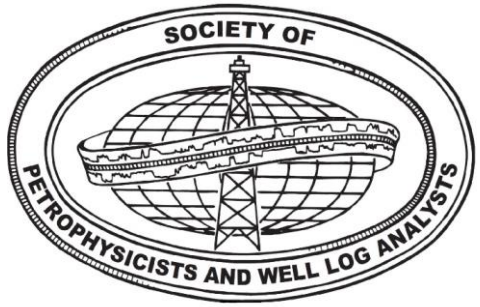
Delineating the geothermal structure and flow properties in a sub-horizontal well with the use of Wireline and LWD data in a Multiphysics approach (SPWLA-5065)

E. Wielemaker, C. Cavalleri, L. Dahlhaus, A. Reynaldos and G. Sosio; Schlumberger
P. Ungemach, M. Antics and Melanie Davaux; Geofluid

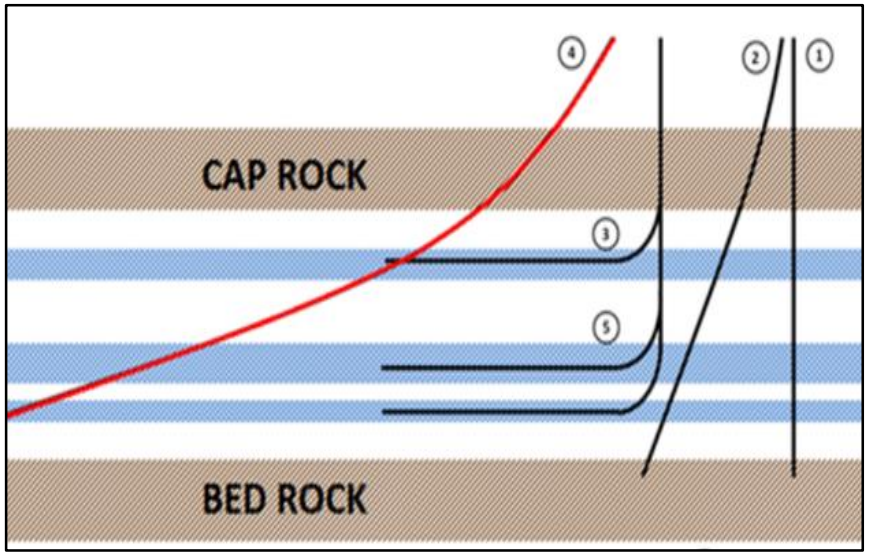
Erik Wielemaker; Schlumberger

September 11, 2020

SPWLA France, Webinar



Introduction



Drilling rig site in Cachan, France (image courtesy Dalkia).

Geothermal

- Rapidly expanding across Western Europe
- Alternative Energy Source
- Logging Technology within Geothermal has been limited
- Promote application of logging within geothermal

Case Study : Paris Basin- Cachan

Target layers :

- Multiple Oolite layers within a Dolomite sequence (Dogger)

Approach:

- Sub-horizontal wells drilled (World Premier for Geothermal)
  - Drawing heat from the different Oolite layers
  - One doublet 500 m3/h vs 300 m3/h for 4 old wells (2 doublets)
- Logging to:
  - Help plan Completion Strategy
  - Determine homogeneity flow properties
  - Layer Continuity

Logging Measurements

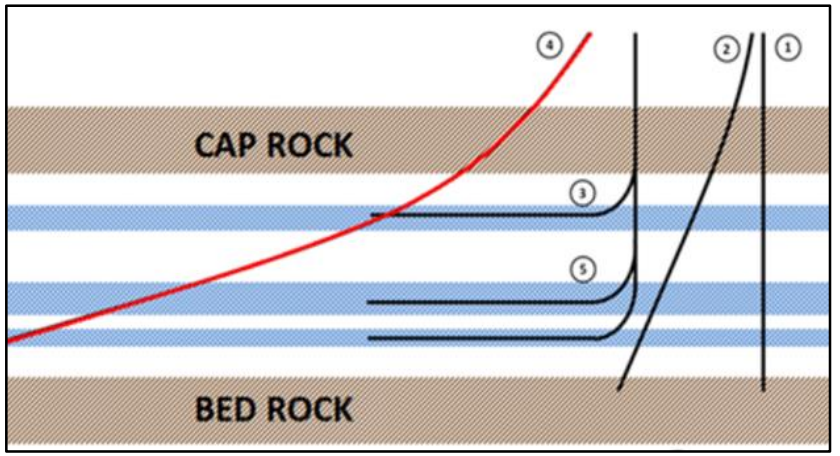
LWD:

- Azimuthal Density- for Geosteering

Wireline on tractor:

- NMR - porosity, mobility and flow capacity
- Sonic - Geomechanics

- Sub-horizontal well required Multiphysics approach to determine heterogeneity of the layers
- Sonic measurements explored to image lateral continuity of the layers.

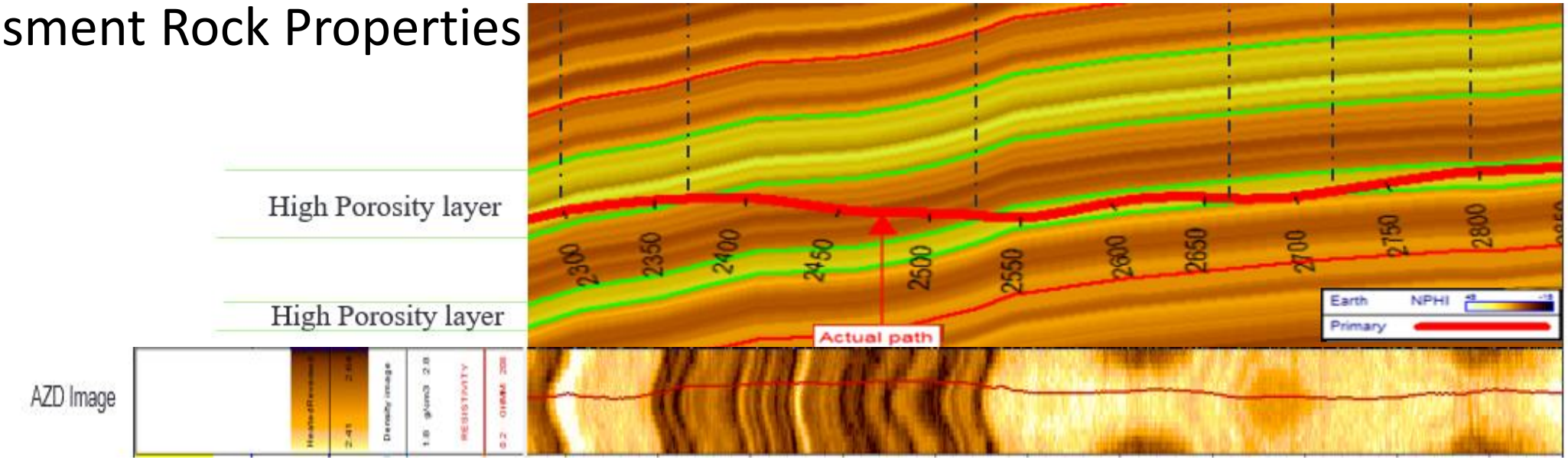


Ungemach et al., Geomodelling and Well Architecture, Key Issues to Sustainable Reservoir Development, 36th Workshop on Geothermal Reservoir Engineering. Stanford

Oolites

- LWD density logs- Geosteering - 1m thin layers

Quick assessment Rock Properties

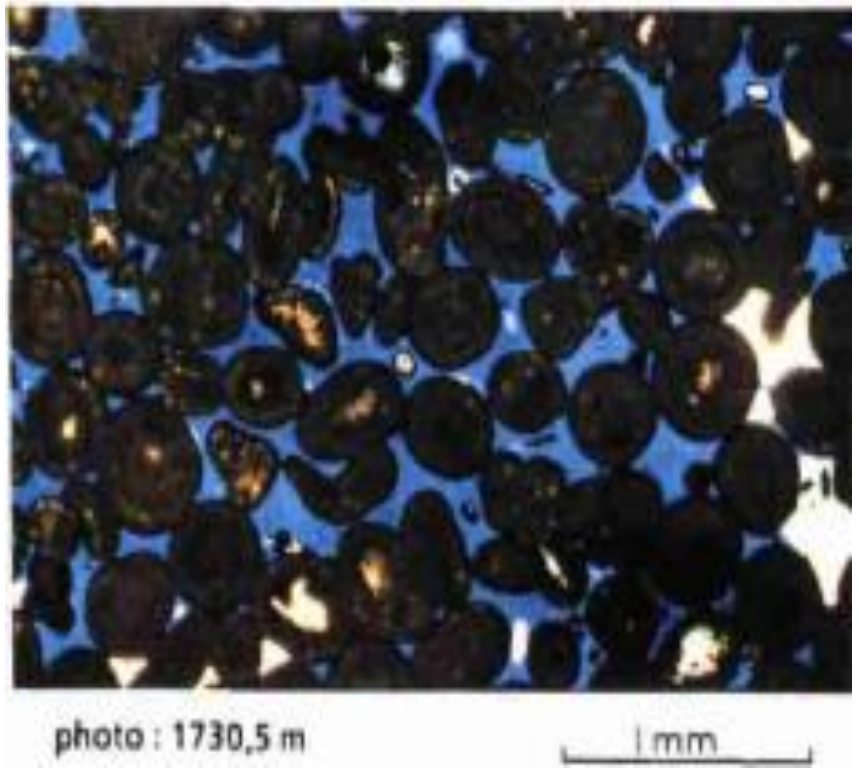


Oolites

- Well connected Primary porosity
- Non- or poorly cemented
- Initial porosity often maintained in these Oolitic formations

- The large pore space porosity is expected to contribute to the majority of the flow potential.

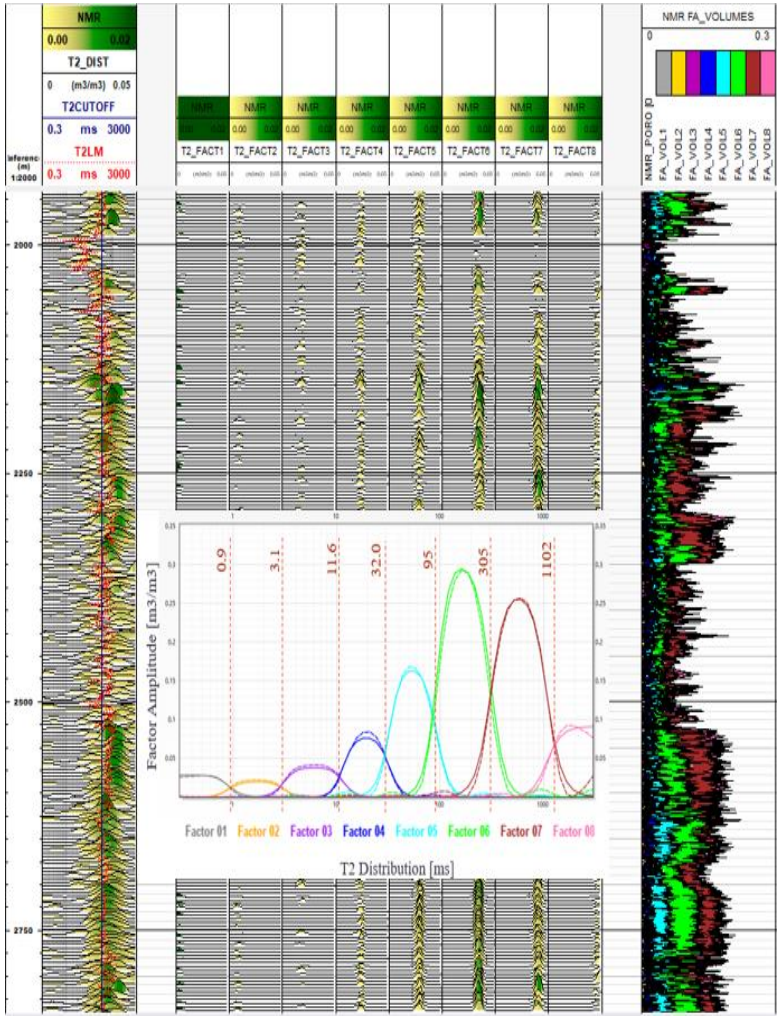
NMR was logged to determine the sections with optimal flow units



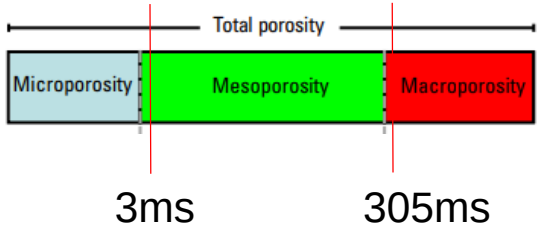
Thin section from typical oolite

NMR & Multi-Physics – Factor Analysis & Partitioning

To identify the Macro Pores (Large T2)
Single Phase

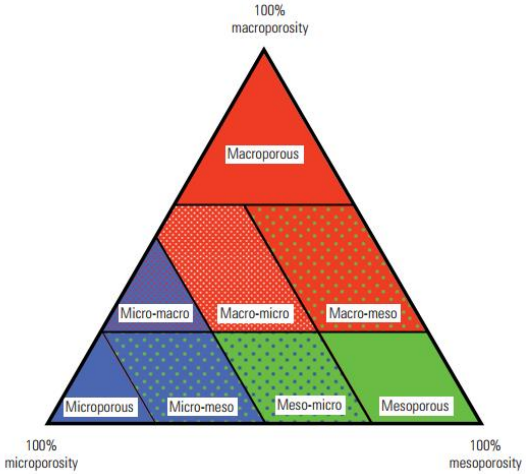


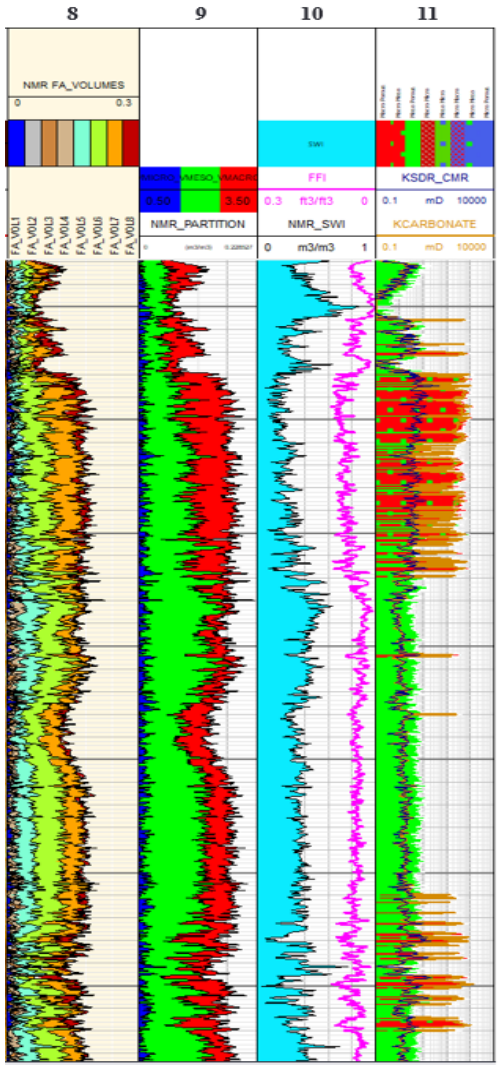
Main pore system classes and permeability from porosity spectrum analysis



Permeability controlled by porosity and macro-pore volumes

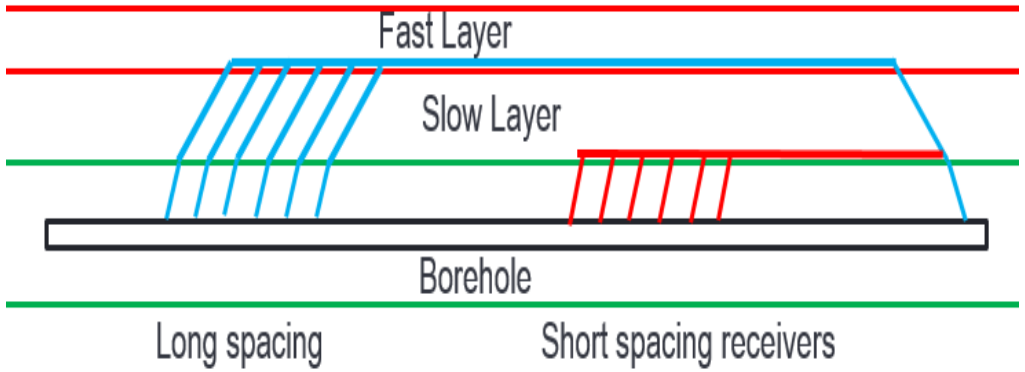
$$k_{macro} = c\,\phi^2 * \left[\frac{\phi_{macro}}{\phi_{meso} + \phi_{micro}}\right]^2$$

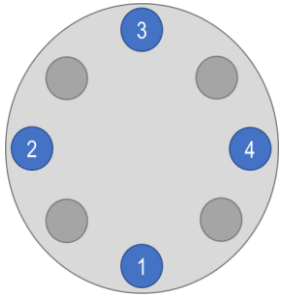


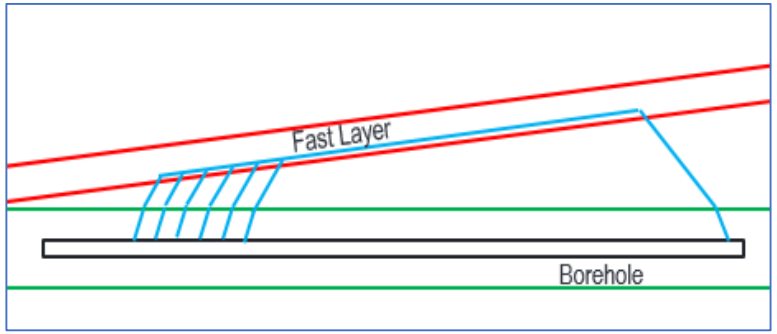


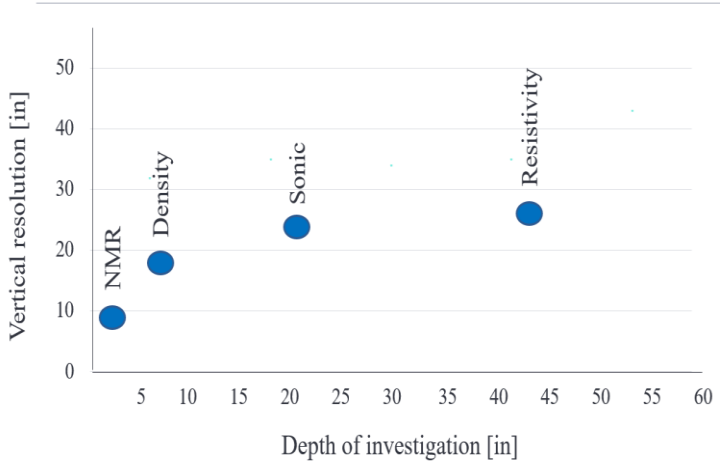
Sonic & Multi-Physics

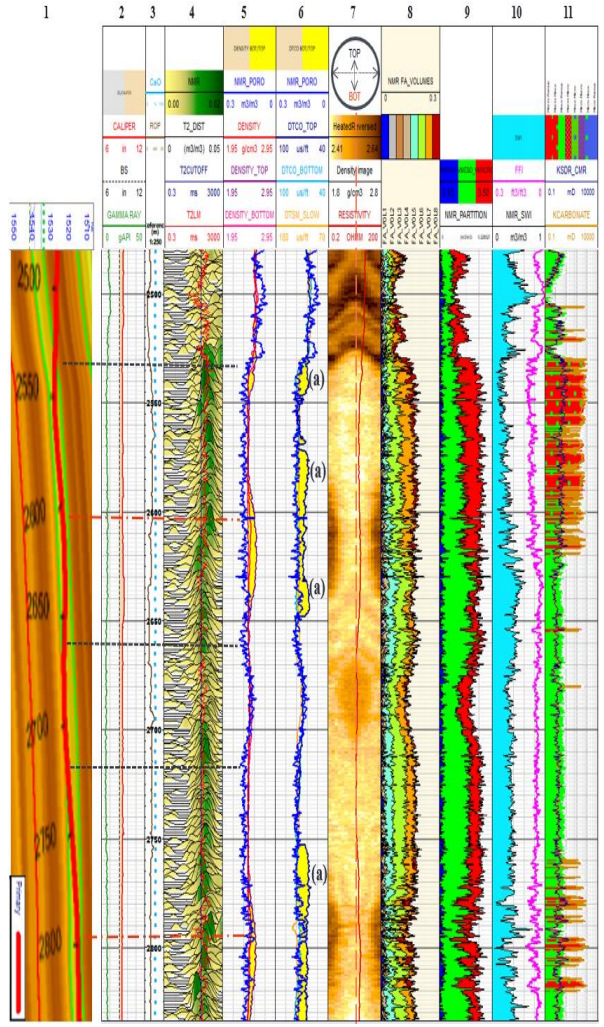
Sonic – Near Spaced Transmitter & Azimuthal arrays



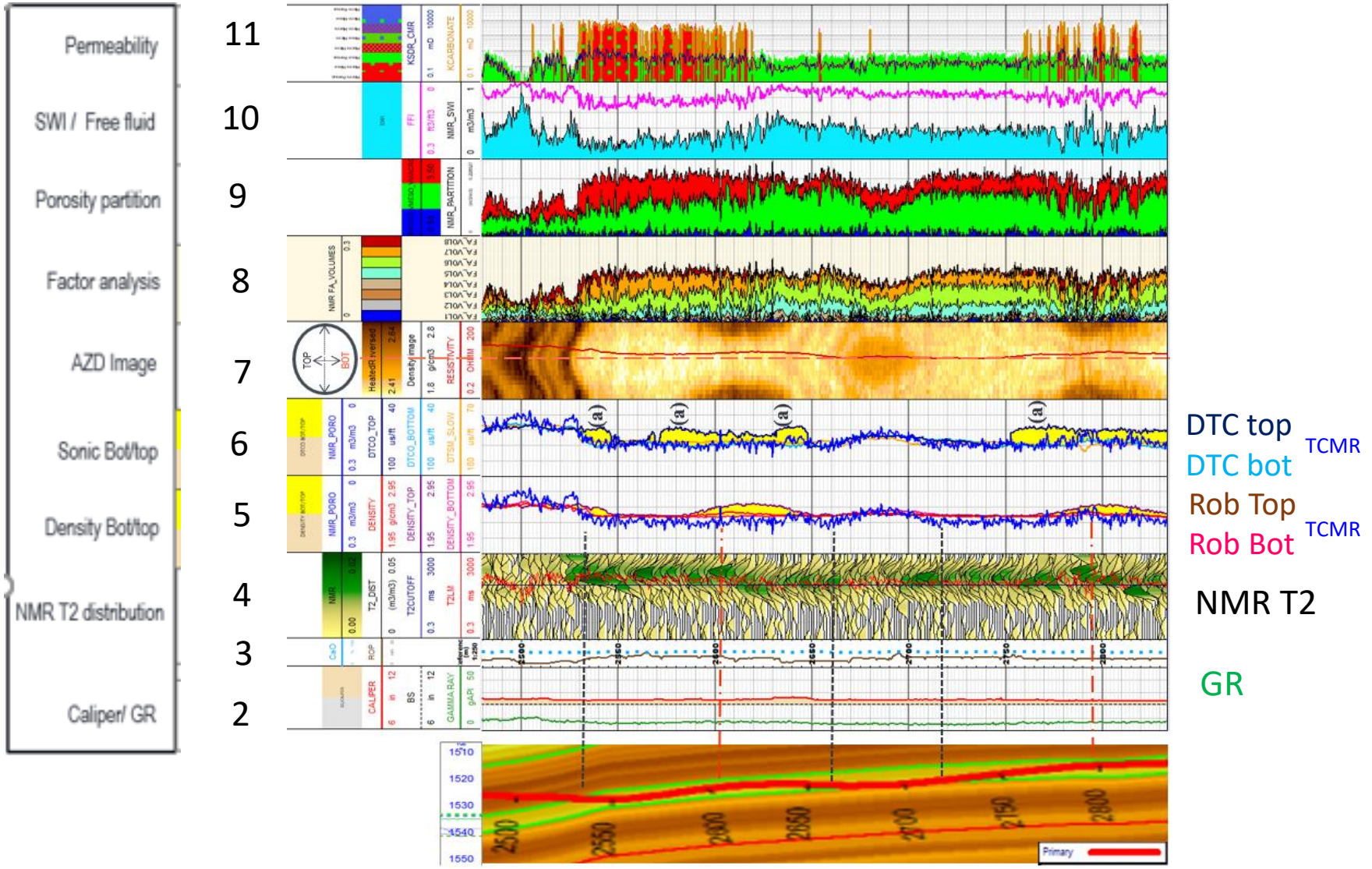




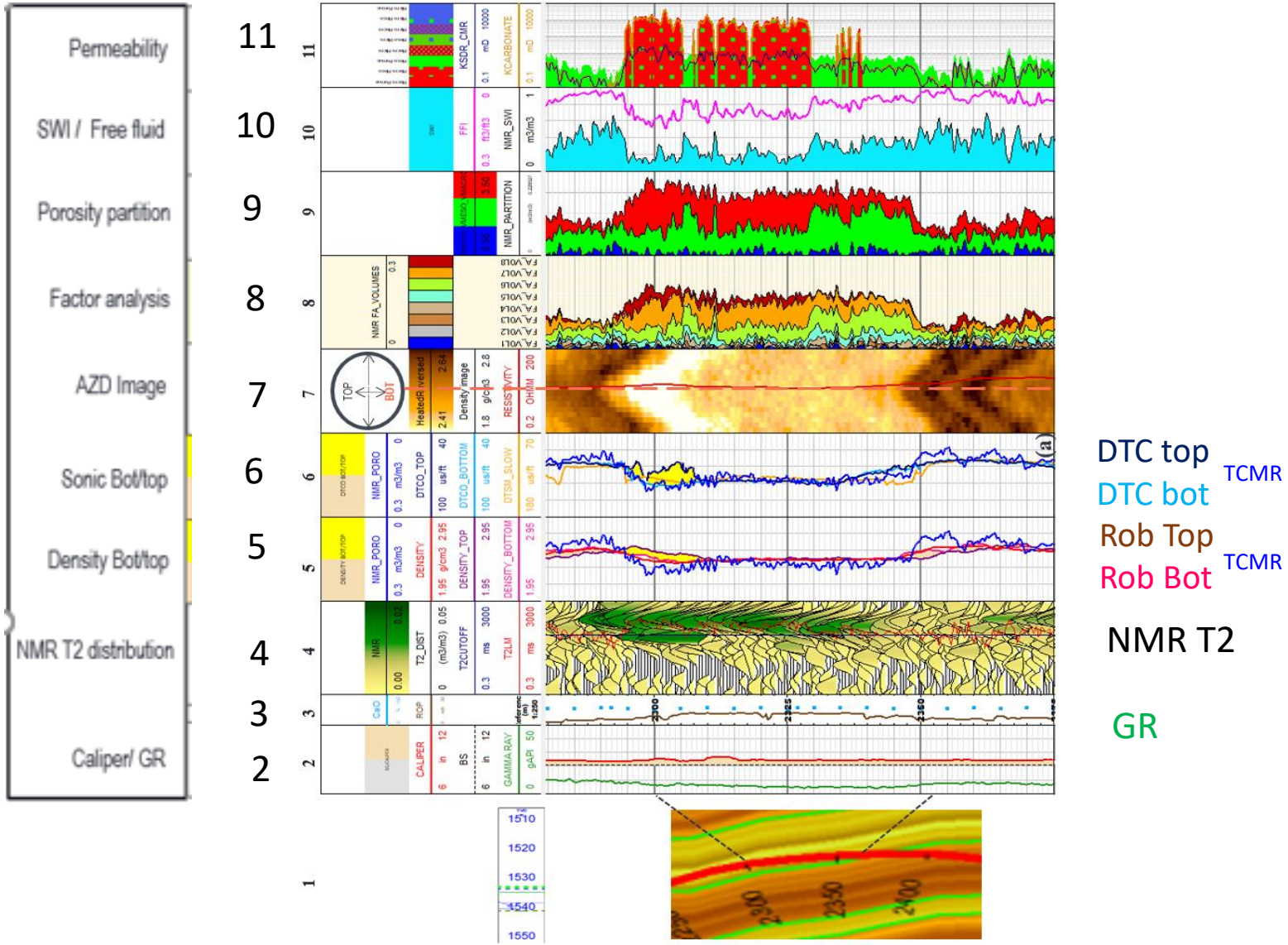




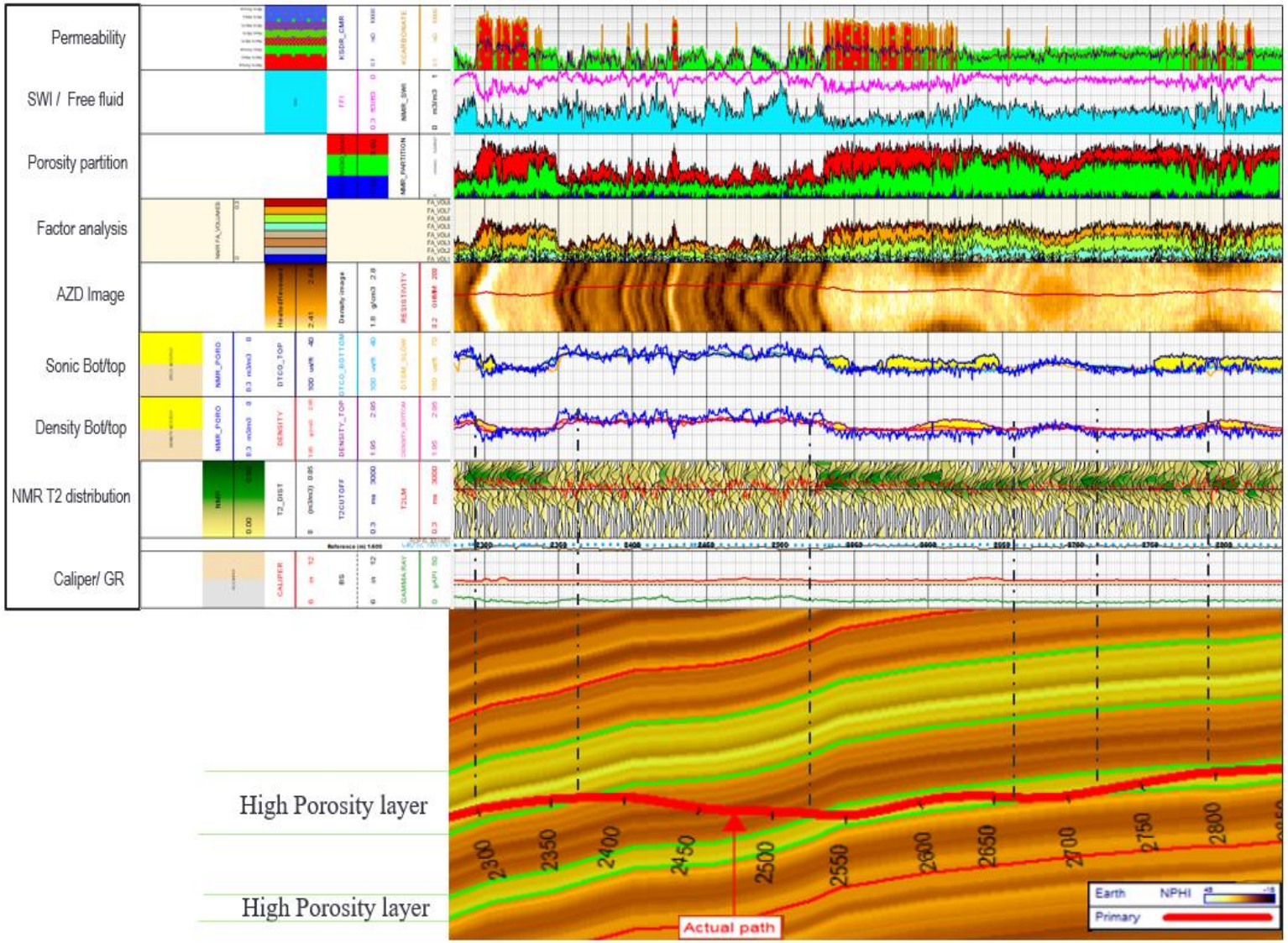
NMR & Multi-Physics- Section A



NMR & Multi-Physics- Section B



NMR & MultiPhysics



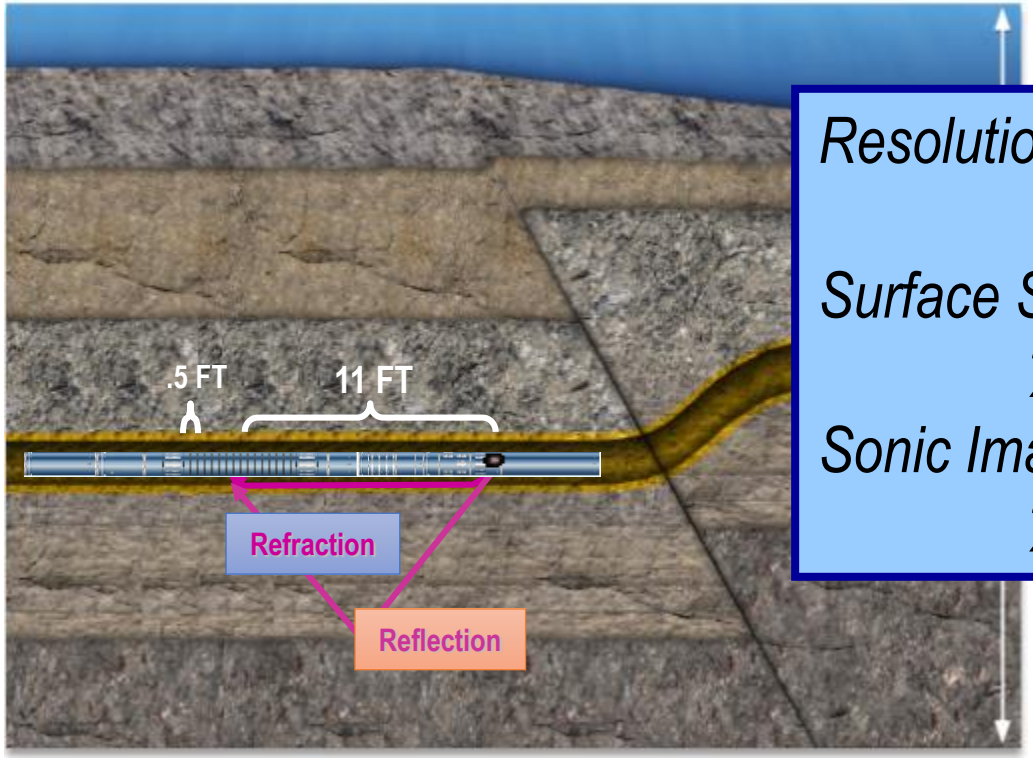
- Measurements integrated to determine the optimal Flow units.
  - Discriminating heterogeneity from measurements affected by layering

- Most optimal flow units identified for Acid Stimulation.
- Doublet's Flow rates were higher than the total of 4 previous wells (2 conventional Doublets)

Sonic Imaging

Sonic logging for formation P slowness uses refracted waves

Sonic Imaging Survey uses reflected waves to image subsurface away from borehole P2P, S2S, P2S, S2P



Resolution: at 3000 m/s

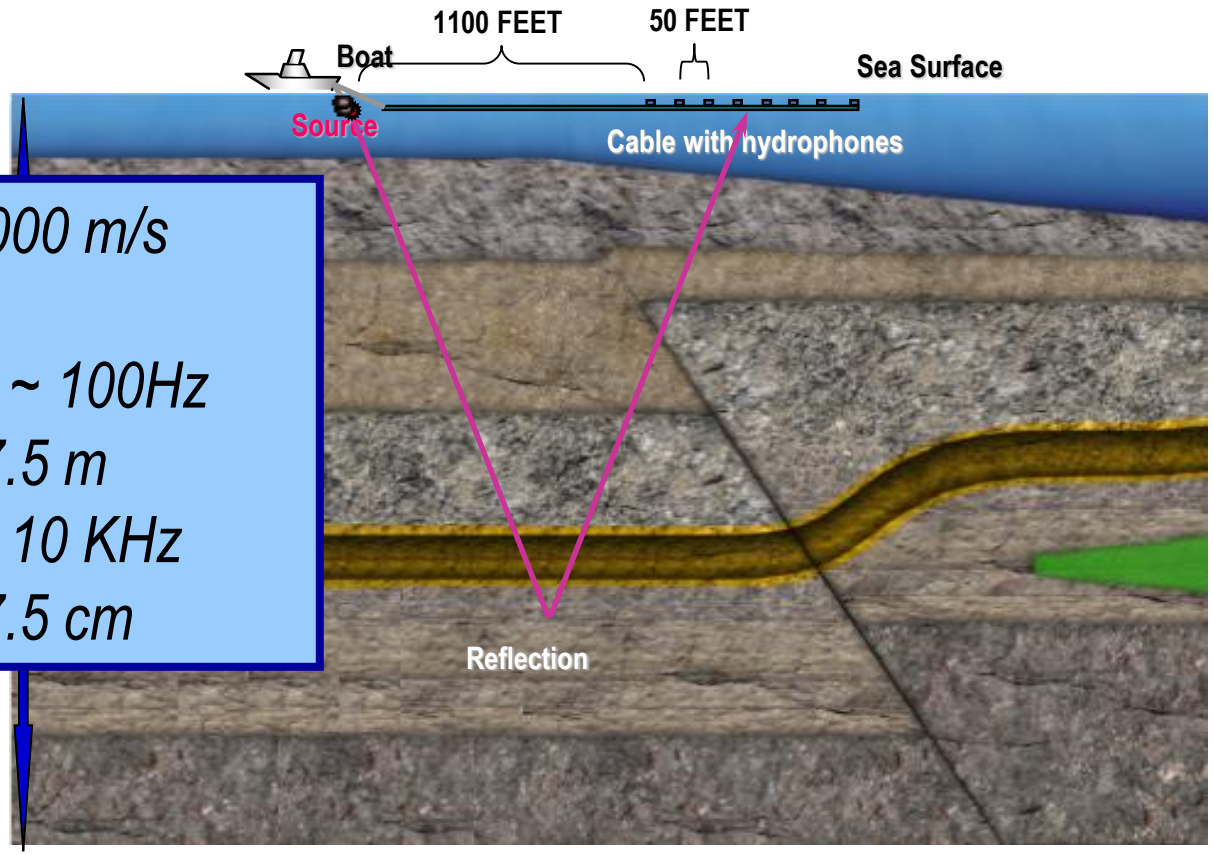
Surface Seismic ~ 100Hz

¼ λ = 7.5 m

Sonic Imaging ~ 10 KHz

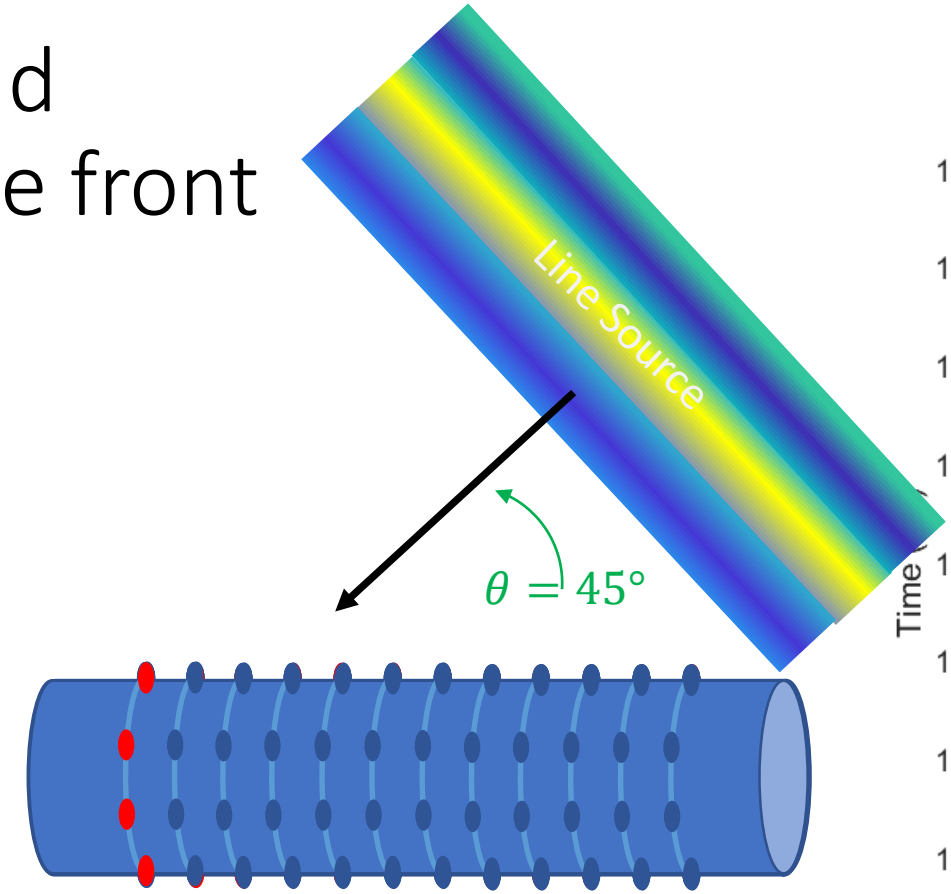
¼ λ = 7.5 cm

Surface Seismic Analogy

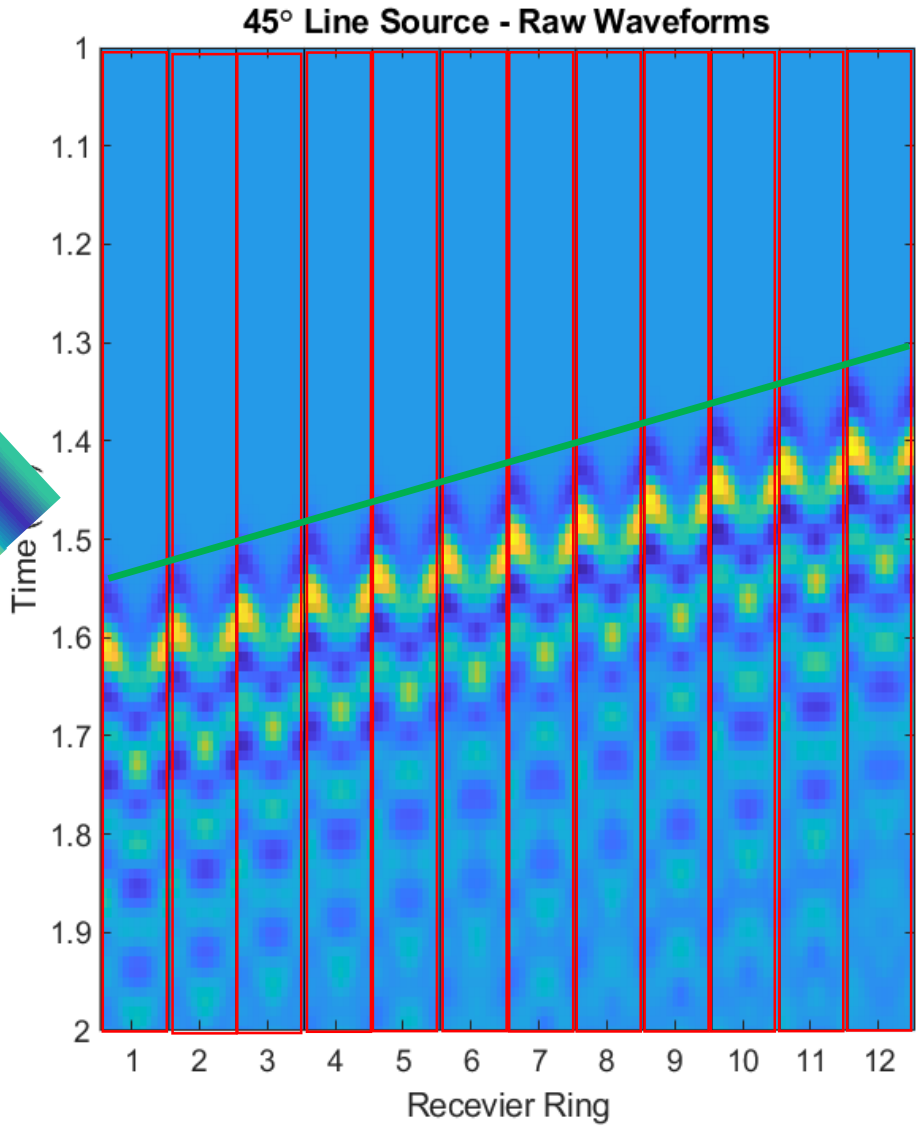


Line Source and Recorded Wave front

Line Source and Recorded Wave front

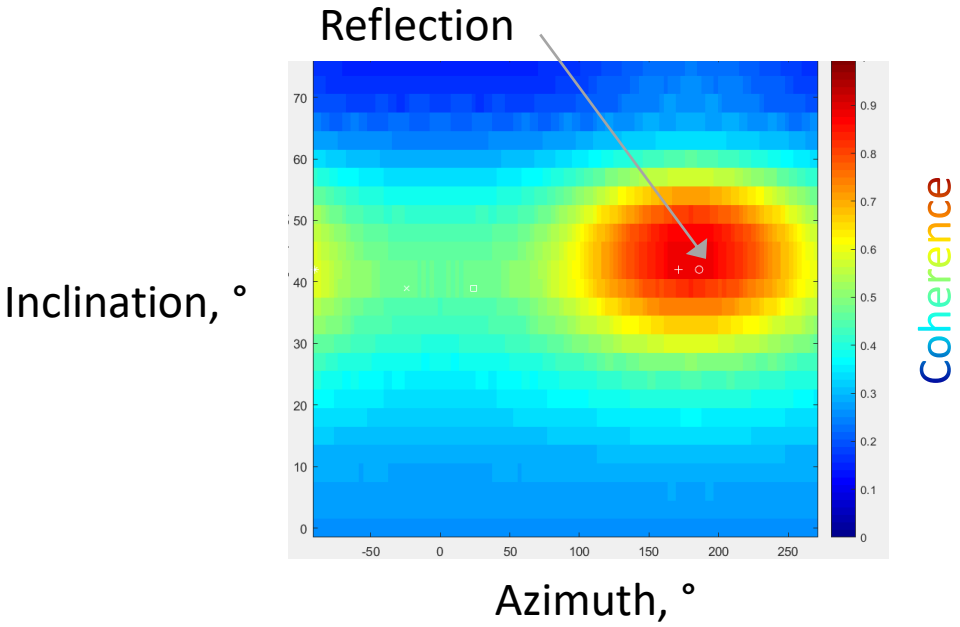


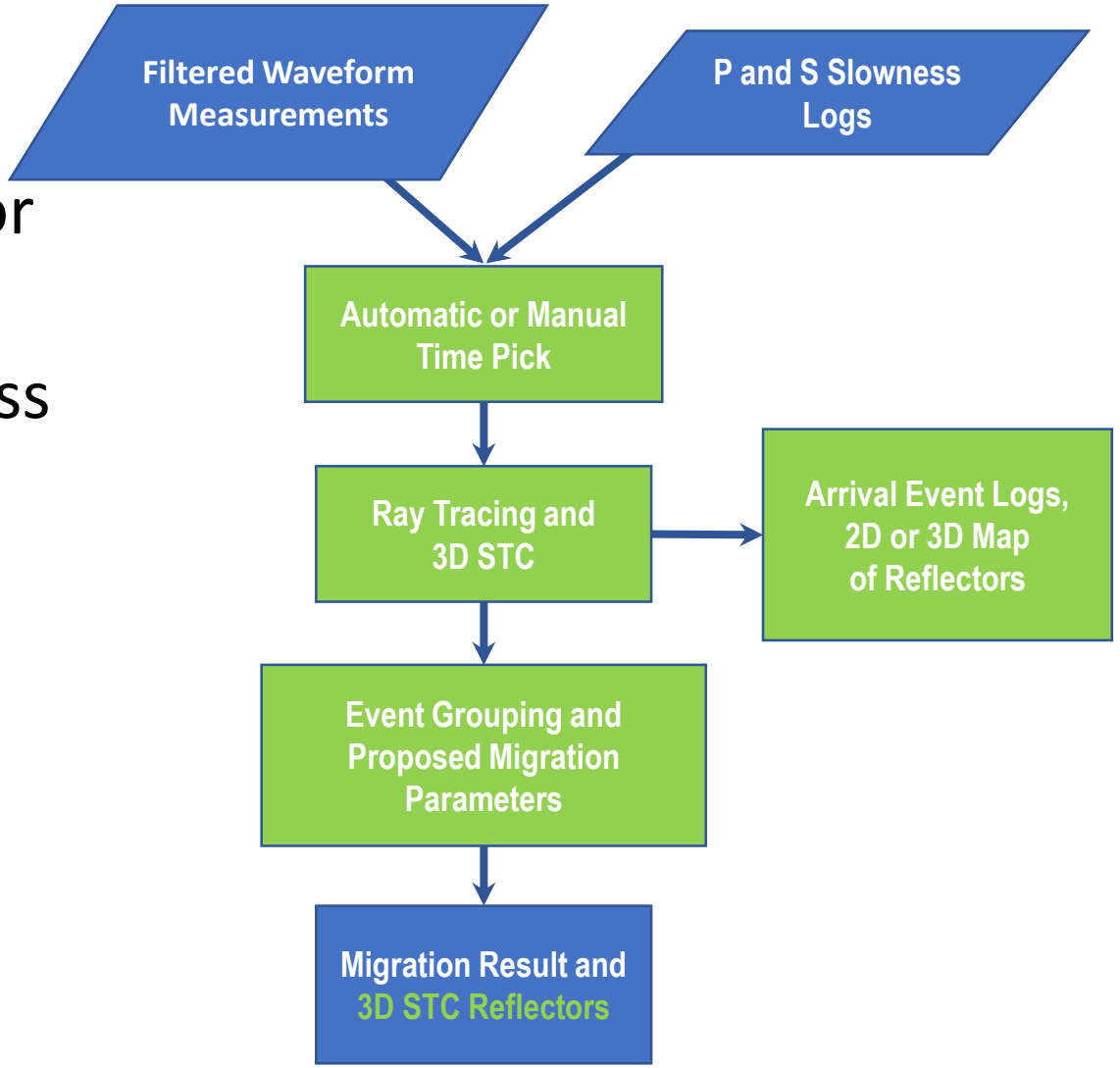
Modeling of a Monopole Wavefield



Linear moveout is function of wavefront incidence angle, θ, and is equal to $s \cos\theta$, where s is the formation slowness.

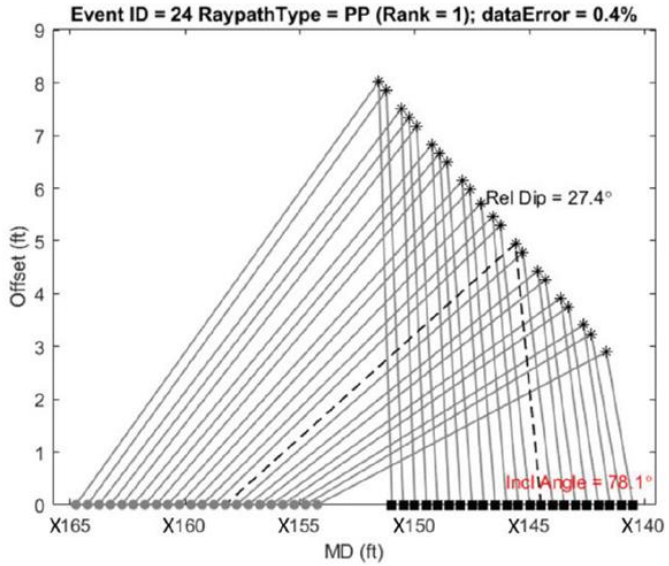
- Determine geometry of sonic reflector planes
- 3D propagation direction and slowness using waveforms and geometry of all receiver sensors

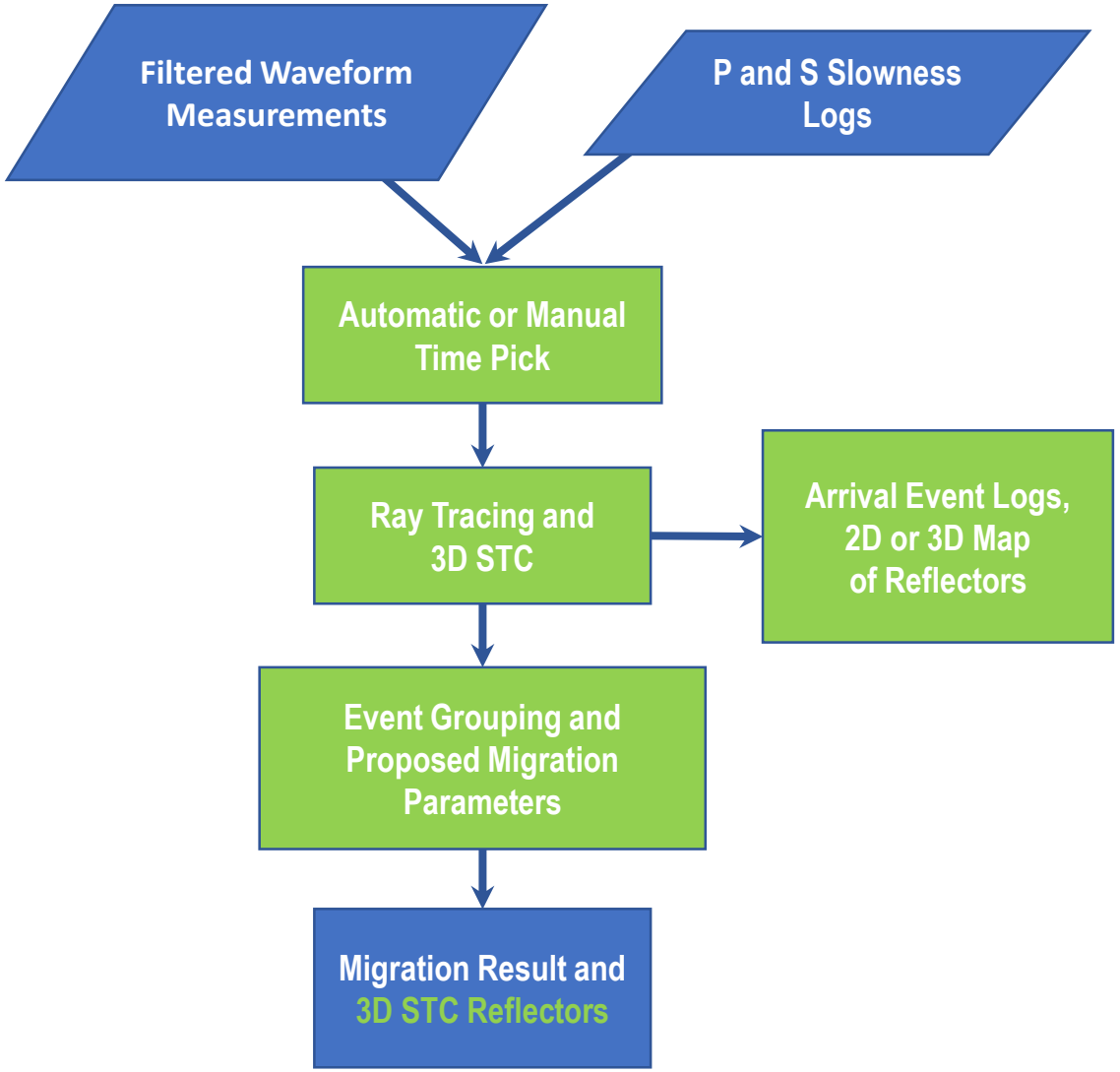




Bennett, 3D Slowness Time Coherence for Sonic Imaging: Geophysics, 2018

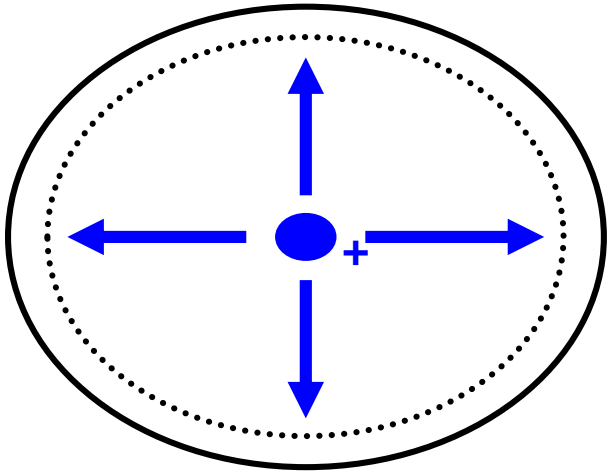
- Determine geometry of sonic reflector planes
- 3D propagation direction and slowness using waveforms and geometry of all receiver sensors

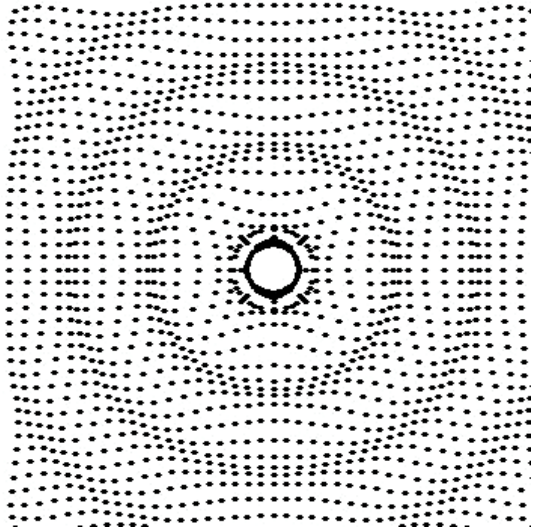


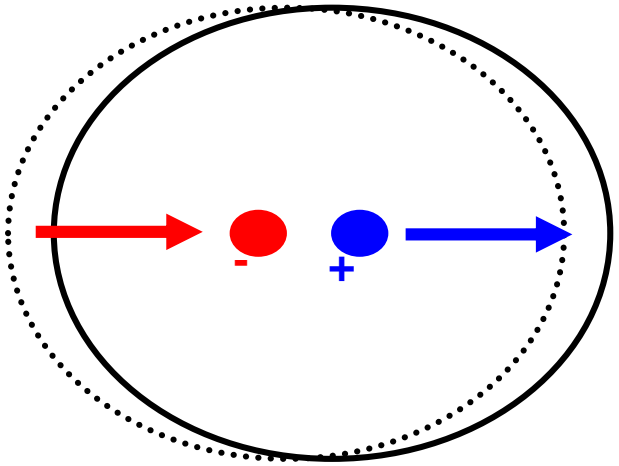


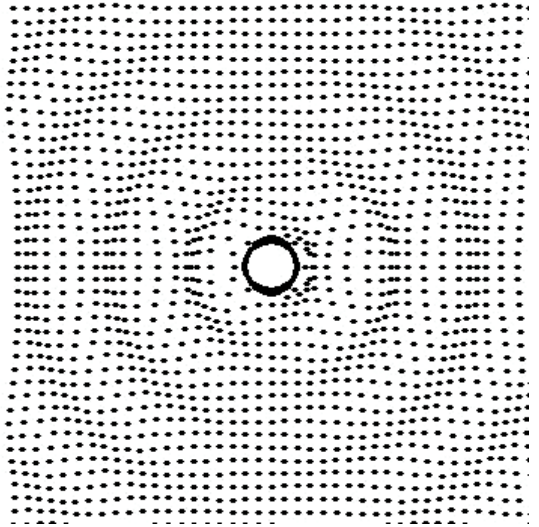
Bennett, 3D Slowness Time Coherence for Sonic Imaging: Geophysics, 2018

Wave Propagation from Monopole and Dipole Source

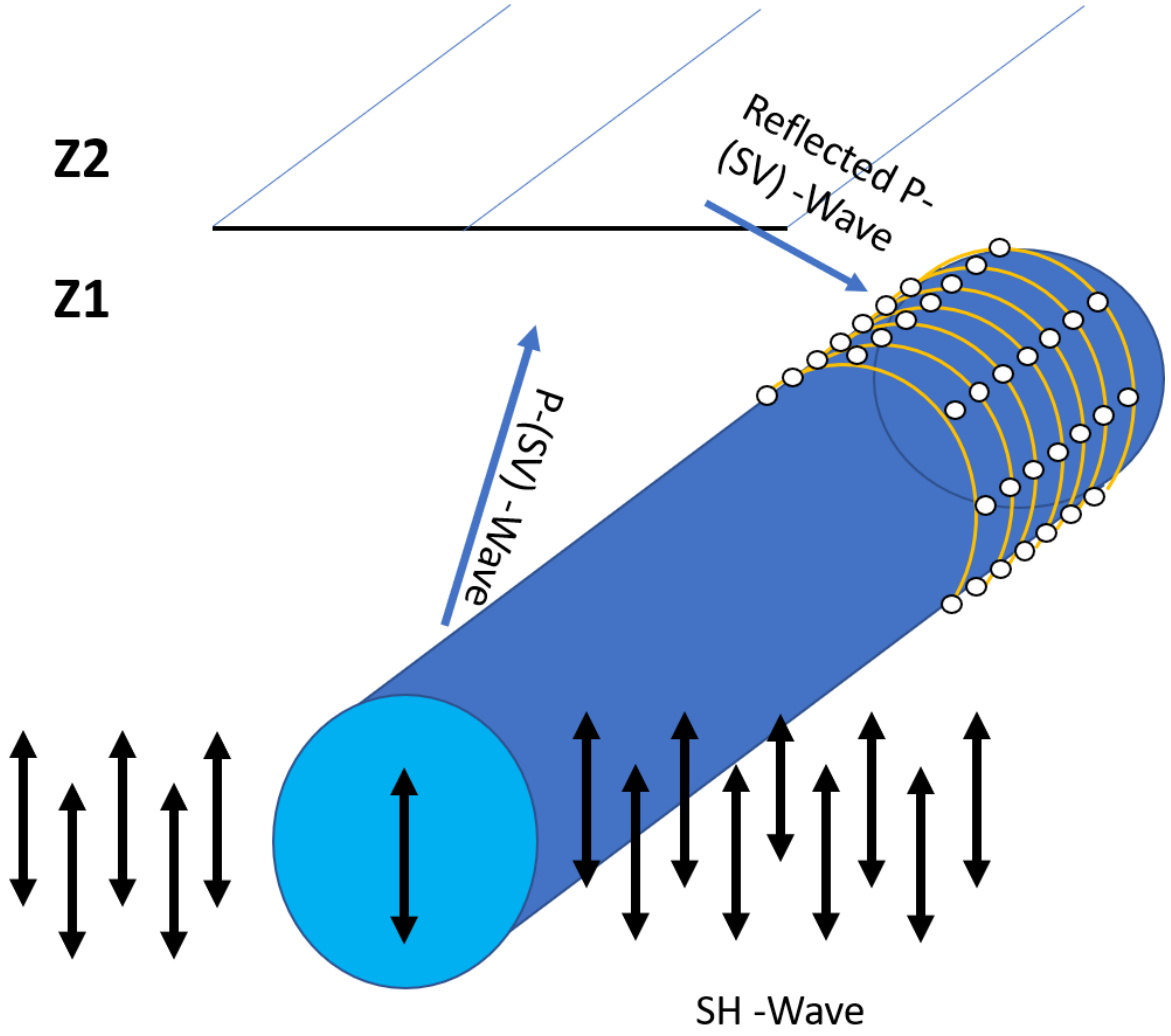


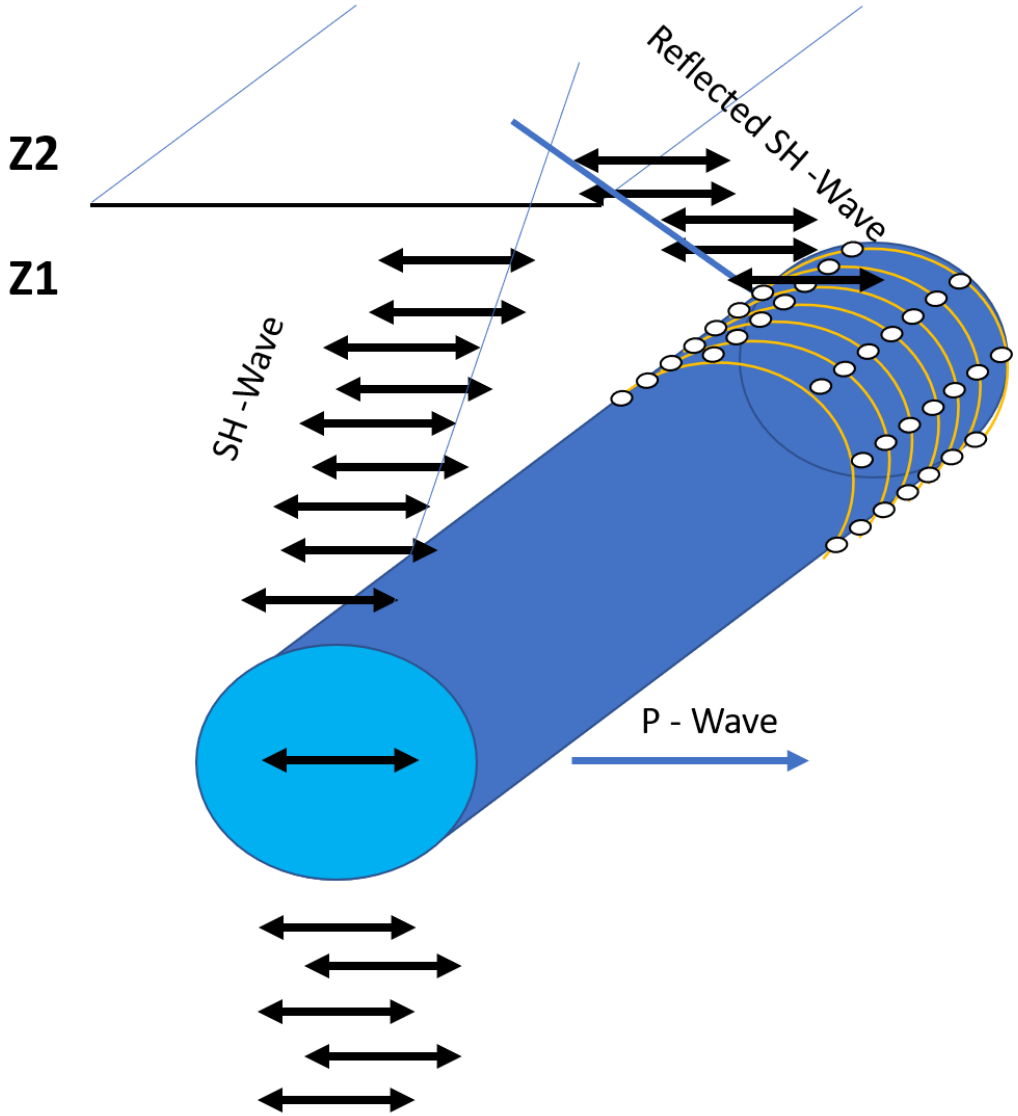




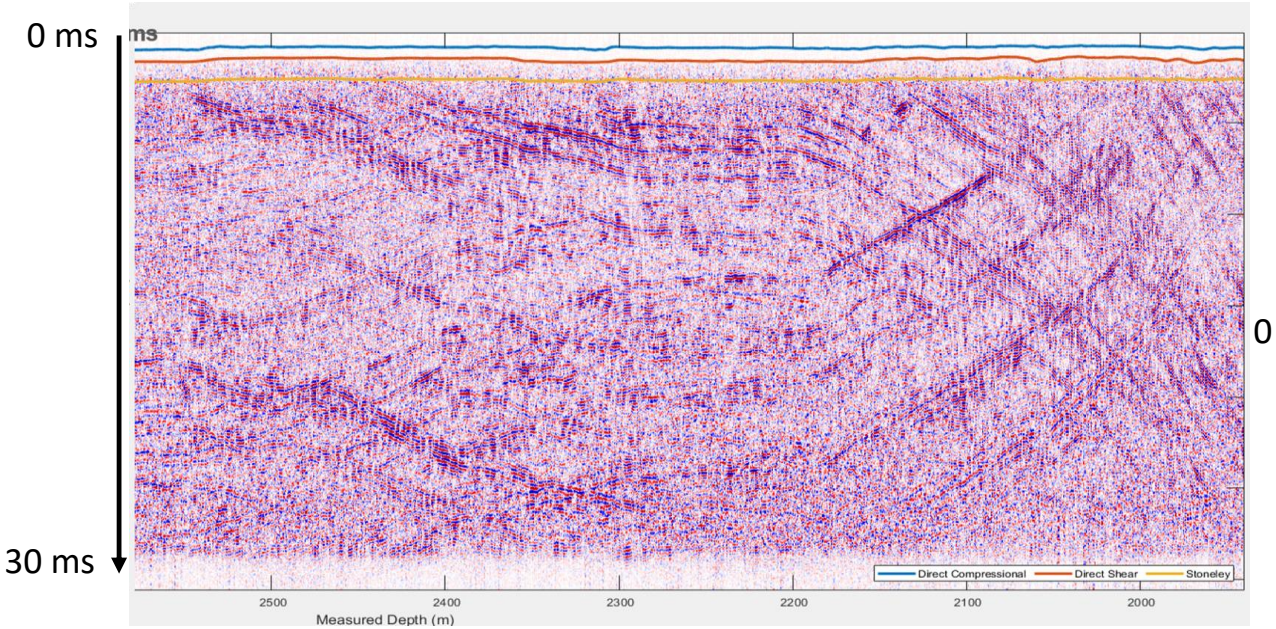


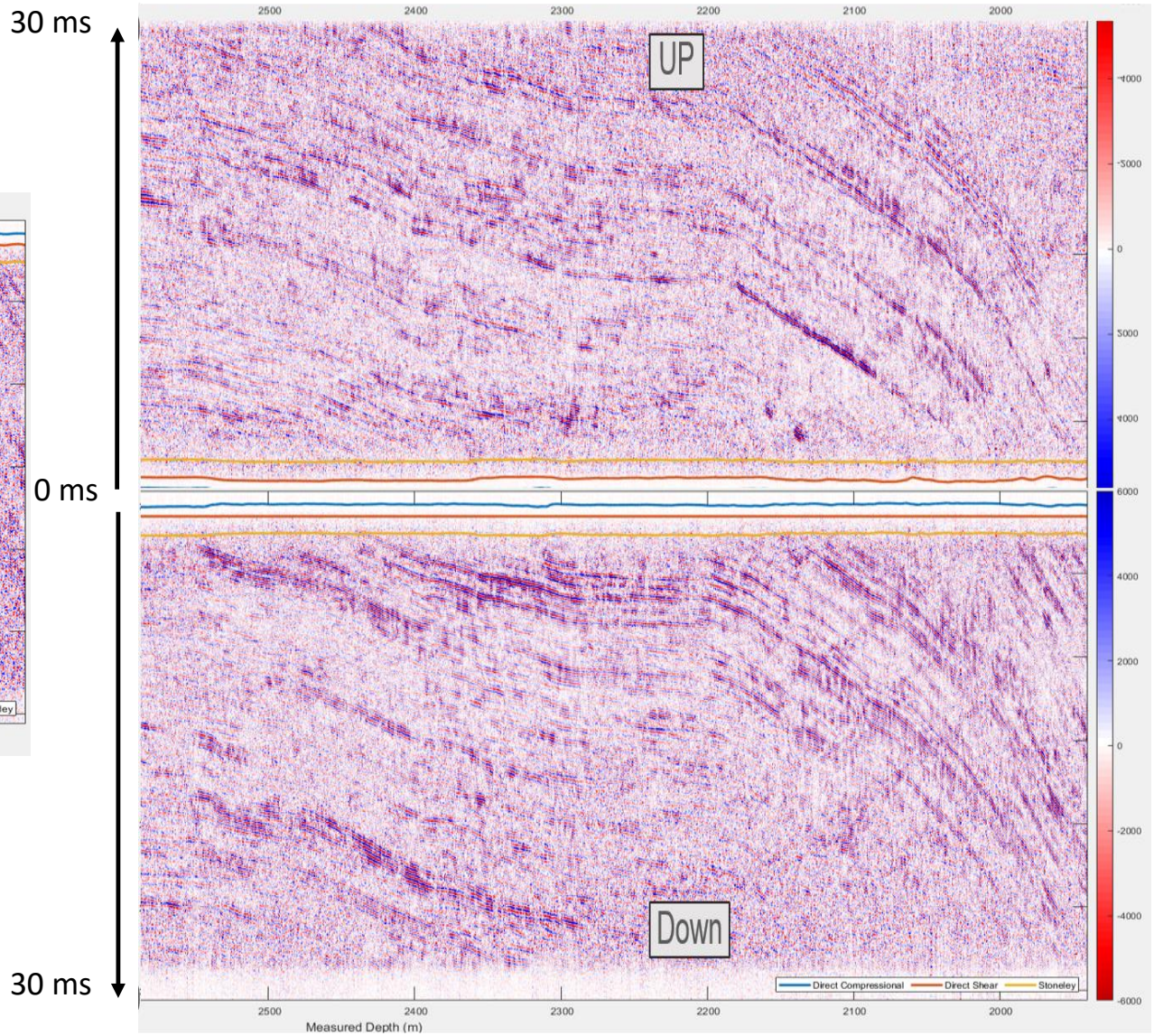
Dipole produces SV and SH waves in the formation



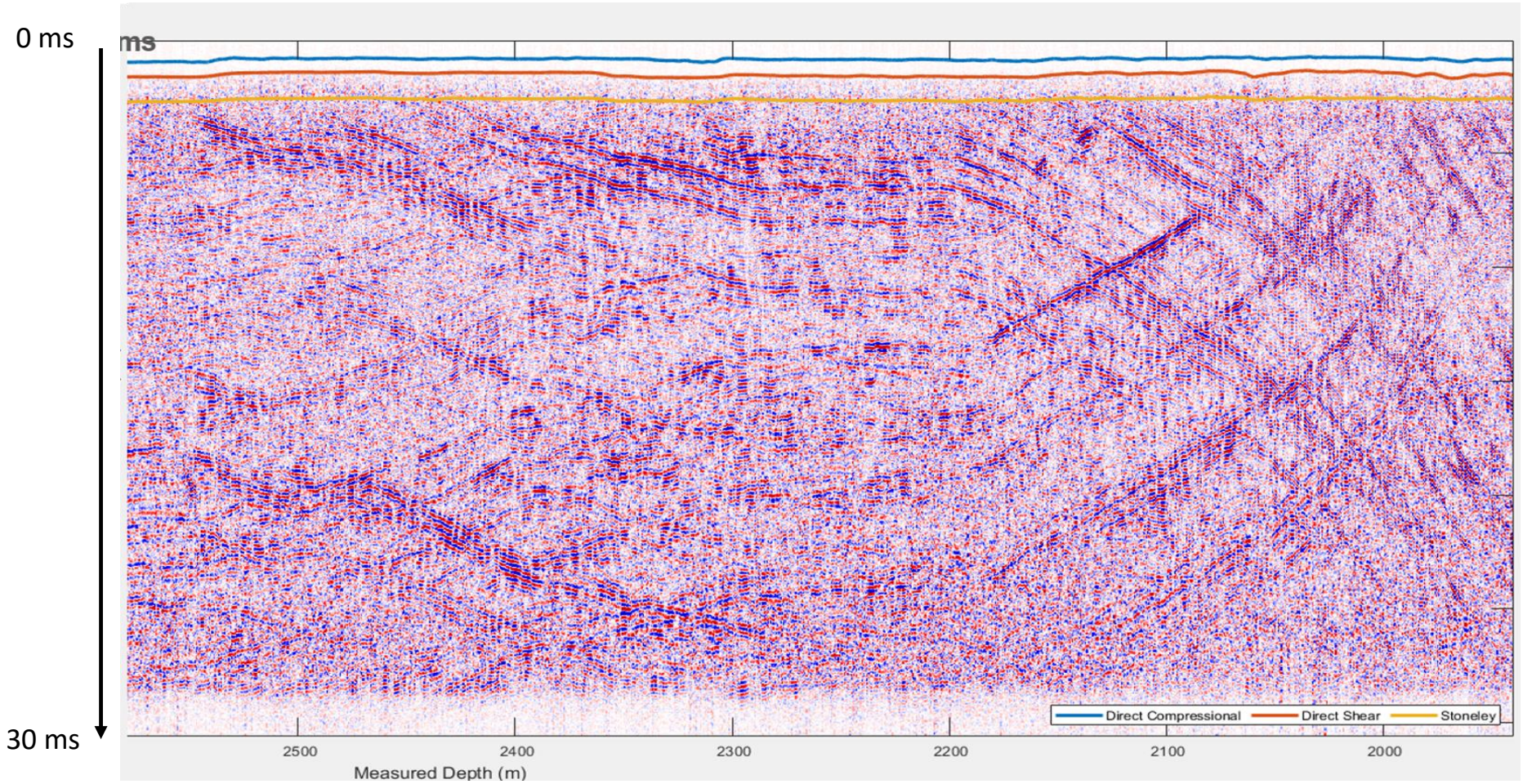


Sonic Imaging- To define layer continuity

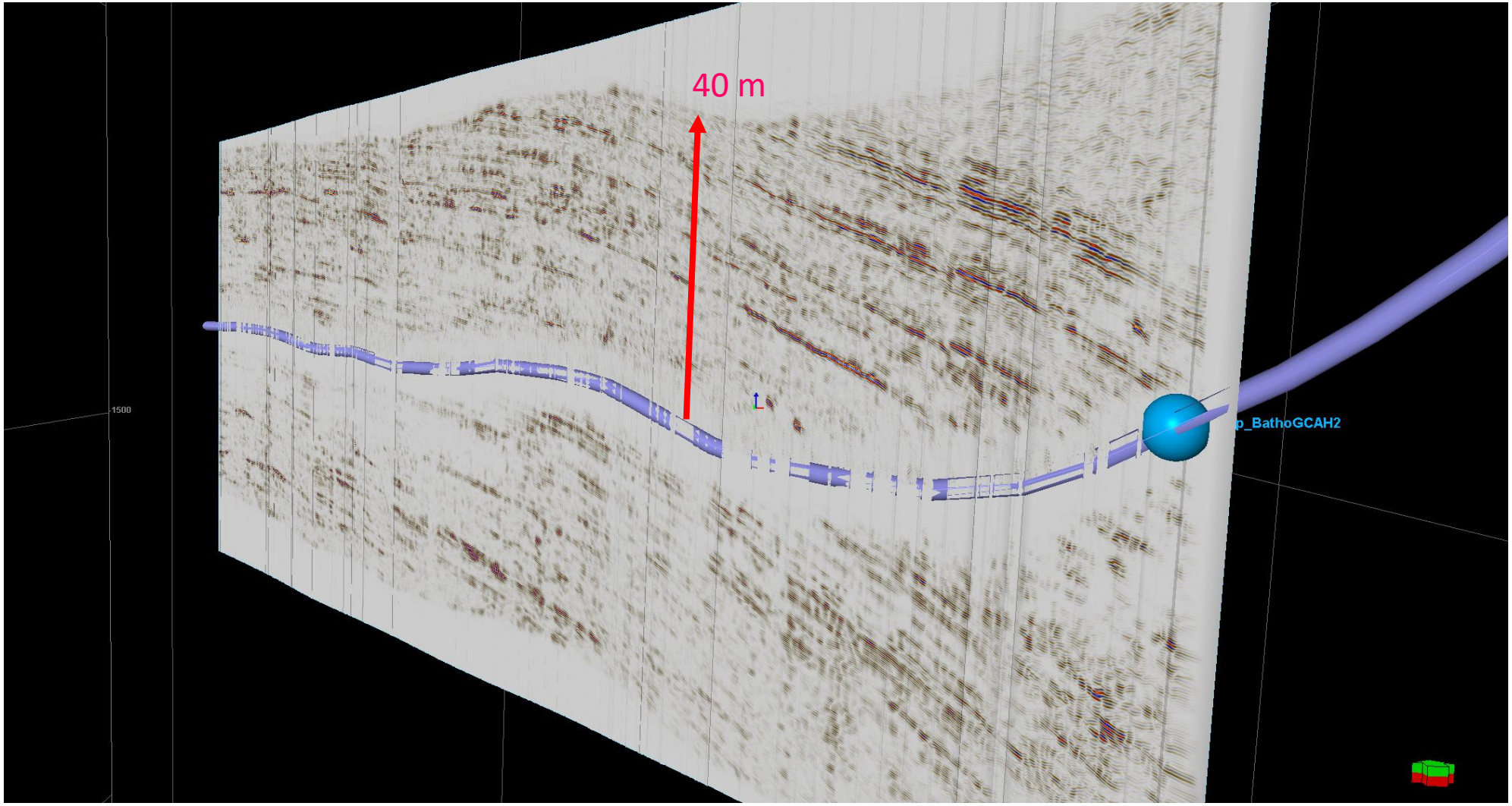




Sonic Imaging- To define layer continuity

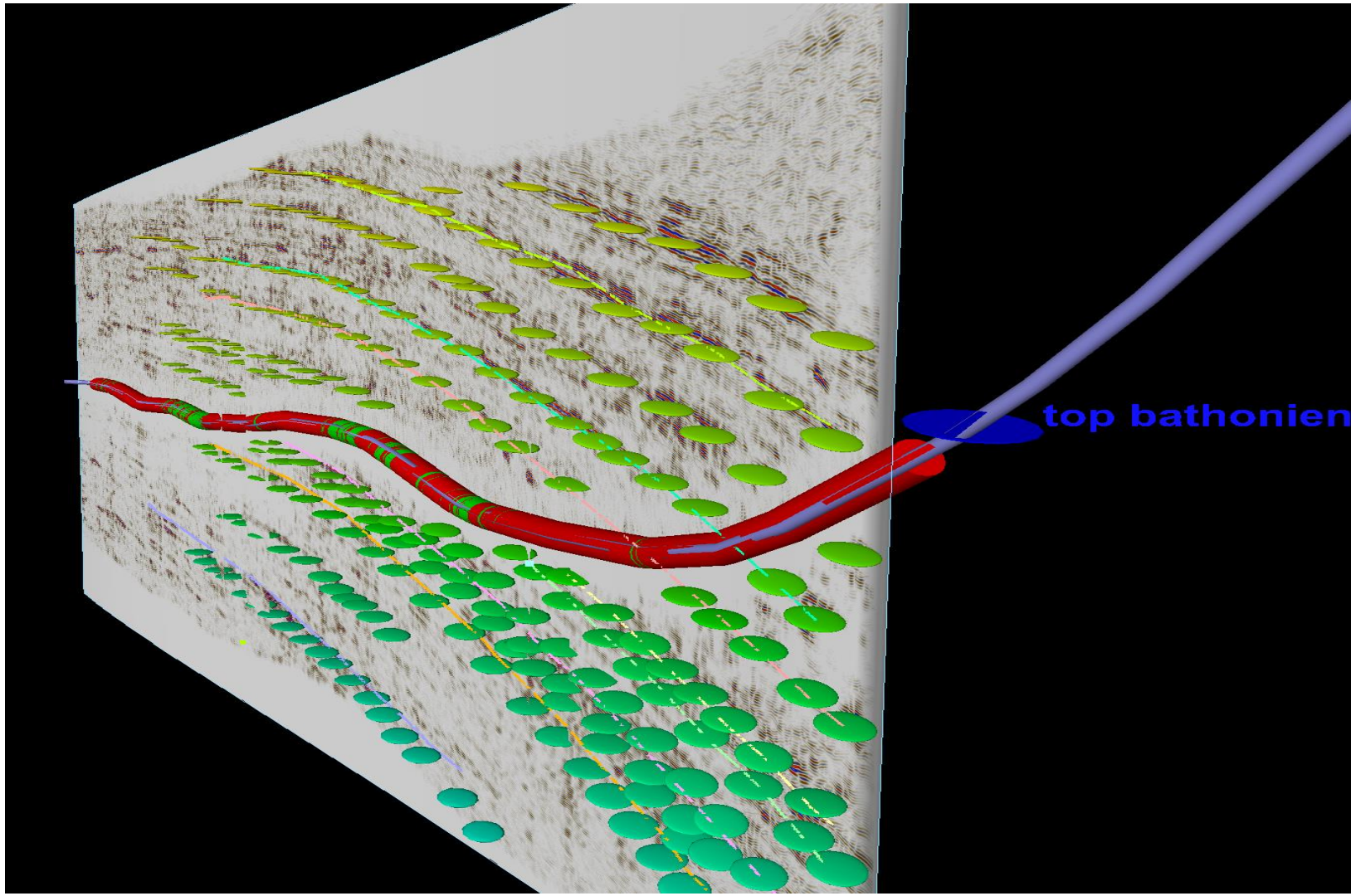


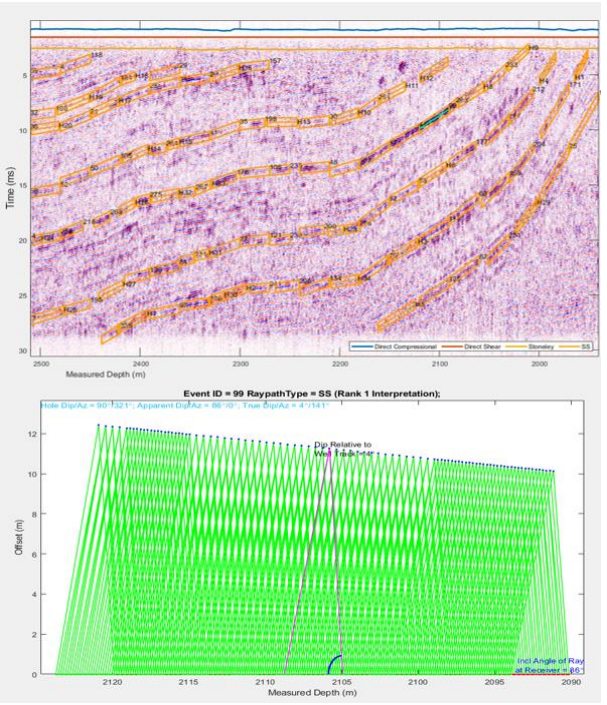
Sonic Imaging- To define layer continuity

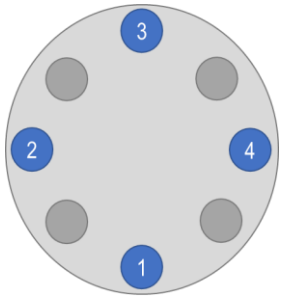


1000 m section

3D STC: Dip & Azimuth for Structural model







Conclusion

- The case study showing LWD and wireline logging critical in reducing the risks involved in developing geothermal plays
- The doublet involving a novel sub-horizontal well design producing 500 m3/hr, more than the two traditional doublets (300 m3/hr total) it replaced
- The NMR in combination with oriented density and sonic were used to interpret the lateral heterogeneity and determine the optimal flow units for further stimulation.
- In addition the Dipole Sonic was explored to determine the continuity of the layers away from the wellbore. Mapping reflectors over 1200 m and up to 40 m from the wellbore!

Acknowledgements

- The authors would like to thank Dalkia (EDF Group), the project owner, and the city of Cachan, the project initiator for the authorization to publish this paper
- We would also like to thank our colleagues N. Bennett, N. Hirabayashi, Y. Karpekin and A. Johansen for their inputs and discussions related to Sonic imaging