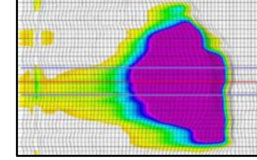
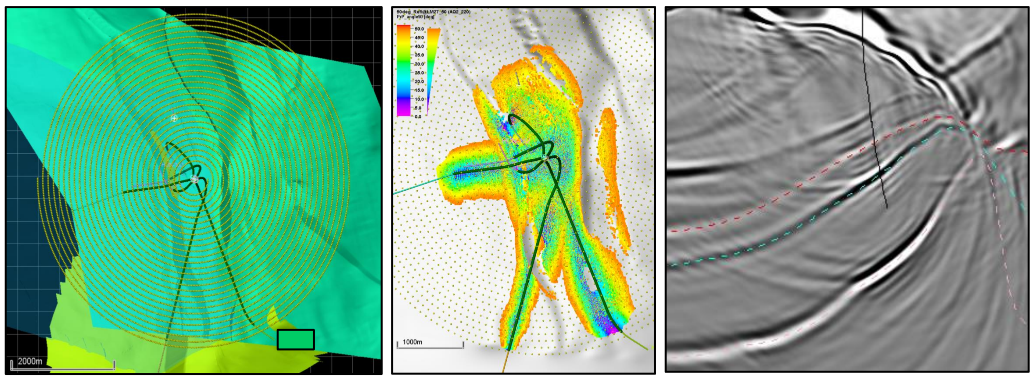


NPD FORCE Geophysical Methods Group

Survey design & modelling



By: *Rafael Guerra (Domain Center Geophysicist)*

Schlumberger

Stavanger, 04-Oct-2022

General BHS Survey Design & Modelling Guidelines

1. Survey Objectives:

- **Time-depth velocity control** → *is boat required for deviated wells?*
- **Wideband, true-amplitude, zero-phase** → *optimize source parameters?*
- **Look-ahead / drilling assistance** → *depth accuracy or thickness resolution required ?*
- **High-resolution imaging (**P- or converted S-waves) → *resolution, lateral illumination and fold?*
- **AVO/AVAZ calibration** → *offset/angle ranges required, antenna position*
- **TTI anisotropy** → *global travel times or local slowness-polarization?*
- **Full Waveform inversion** → *which parameters we want to invert?*
- **Fractures characterization** → *HTI, ORT or lower symmetry media*
- **Seismic multiples study** → *1D reflectivity modelling*
- **Time-Lapse response** → *rock physics / geomechanics*
- **Microseismic monitoring** → *minimum magnitude detectable, MT invertibility, …*

2. Geological model/velocity model complexity

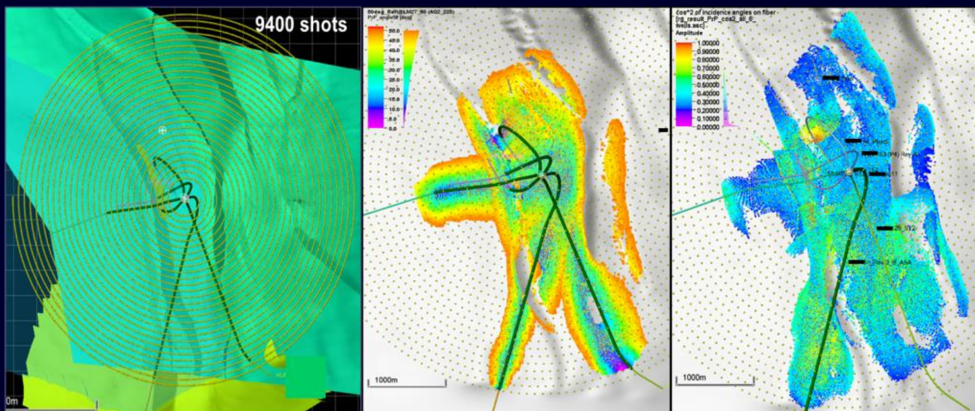
- Flat and boring or high dips? Nearby faults, gas pockets or salt domes ?
- Are there strong lateral or vertical velocity variations?
- Is there a preferential dip direction to shoot 2D survey?

General BHS Modelling Guidelines *(cont.)*

3. **Input data available:** *quantity and quality*
4. **Modelling technique:** *conditioned by all three previous points*
5. **Well conditions & well geometry:** *type of tool or fiber optics and conveyance*
6. **Surface conditions:** *where sources can be deployed*
7. **Equipment available:** *if not in place, feasibility to import equipment in time*
8. **Project cost:** *any technical solutions must be realistic & cost-effective*

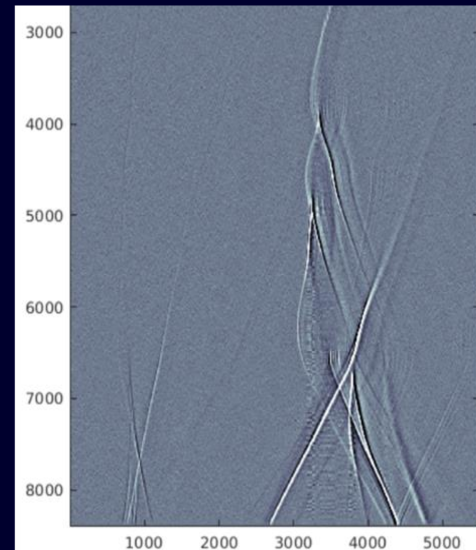
Pre-survey Geophysical Modelling: *Feasibility & Geometry Optimization*

- Illumination, fold, incidence angles at targets & at fiber
- Anisotropic synthetics and moment tensor sources
- Low-frequency strain modeling vs DAS data



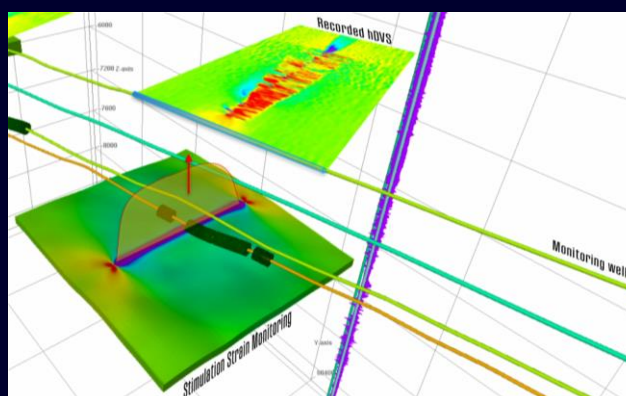
Incidence angle < 50°

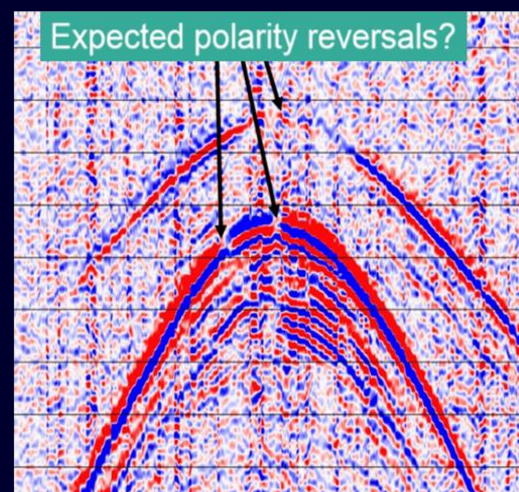
$\cos^2 > 0.2$



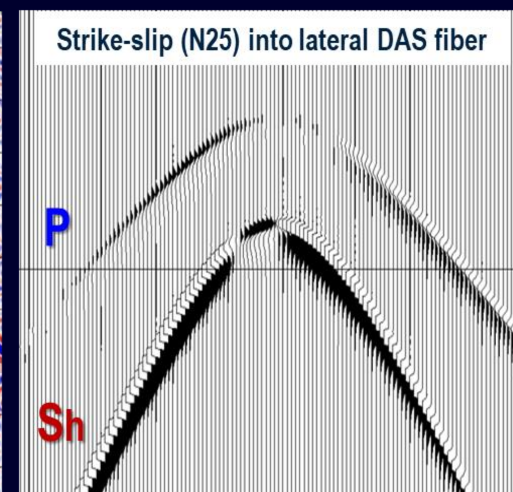
Omega 3D visco-elastic anisotropic Finite Differences used in complex surveys

DAS box frequency response can be applied to synthetics



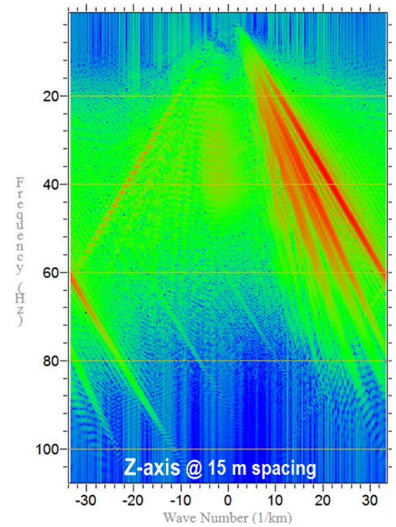


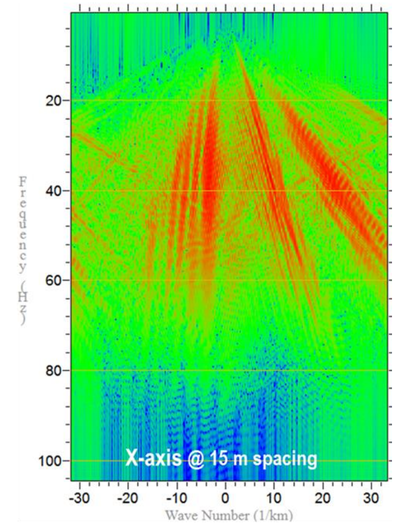
(Diller and Richter, 2019)



(Leaney, 2019)

Standard Zero-offset VSP design





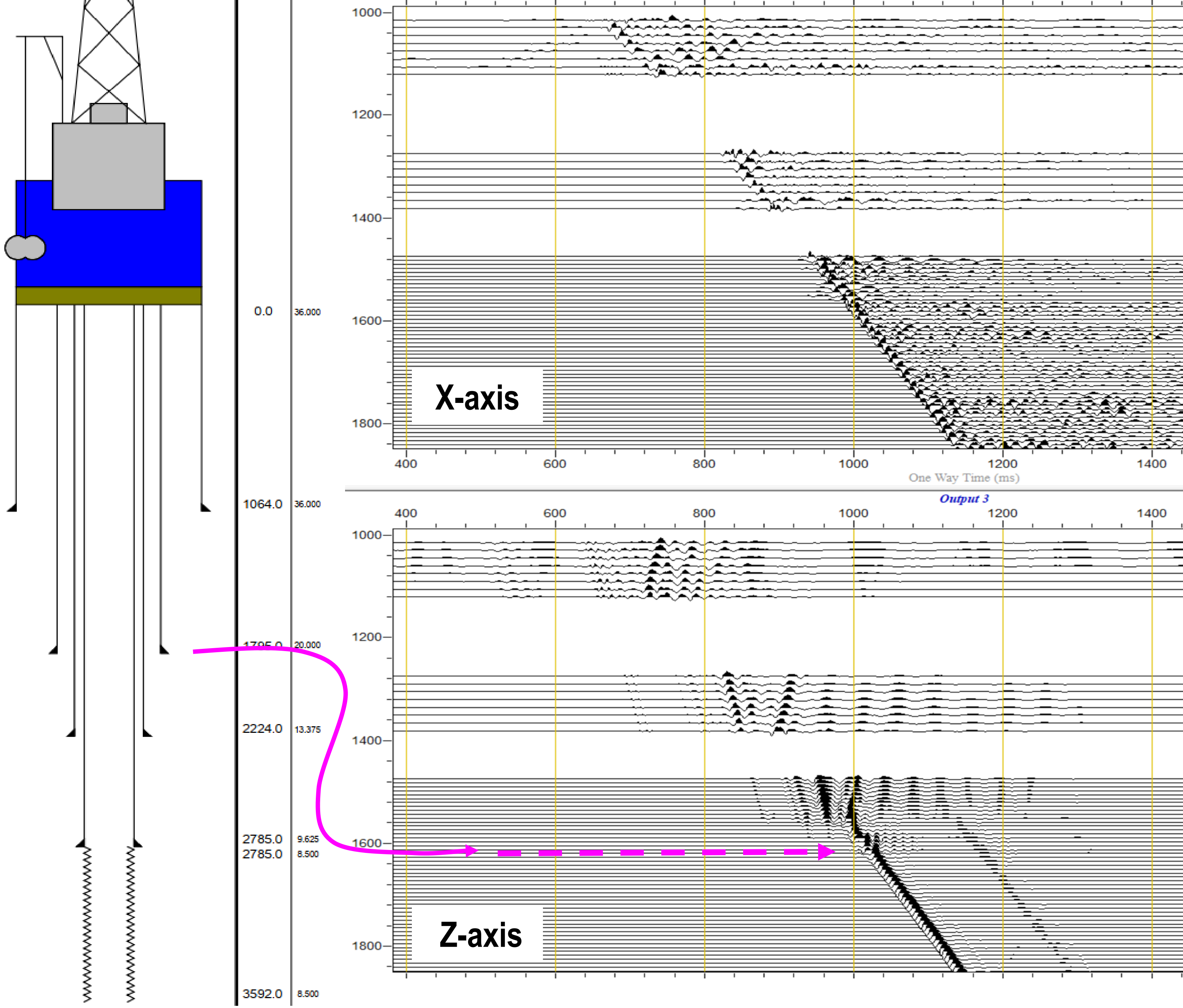
- 3C / 4C sensors spaced @15 m *(5 - 30 m)*
  For DAS fiber optics, @5m *(1 - 10 m)*
- Irregular spacing is OK
- To avoid aliasing spacing: **DZ < Vmin / 2* Fmax**

  E.g.: P-waves, ***Vmin*** *= 2250 m/s and* ***Fmax*** *= 75 Hz → **DZ** < 15 m*

  Higher frequencies, fine layering, complex geology, S-wave or tube waves require shorter spacing (~7.5 m)
- Aliasing avoided with median filters *when the downgoing & upgoing moveouts are known*
- Short spacing is recommended for high resolution applications, higher SNR results and also in complex geology with rich content of different wavefields
- VSPs can be recorded in OH or CH, fair cementation required over near vertical sections.
  No cement required if deviation > ~30°
- **Standard VSP program:** *record at 15 m from TD up to as shallow as possible (no ringing on Z-axes) and then at ~120 m up to surface (or seabed) if data quality allows*

ZVSP
8-shuttles

Vertical well



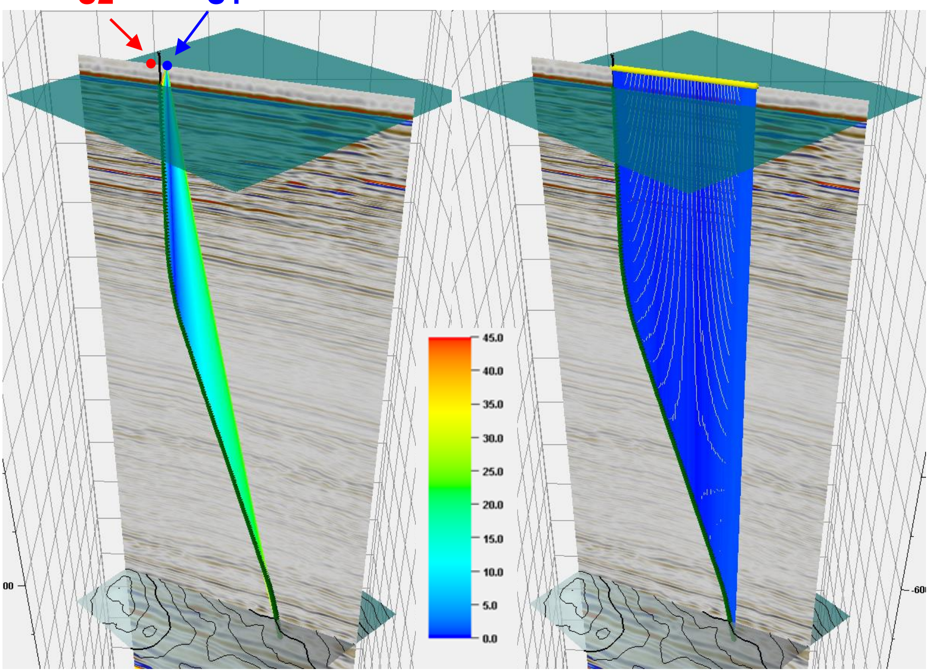
- 3C
- Airguns
- Nearly vertical
- 2, 3, 4 casings

Rig source or boat VIVSP?

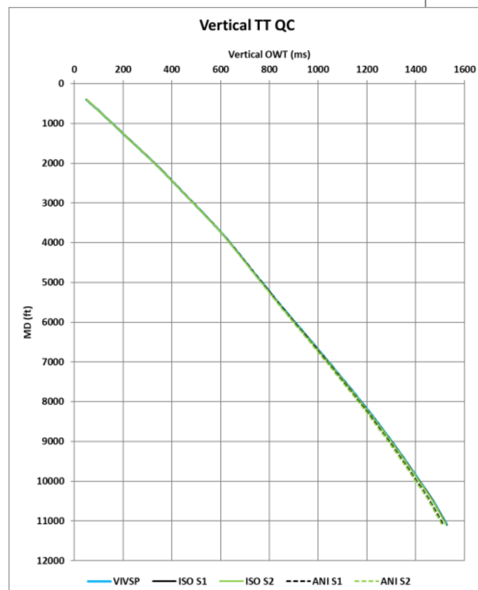
- Well step-out > ~500 m?
- Flat and boring geology?
- Propagation angles high?
- Velocity variations strong?
- Anisotropy high?

2 rig sources tested at +/- 200 ft offset

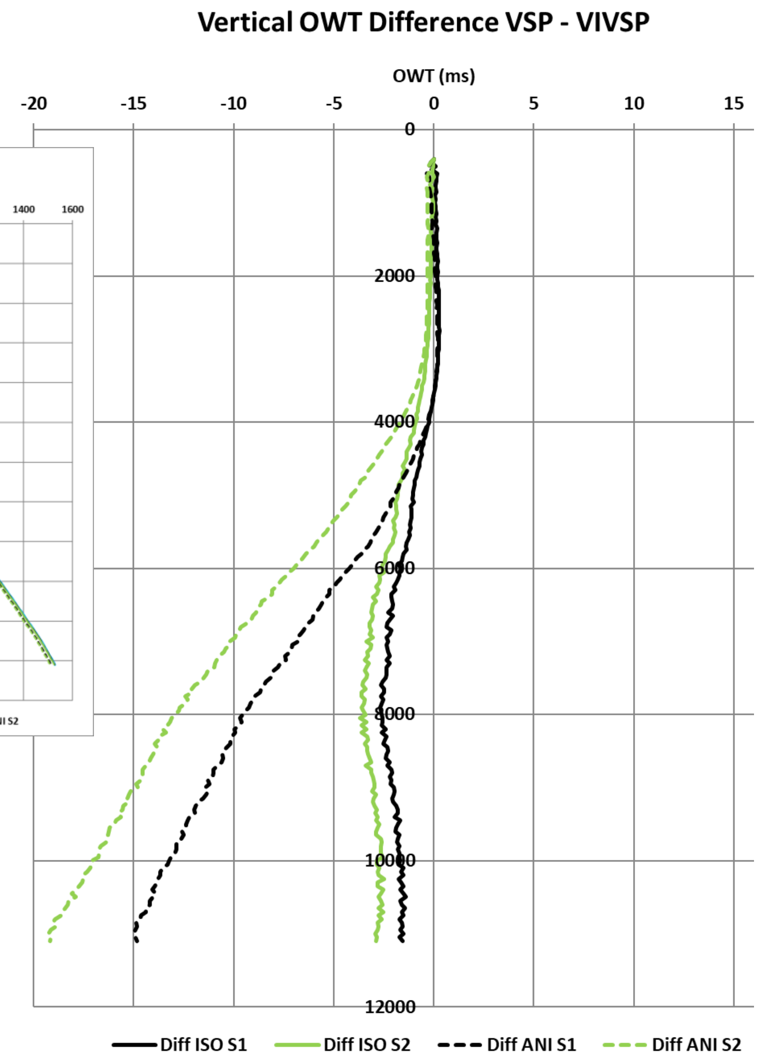
VIVSP or Walkabove



***VTI model:** epsilon < ~0.20, delta < ~0.10*



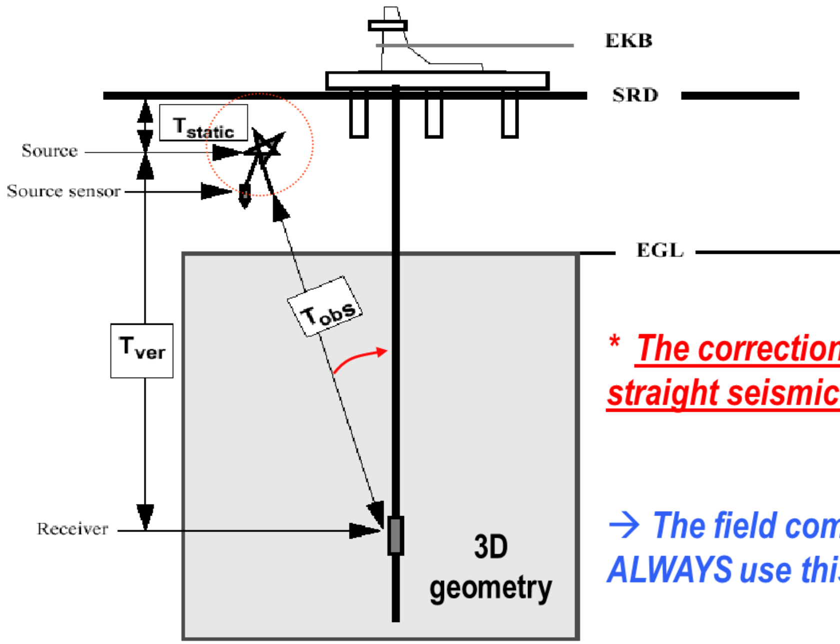
(Dahlhaus, 2021)



Two rig source positions tested and isotropic vs anisotropic model

Test accuracy of isotropic straight ray path assumption

Standard Method: *Cosine Correction*



** The correction assumes straight seismic ray paths*

→ The field computations ALWAYS use this method

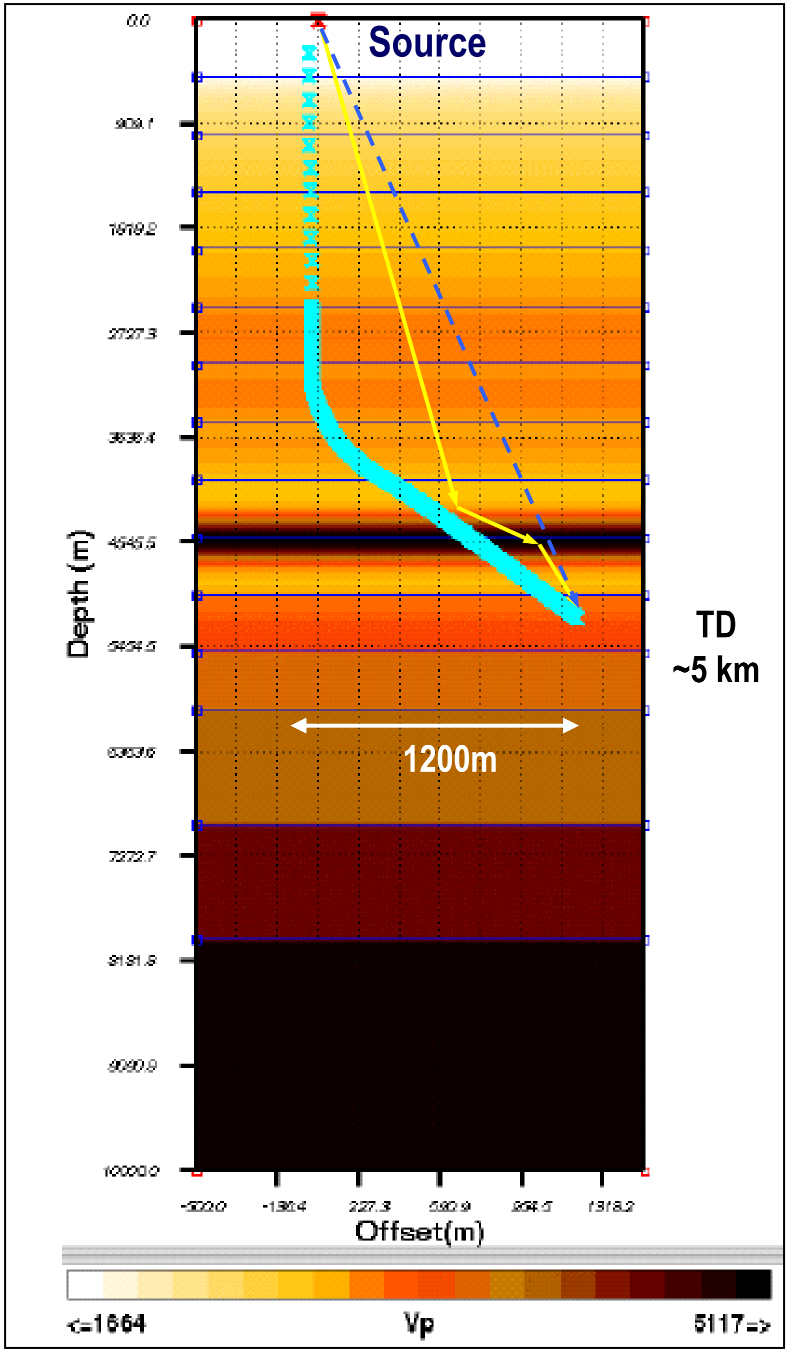
Examples of T-Z listing in field reports:

Stack Summary Listing (1/6)
Survey_WAVEFIELD_RECEIVER_Z_for_Report.ldf

Stack Number	Measured Depth [ft]	True Vertical Depth [ft]	Measured Time [s]	One-way Vertical Time [s]	Two-way Vertical Time [s]	Interval Velocity [ft/s]	Average Velocity [ft/s]	RMS Velocity [ft/s]
	0	0	0	0	0			
						5388.3		
43	391.0	345.0	0.0772	0.0640	0.1280		5388.3	5388.3
						6479.9		
43	441.0	395.0	0.0830	0.0717	0.1435		5505.7	5516.1
						7242.3		
43	491.0	445.0	0.0883	0.0786	0.1573		5658.2	5688.7
						7403.8		
43	541.0	495.0	0.0938	0.0854	0.1708		5796.2	5842.7
						6608.5		
42	791.0	745.0	0.1282	0.1232	0.2465		6045.6	6088.1
						7747.9		
42	841.0	795.0	0.1341	0.1297	0.2594		6130.3	6181.2
						9031.1		
42	891.0	845.0	0.1392	0.1352	0.2704		6249.1	6323.2
						[illegible]		

Stack Summary Listing

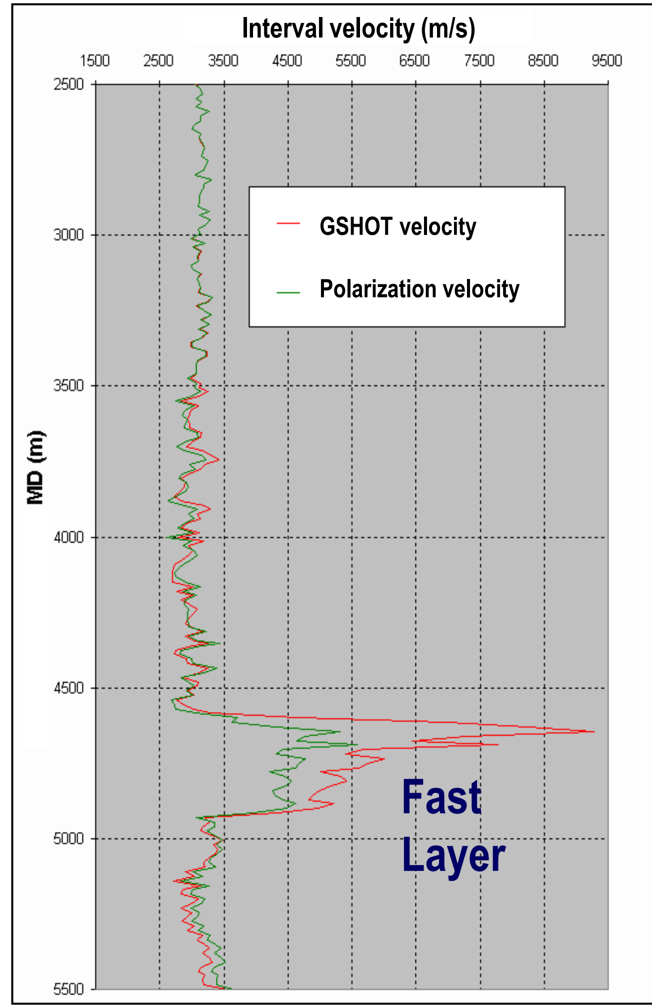
Stack number	Well depth[m]	TVD from SRD[m]	TT[ms]	TT(TVD Corrected)[ms]	TWT(TVD Corrected)[ms]	Interval Velocity[m/s]	Average Velocity[m/s]	RMS Velocity[m/s]
62	49.99	39.06	91.07	31.29	62.59	983.77	1248.08	1248.08
61	51.54	40.61	92.47	32.87	65.74	1654.13	1235.39	1236.68
60	125.04	114.10	103.98	77.30	154.60	1806.41	1476.07	1490.97
59	200.01	188.92	133.79	118.72	237.44	1895.72	1591.32	1608.06
58	274.96	263.84	168.02	158.24	316.48	1818.54	1667.34	1684.51
57	350.01	338.83	206.17	199.48	398.95	2300.44	1698.59	1713.08



ATTENTION

VSPs in deviated wells <u>or</u> vertical wells in strongly dipping layers (>10°)

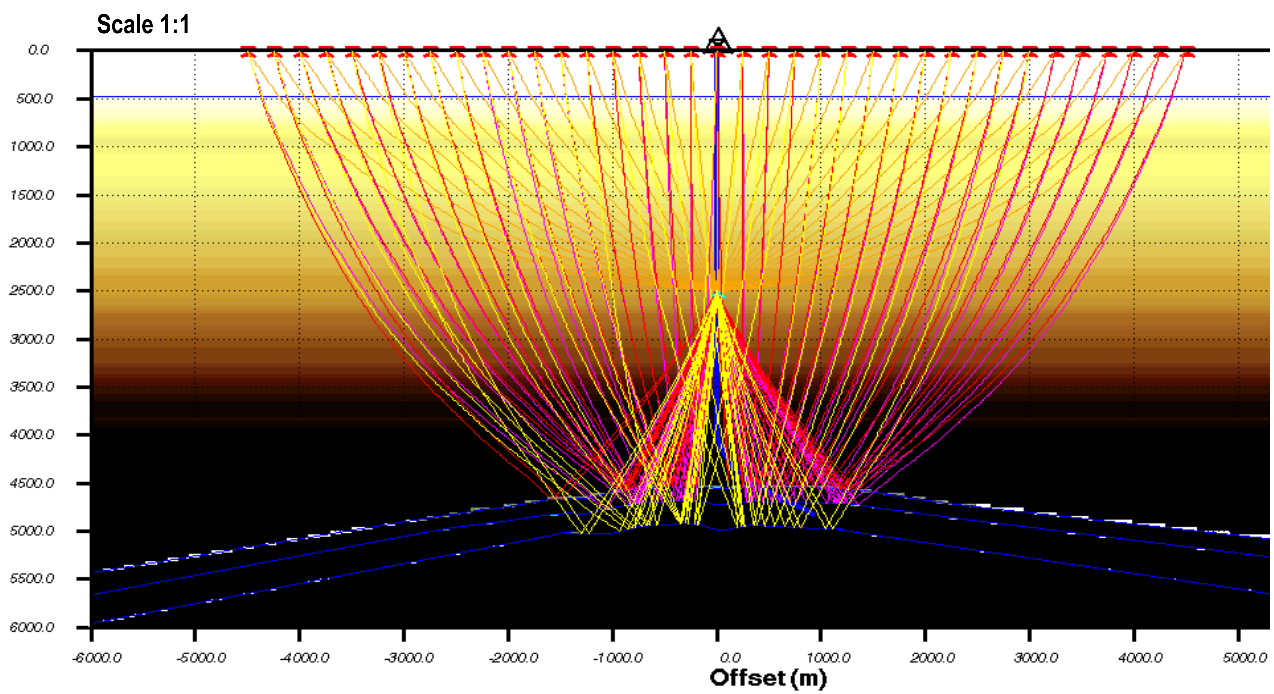
→ **Strong velocity contrasts** refract the P-waves and affect the std method accuracy

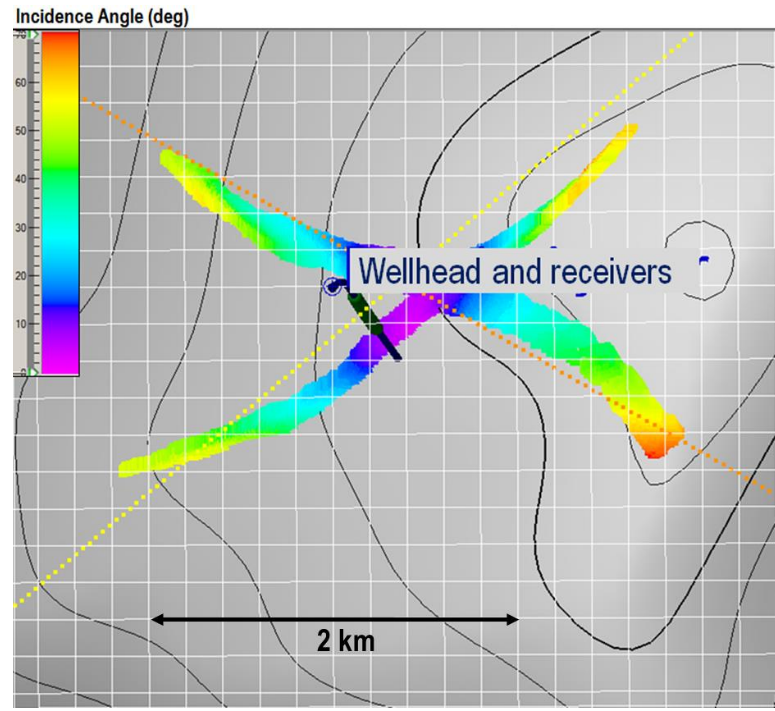


Improvements on standard method:

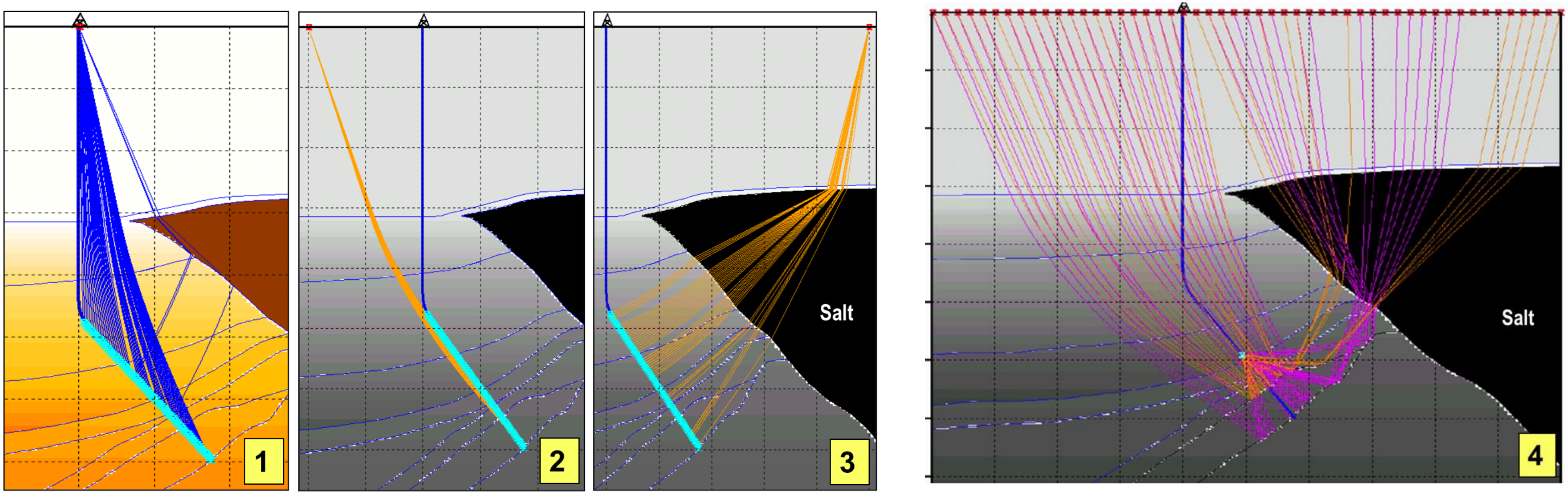
- *3C polarization method*
- *Ray-based tomography*
- *FWI*

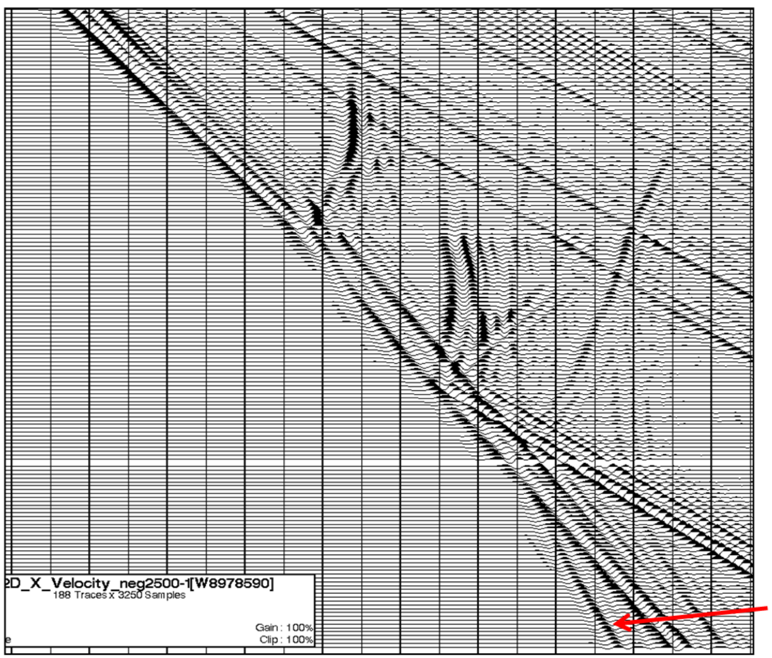
Standard Walkaway VSP design

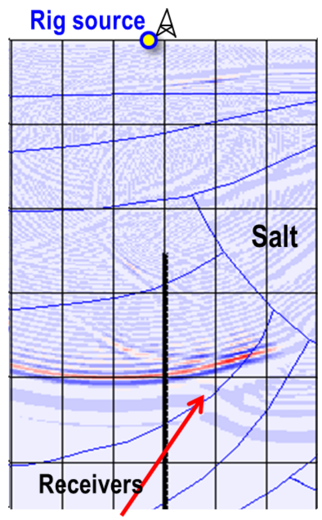




- Direct P-wave angles at receivers **> ~90°** *(for VTI estimation)*
- Reflection angles at target are **< ~45°** (imaging), and **< ~60°** *(AVO)*
- For imaging, the receiver array is *typically* ~1 km above the target
- For local TTI estimation, place ~12 receivers across shales of interest
- For AVO, place receivers immediately above the interfaces of interest
- In complex geology reflected points can deviate from the 2D plane and a 3D solution is required

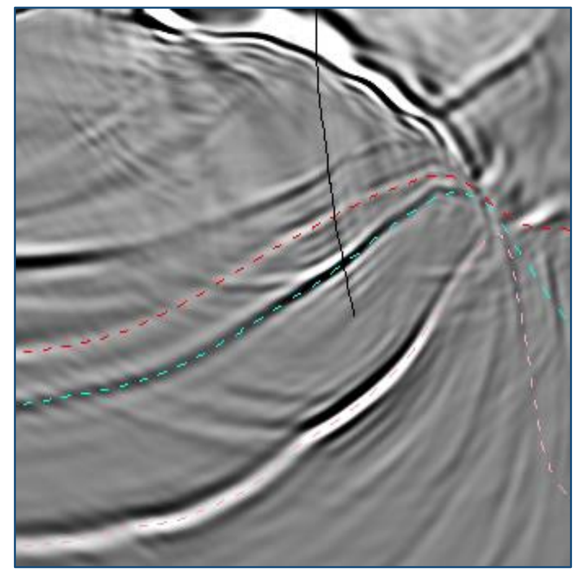






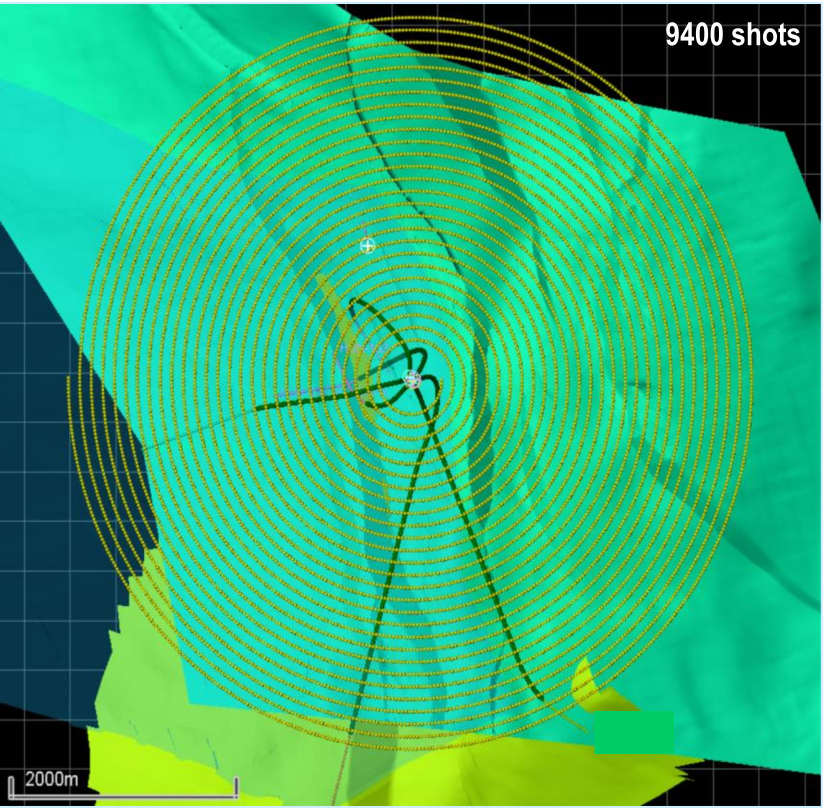
Salt arrivals come earlier than sediment arrivals

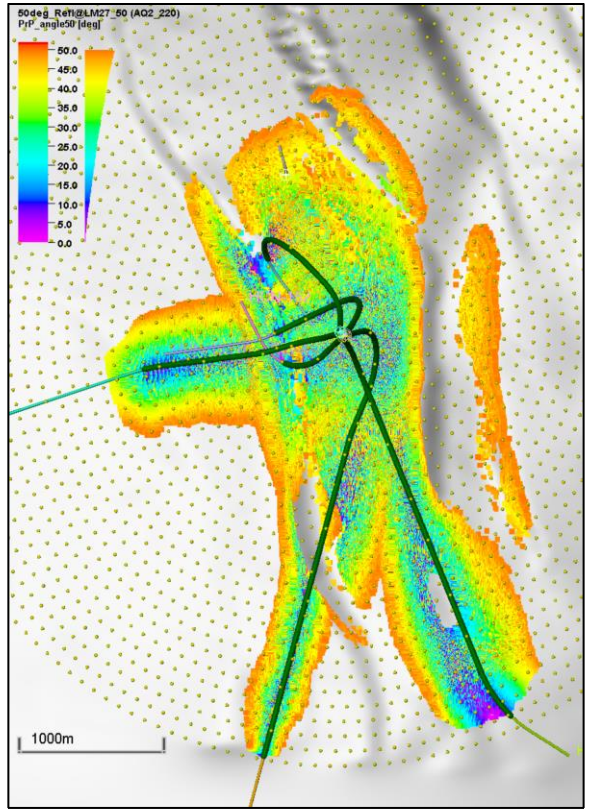
→ **Headwaves & multiple arrivals are properly modelled**



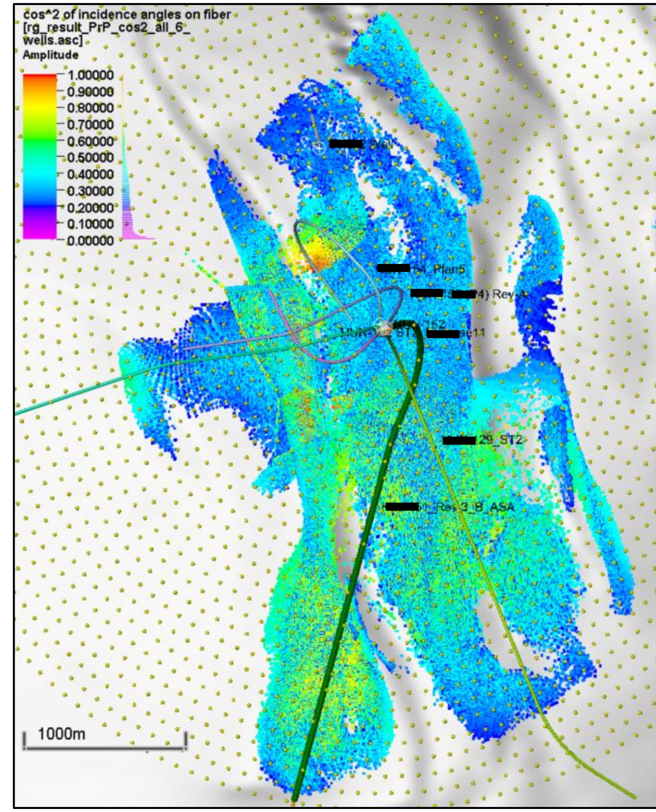
Walkaway TTI 3D Finite Differences + RTM Imaging *(Lal Khaitan et al., 2022)*

DAS modeling – *cosine square directivity*





Incidence angle < 50°



$cos^2 > 0.2$

NOTE: *recording 3DVSPs in 4 well simultaneously requires only 2 DAS boxes of latest generation*

Q & A