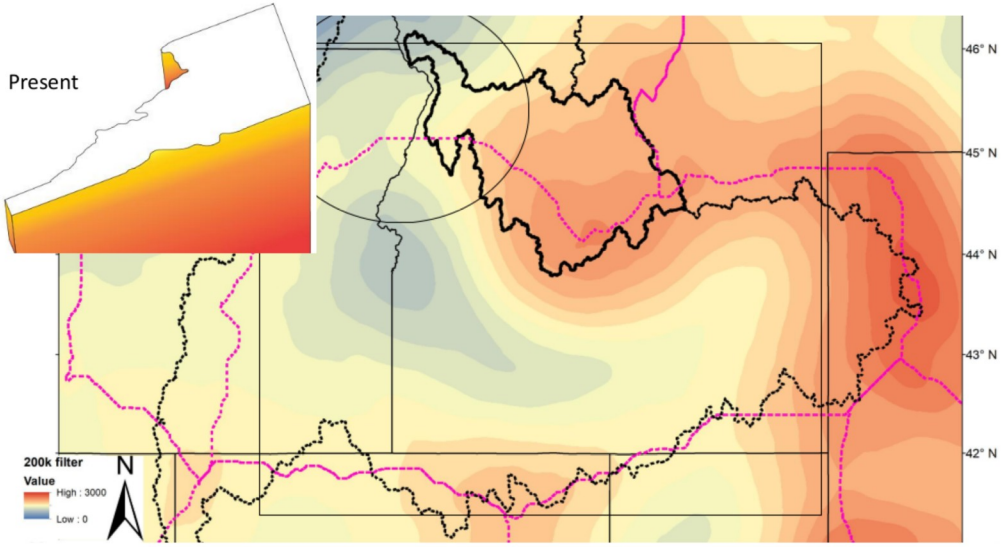
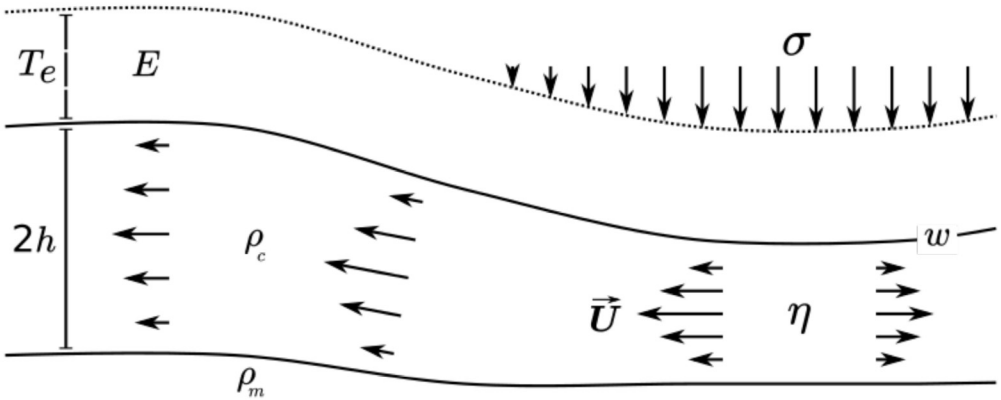
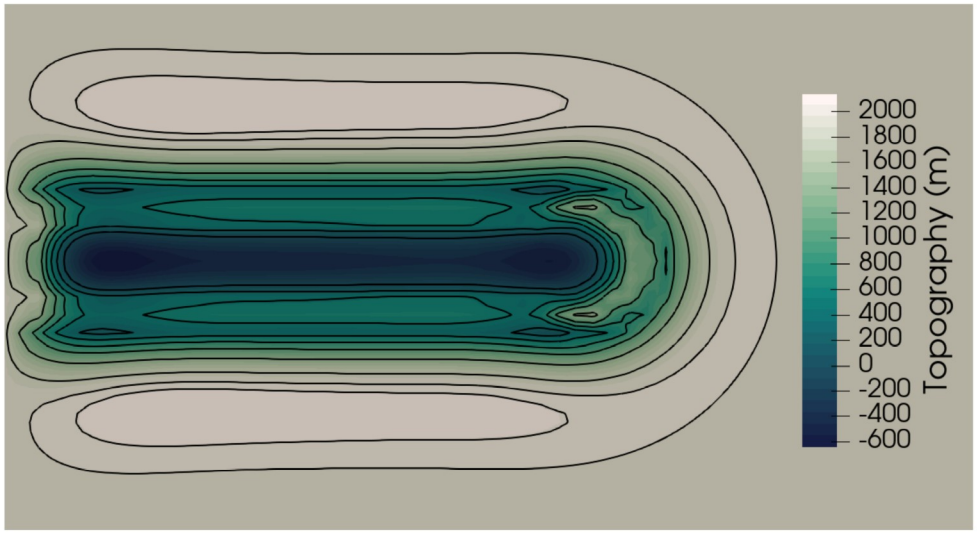
Numerical models of lower crustal flow explain Yellowstone's "tectonic parabola"

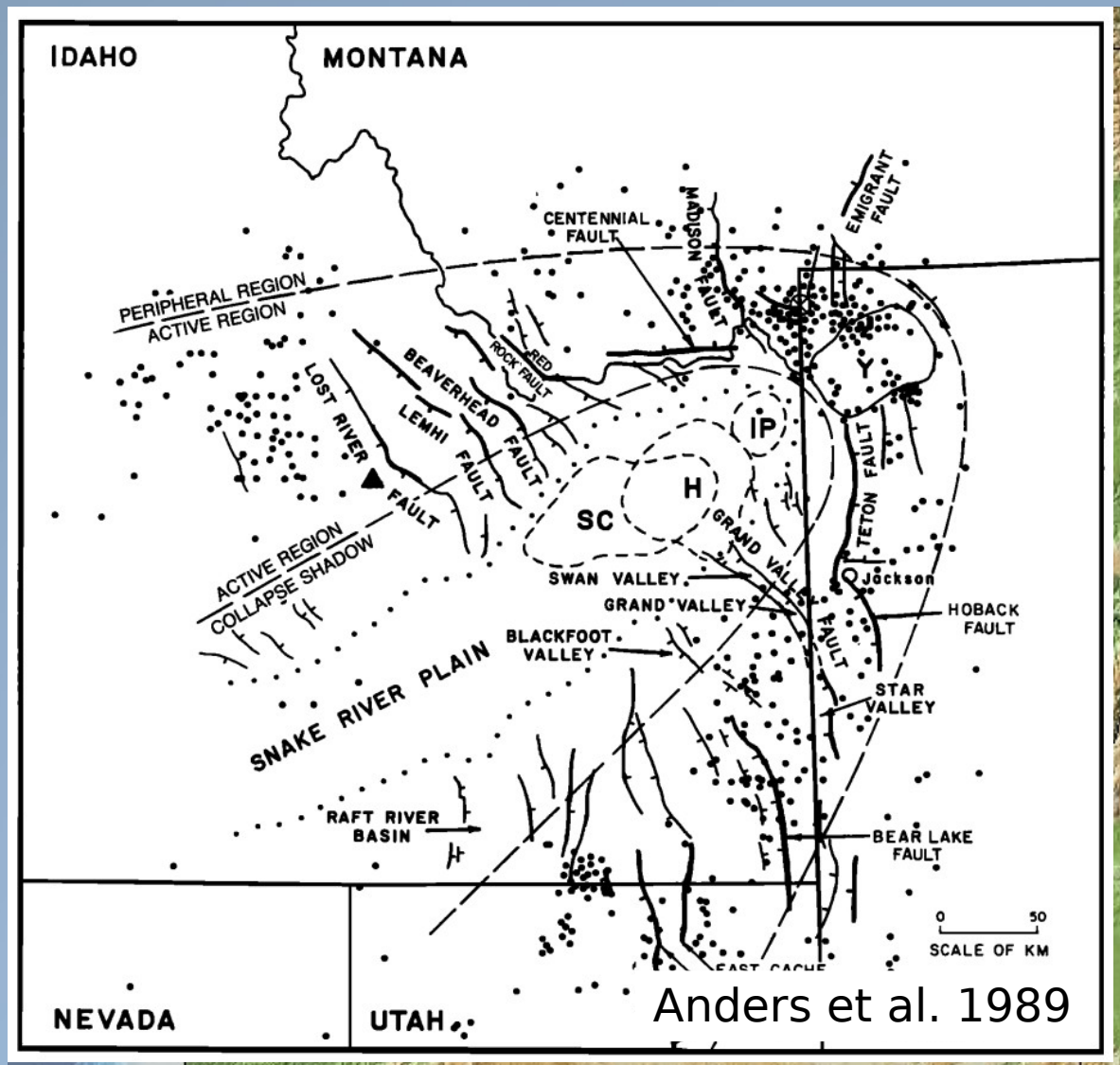




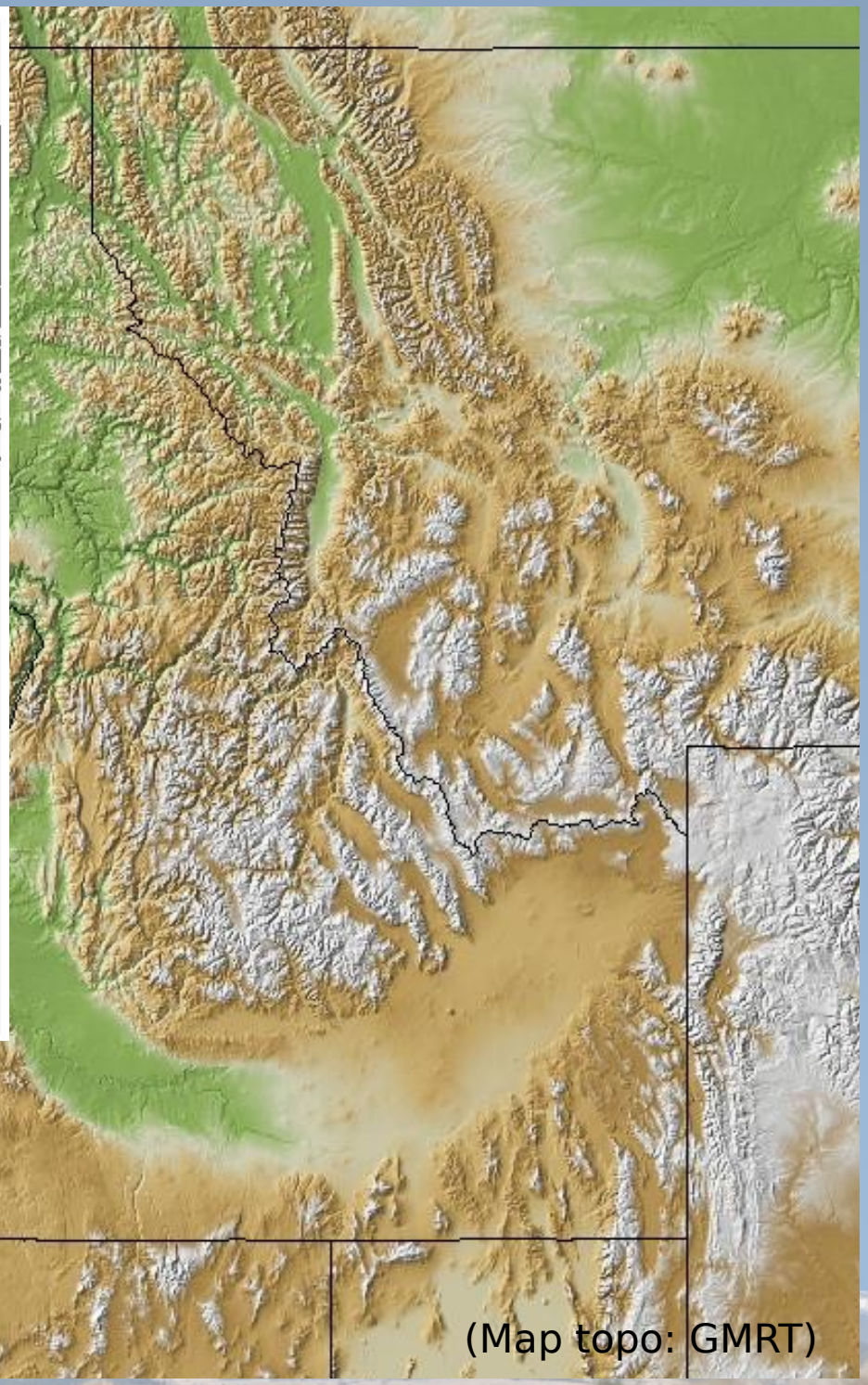


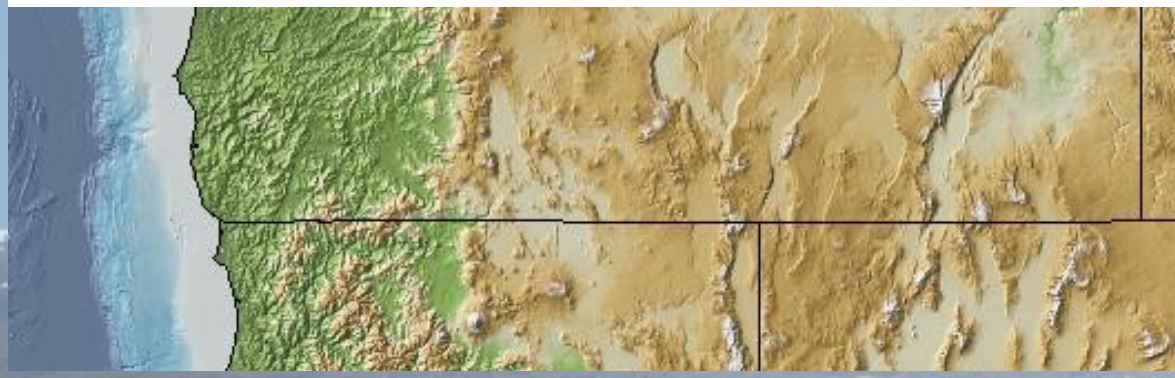
Jonathan Perry-Houts – Nov. 12, 2020

CIG Webinar



Anders et al. 1989





(Map topo: GMRT)

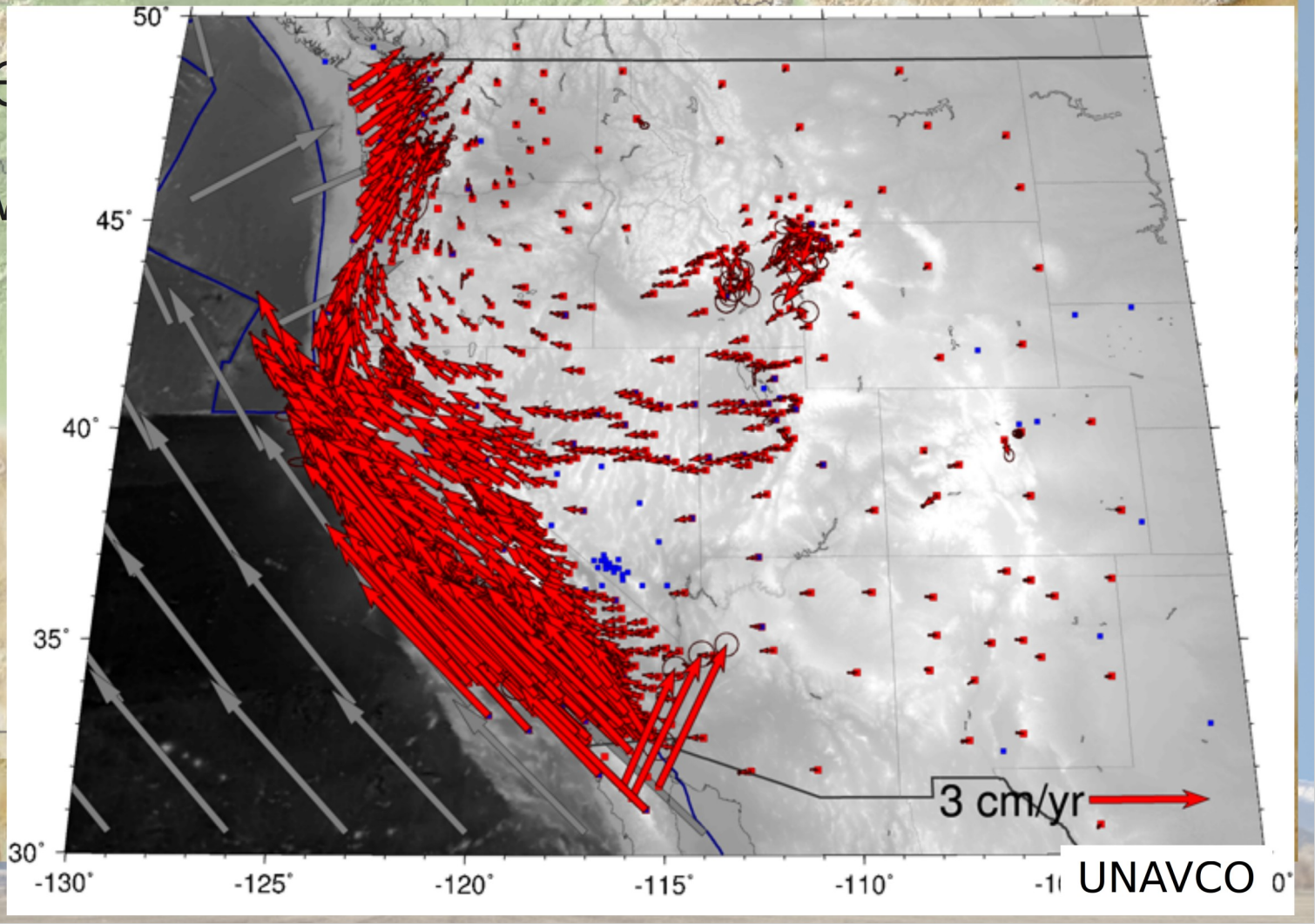
Proposed origins of the tectonic parabola

- Tectonic deformation
- Plume flattening
- Crustal flow

(Map topo: GMRT)

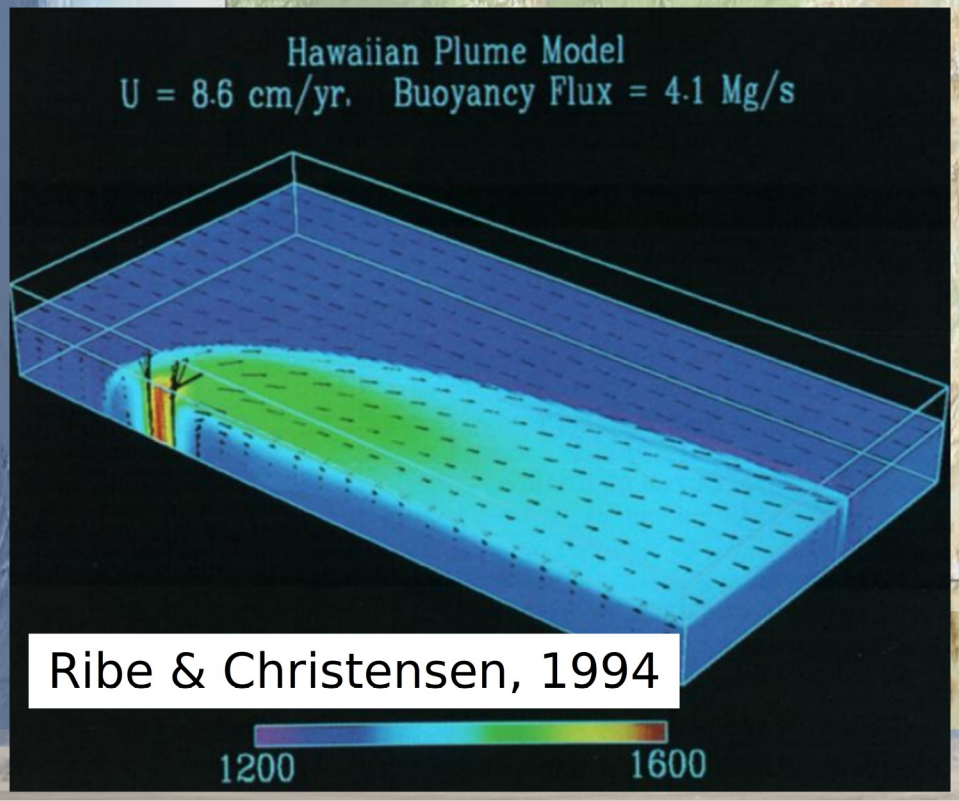
Proposed origins of the tectonic parabola

- Tectonic deformation
- Plume flatte
- Crustal flow

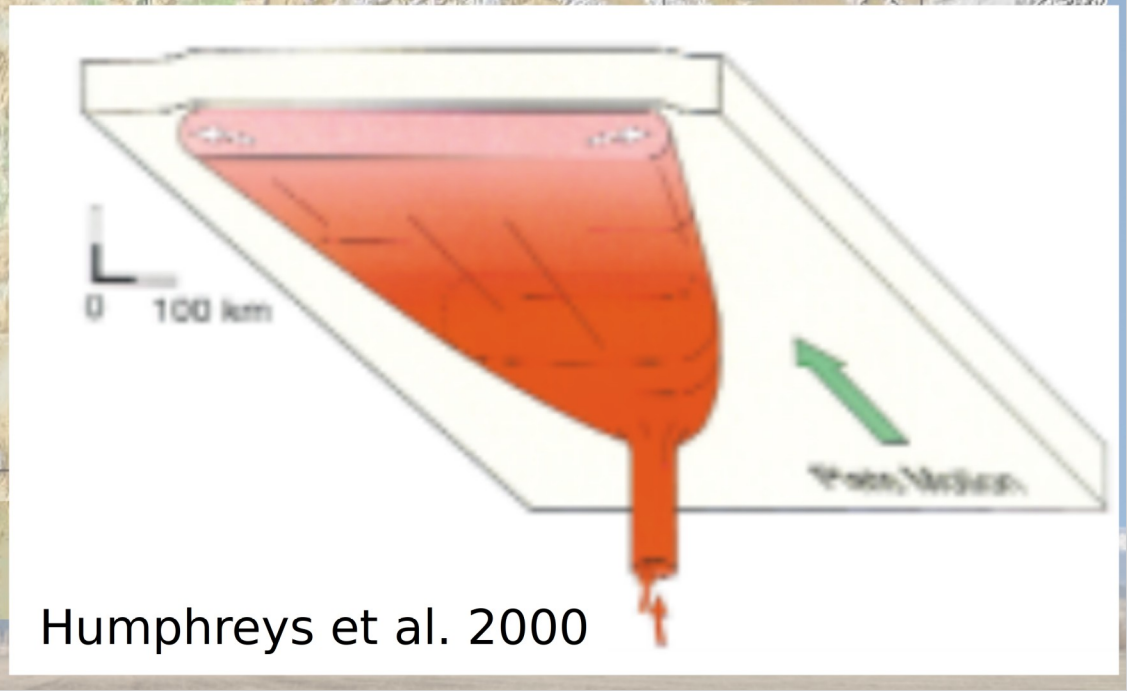


Proposed origins of the tectonic parabola

- Tectonic deformation
- **Plume flattening**
- Crustal flow

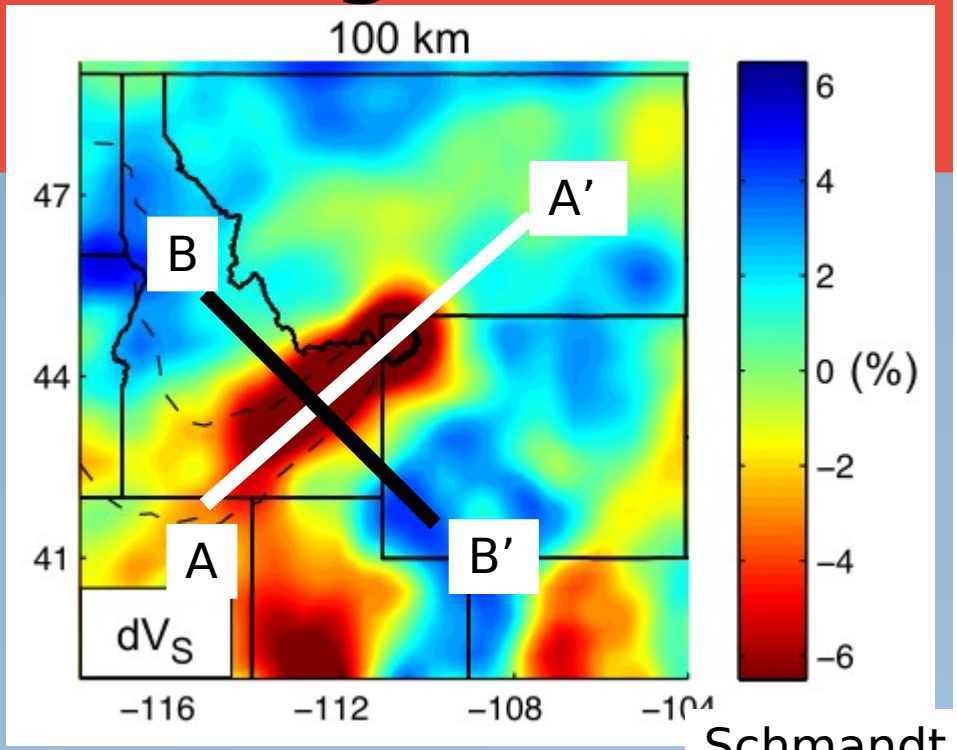


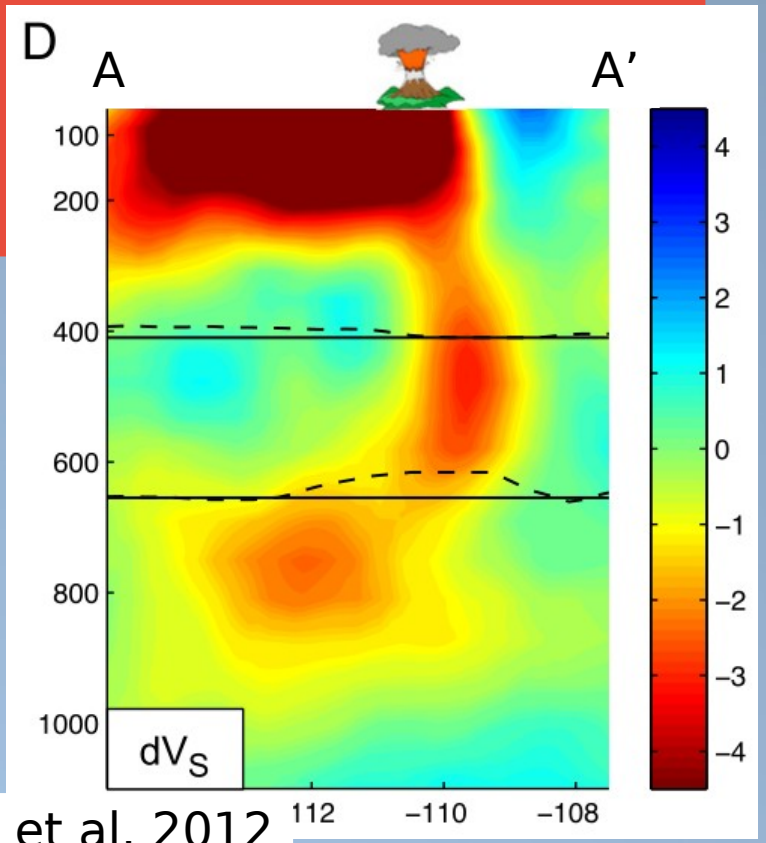
Ribe & Christensen, 1994



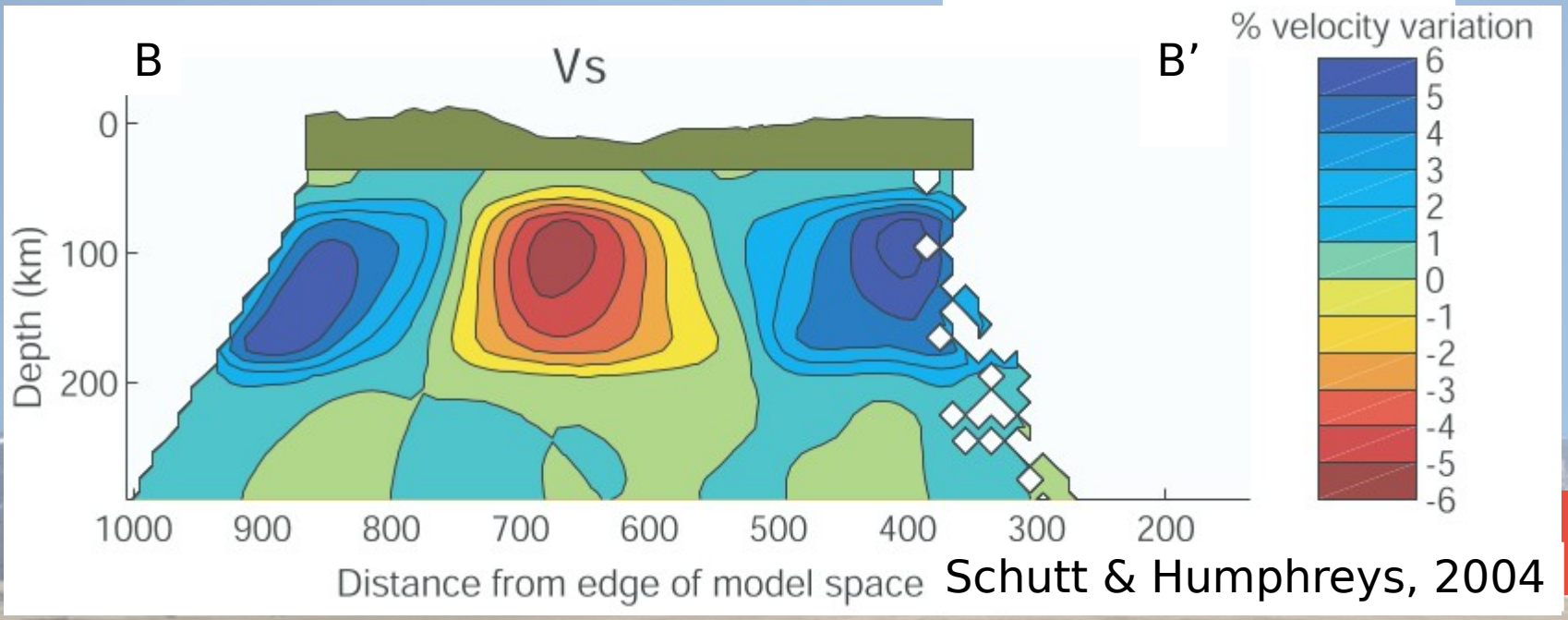
Humphreys et al. 2000

Plume flattening

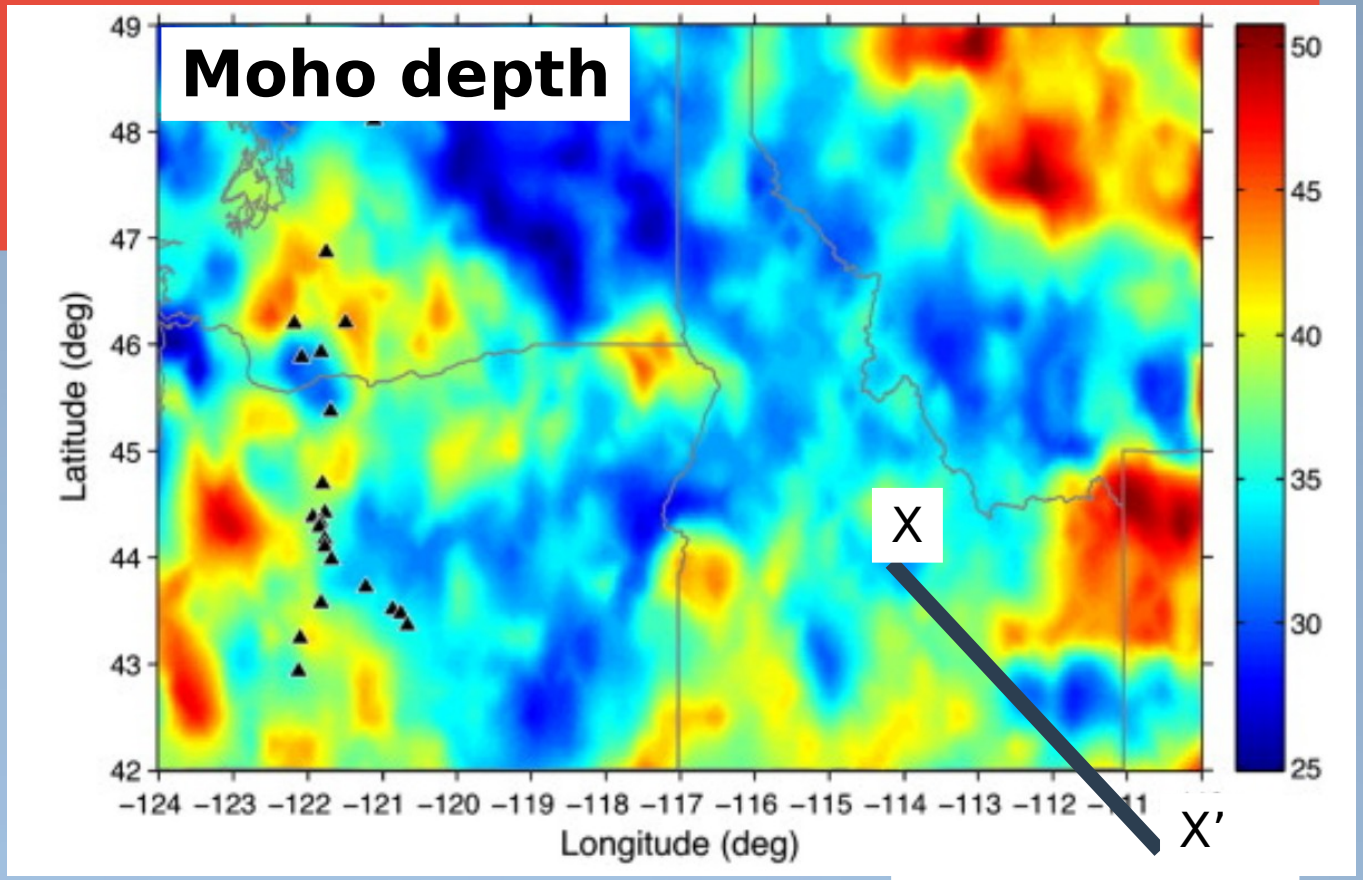




Schmandt et al. 2012



Schutt & Humphreys, 2004



Gao et al. 2011

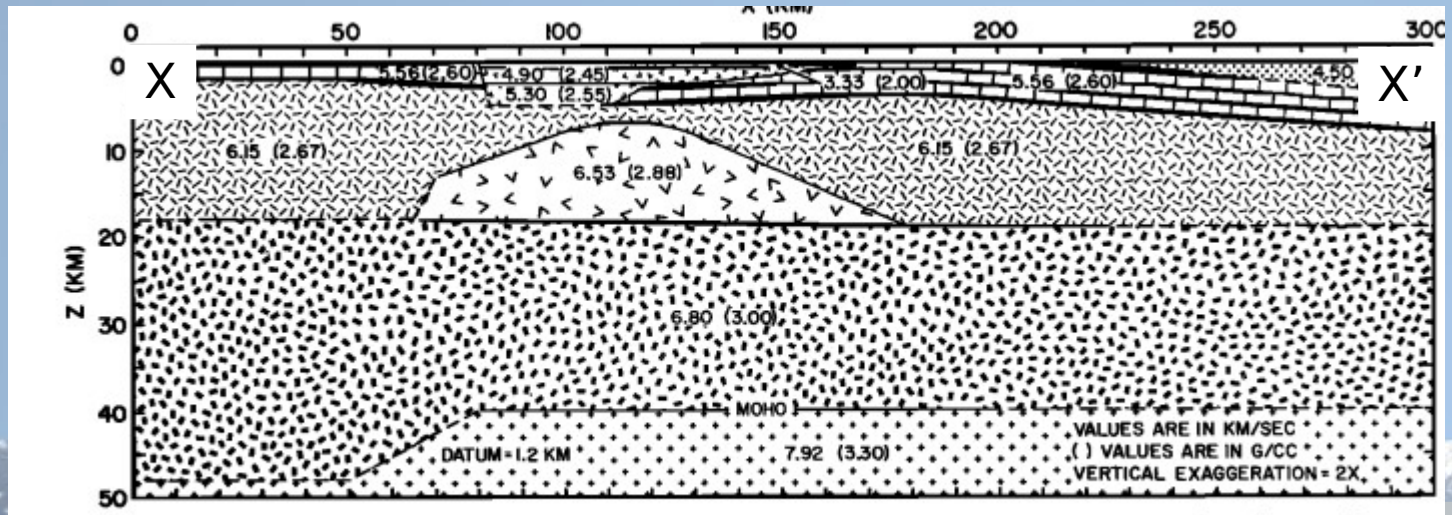
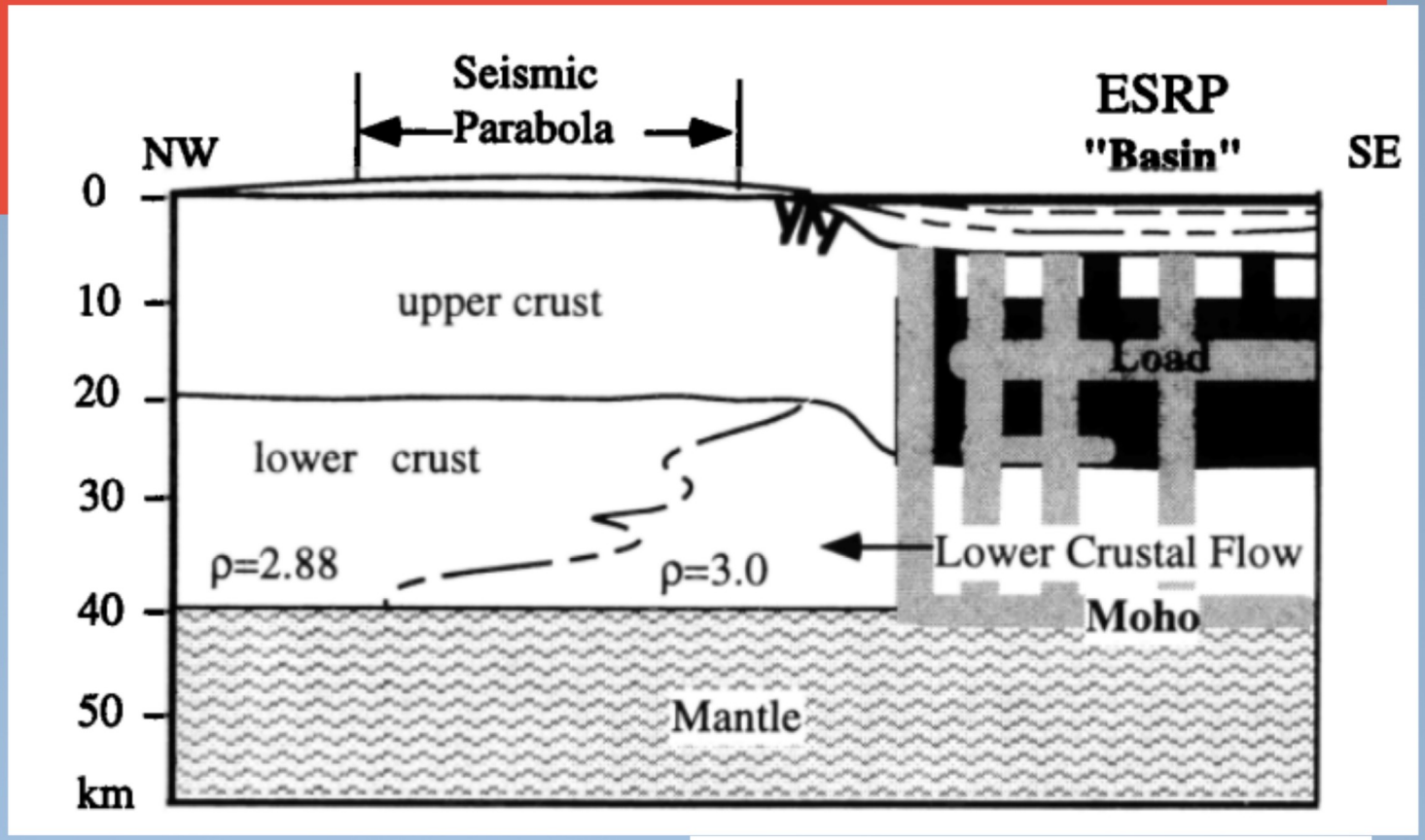
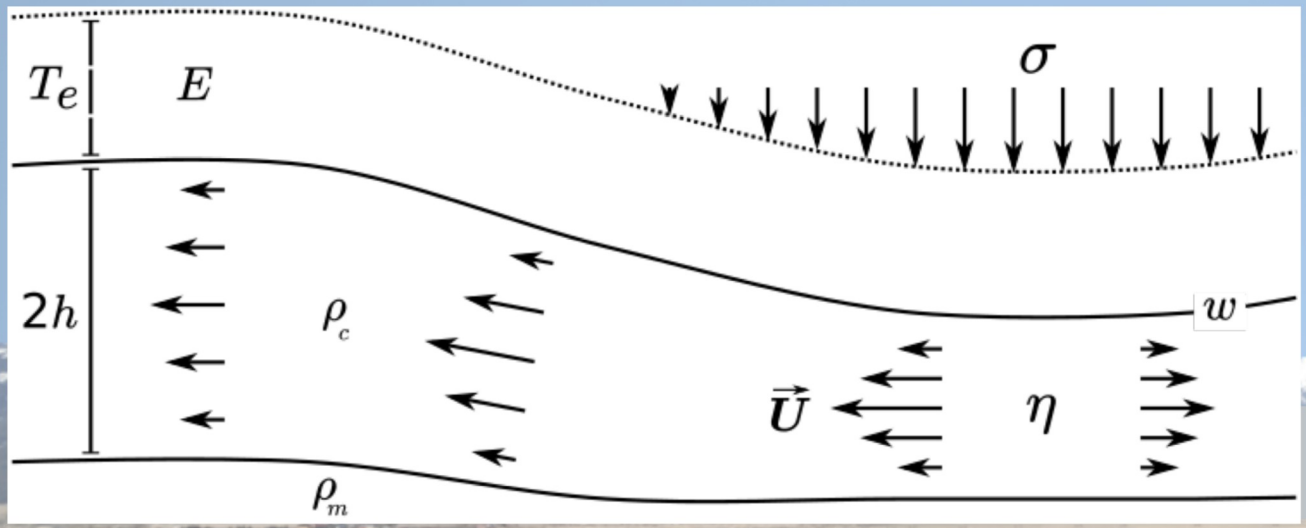


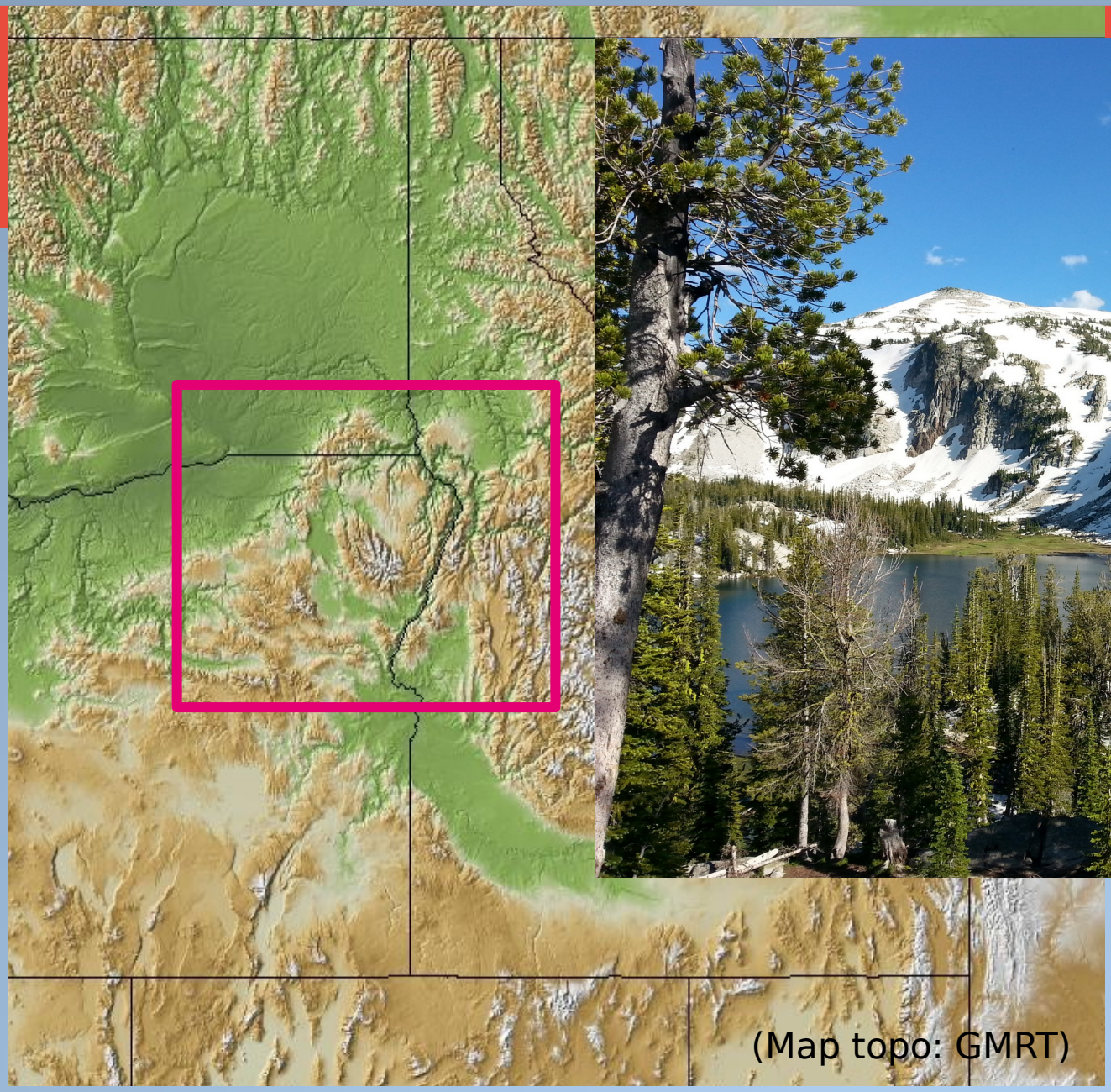
Fig. 13. Inferred crustal model across the eastern Snake River Plain. The datum for the crustal model is 1.2-km elevation. Interfaces are dashed where no seismic control

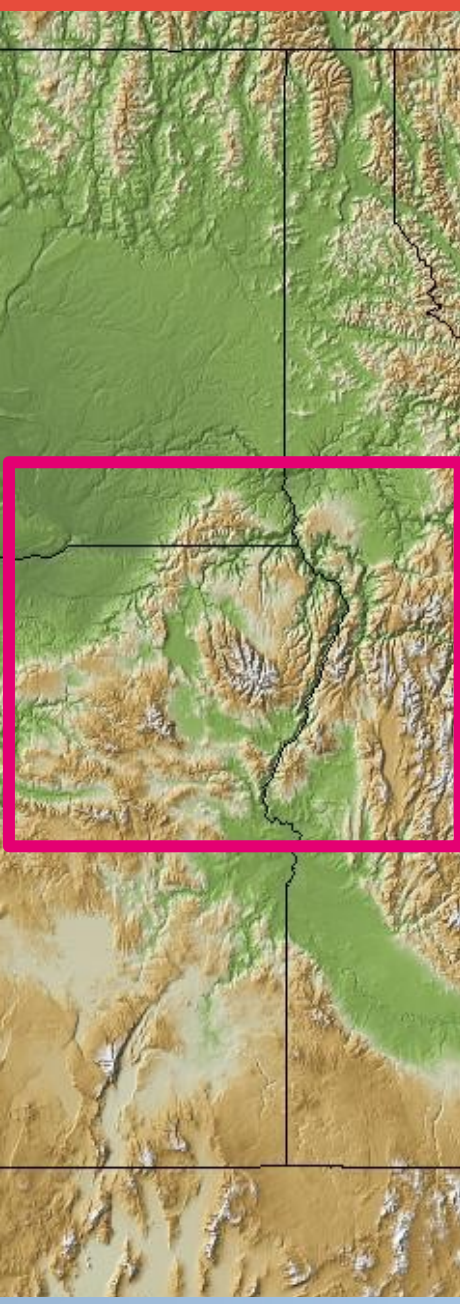
Sparlin et al. 1982

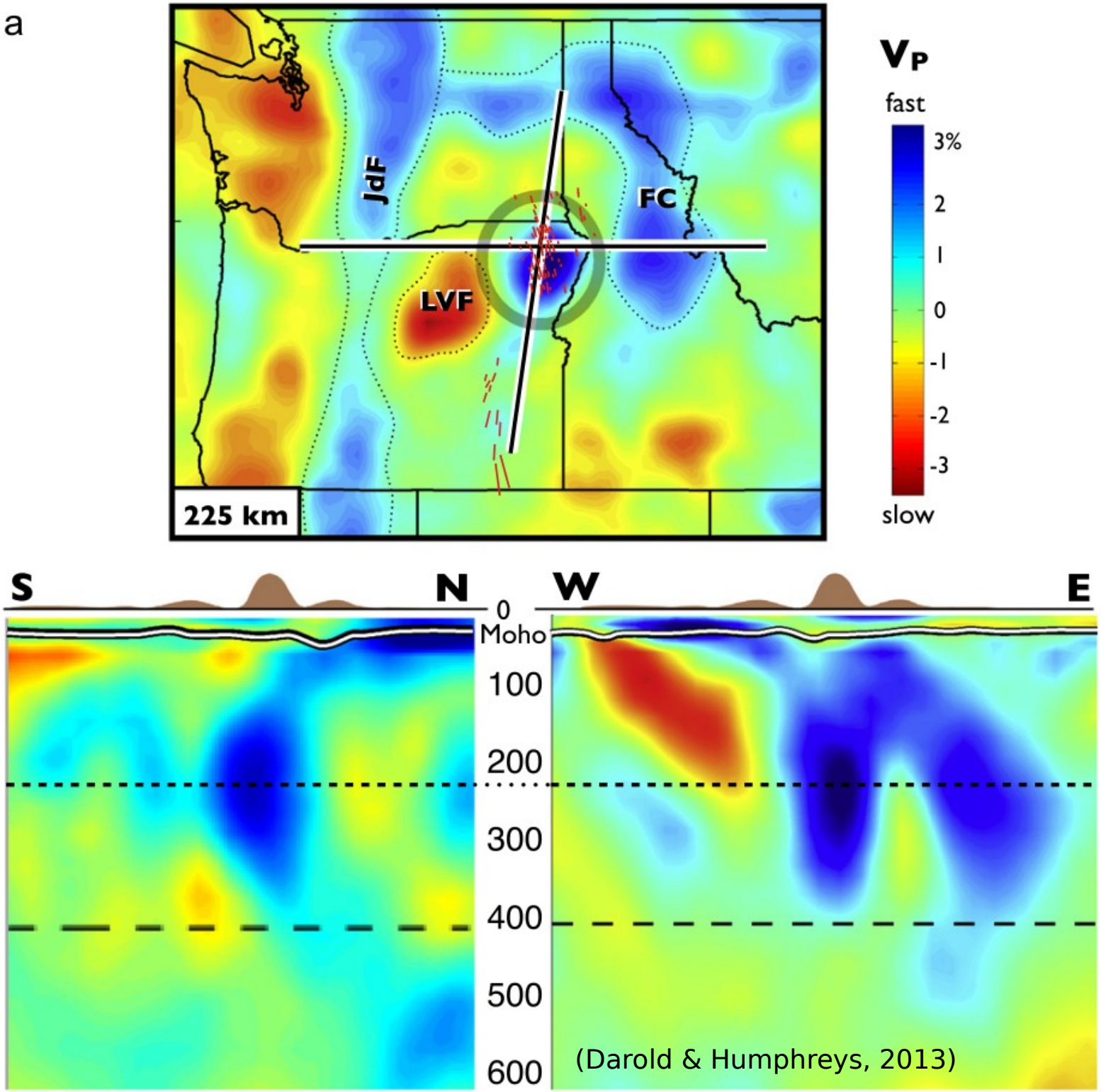


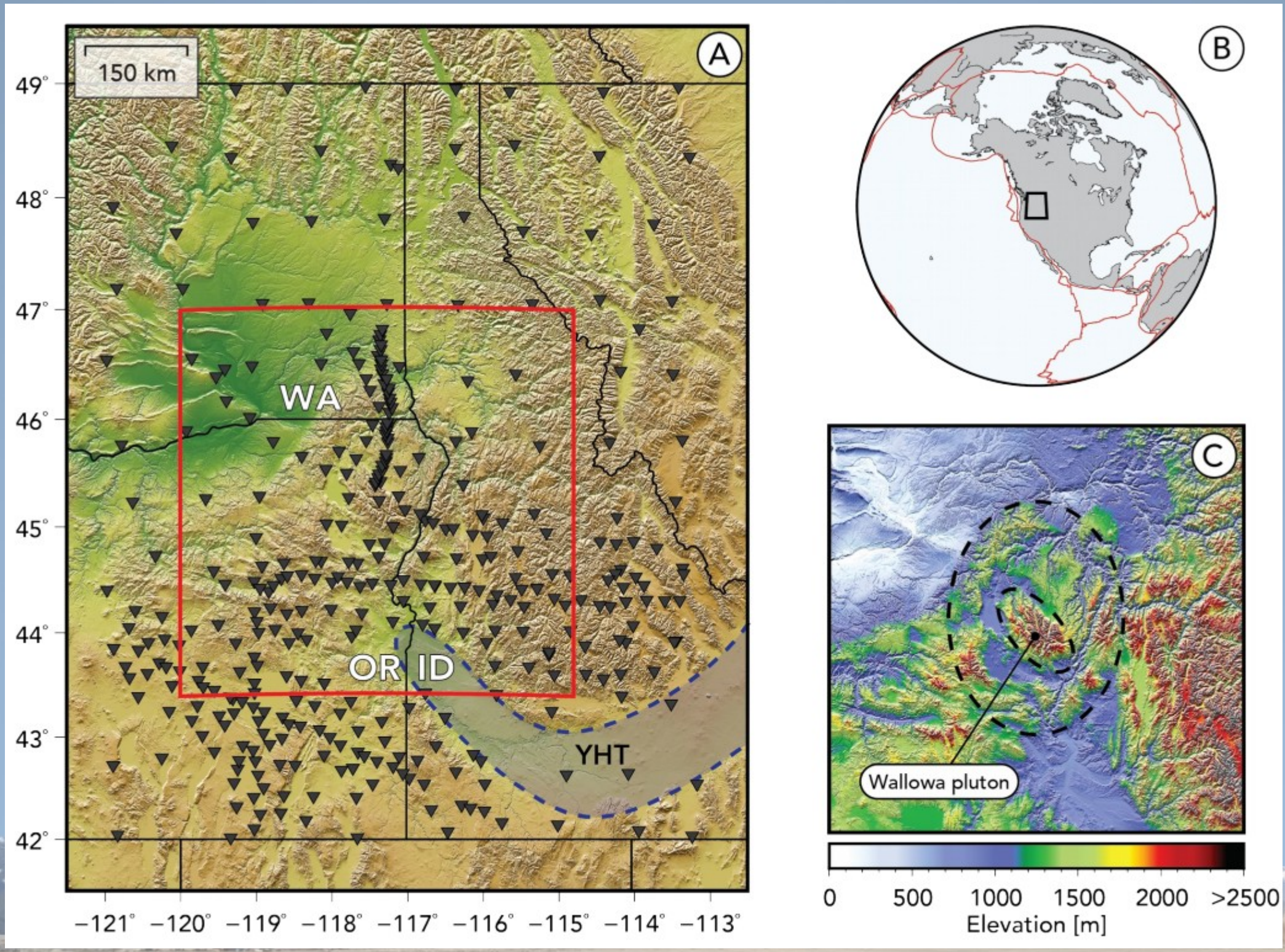
McQuarrie & Rodgers, 1998

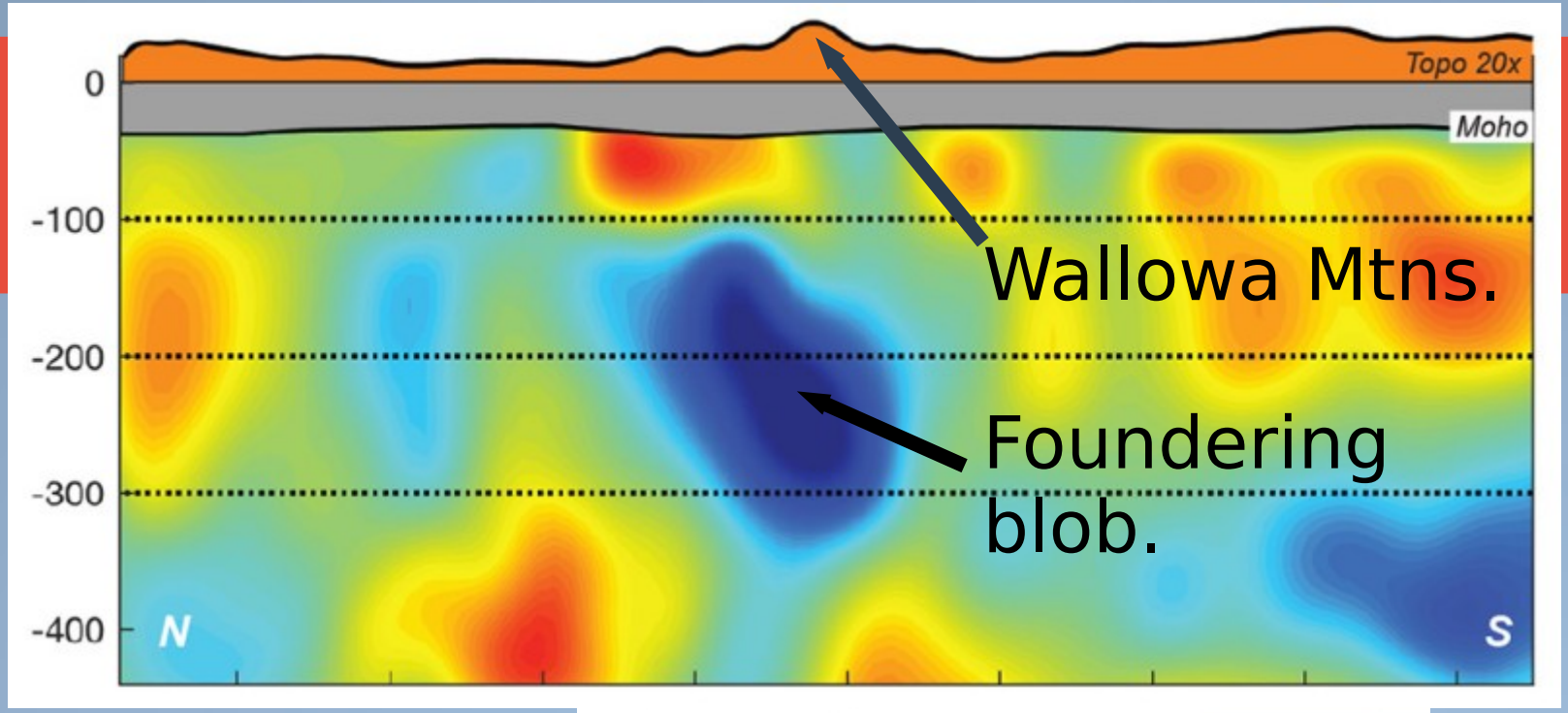


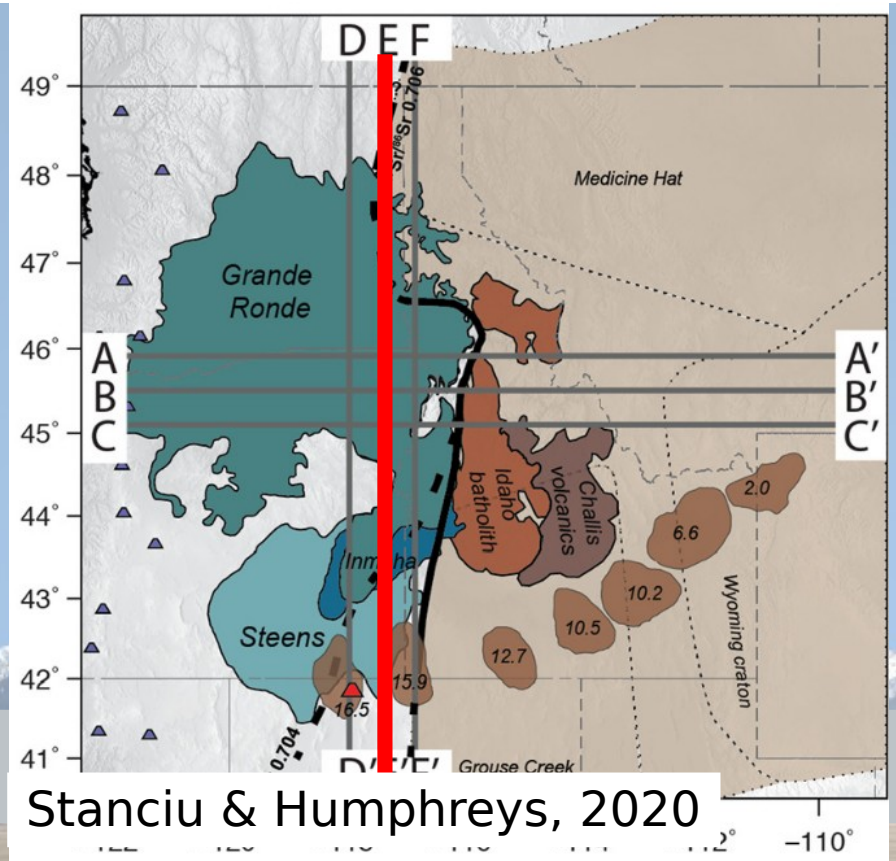

(Map topo: GMRT)



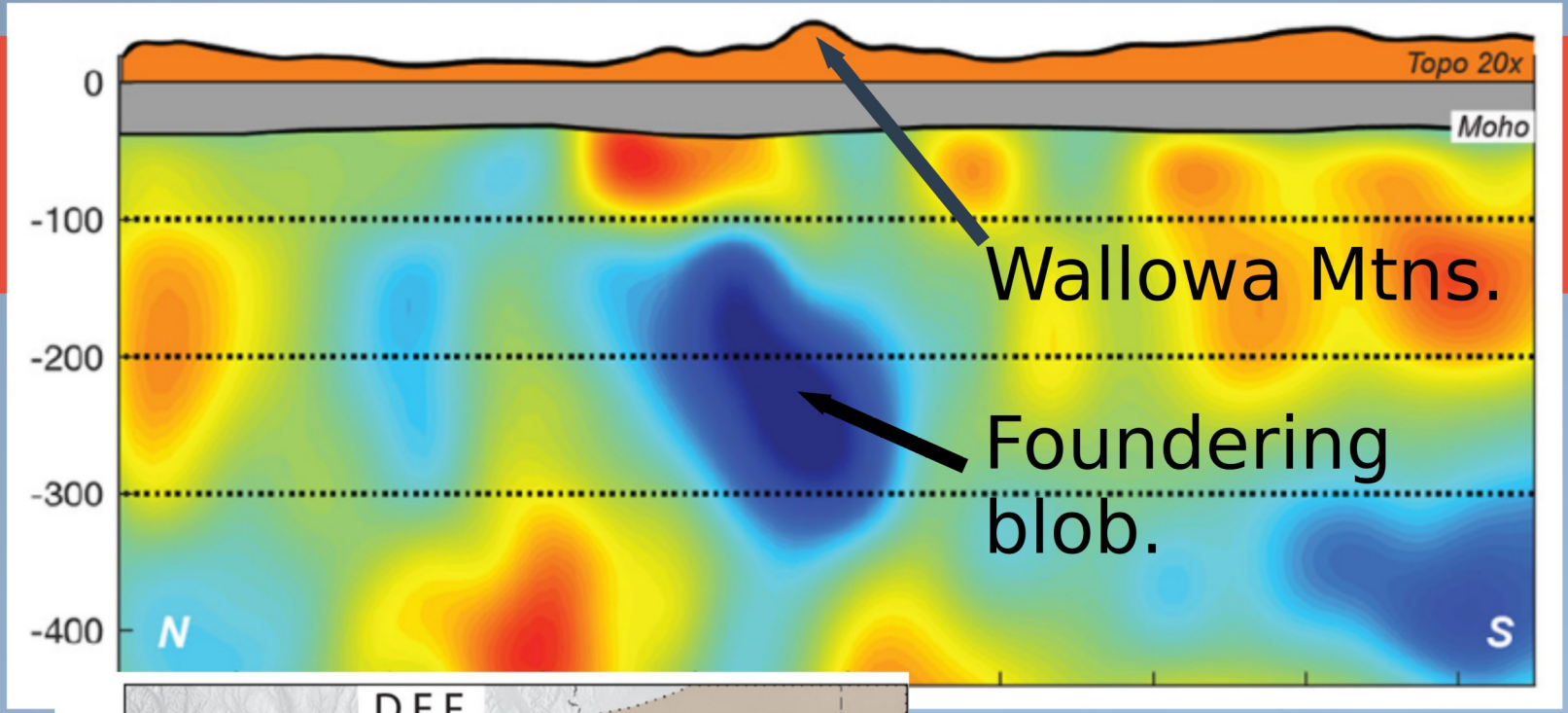

a
JdF
FC
LVF
225 km
V_P
fast
3%
2
1
0
-1
-2
-3
slow
S
N
W
E
0
Moho
100
200
300
400
500
600
(Darold & Humphreys, 2013)

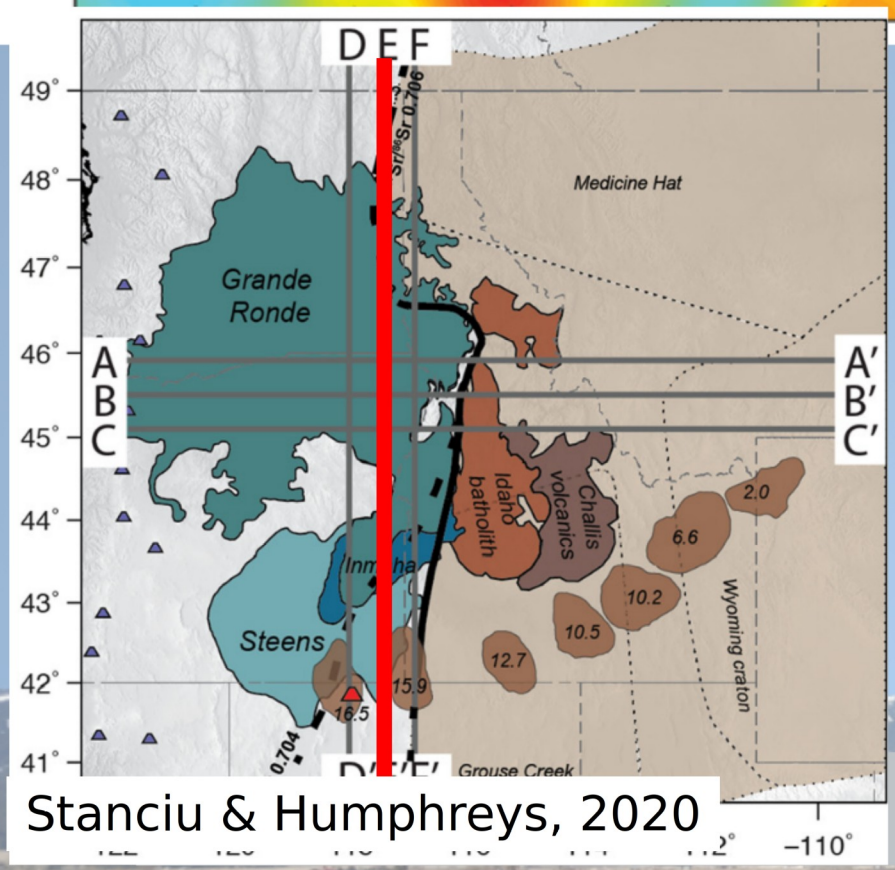

A
150 km
49°
48°
47°
46°
45°
44°
43°
42°
WA
OR ID
YHT
−121°
−120°
−119°
−118°
−117°
−116°
−115°
−114°
−113°
B
C
Wallowa pluton
0
500
1000
1500
2000
>2500
Elevation [m]



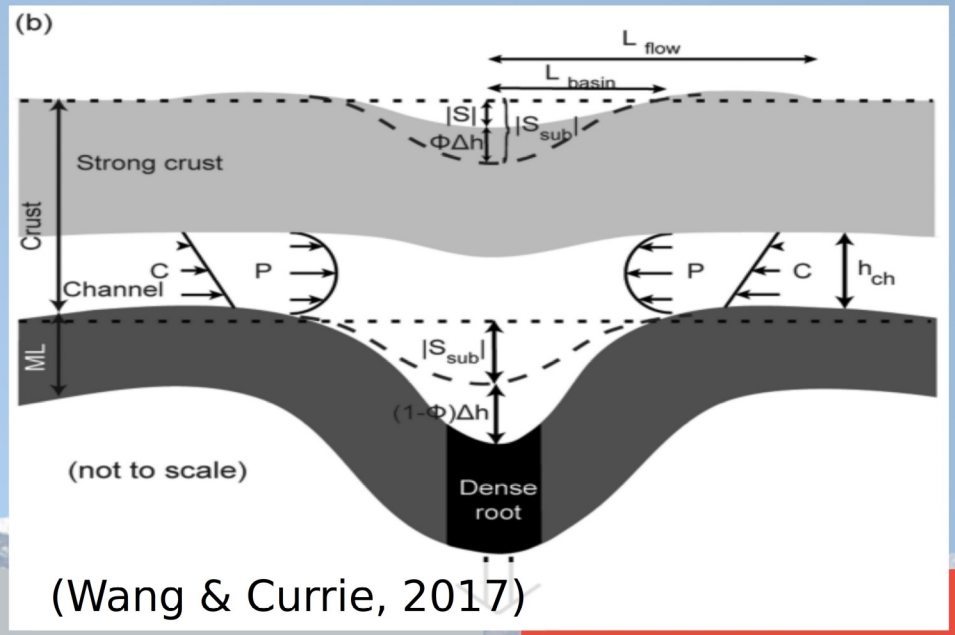


Stanciu & Humphreys, 2020



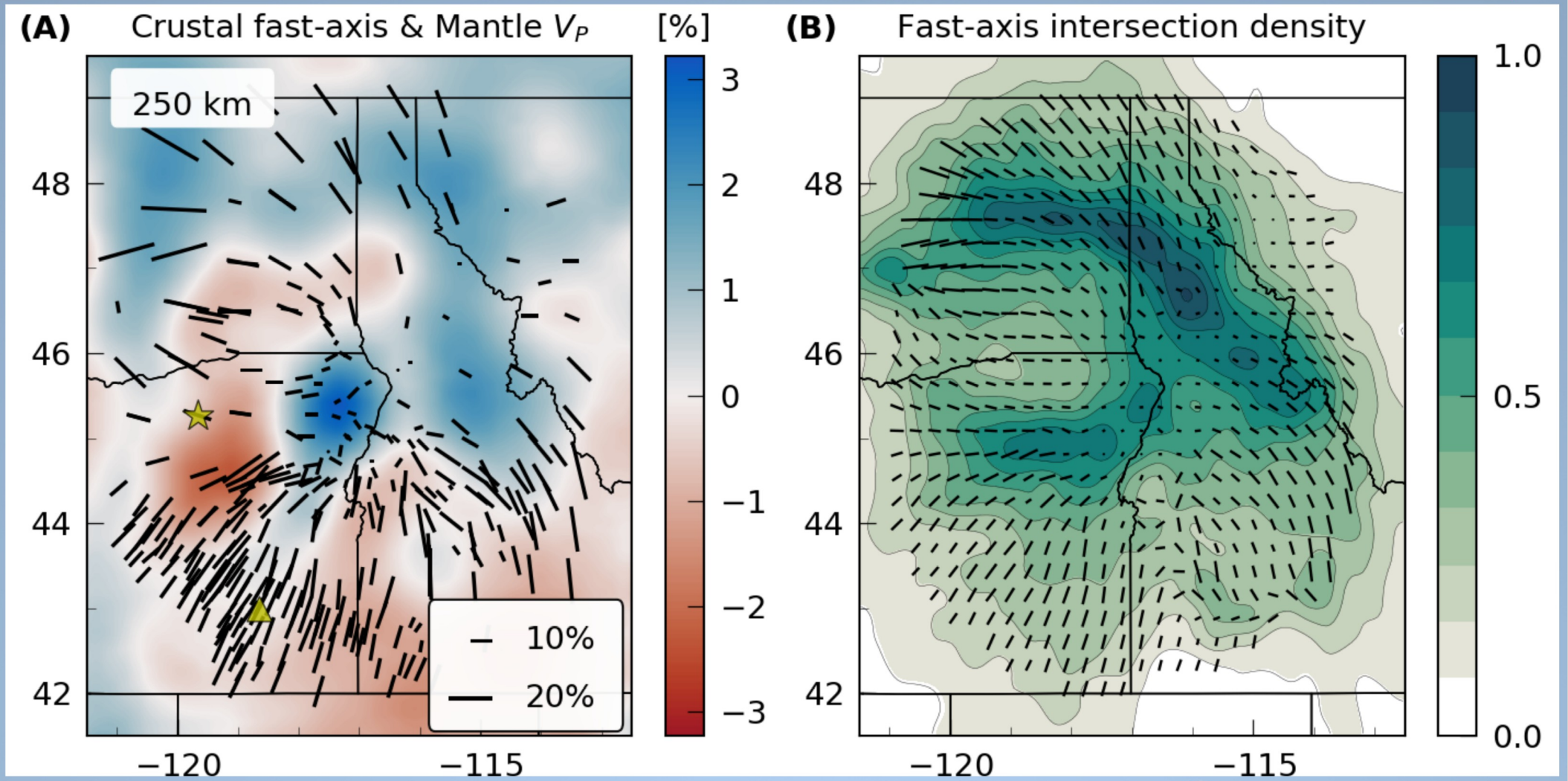


Stanciu & Humphreys, 2020



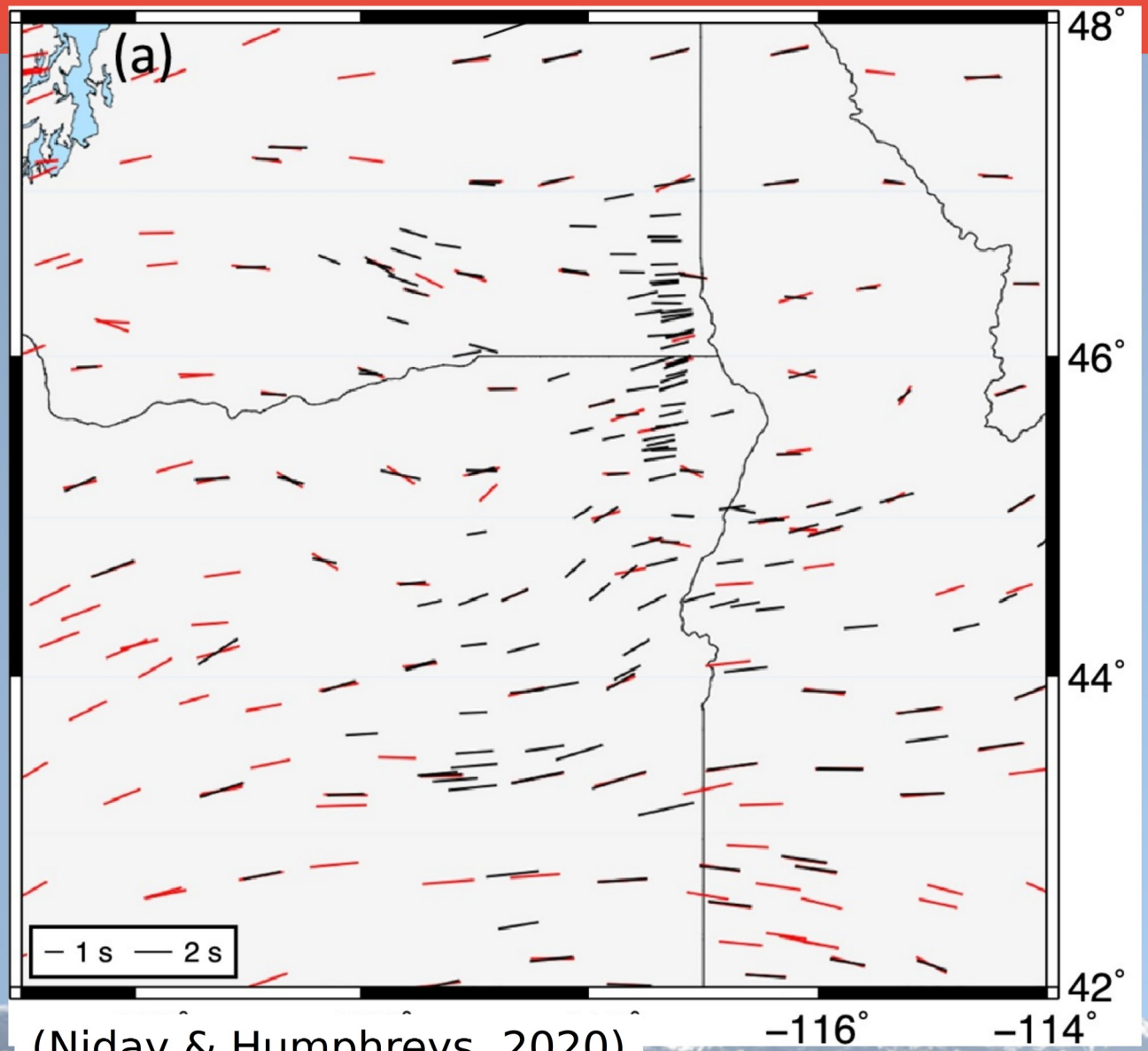
(Wang & Currie, 2017)

Crustal anisotropy (ambient noise)

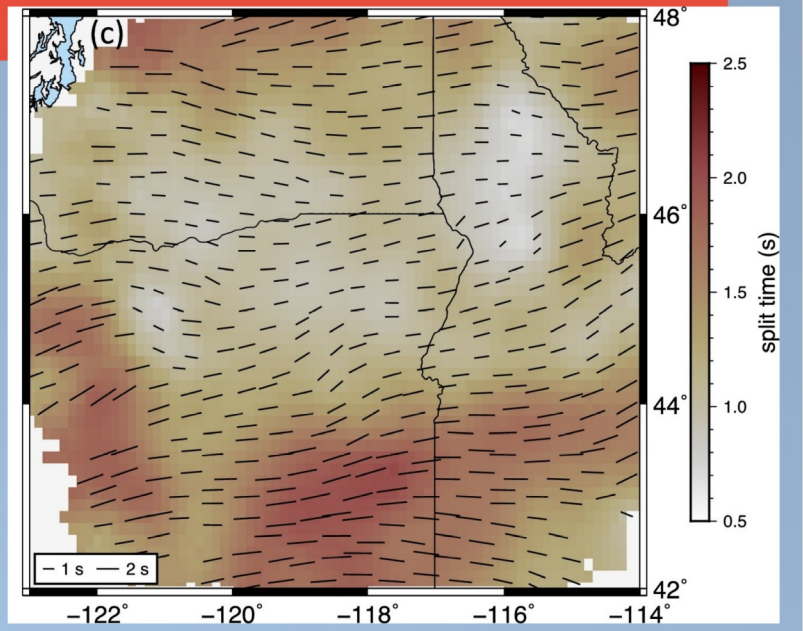


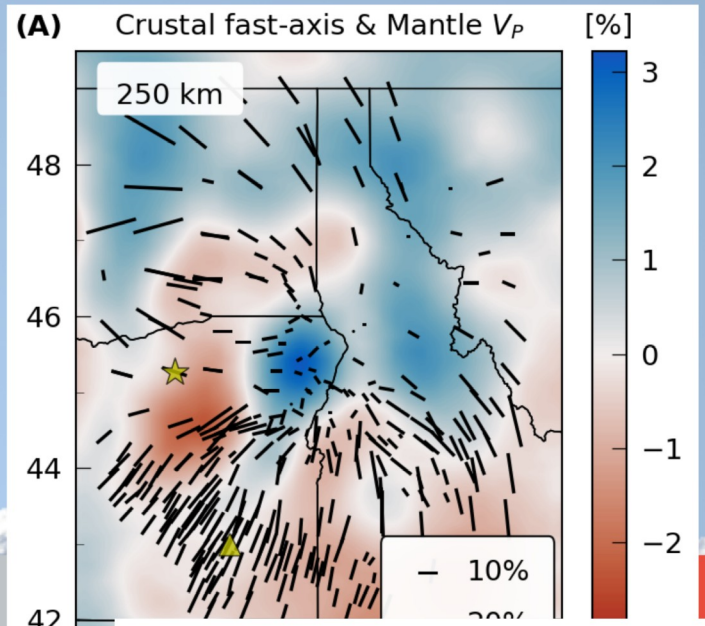
(Castellanos et al. 2020)

Mantle anisotropy (SKS Splits)

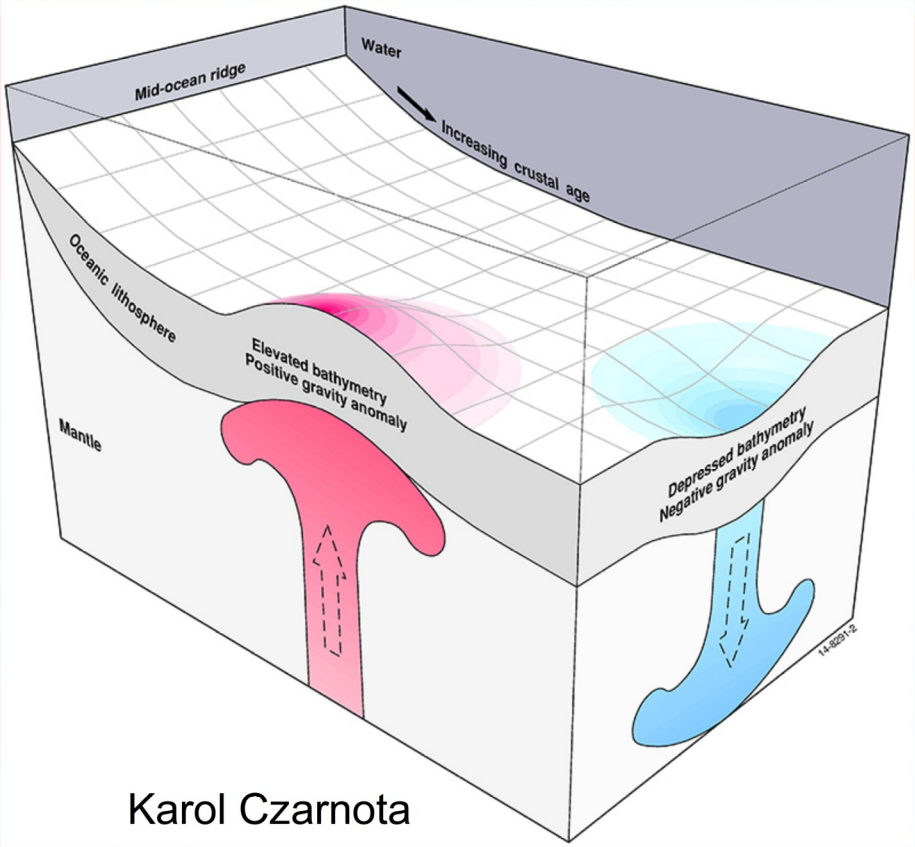


(Niday & Humphreys, 2020)

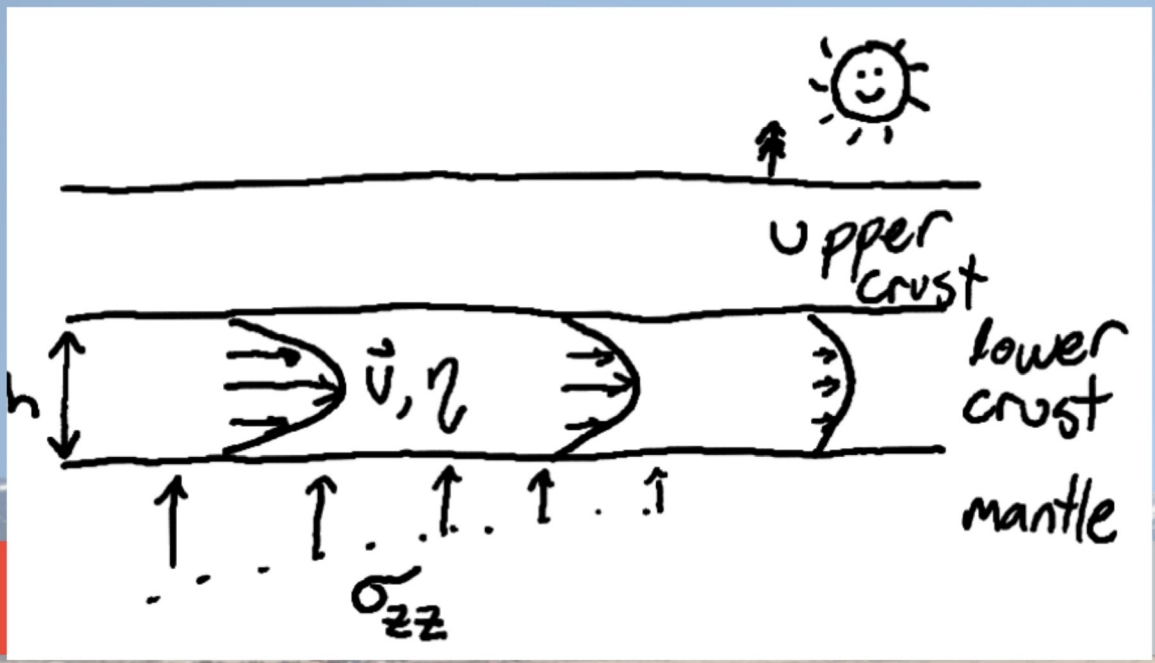


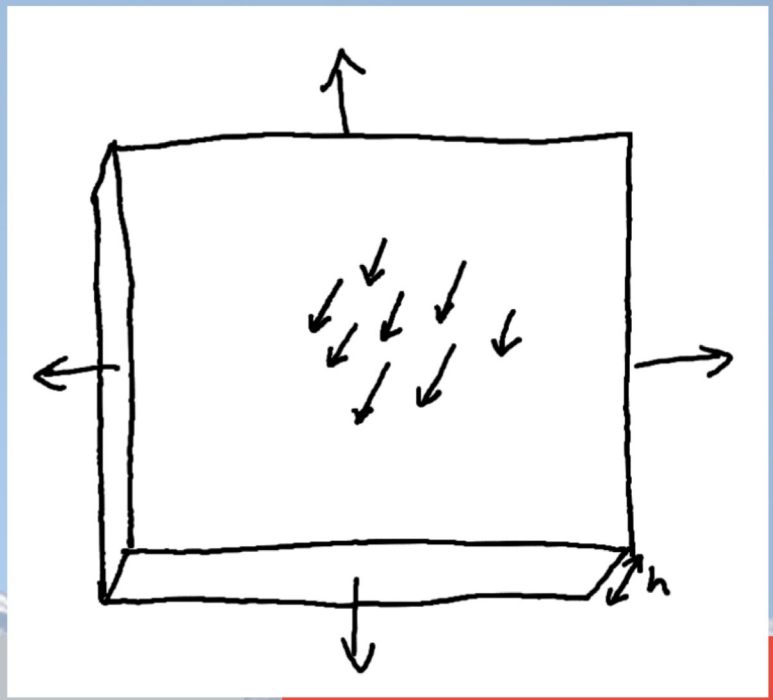


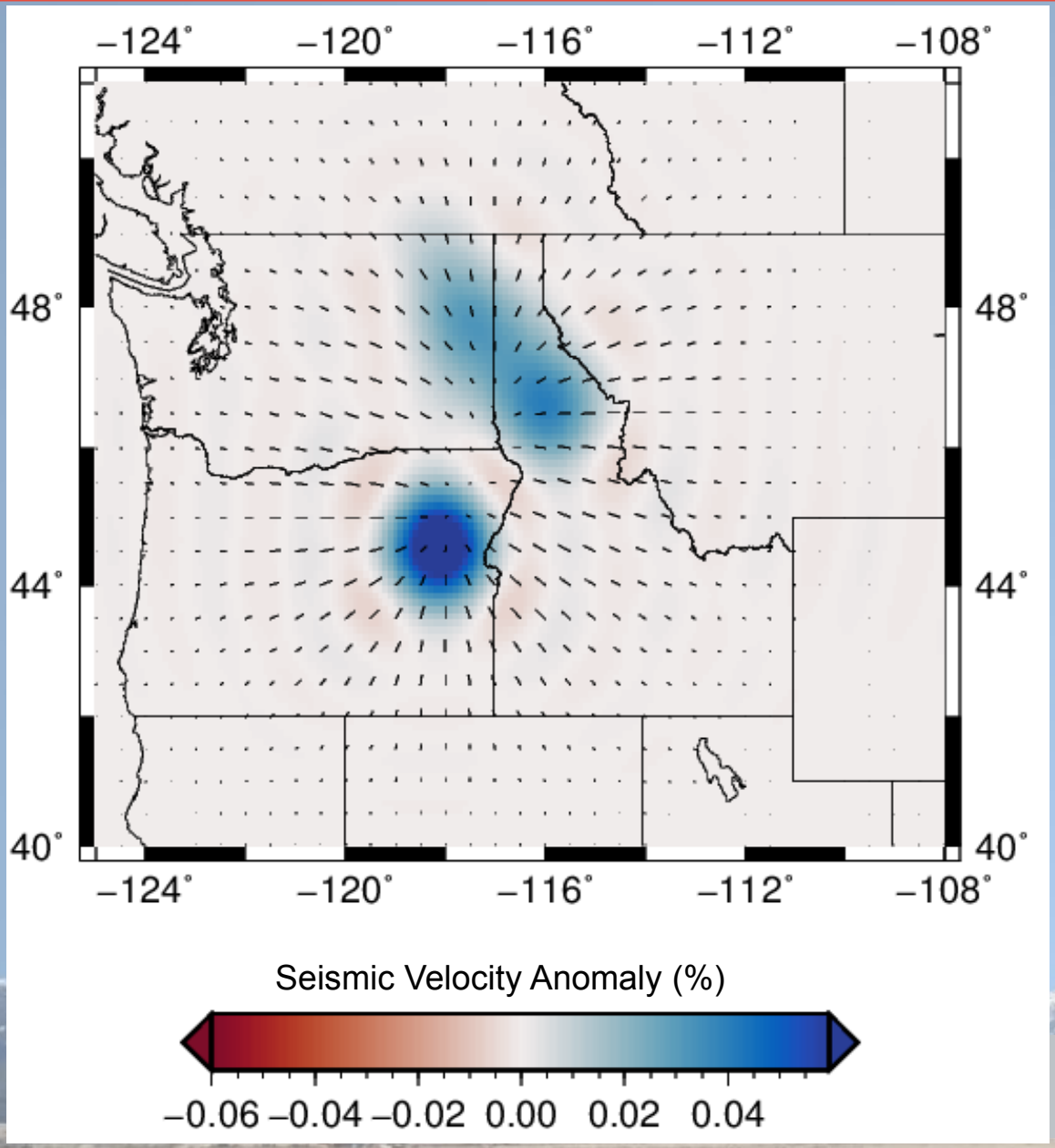
(Castellanos et al. 2020)

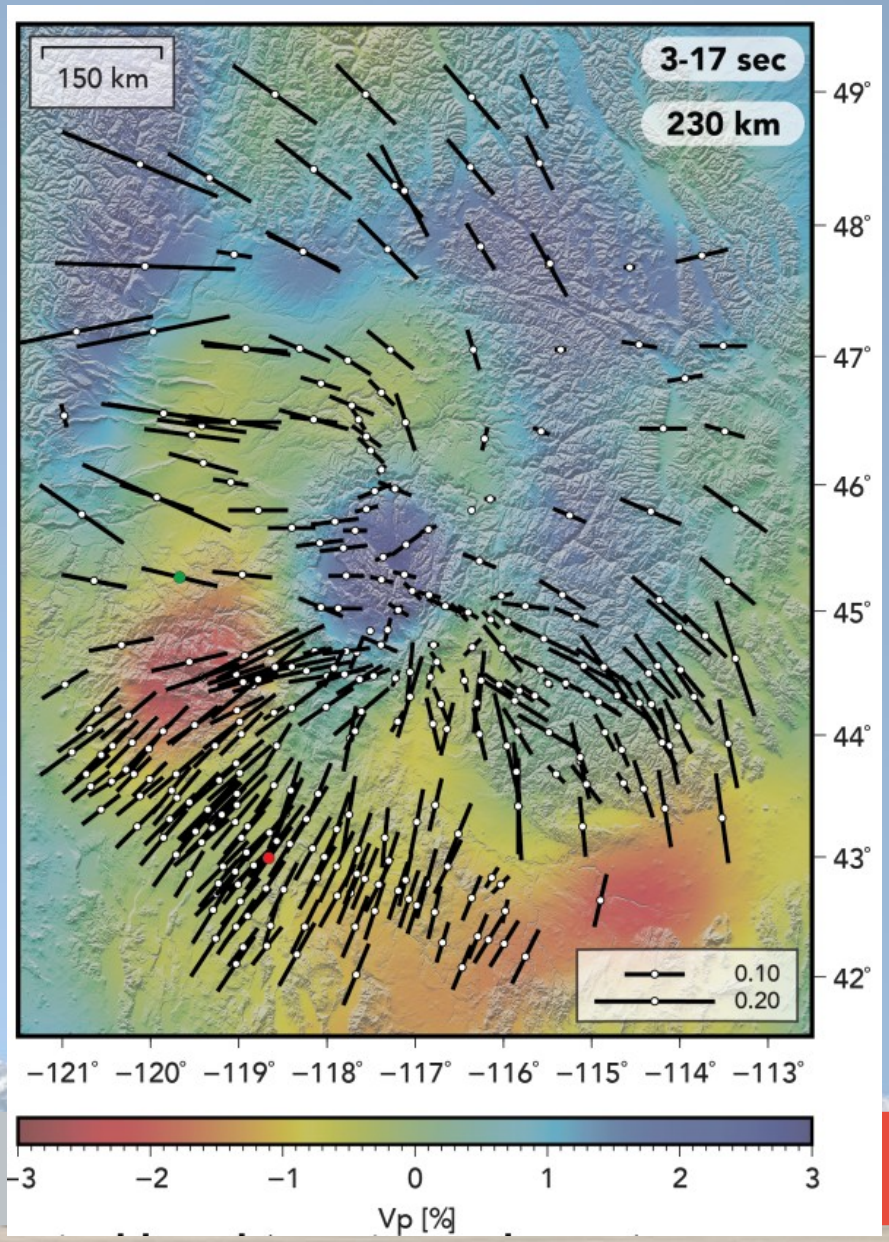


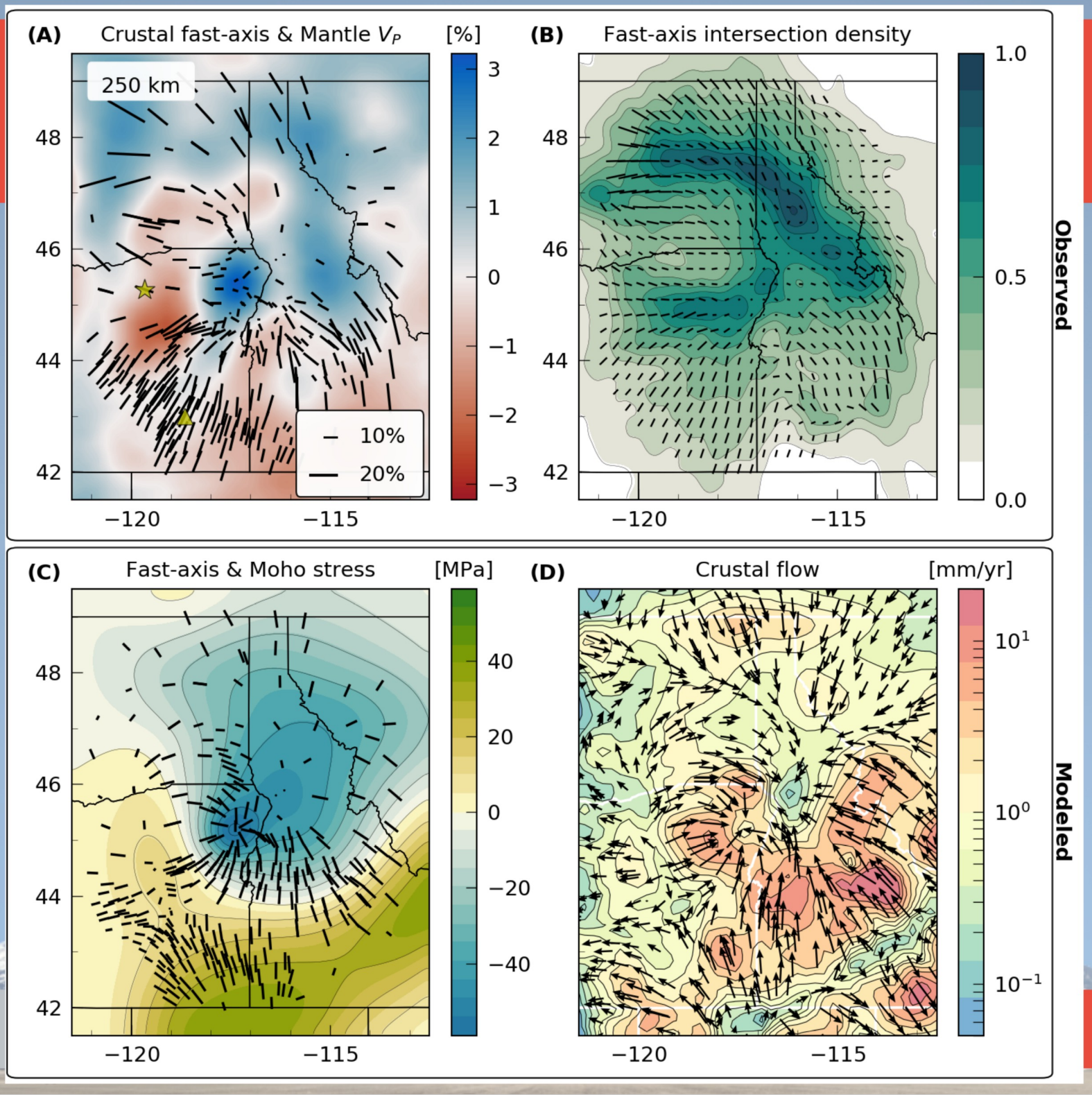
Karol Czarnota



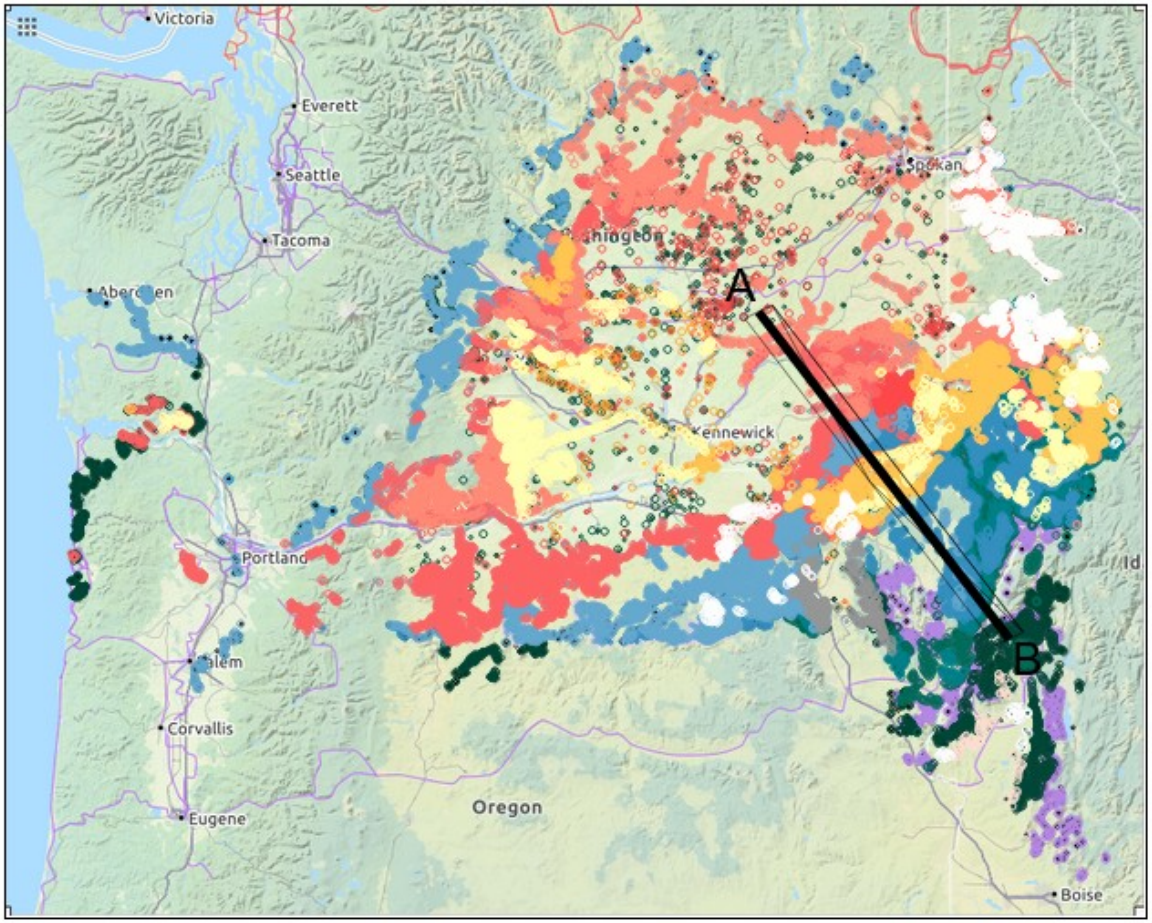



−124°
−120°
−116°
−112°
−108°
48°
44°
40°
Seismic Velocity Anomaly (%)
−0.06 −0.04 −0.02 0.00 0.02 0.04


150 km
3-17 sec
230 km
49°
48°
47°
46°
45°
44°
43°
42°
0.10
0.20
−121° −120° −119° −118° −117° −116° −115° −114° −113°
−3 −2 −1 0 1 2 3
Vp [%]

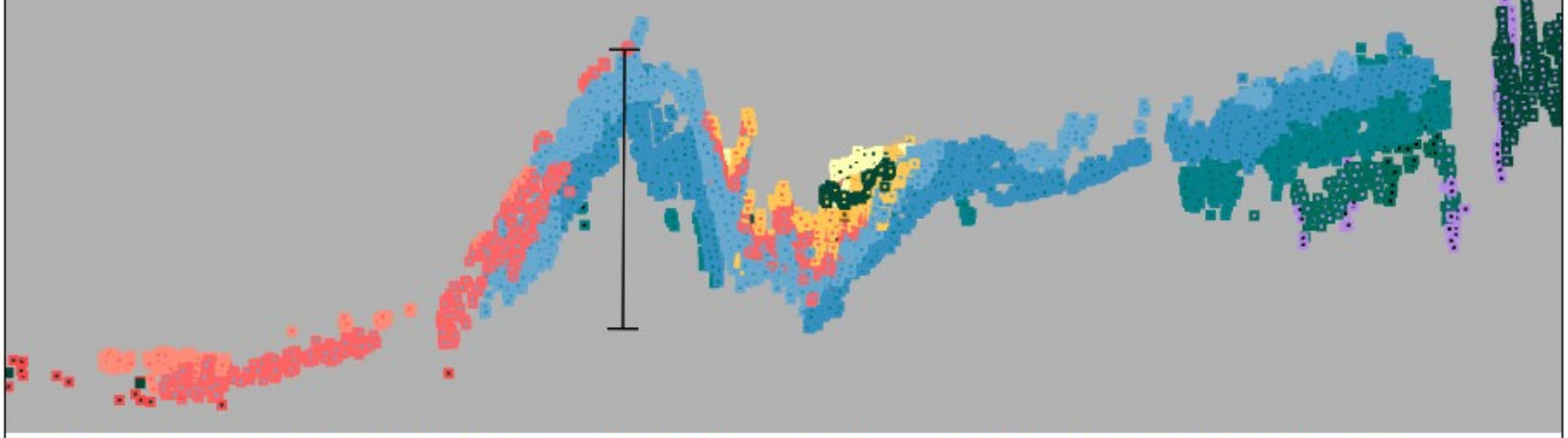


(Castellanos et al. 2020)

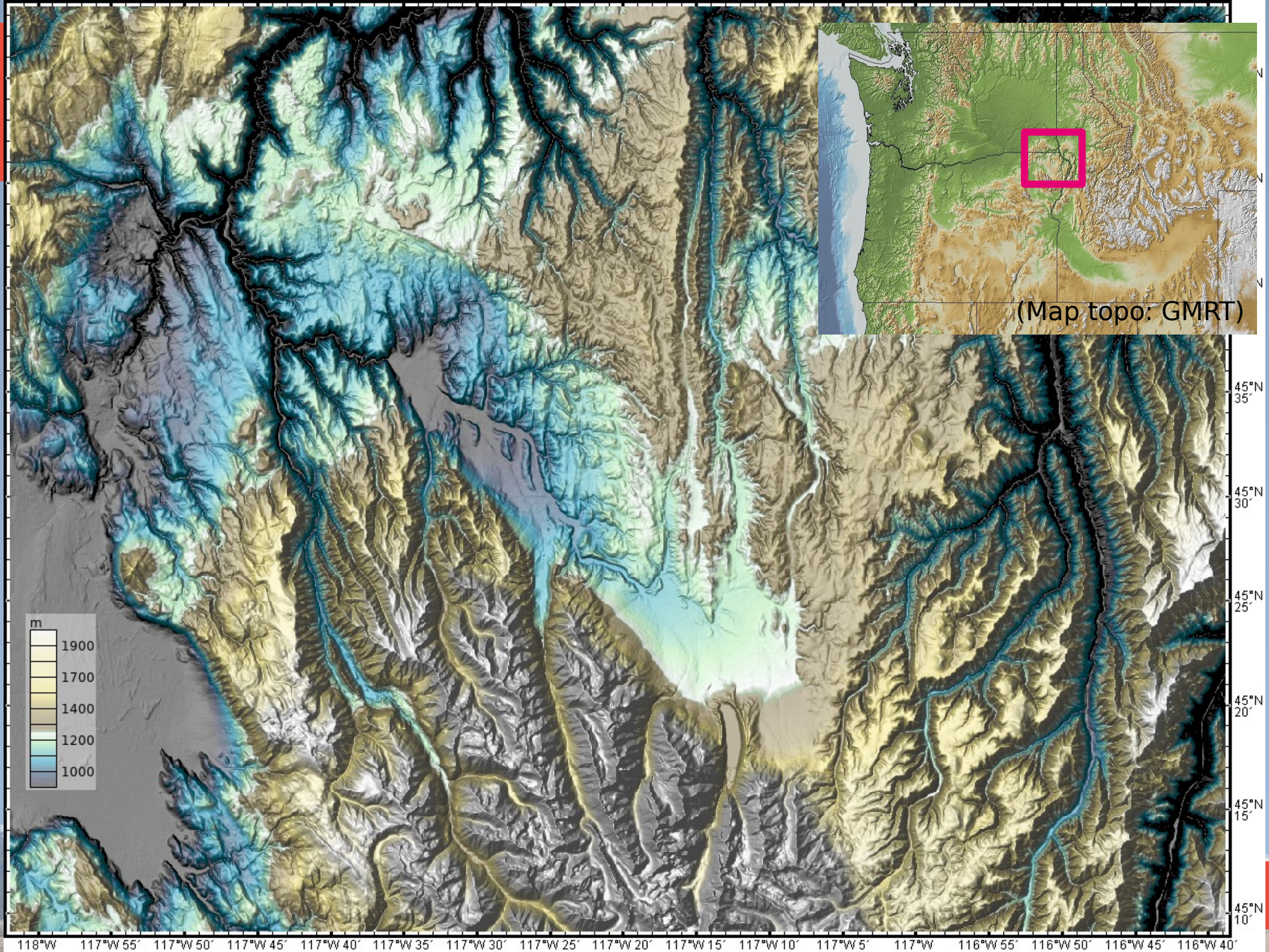


- Legend
  - SEDIMENT
  - POWDER RIVER
  - UPR. SADDLE MTN
  - LWR. SADDLE MTN
  - SADDLE MTN
  - WEISER
  - UPR. WANAPUM
  - LWR. WANAPUM
  - WANAPUM
  - GRN2
  - GRR2
  - GRN1
  - GRR1
  - CRB
  - PICTURE GORGE
  - IMNAHA
  - OLDER
- Instructions
- Credits

https://jperryhouts.github.io/CRB-Explorer/



A: (-118.50, 46.76) | B: (-116.67, 45.11) | Length: 231.82 km | Thickness: 26.20 km | Pitch: 0.00 ° | Ruler: 1.35 km


(Map topo: GMRT)
m
1900
1700
1400
1200
1000
45°N 35′
45°N 30′
45°N 25′
45°N 20′
45°N 15′
45°N 10′
118°W
117°W 55′
117°W 50′
117°W 45′
117°W 40′
117°W 35′
117°W 30′
117°W 25′
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117°W
116°W 55′
116°W 50′
116°W 45′
116°W 40′

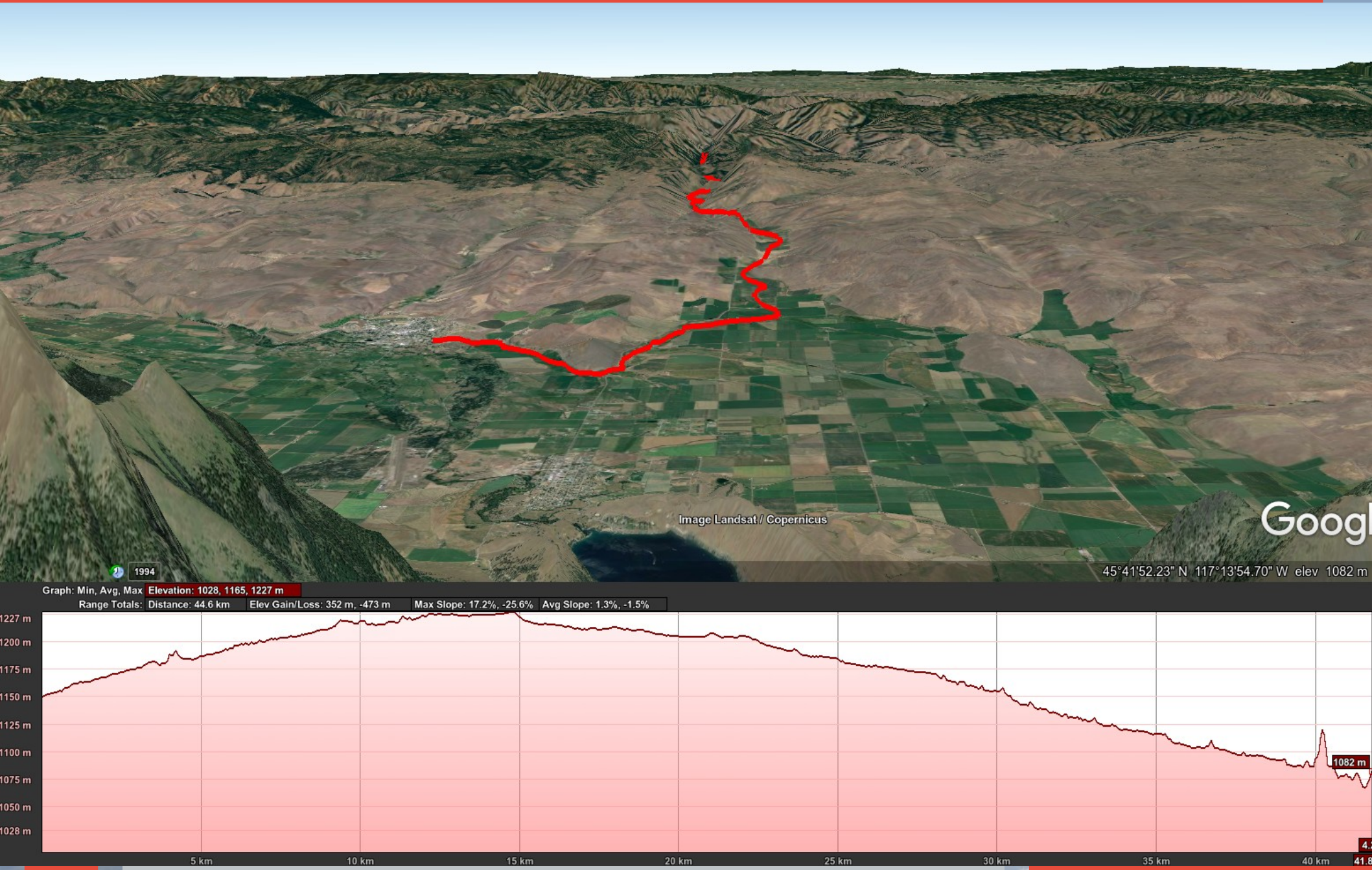


Image Landsat / Copernicus
Google
1994
45°41'52.23" N 117°13'54.70" W elev 1082 m
Graph: Min, Avg, Max Elevation: 1028, 1165, 1227 m
Range Totals: Distance: 44.6 km Elev Gain/Loss: 352 m, -473 m Max Slope: 17.2%, -25.6% Avg Slope: 1.3%, -1.5%
1227 m
1200 m
1175 m
1150 m
1125 m
1100 m
1075 m
1050 m
1028 m
1082 m
5 km
10 km
15 km
20 km
25 km
30 km
35 km
40 km

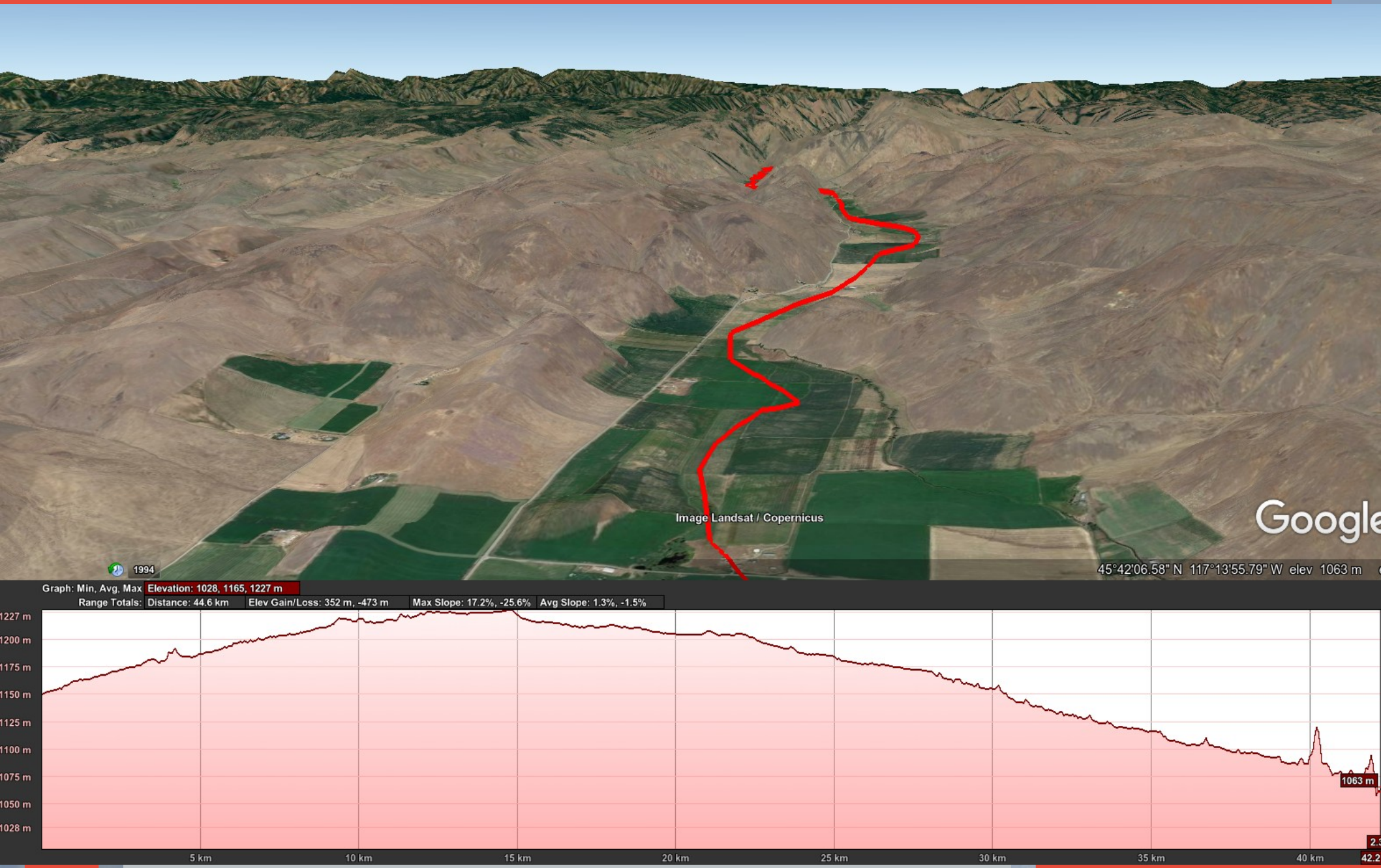
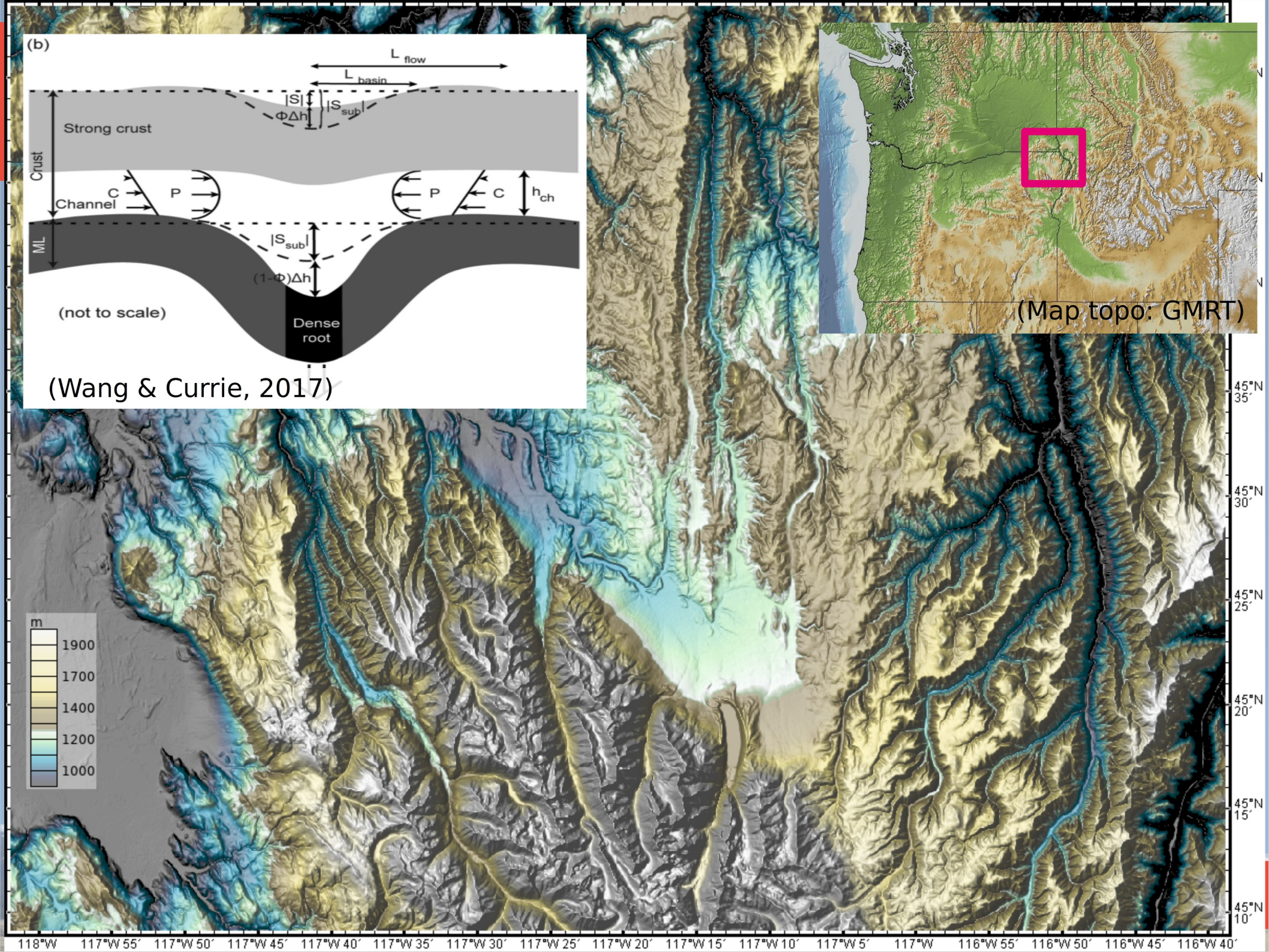


Image Landsat / Copernicus
Google
1994
45°42'06.58" N 117°13'55.79" W elev 1063 m
Graph: Min, Avg, Max Elevation: 1028, 1165, 1227 m
Range Totals: Distance: 44.6 km Elev Gain/Loss: 352 m, -473 m Max Slope: 17.2%, -25.6% Avg Slope: 1.3%, -1.5%
1227 m
1200 m
1175 m
1150 m
1125 m
1100 m
1075 m
1050 m
1028 m
1063 m
5 km
10 km
15 km
20 km
25 km
30 km
35 km
40 km


(b)
L flow
L basin
|S|
|S sub|
ΦΔh
Strong crust
Crust
C
P
Channel
P
C
h ch
ML
|S sub|
(1-Φ)Δh
(not to scale)
Dense root
(Wang & Currie, 2017)
(Map topo: GMRT)
m
1900
1700
1400
1200
1000
45°N 35′
45°N 30′
45°N 25′
45°N 20′
45°N 15′
45°N 10′
118°W
117°W 55′
117°W 50′
117°W 45′
117°W 40′
117°W 35′
117°W 30′
117°W 25′
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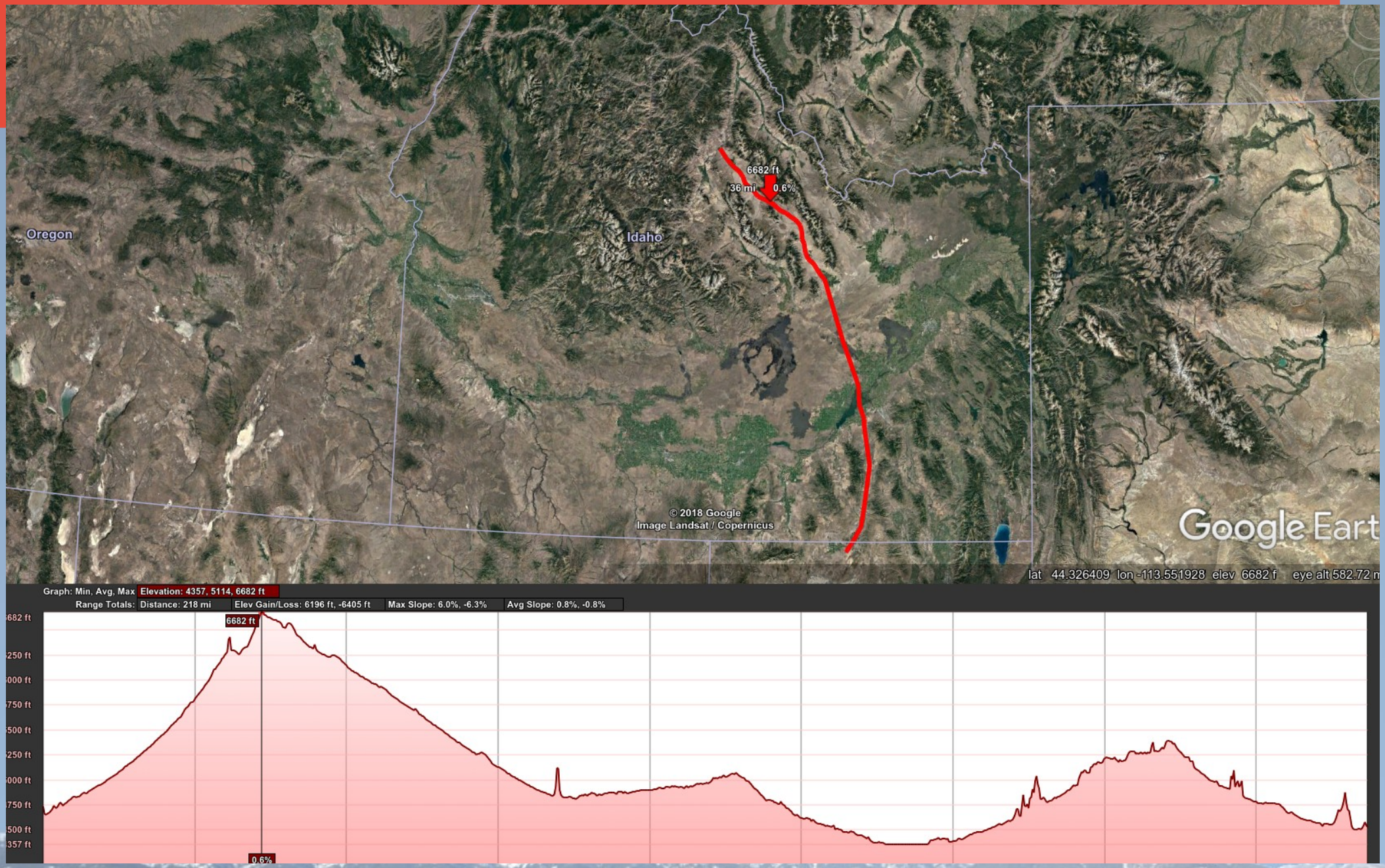
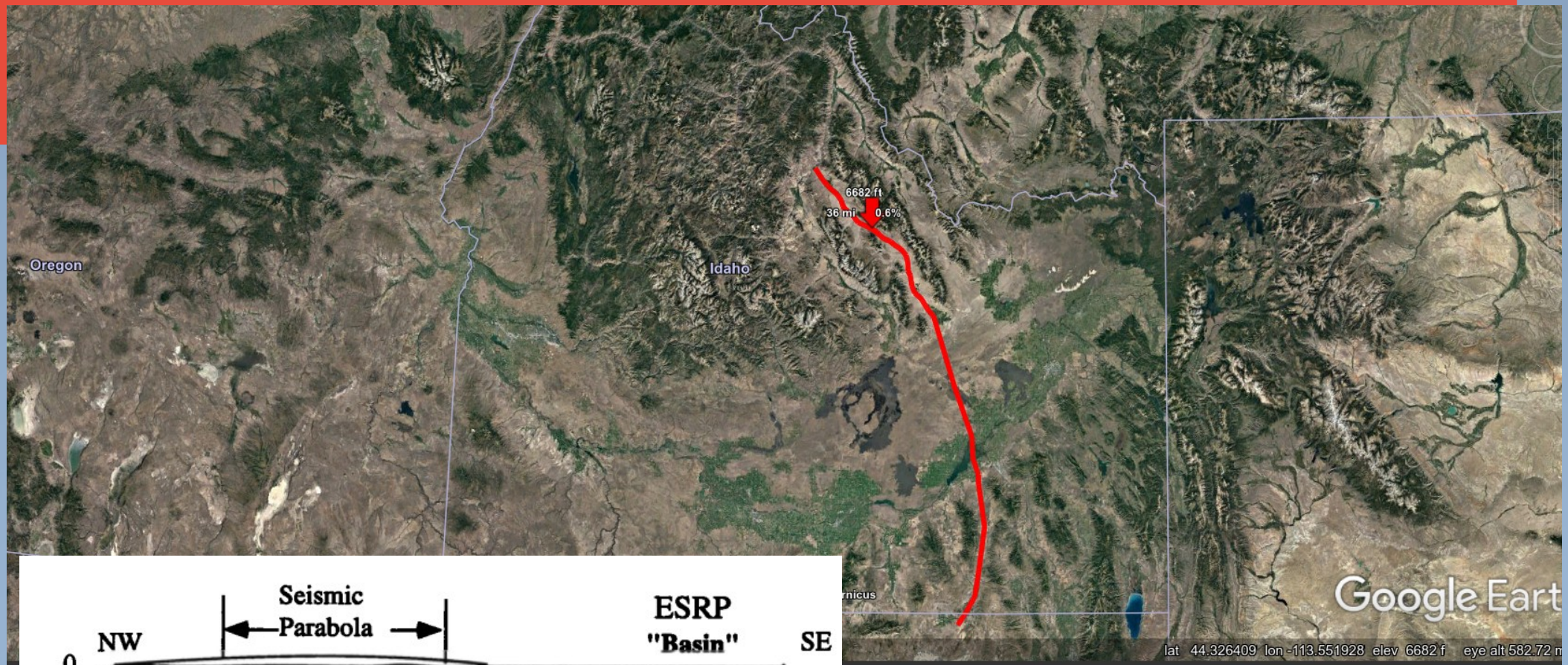
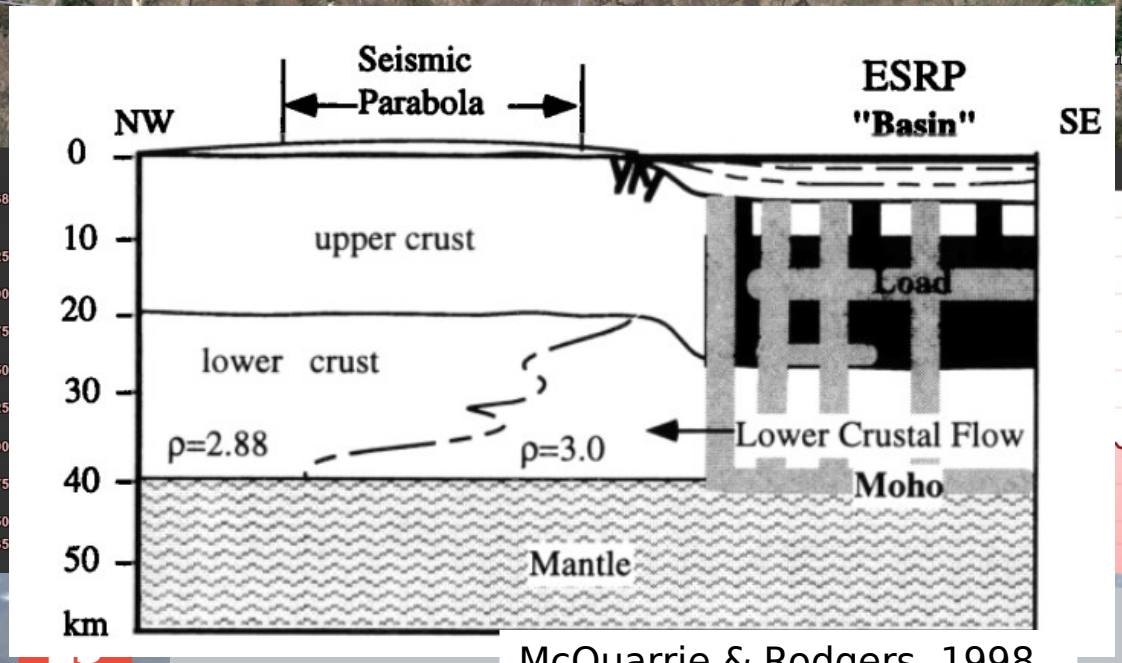
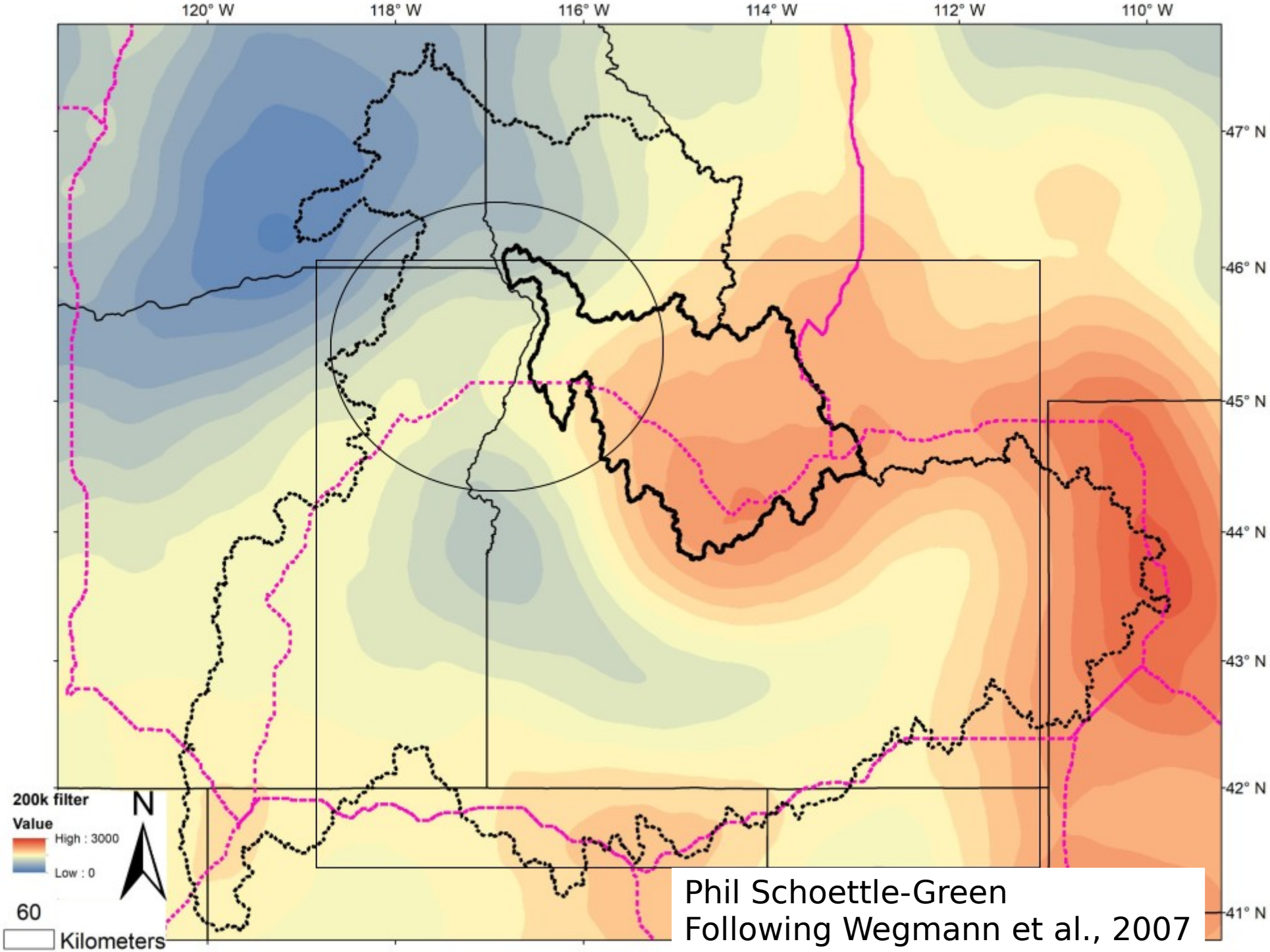
117°W 5′
117°W
116°W 55′
116°W 50′
116°W 45′
116°W 40′


6682 ft
36 mi
0.6%
Oregon
Idaho
© 2018 Google
Image Landsat / Copernicus
Google Eart
lat 44.326409 lon -113.551928 elev 6682 f eye alt 582.72 m
Graph: Min, Avg, Max Elevation: 4357, 5114, 6682 ft
Range Totals: Distance: 218 mi
Elev Gain/Loss: 6196 ft, -6405 ft
Max Slope: 6.0%, -6.3%
Avg Slope: 0.8%, -0.8%
6682 ft
0.6%

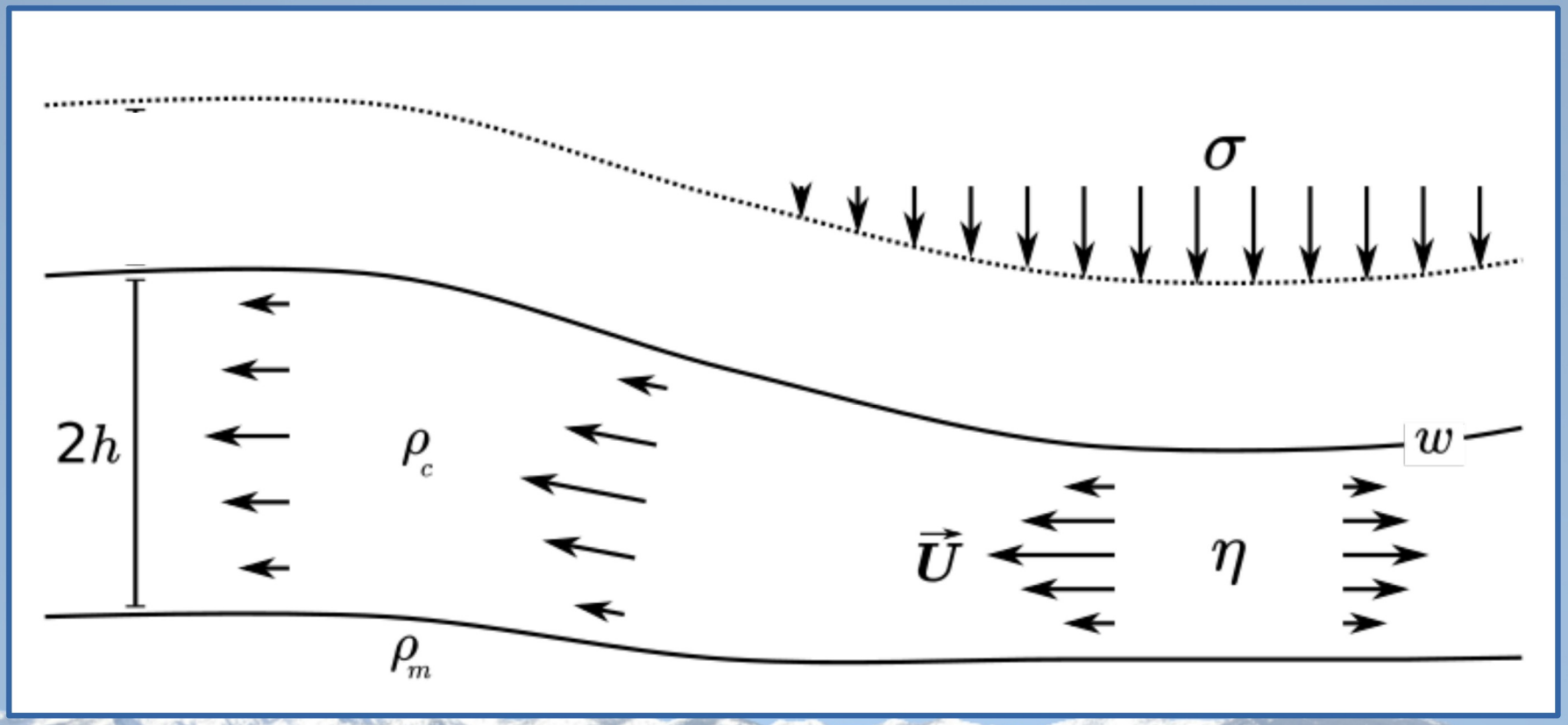




McQuarrie & Rodgers, 1998

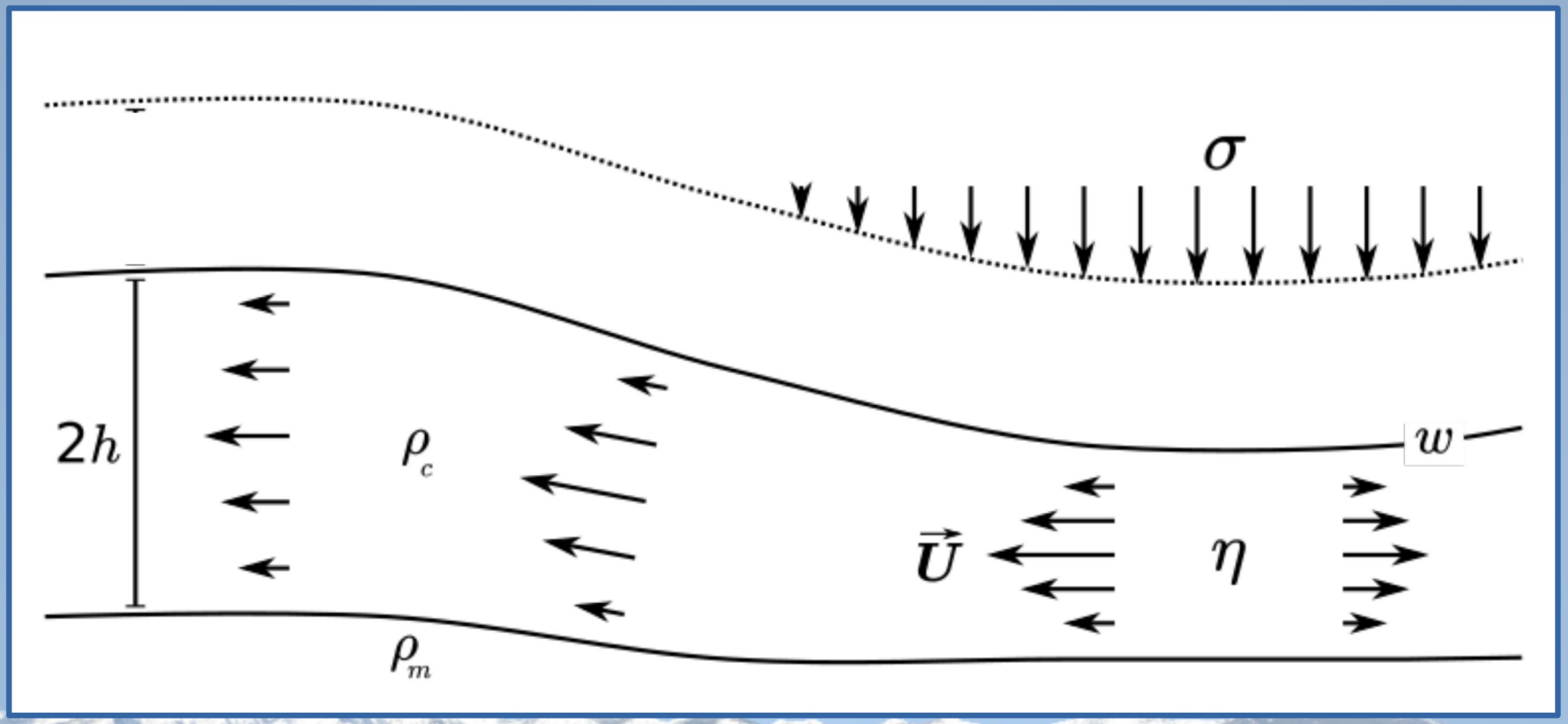


Phil Schoettle-Green
Following Wegmann et al., 2007

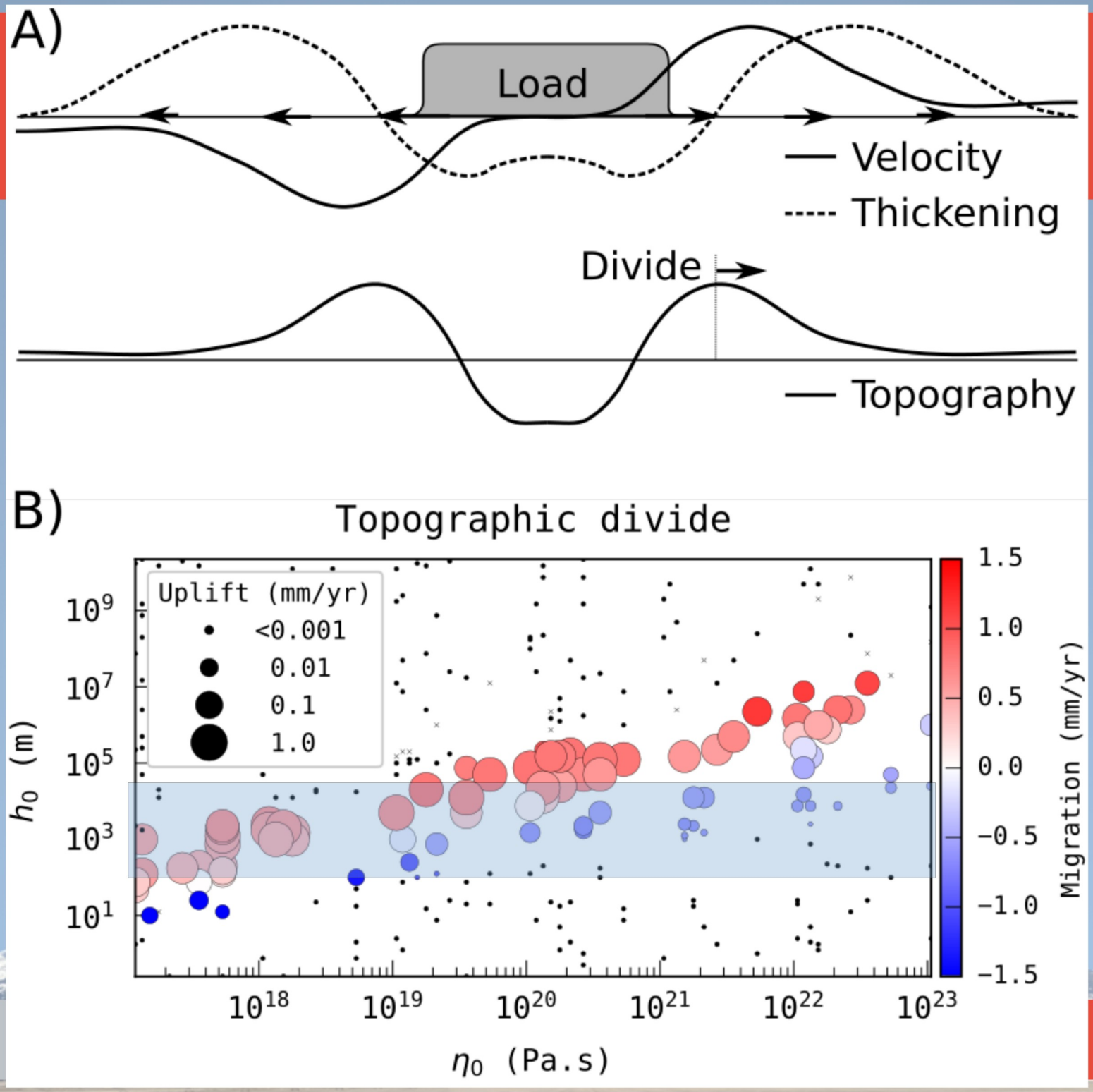


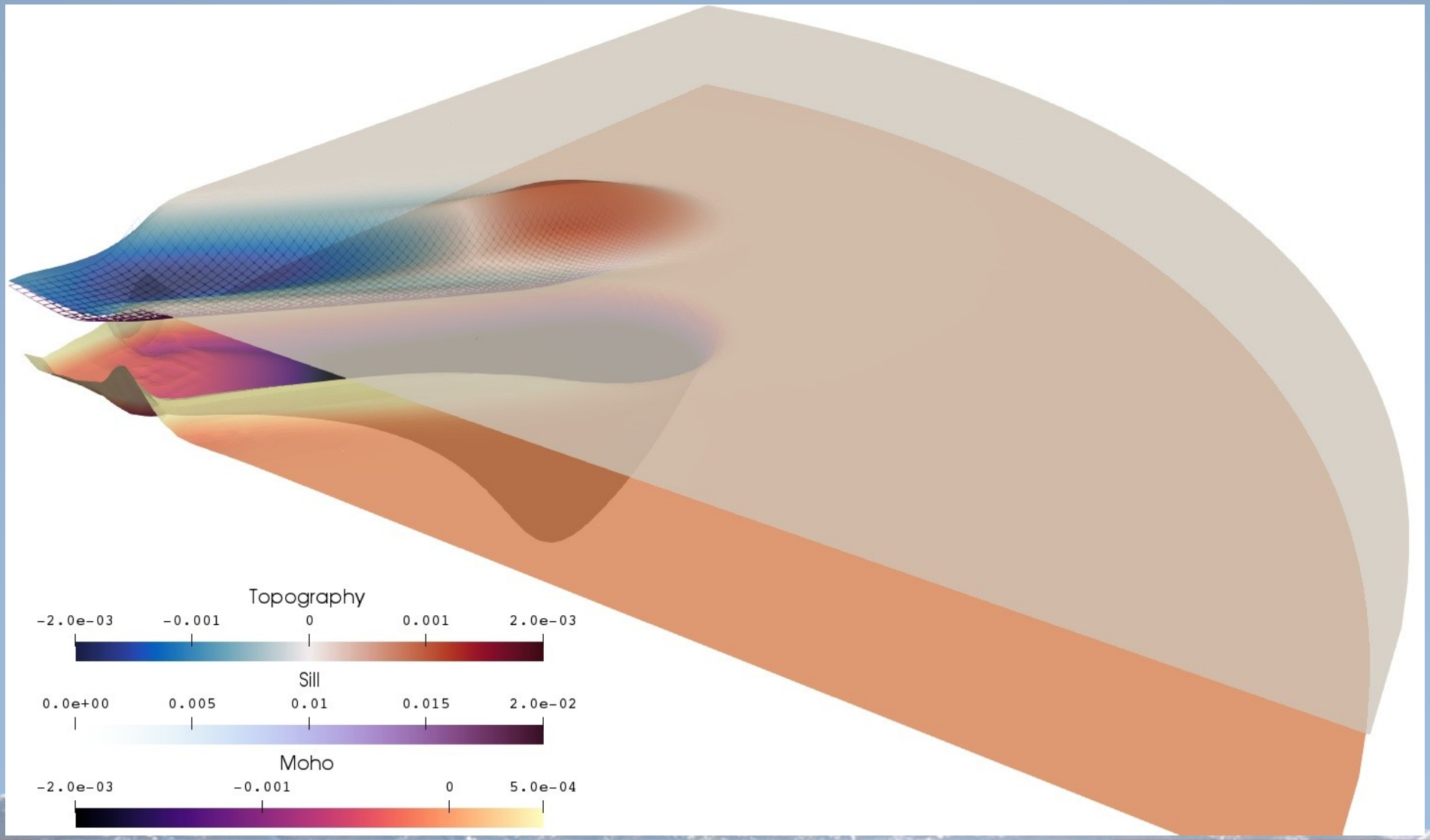
(Perry-Houts & Humphreys, In review)

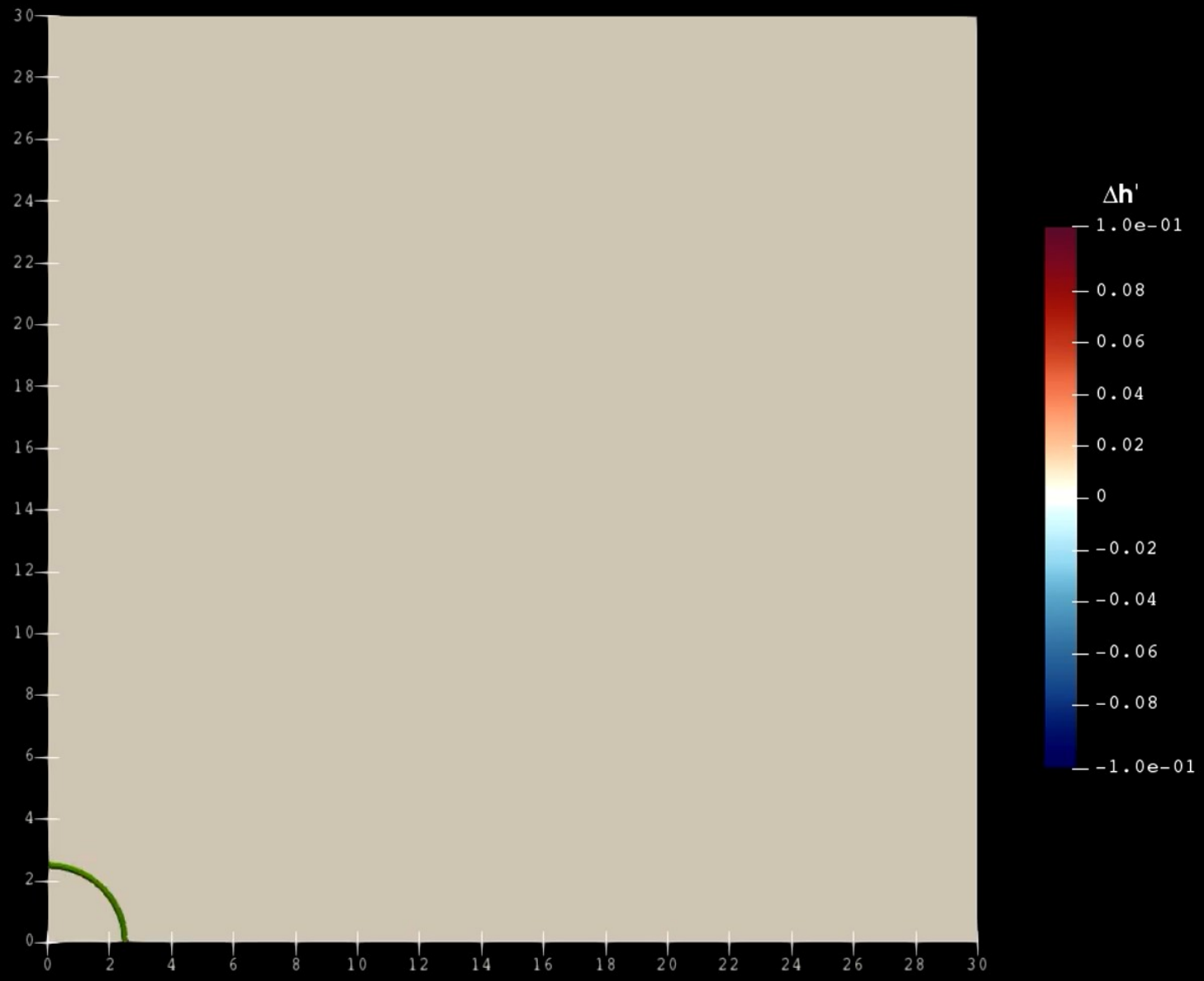
$$\eta\nabla^2\vec{U}-\frac{2\eta}{h^2}\vec{U}+(\rho_m-\rho_c)g\nabla(w-2h)=0 \qquad \dot{h}=-\frac{2}{3}h(\nabla\cdot\vec{U})$$



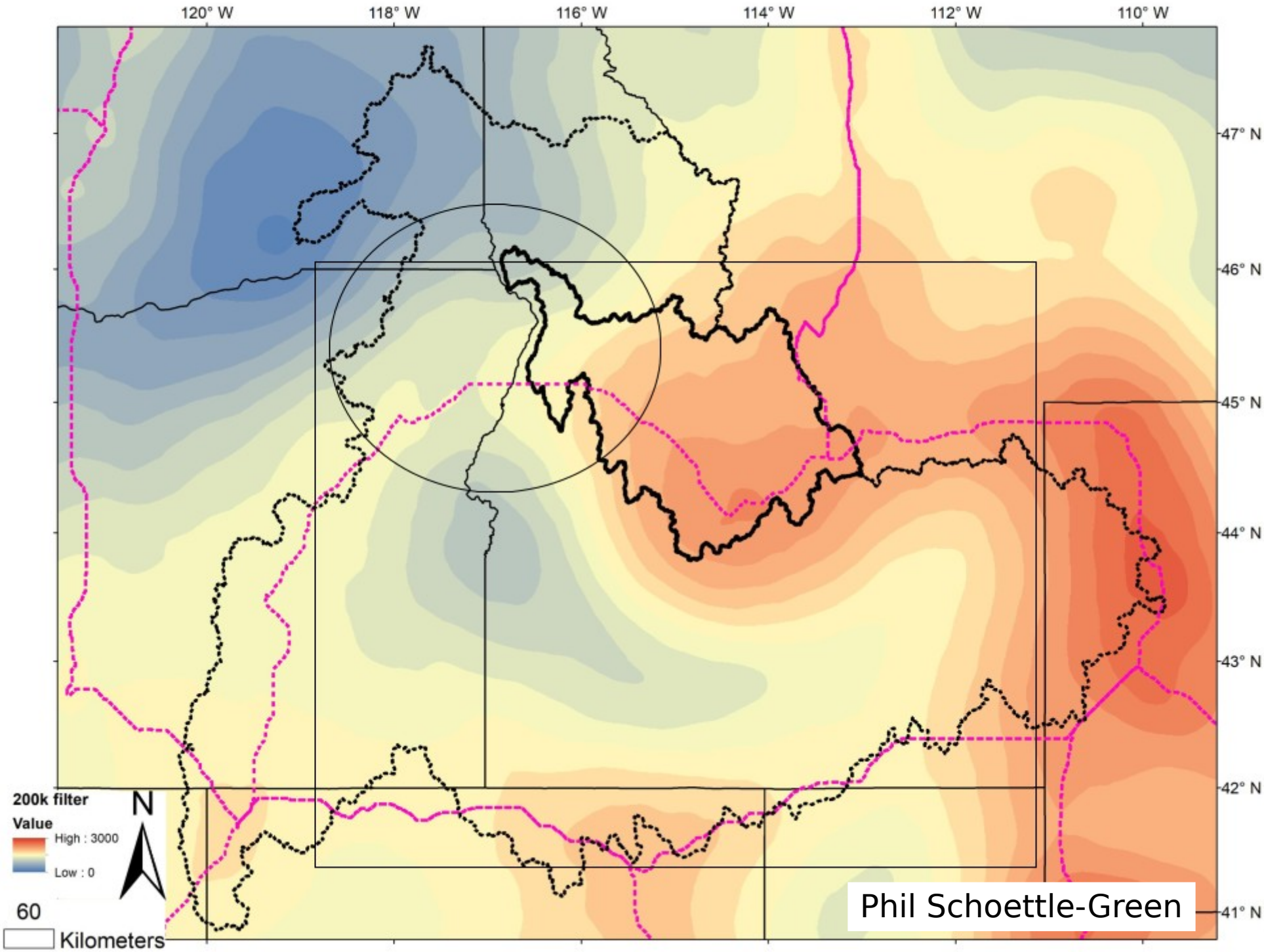
(Perry-Houts & Humphreys, In review)


A)
Load
Velocity
Thickening
Divide
Topography
B)
Topographic divide
Uplift (mm/yr)
<0.001
0.01
0.1
1.0
h_0 (m)
10^9
10^7
10^5
10^3
10^1
10^{18}
10^{19}
10^{20}
10^{21}
10^{22}
10^{23}
η_0 (Pa.s)
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
Migration (mm/yr)


Topography
-2.0e-03
-0.001
0
0.001
2.0e-03
Sill
0.0e+00
0.005
0.01
0.015
2.0e-02
Moho
-2.0e-03
-0.001
0
5.0e-04

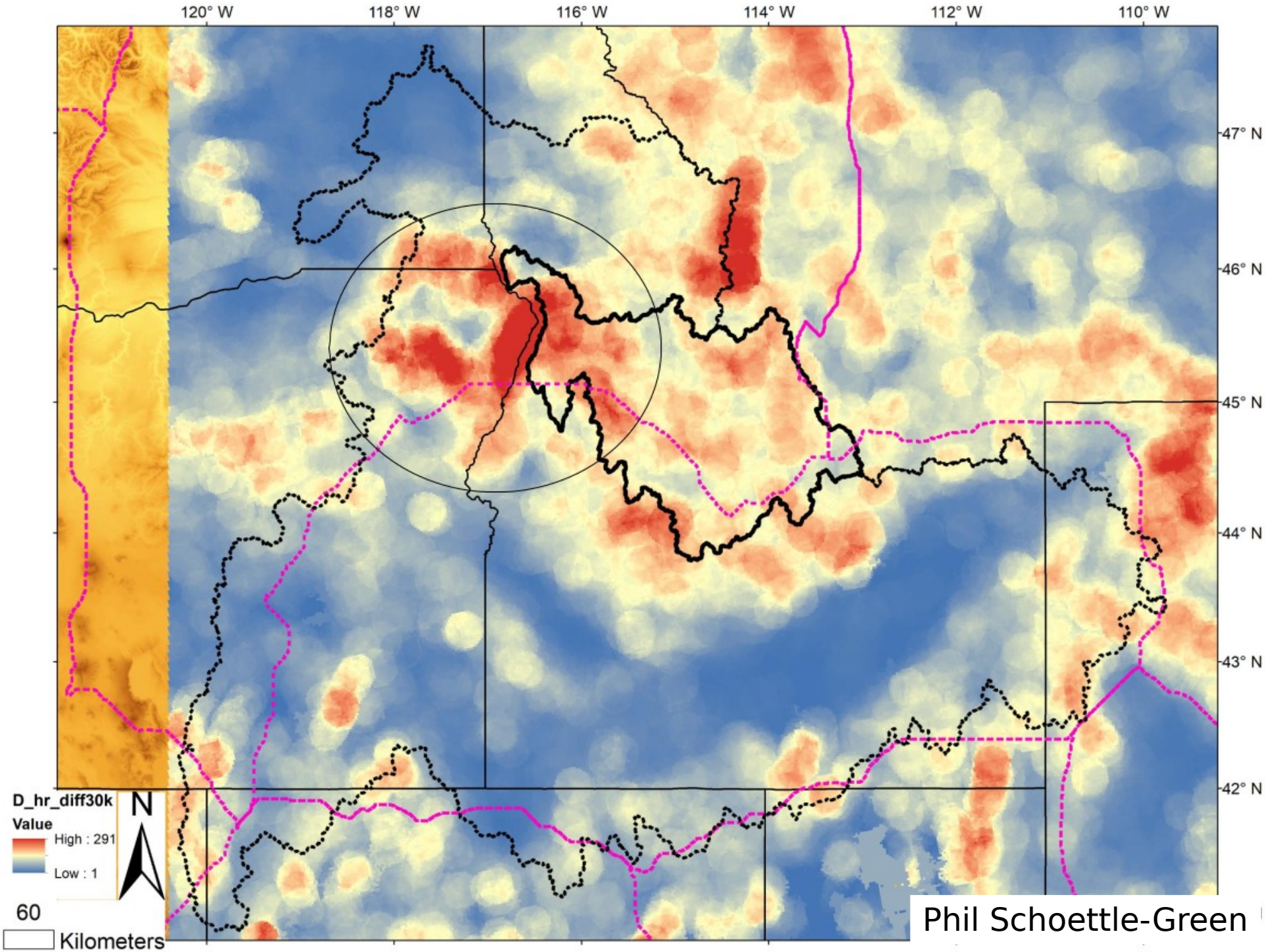

Δh'
1.0e-01
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
-1.0e-01
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30

Active reorganization at major divide breach

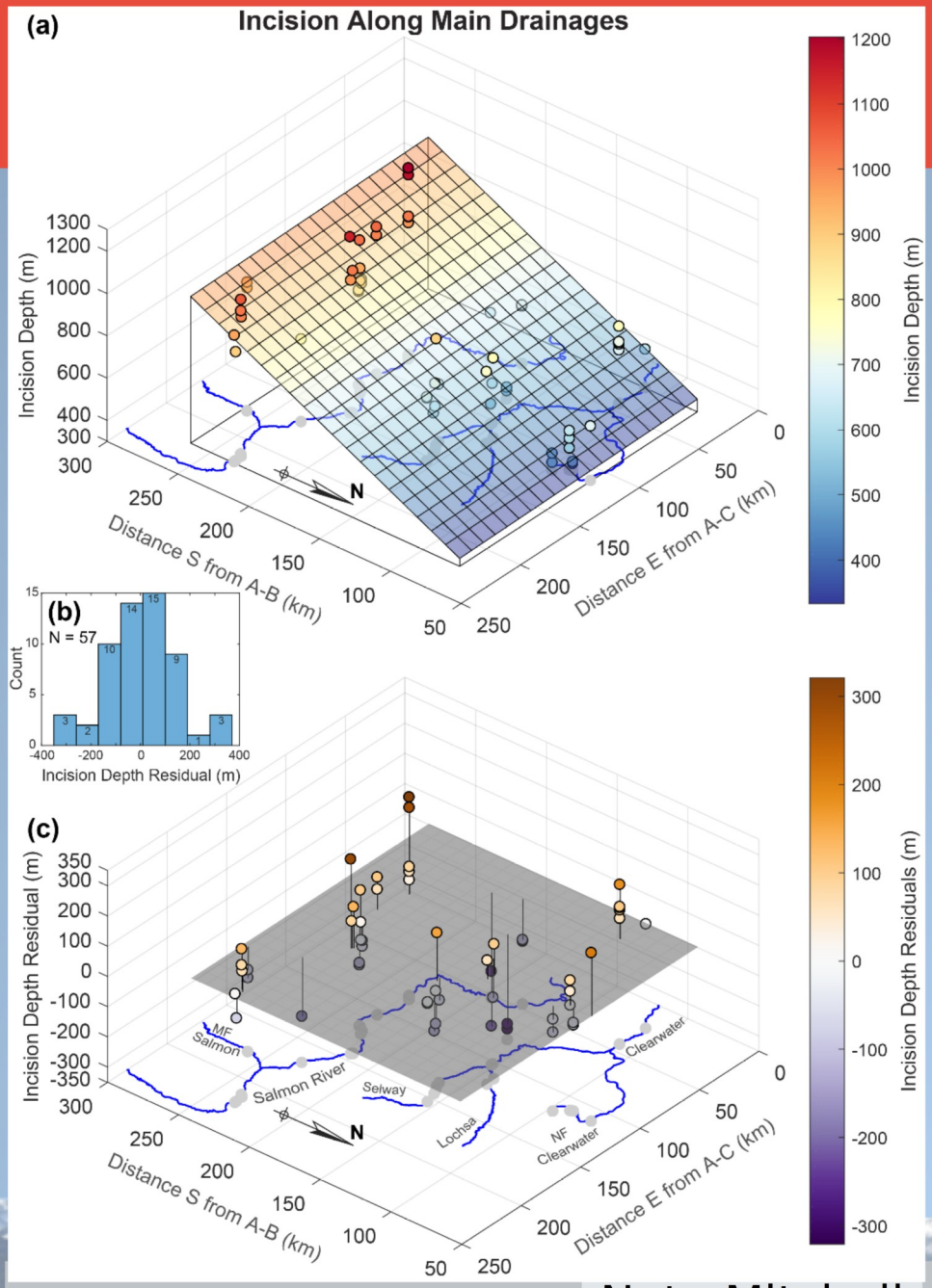


Phil Schoettle-Green

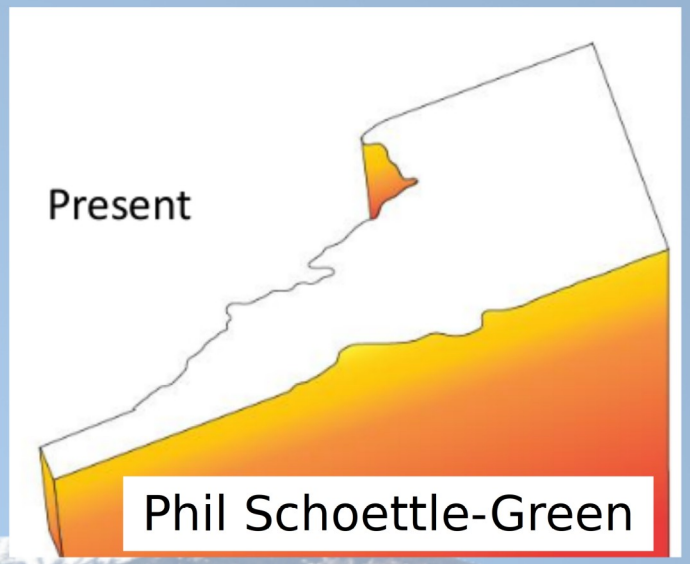
Relief differences across drainage divides



Phil Schoettle-Green



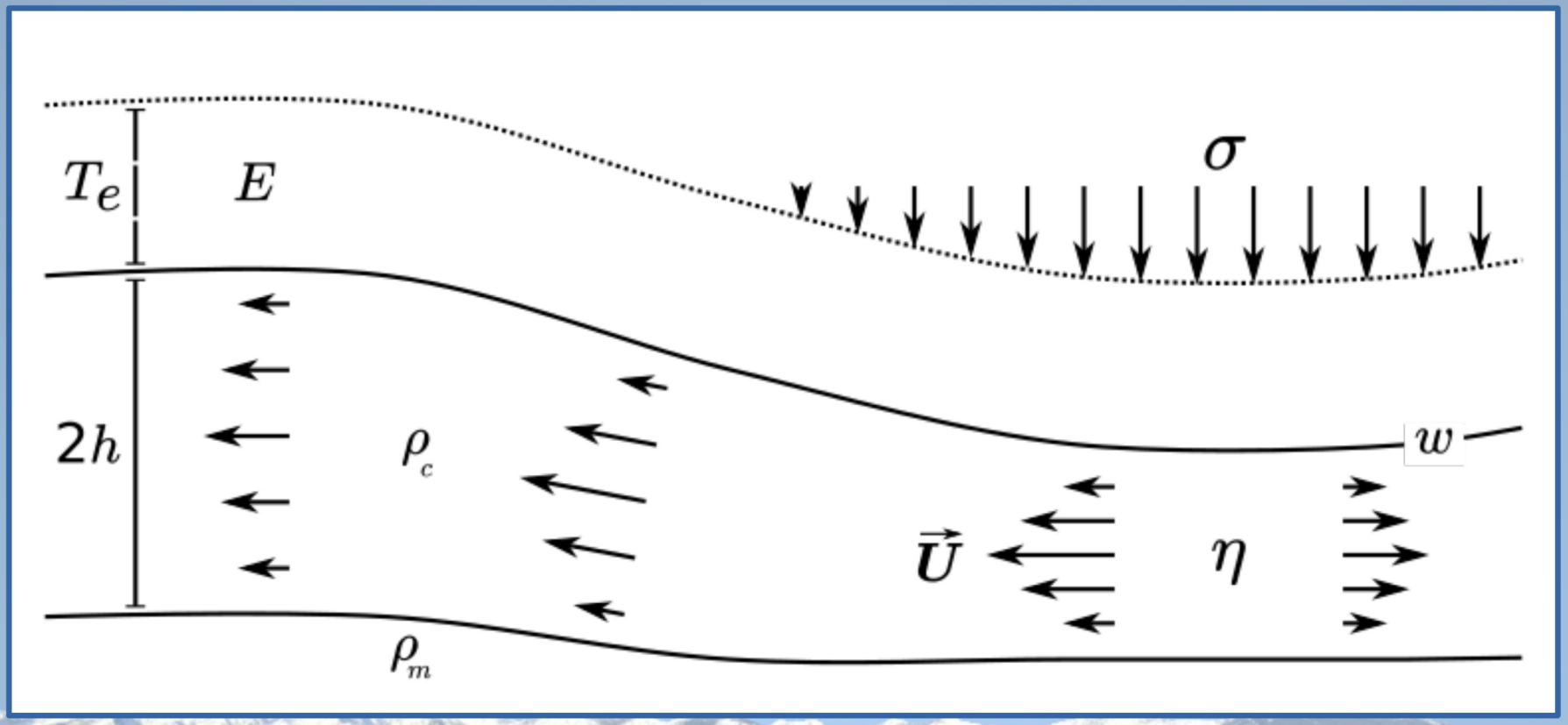
Nate Mitchell



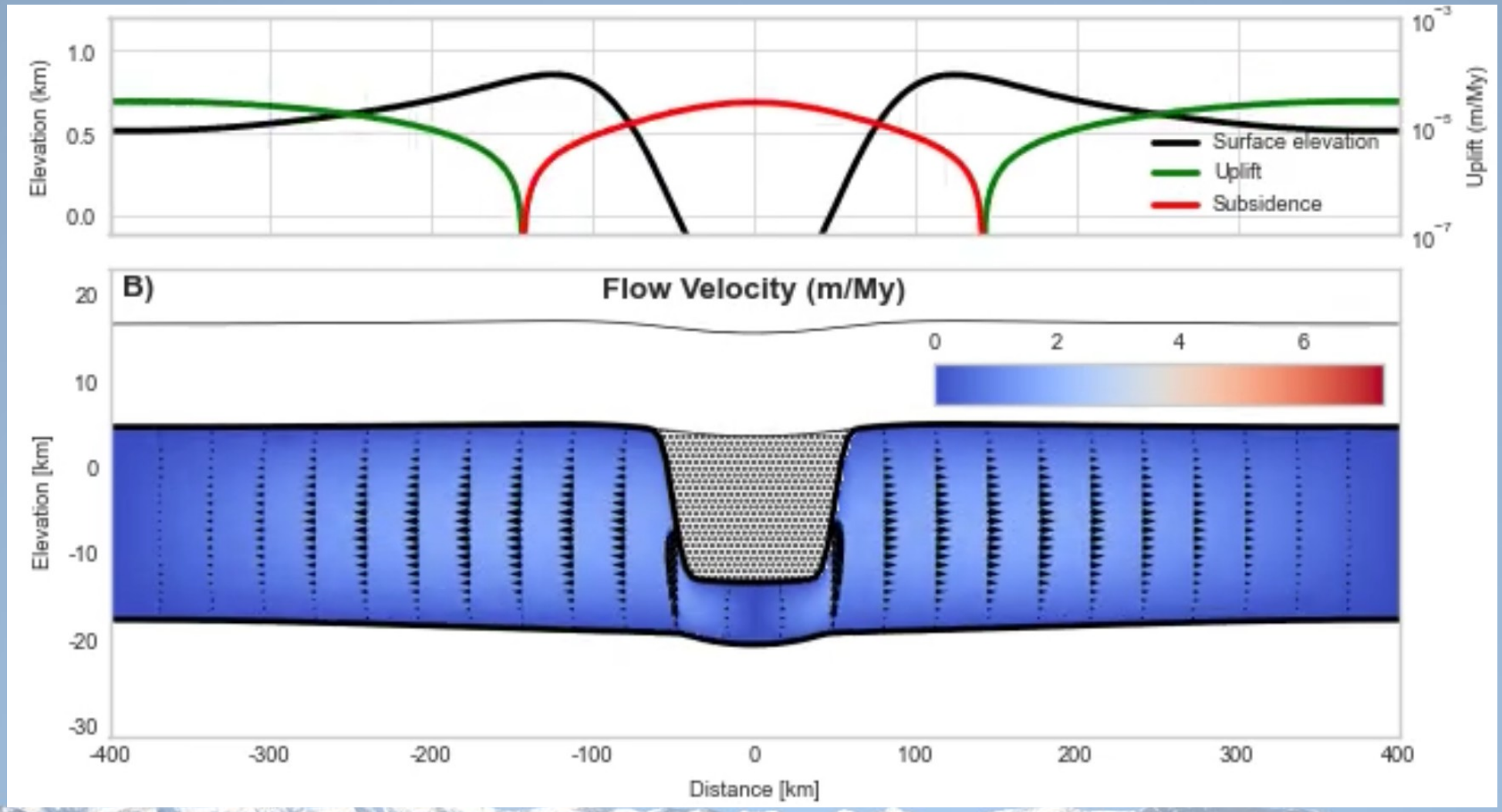
Phil Schoettle-Green

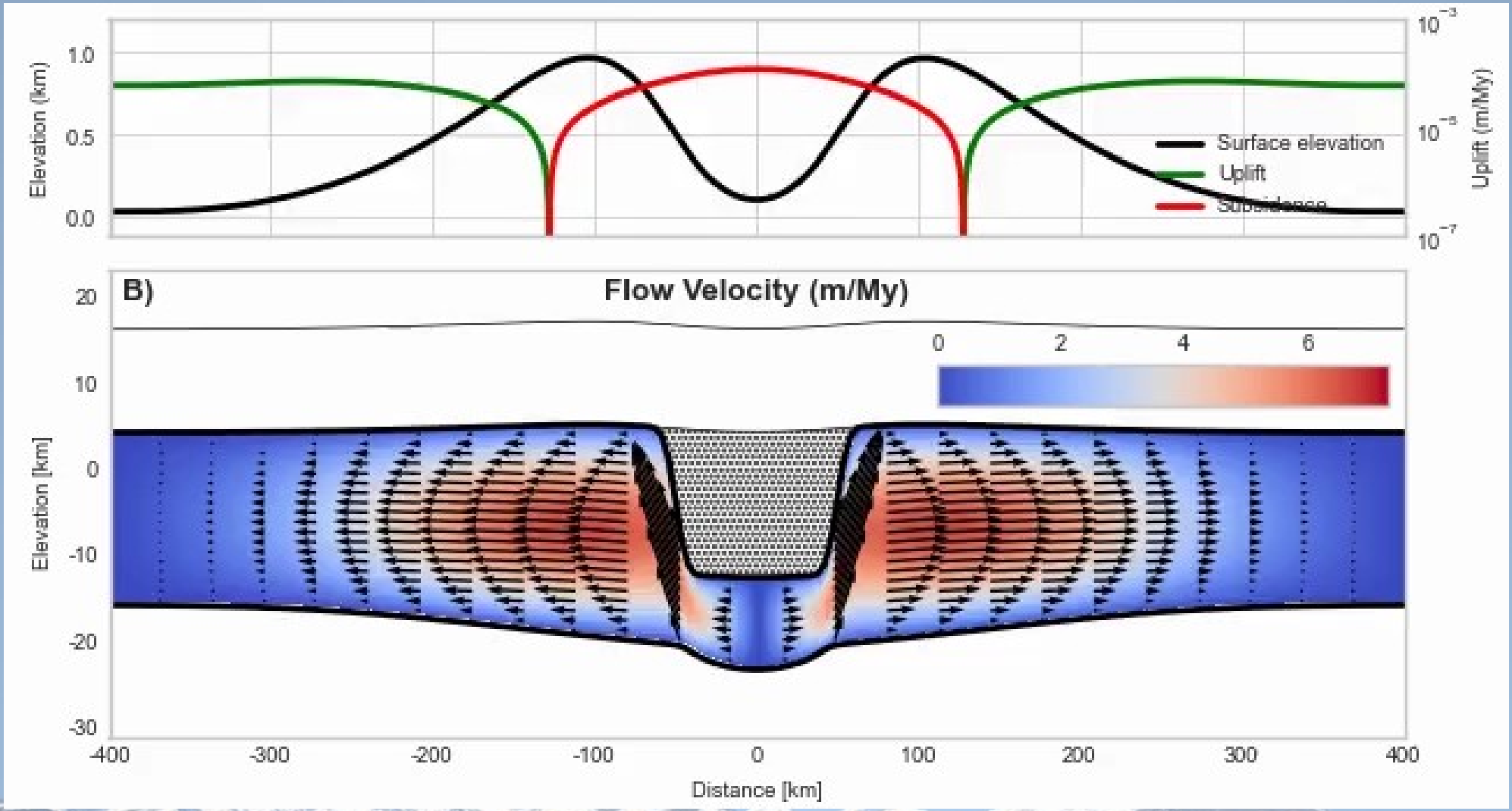
$$\eta \nabla^2 \vec{U} - \frac{2\eta}{h^2}\vec{U} + (\rho_m - \rho_c) g \nabla (w - 2h) = 0 \qquad \dot{h} = -\frac{2}{3} h (\nabla \cdot \vec{U})$$

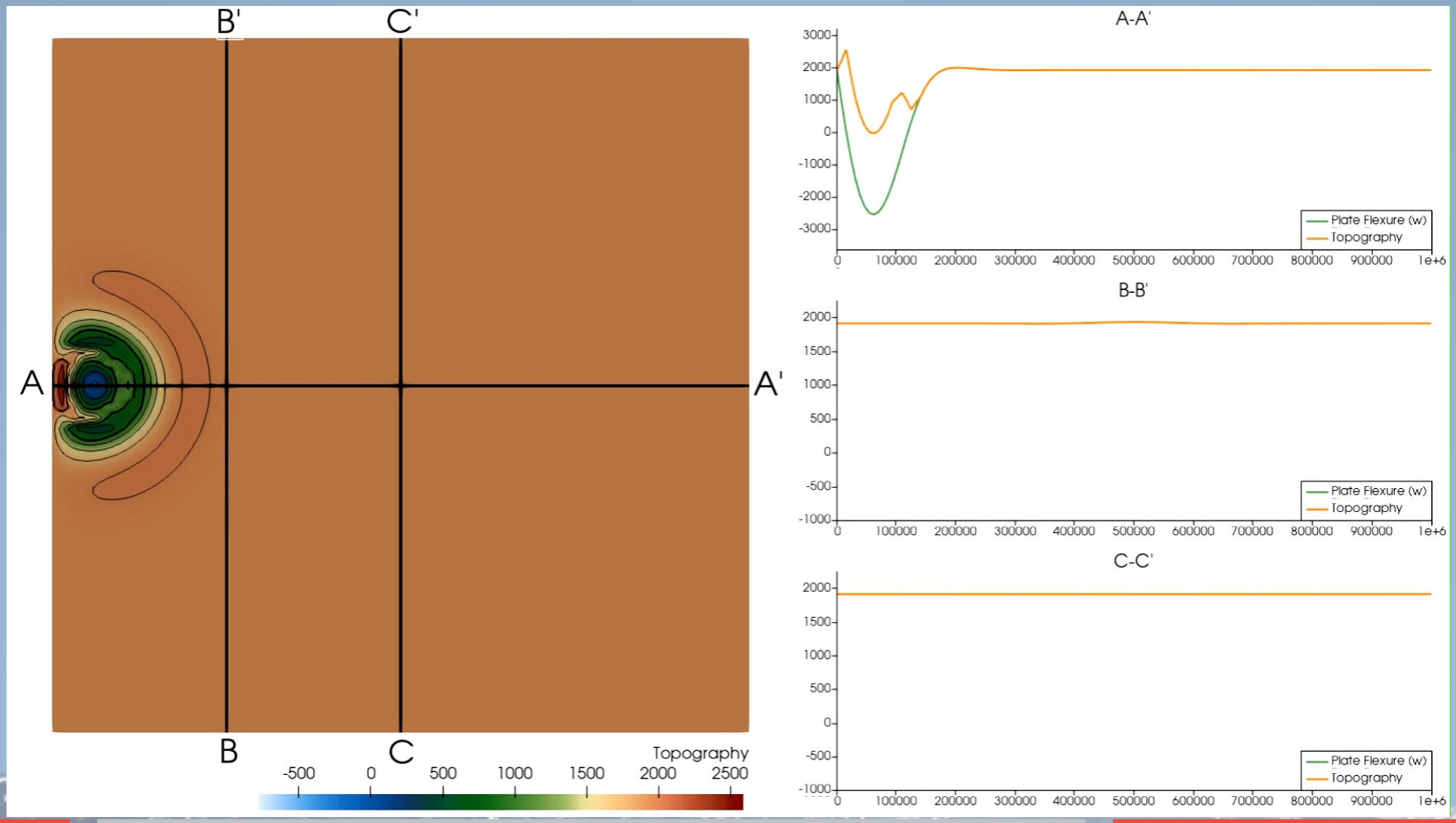
$$D \nabla^4 w + \rho_m g w + 2(\rho_c - \rho_m) g h = -\sigma \qquad D = \frac{E T_e^3}{12(1-\nu^2)}$$

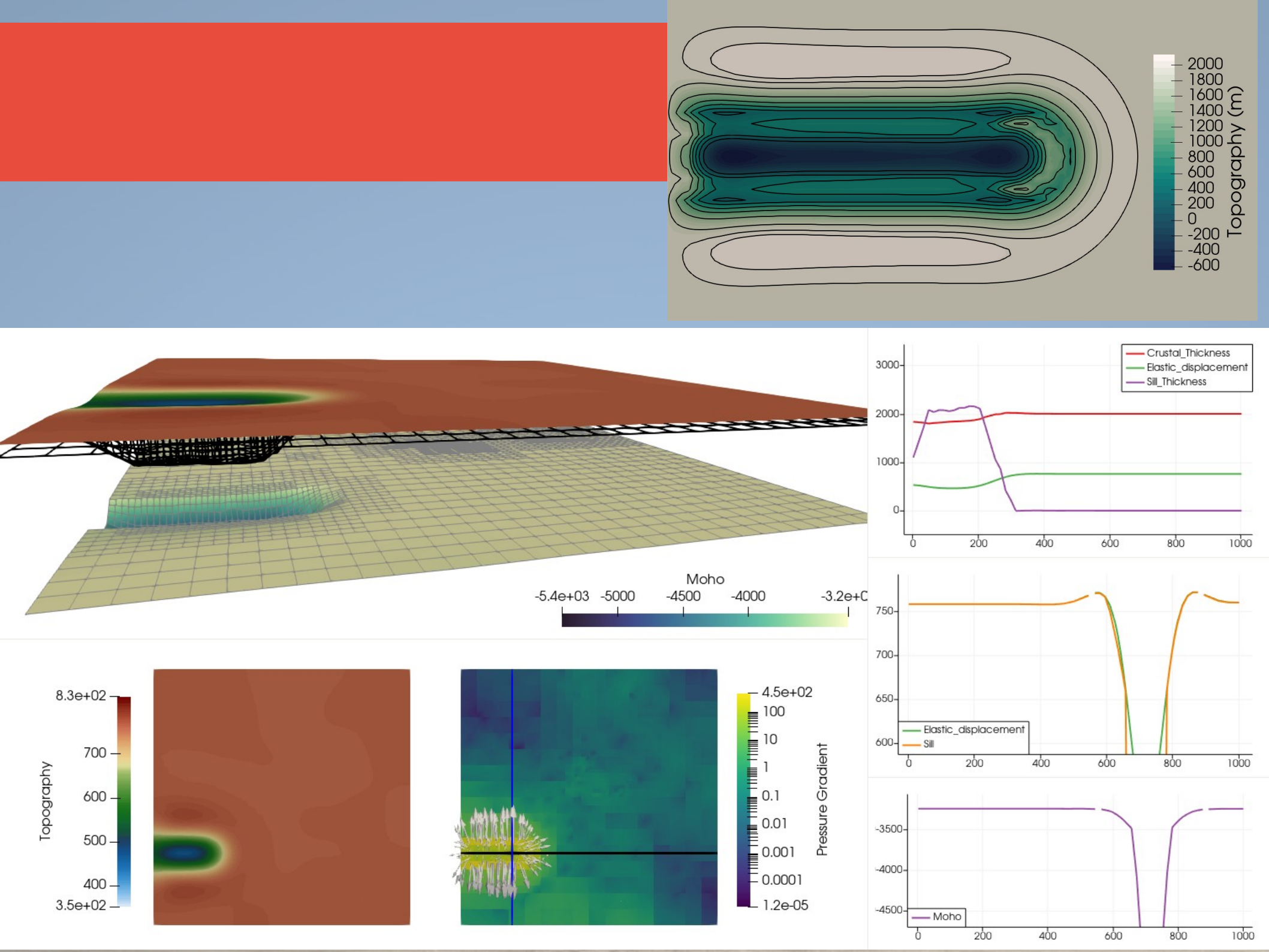


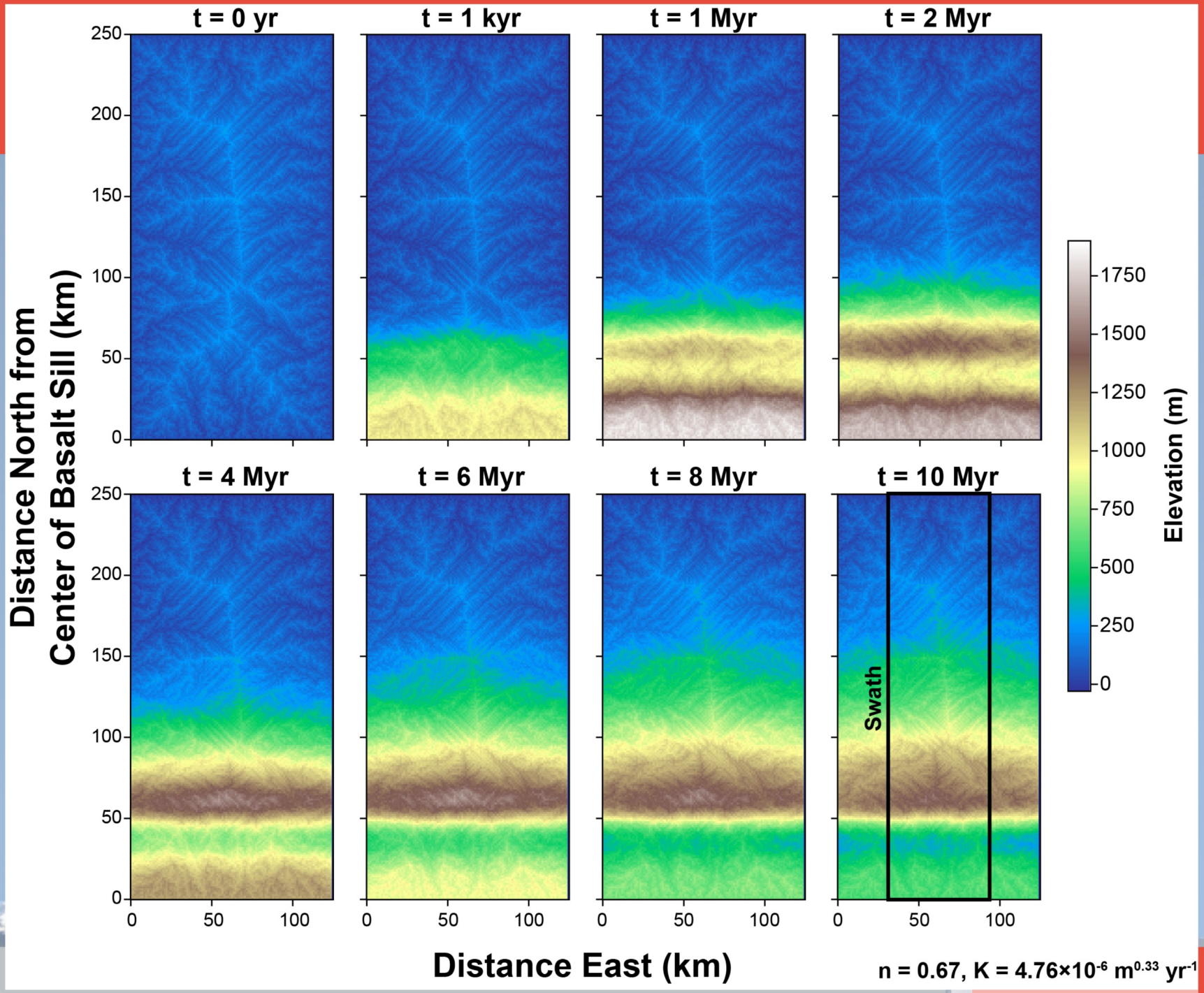
(Perry-Houts & Humphreys, In review)


Elevation (km)
1.0
0.5
0.0
Uplift (m/My)
Surface elevation
Uplift
Subsidence
B)
Flow Velocity (m/My)
0
2
4
6
Elevation [km]
20
10
0
-10
-20
-30
-400
-300
-200
-100
0
100
200
300
400
Distance [km]

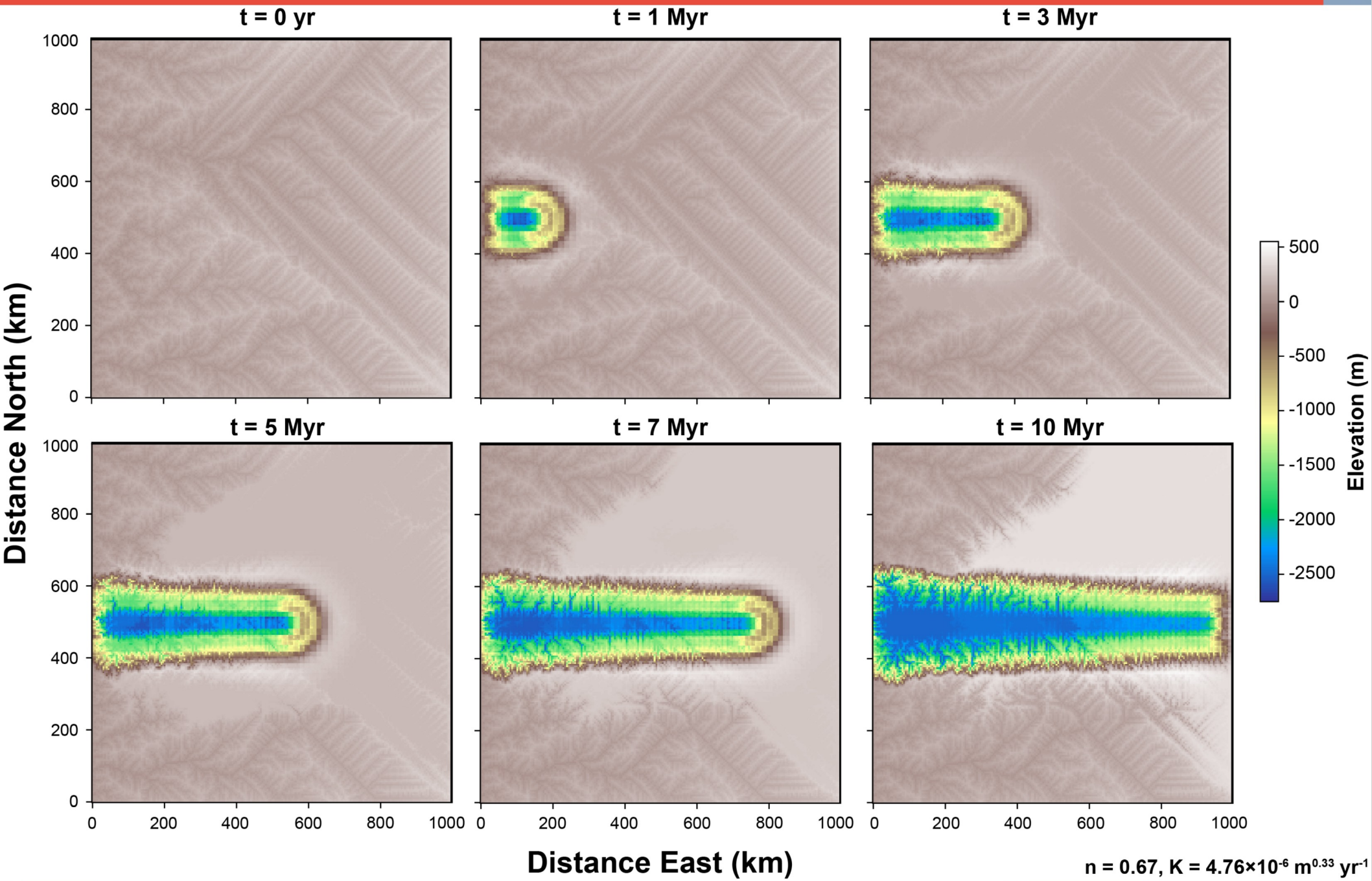

Elevation (km)
1.0
0.5
0.0
Uplift (m/My)
Surface elevation
Uplift
Subsidence
B)
Flow Velocity (m/My)
0
2
4
6
Elevation [km]
20
10
0
-10
-20
-30
-400
-300
-200
-100
0
100
200
300
400
Distance [km]

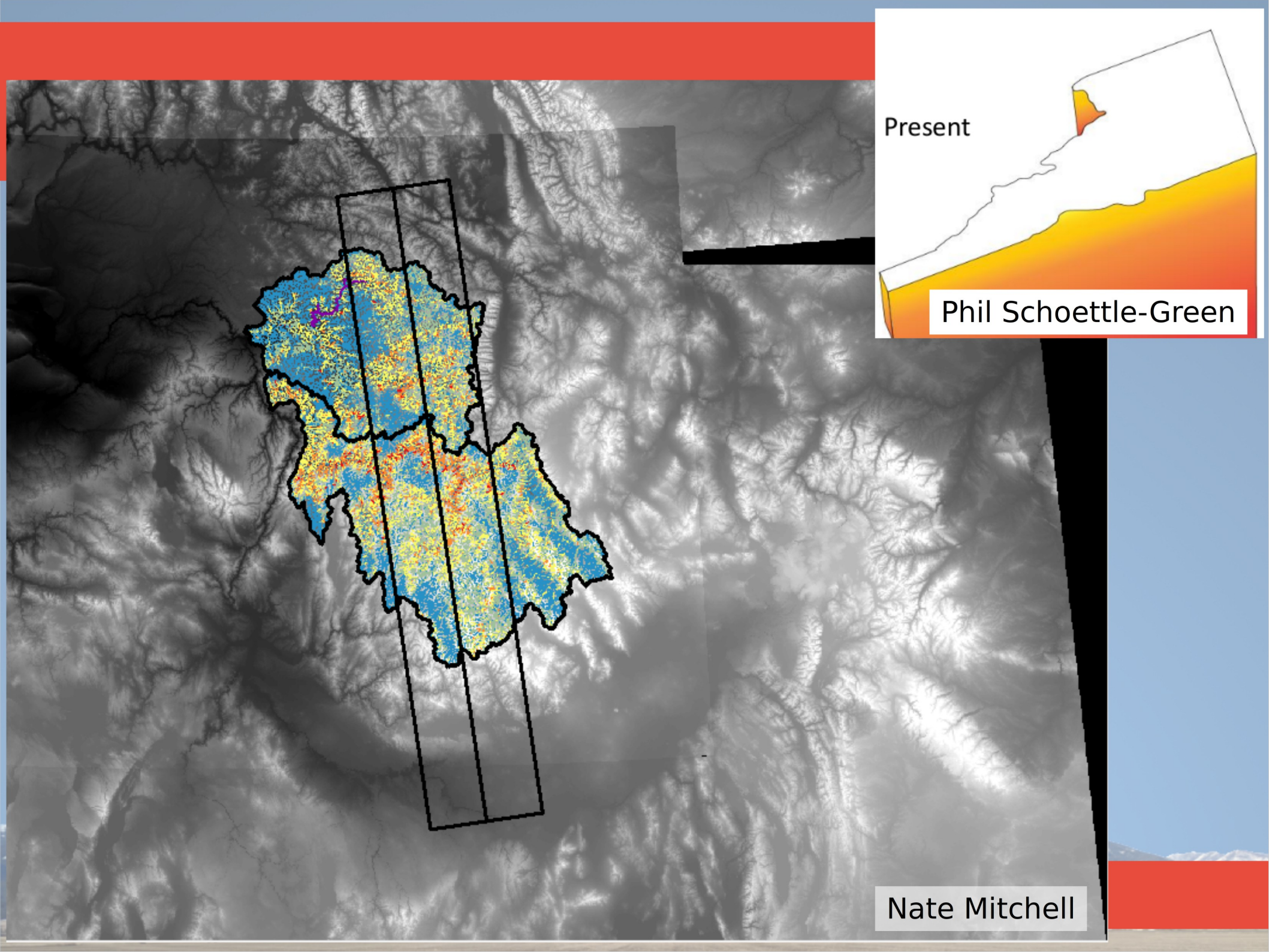

B'
C'
A
A'
B
C
Topography
-500
0
500
1000
1500
2000
2500
A-A'
B-B'
C-C'
Plate Flexure (w)
Topography
0
100000
200000
300000
400000
500000
600000
700000
800000
900000
1e+6

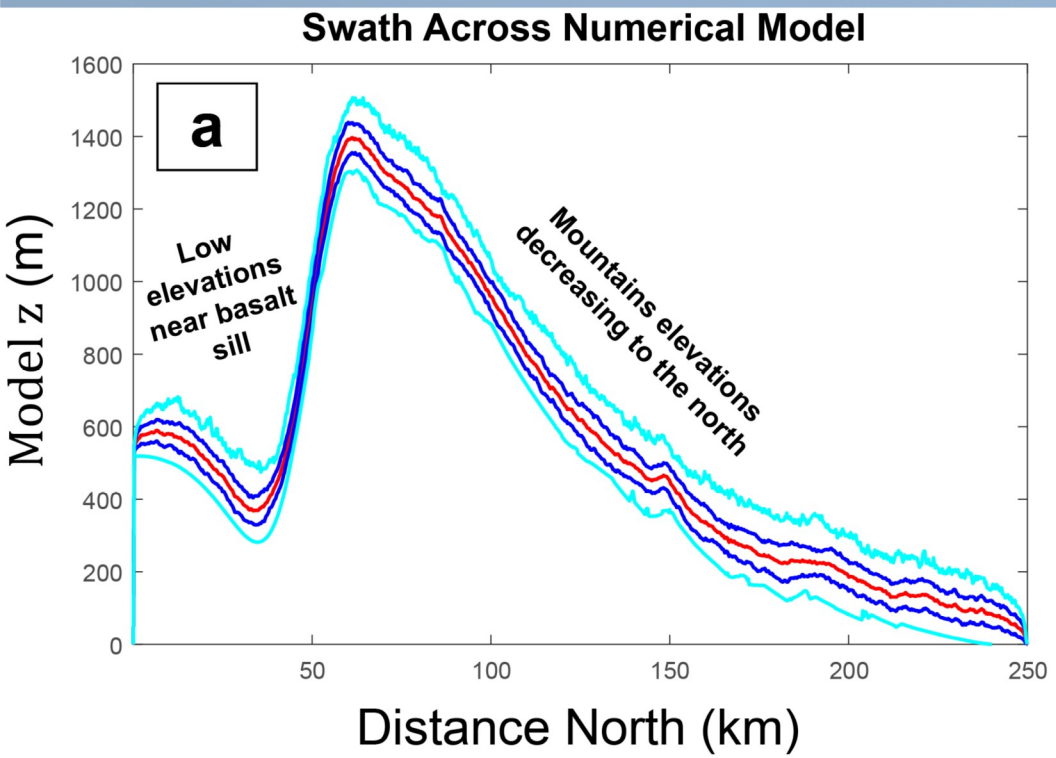

Topography (m)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
-200
-400
-600
Moho
-5.4e+03
-5000
-4500
-4000
-3.2e+0
Crustal_Thickness
Elastic_displacement
Sill_Thickness
3000
2000
1000
0
0
200
400
600
800
1000
Elastic_displacement
Sill
750
700
650
600
Moho
-3500
-4000
-4500
Topography
8.3e+02
700
600
500
400
3.5e+02
Pressure Gradient
4.5e+02
100
10
1
0.1
0.01
0.001
0.0001
1.2e-05

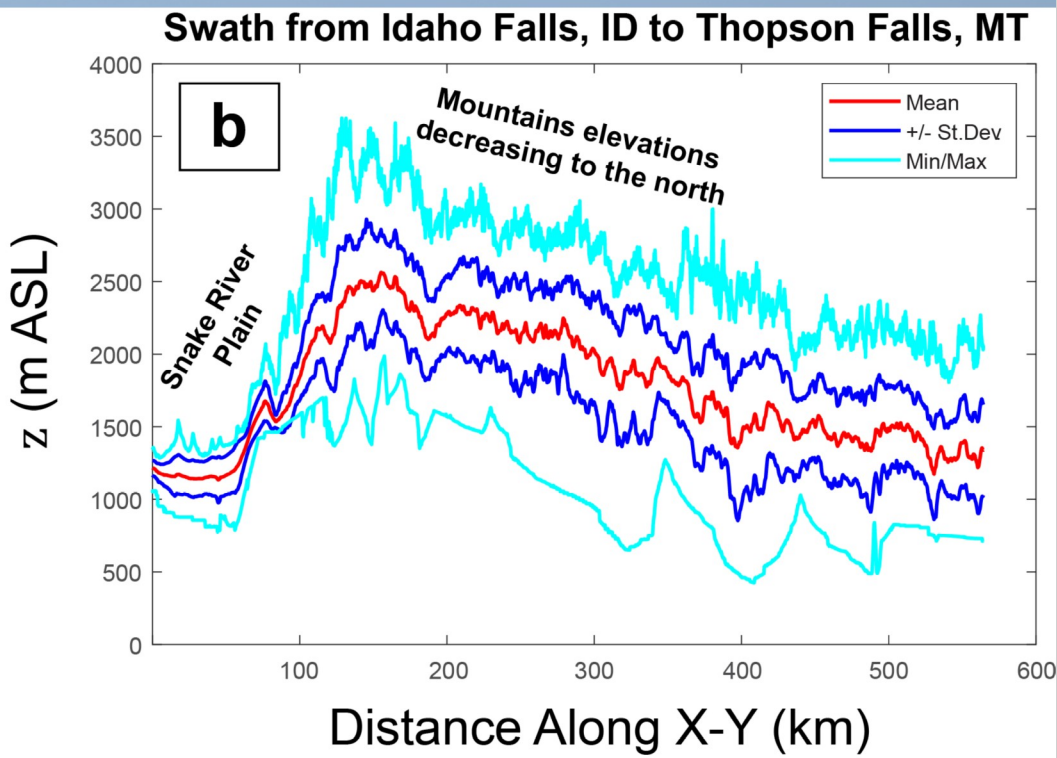


Nate Mitchell

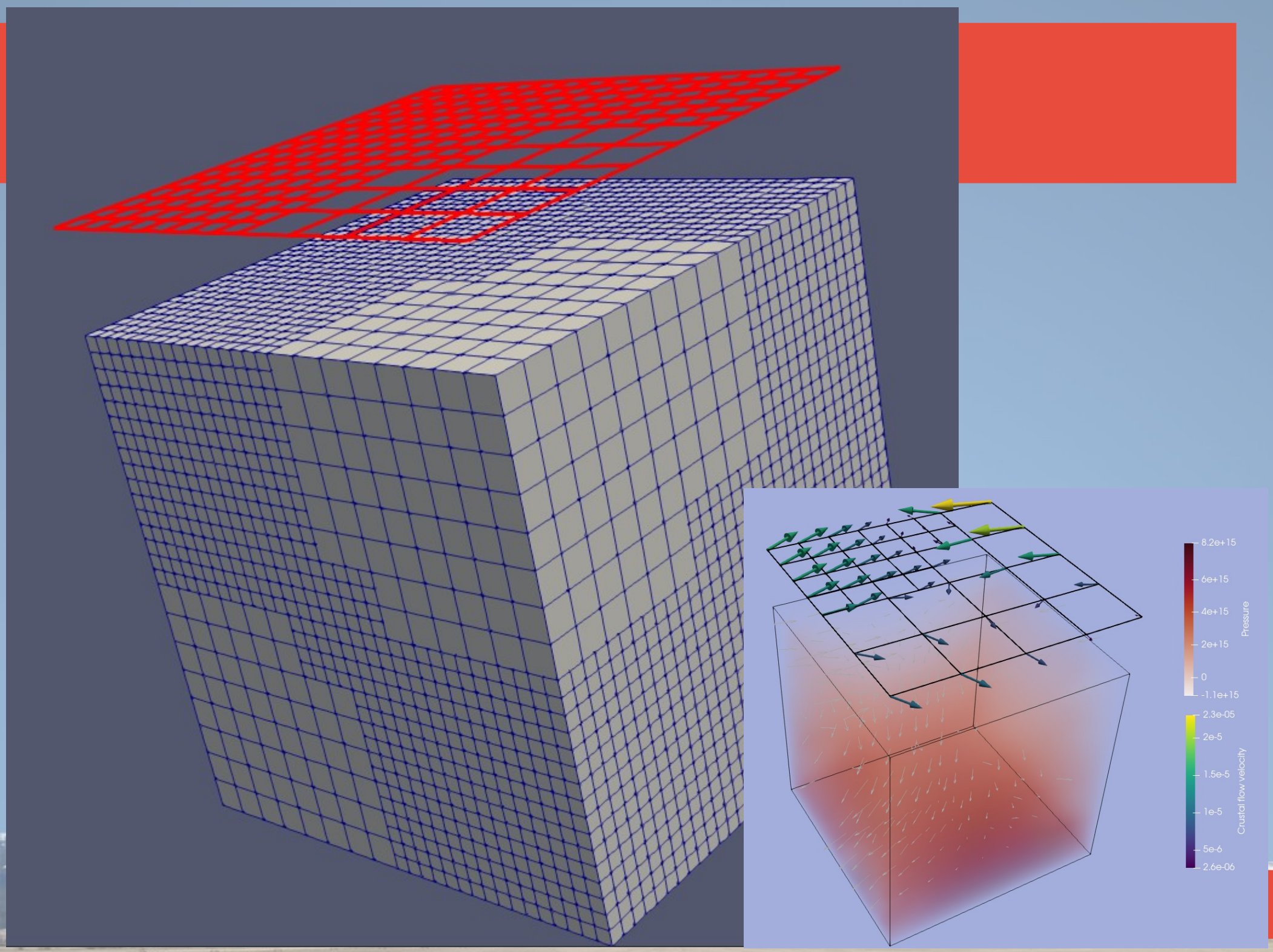

t = 0 yr
t = 1 Myr
t = 3 Myr
t = 5 Myr
t = 7 Myr
t = 10 Myr
Distance North (km)
Distance East (km)
0
200
400
600
800
1000
Elevation (m)
500
0
-500
-1000
-1500
-2000
-2500
n = 0.67, K = 4.76×10^-6 m^0.33 yr^-1


Present
Phil Schoettle-Green
Nate Mitchell





Nate Mitchell


8.2e+15
6e+15
4e+15
2e+15
0
-1.1e+15
Pressure
2.3e-05
2e-5
1.5e-5
1e-5
5e-6
2.6e-06
Crustal flow velocity

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