Microseismic Monitoring: Beyond Hydraulic Fracture Geometry

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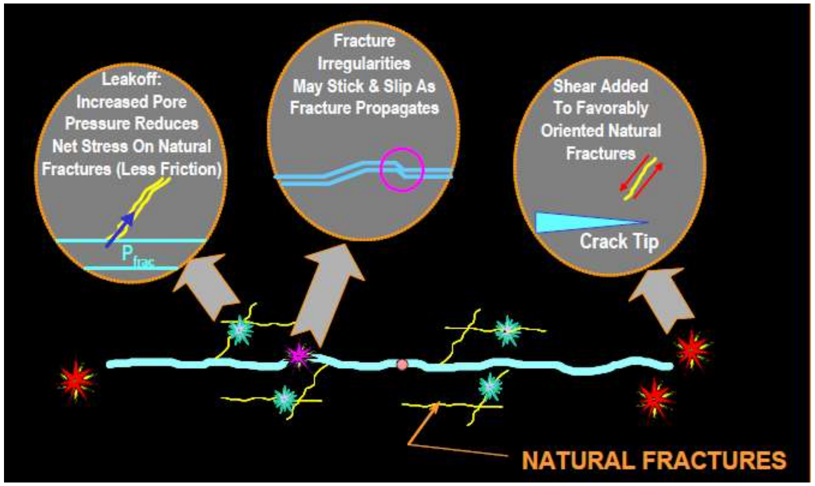
Outline

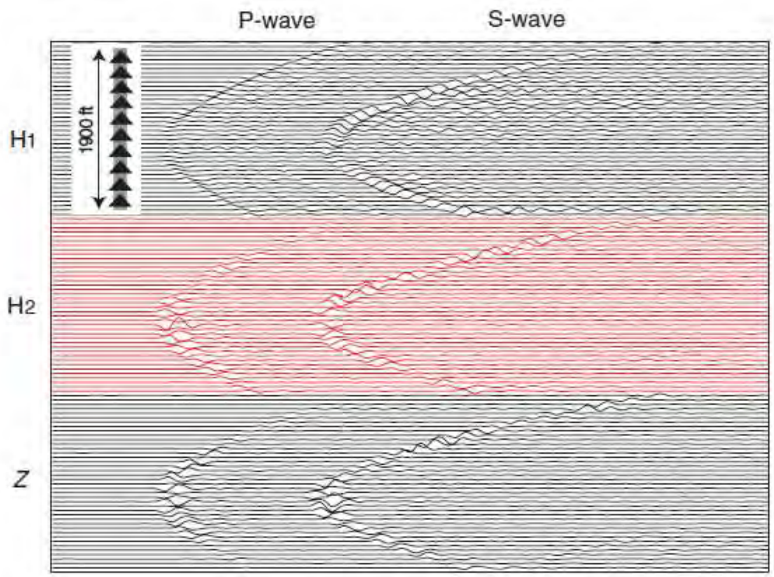
- Microseismic Monitoring
- Microseismic Source Analysis
- Stress Inversion with Source Mechanisms
- Microseismic Interpretation with Stress Inversion
- Velocity Anisotropy & Attenuation
- Conclusions

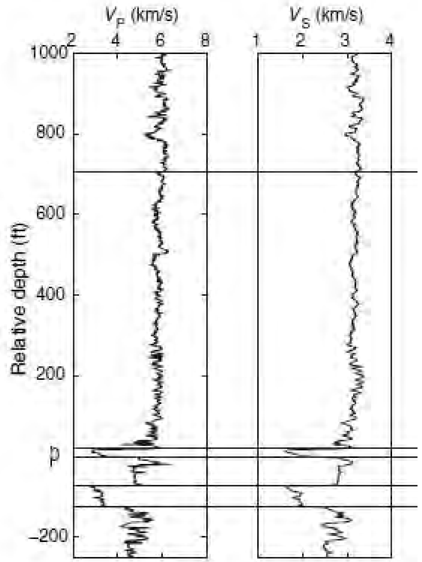
Microseismic Monitoring

- Micro-earthquake by Definition
- Dot in a Box
- For Engineers
  - Mapped Fractures
  - Stimulated Reservoir/Rock Volume
- For Geophysicists



Davis, 2009





Yang and Zoback, *Interpretation*, August, 2014

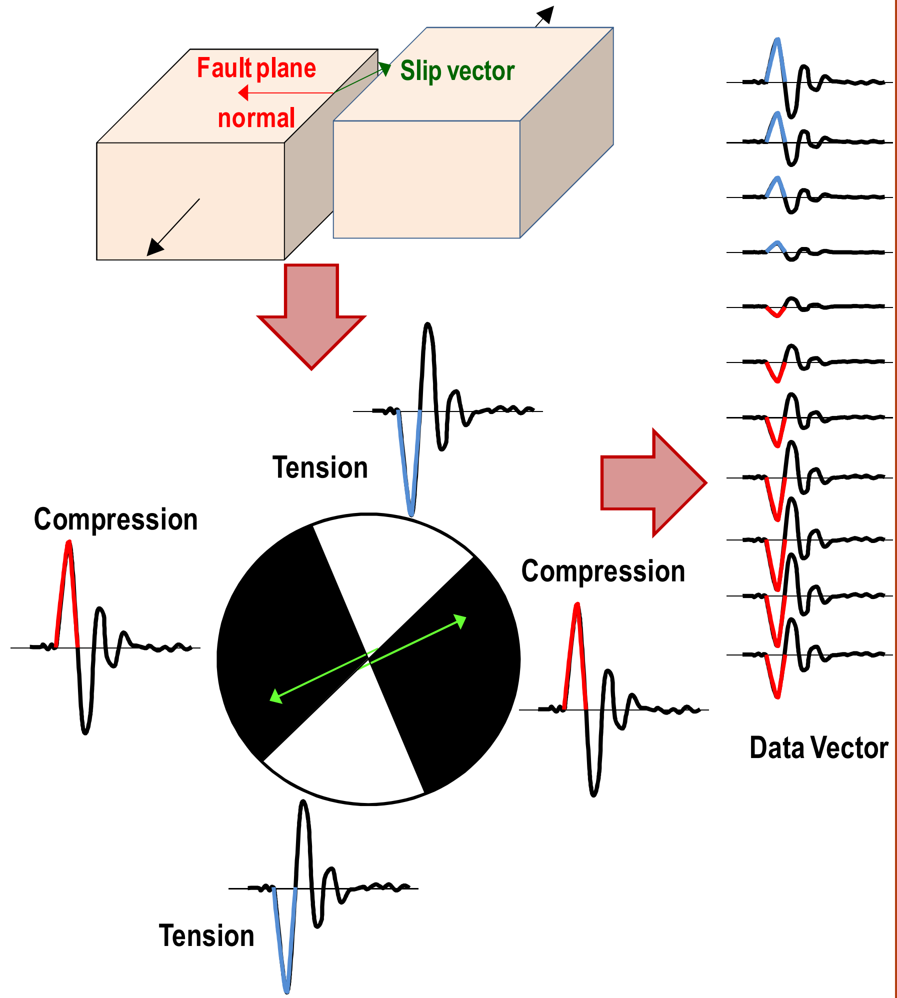
Microseismic Source Analysis

- Spectrum-based Analysis
  - Moment Magnitude
  - Source Parameters (Size, Slip Amount, Stress Drop, Corner Frequency etc.)
- Moment Tensor Inversion

$$u_n(x,t) = MT_{ij} * G_{ni,j}$$

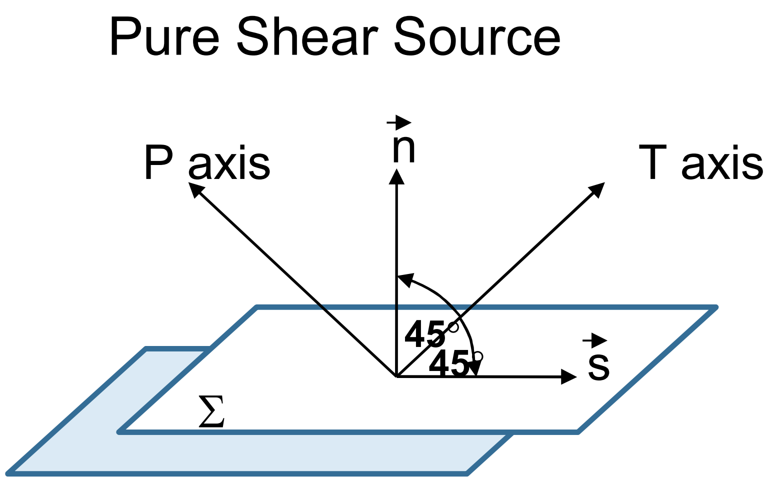
$$MT = \lambda A[u](\vec{s} \bullet \vec{n})I + \mu A[u](\vec{s}\vec{n}^T + \vec{n}\vec{s}^T)$$

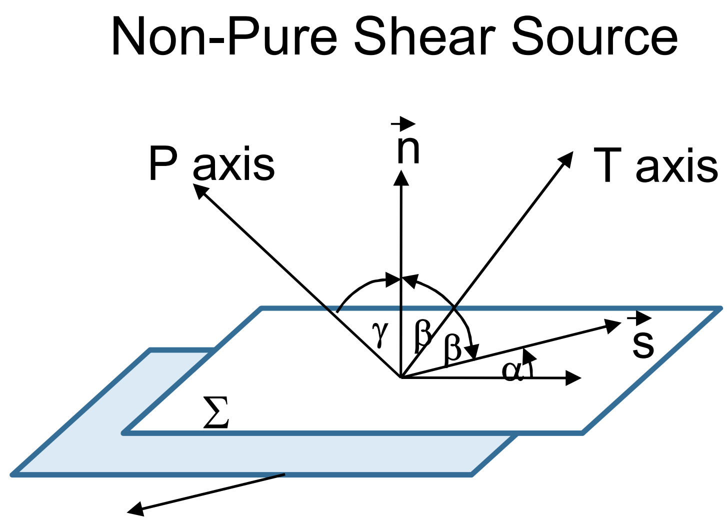
$$MT_{ij} = \lambda A[u]n_k s_k \delta_{ij} + \mu A[u](s_i n_j + s_j n_i)$$



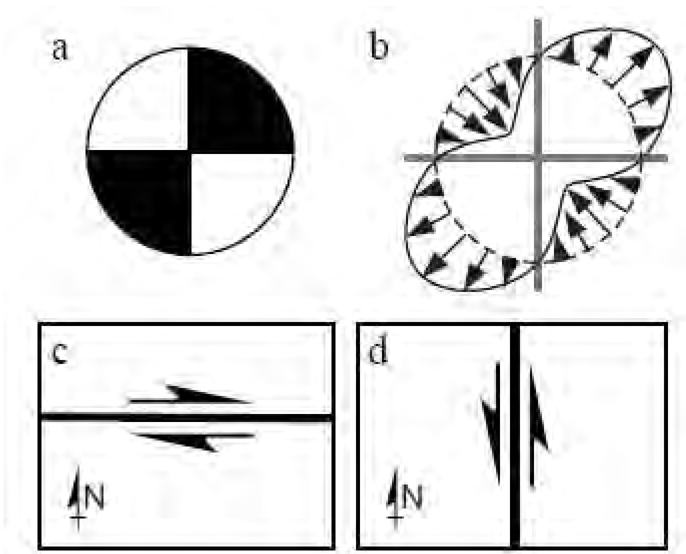
Warpinski et al., *SPEJ,* 2013

From Moment Tensor to Fault Plane Solutions





Reproduction after Vavrycuk, 2001



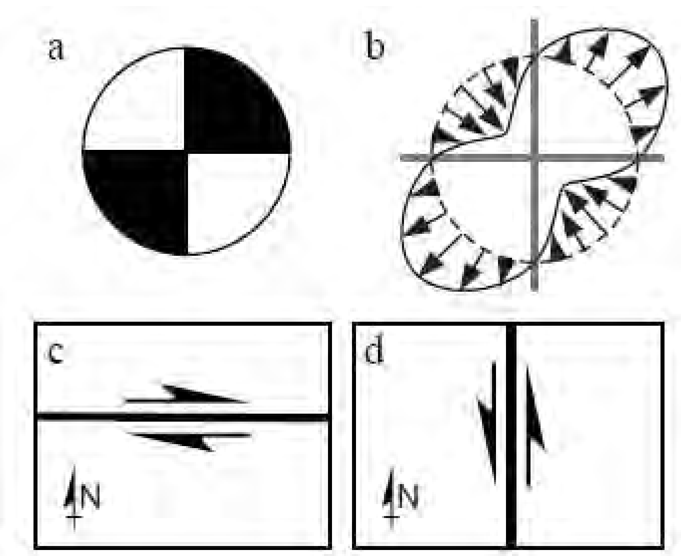
Vince Cronin, 2004

Ambiguity between Fault Plane Normal Direction and Slip Direction

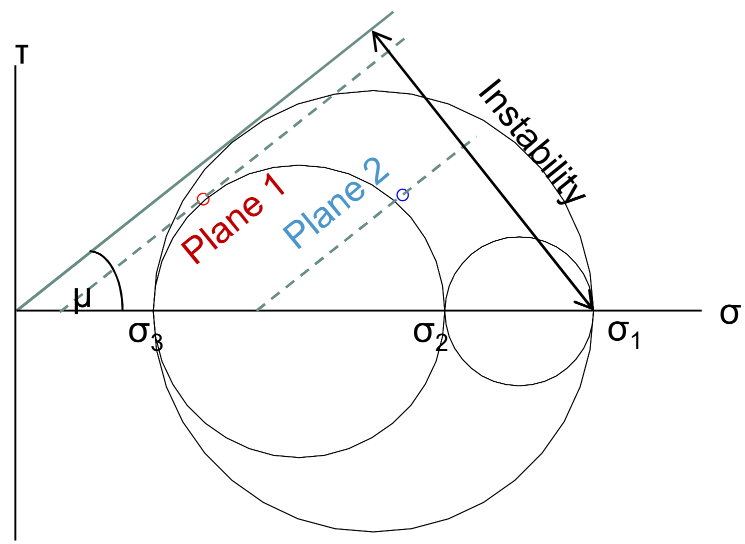
Stress Inversion with Source Mechanisms

- Principal Stresses Orientation & Stress Ratio $R = \frac{\sigma_1 - \sigma_2}{\sigma_1 - \sigma_3}$
- Various Formations Existed in Traditional Earthquake Seismology
- Big Assumption: Homogeneous Stress around Events / Earthquakes
- Application to Fracturing Monitoring is limited

- New: Unstructured Damped Stress Inversion (Li & Du, 2019)

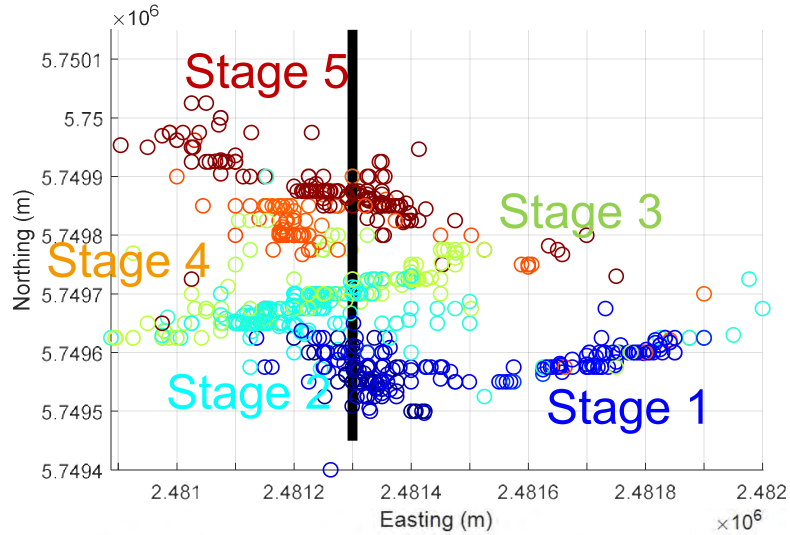


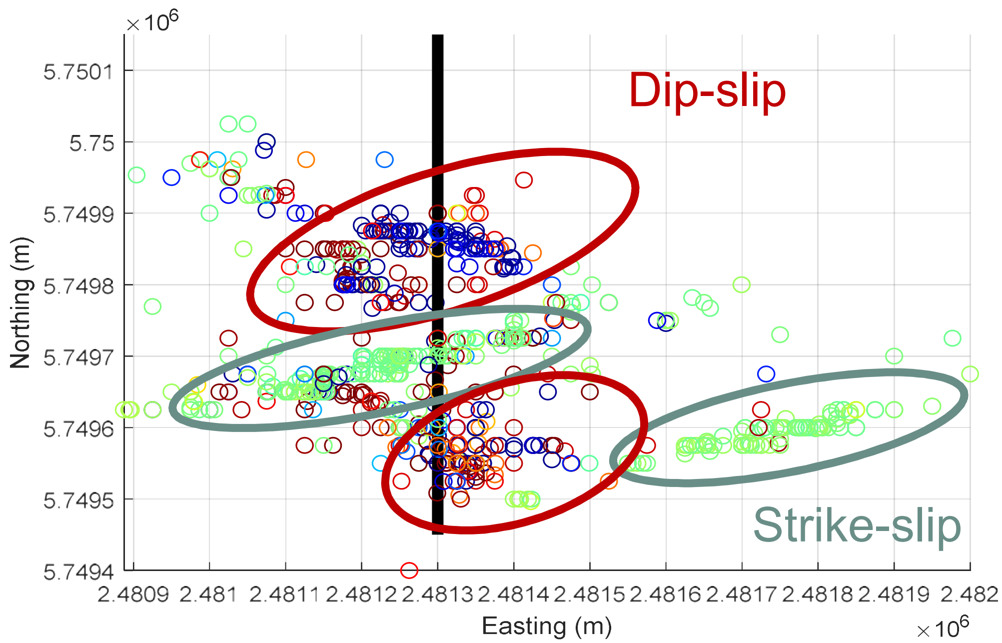
Vince Cronin, 2004

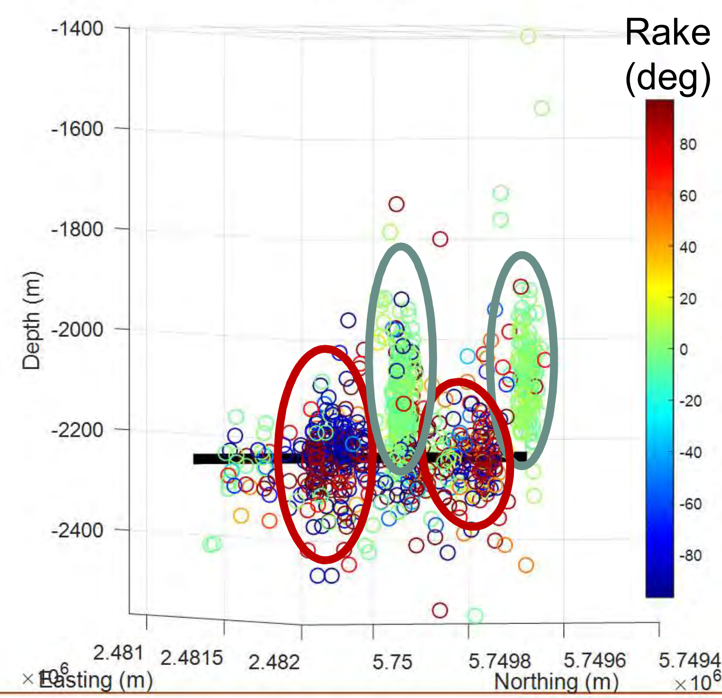


Stress Inversion: Field Case

- Unconventional Shale Play in Vaca Muerta, 5 Stages
- Surface Receiver Array

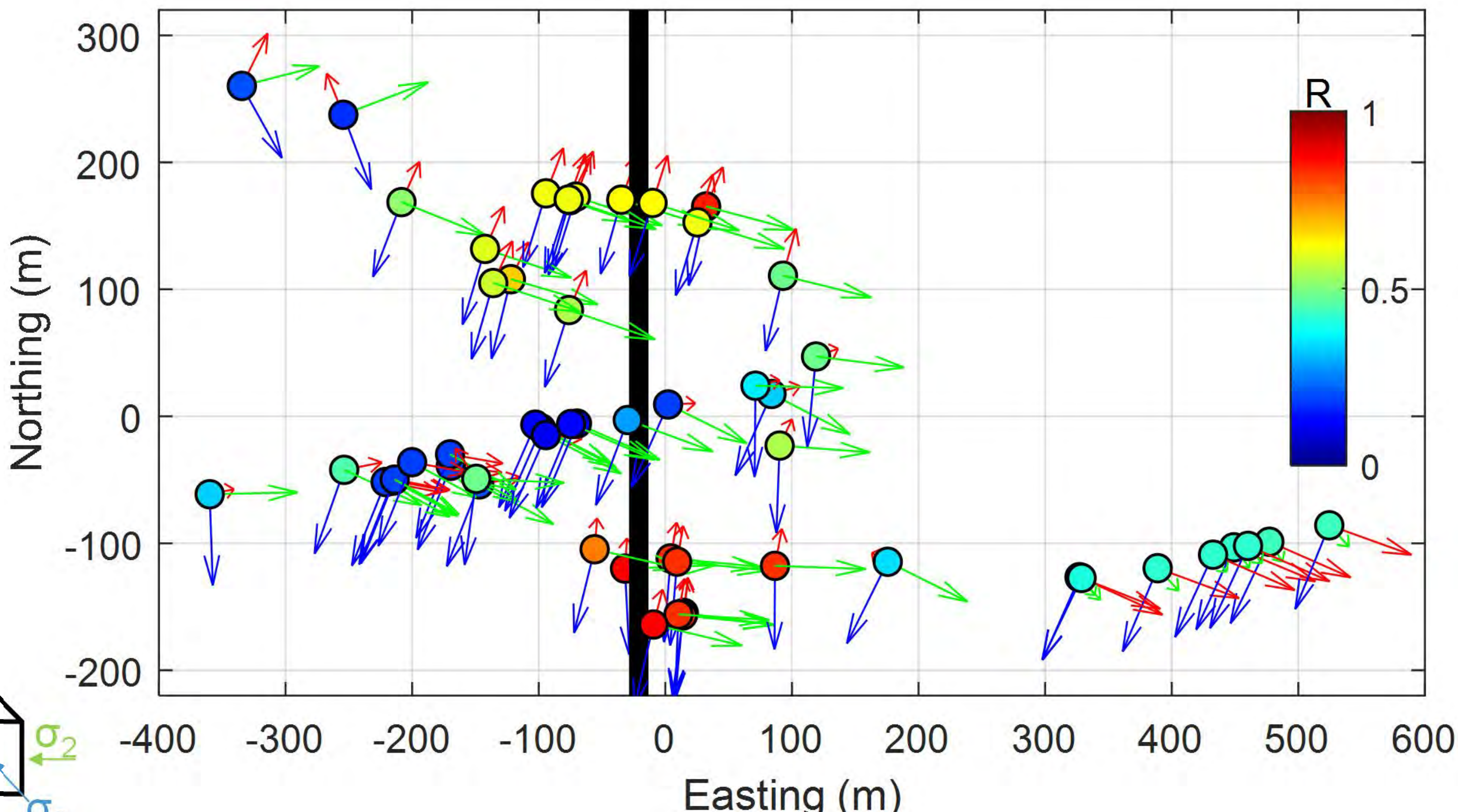


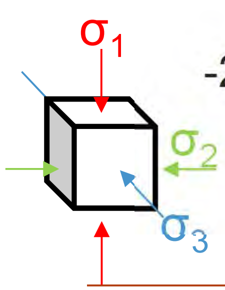




Field Case Results: Stress Direction & Stress Ratio

At all nodes: σ_{hmin} is SSW-NNE
=> HF will open towards SSW-NNE



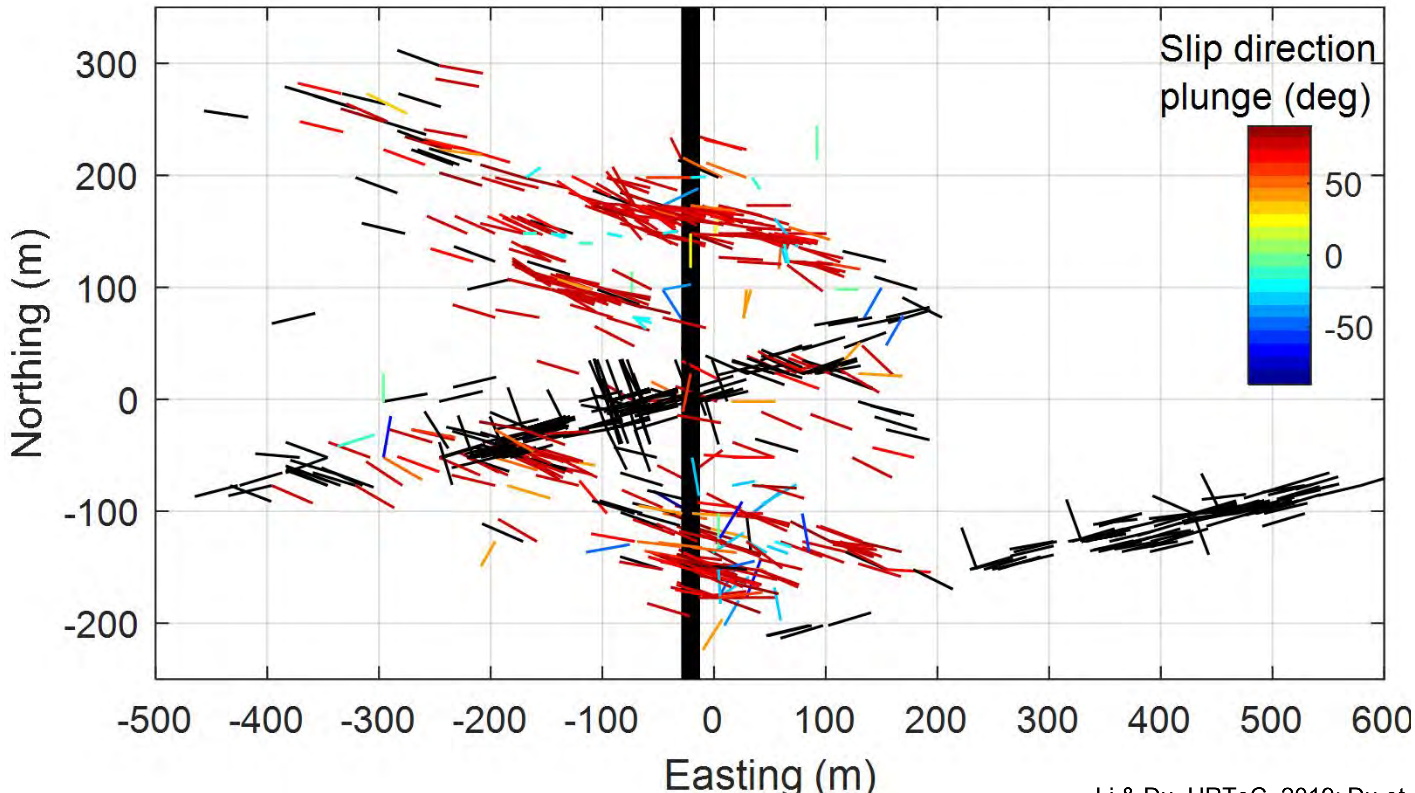


Li & Du, URTeC, 2019

TOTAL

Field Case Results: Interpretation

- Black Lines: Strike Slip Events
- Others: Dip Slip Events
  - **Most of them Slipping in near Vertical Direction, limited true Bedding Plane Slip Events**

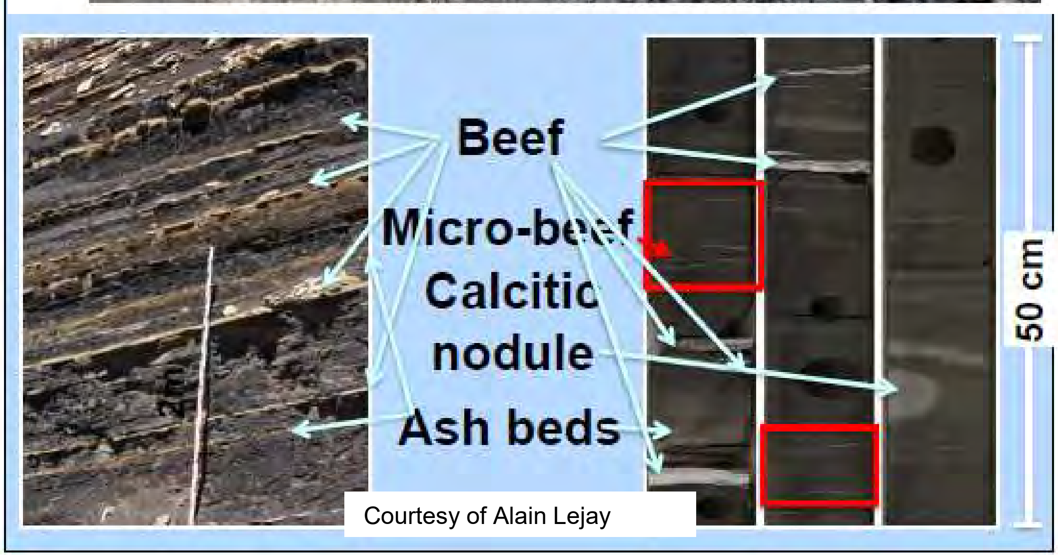


Li & Du, URTeC, 2019; Du et al., SEG 2019

Argentina: Vaca Muerta Formation

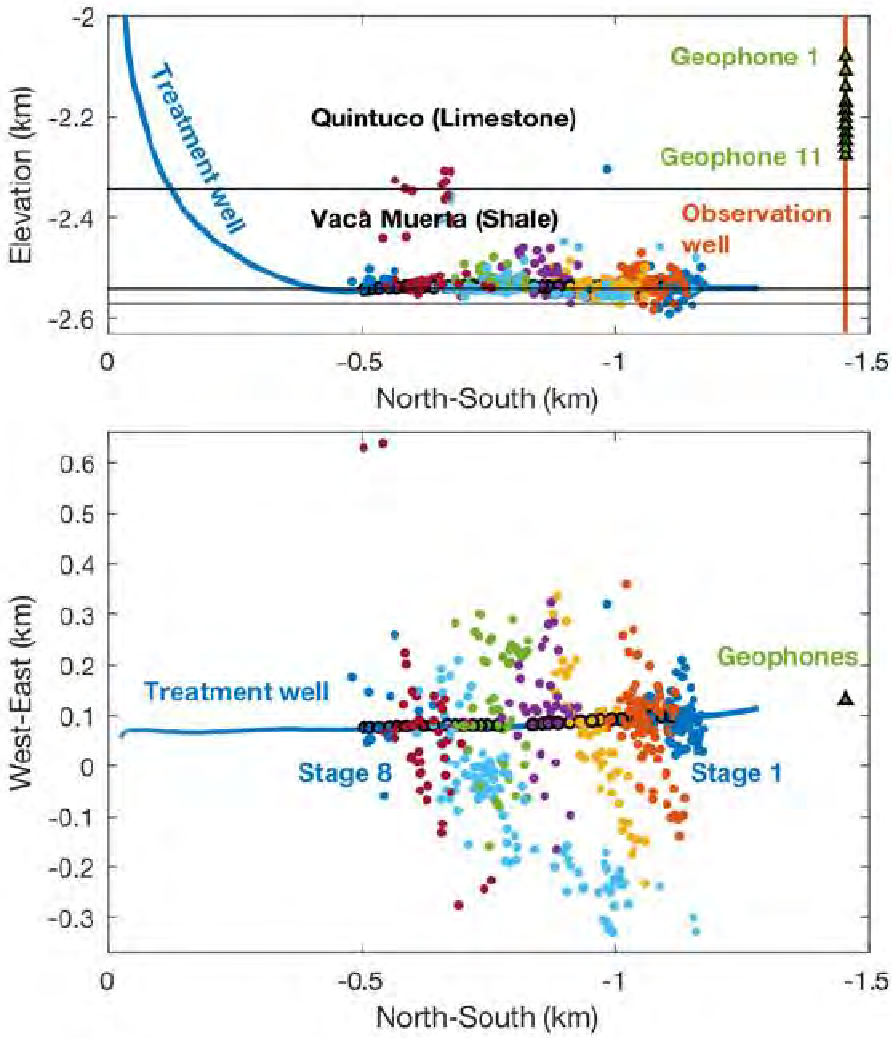
Gale et al., *AAPG,* 2014

Beefs are lenticular or sigmoidal, from a few dcm to several 10's of m.

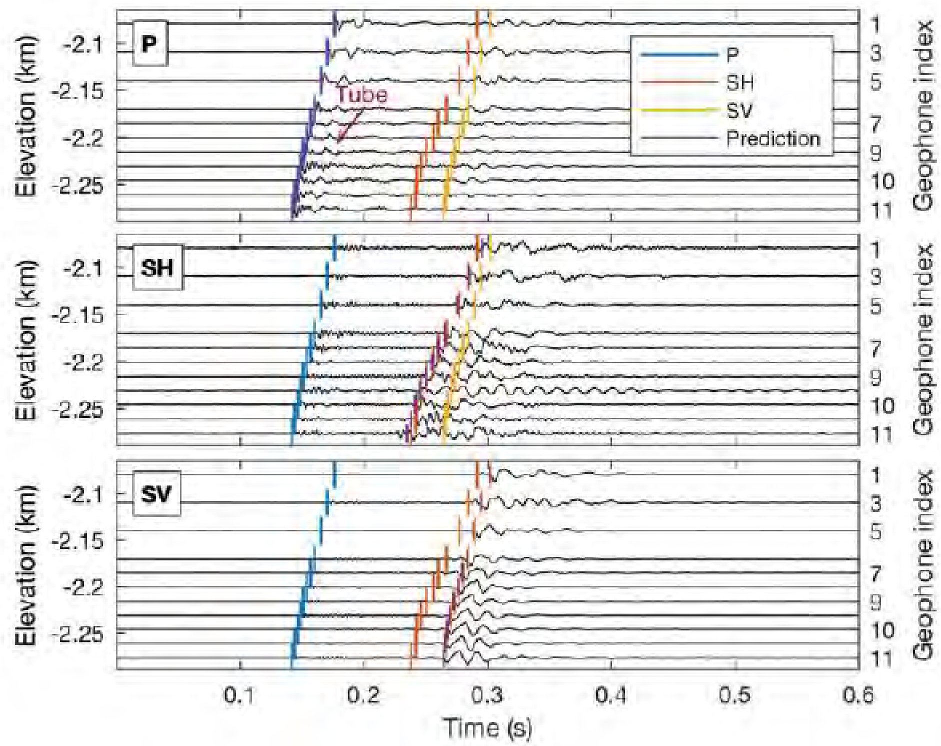


Courtesy of Alain Lejay

Velocity Anisotropy: Acquisition Geometry & Perf Data



Perforation Data



Zhang, Du and Mavko, *GJI*, 2018

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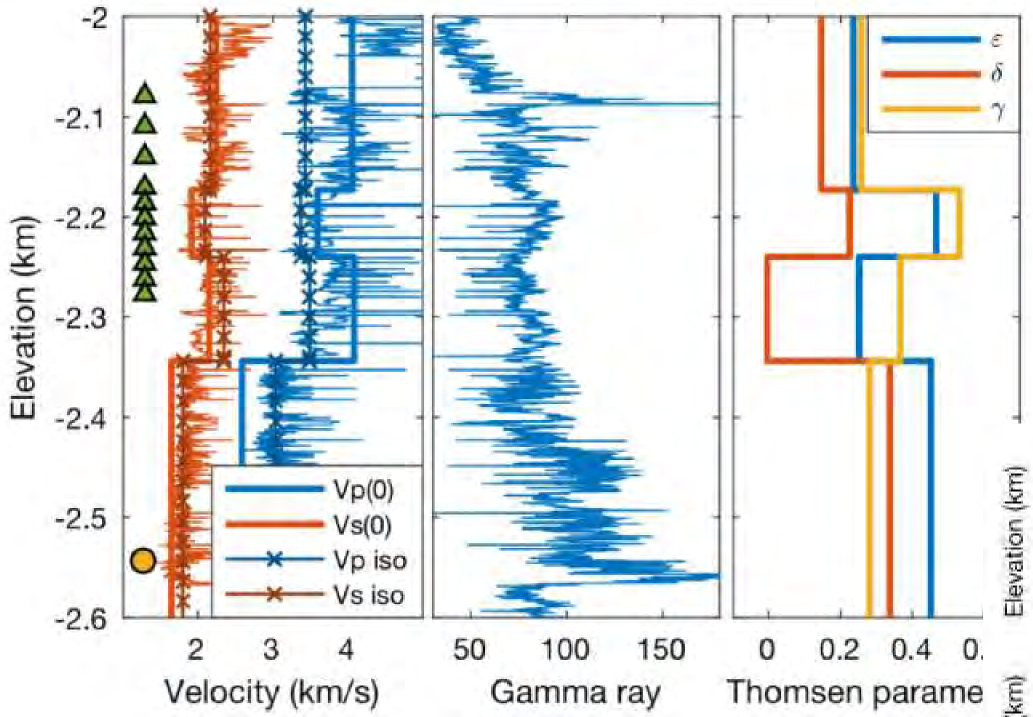
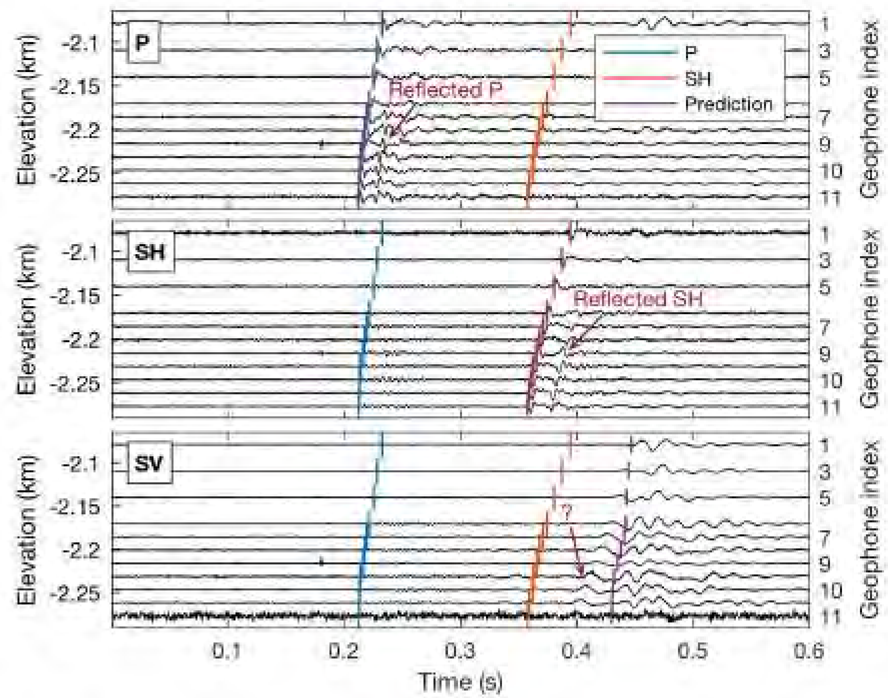
Velocity Anisotropy: Results

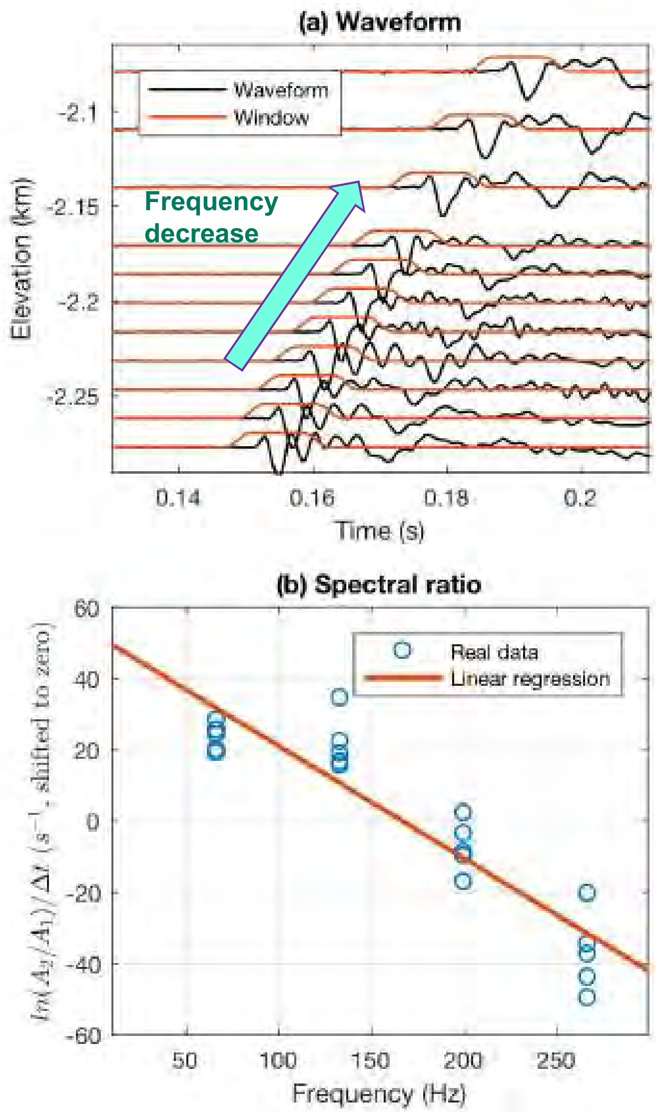


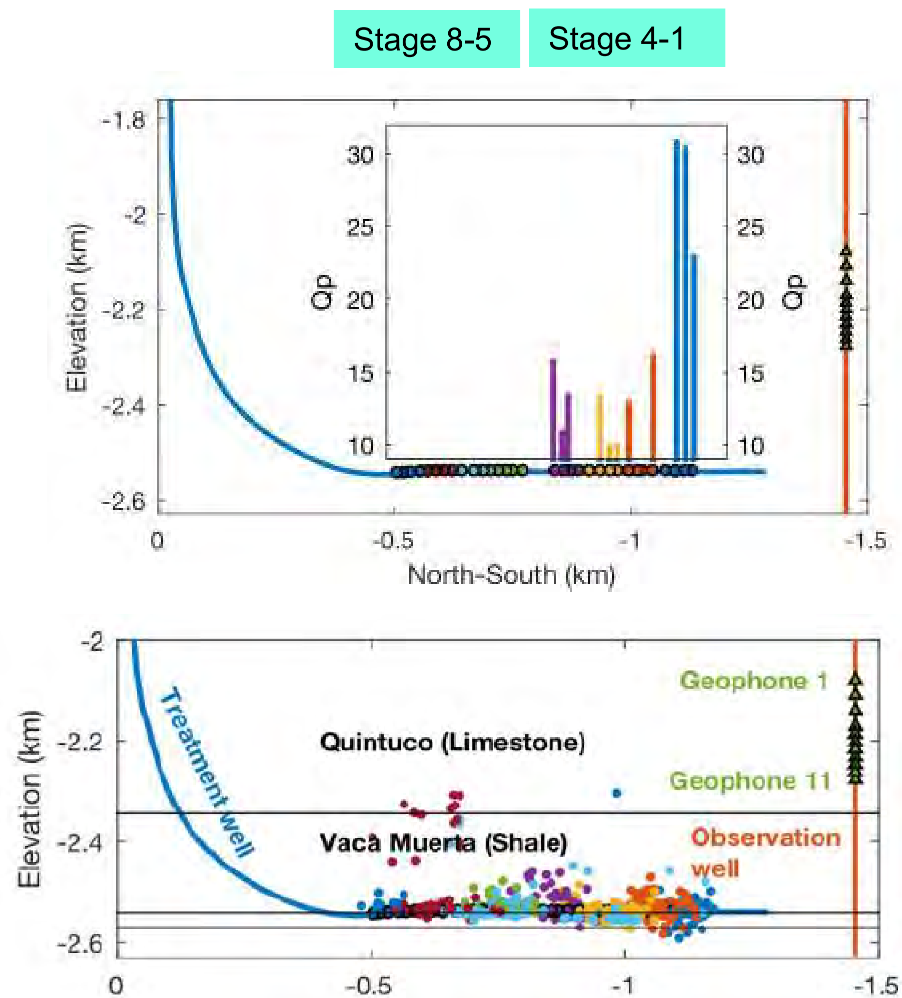
Perforation Data



Zhang, Du and Mavko, *GJI*, 2018

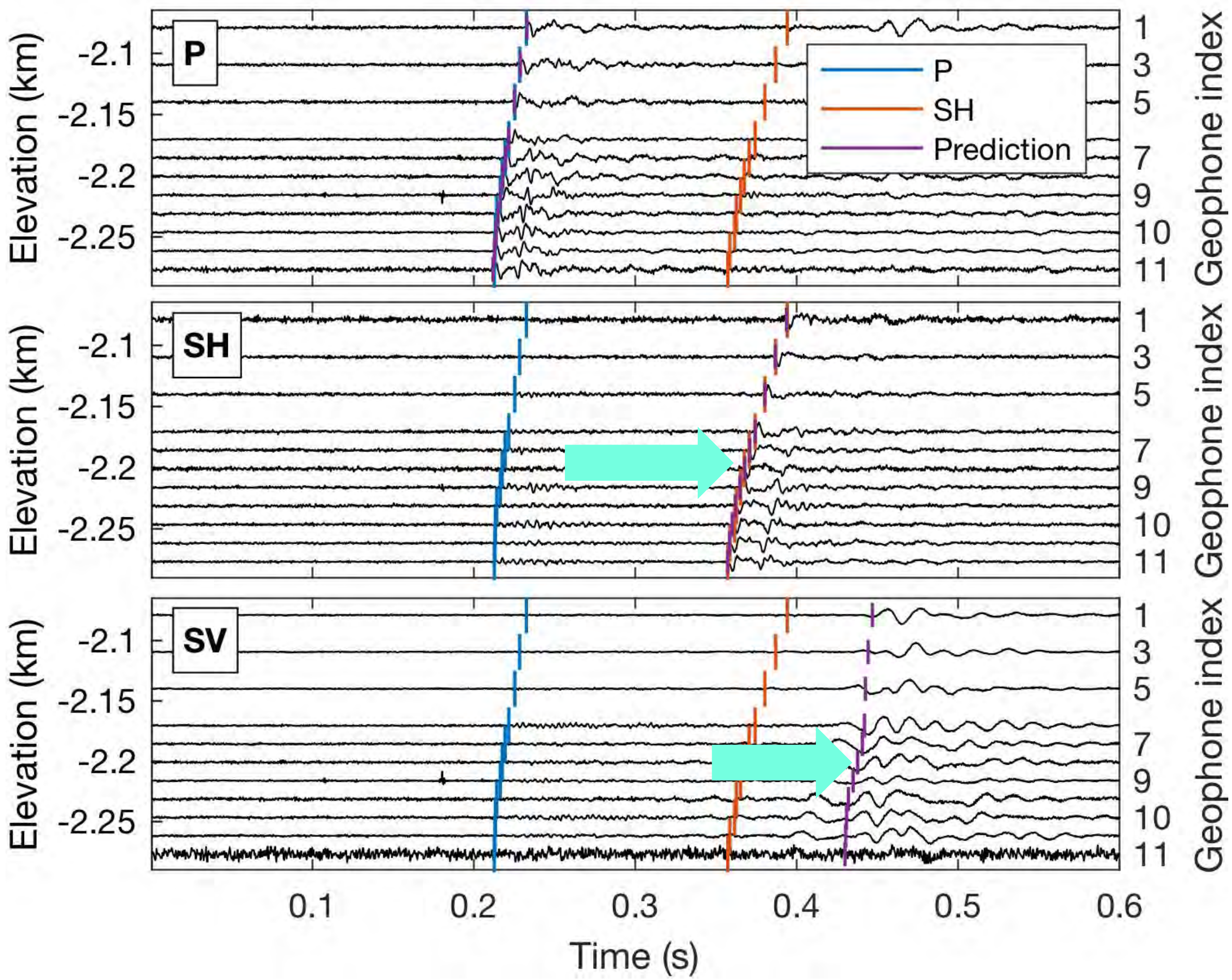
ATTENUATION





Zhang, Du and Mavko, *GJI*, 2018

Observations from Field Data



Frequency Difference between Sh and Sv

Zhang, Du and Mavko, *GJI,* 2018

TOTAL

Conclusions

- Microseismic monitoring provides hydraulic fracture geometry and growth behaviors / unconventional development
- Microseismic waveforms carry much more Information for reservoir characterization and interpretation
  - Moment tensor, fault plane solutions
  - Stress directions and stress ratio
  - Friction coefficient, true fault plane identification
  - Velocity anisotropy
  - Attenuation & potential attenuation tomography
  - Natural fracture characterization

- This requires careful planned field acquisition and processing

Acknowledgements

Total S. A., Total Austral and its Partners for publication permissions!

Thanks!