Creation of a Stratigraphical Consistent Seismic Profile for Geologically Informed Machine Learning Interpretation

Emery, David J. – member of CREWES Data Science Initiative

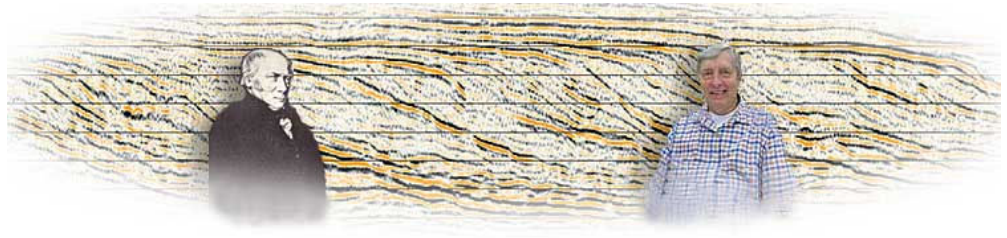
Supervisors: Trad, D. O., and Pedersen, P.,

CREWES meeting December 8th, 2023

NSERC CRSNG

UNIVERSITY OF CALGARY
FACULTY OF SCIENCE
Department of Earth, Energy, and Environment

Seismic Stratigraphy - Geometry and Character Classification



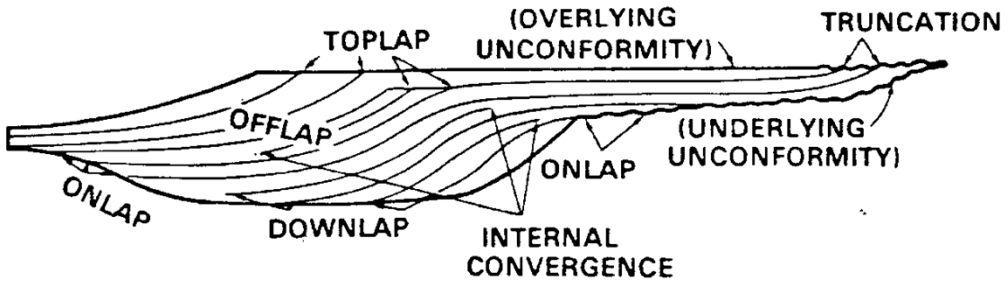
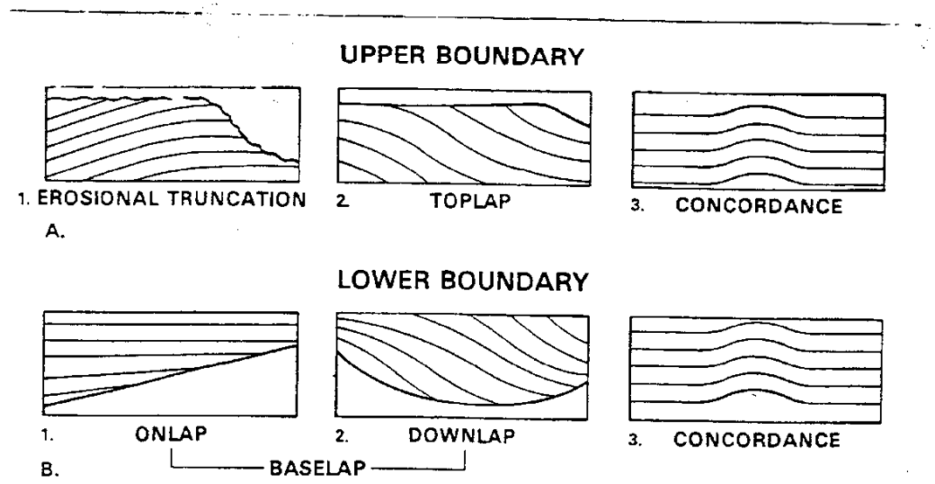
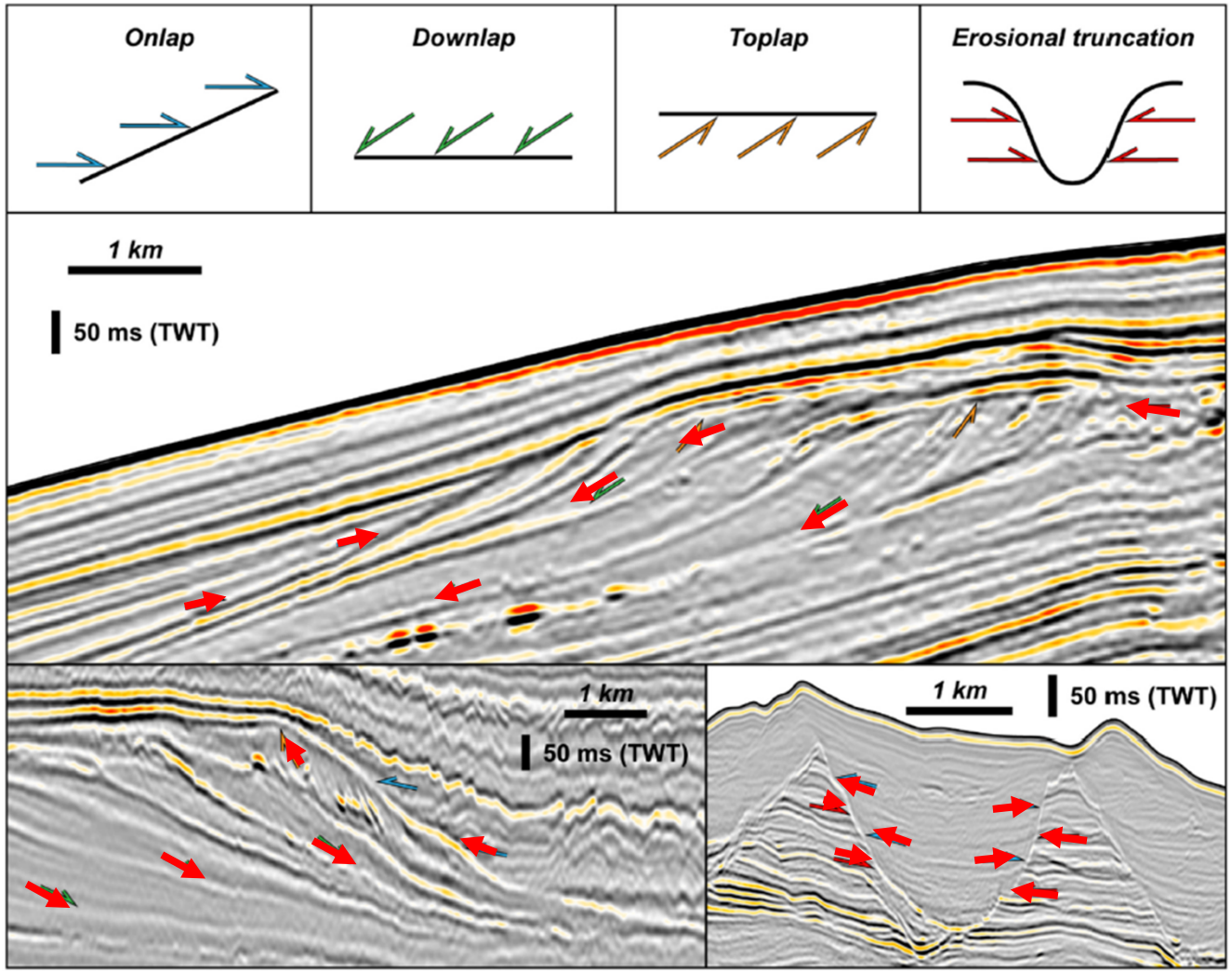


FIG. 1—Seismic stratigraphic reflection terminations within idealized seismic sequence.

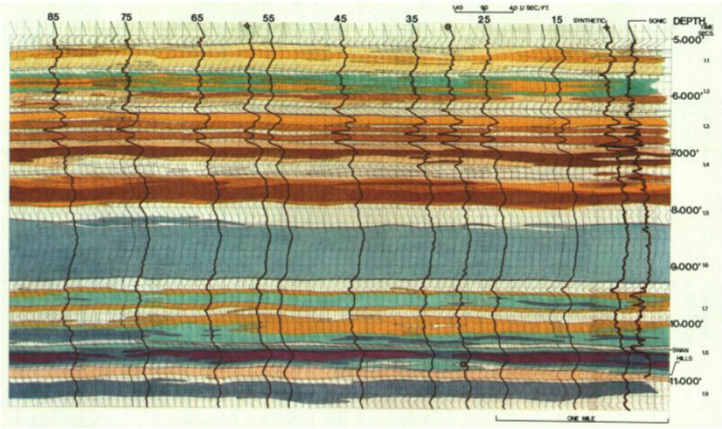


Mitchum, Vail & Sangree 1977

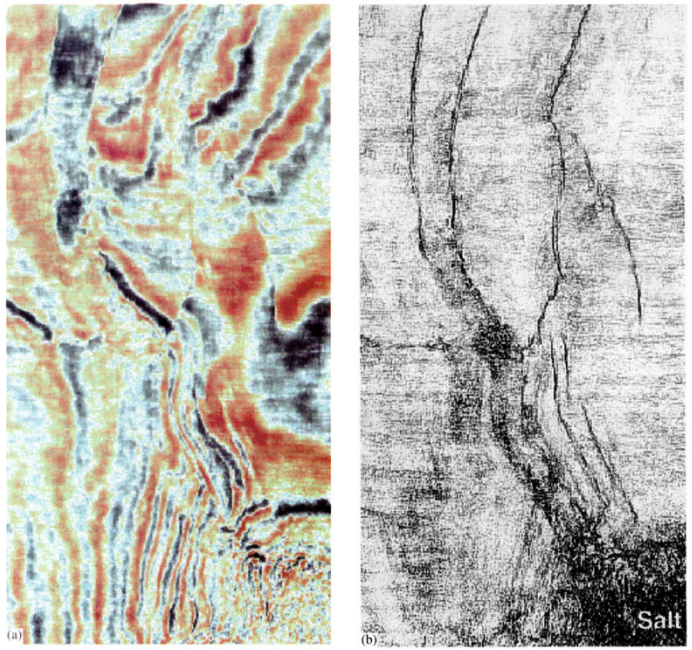


Posamentier 2022

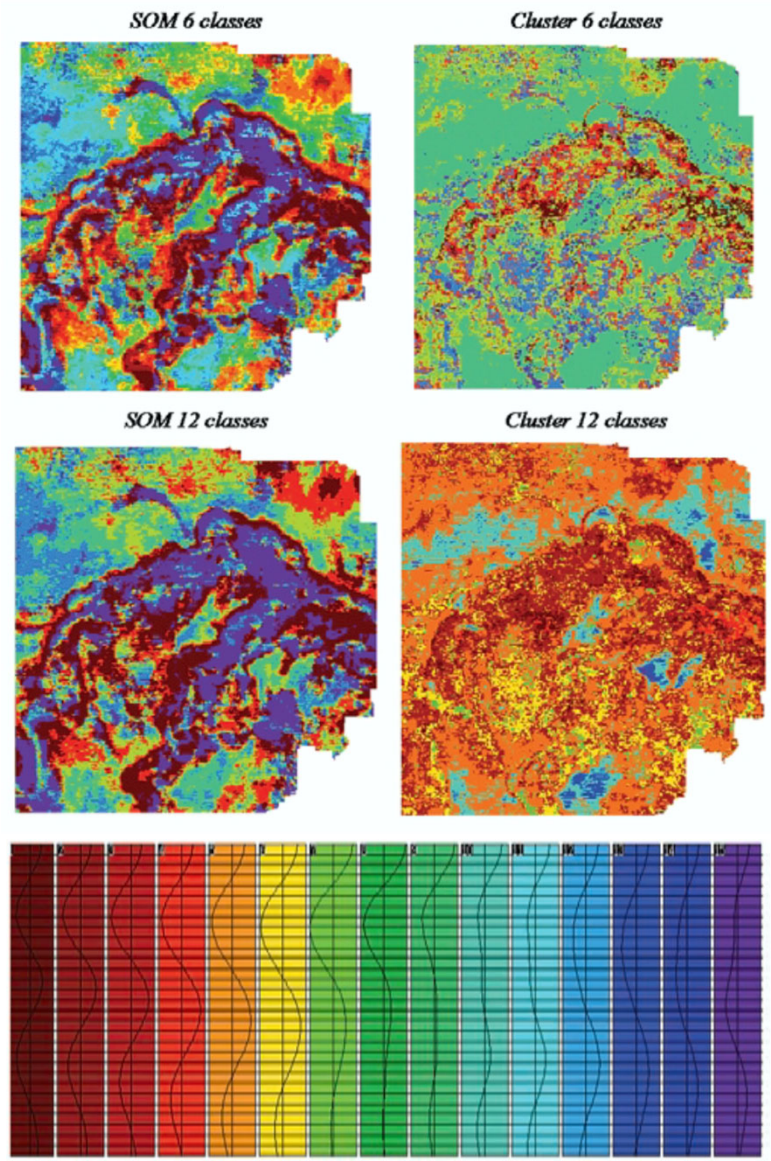
Seismic Stratigraphy - Geometry and Character Classification



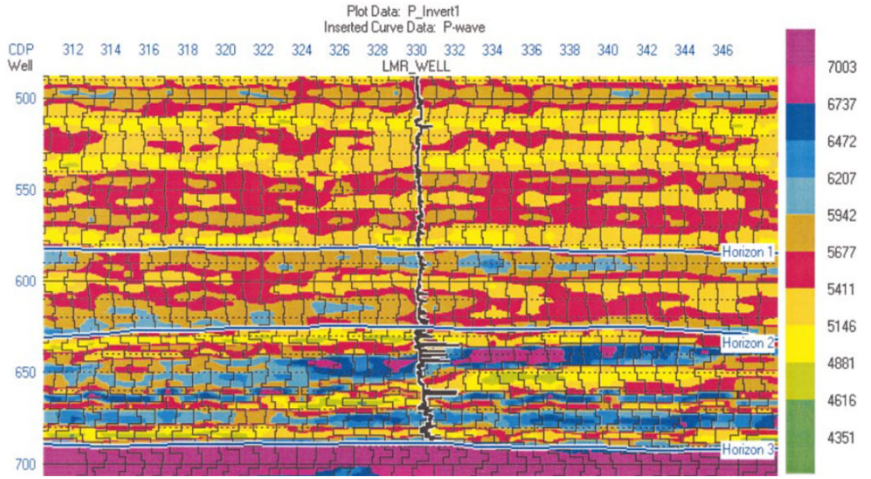
Lindseth 1979



Bahorich 1995



Coleou et. al. 2003



Russell 2003

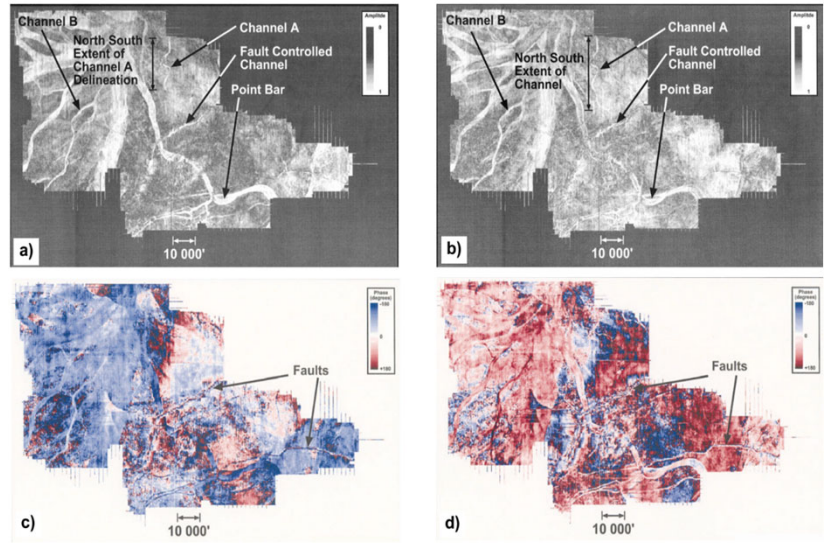
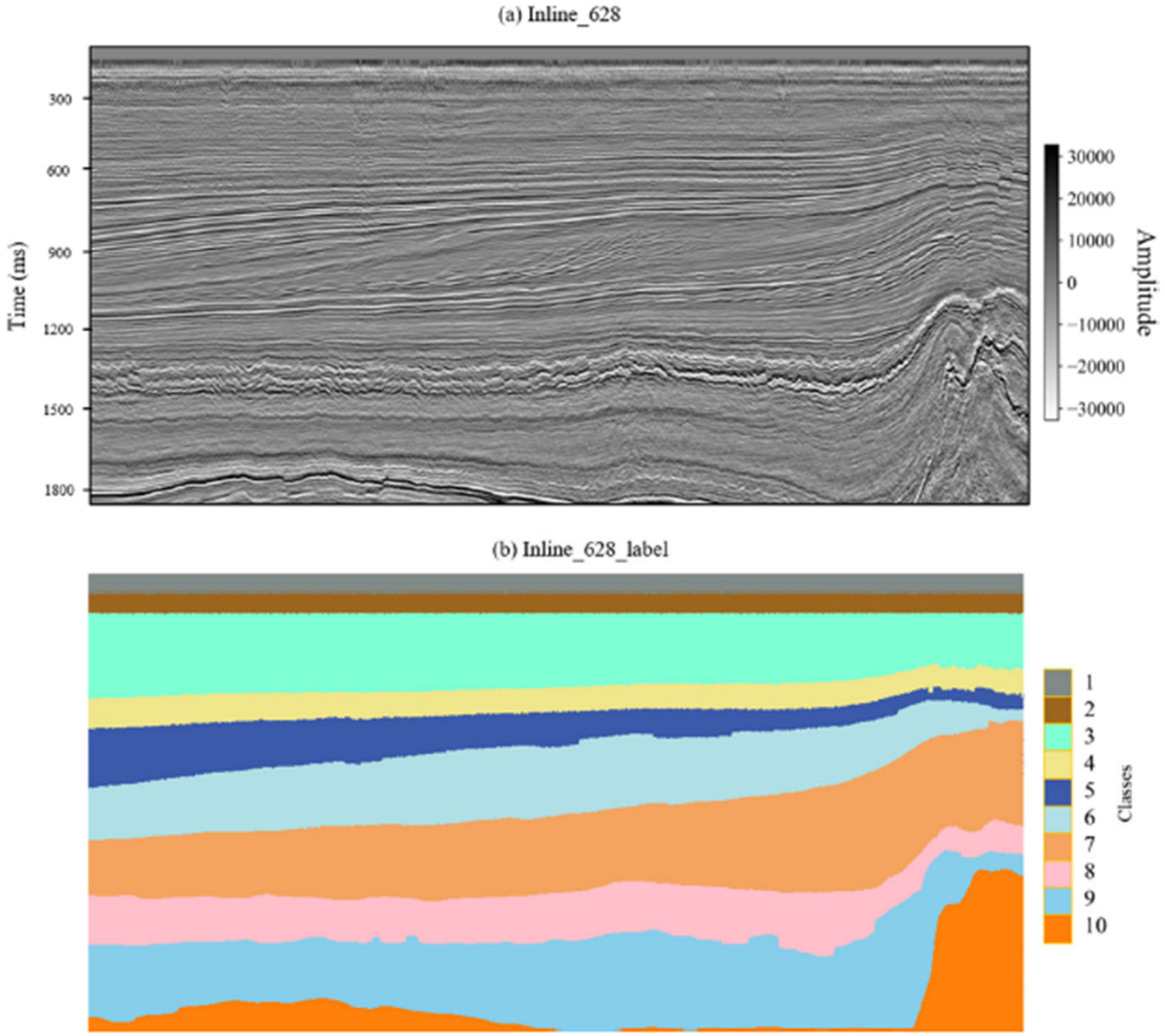


Figure 10. Gulf of Mexico (a) 16-Hz energy map, (b) 26-Hz energy map, (c) 16-Hz phase map, (d) 26-Hz phase map.

Partkya 1999

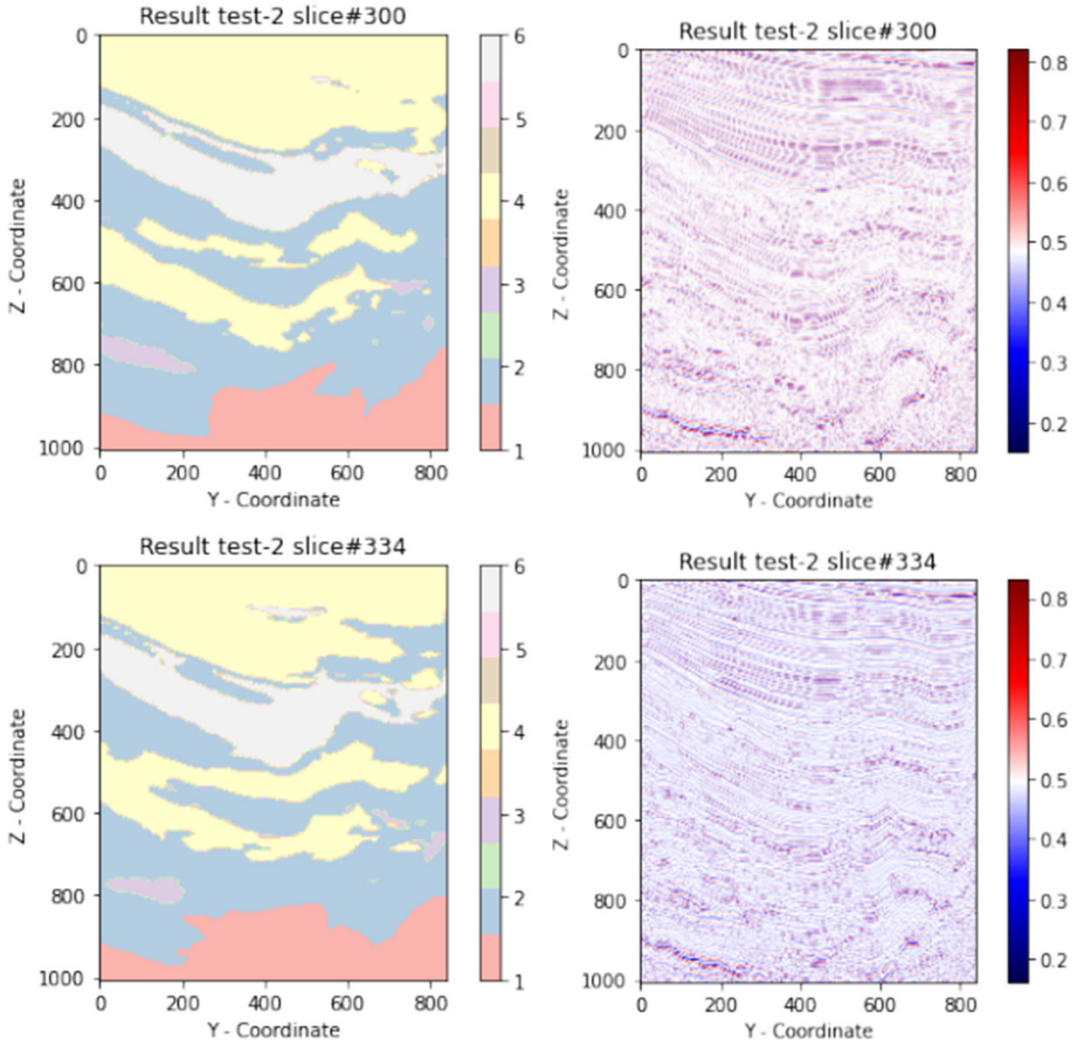
ML Seismic Facies Analysis (pattern recognition)

Netherlands F3 seismic dataset



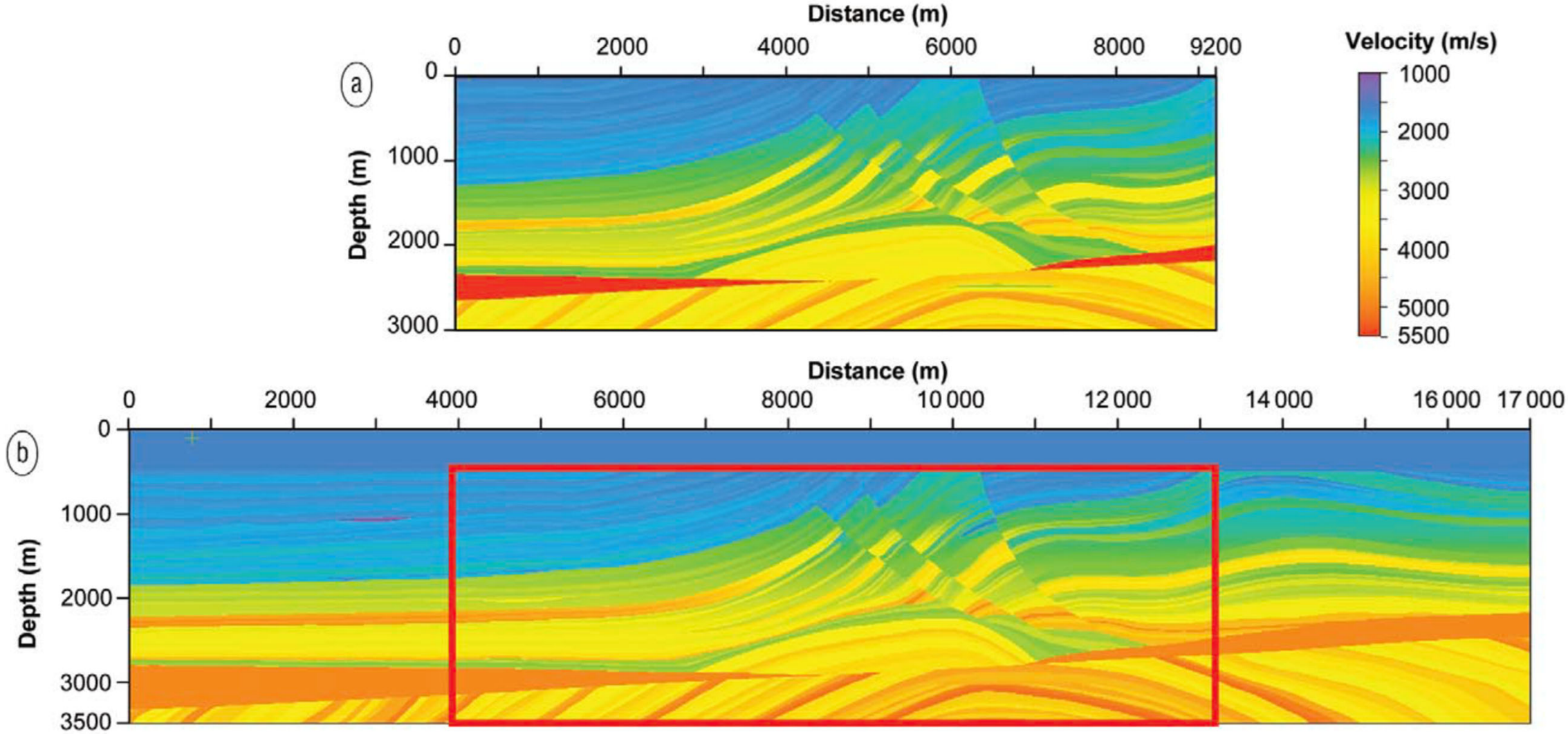
Wang & Chen 2023

Parahika 3D Taranaki Basin NZ



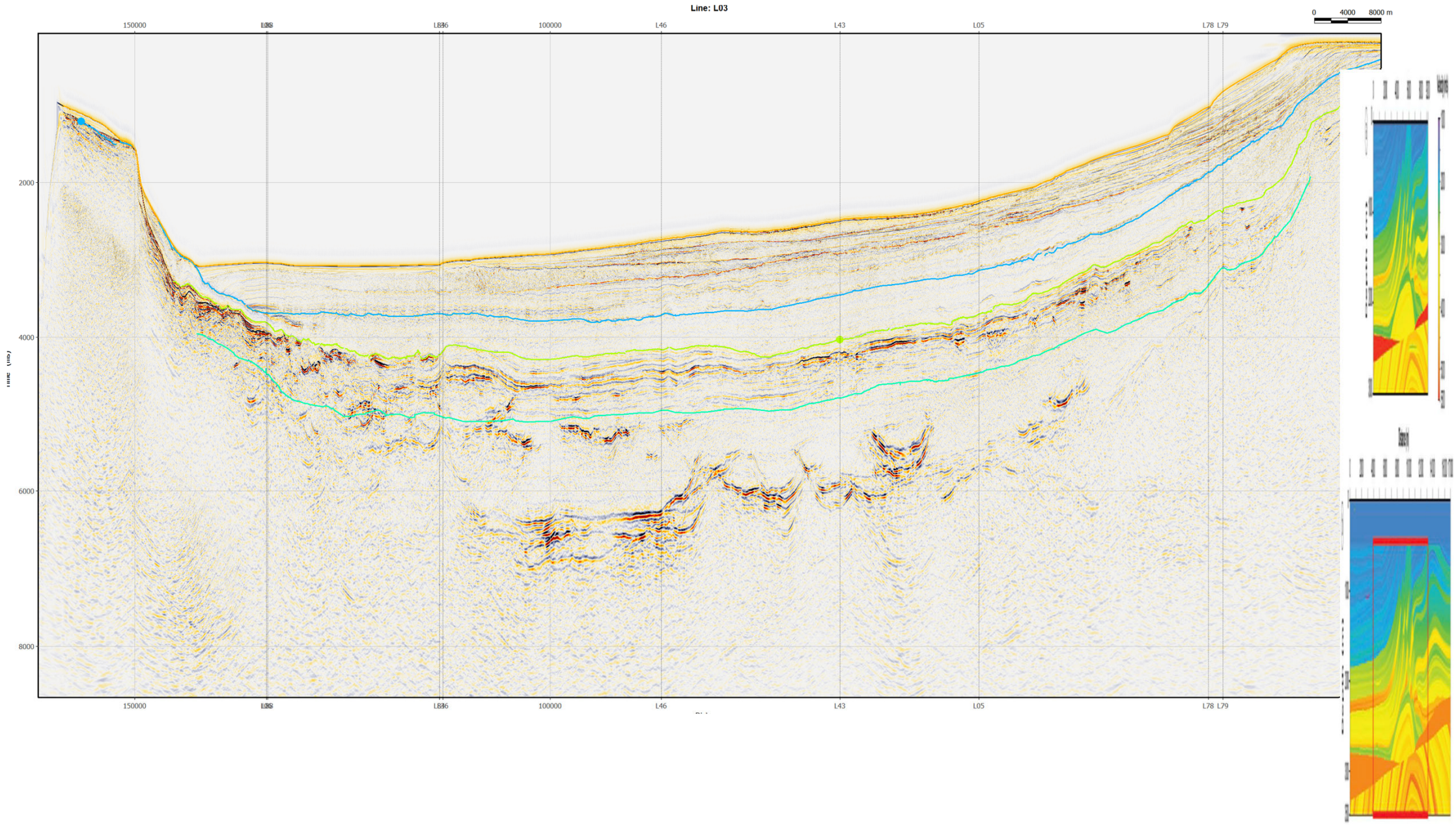
Souza et. al. 2021

Geophysical Models - Marmousi2 – 106 layers



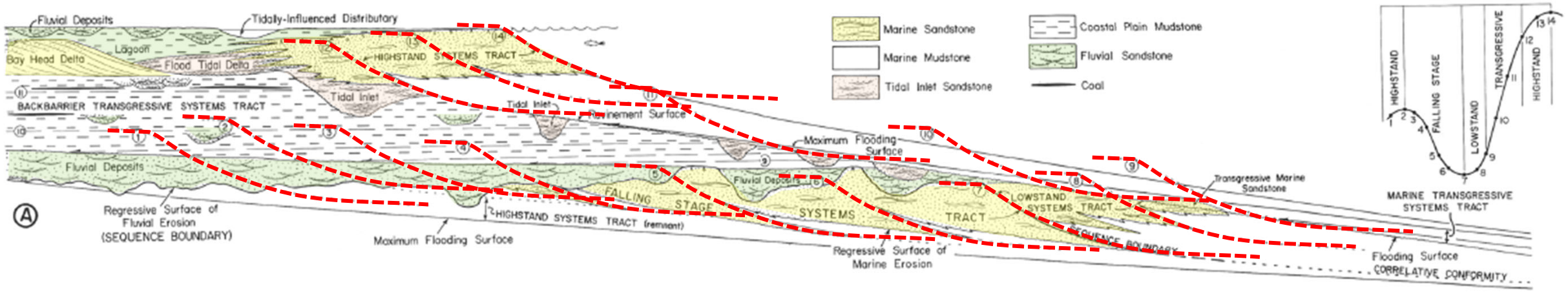
Martin, Wiley and Markurt, 2006

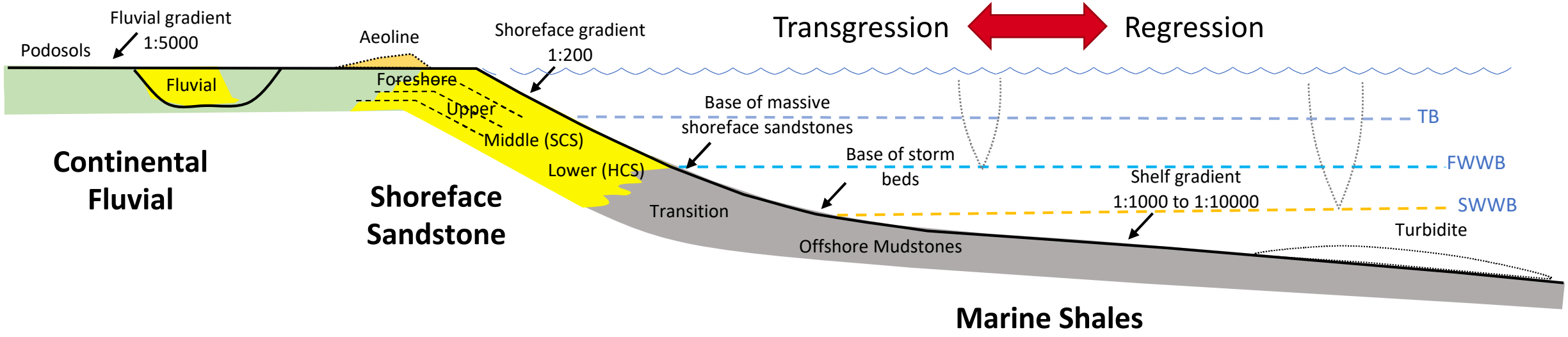
Rockall Trough (180 km)



Plint & Nummedal, 2000 – Exercise in Sequence Stratigraphy

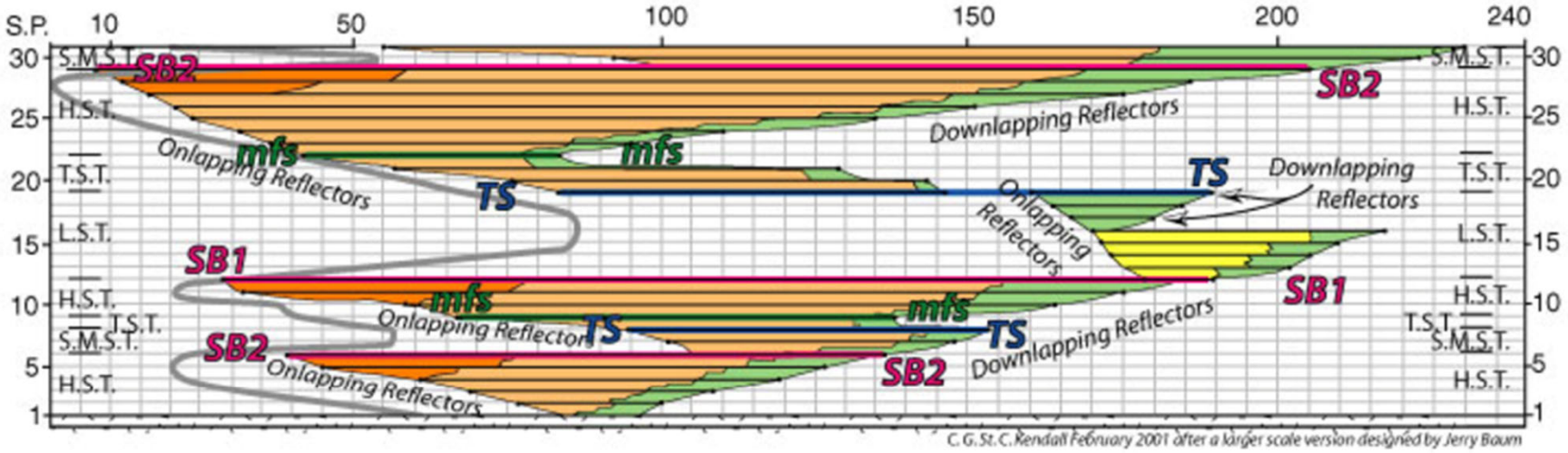
14-stage model to demonstrate geological stratigraphic concepts





Walther's Law (1890) – Wheeler Chronostratigraphy (1958)

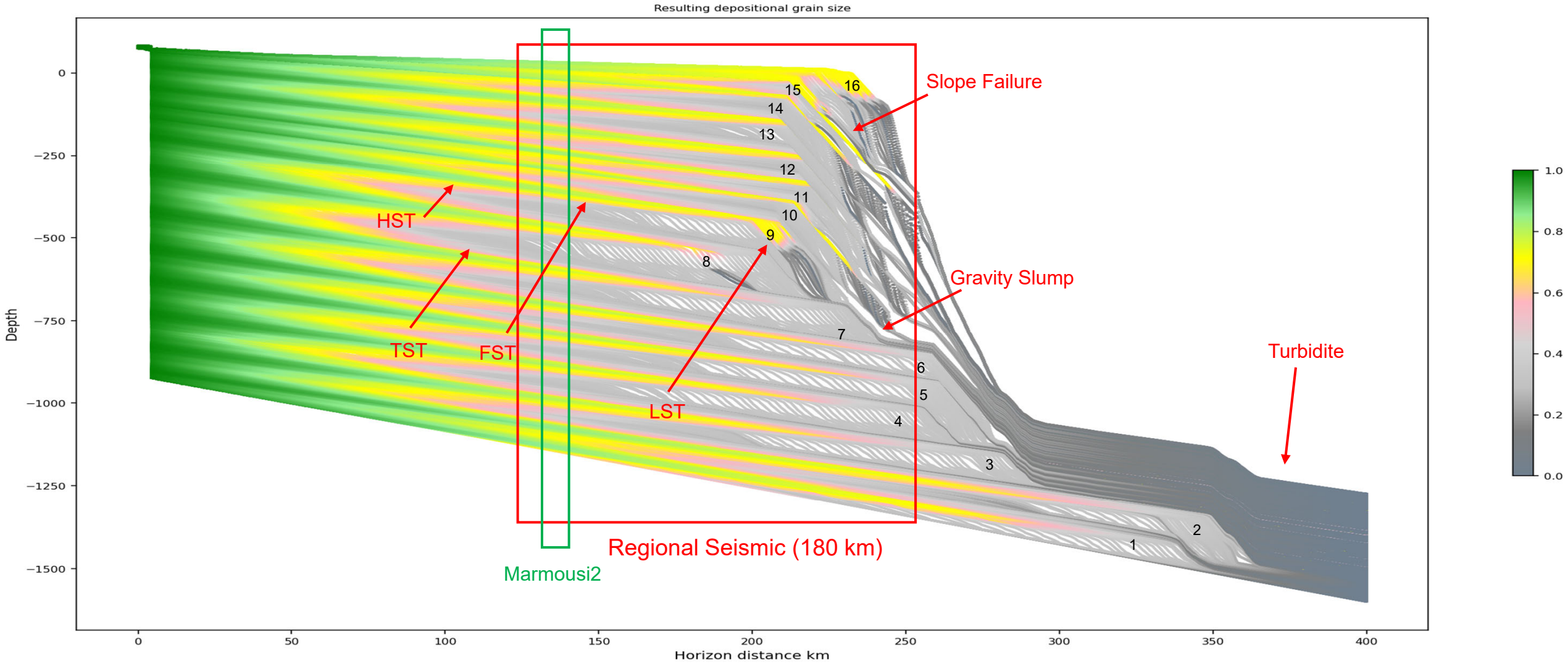
- Walther's Law - vertical succession of facies reflects lateral environmental changes.
- Wheeler display is a method of display of information based on geological time.



REFLECTOR & TERMINATIONS
SEA LEVEL
ALLUVIUM
NEARSHORE
MARINE SHALE
PROXIMAL FAN
BASEMENT
1 NUMBER AT BASE OF LAYER

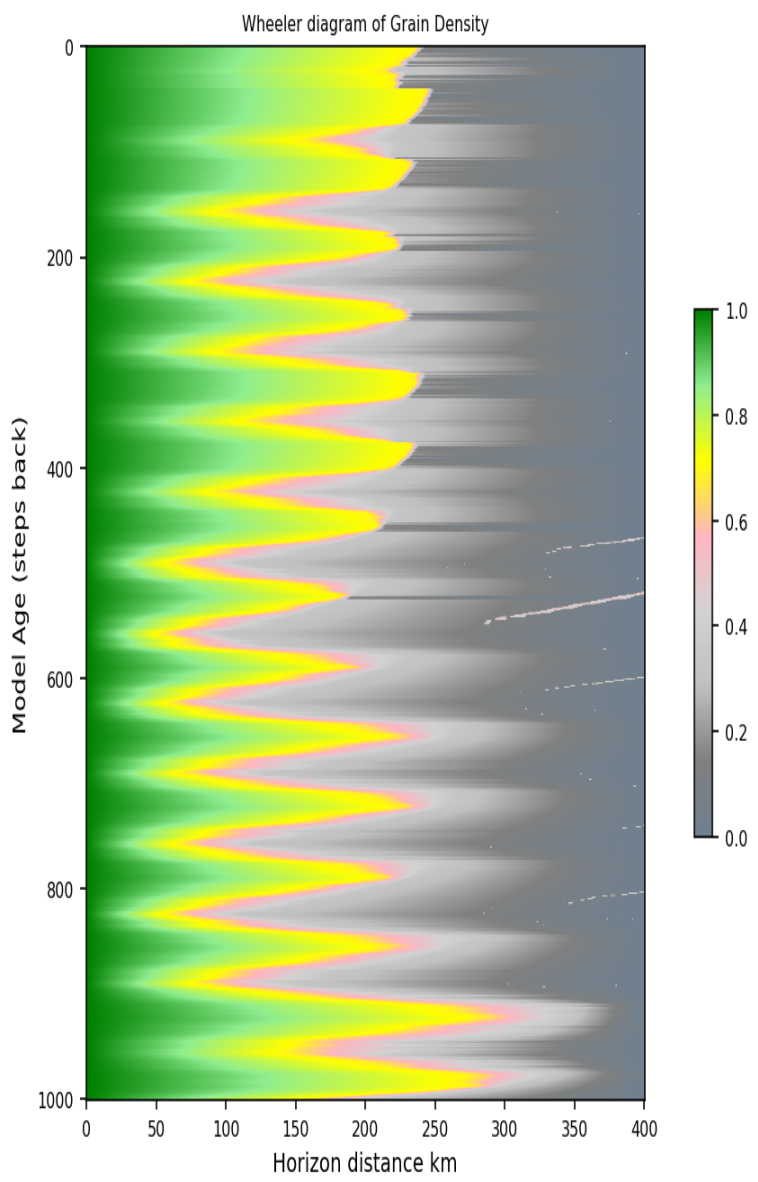
Onlap to the left and downlap to the right.
L.S.T. =*Lowstand system tract;* T.S.T. =*Transgressive system tract;*
H.S.T. =*Highstand system tract; and* S.M.S.T. = *Shelf Margin System Tract.*
Sequence Boundaries:- *Top of layer 5 (type 2);Top of layer 11 (type 1); and Top of layer 28 (type 2).*
Transgressive Surfaces:- *Top of layer 7; and Top of layer 19*
Ravinement Surfaces:- *Top of Layer 7; and Top of Layer 19*
Maximum Flooding Surfaces:- *Top of Layer 8; and Top of Layer 21*
Condensed Sequences:- *Layer 8; and Layers 19-21*

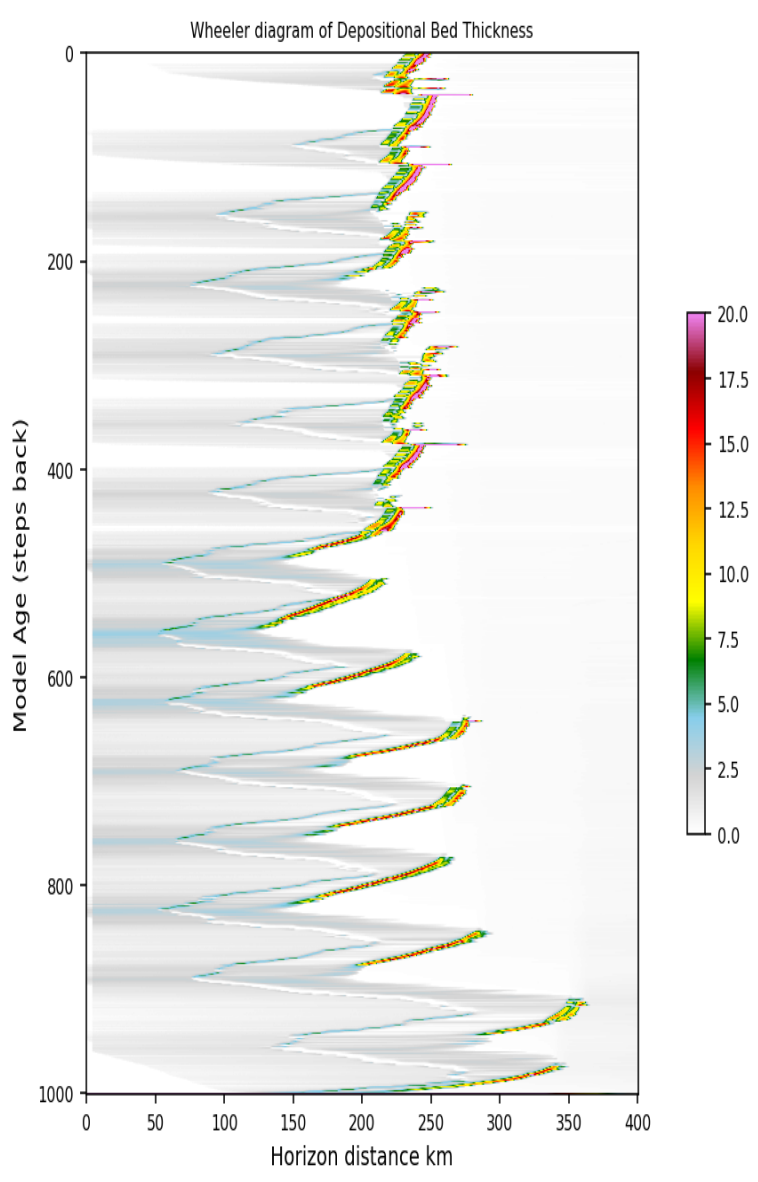
Resulting Geological Model (1000 layers)

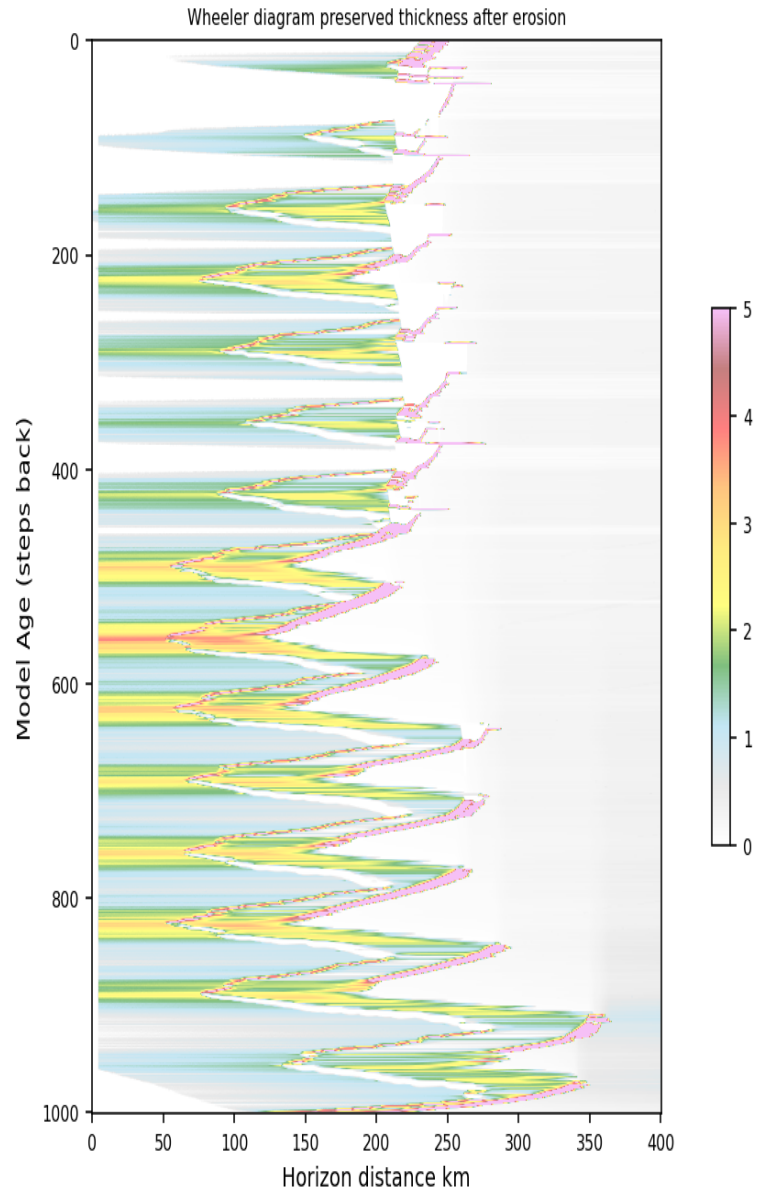


- a constant sediment supply and lithostatic subsidence rate (1.5 km or 1.5 m/surface),
- single 500 m tectonic fault with maximum displacement 1/3 the way into the model and
- 3-second (± 40 m), 15-fourth (± 20 m), 75-fifth (± 2 m), order eustatic events.

Wheeler Display of model attributes

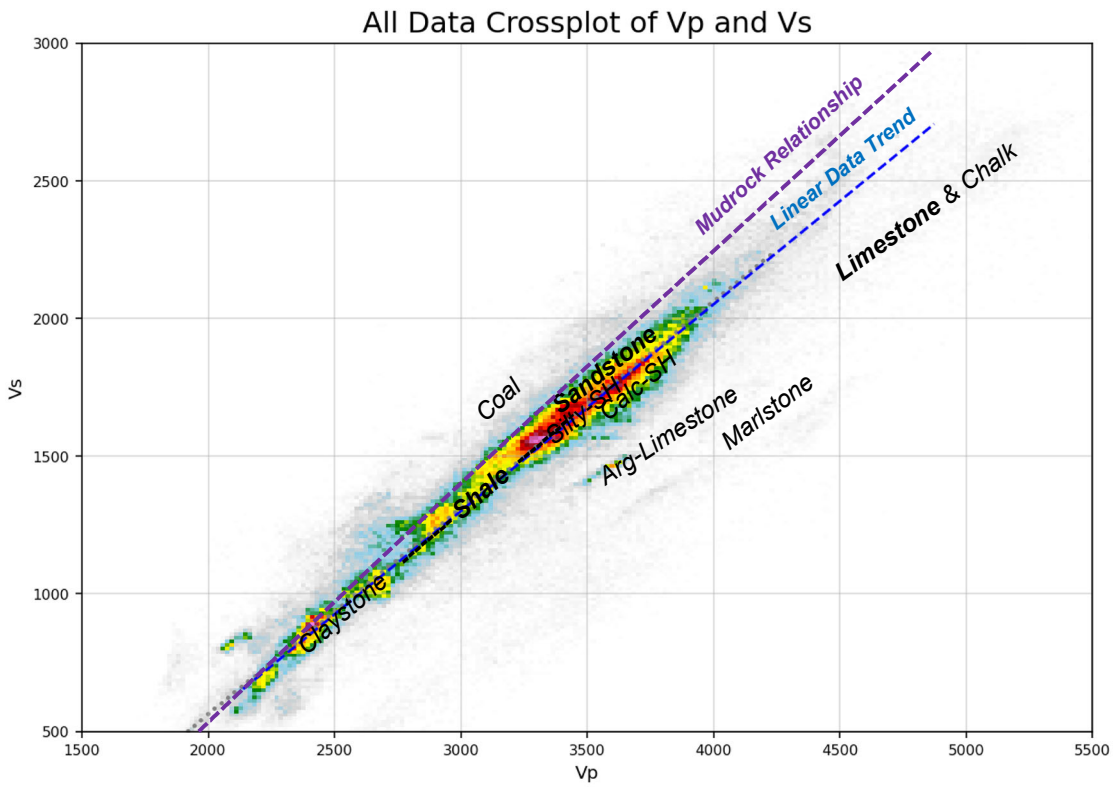


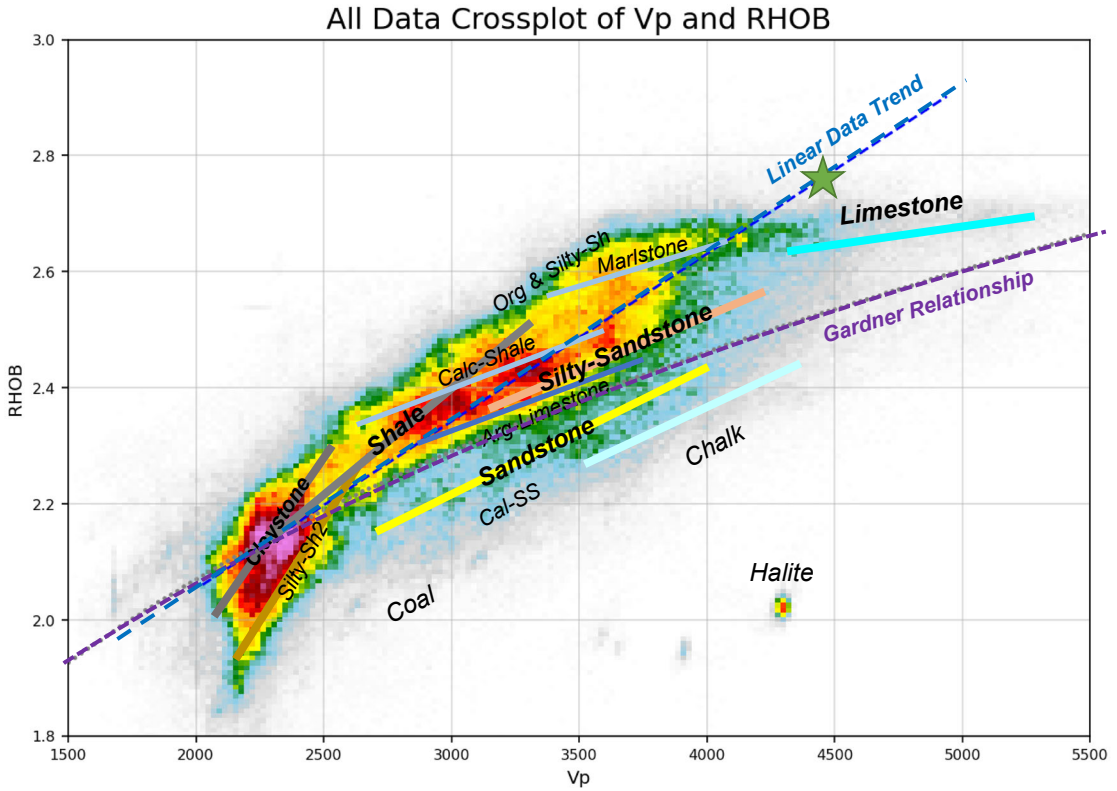




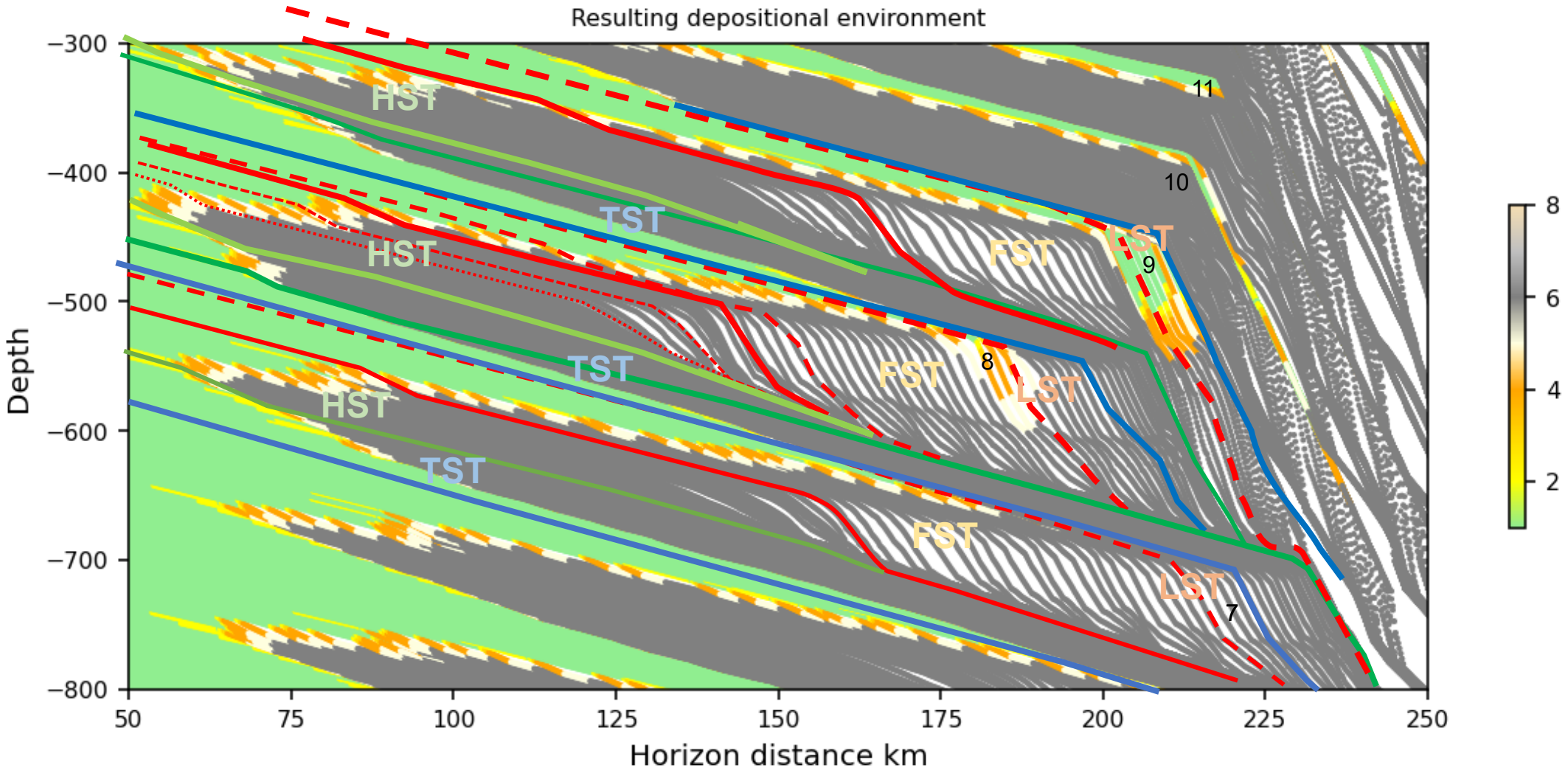
Petrophysical Attribute Cross Plots

Machine Learning Mineralogy Classification Comparison to Empirical Log Relationship and Implication for Physics Informed Modeling, 2022, Emery, D. J., Guarido, M., and Trad, D. O., CREWES Report



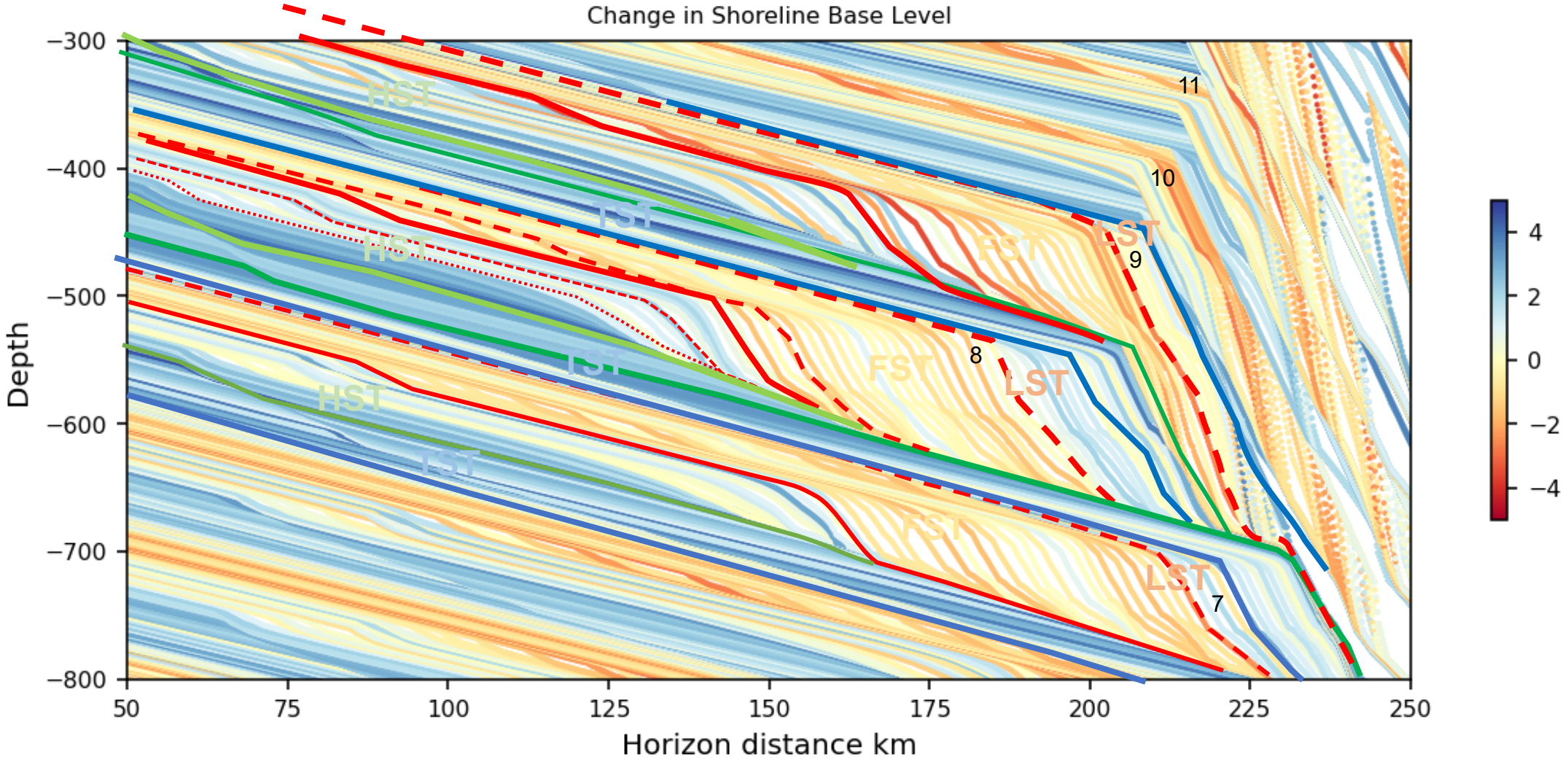


Depositional Environment



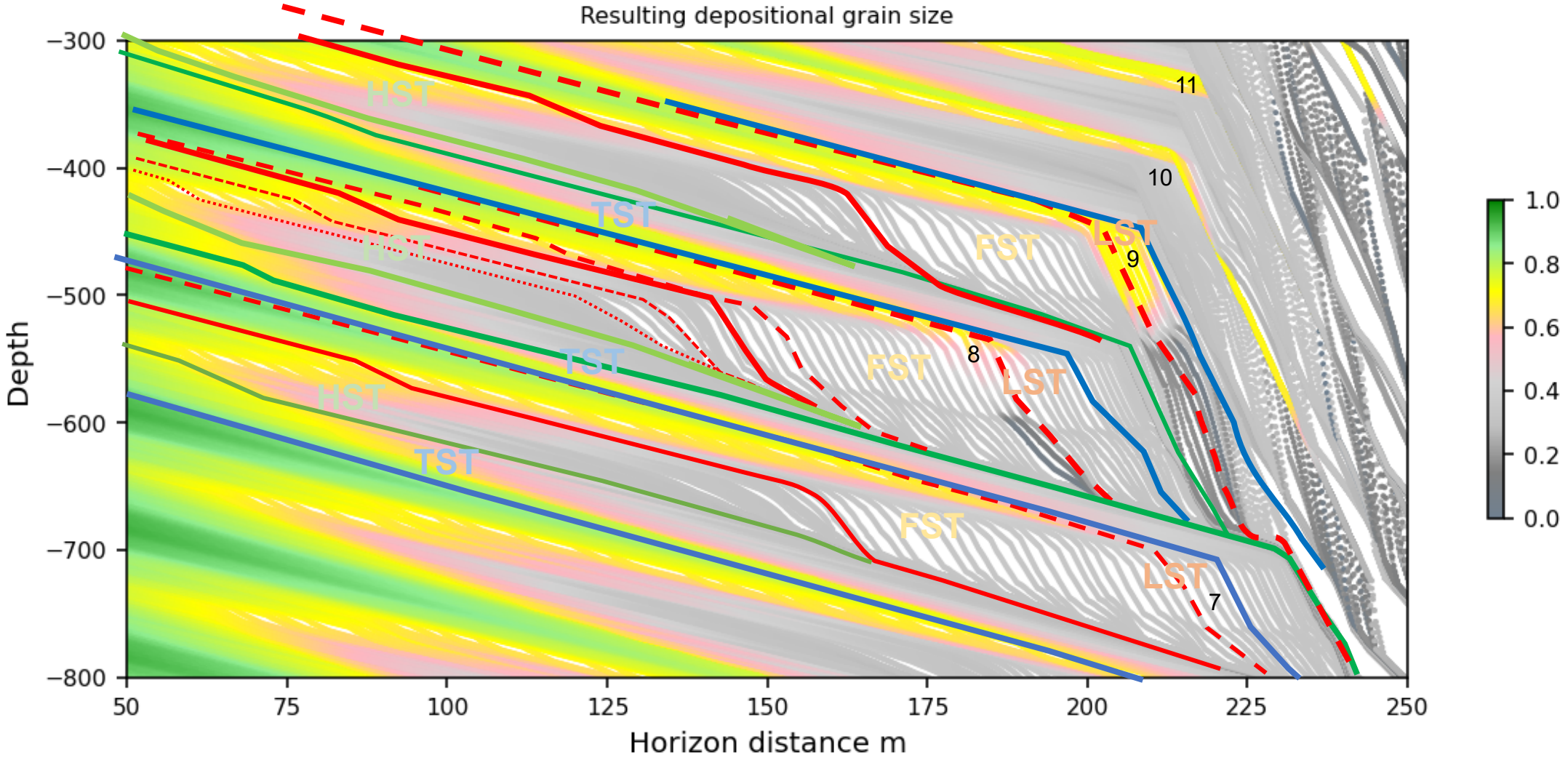
Coastal Plain (green), Near Shoreface (yellow), Mid Shoreface (amber), lower Shoreface (orange), Offshore (grey), Turbidite (tan)

Net Base Level Change



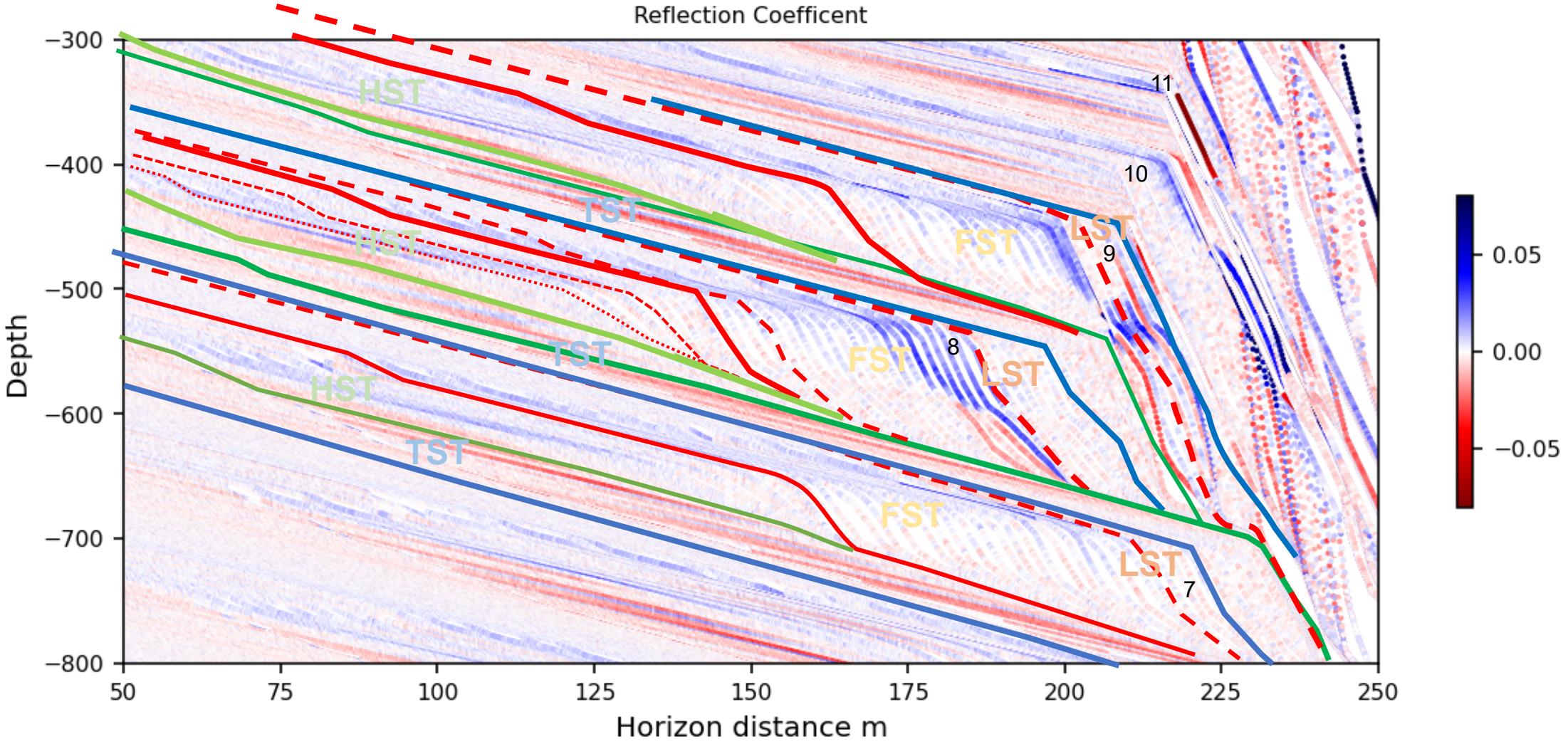
Base Level Change is the sum of the Eustacy, Faulting, and Lithostatic tilt

Significant surface in sequence stratigraphy



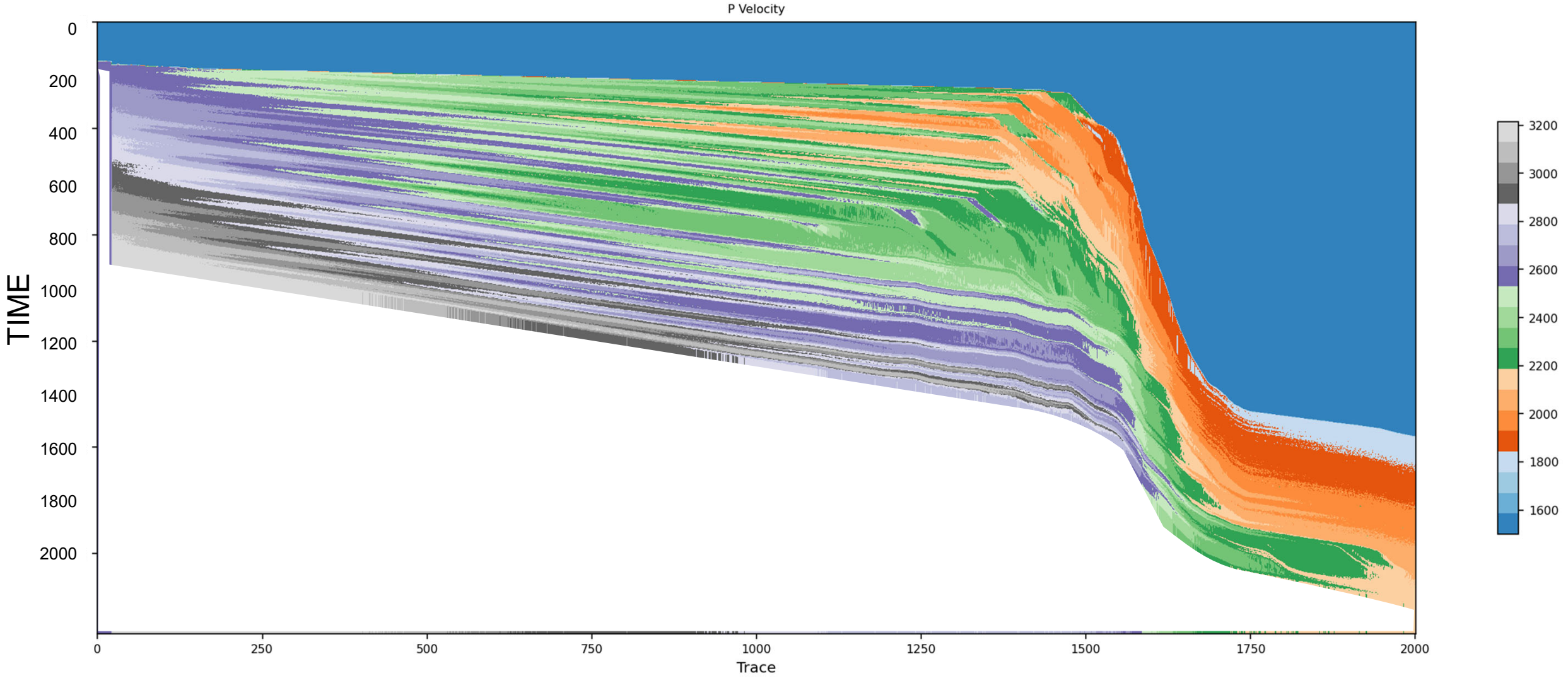
Coloured by the % of input sediment deposited (0.75 represents the likely shoreline)

PP Reflection Coefficients in Depth



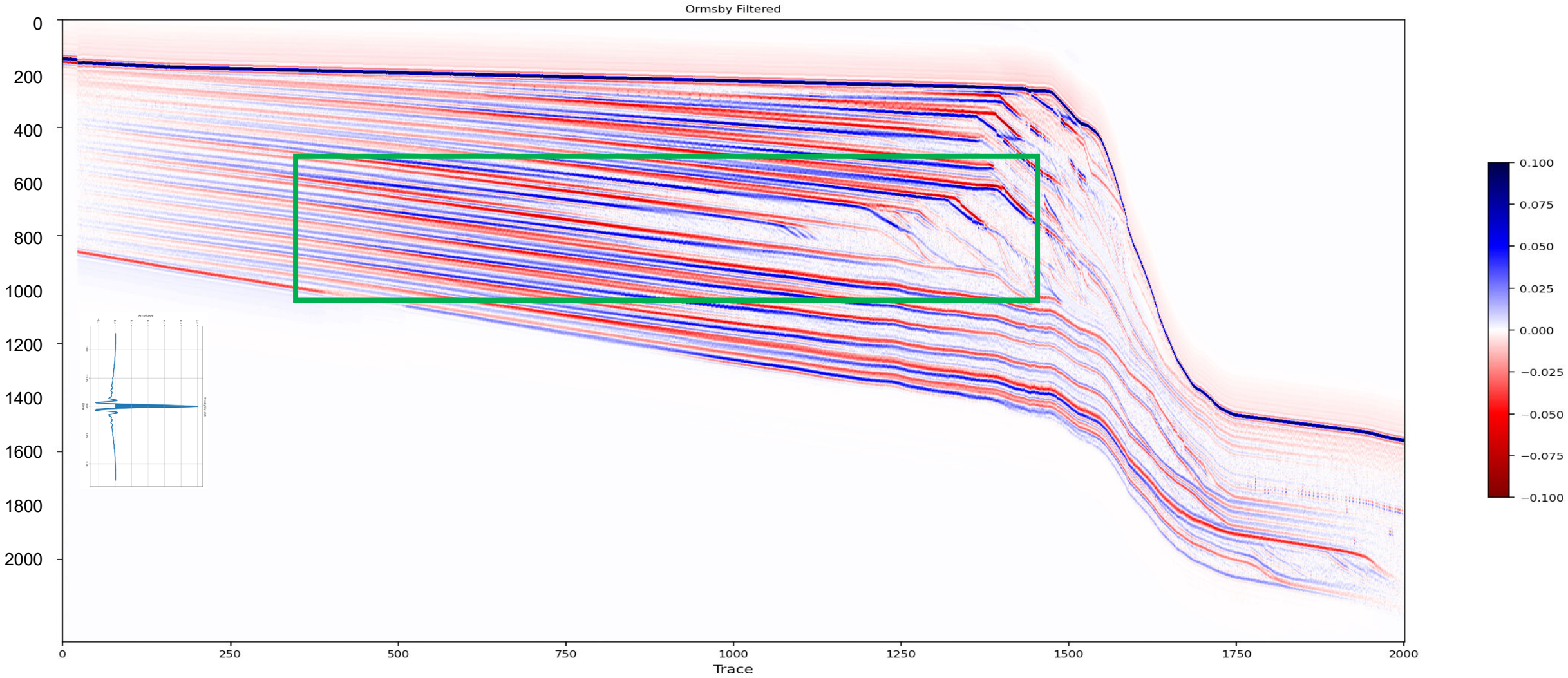
Reflection Coefficient between each Wheeler surfaces

P wave velocity



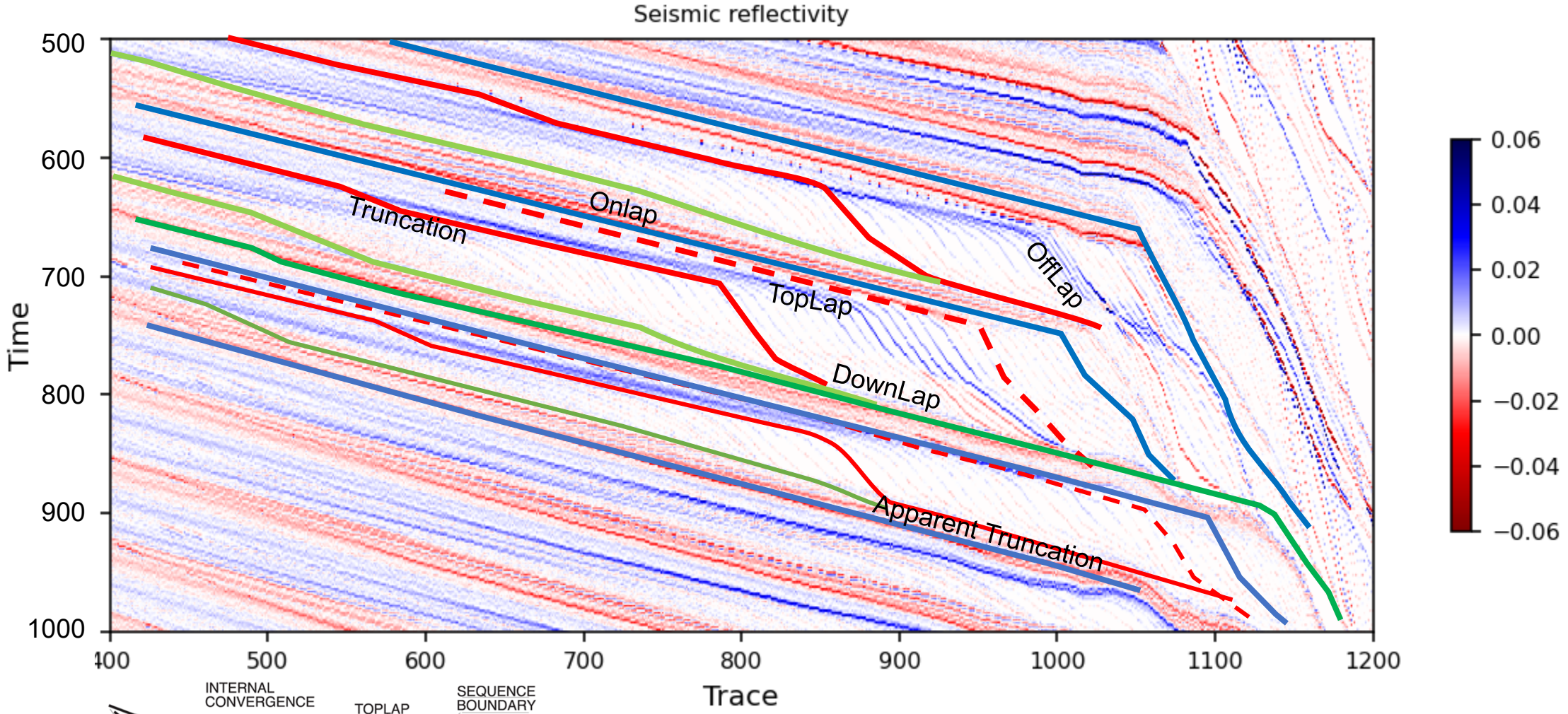
The program creates detailed logs that can be used for both geological correlation and creating seismic profiles

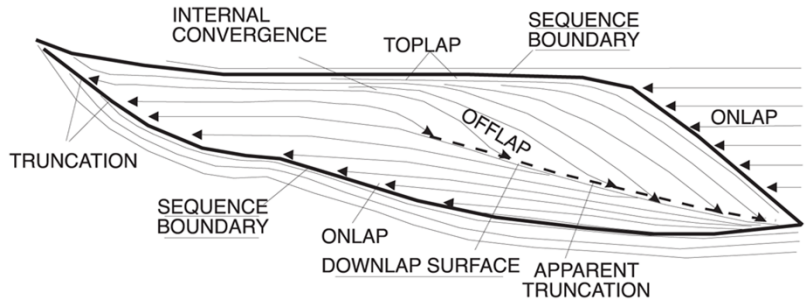
Seismic Profile using 3/8/90/140 Ormsby wavelet



Multiple models with multiple wavelets along with vertical time distortion

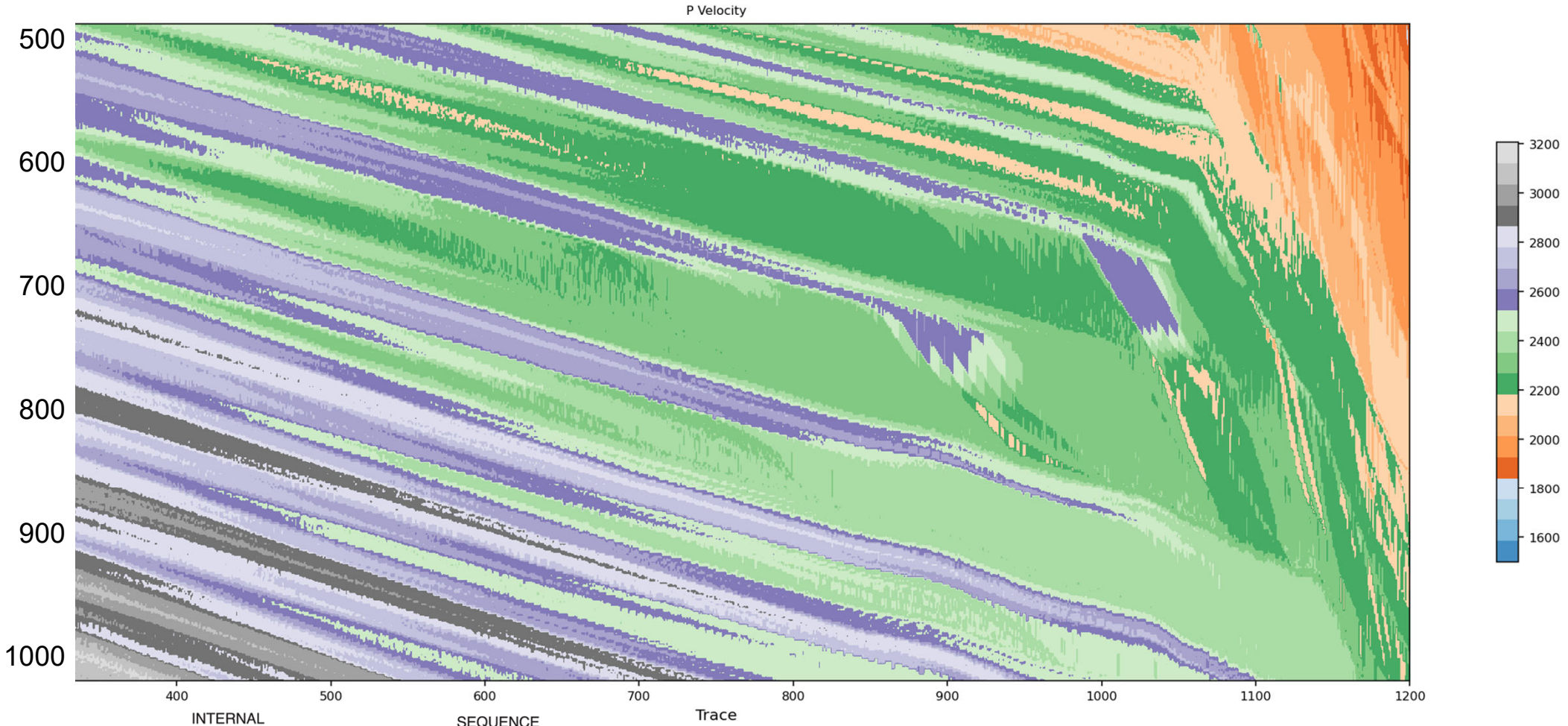
Reflection Coefficients in Time

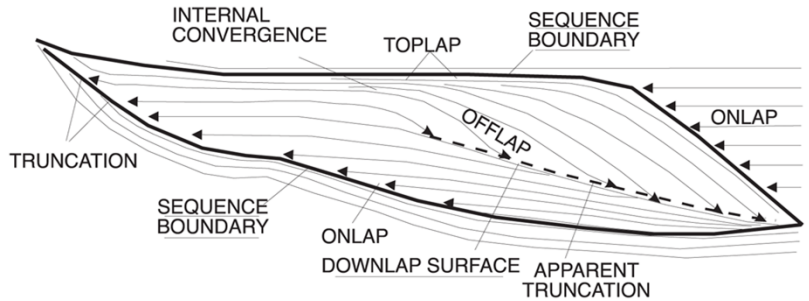




Seismic reflection surface of Sequence stratigraphy.
Conceptional geological geometries.

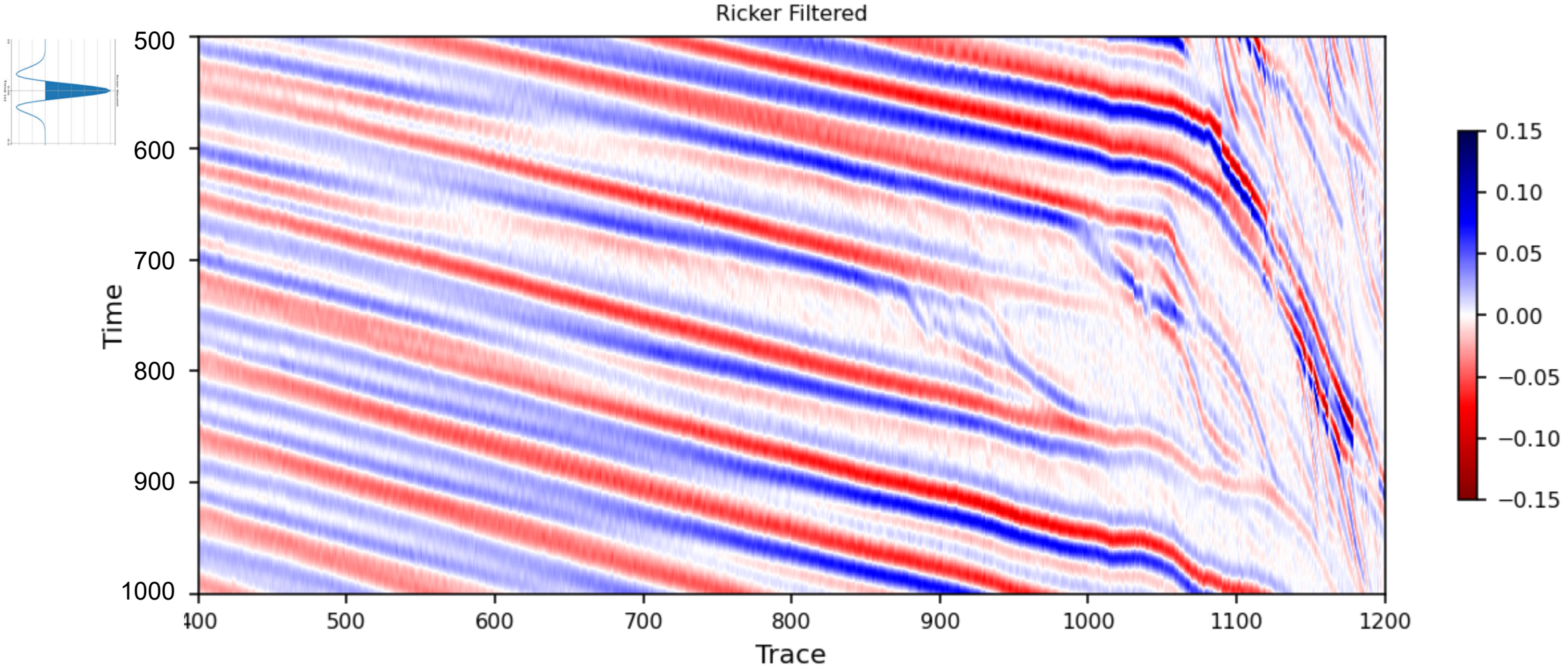
P wave velocity





P velocity, Shear velocity & Density

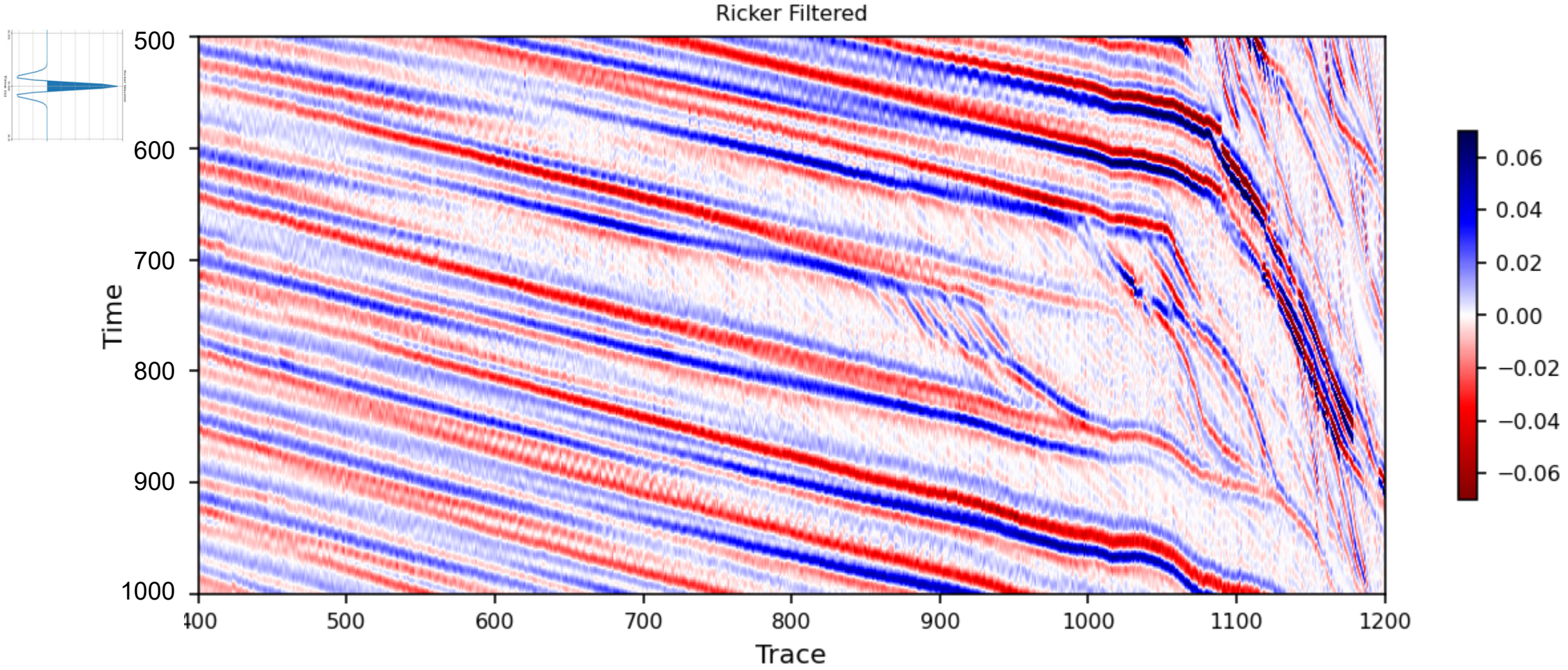
Ricker 25 Hz



Significantly reduced resolution following application of a wavelet

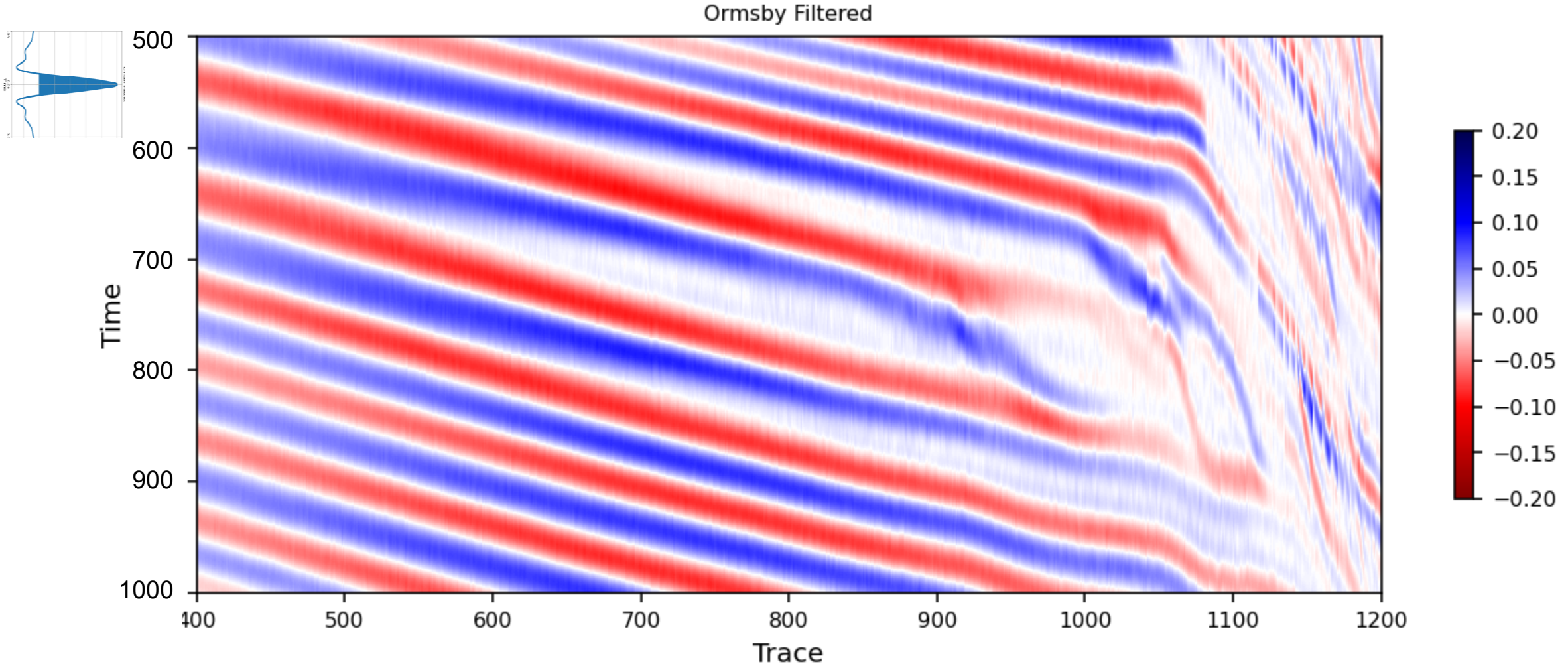
Merging of surfaces into a single seismic event

Ricker 45 Hz



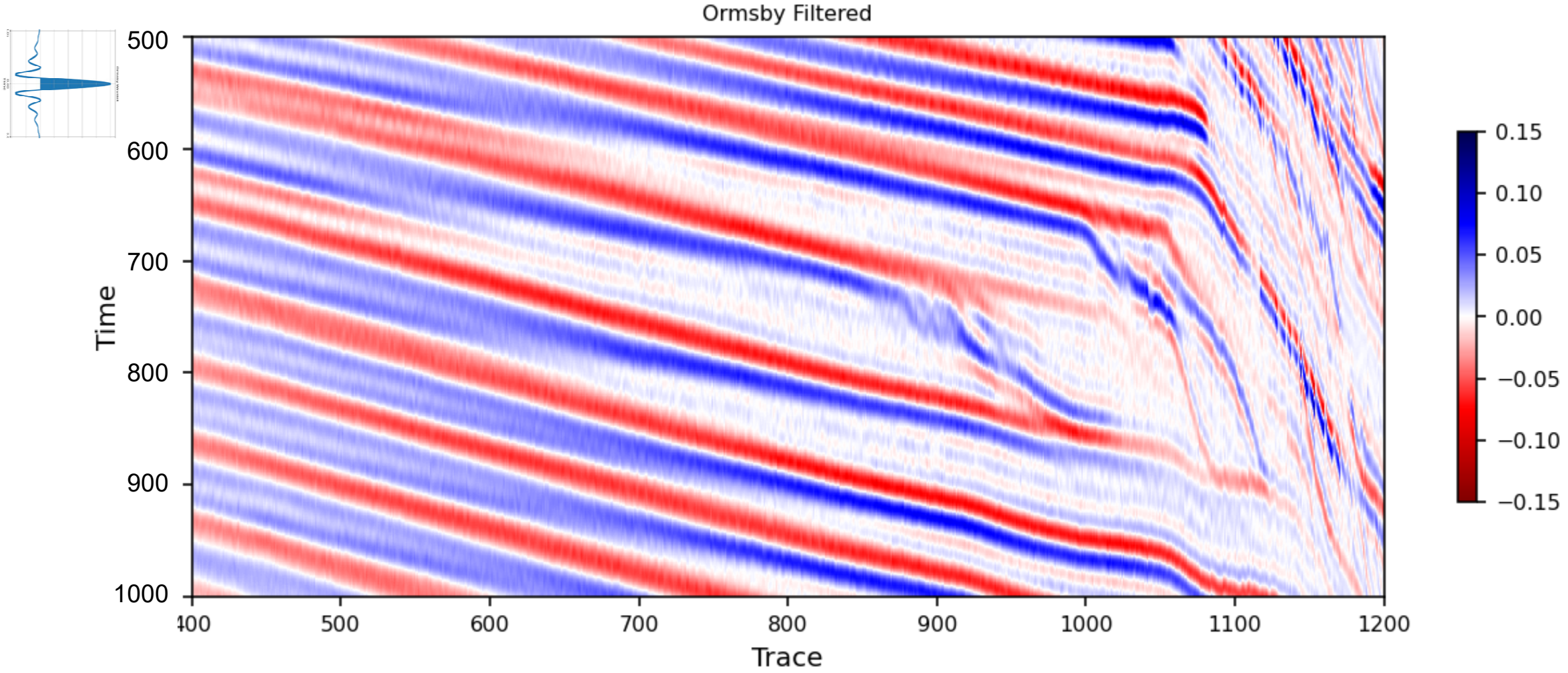
Improved resolution with the increase in frequency

Ormsby 4-10-18-60 (Deghosted Marine)



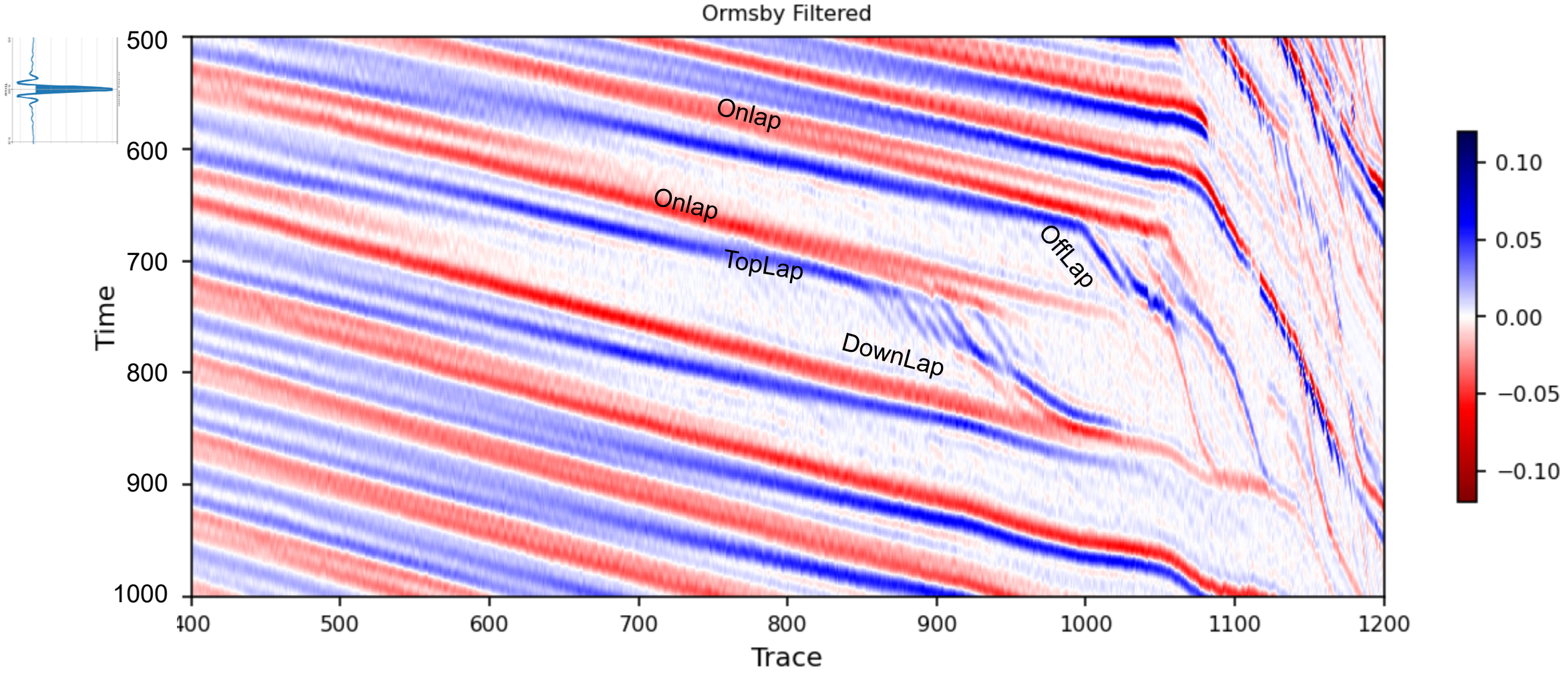
Decrease resolution with the domination of low frequency

Ormsby 6-12-60-90 (Conventional WCAN)



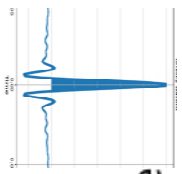
Broader frequency band give the appearance of lower resolution

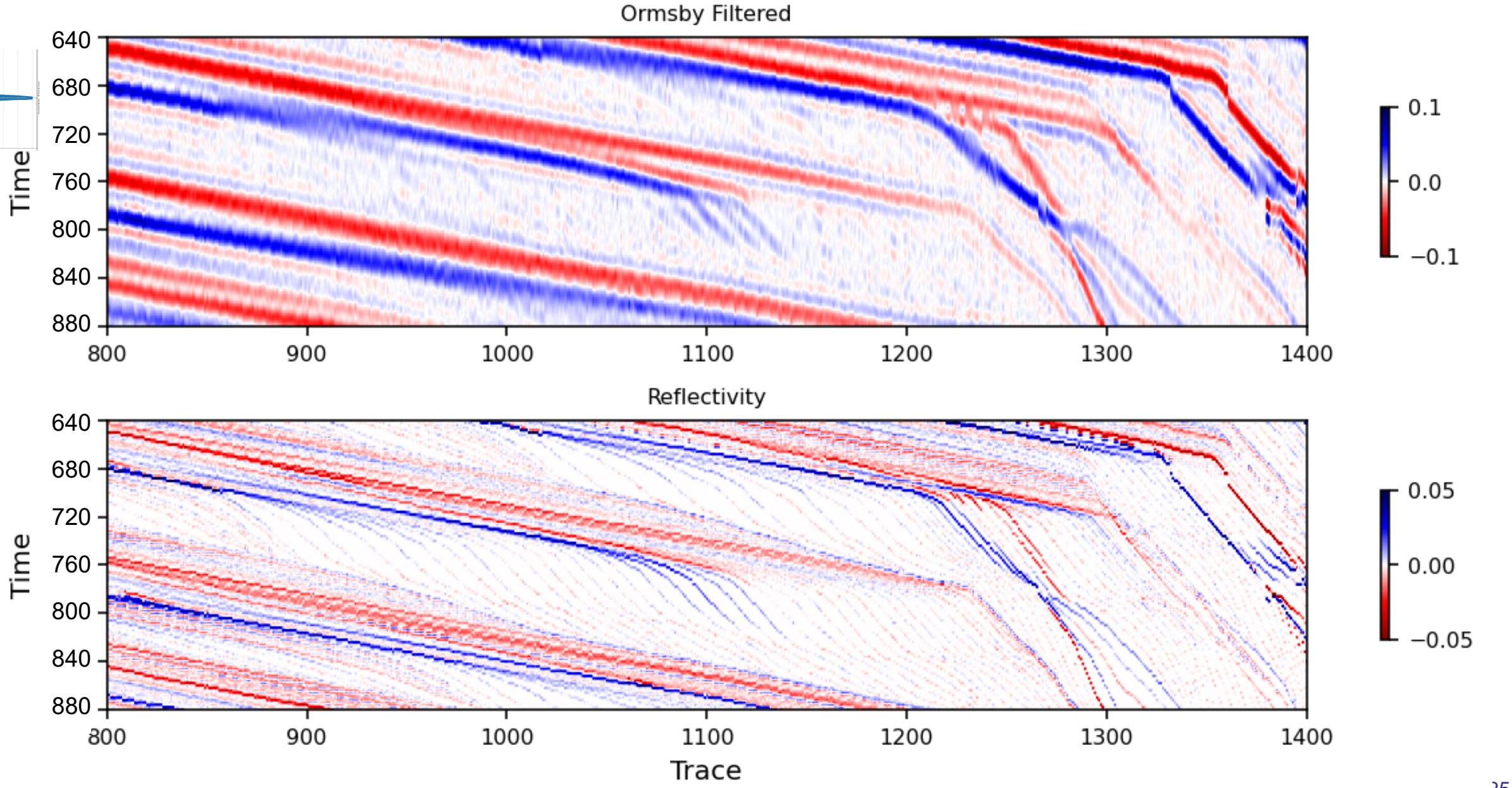
Ormsby 3-8-90-140 (Broadband WCAN)



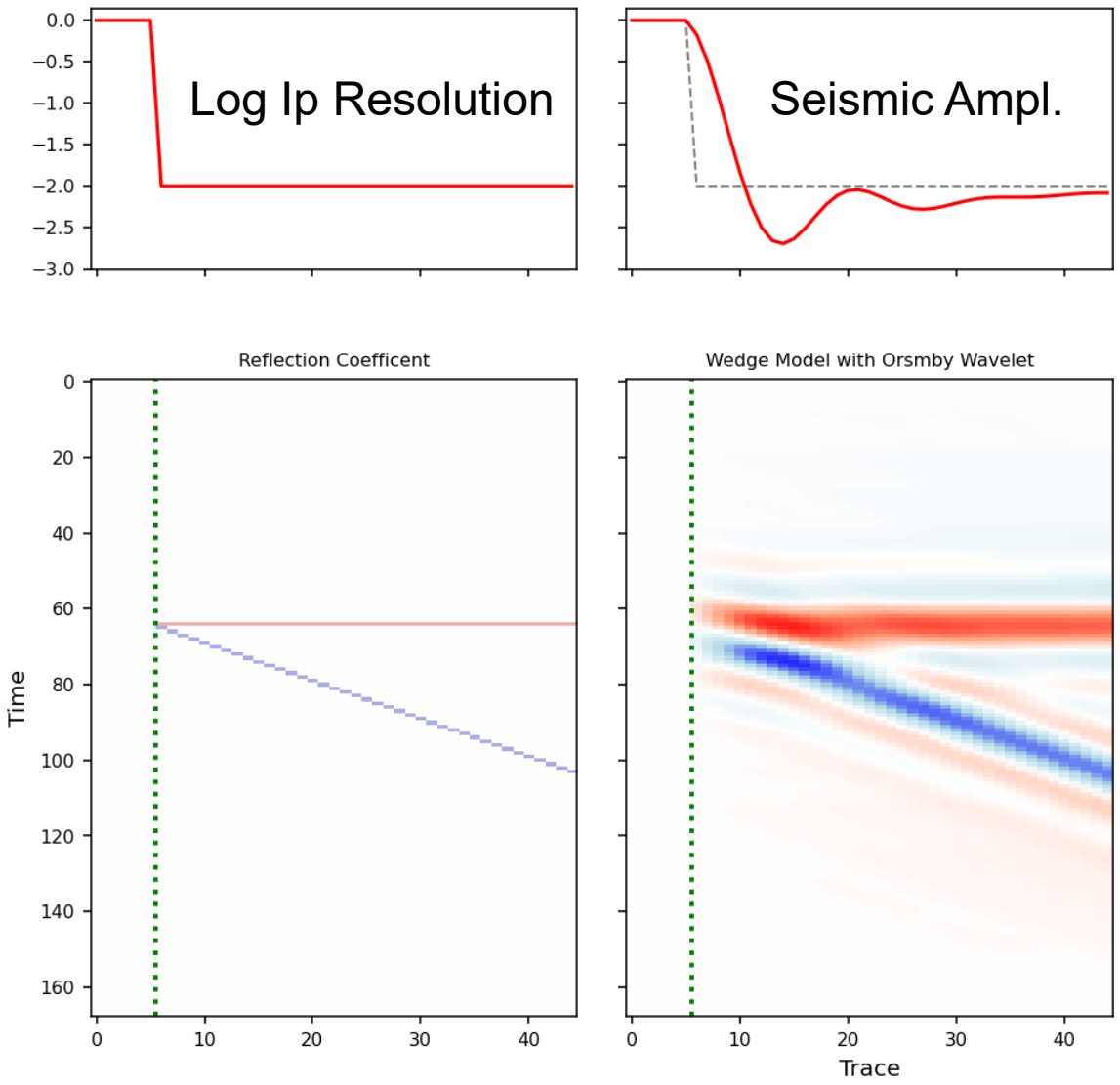
Broadband seismic reduces side lobe effect and improves detection of the onlap, toplap, offlap and downlap events

Comparison of a high resolution seismic and the desire reflection series



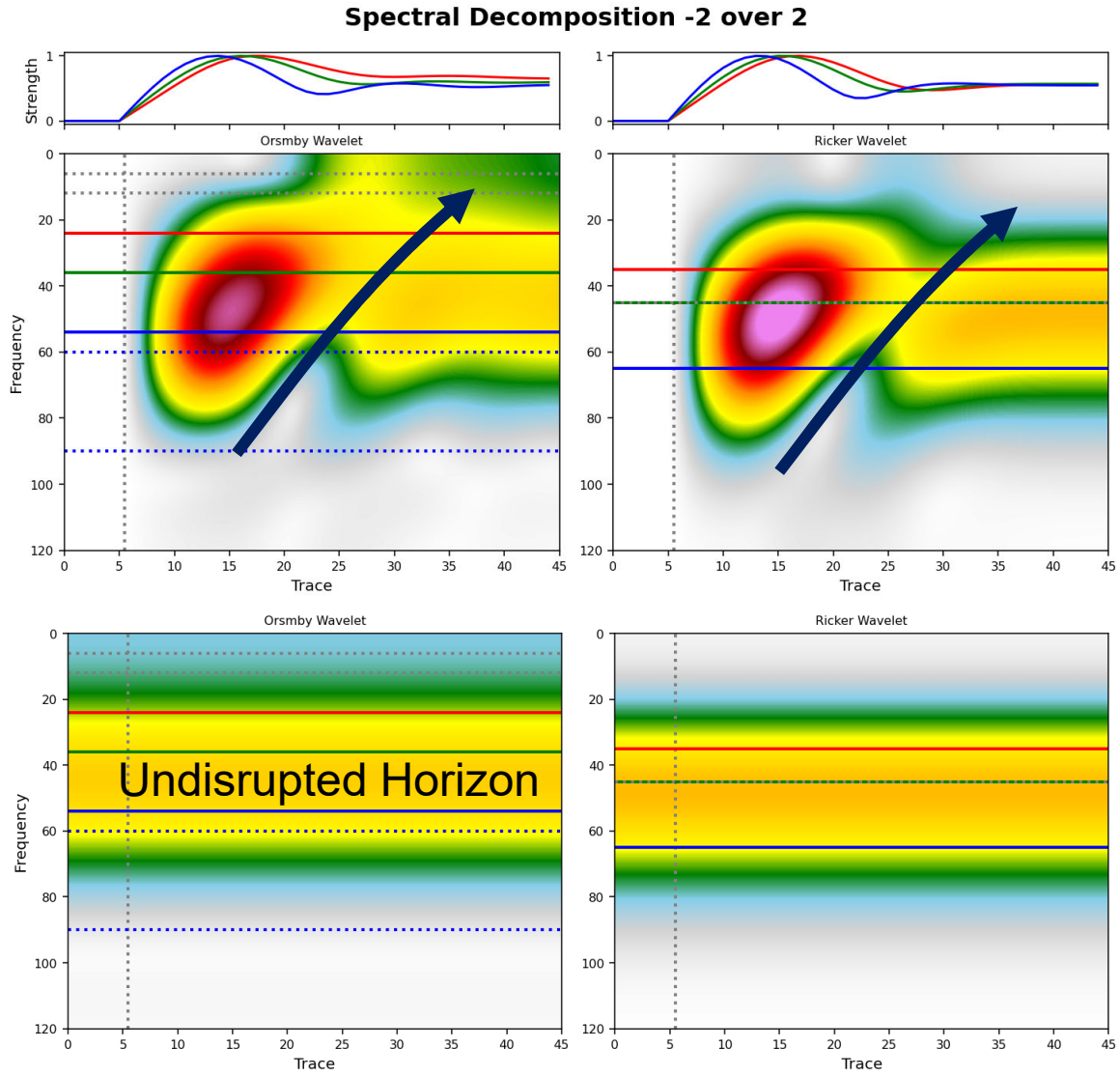


Future Work - Spectrum Decomposition

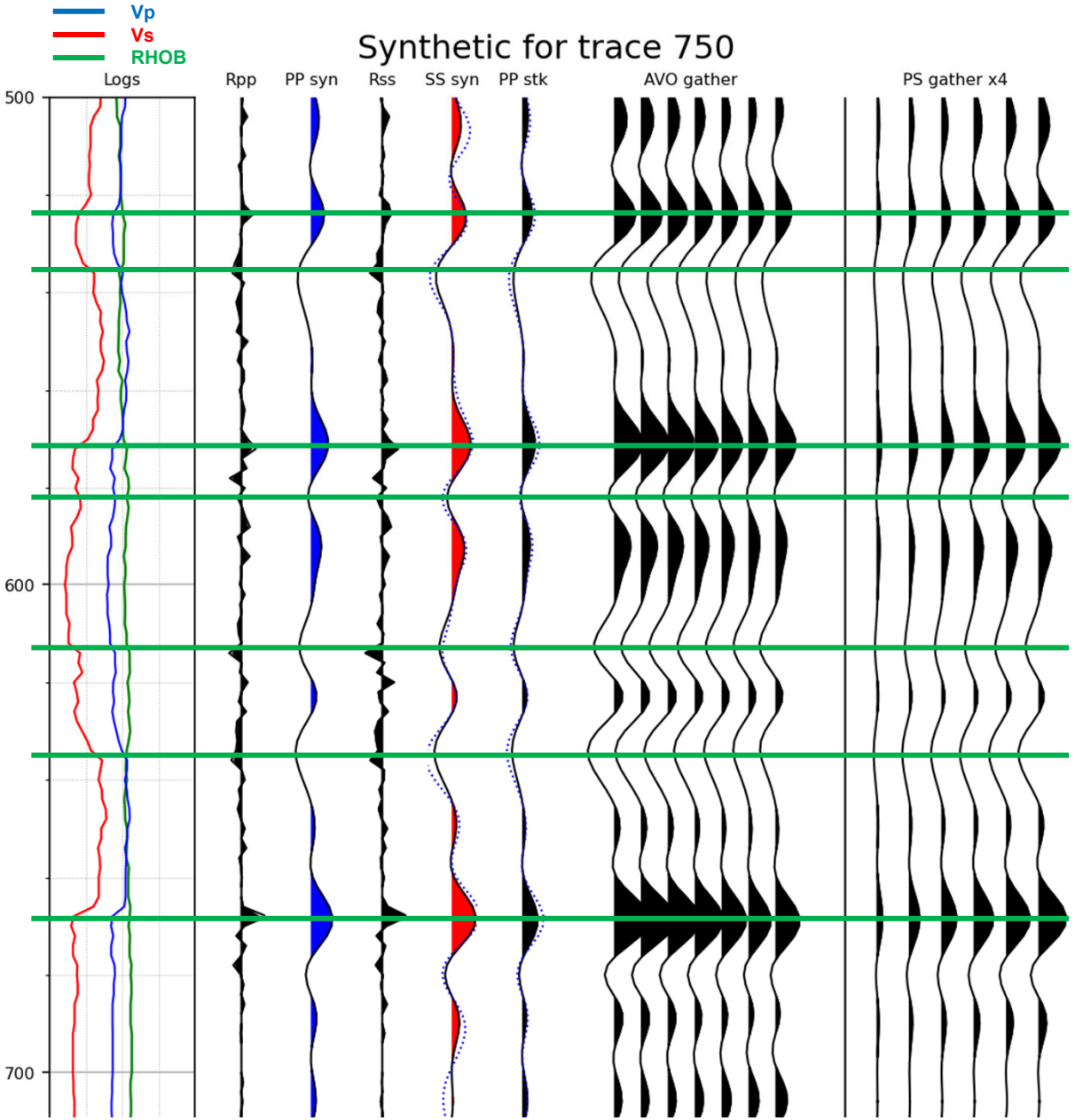


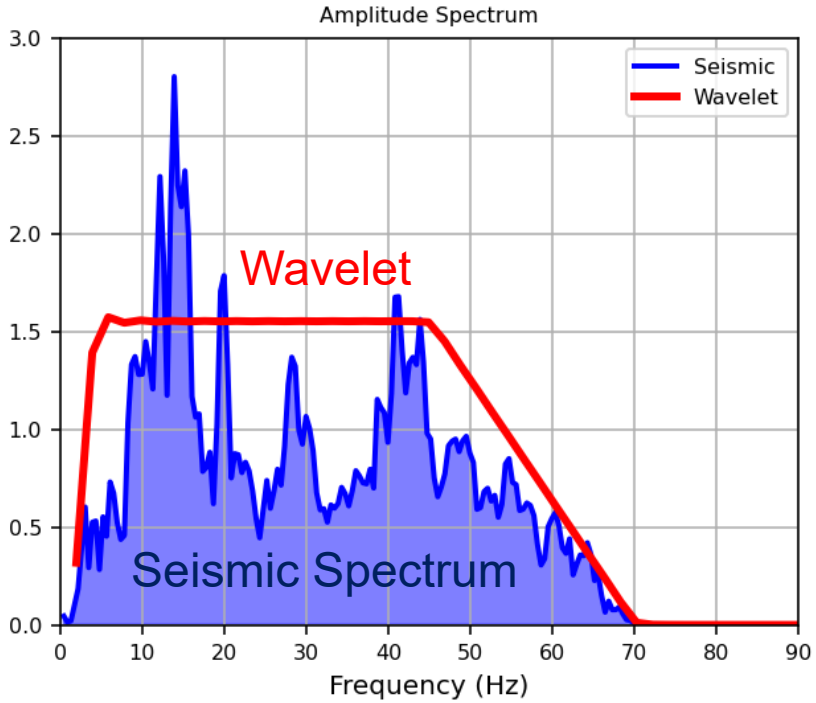
Ormsby

Ricker



Future Work - Synthetic gathers





- Refine the 2D modelling to include additional lithologies
- Extend into 3D
- Model the spectral and AVO effects of the stratigraphic truncation
- Add fluid effects

Acknowledgements

Thank the sponsors of CREWES for their continued support.

NSERC (Natural Science and Engineering Research Council of Canada) through the grant CRDPJ 543578-19


Thank You!

Basic Outline of python script for stratigraphic model

Determine the amount of sediment being added to the model.

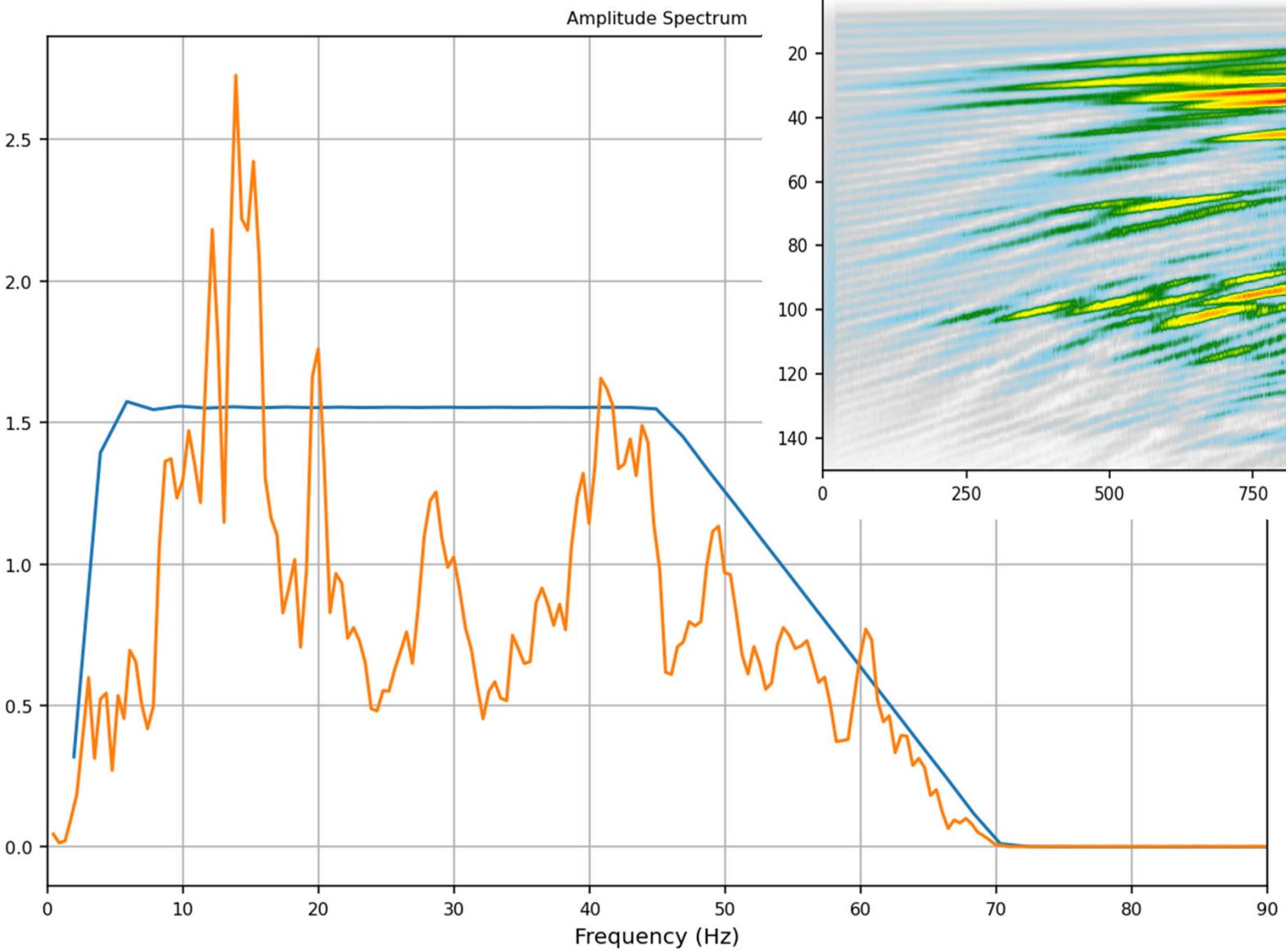
- Apply lithospheric, eustacy, and faulting to topography.
- Determine the base level
  - Fluvial erosion (adding any additional sediment to the model)
  - Deposit coastal plain
- Determine the new base level and apply marine erosion
  - Determine if the coast has become over steepened
  - Deposit onto the near shore dunes (1/3 eroded sediment), and
  - offshore as turbidite deposits (2/3)
- Deposit shoreface sediments
- Offshore deposits up to the baseline until sediment becomes fine-grained
- Offshore deposit fine grain sediment
- Deposit turbidite
- Determine if the deposition slope exceeds a triggering grade
  - Erode the slope down to a failure surface
  - Deposit gravity slump
- Compact the sediment

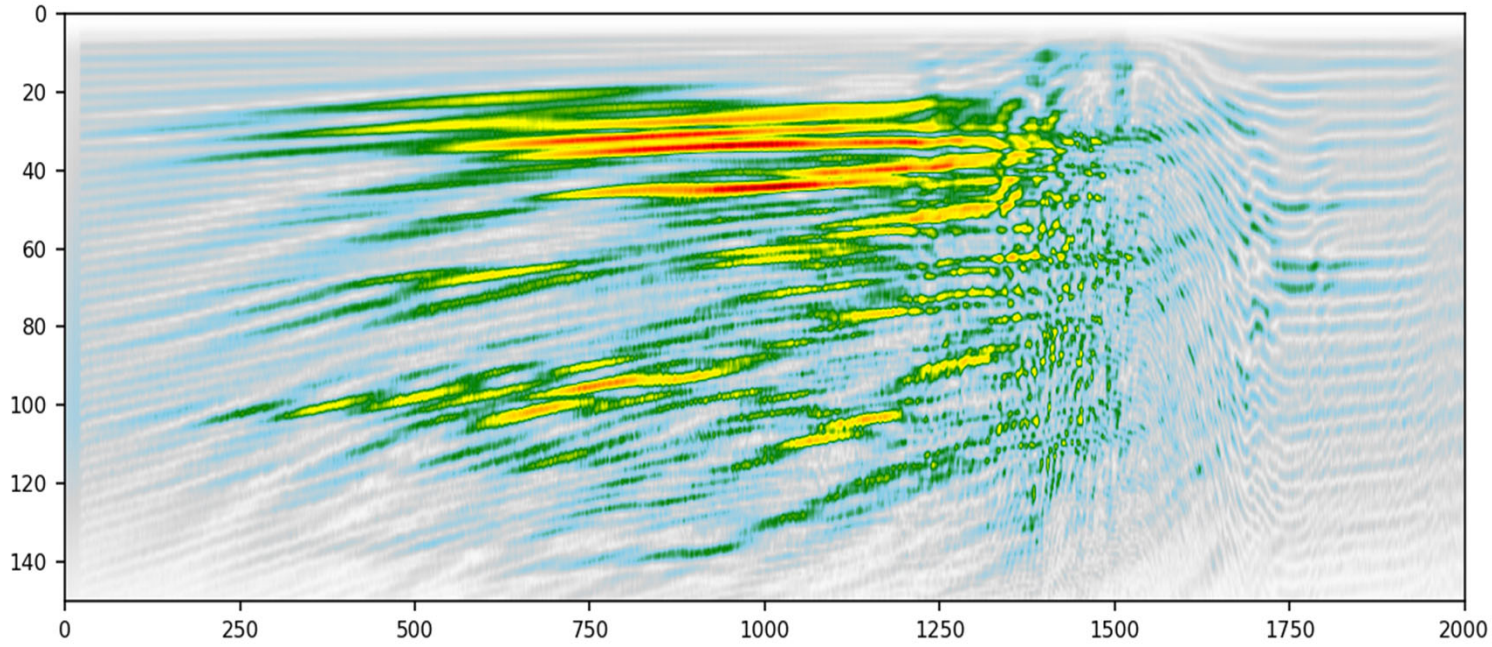
Move to the next step

```
[3]  CG_cutoff = 0.70   #Coarse Grain Cuttoff
     OSfraction = 0.33   #W hen offshore sedimentation stc
     FluvialScaler = 0.75 # 0-1 with 1 applying 100% fluvi
     ErosionScaler = 0.75  #0-1 with 1 applying 100% full
     Tpercent = 0.66    # Percentage split between offshor
```

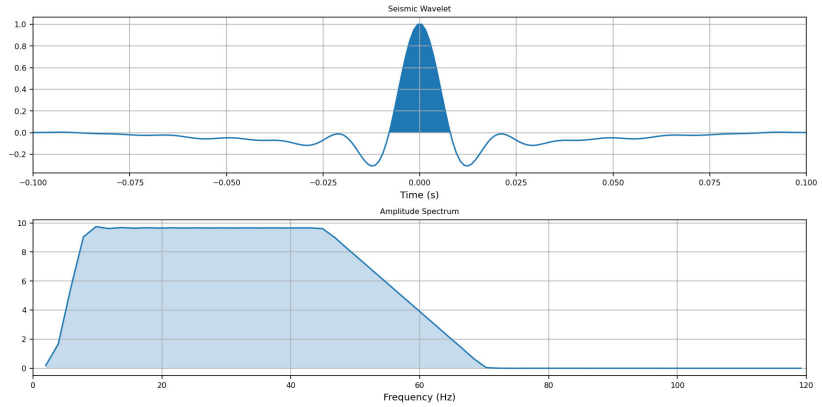
```
[4]  # Bulk setting the model parameters
     Steps = 501
     Csize = 200
     nCells = 3001
     WaterDepth = 100
     InitialHgt = 50
     Subsidence = 200
     Fault = 250
     Fault3 = False
     FaultDuration = 0.90   #Enter a percentage
     SedPercent = 200
     Eustacy2 = 2     #2
     Sealevel2 = 30
     Eustacy2shift = -0.66
     Eustacy3 = Eustacy2 * 12     #12
     Sealevel3 = Sealevel2 * 0.2   #0.2
     Eustacy4 = Eustacy3 * 4       #4
     Sealevel4 = Sealevel3 * 0.1   #0.1
     TB = 1.25
     FWB = 3
     SWB = 5
```

Amplitude Spectrum

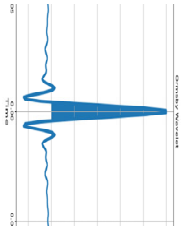


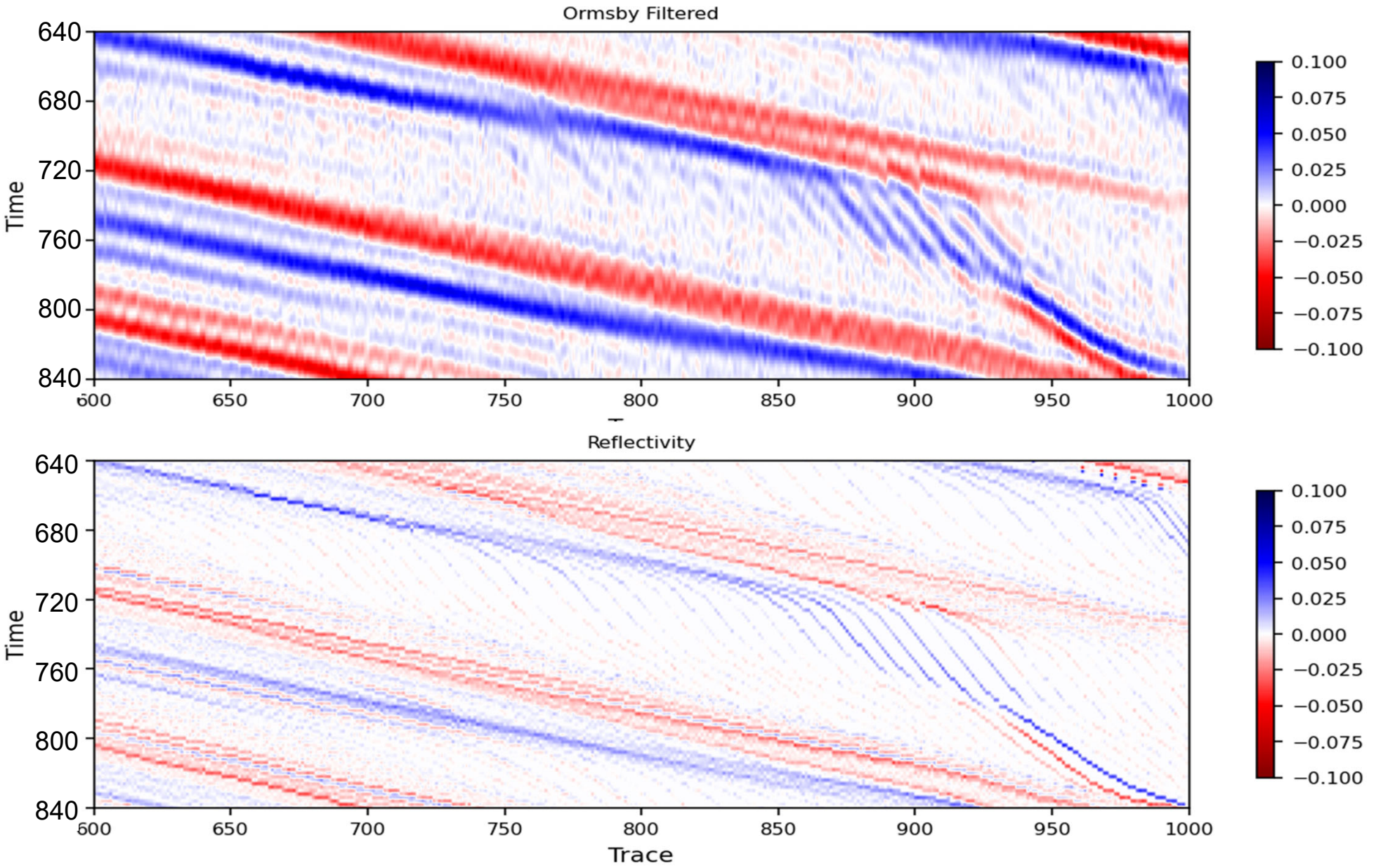


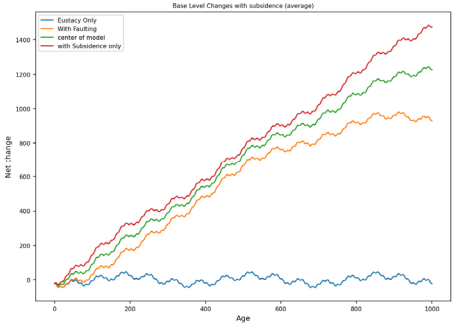
Ormsby 3/8/45/70

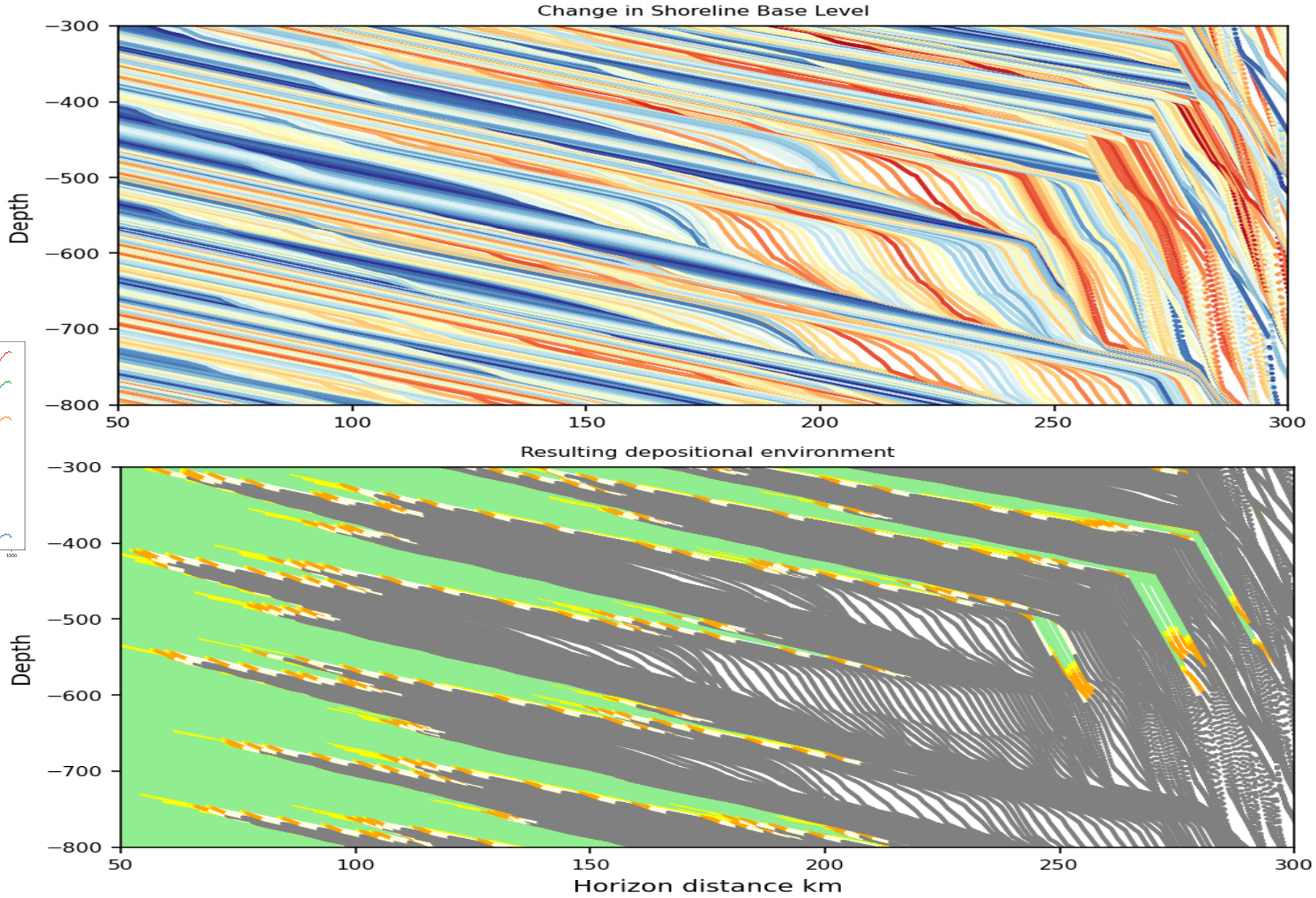


Same parameters but no coastal plain erosion






Base Level Changes with subsidence (average)
Eustacy Only
With Faulting
center of model
with Subsidence only
Net change
Age


Change in Shoreline Base Level
Depth
Resulting depositional environment
Depth
Horizon distance km