Interactions between Subduction and mantle plumes in Venus

By: Hiva Mohammadzadeh (Los Angeles Pierce College, now at UC Berkeley)

Mentors: Prof. Dave Stegman(UCSD) and Dr. Suzanne Smrekar(NASA, JPL)

Sponsored by: CIG

What we know about Venus?

- Similar size and density as Earth
- Similar heat budget to the Earth
- Old planet but Young surface
- Does not have system of plate tectonics

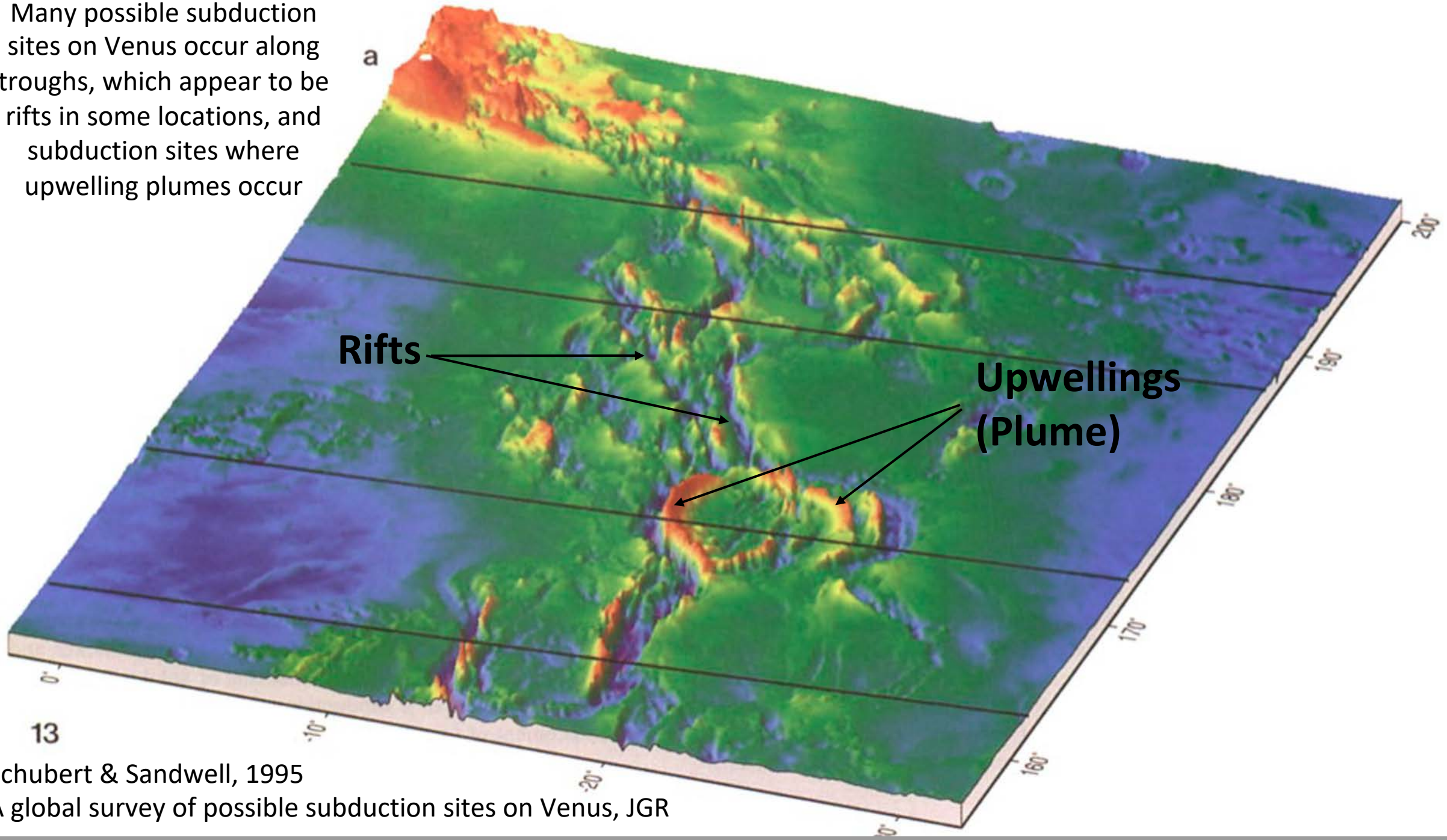
What we know about Venus?

- Similar size and density as Earth
- Similar heat budget to the Earth
- Old planet but Young surface
- Does not have system of plate tectonics

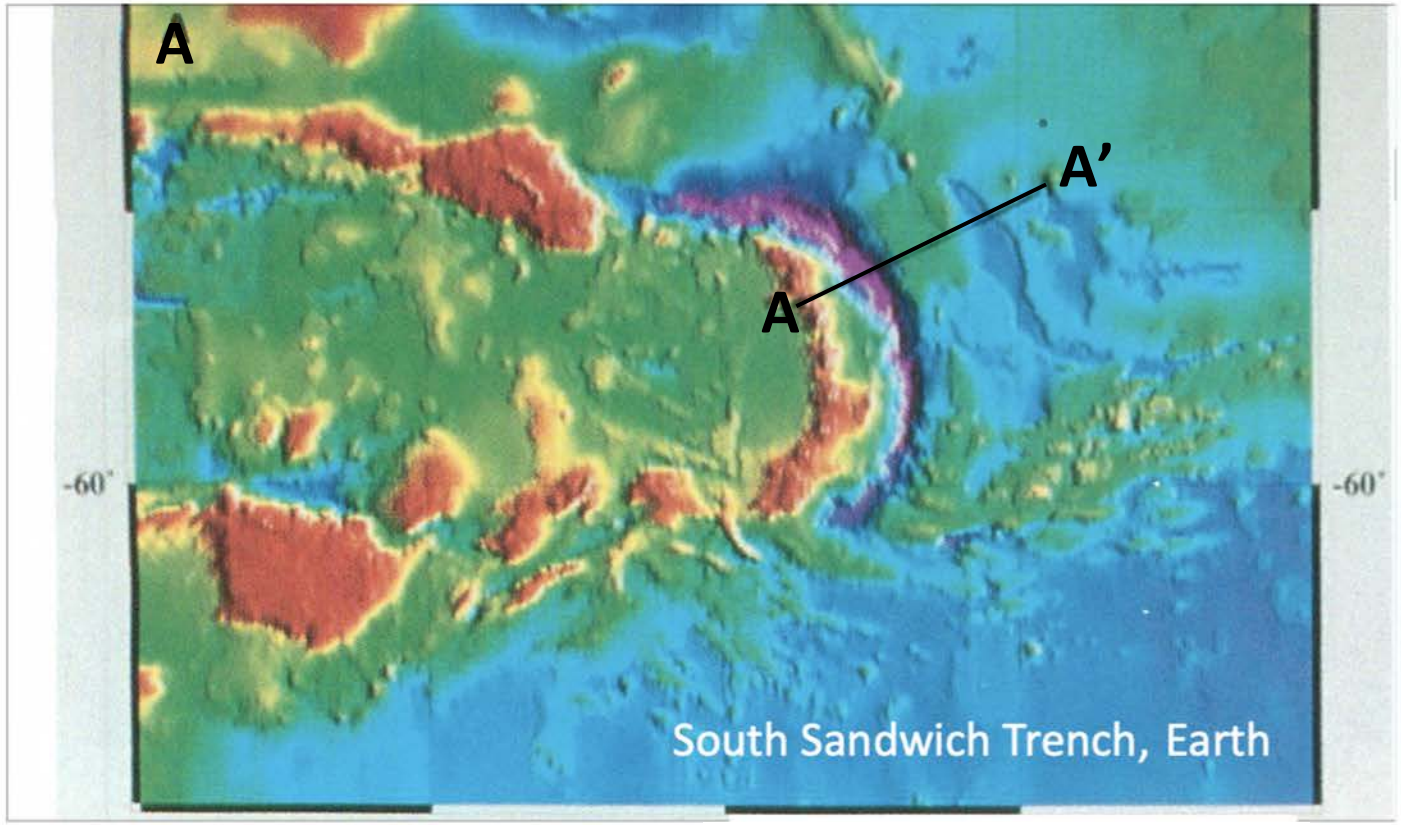
Subduction

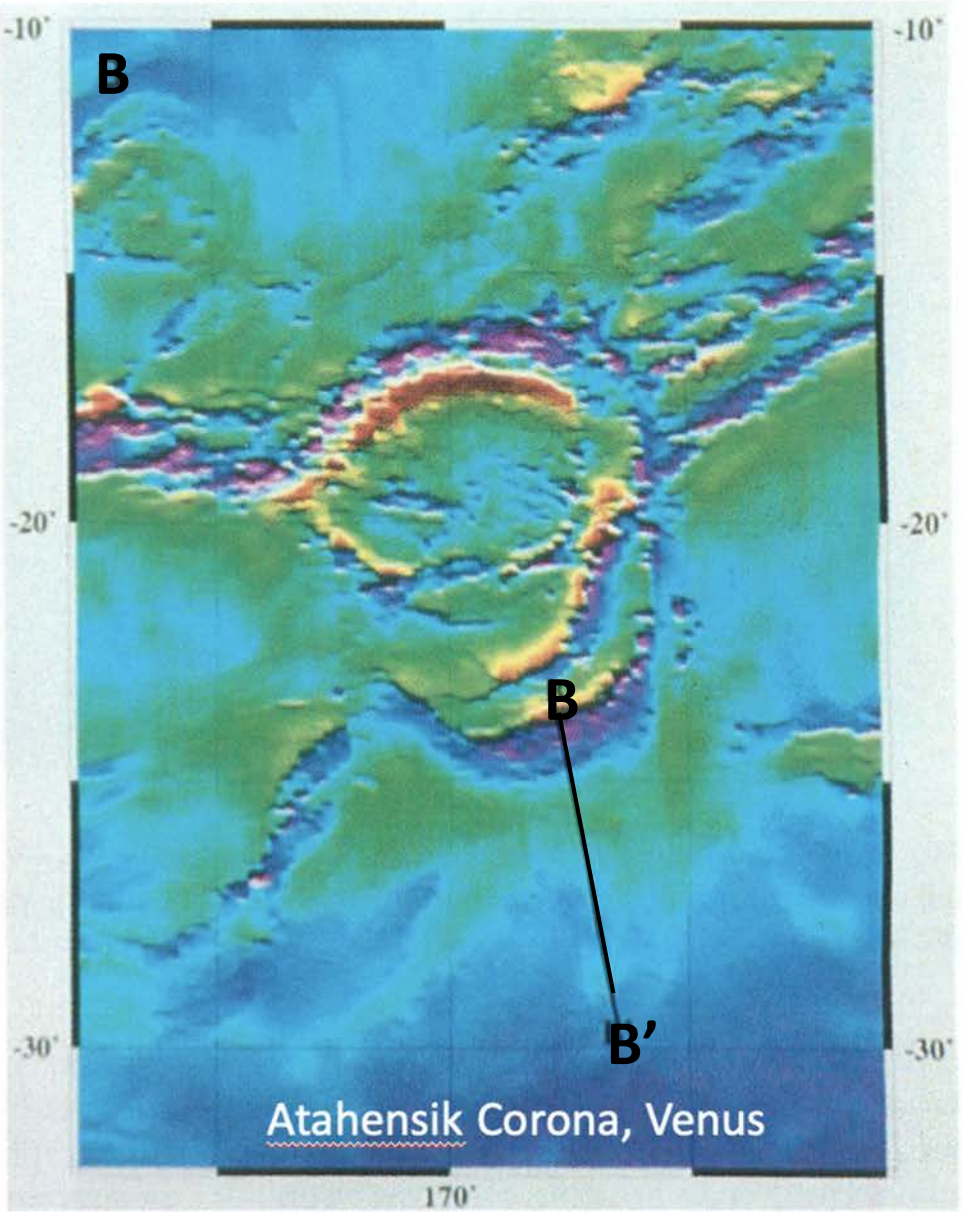
- How?
- Plate ‘foundering’, or ‘Roll-back’ subduction?
- Plate tectonics dominates plate processes today
- How subduction begins
- How plate tectonics starts

Many possible subduction sites on Venus occur along troughs, which appear to be rifts in some locations, and subduction sites where upwelling plumes occur



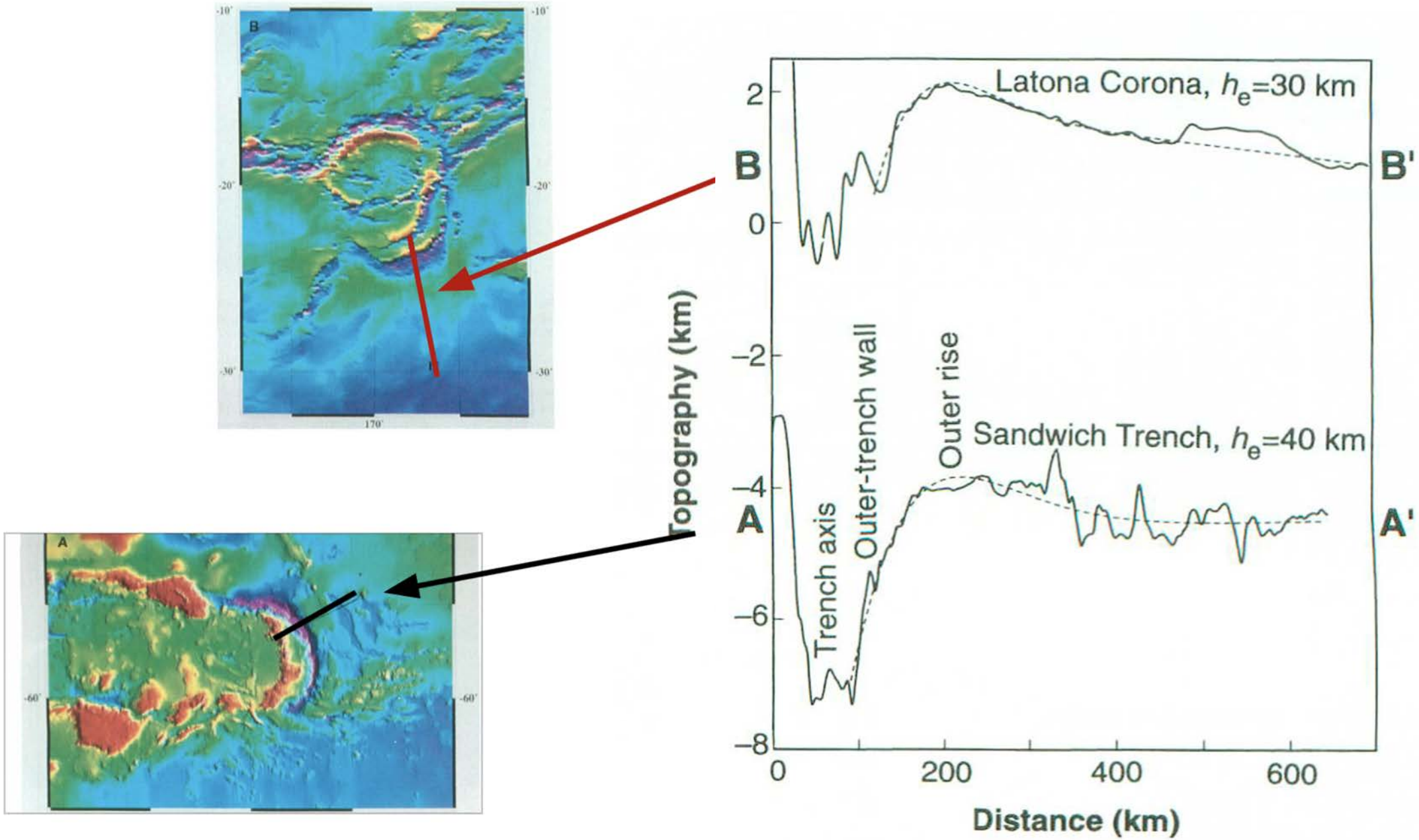
Schubert & Sandwell, 1995
A global survey of possible subduction sites on Venus, JGR





Possible subduction zones on Venus are morphologically similar, with similar lithospheric strength

Sandwell and Schubert, 1992

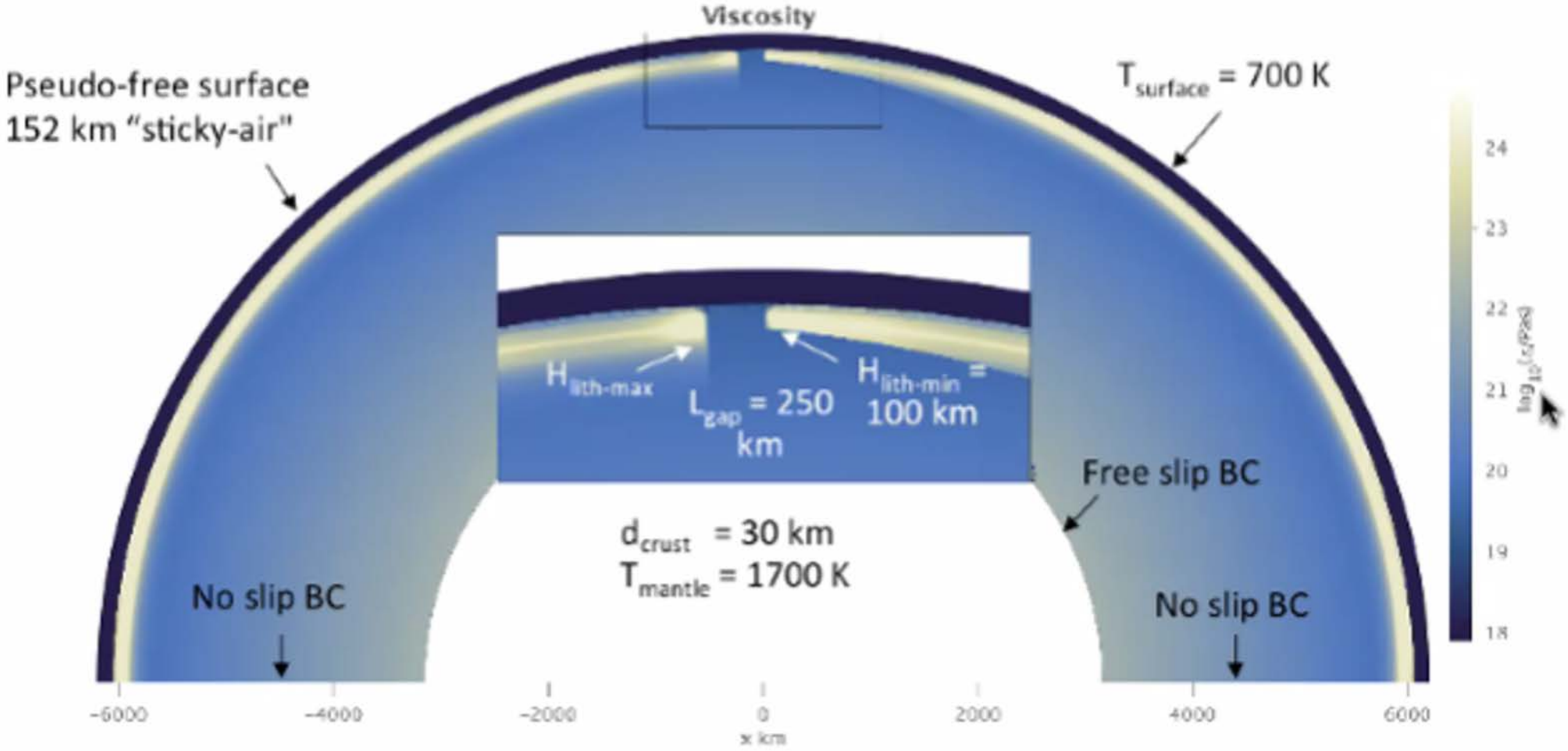


Sandwell and Schubert, 1992

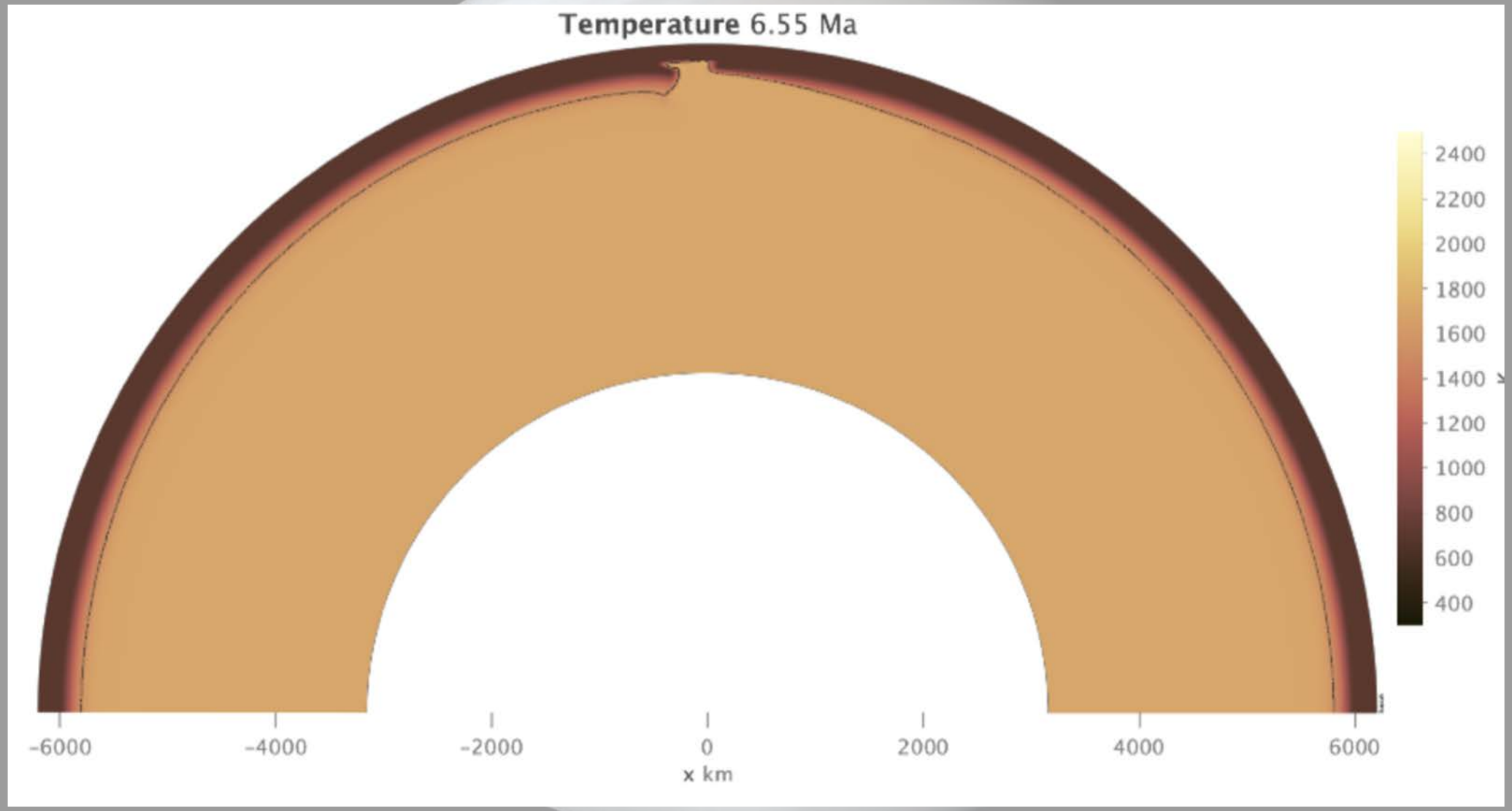
Based on these observations, goals of our project

- Find a range of conditions where subduction can or cannot happen on Venus and how plumes may assist in that
- This project will use numerical models of mantle convection to examine this relationship and further constrain the interior structure of Venus
- Will be implementing the StagYY Code (Tackley, 2008)
- Parameters that we'll be varying and using are
  - 20 km and 30 km crust
  - Range of different radius and location values for our plume

Model Setup


Viscosity
Pseudo-free surface
152 km "sticky-air"
$T_{surface}$ = 700 K
$H_{lith-max}$
L_{gap} = 250 km
$H_{lith-min}$ = 100 km
Free slip BC
d_{crust} = 30 km
T_{mantle} = 1700 K
No slip BC
No slip BC
-6000
-4000
-2000
0
2000
4000
6000
x km
24
23
22
21
20
19
18
$\log_{10}(\eta/Pas)$

Subduction initiation without plume assistance



Parameters: Lithosphere of 250 km, Maximum Viscosity of 1e24 Pa*s, Crustal thickness of 30 km

Goal-Examine plume assisted subduction initiation

- From previous runs and models, we had some models that the conditions weren't favorable for them to develop into subduction.
- Find out if this is just because of the present of a gap
- Will the insertion of a mantle plume there add that extra force and push them into being unstable.

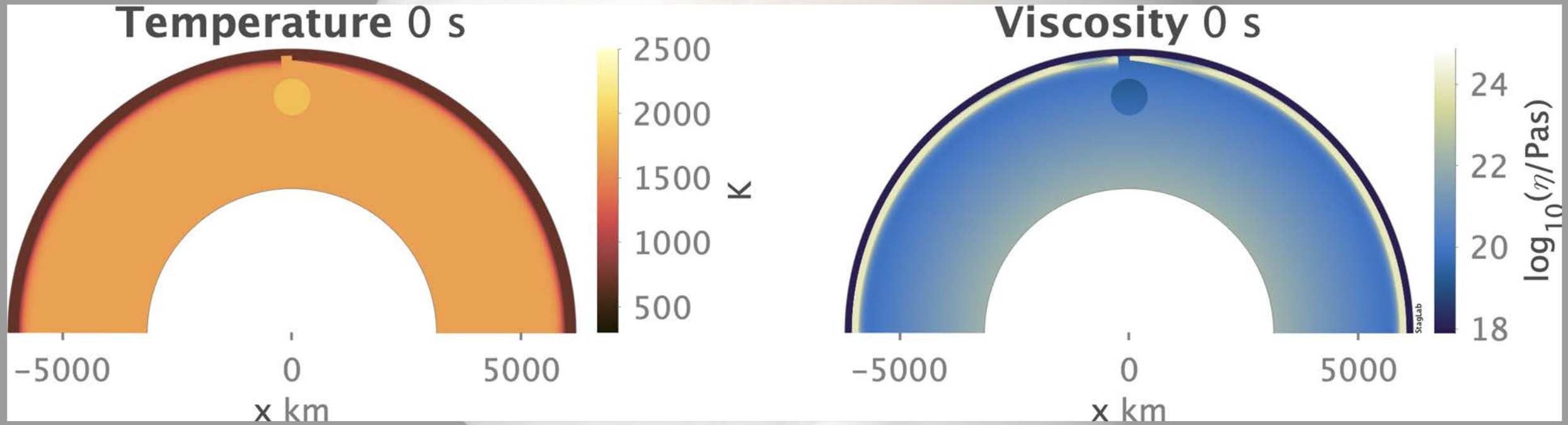
Implementing the StagYY Code reference tackley 2008

```
!can add the additional temperature feature
!Add plume temperature logic here. temperature field is done
!Add a circular plume feature- a circle below the plate interface gap
!y-z coordinate
!Identify the location of the center point of the plume in terms of the variables used to define the temperature field
!y is x and z is y in this case
!If these conditions are met, then we set the temperature to be something else
!T is the actual temperature field in this case

!If these conditions are met and if the points that I'm looking for in the circle of this radius that is centered at this point
!then T = t0init + 200 or 300 or hotter plume
!variables needed - depth, t0_init, y, z, distance to the center,
!400 km radius
!2000km depth
!depth is the depth below the surface

!The 1.618*10**7 comes from the depth of the plume's center which is R=5150km from the center of the planet.
!The radius of the CMB is 3150, and the plume is being located 2000km above the CMB, then that is 5150km
!Then pi*R_plume_depth = 16180km

        y_km = y * 1.618*10**7
        y_0 = y_mid* 1.618*10**7
        z_0 = 2000000
!center = (y_0, z_0)
        plumeRadius = 500000

        distanceFromCenter = SQRT((y_km-y_0)**2 + (z-z_0)**2)
        if(distanceFromCenter <= plumeRadius) then
 !if (y< y_0) then
                print*, 'y=',y*(10**8)
                print*, 'y_mid=',y_mid
                print*, 'distanceFromCenter=', distanceFromCenter
                T = t0_init + 200
        endif
```

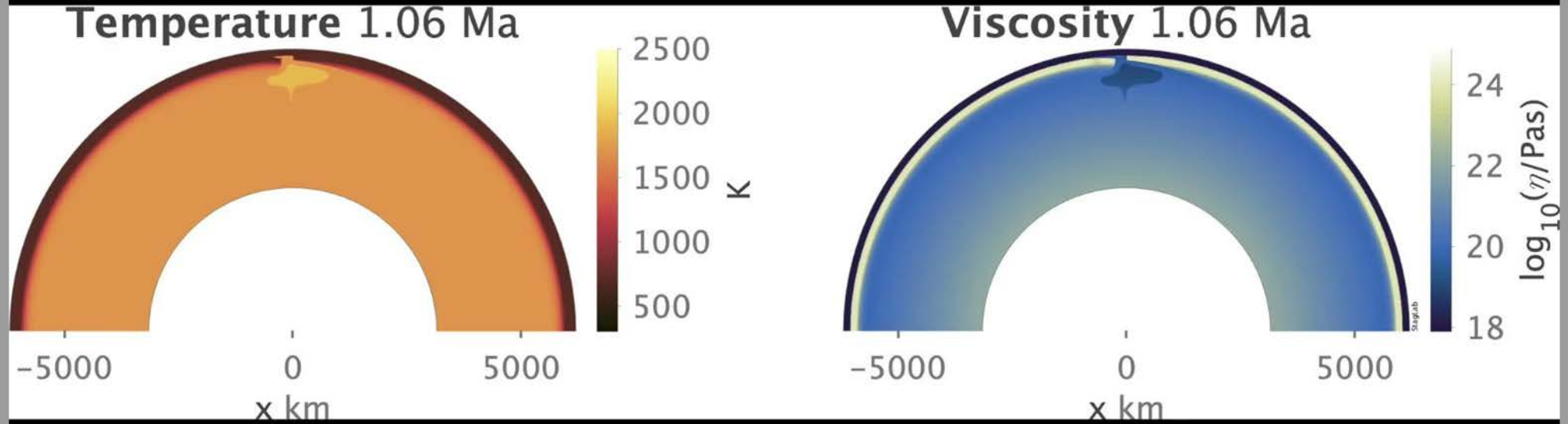
Feature that controls depth of plume in meters

Feature that controls the radius of plume in meters

Initial conditions – Plume of 400 km radius at 1000 km depth

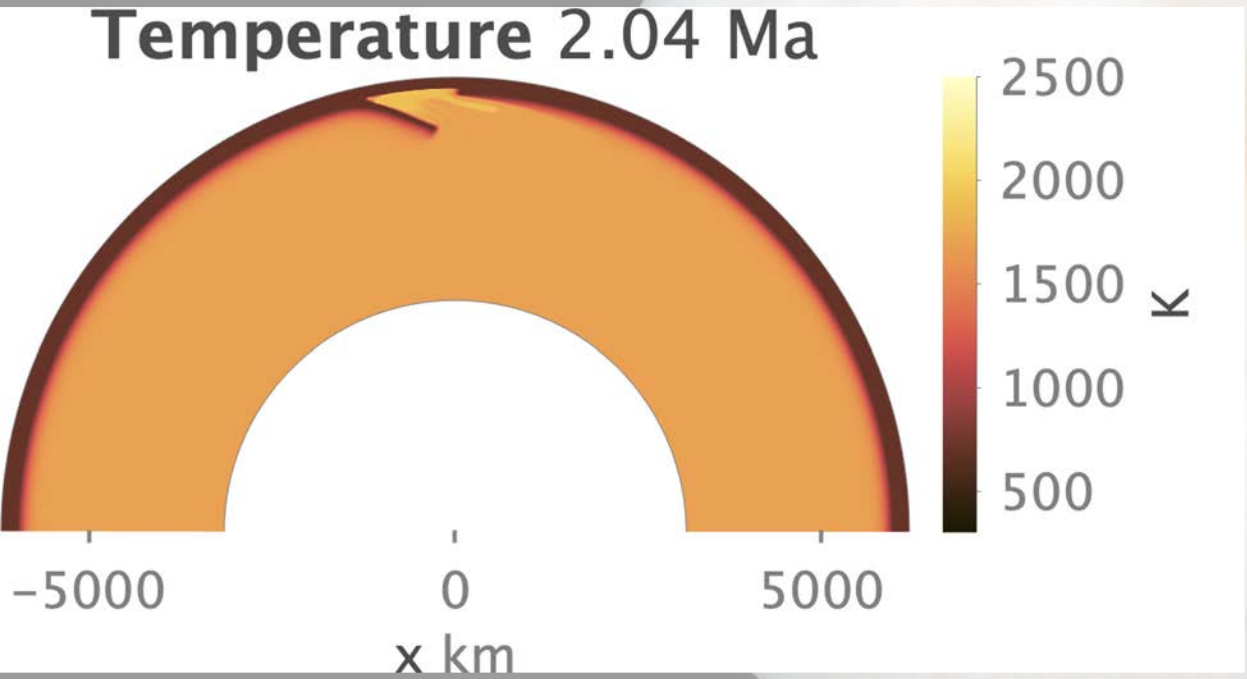


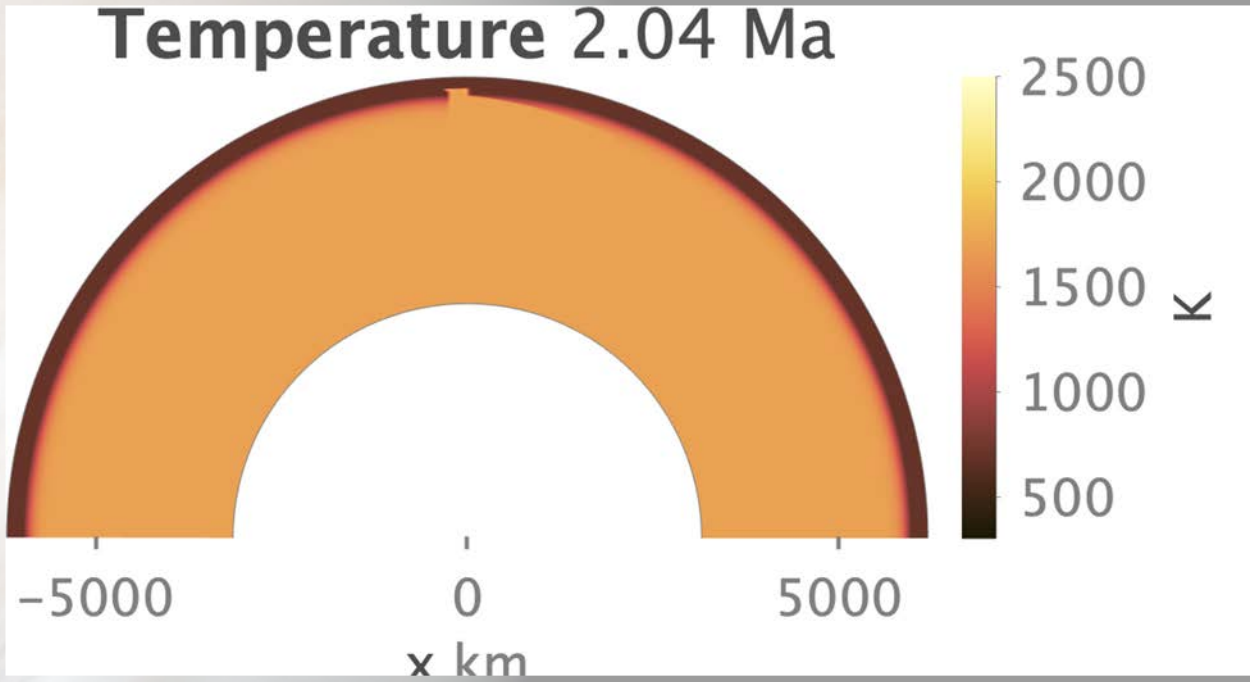
Plume speeded up subduction initiation



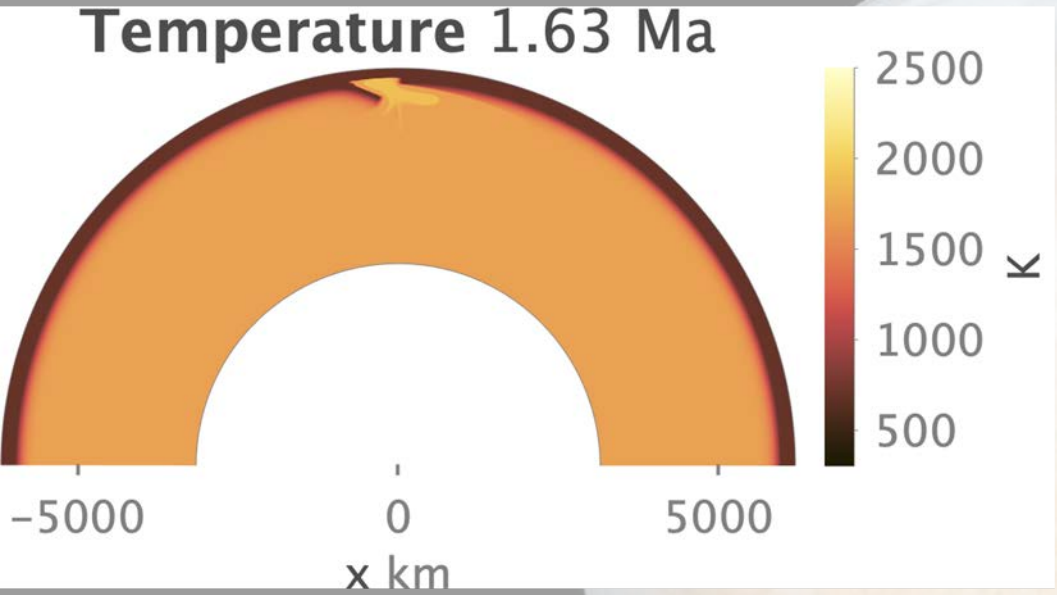
Parameters: Lithosphere thickness of 250 km , Maximum Viscosity of 1e24 Pa*s , 20 km thick crust, 400 km radius plume

Results: 300 km radius plume vs No plume

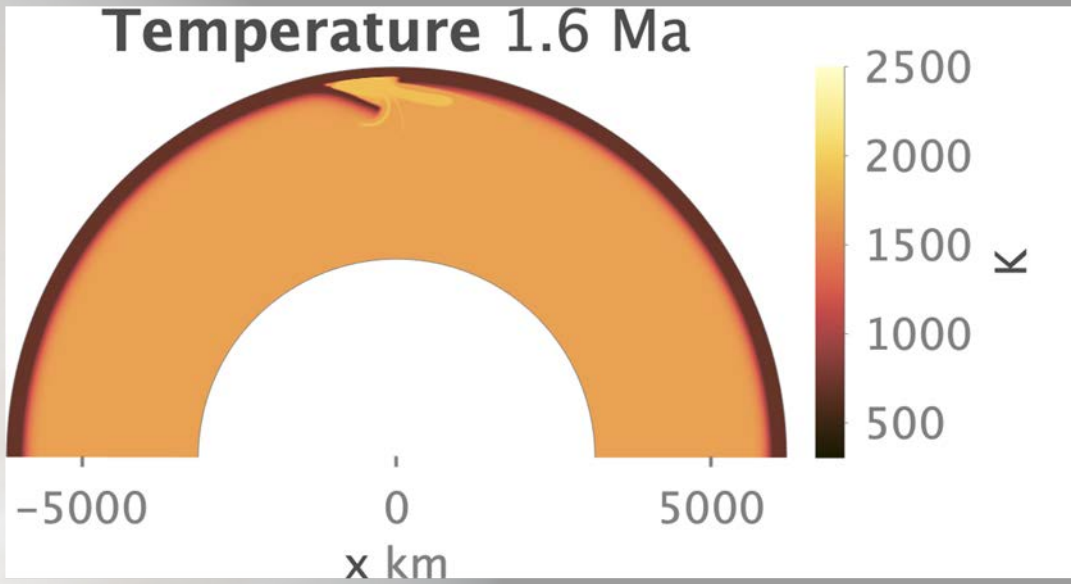




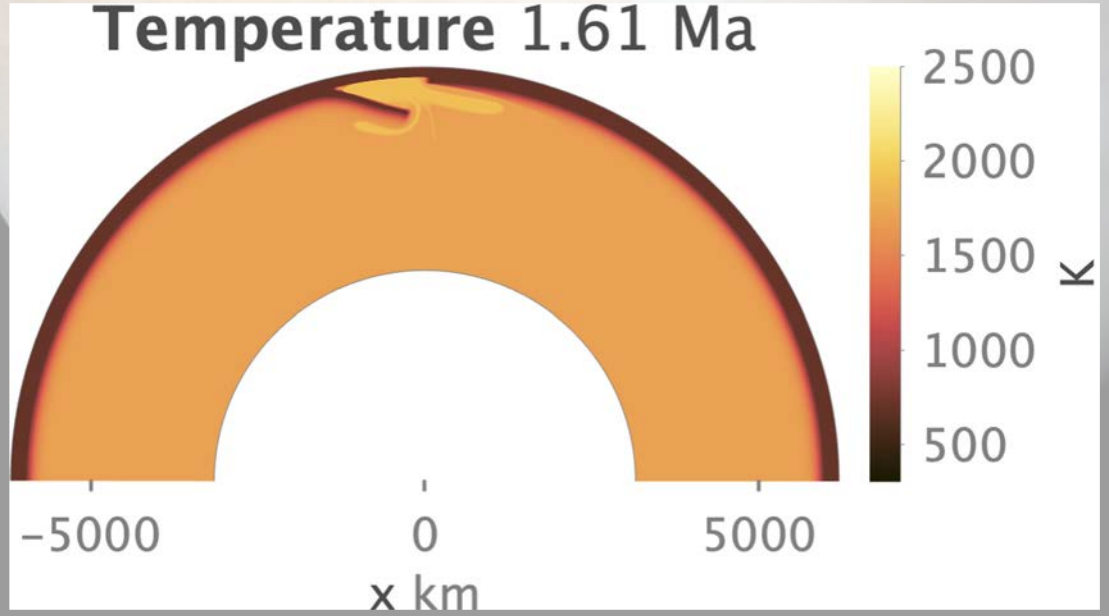
Changing the size of the plume



300 km

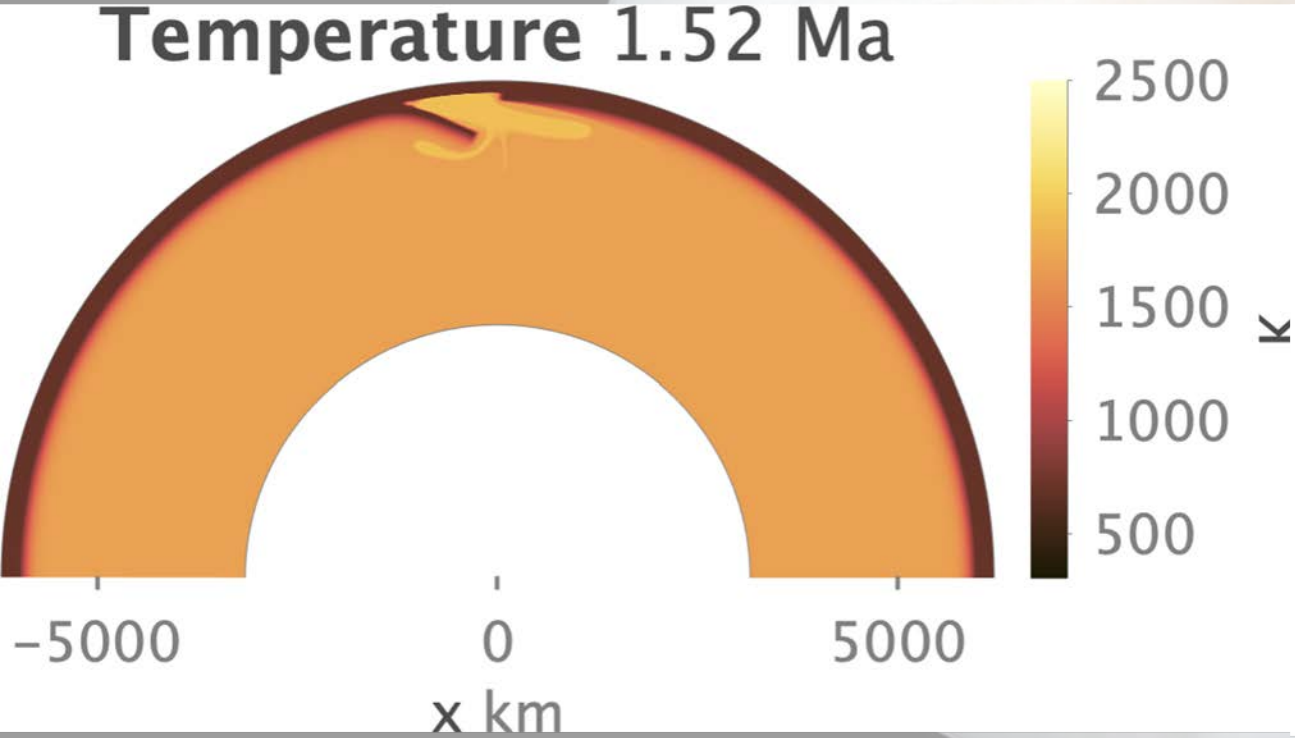


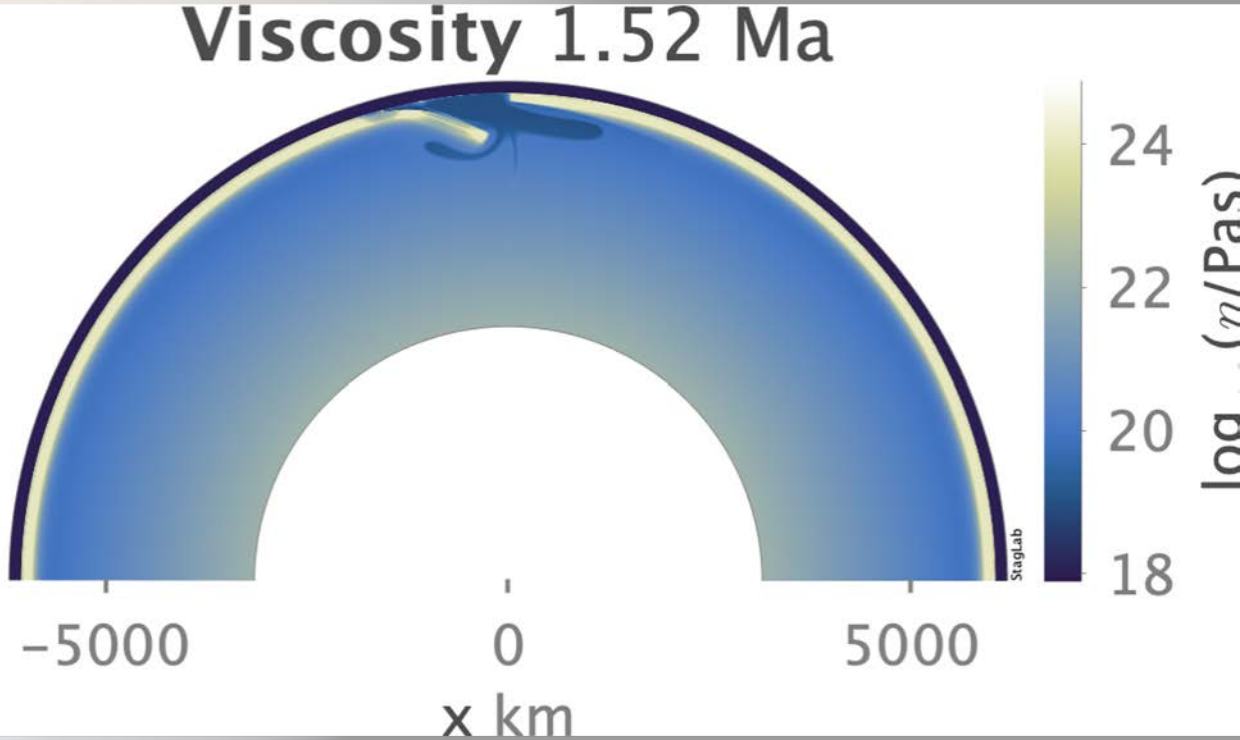
400 km



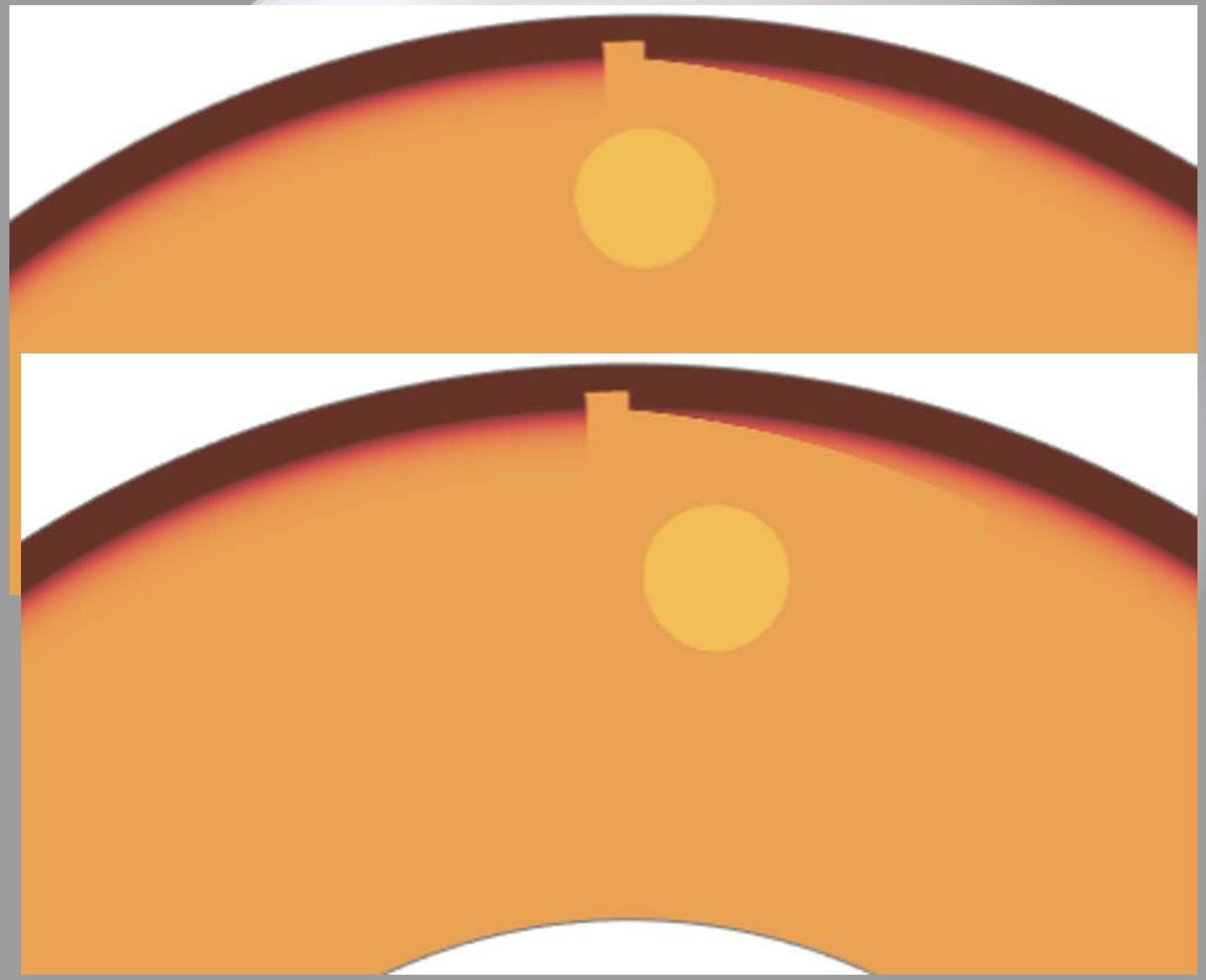
500 km

Challenge: How can we prevent the plume from interacting with the sinking slab tip?

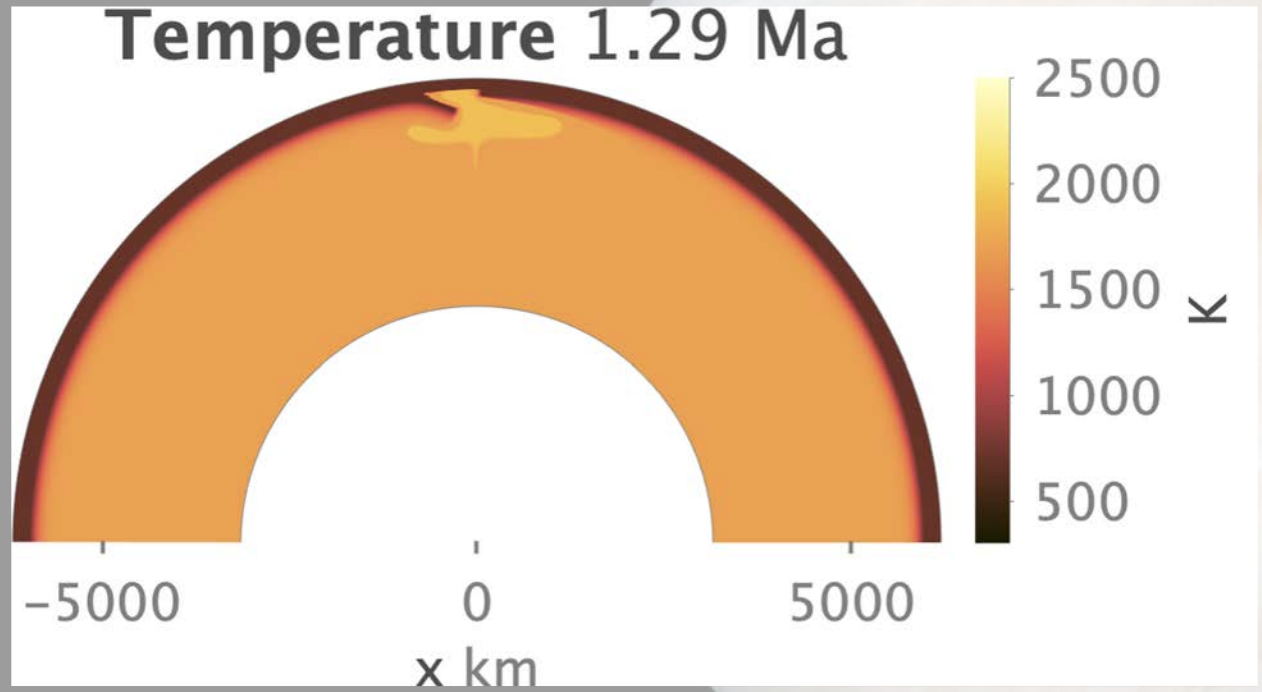




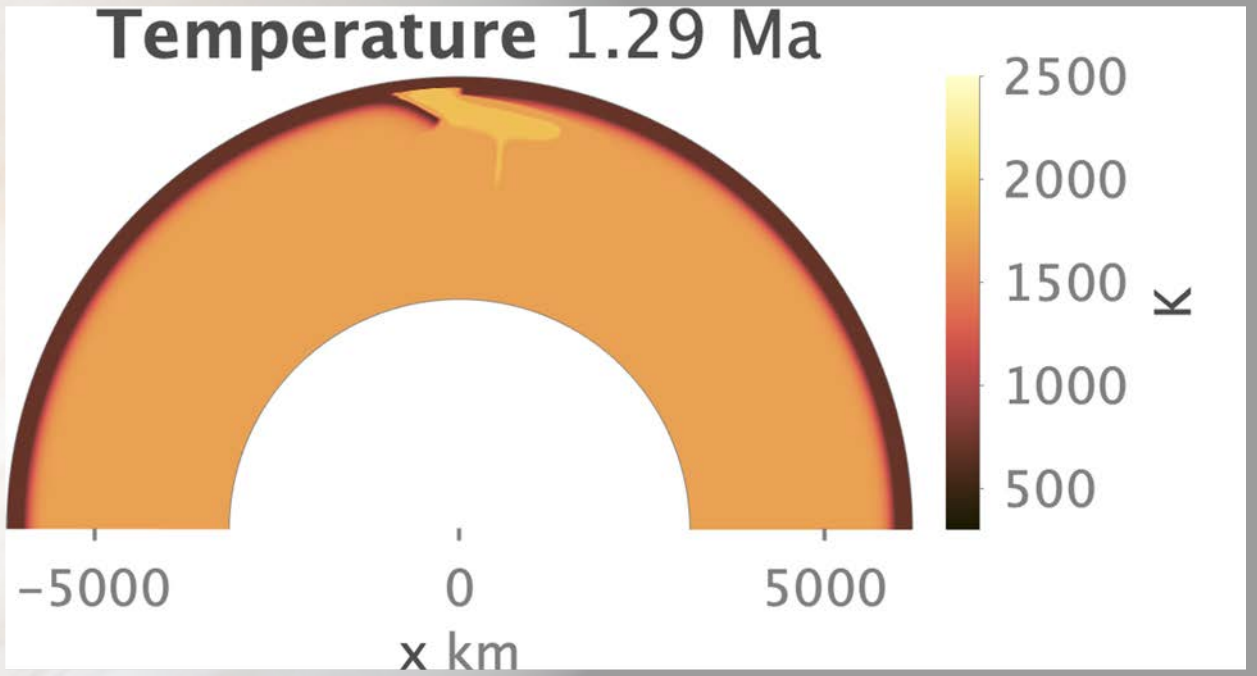
Plume moved to the right by 485 km



Changing the Location of the plume changes plume-lithosphere dynamics

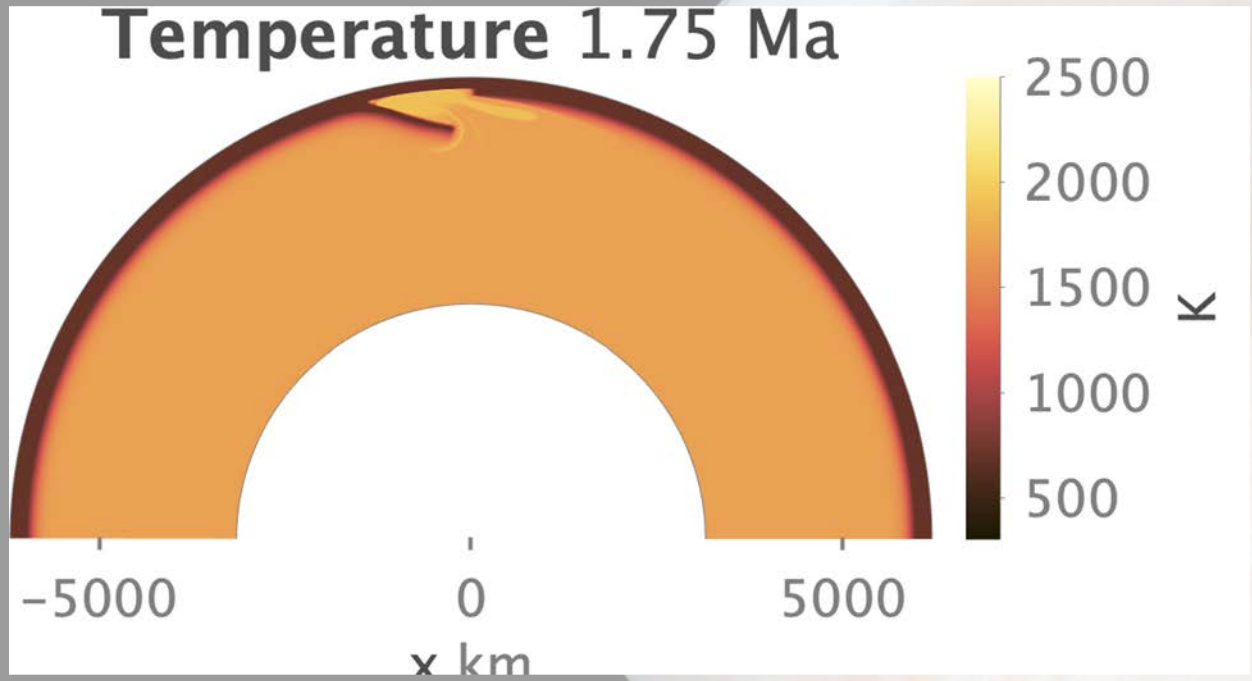


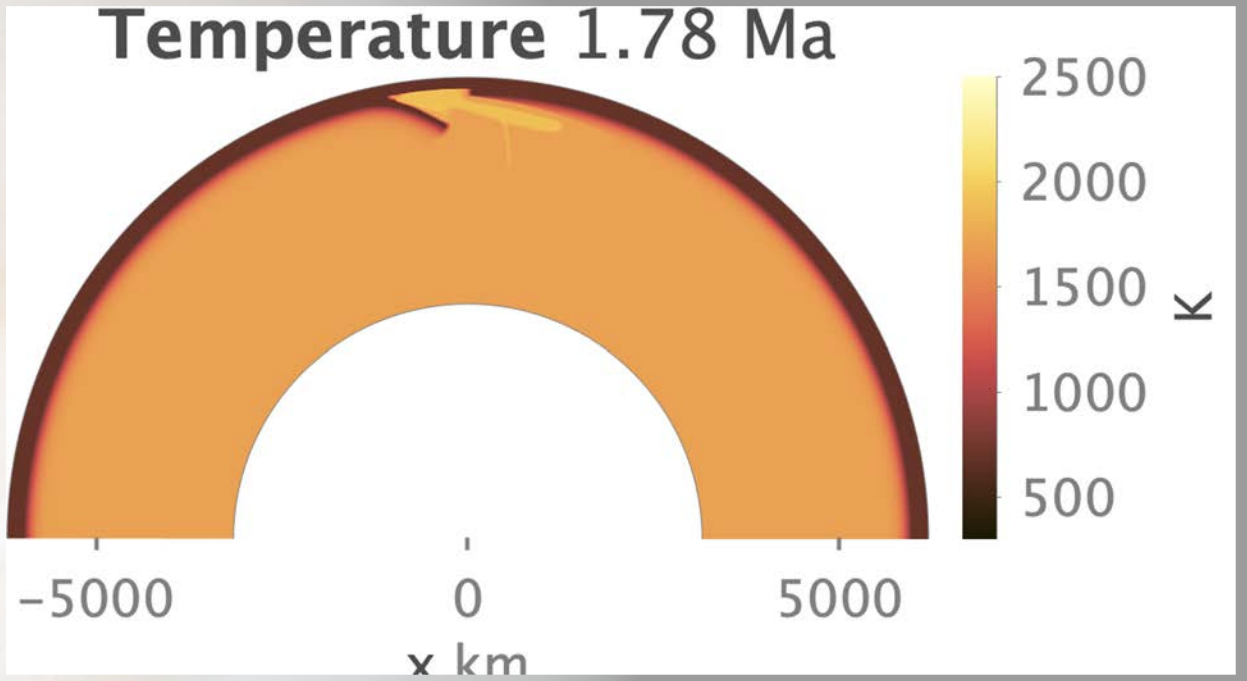
500 km radius plume placed 2000 km deep and Centered in the middle below the gap



500 km radius plume placed 1800 km deep and moved to the right by 485 km

Changing the size and moving of the plume





400 km radius plume
2000 km deep
Centered in the middle
below the gap

400 km radius plume
1900 km deep
Off-center of the gap
to the right by 485 km

Conclusion

- Plume-lithosphere interactions assist in the onset of subduction
- Location of the plume/upwelling changes plume-lithosphere dynamics
- Increasing the size of the plume speeds up subduction initiation

Next steps/Remaining questions

- Can the plume help initiate subduction in models with thicker lithosphere and buoyant crust
- Vary the temperature of the plume and examine its effect on the timing of subduction
- Run a full suite of models where we systematically vary temperature, size, and location of plume to study timing of the onset of subduction and compare to non-plume models
- See the long-term effect of the plume

Acknowledgements

Thank you, Prof. Dave Stegman and Dr. Sue Smrekar for being amazing mentors and supporting me throughout this project

Thank you, CIG for sponsoring and supporting the program, through NSF grant EAR-155090

Thank you, all of the mentors and authorities at CIG and SMOREs participants for the opportunity and support

COMPUTATIONAL INFRASTRUCTURE for GEODYNAMICS

NSF

UNIVERSITY OF CALIFORNIA · SAN DIEGO · LET THERE BE LIGHT

NASA

JPL Jet Propulsion Laboratory

Thank you!
Any questions?