ERD wellbore positioning with LWD Seismic

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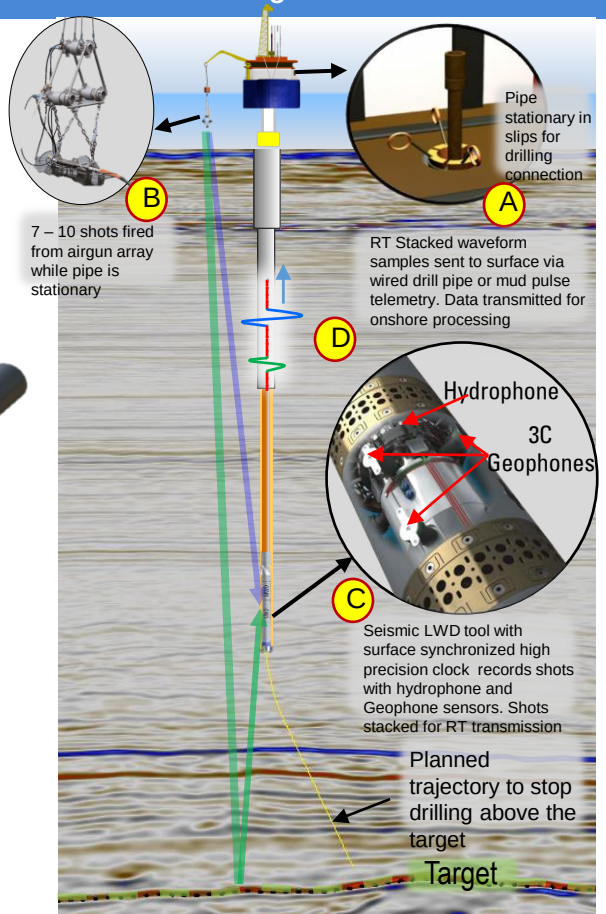
Agenda

- Intro to LWD Seismic AKA Seismic While Drilling
- Lateral wellbore positioning using seismic travel time
- Modelling example and results
- Case study
- Conclusion

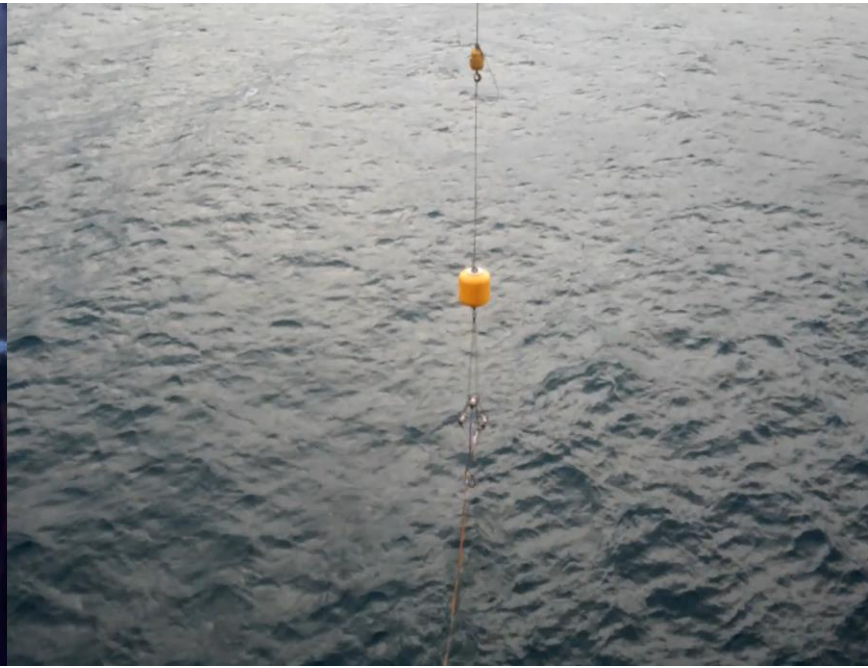
Seismic While Drilling

- Length: ~ 14 ft
- Pressure Rating: 23k – 30k PSI
- Any Hole size > 8 3/8”
- Any Hole angle



ZERO RIG TIME FOR NORMAL DRILLING ACQUISITION

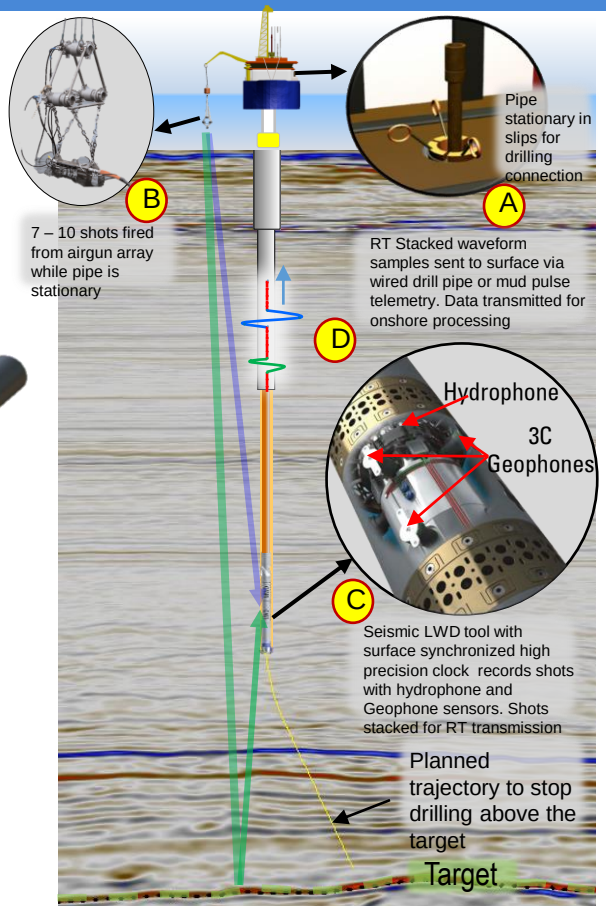
4 x Playback Speed

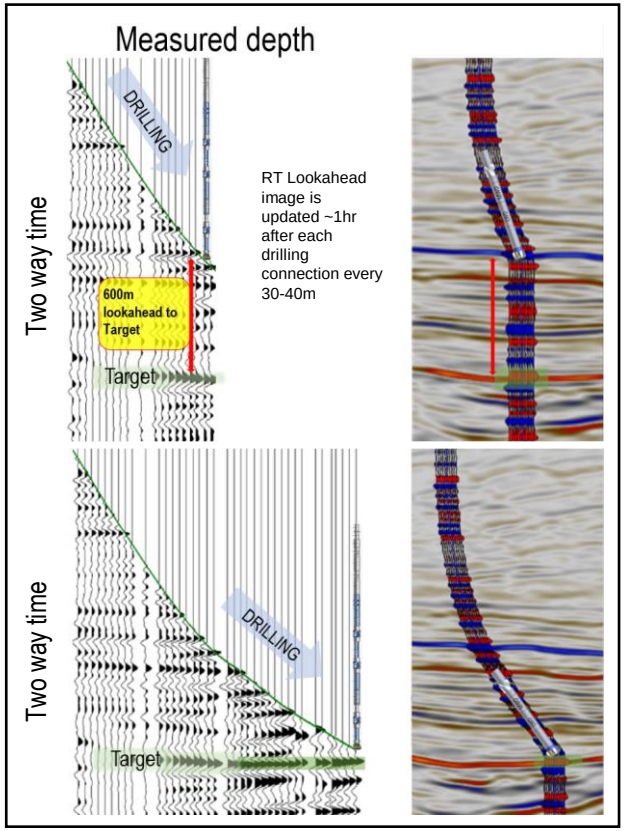


4 x Playback Speed when shooting

Seismic While Drilling

- Length: ~ 14 ft
- Pressure Rating: 23k – 30k PSI
- Any Hole size > 8 3/8”
- Any Hole angle





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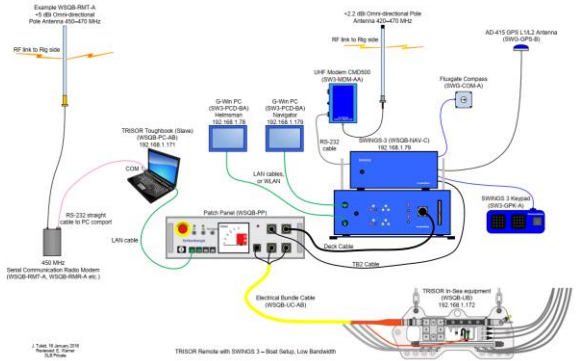
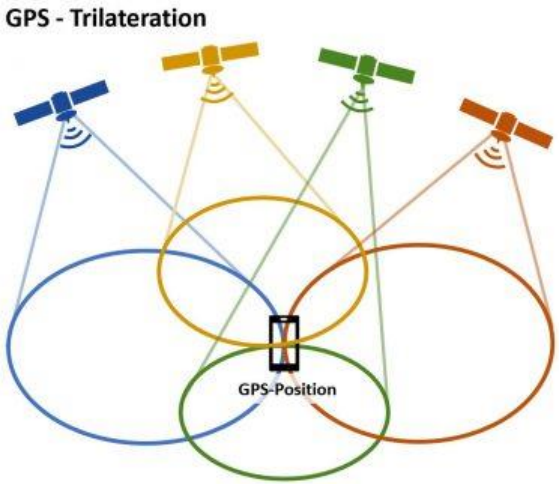
Seismic airgun deployment from a vessel

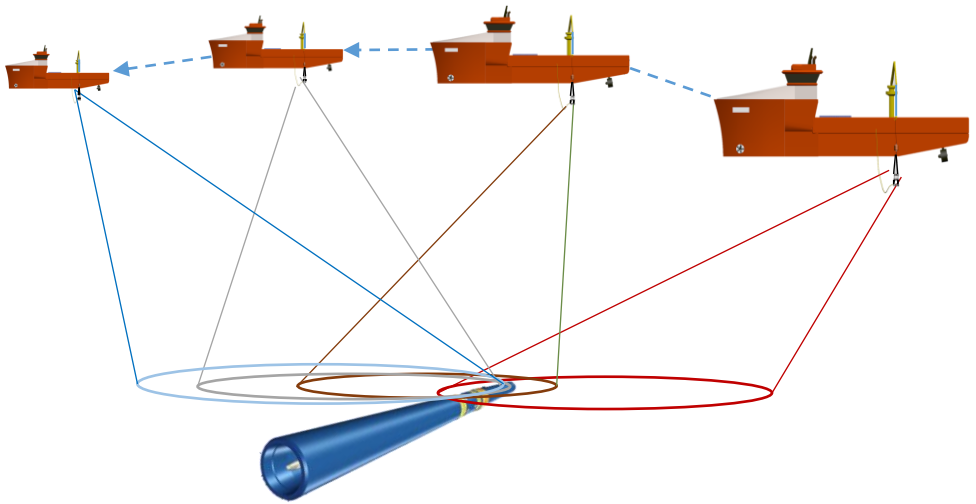
Gun GPS Positioning system accuracy

Horizontal Position Accuracy (RMS)	
Single point L1	1.5 m
Single point L1/L2	1.2 m
NovAtel CORRECT™	
» SBAS[4]	60 cm
» DGPS	40 cm
» PPP [5]	
TerraStar-L	40 cm
TerraStar-C	4 cm

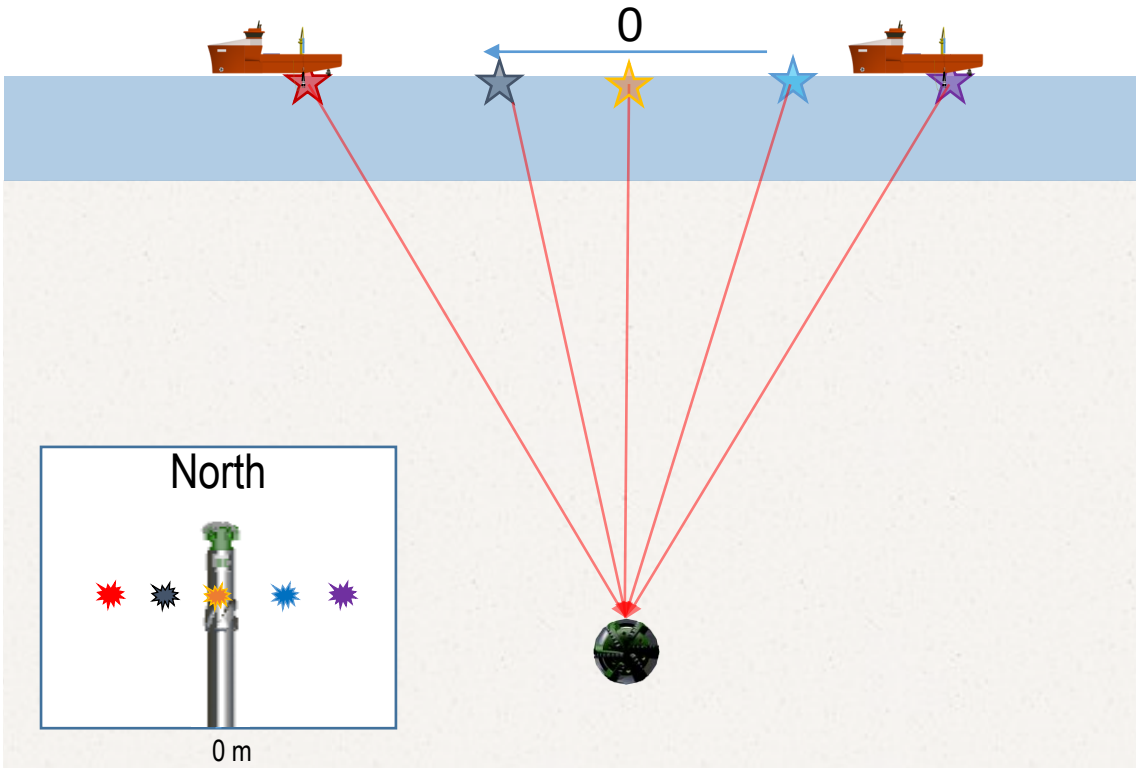


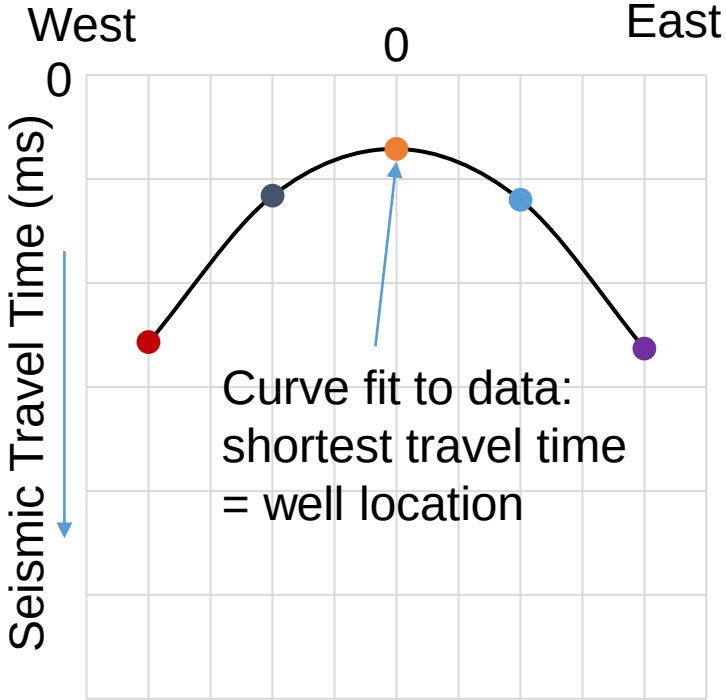
Borehole seismic : “GPS for the BHA”





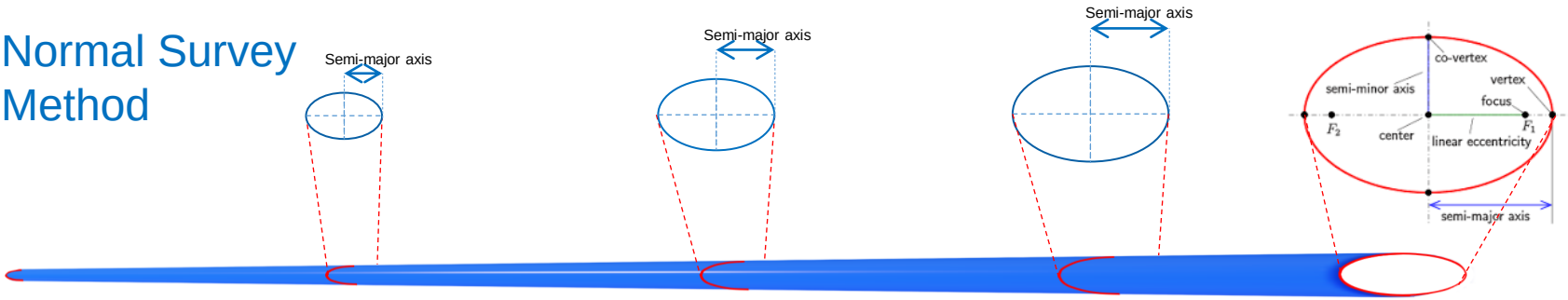
Lateral position of the well from seismic travel time



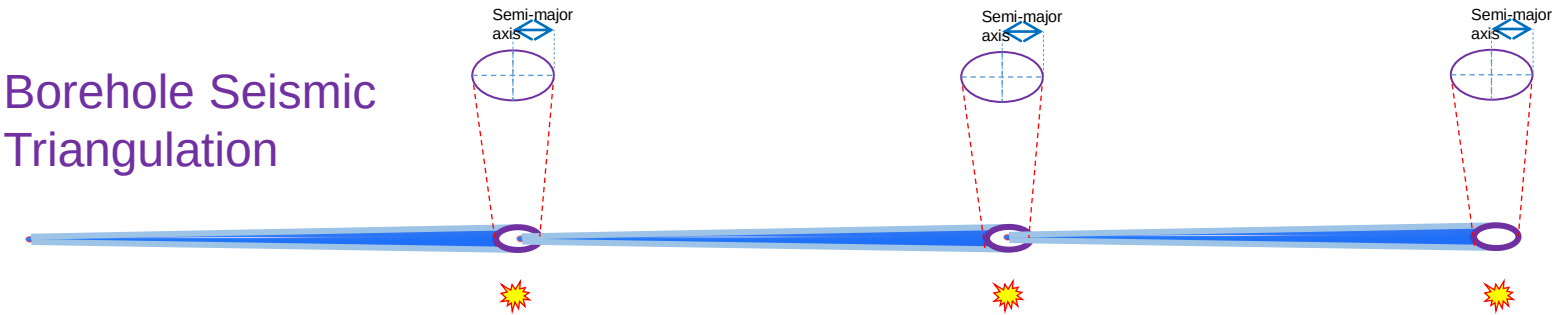


Lateral uncertainty of wellbore position

Normal Survey Method



Borehole Seismic Triangulation

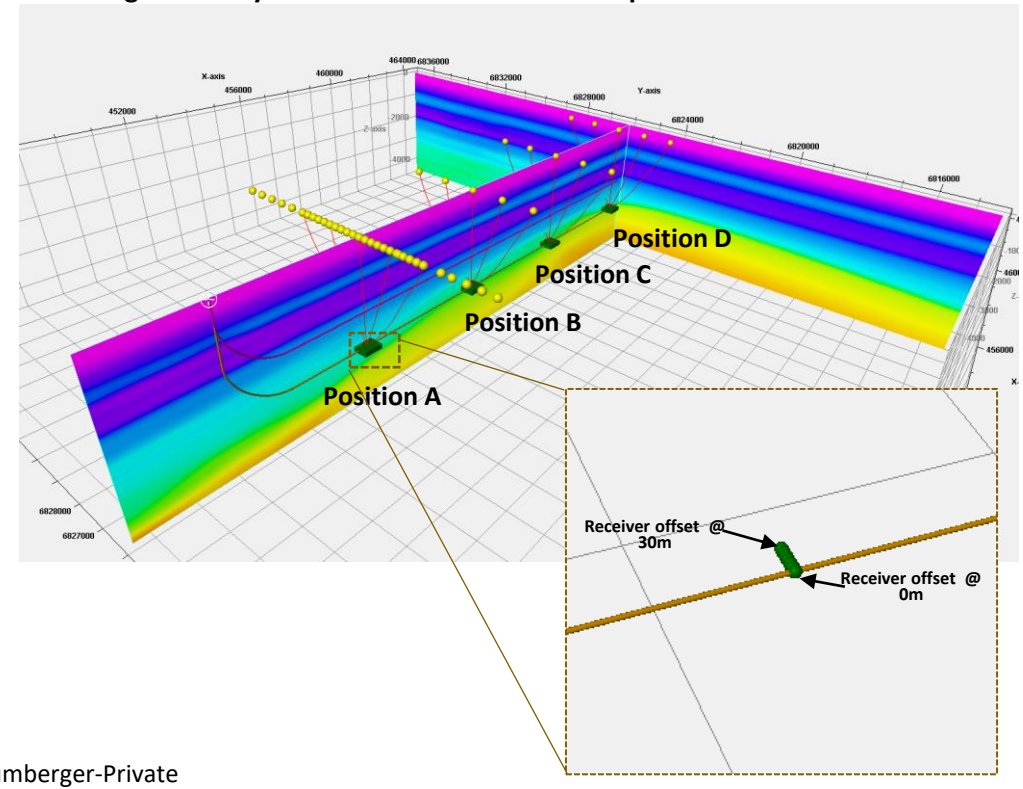


Experiment - Model Inputs

- Two ERD wells built [horizontal paths at 2000m & 3000m TVD]
- Four position of receivers (A, B, C, D) along the well trajectory.
- For each downhole receiver position, Receiver offset shifted by 5m up to 30m to observe sensitivity.

Real Velocity model relatively flat with some small lateral variation observed.

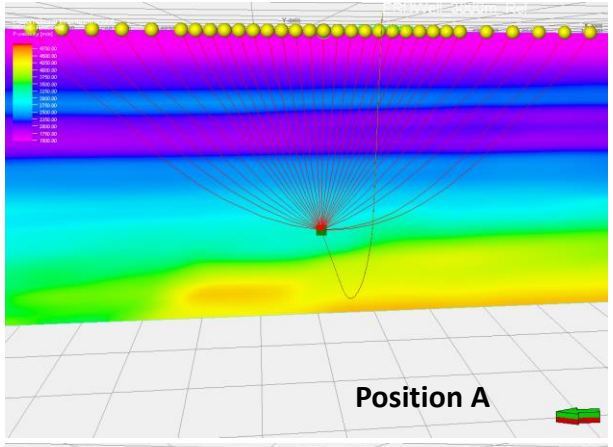
Larger velocity variation observed in the deeper section.

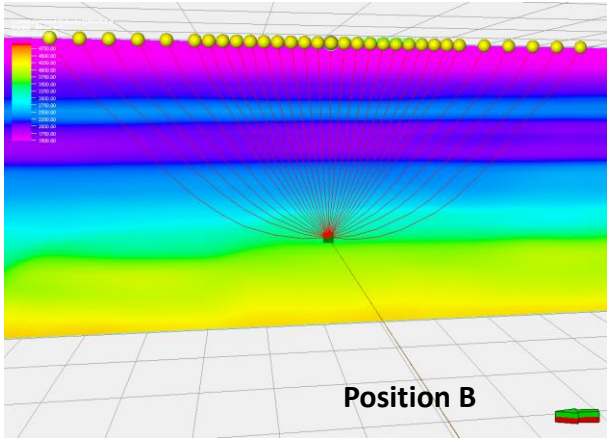


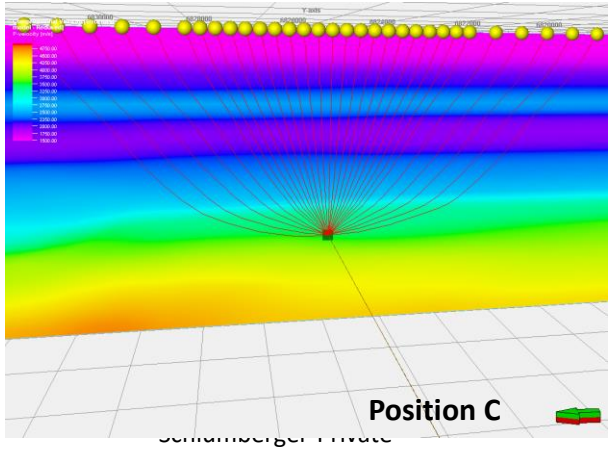
EXPERIMENT 1

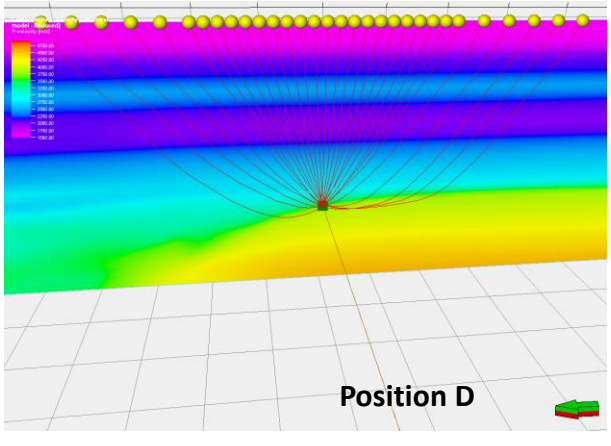
- ERD Well = 3000m

- 4 receiver positions (A, B, C, D) along the horizontal well path









EXPERIMENT 1 – RESULTS

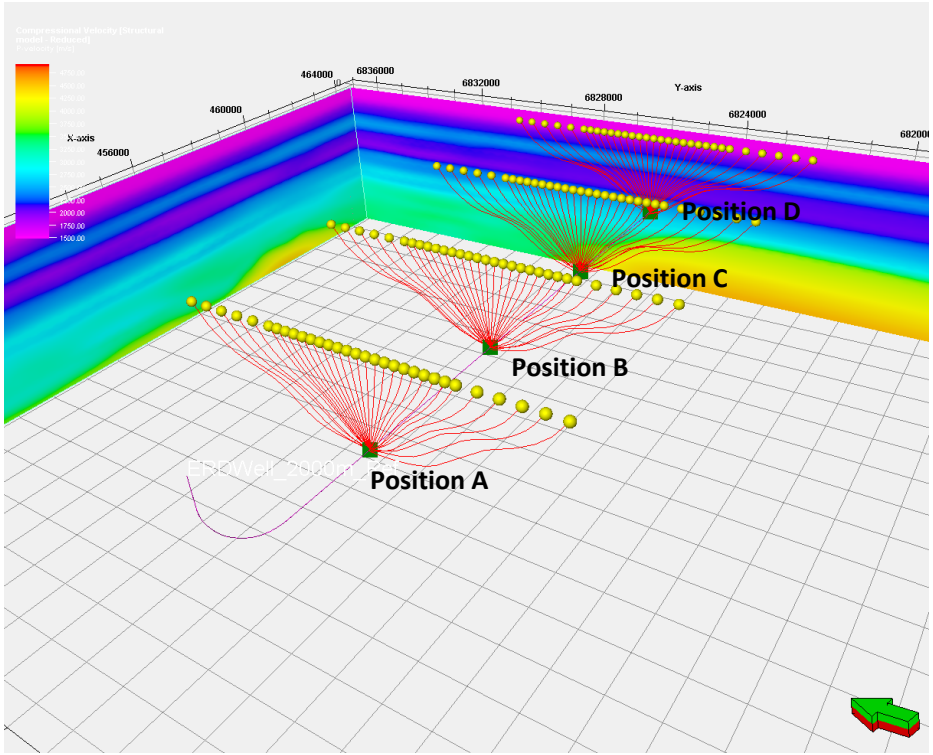
		Source Deployment [m]										Error [m]									
	Receiver Offset reference [m]	200	400	600	800	1000	1200	1400	1600	1800	2000	Diff 200	Diff 400	Diff 600	Diff 800	Diff 1000	Diff 1200	Diff 1400	Diff 1600	Diff 1800	Diff 2000
POSITION A	0	-17.1	-12.1	-5.7	0.4	3.6	5.8	10.8	9.2	0.8	-8.0	-17.1	-12.1	-5.7	0.4	3.6	5.8	10.8	9.2	0.8	-8.0
	5	-11.4	-2.9	1.4	10.7	9.3	11.7	14.2	15.0	5.0	-3.0	-16.4	-7.9	-3.6	5.7	4.3	6.7	9.2	10.0	0.0	-8.0
	10	-7.1	-0.6	5.0	12.9	12.9	16.7	17.5	16.7	9.2	2.0	-17.1	-10.6	-5.0	2.9	2.9	6.7	7.5	6.7	-0.8	-8.0
	15	-0.2	5.0	11.4	15.0	15.0	21.7	21.7	20.8	13.3	5.0	-15.2	-10.0	-3.6	0.0	0.0	6.7	6.7	5.8	-1.7	-10.0
	20	8.6	12.1	14.3	23.6	22.1	26.7	25.8	26.7	16.7	10.0	-11.4	-7.9	-5.7	3.6	2.1	6.7	5.8	6.7	-3.3	-10.0
	25	12.9	18.6	22.1	28.6	26.4	31.7	33.3	31.7	21.7	15.0	-12.1	-6.4	-2.9	3.6	1.4	6.7	8.3	6.7	-3.3	-10.0
	30	18.6	20.7	26.4	30.0	32.9	37.5	36.7	35.0	25.0	20.0	-11.4	-9.3	-3.6	0.0	2.9	7.5	6.7	5.0	-5.0	-10.0
POSITION B	0	10.7	11.4	12.1	13.6	17.5	15.8	13.3	11.7	9.0	4.0	10.7	11.4	12.1	13.6	17.5	15.8	13.3	11.7	9.0	4.0
	5	17.1	16.4	18.6	17.9	23.3	21.7	18.3	15.8	14.0	8.0	12.1	11.4	13.6	12.9	18.3	16.7	13.3	10.8	9.0	3.0
	10	21.4	21.4	21.4	23.6	25.8	25.0	22.5	20.8	19.0	12.0	11.4	11.4	11.4	13.6	15.8	15.0	12.5	10.8	9.0	2.0
	15	26.4	27.1	27.1	27.1	33.3	30.0	26.7	24.2	23.0	17.0	11.4	12.1	12.1	12.1	18.3	15.0	11.7	9.2	8.0	2.0
	20	32.1	32.1	32.1	32.1	40.8	35.0	31.7	28.3	28.0	21.0	12.1	12.1	12.1	12.1	20.8	15.0	11.7	8.3	8.0	1.0
	25	37.1	36.4	37.1	37.1	42.5	39.2	35.8	32.5	32.0	25.0	12.1	11.4	12.1	12.1	17.5	14.2	10.8	7.5	7.0	0.0
	30	43.6	42.1	42.1	41.4	49.2	44.2	40.8	36.7	37.0	28.0	13.6	12.1	12.1	11.4	19.2	14.2	10.8	6.7	7.0	-2.0
POSITION C	0	3.8	5.3	7.7	11.0	15.3	11.7	12.3	10.4	9.4	12.7	3.8	5.3	7.7	11.0	15.3	11.7	12.3	10.4	9.4	12.7
	5	7.2	7.7	17.8	19.9	15.9	18.4	15.6	15.6	14.6	15.4	2.2	2.7	12.8	14.9	10.9	13.4	10.6	10.6	9.6	10.4
	10	13.0	14.5	17.0	27.1	22.0	21.0	23.1	20.9	18.5	19.9	3.0	4.5	7.0	17.1	12.0	11.0	13.1	10.9	8.5	9.9
	15	18.9	21.0	22.0	31.0	25.5	26.9	26.3	24.8	22.6	23.9	3.9	6.0	7.0	16.0	10.5	11.9	11.3	9.8	7.6	8.9
	20	22.9	27.0	29.1	33.6	32.4	32.7	31.7	28.6	27.1	29.0	2.9	7.0	9.1	13.6	12.4	12.7	11.7	8.6	7.1	9.0
	25	27.7	30.6	34.0	40.8	37.4	36.0	36.5	34.0	31.2	33.0	2.7	5.6	9.0	15.8	12.4	11.0	11.5	9.0	6.2	8.0
	30	30.7	29.5	32.9	47.0	42.3	42.0	38.1	38.9	35.4	37.2	0.7	-0.5	2.9	17.0	12.3	12.0	8.1	8.9	5.4	7.2
POSITION D	0	-3.9	-1.7	-1.2	4.9	-4.1	-4.7	-11.8	-32.8	-55.0	-68.9	-3.9	-1.7	-1.2	4.9	-4.1	-4.7	-11.8	-32.8	-55.0	-68.9
	5	1.9	1.2	8.6	11.2	-1.6	2.0	-5.4	-28.2	-49.7	-64.0	-3.1	-3.8	3.6	6.2	-6.6	-3.0	-10.4	-33.2	-54.7	-69.0
	10	6.4	0.6	13.4	20.6	11.3	4.6	4.7	-20.9	-46.3	-50.7	-3.6	-9.4	3.4	10.6	1.3	-5.4	-5.3	-30.9	-56.3	-60.7
	15	10.7	7.0	11.6	13.0	4.1	8.3	-0.1	-21.2	-44.8	-57.3	-4.3	-8.0	-3.4	-2.0	-10.9	-6.7	-15.1	-36.2	-59.8	-72.3
	20	20.0	8.8	35.9	20.1	8.8	20.7	10.2	-14.0	-36.6	-49.9	0.0	-11.2	15.9	0.1	-11.2	0.7	-9.8	-34.0	-56.6	-69.9
	25	21.7	10.9	17.4	22.2	23.2	15.4	9.2	-7.9	-32.7	-52.5	-3.3	-14.1	-7.6	-2.8	-1.8	-9.6	-15.8	-32.9	-57.7	-77.5
	30	27.0	24.1	16.4	25.8	22.8	21.8	13.3	-6.4	-33.1	-43.5	-3.0	-5.9	-13.6	-4.2	-7.2	-8.2	-16.7	-36.4	-63.1	-73.5

-10 0 +1

EXPERIMENT 2 – ERD 2000M

- ERD Well = 2000m

- 4 receiver positions (A, B, C, D) along the horizontal well path

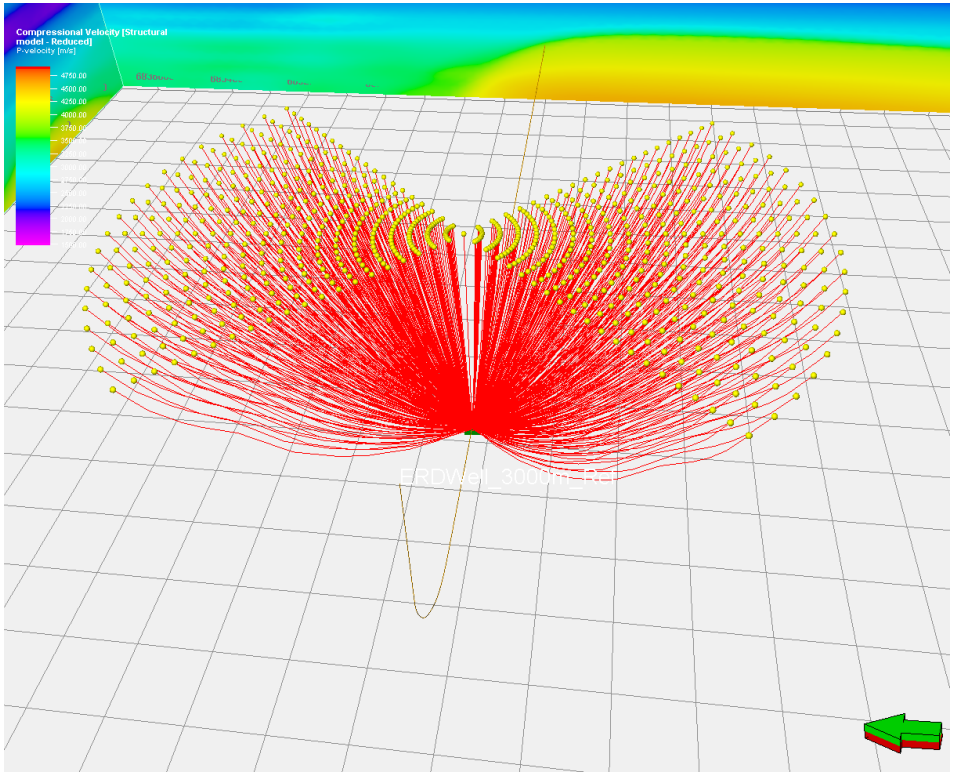


EXPERIMENT 2 – RESULTS

		Source Deployment [m]										Error [m]									
	Receiver Offset reference [m]	200	400	600	800	1000	1200	1400	1600	1800	2000	Diff 200	Diff 400	Diff 600	Diff 800	Diff 1000	Diff 1200	Diff 1400	Diff 1600	Diff 1800	Diff 2000
POSITION A	0	-5.4	-5.1	-4.5	4.3	3.9	3.8	5.5	3.4	4.5	6.1	-5.4	-5.1	-4.5	4.3	3.9	3.8	5.5	3.4	4.5	6.1
	5	-3.4	-1.6	-1.0	3.9	5.8	6.2	10.0	6.9	7.9	9.1	-8.4	-6.6	-6.0	-1.1	0.8	1.2	5.0	1.9	2.9	4.1
	10	1.2	3.4	13.0	17.7	13.2	6.2	14.2	14.2	15.5	14.4	-8.8	-6.6	3.0	7.7	3.2	-3.8	4.2	4.2	5.5	4.4
	15	3.9	1.7	7.8	5.4	11.5	12.6	12.9	12.3	18.7	17.1	-11.1	-13.3	-7.2	-9.6	-3.5	-2.4	-2.1	-2.7	3.7	2.1
	20	8.9	11.4	18.5	8.2	16.1	16.2	15.7	16.9	23.3	21.0	-11.1	-8.6	-1.5	-11.8	-3.9	-3.8	-4.3	-3.1	3.3	1.0
	25	14.4	17.7	18.3	22.6	25.2	15.4	26.7	24.3	26.3	26.6	-10.6	-7.3	-6.7	-2.4	0.2	-9.6	1.7	-0.7	1.3	1.6
	30	18.9	21.6	40.4	7.8	17.3	28.8	22.5	22.3	23.8	26.7	-11.1	-8.4	10.4	-22.2	-12.7	-1.2	-7.5	-7.7	-6.2	-3.3
POSITION B	0	-1.0	-1.4	-1.6	0.7	0.4	1.4	3.7	4.6	5.5	6.9	-1.0	-1.4	-1.6	0.7	0.4	1.4	3.7	4.6	5.5	6.9
	5	4.9	4.3	-1.6	6.2	5.6	6.7	9.1	8.4	11.4	12.5	-0.1	-0.7	-6.6	1.2	0.6	1.7	4.1	3.4	6.4	7.5
	10	10.5	10.8	6.2	4.3	10.6	12.6	11.8	10.9	14.6	17.0	0.5	0.8	-3.8	-5.7	0.6	2.6	1.8	0.9	4.6	7.0
	15	14.2	15.0	14.6	12.8	15.4	16.9	16.4	16.9	20.4	20.4	-0.8	0.0	-0.4	-2.2	0.4	1.9	1.4	1.9	5.4	5.4
	20	17.8	20.1	19.6	17.4	22.0	20.5	24.3	21.5	25.1	24.7	-2.2	0.1	-0.4	-2.6	2.0	0.5	4.3	1.5	5.1	4.7
	25	22.5	23.4	21.6	23.4	21.7	25.9	26.5	26.5	29.4	27.6	-2.5	-1.6	-3.4	-1.6	-3.3	0.9	1.5	1.5	4.4	2.6
	30	28.3	28.6	26.2	28.2	29.3	28.4	29.4	30.7	32.9	32.8	-1.7	-1.4	-3.8	-1.8	-0.7	-1.6	-0.6	0.7	2.9	2.8
POSITION C	0	-2.9	-2.4	-2.5	-20.5	1.7	4.9	10.3	-0.8	-7.6	6.3	-2.9	-2.4	-2.5	-20.5	1.7	4.9	10.3	-0.8	-7.6	6.3
	5	1.9	3.5	1.1	-13.8	2.0	10.5	20.3	4.7	-4.3	6.4	-3.1	-1.5	-3.9	-18.8	-3.0	5.5	15.3	-0.3	-9.3	1.4
	10	6.3	3.3	12.9	-11.6	15.3	18.9	24.6	4.7	11.2	98.4	-3.7	-6.7	2.9	-21.6	5.3	8.9	14.6	-5.3	1.2	88.4
	15	10.8	7.3	18.7	9.6	20.6	15.1	21.0	10.6	26.6	23.3	-4.2	-7.7	3.7	-5.4	5.6	0.1	6.0	-4.4	11.6	8.3
	20	16.0	10.6	15.9	-4.1	23.2	27.8	26.2	11.4	27.9	23.7	-4.0	-9.4	-4.1	-24.1	3.2	7.8	6.2	-8.6	7.9	3.7
	25	18.3	14.9	21.4	1.3	42.1	26.1	35.0	18.7	18.1	34.4	-6.7	-10.1	-3.6	-23.7	17.1	1.1	10.0	-6.3	-6.9	9.4
	30	23.7	19.8	28.6	1.5	28.9	26.3	36.8	6.6	20.6	36.4	-6.3	-10.2	-1.4	-28.5	-1.1	-3.7	6.8	-23.4	-9.4	6.4
POSITION D	0	0.1	-0.2	-1.0	-15.6	-10.8	0.4	-9.2	-7.5	-5.6	-9.2	0.1	-0.2	-1.0	-15.6	-10.8	0.4	-9.2	-7.5	-5.6	-9.2
	5	5.9	1.7	-0.8	-6.4	-14.6	5.2	20.6	-3.4	-11.7	-2.9	0.9	-3.3	-5.8	-11.4	-19.6	0.2	15.6	-8.4	-16.7	-7.9
	10	11.8	6.7	11.2	-1.0	-6.5	12.0	24.2	11.7	0.9	5.5	1.8	-3.3	1.2	-11.0	-16.5	2.0	14.2	1.7	-9.1	-4.5
	15	18.9	16.3	9.3	0.9	15.5	6.3	12.0	12.0	13.9	7.8	3.9	1.3	-5.7	-14.1	0.5	-8.7	-3.0	-3.0	-1.1	-7.2
	20	23.5	20.3	29.6	13.0	14.7	16.0	15.5	19.9	11.6	137.4	3.5	0.3	9.6	-7.0	-5.3	-4.0	-4.5	-0.1	-8.4	117.4
	25	25.9	23.4	30.2	7.5	19.3	27.2	28.6	21.9	5.6	18.6	0.9	-1.6	5.2	-17.5	-5.7	2.2	3.6	-3.1	-19.4	-6.4
	30	30.0	24.2	37.1	14.3	25.7	31.7	24.0	27.6	31.5	21.5	0.0	-5.8	7.1	-15.7	-4.3	1.7	-6.0	-2.4	1.5	-8.5
												-10				0					+1 0

EXPERIMENT 3 – Influence of Azimuth deployment

- ERD Well = 3000m
- 1 receiver position (A) along the horizontal well path
- 801 sources deployment with 5 sources per deployment
- Is there an optimum Azimuth that minimize the error?

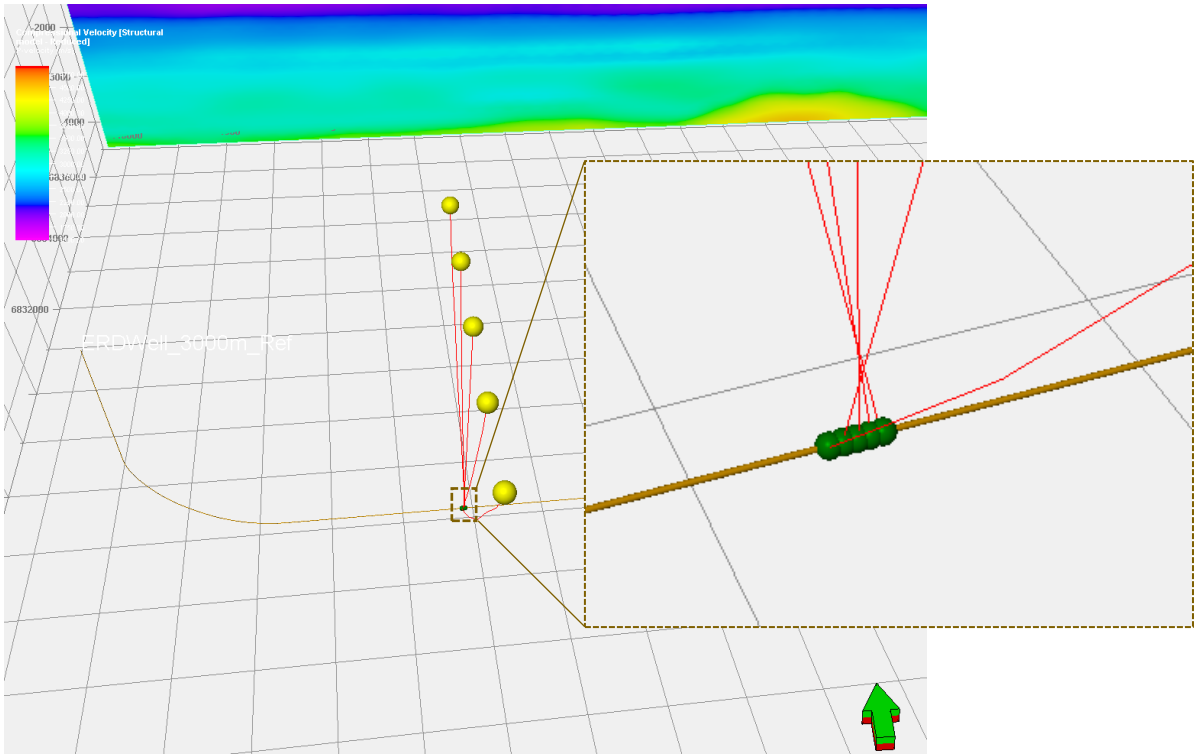


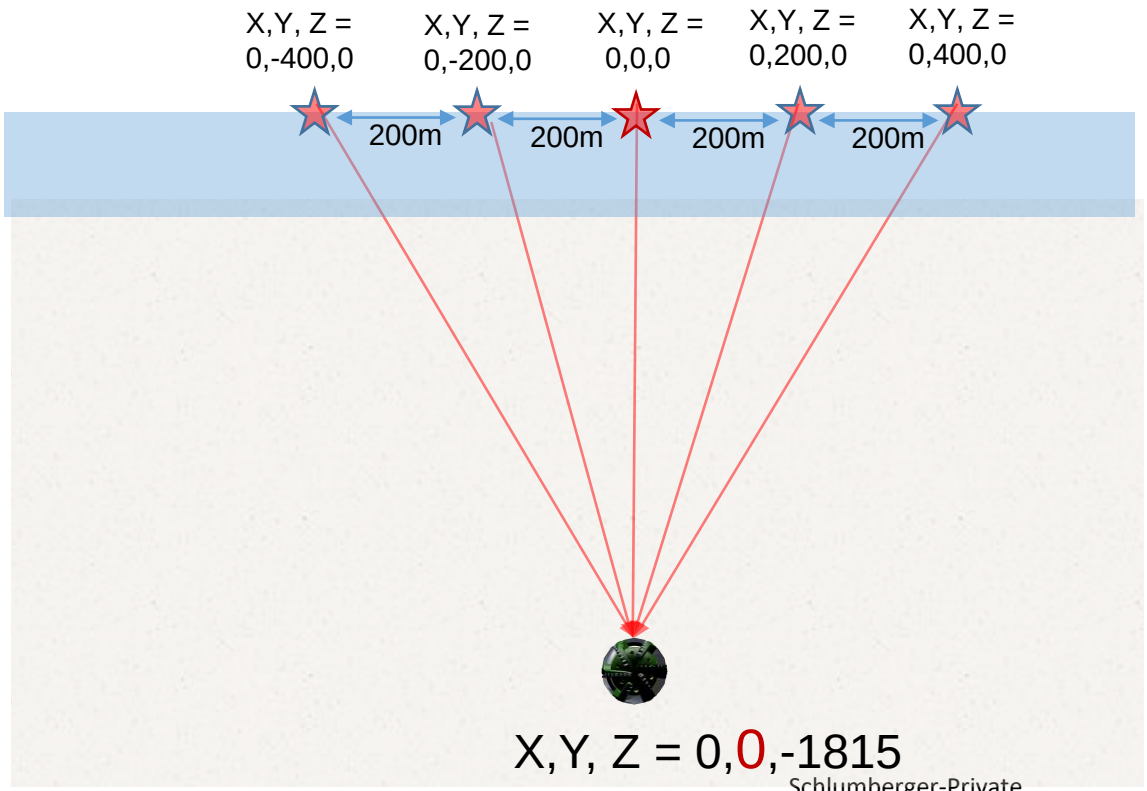
EXPERIMENT 3 – RESULTS

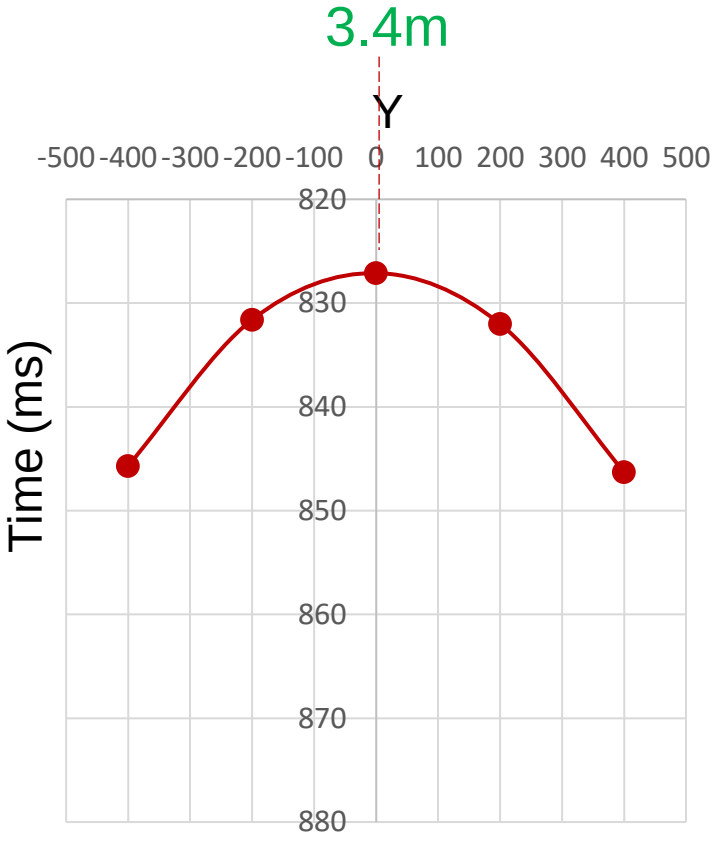
		Source Deployment [m]										Error [m]									
	Azimuth (deg)	200	400	600	800	1000	1200	1400	1600	1800	2000	Diff 200	Diff 400	Diff 600	Diff 800	Diff 1000	Diff 1200	Diff 1400	Diff 1600	Diff 1800	Diff 2000
POSITION A	0	-16.3	-11.4	-6.1	-0.7	-2.1	9.7	6.7	4.8	3.4	-9.3	-16.3	-11.4	-6.1	-0.7	-2.1	9.7	6.7	4.8	3.4	-9.3
	5	-15.8	-11.3	-5.3	0.5	14.6	10.1	20.8	11.4	5.7	0.2	-15.8	-11.3	-5.3	0.5	14.6	10.1	20.8	11.4	5.7	0.2
	10	-15.6	-11.4	-6.3	-0.5	-0.2	0.3	7.9	5.3	8.5	-2.2	-15.6	-11.4	-6.3	-0.5	-0.2	0.3	7.9	5.3	8.5	-2.2
	15	-14.6	-10.8	-6.0	1.0	2.3	16.3	14.4	11.5	12.3	3.6	-14.6	-10.8	-6.0	1.0	2.3	16.3	14.4	11.5	12.3	3.6
	20	-13.9	-10.2	-5.0	2.2	7.1	-1.3	14.9	8.4	10.8	9.2	-13.9	-10.2	-5.0	2.2	7.1	-1.3	14.9	8.4	10.8	9.2
	25	-12.9	-9.3	-4.8	2.6	11.1	23.3	12.4	16.0	13.7	11.7	-12.9	-9.3	-4.8	2.6	11.1	23.3	12.4	16.0	13.7	11.7
	30	-11.7	-8.7	-4.7	2.3	22.4	12.2	14.7	20.7	11.8	16.8	-11.7	-8.7	-4.7	2.3	22.4	12.2	14.7	20.7	11.8	16.8
	35	-11.3	-8.1	-4.5	2.3	10.5	14.8	15.1	17.7	13.7	10.0	-11.3	-8.1	-4.5	2.3	10.5	14.8	15.1	17.7	13.7	10.0
	40	-9.2	-7.0	-3.5	2.2	10.6	10.1	20.6	16.8	12.2	11.8	-9.2	-7.0	-3.5	2.2	10.6	10.1	20.6	16.8	12.2	11.8
	45	-8.2	-6.0	-2.9	2.0	9.5	9.4	15.6	10.2	17.8	10.2	-8.2	-6.0	-2.9	2.0	9.5	9.4	15.6	10.2	17.8	10.2
	135	13.6	9.0	3.1	-1.9	-4.0	-11.3	-15.1	-15.5	10.0	16.3	13.6	9.0	3.1	-1.9	-4.0	-11.3	-15.1	-15.5	10.0	16.3
	140	14.3	9.0	3.5	-0.6	-3.9	-17.1	-1.4	-8.0	10.2	18.7	14.3	9.0	3.5	-0.6	-3.9	-17.1	-1.4	-8.0	10.2	18.7
	145	14.7	9.2	3.5	-1.4	-6.8	-17.4	-6.3	-3.5	14.8	24.1	14.7	9.2	3.5	-1.4	-6.8	-17.4	-6.3	-3.5	14.8	24.1
	150	15.1	9.7	4.2	-0.4	-6.0	3.2	-2.5	-4.4	13.7	30.5	15.1	9.7	4.2	-0.4	-6.0	3.2	-2.5	-4.4	13.7	30.5
	155	15.7	9.9	4.5	-1.6	-8.9	-8.2	-0.5	-4.5	12.5	25.3	15.7	9.9	4.5	-1.6	-8.9	-8.2	-0.5	-4.5	12.5	25.3
	160	16.3	10.9	5.1	0.5	-7.0	4.1	-1.0	-4.8	15.9	26.6	16.3	10.9	5.1	0.5	-7.0	4.1	-1.0	-4.8	15.9	26.6
	165	16.3	11.2	5.1	-0.2	8.1	5.6	5.1	-7.1	10.7	25.6	16.3	11.2	5.1	-0.2	8.1	5.6	5.1	-7.1	10.7	25.6
	170	15.5	11.2	5.7	0.9	6.1	3.4	-7.1	-4.3	6.9	21.4	15.5	11.2	5.7	0.9	6.1	3.4	-7.1	-4.3	6.9	21.4
	175	15.5	11.2	6.0	1.0	14.1	-4.4	-2.1	-5.5	3.4	19.8	15.5	11.2	6.0	1.0	14.1	-4.4	-2.1	-5.5	3.4	19.8

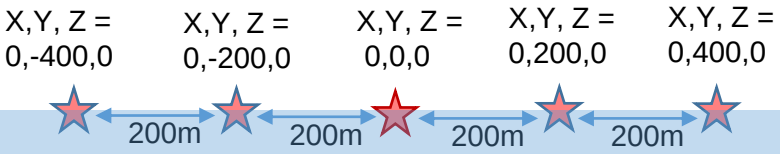
EXPERIMENT 4 – Moving RECEIVERS position

- ERD Well = 3000m
- 5 receiver positions along the horizontal well path spaced 10m or 30m apart.
- 5 sources deployed
- Can we still locate the receiver if each measurement is taken with the receiver moving by 1 joint or 1 stand? (+10m or +30m)?
- No significant impact on results. Data may be acquired during drilling connections.



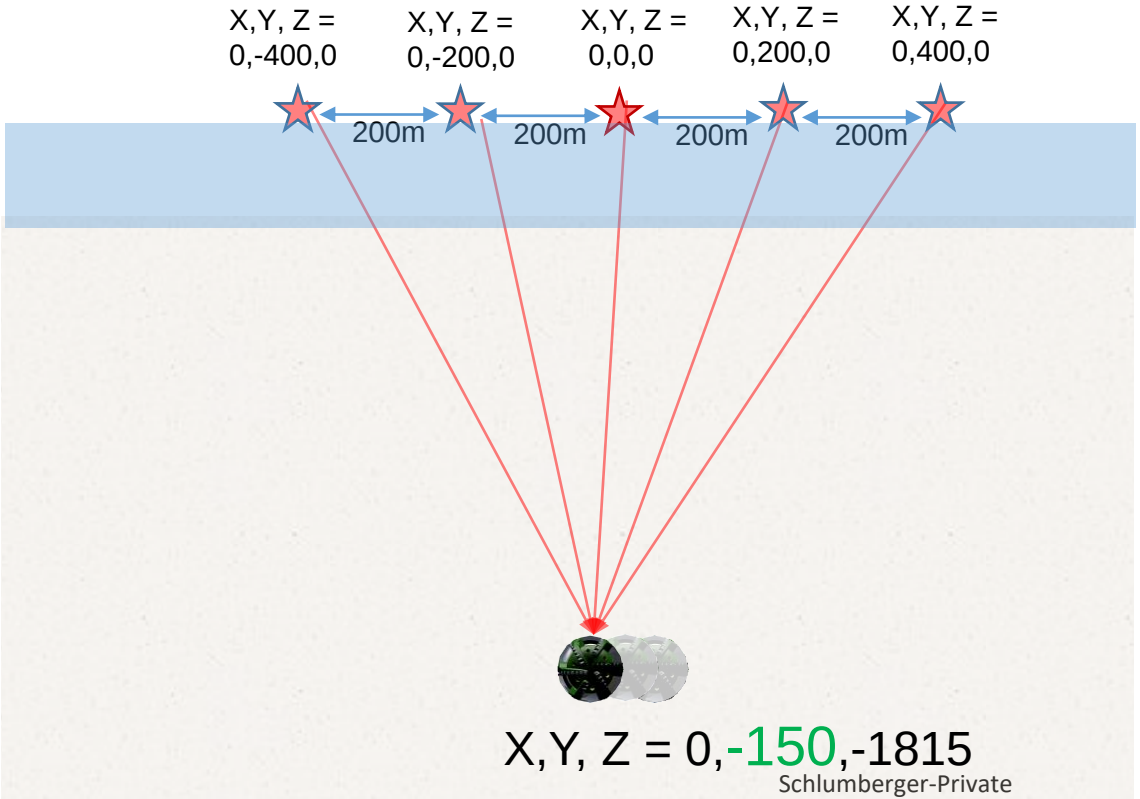

X,Y, Z = 0,-400,0
X,Y, Z = 0,-200,0
X,Y, Z = 0,0,0
X,Y, Z = 0,200,0
X,Y, Z = 0,400,0
200m
200m
200m
200m
X,Y, Z = 0,0,-1815

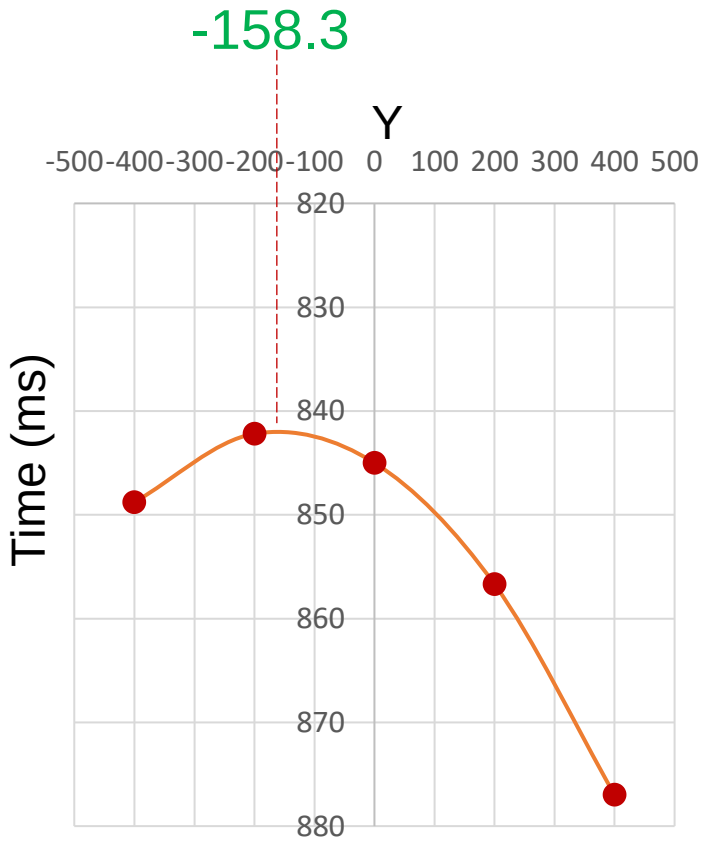

3.4m
Y
-500 -400 -300 -200 -100 0 100 200 300 400 500
Time (ms)
820
830
840
850
860
870
880



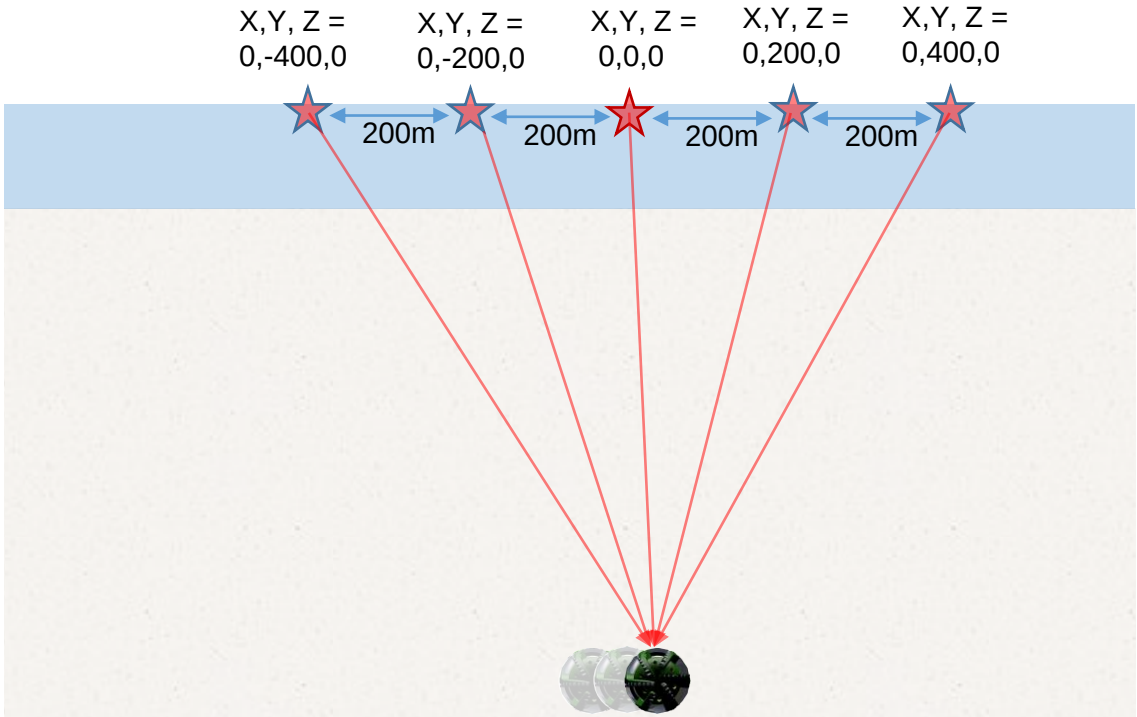
X,Y, Z = 0,???,-1815

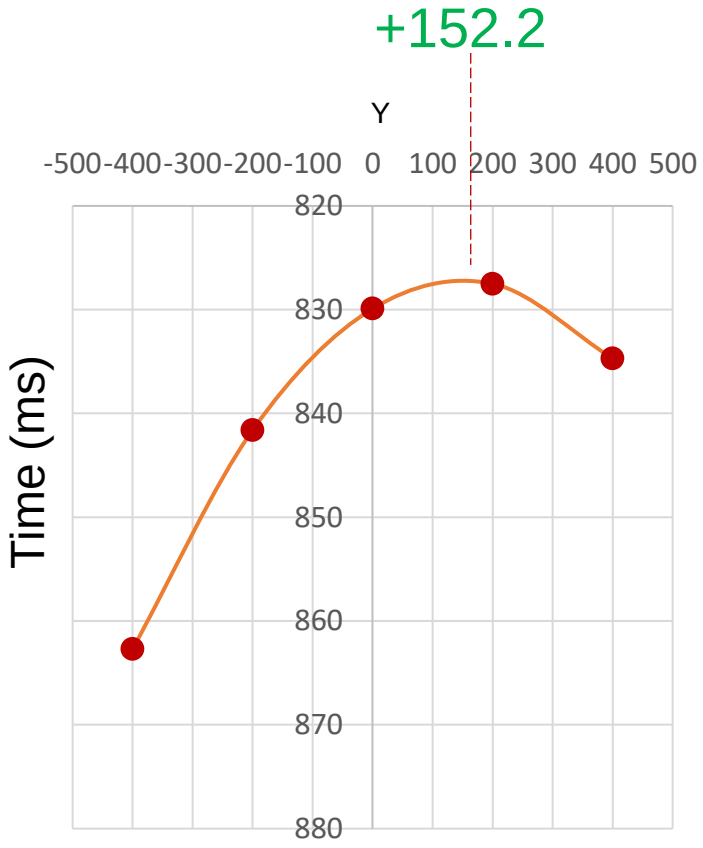
Modeling Case Study 1





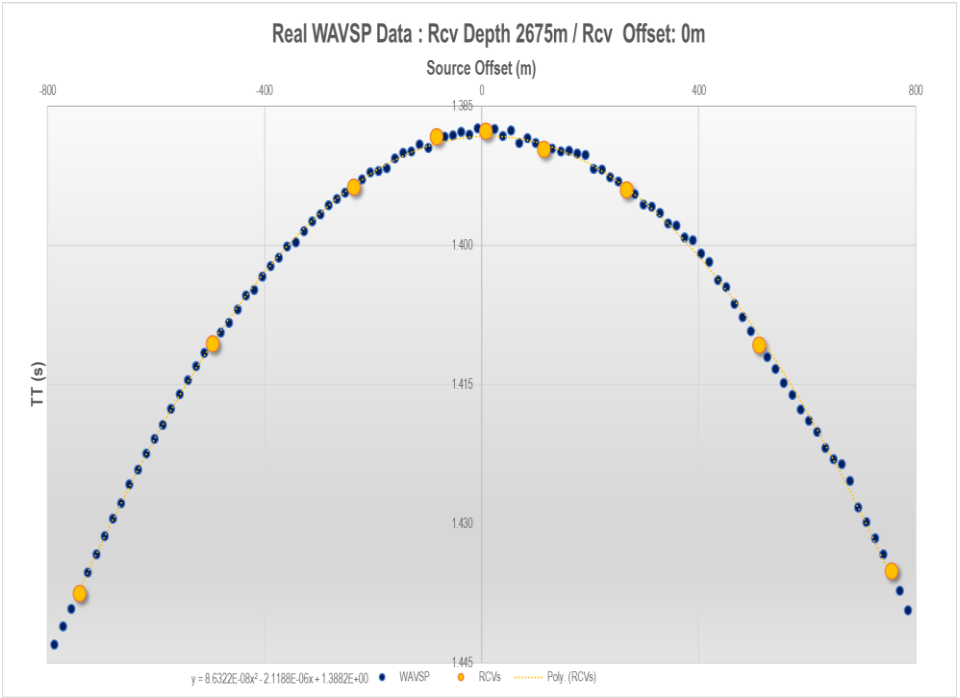
Modeling Case Study 1





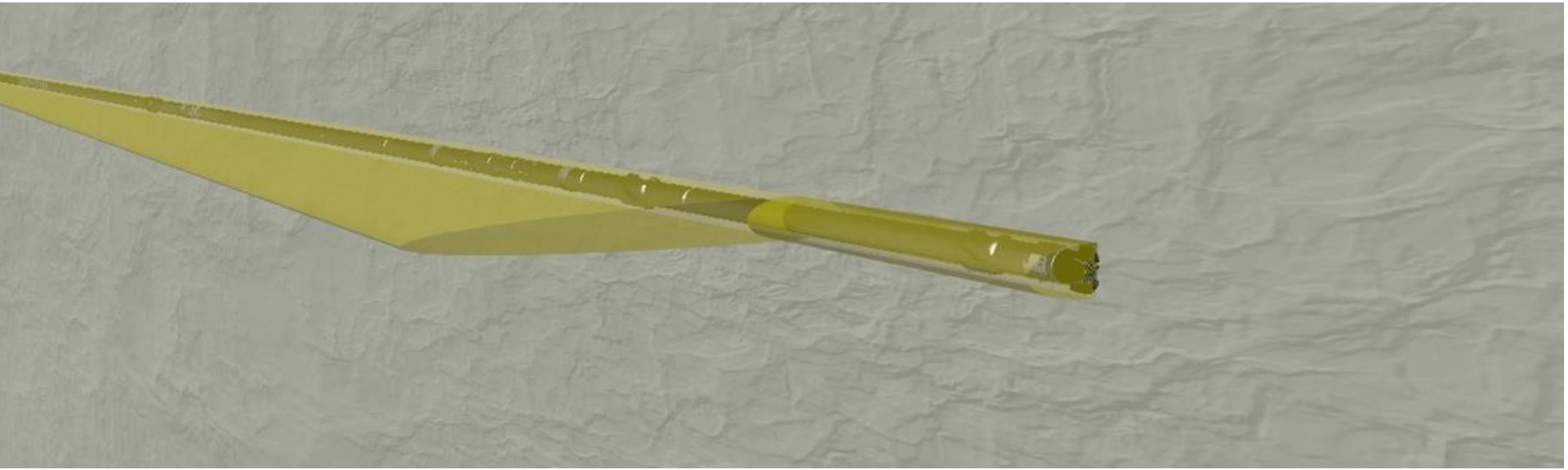
Case Study 2

- Wireline acquisition of a walkaway line in a vertical well
  - Same airgun and positioning equipment
  - Downhole WL tool instead of LWD tool
- Flat Layers Overburden
- Walkaway Line considered for 1 receiver position
  - 800+ Source position at surface
  - Receiver Depth: 2675m
- Decimation of WA source position to mimic deployment of autonomous sources
  - 9 symmetrical positions of the sources selected over 1600m lateral deployment

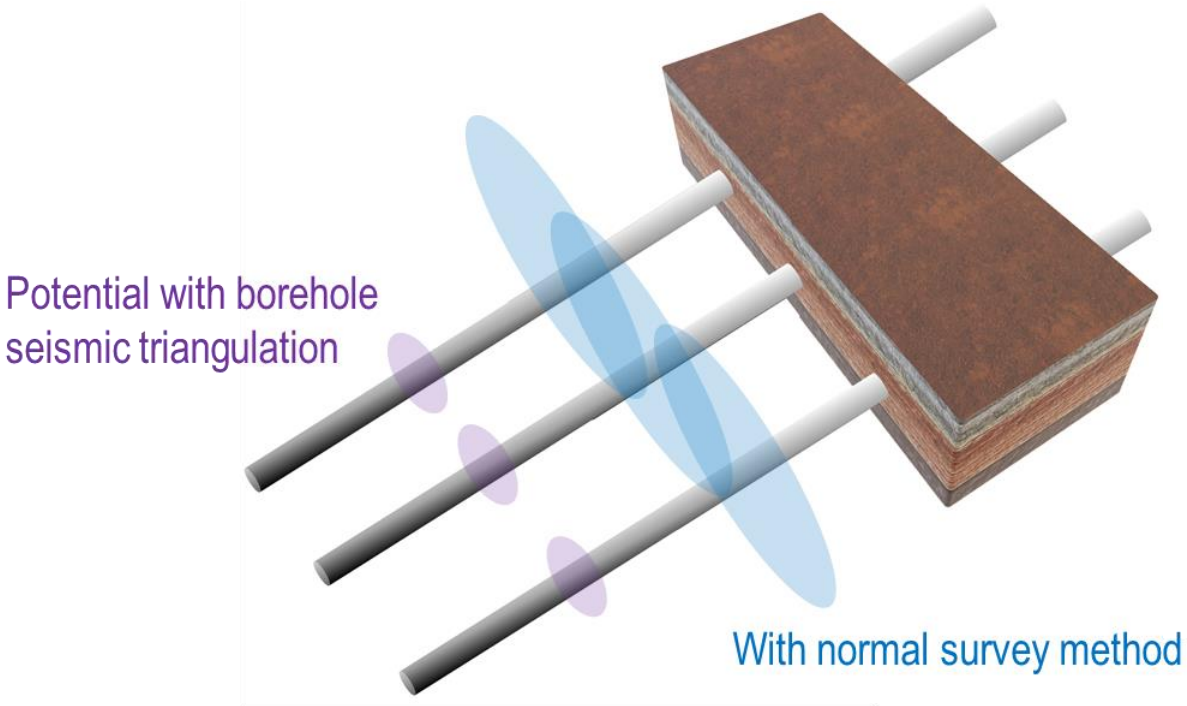


- Calculated receiver offset from 9 points
  - 2.27m calculated vs 0m actual

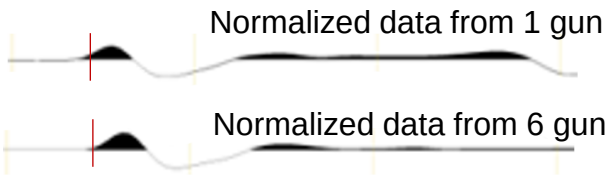
Animation of seismic Positioning while drilling



Drill horizontals closer together?



Acquisition in the future?



- Wellbore positioning only requires 1 seismic gun. Low noise in high deviation wells. No need for reflection data and high power
- Small HP air supply requirement
- Autonomous vehicle / marine drones could be a viable option

Conclusion

- Seismic LWD is a mature technology
- Modelling has shown that seismic measurements can reduce lateral uncertainty of the wellbore position
- The technique is best suited to environments with a flat overburden for absolute wellbore position
- Relative wellbore positioning is expected to be more robust if survey conducted in both wells
- First seismic LWD positioning acquisition test in a horizontal well – Oct 2022
- Future potential to increase survey efficiency and reduce cost