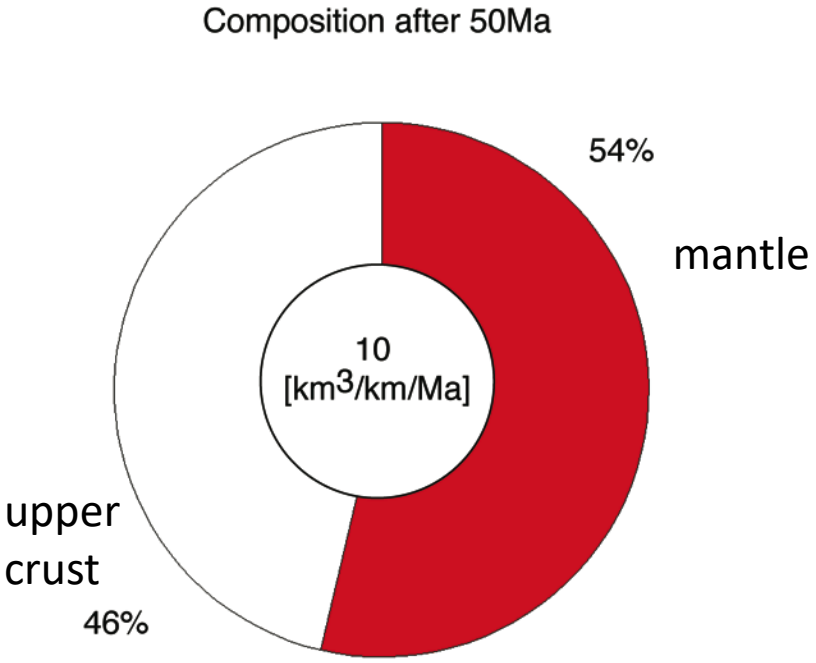




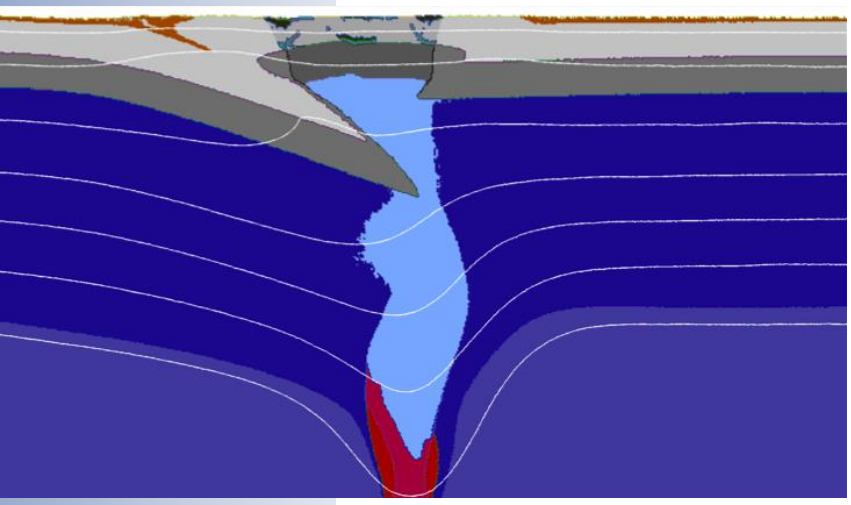
Minimal melt production,
Long preserved Moho topography

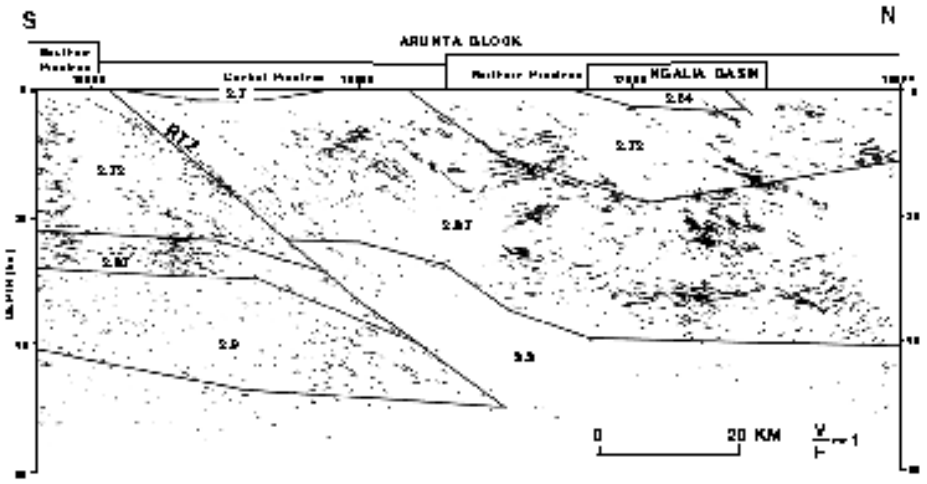
最小熔融产物
长期保存的莫霍面形态





Modeling vs geology





After Goleby et al., 1989

MECHANICAL STABILITY OF THE REDBANK THRUST ZONE, CENTRAL AUSTRALIA

雷德班克的逆冲带的力学稳定性，
澳大利亚中部

erosion/sedimentation

free slip, T = 0

Initial setup:

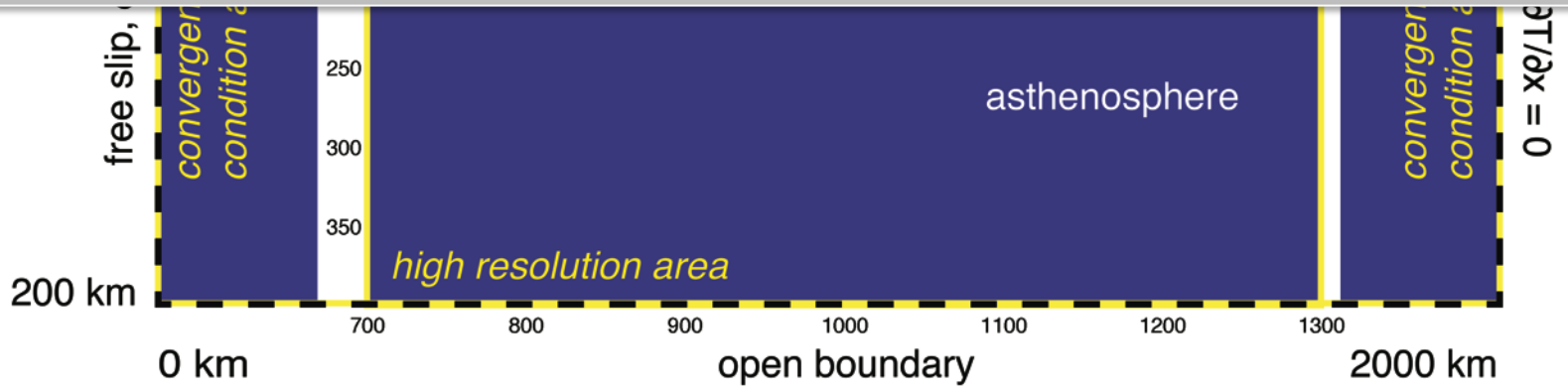
Compression for 6Ma at rates: 0.5, 1, 2, 3 cm/a

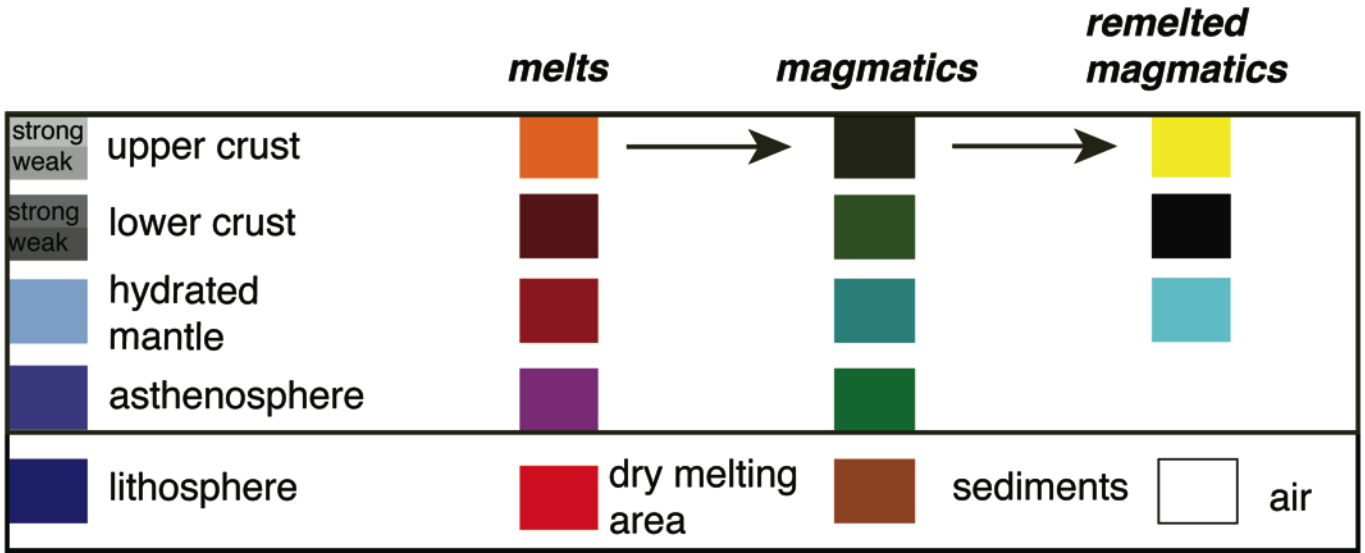
Lithospheric thickness: 60, 80, 100, 200, 300 km

初始设置

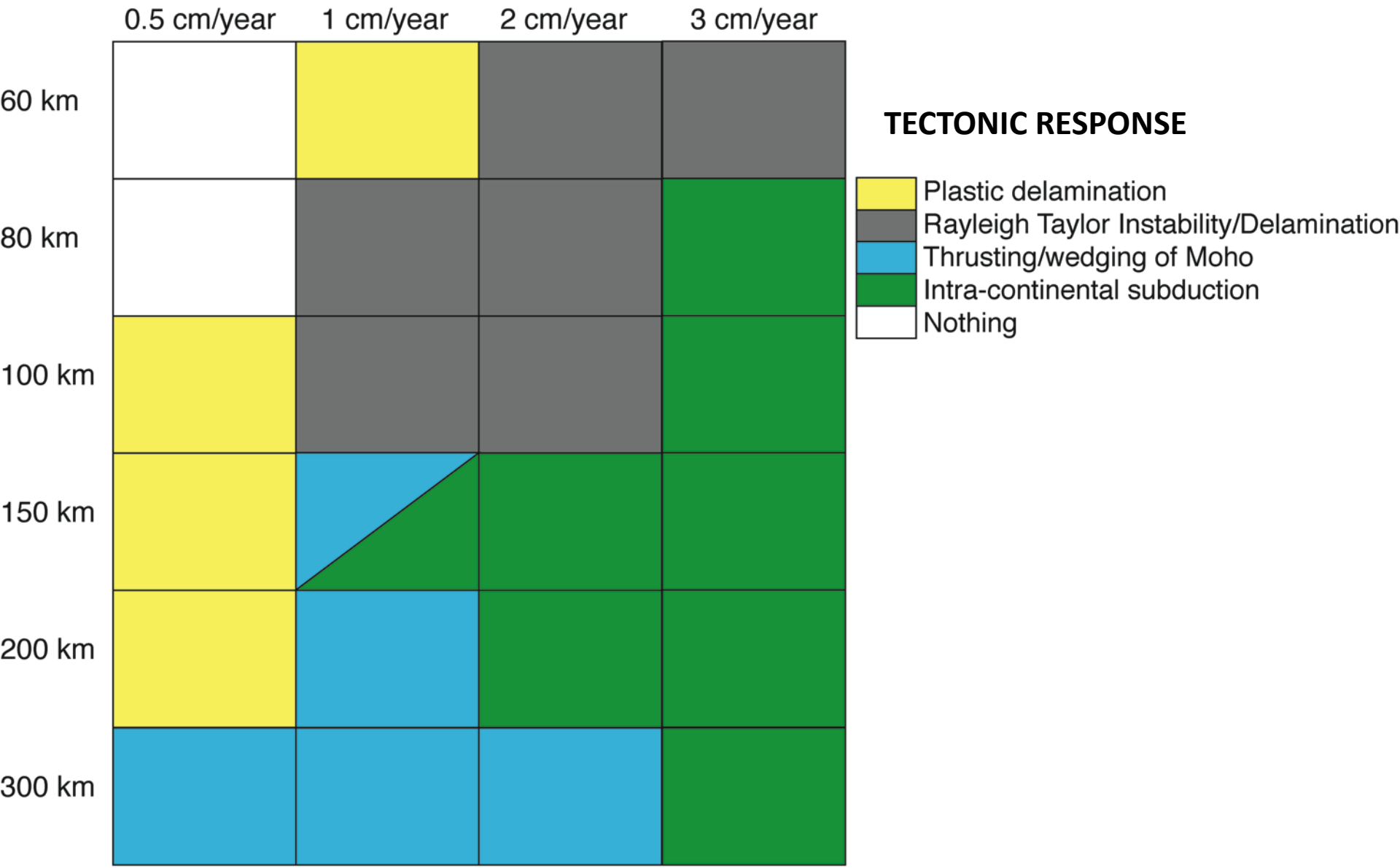
6Ma压缩:

岩石圈厚度:

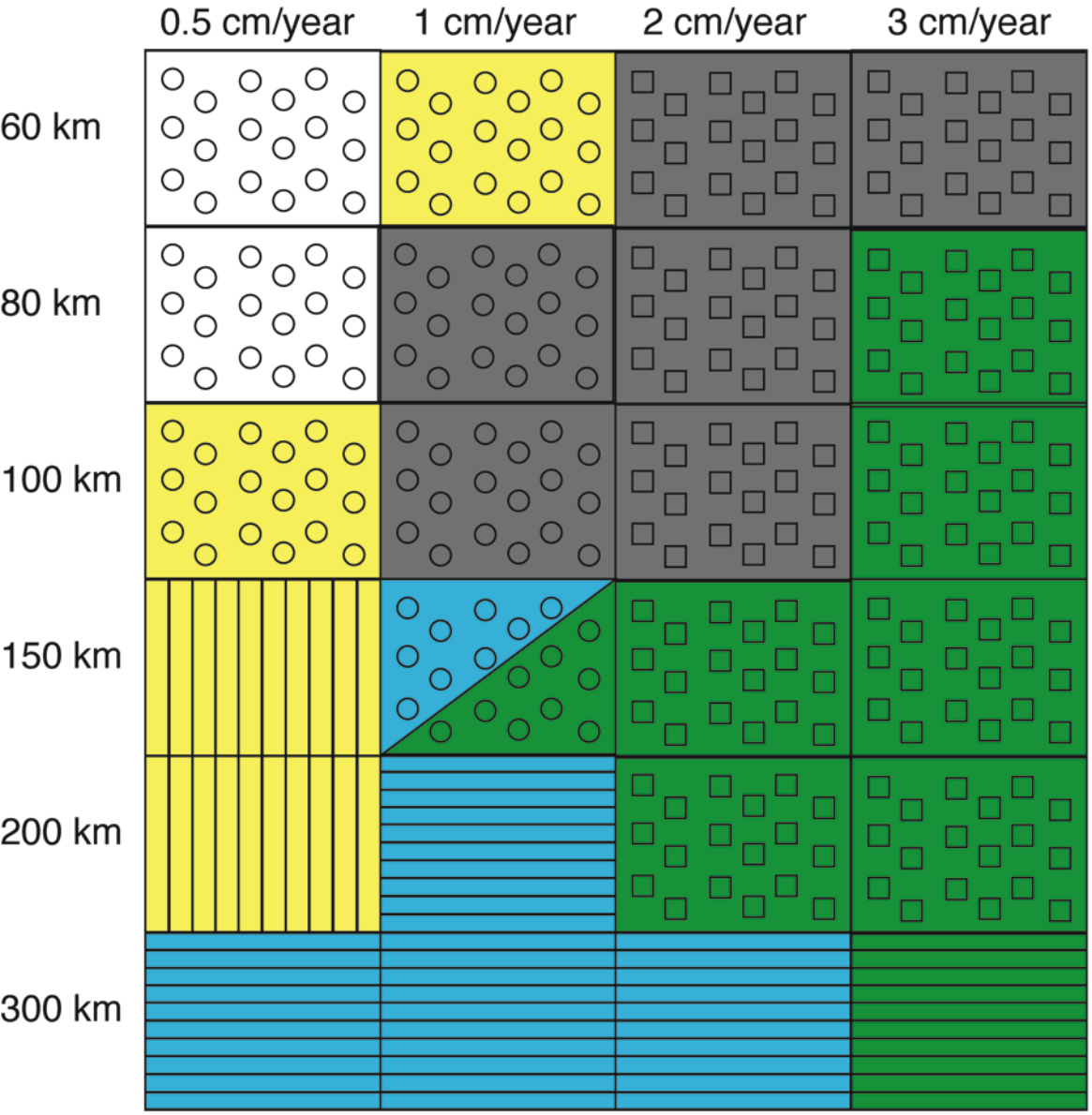




To conclude:


0.5 cm/year
1 cm/year
2 cm/year
3 cm/year
60 km
80 km
100 km
150 km
200 km
300 km
TECTONIC RESPONSE
Plastic delamination
Rayleigh Taylor Instability/Delamination
Thrusting/wedging of Moho
Intra-continental subduction
Nothing

To conclude:



TECTONIC RESPONSE

- Plastic delamination
- Rayleigh Taylor Instability/Delamination
- Thrusting/wedging of Moho
- Intra-continental subduction
- Nothing

MAGMATIC RESPONSE

- Melting of the lower crust
- No melting
- Only hydrous intrusions
- bi-modal melting

Lithospheric age and compression rates control tectonic behavior of amalgamated block and a degree of melting that occurs in these zones

岩石圈的年龄和压缩率控制构造行为特征。包括块汇聚，以及这些区域的一定程度熔融

Magma emplacement in 3D

preliminary study

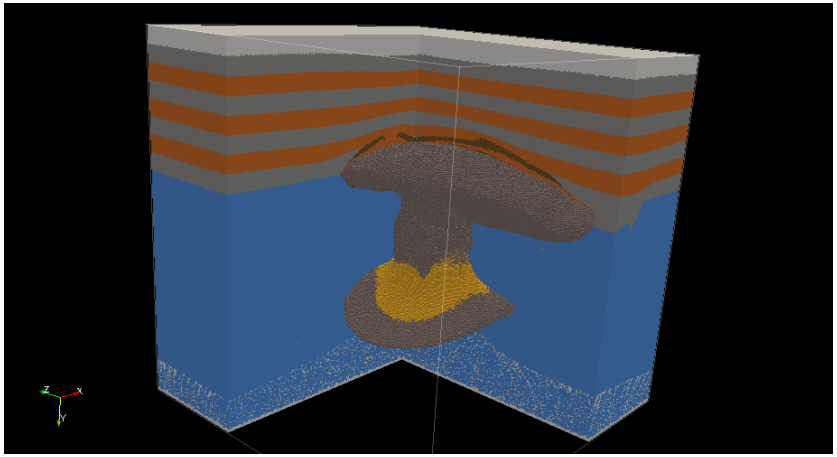
3D环境下岩浆侵位初步研究

Weronika Gorczyk

Centre for Exploration Targeting,
University of Western Australia;

Katharina Vogt

Faculty of Geosciences, Utrecht University



CCFS

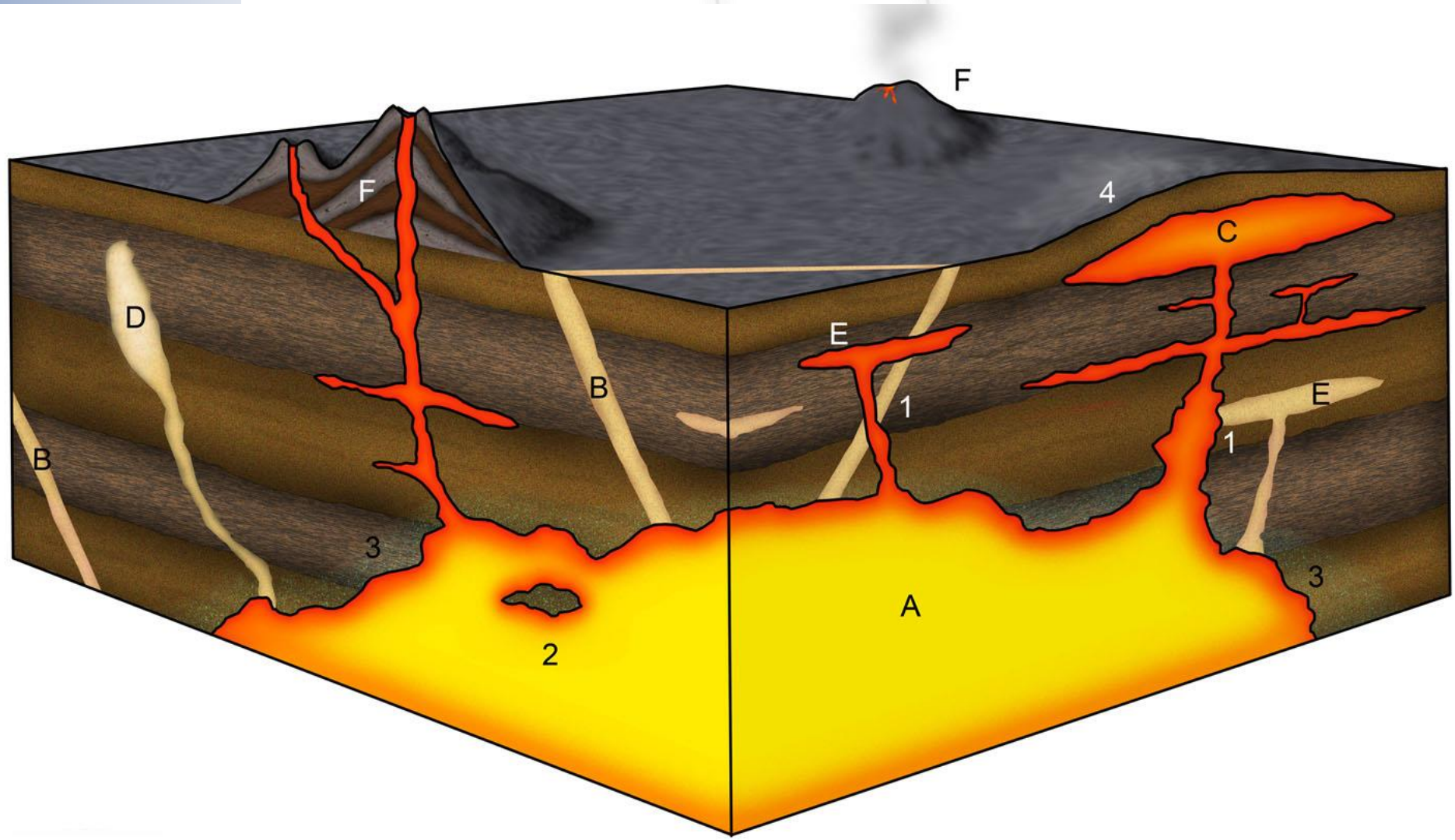
Centre for EXPLORATION TARGETING

PAWSEY supercomputing centre

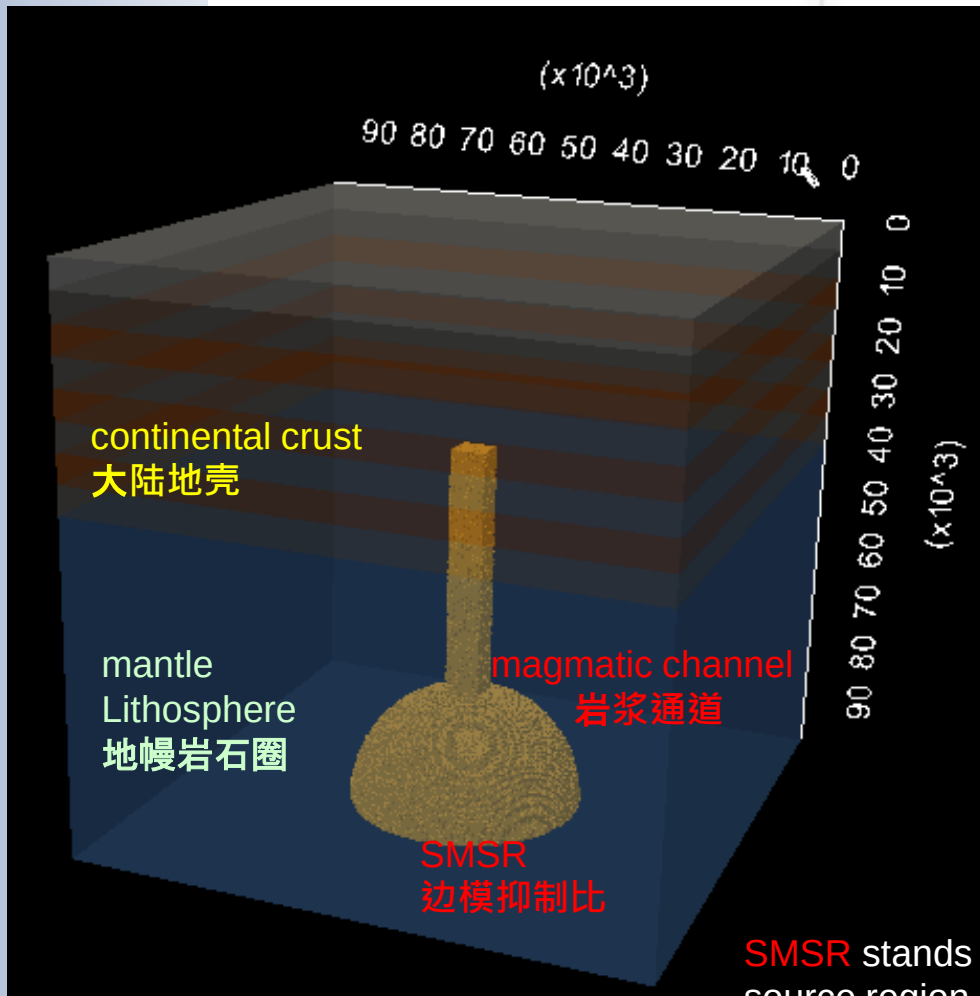
THE UNIVERSITY OF WESTERN AUSTRALIA
Achieve International Excellence

Universiteit Utrecht

Introduction



Model setup



Staggered grid resolution is
197 x 197 x 197 nodal points.
Grid step is
0.5km x 0.5 km x 0.5 km.

交错网格分辨率为
197 x 197 x 197个节点
每个网格为
0.5km x 0.5 km x 0.5 km

SMSR stands for sub-lithospheric magmatic source region
SMSR代表下岩石圈岩浆源区

Physical parameters:

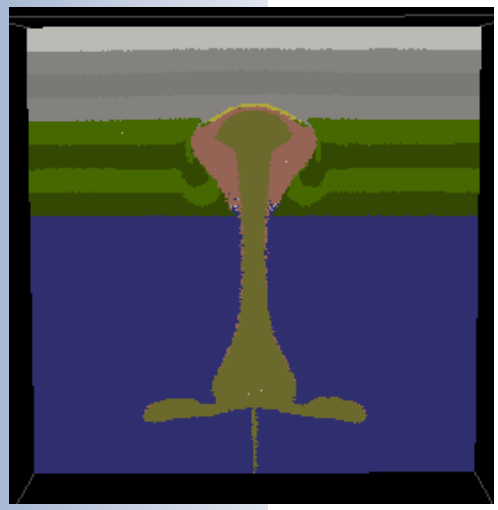
Material	Flow low	$1/A_D[Pa^n s]$	n	E_a [J]	V_a [J/bar]	sin(φ)
Felsic crust 长英质	wet qrz	$1.97x10^{17}$	2.3	$154x10^3$	0	0.1 -0
Mafic crust 镁铁质	palg	$4.8x10^{22}$	3.2	$238x10^3$	0	0.1- 0
Mantle 地幔	dry ol	$3.98x10^{16}$	3.5	$532x10^3$	1.6	0.6
SMSR, channel	Const nu=10^{18} [Pas]					

Investigated:

- Crust composition
- Moho temperature
- Extension at .7 cm/yr
- C - cohesion
- γ_c - is the strain limit for fracture related weakening

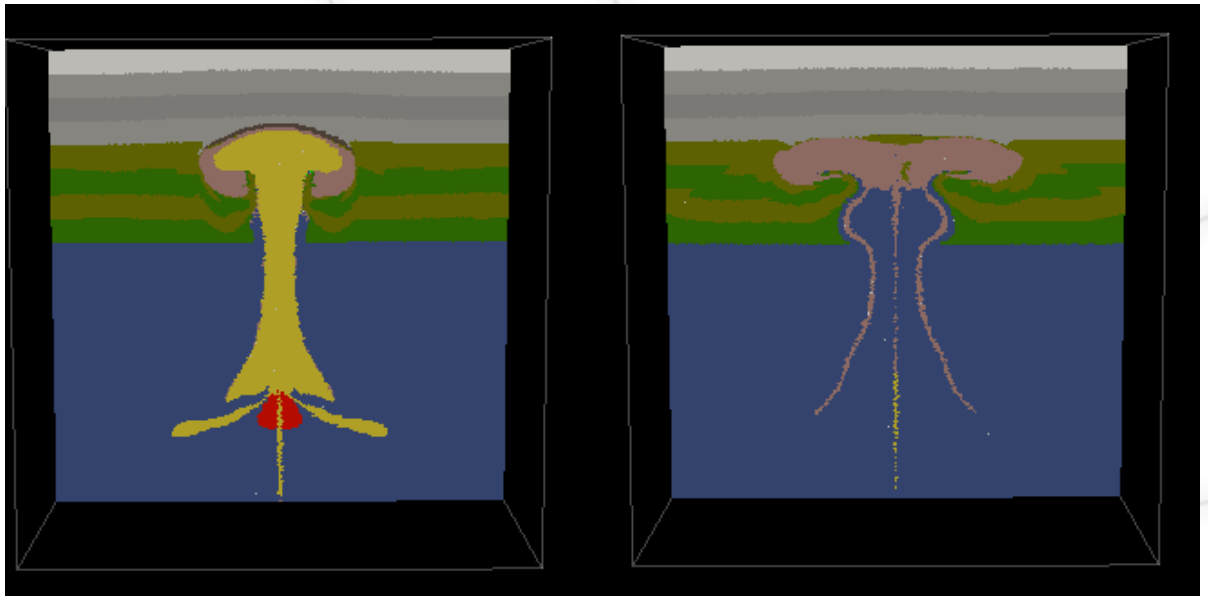
Moho temperature:莫霍面温度

400°C



600°C

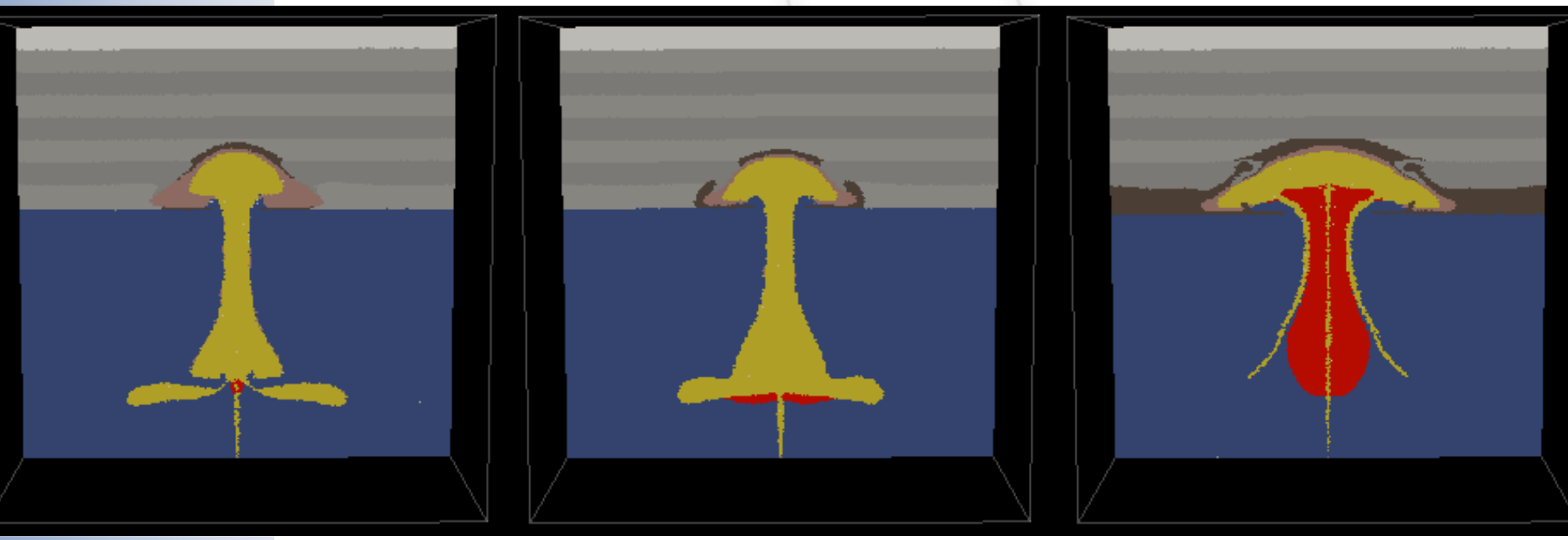
800°C



~ 0.22Ma

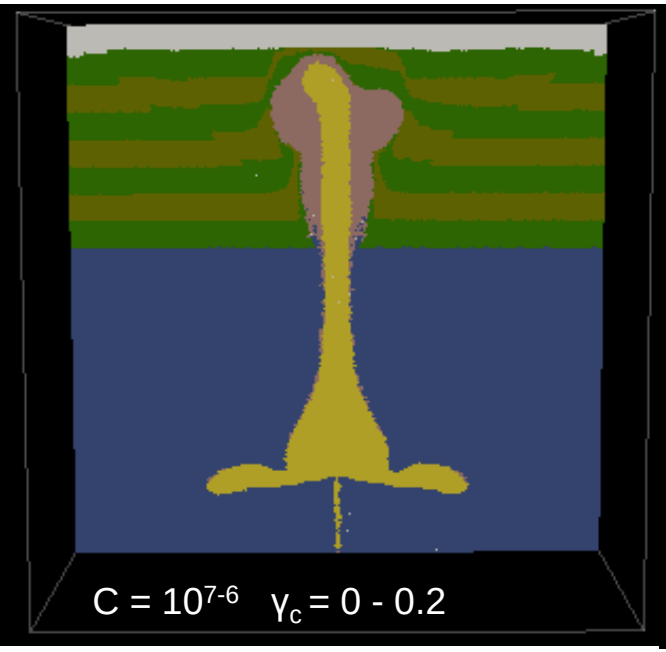
Moho temperature:

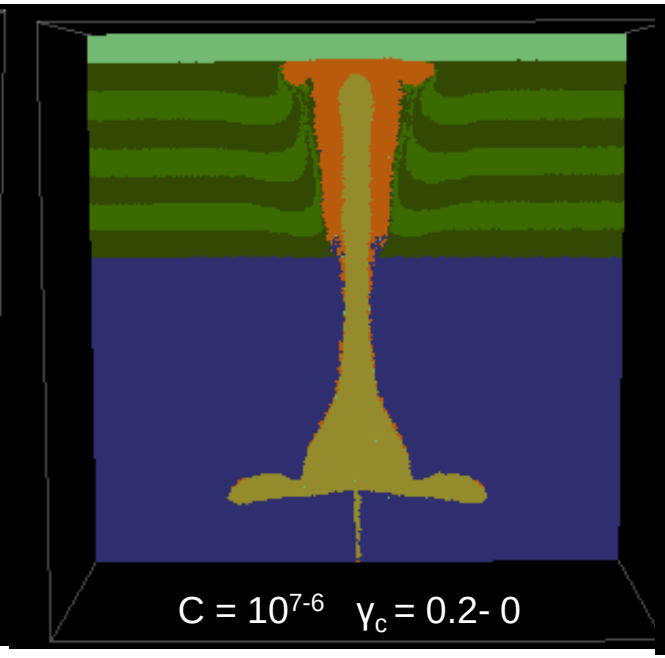
400°C 600°C 800°C

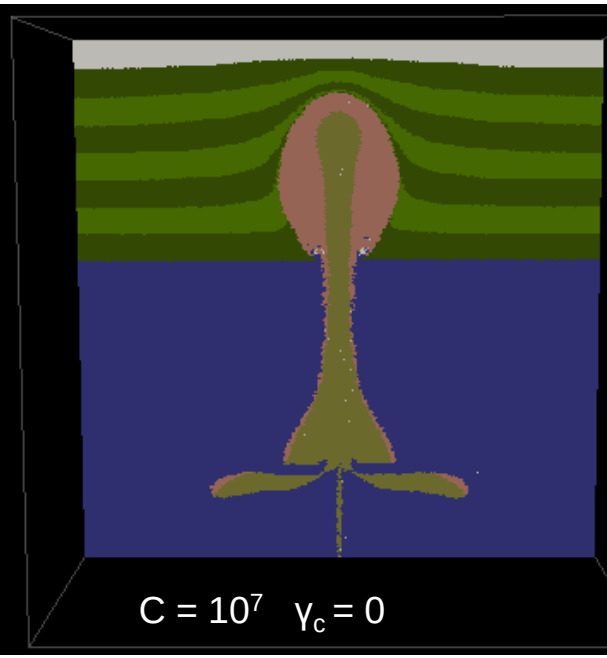


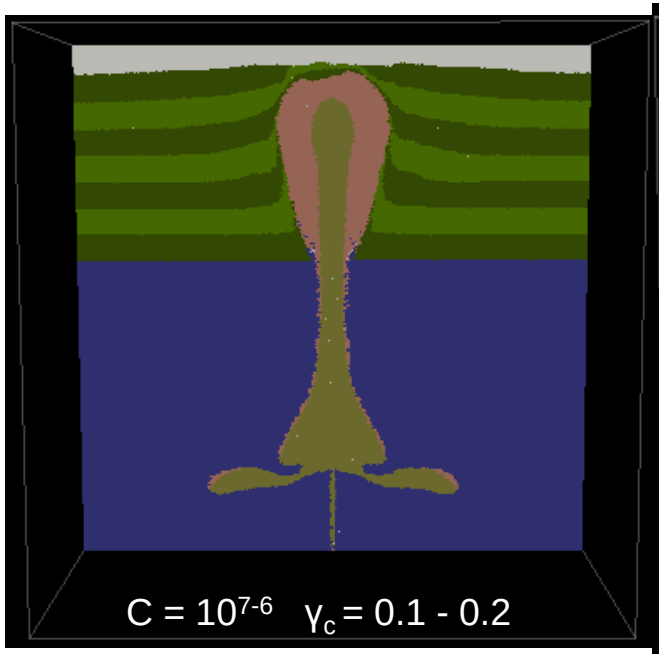
~ 0.22Ma

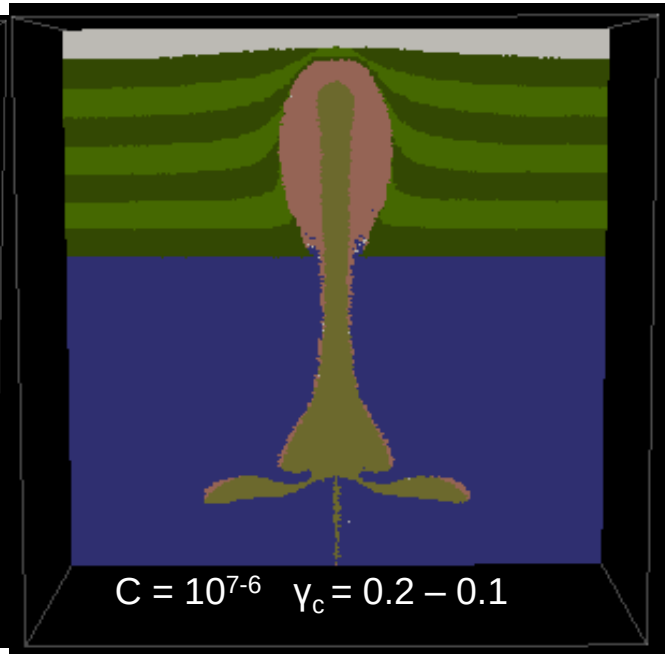
Cohesion and strain limit:内聚与应变限制

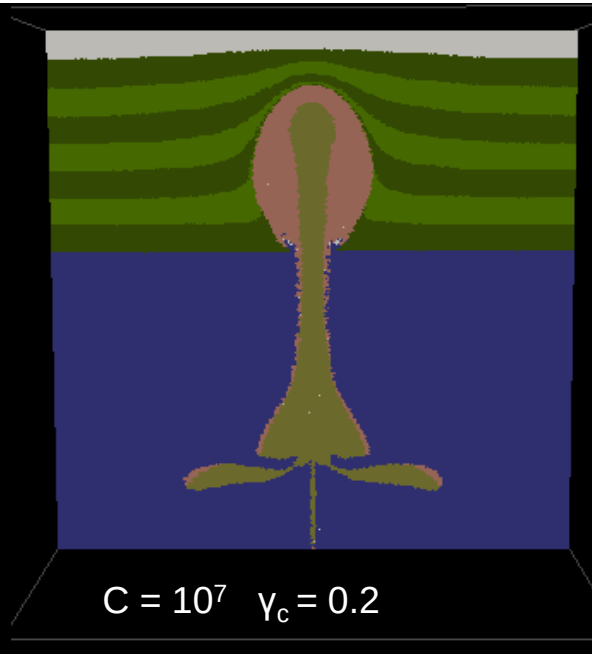




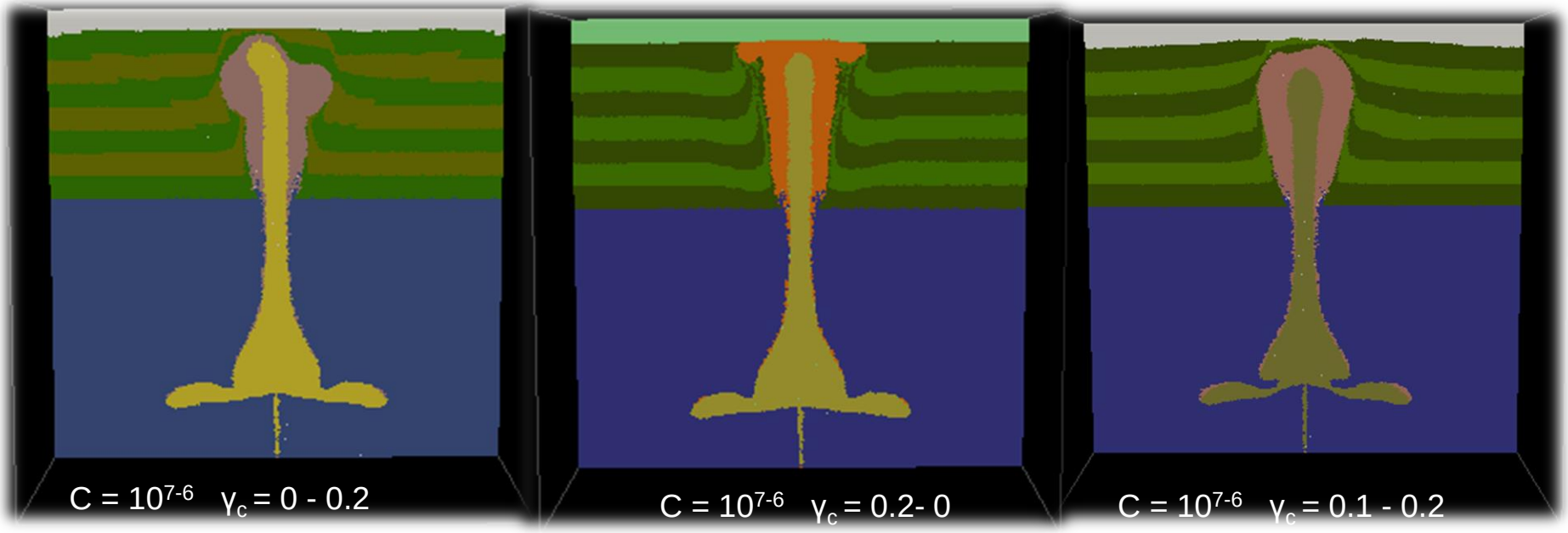


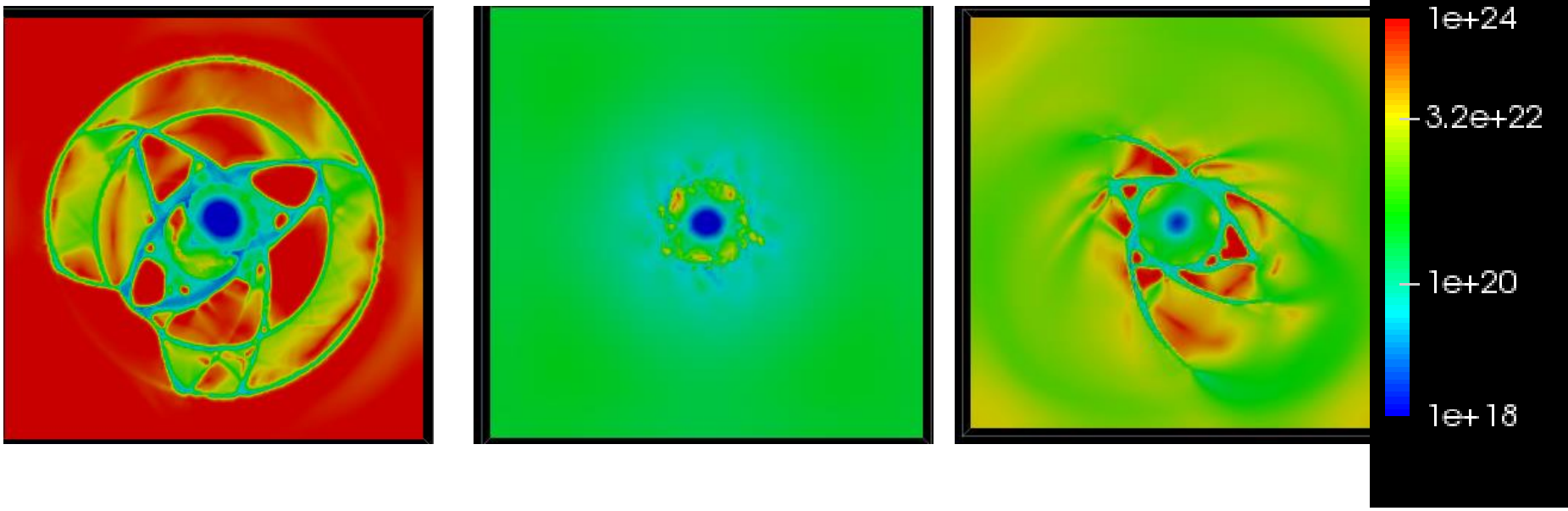




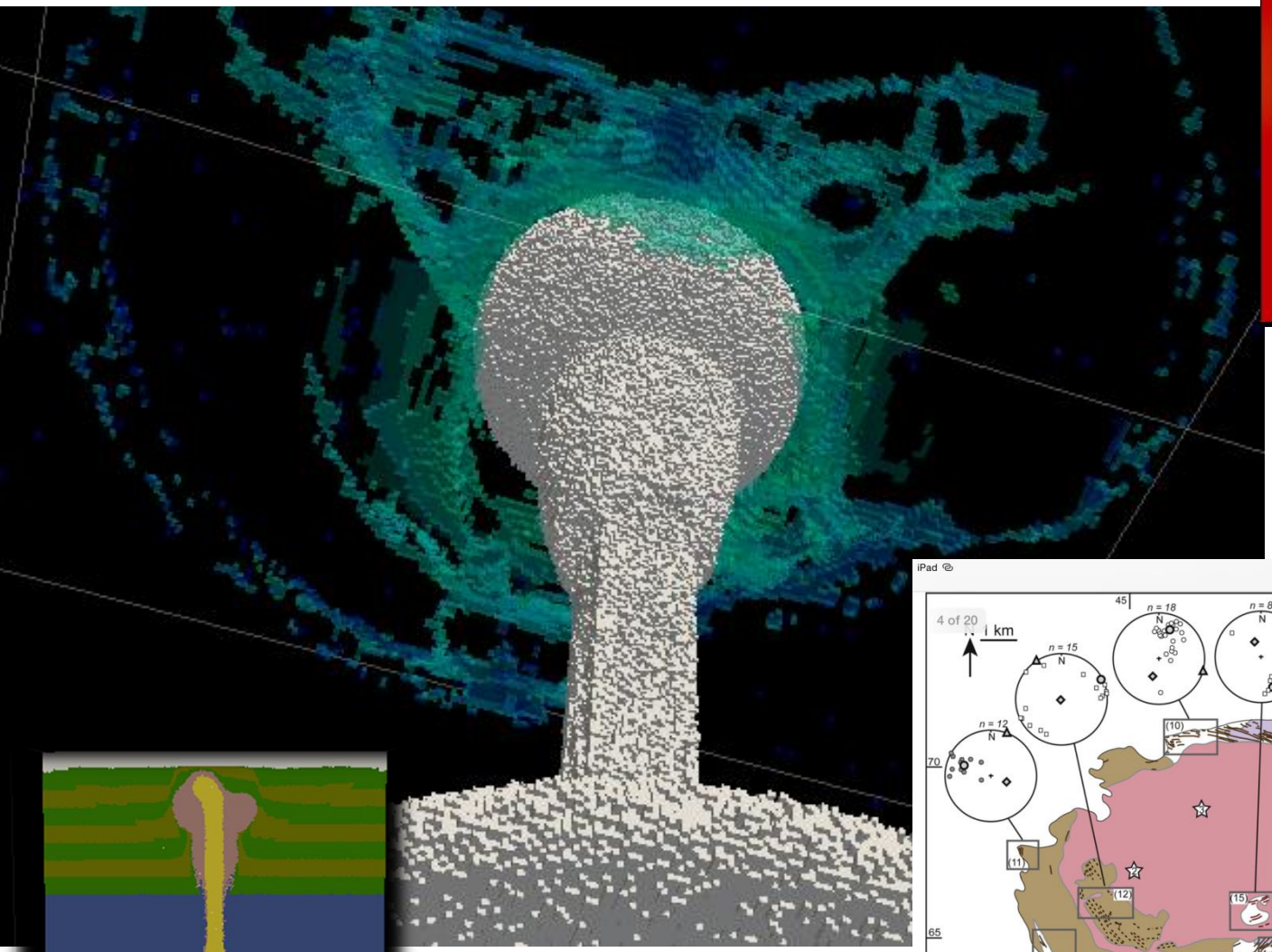


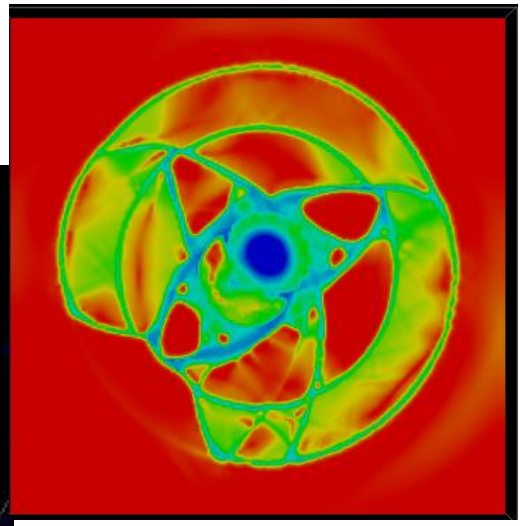
Cohesion and strain weakening/hardening:内聚与应变弱化/硬化

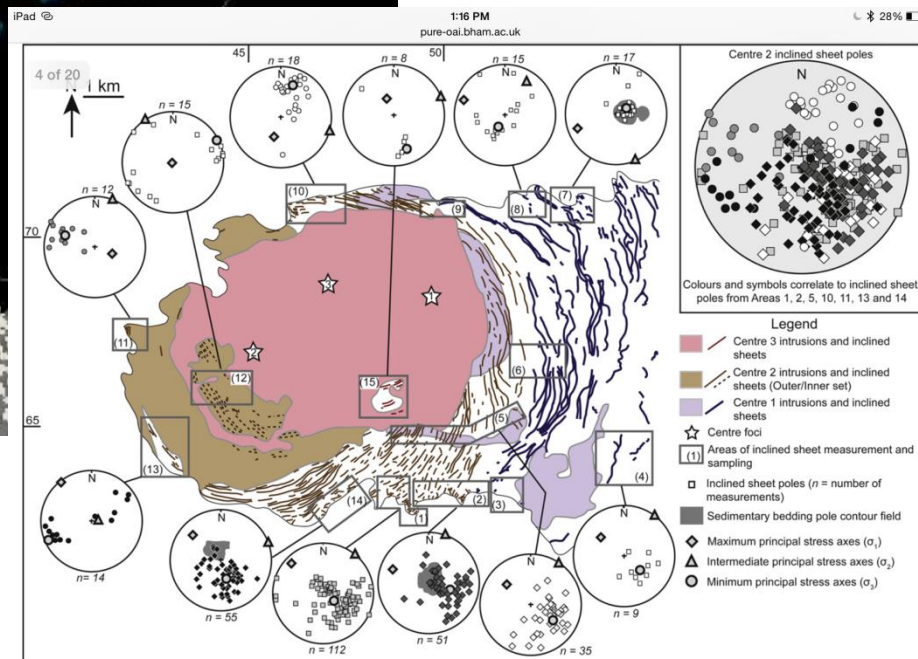




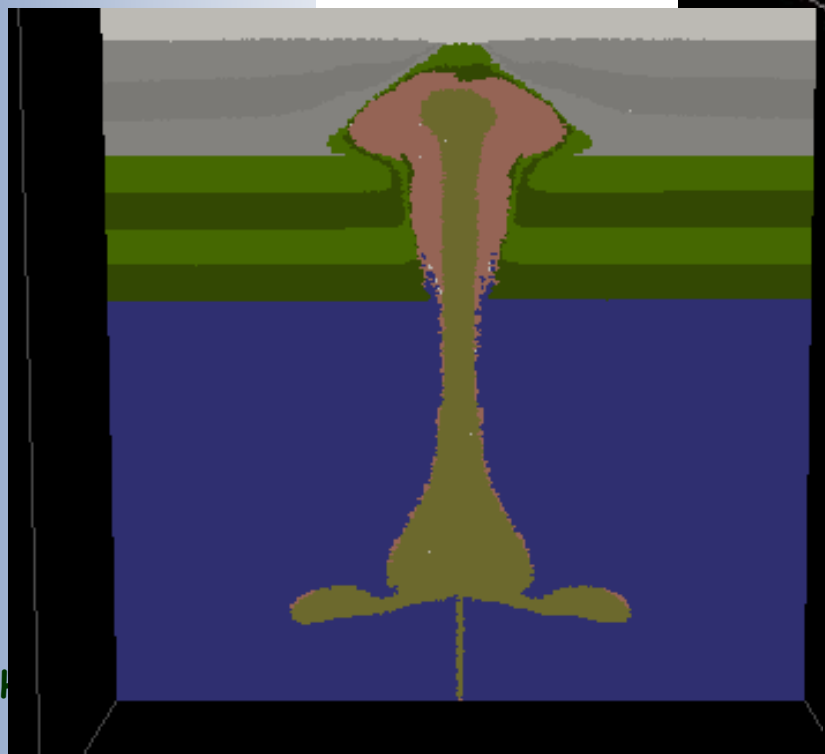
Ring complexes 环形杂岩

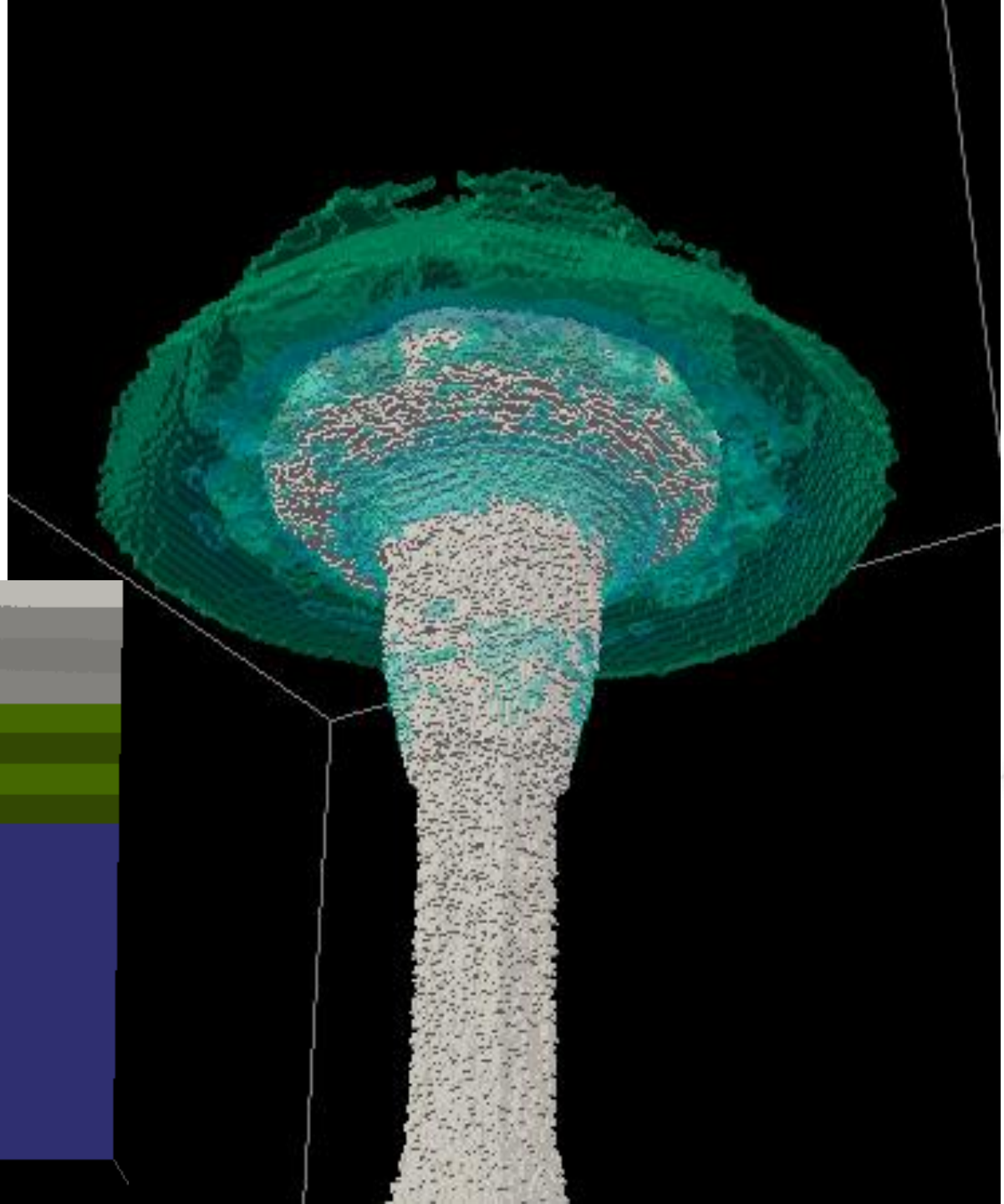


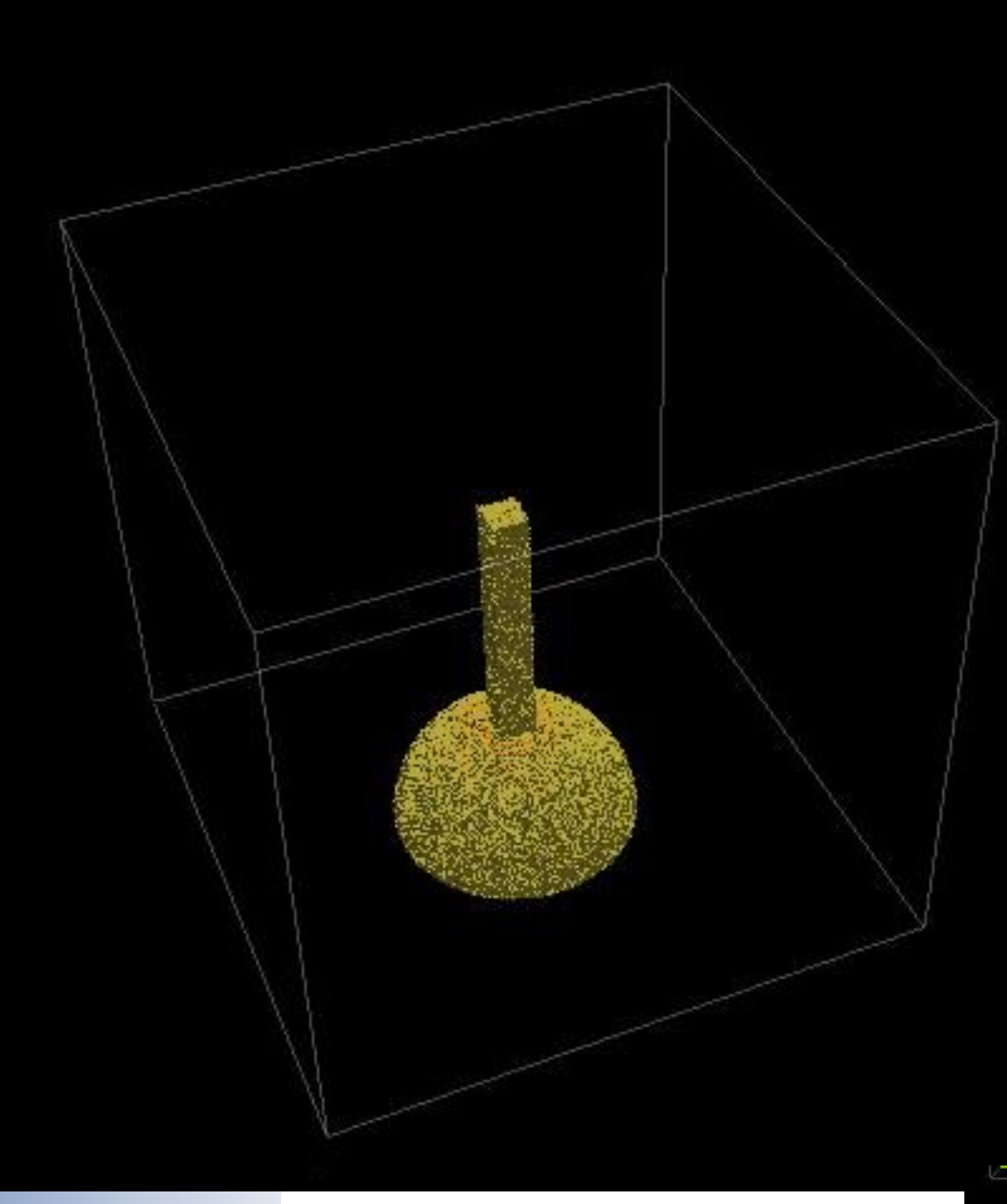




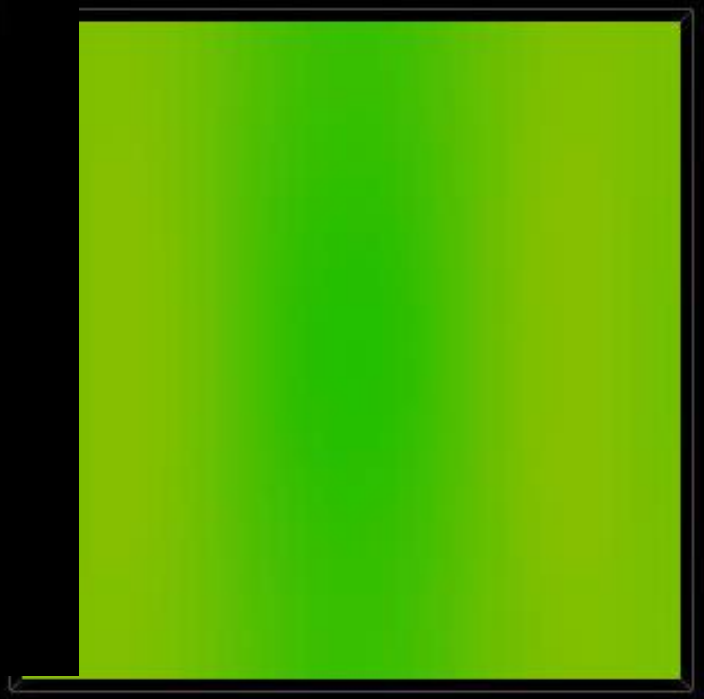
Ring complexes

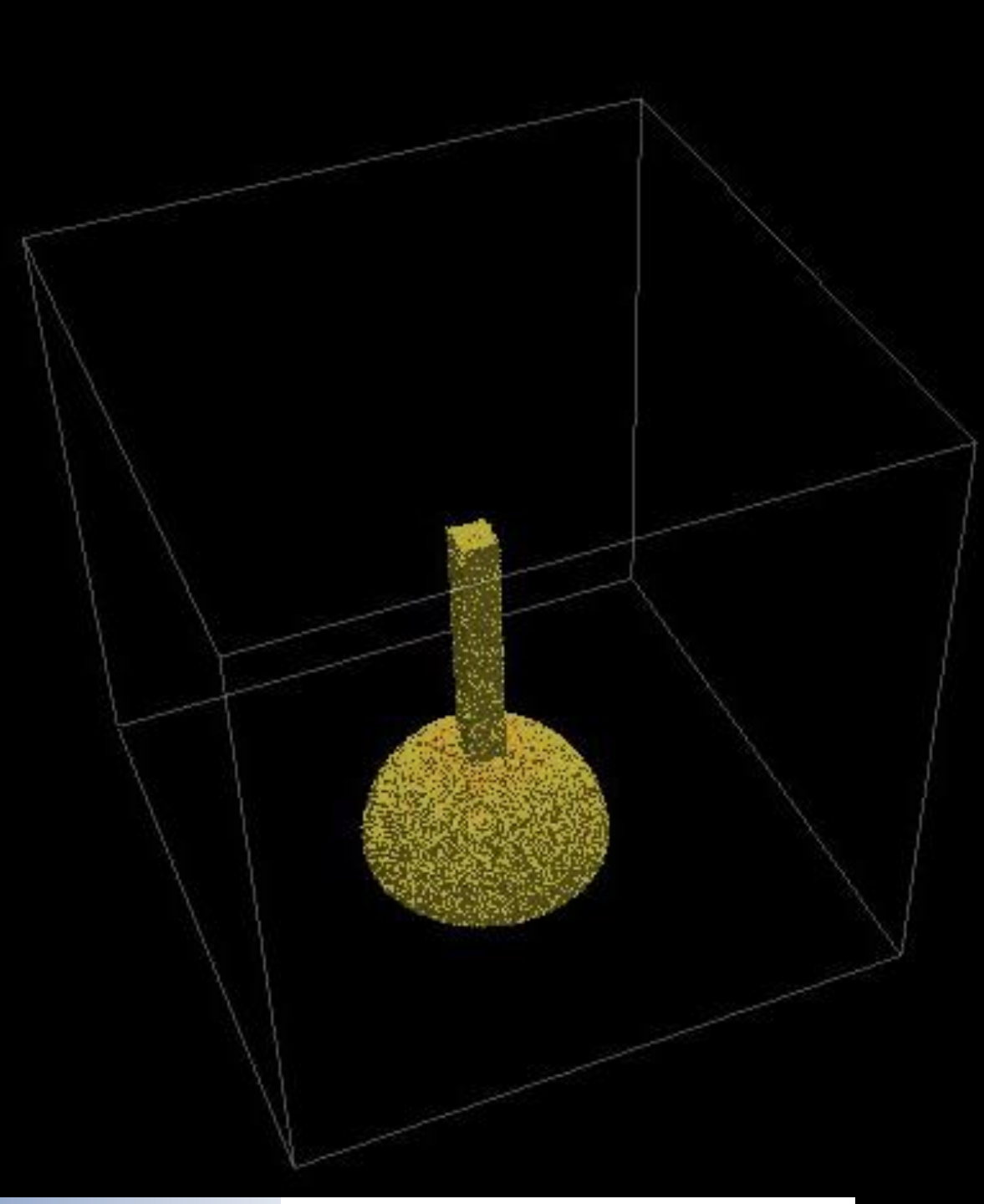




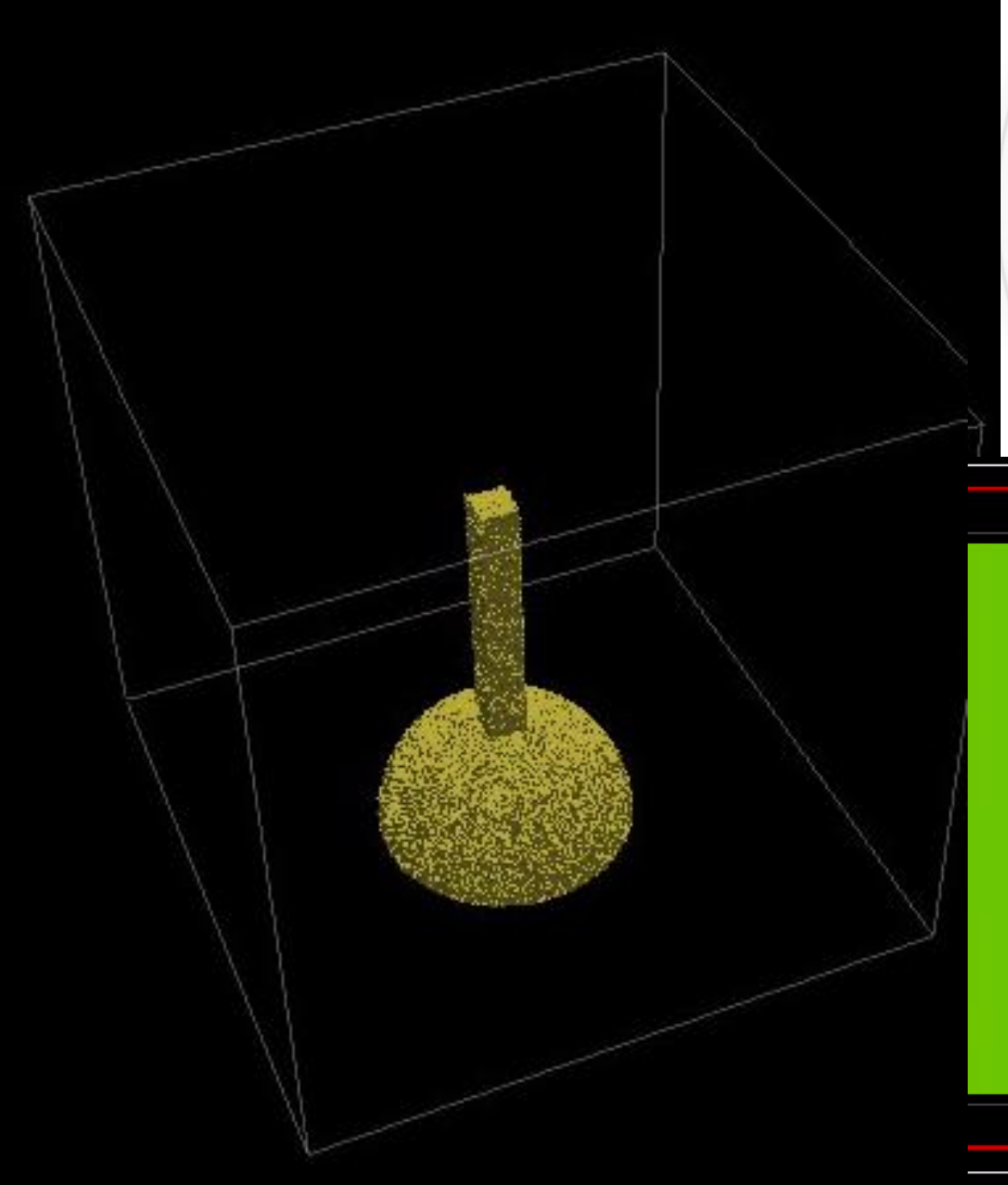


Extension: 0.7 cm/yr
Crust: upper: felsic
lower: mafic
地壳上部：长英质
地壳下部：铁镁质

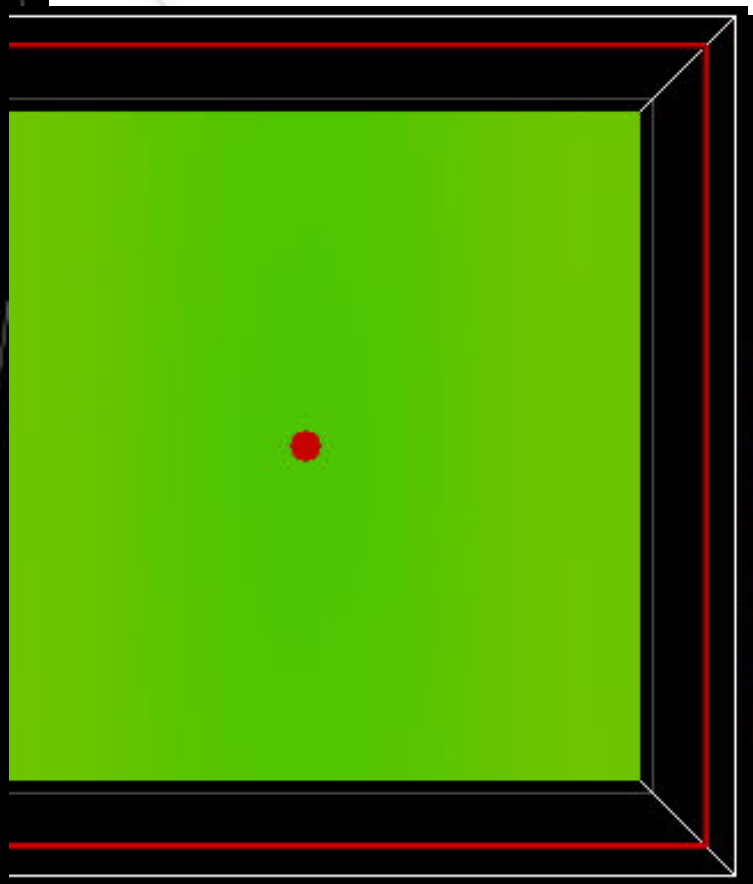


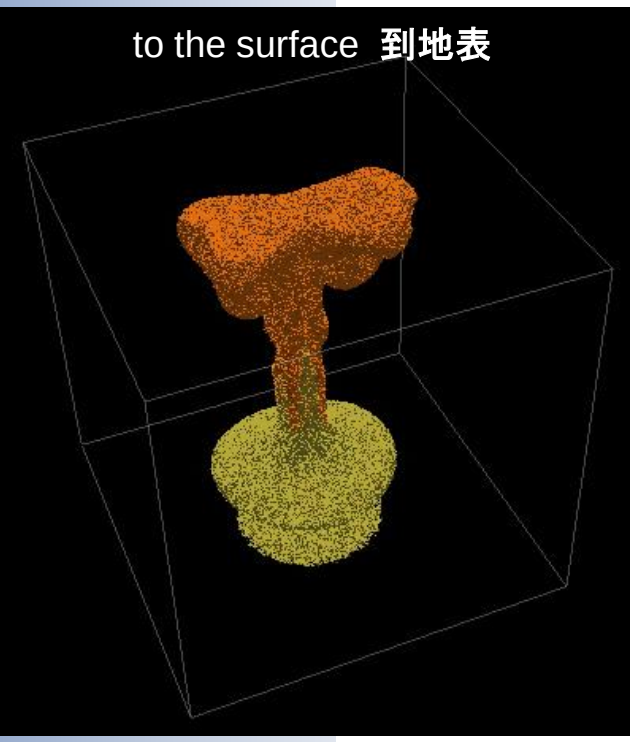


Extension: 0.7 cm/yr
Crust: upper: mafic
lower: mafic

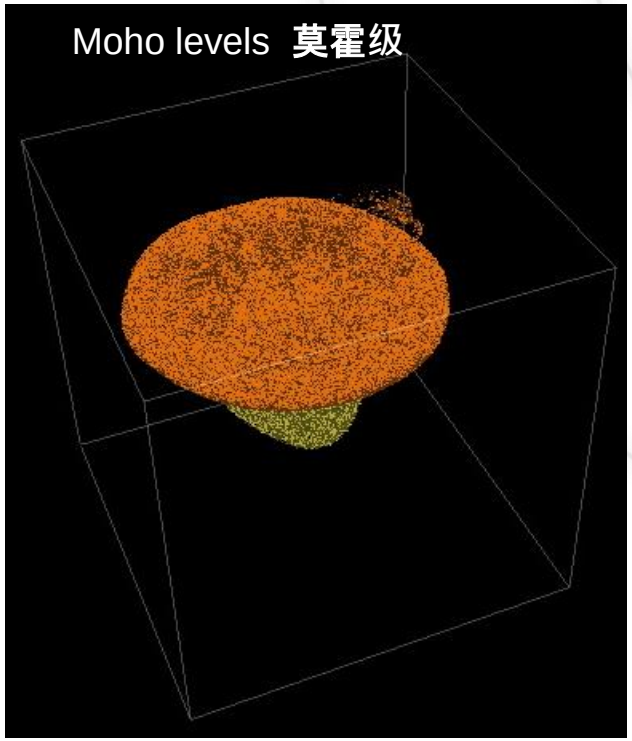


Extension: 0.7 cm/yr
Crust: upper: felsic
lower: felsic

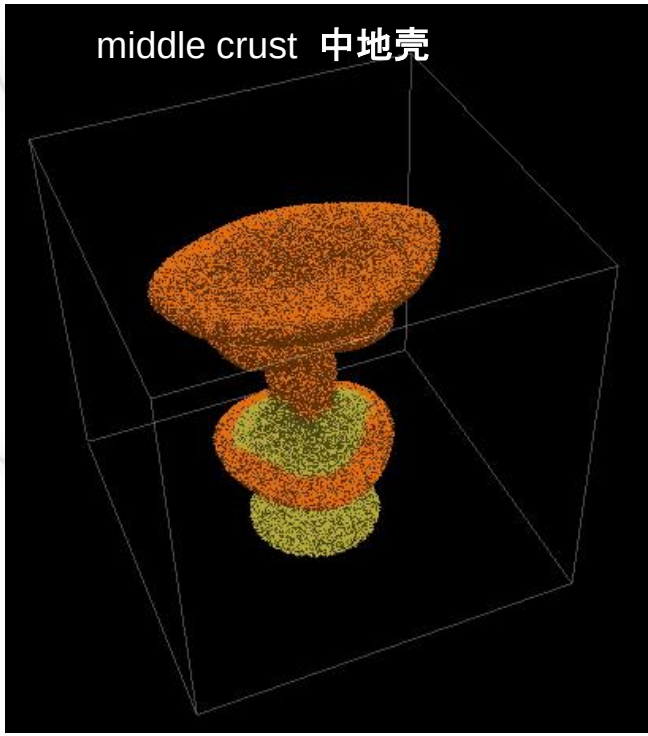




Crust: upper: mafic
lower: mafic



Crust: upper: felsic
lower: felsic



Crust: upper: felsic
lower: mafic

In nature **melt and magma transport** is a complex process:
本质上熔融和岩浆运移是一个复杂的过程
- small-scale movement of melt (melt segregation on decimeter scale)
-large-scale ascent from the source region through the continental crust to the site of final emplacement
-小规模熔融（以分米为单位）
-从源区穿过大陆地壳的大规模上侵到达最终停留点

Physical transport mechanisms: 物理运移机制

- Propagating fracture zones 扩散断裂带
- diffusion 扩散作用
- High permeability channels formed by 高渗透性通道（由以下两点组成）
  - Melt infiltration 熔融渗透
  - Stress driven melt segregation 压力驱动的分融

This study

- focuses on the large scale ascent **集中在大规模上侵**
- is not able to resolve these open questions **无法解决这些开放性问题**
- give first order estimates on intrusion geometries and related feedbacks between intruding magma and host lithologies.
  侵入几何形态上的一阶估算而且与侵入岩浆和围岩之间有回馈相关
- the viscosity contrast between melt/magma (i.e. 10^{4}–^{14} Pas), and continental crust (i.e.: 10^{22}–^{26}Pas) in natural settings is too high to be resolved numerically at the current stage.
  自然环境中的熔融/岩浆粘度比(i.e. 10^{4}–^{14} Pas),，大陆地壳(i.e.: 10^{22}–^{26}Pas) 对于目前阶段的数值解运算来说太高
- rheology employed in this study is visco-plastic and neglects the elastic response of rocks
  本研究中引入的流变学是粘-塑性的，并忽视了岩石的弹性响应

THE UNIVERSITY OF WESTERN AUSTRALIA

Thank you

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