Ultra-deep 3D Electromagnetic Inversion for Anisotropy, a Guide to Understanding Complex Fluid Boundaries in a Turbidite Reservoir

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Material First Presented at SPWLA Symposium 2022

Clegg, Nigel, Sinha, Supriya, Rodriguez, Karol Riofrio, Walmsely, Arthur, Sviland-Østre, Stig, Lien, Theodor, Mouatt, Joanna, Marchant, David, and Christoph Schwarzbach. "Ultra-Deep 3D Electromagnetic Inversion for Anisotropy, a Guide to Understanding Complex Fluid Boundaries in a Turbidite Reservoir." Paper presented at the SPWLA 63rd Annual Logging Symposium, Stavanger, Norway, June 2022. doi: https://doi.org/10.30632/SPWLA-2022-0119

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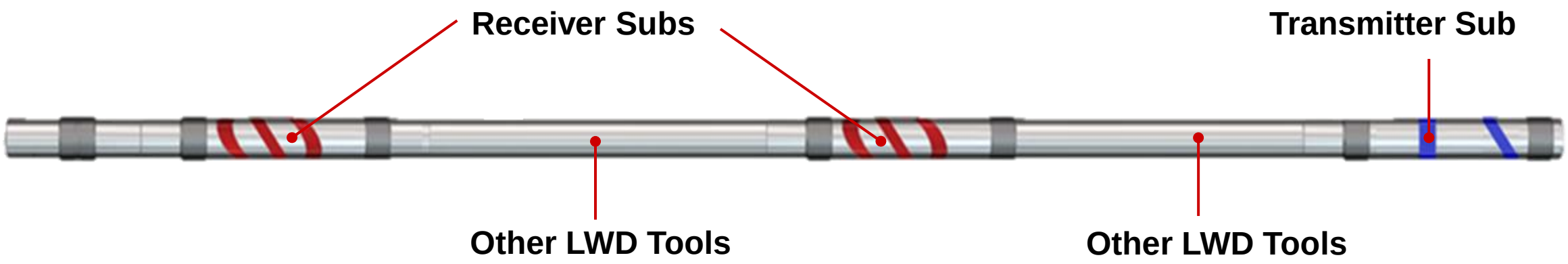
Ultra-Deep Resistivity Logging While Drilling Tools



Get a Clear View of the Reservoir

Geosteer

Deep-reading measurements reveal reservoir structure early for timely geosteering decisions, minimizing well tortuosity

Geomap

Map surrounding reservoir and fluid boundaries for improved future well placement and reserves estimation

Geostop

Land well above on just inside the reservoir without the need for preliminary pilot hole

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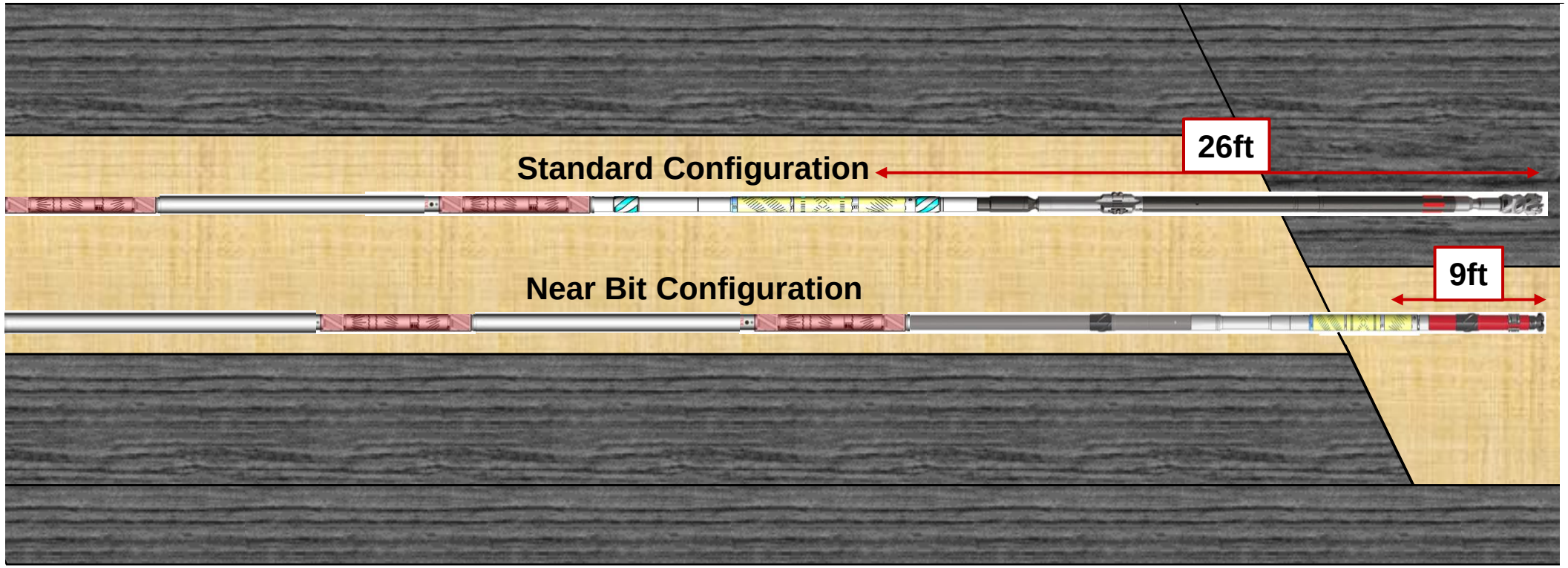
Transmitter Position



Inversion Measure Point at the Transmitter. In Addition Shallow Bulk Resistivity, Anisotropy and Azimuthal Resistivity Images are Available for Direct Measurement of the Formation.

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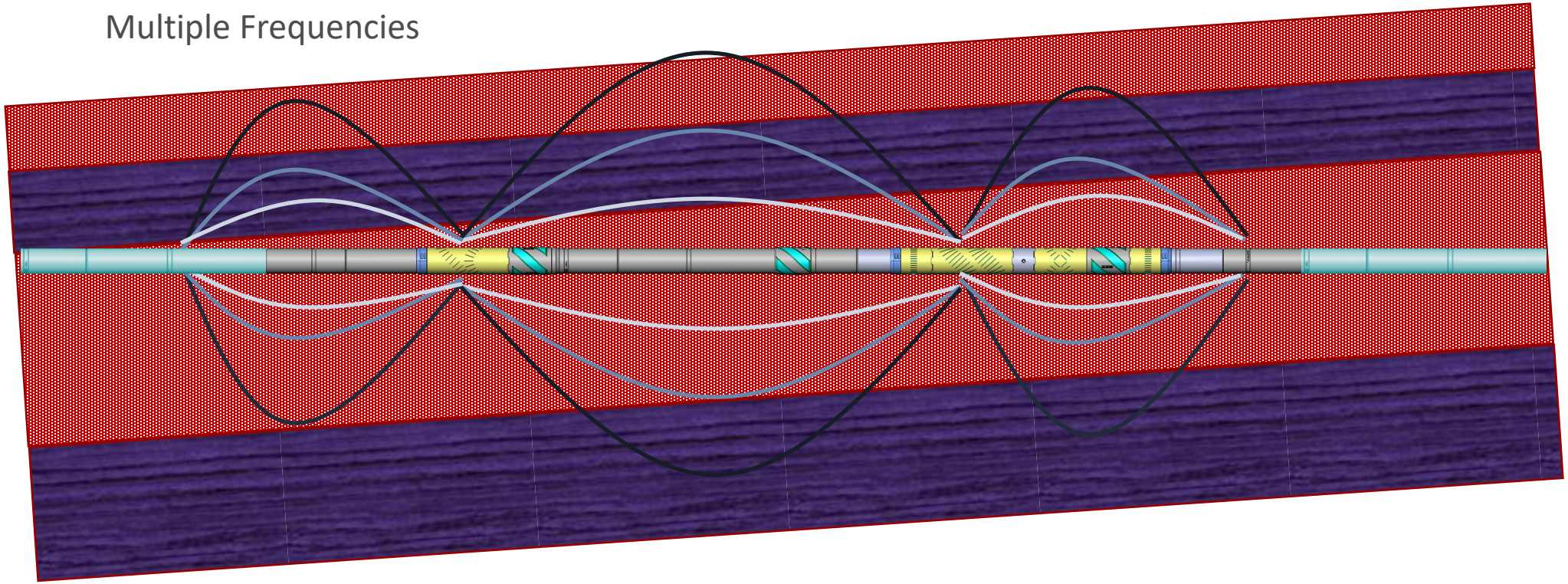
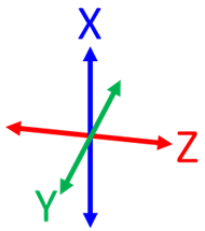
Why Electromagnetic Inversion?

Multiple Frequencies

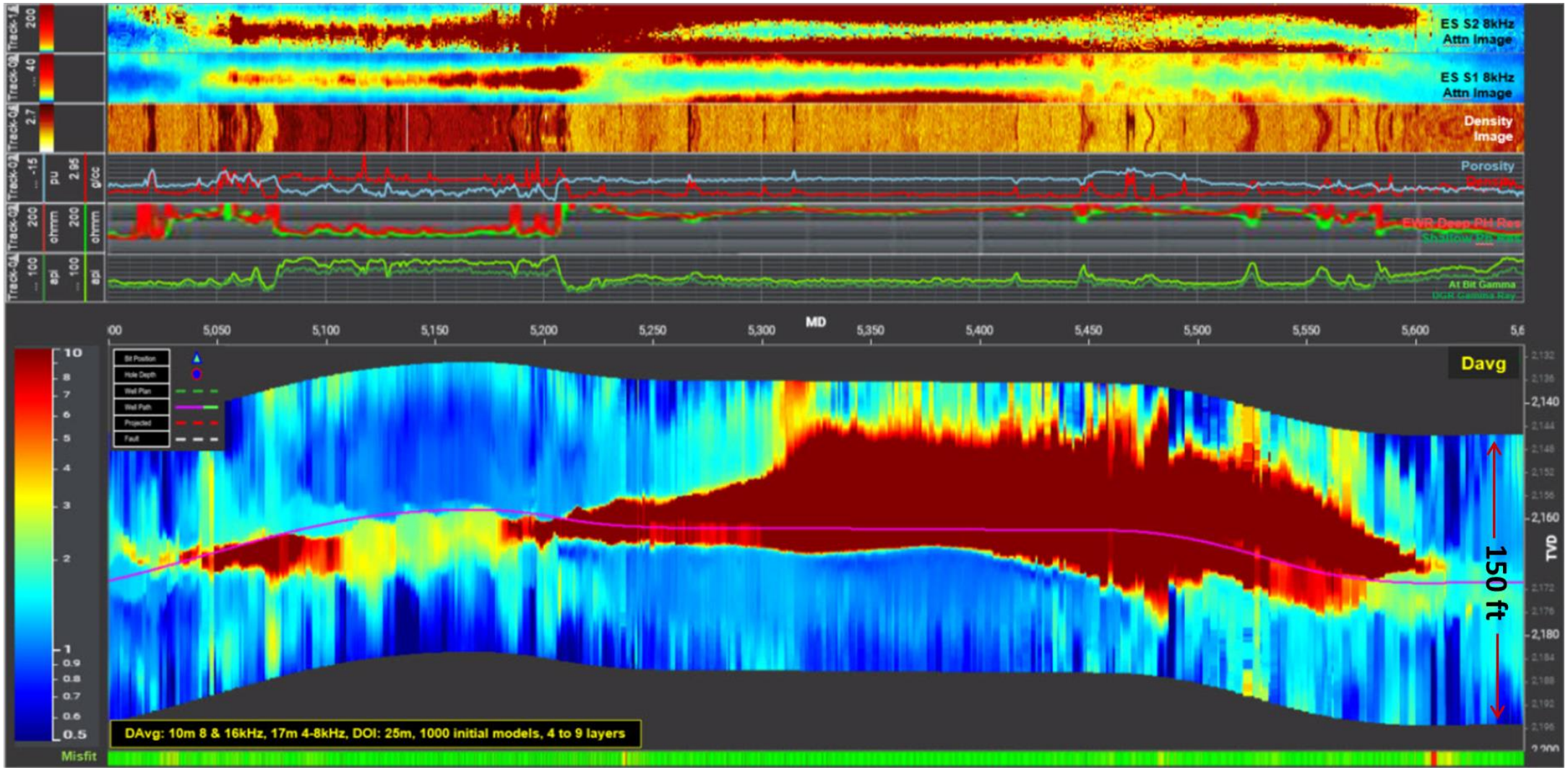




$$\begin{pmatrix} XX & XY & XY \\ YX & YY & YZ \\ ZX & ZY & ZZ \end{pmatrix}$$

Electromagnetic field represented as 9 components for each transmission frequency.
Inversion matches this data to models representing the subsurface geology and fluids.

Multi-Layered Turbidite 1D Inversion Example



Sinha, Supriya, Riofrio, Karol, Walmsley, Arthur, Clegg, Nigel, Sviland-Østre, Stig, and Nicolas Gueze. "Real-Time 3D Imaging of Complex Turbiditic Reservoir Architecture." Paper presented at the SPWLA 62nd Annual Logging Symposium, Virtual Event, May 2021. doi: https://doi.org/10.30632/SPWLA-2021-0041

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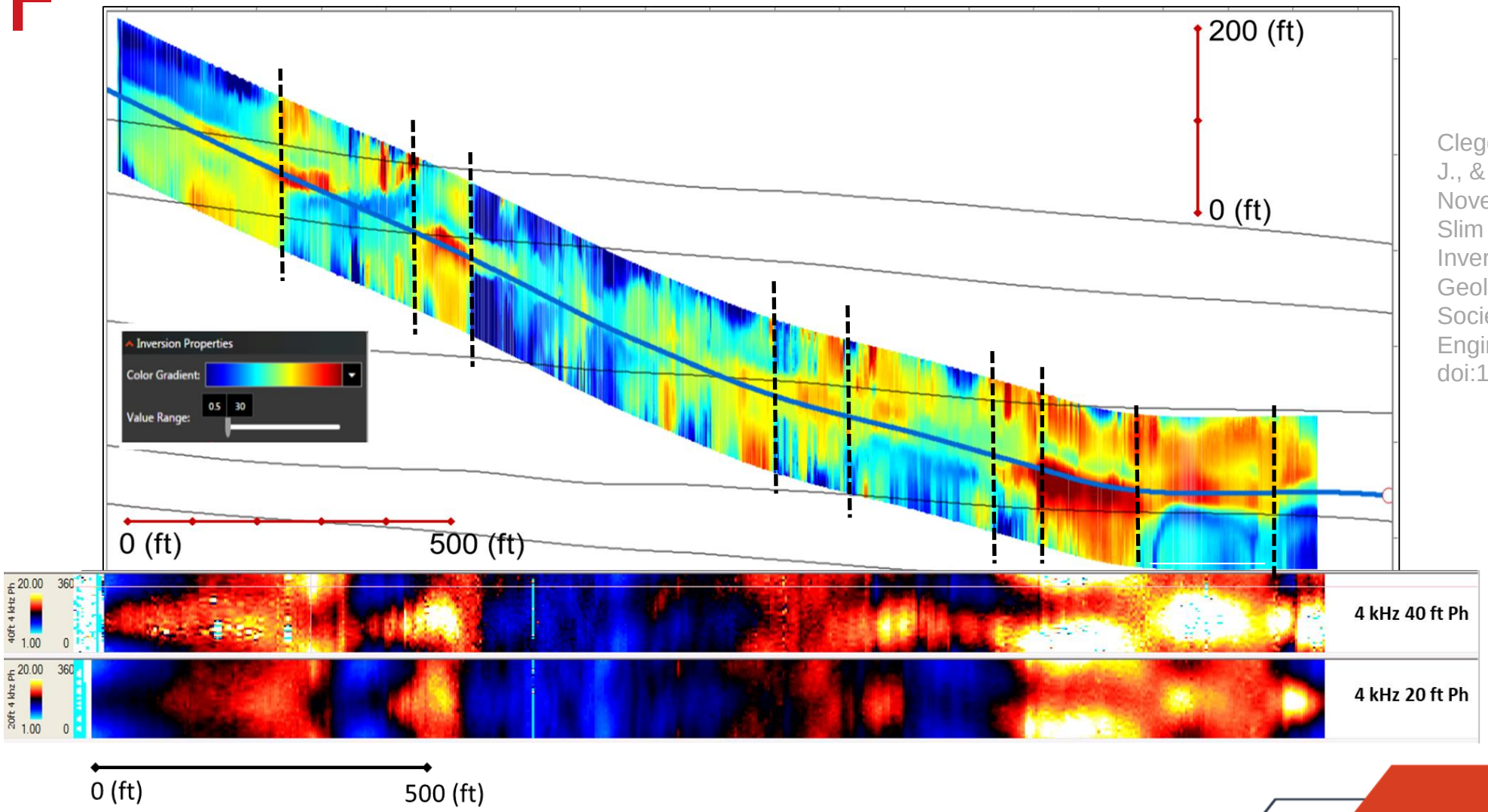
Azimuthal Images – The Key to 3D



Clegg, N., Hansen, E., Ma, J., & Lozinsky, C. (2019, November 11). Verification of Slim Ultra-deep Resistivity Inversions in a Complex Geological Environment. Society of Petroleum Engineers. doi:10.2118/197189-MS

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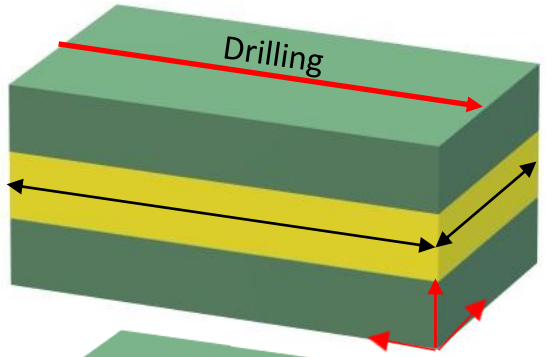
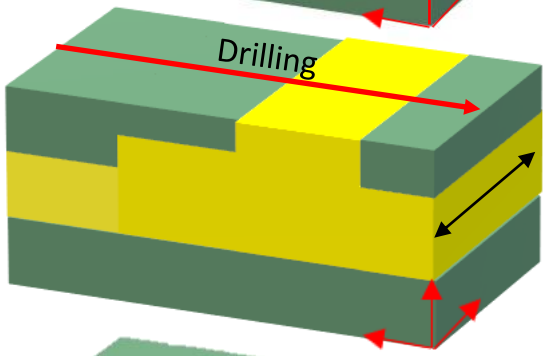
Inversion Dimensionality

1D



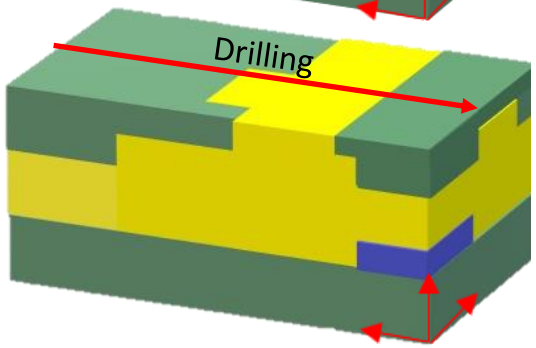
- 1D inversion assumes changes only happen above and below the wellbore

2D



- 2.5D inversion assumes a plane of infinite strike, so changes happen above/below the wellbore and along the wellbore

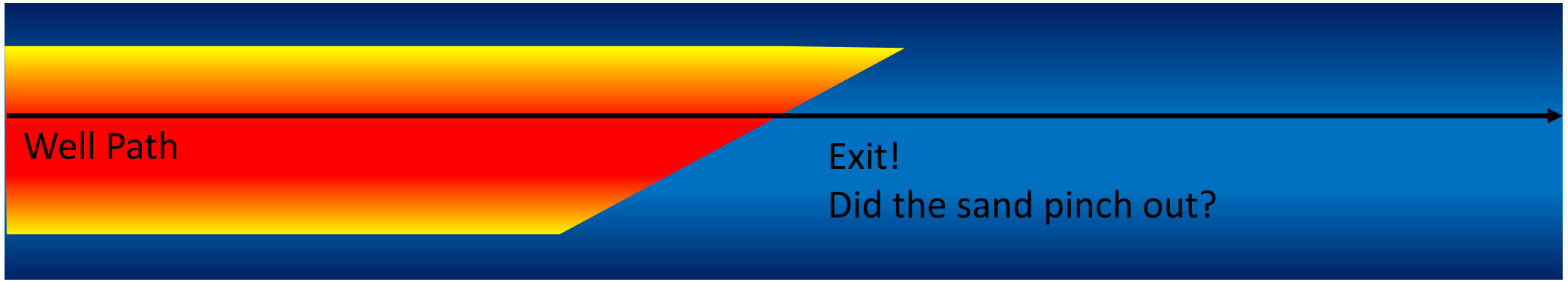
3D



- 3D inversion permits changes in all directions

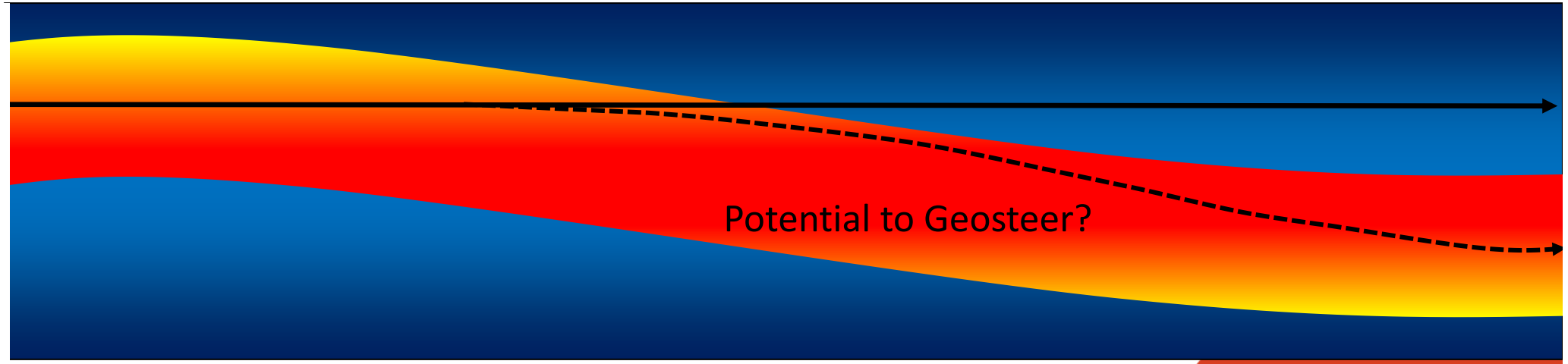
Channel Sand

Side View
(1D)

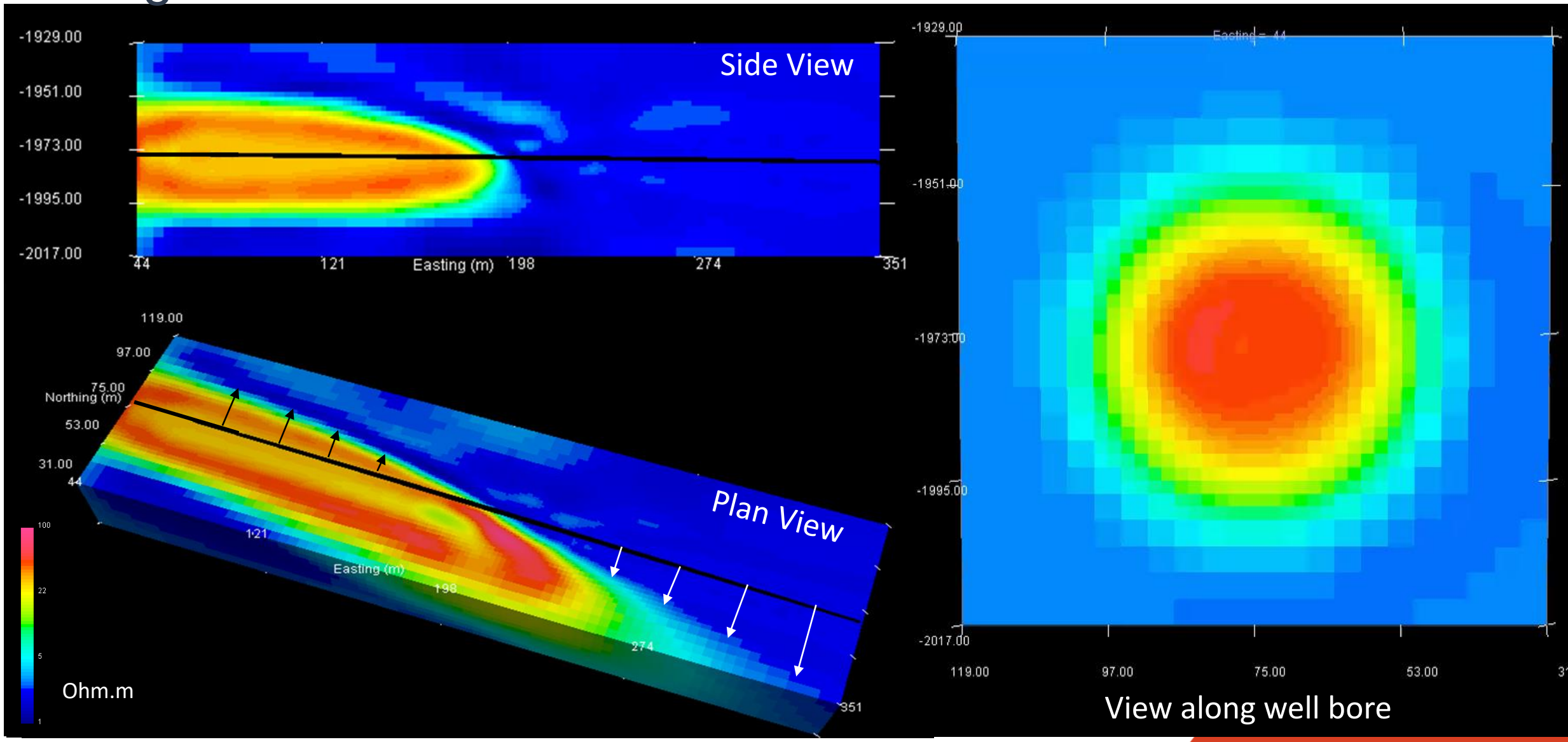


Side-track? Missed Pay?

Plan View

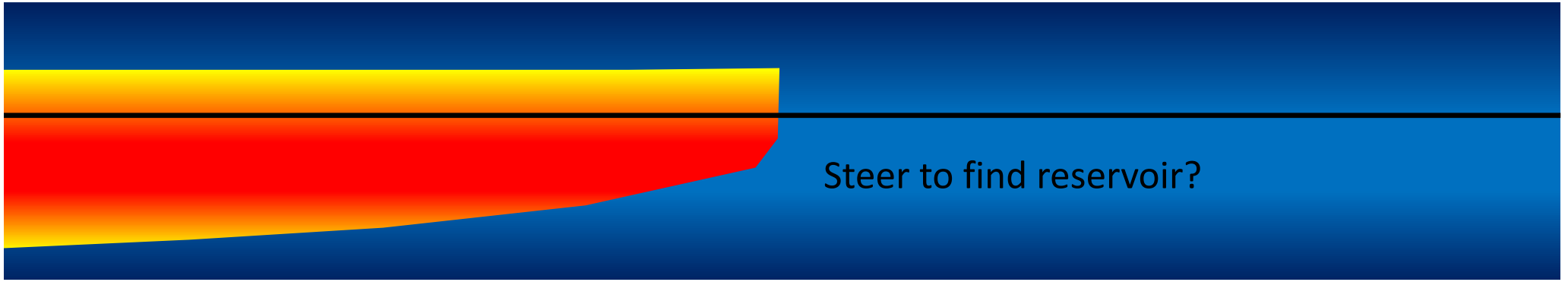


Exiting a Channel Sand

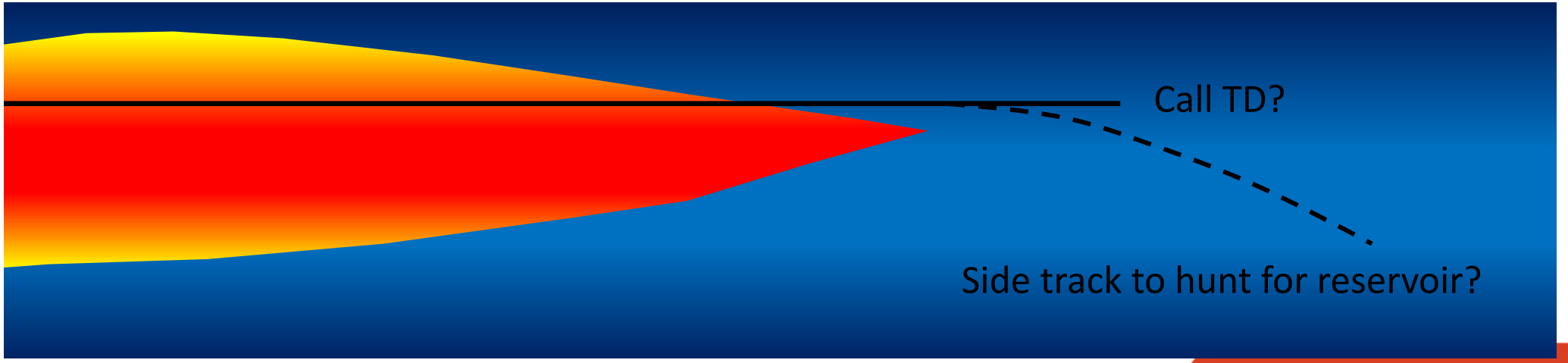


Channel Sand Again?

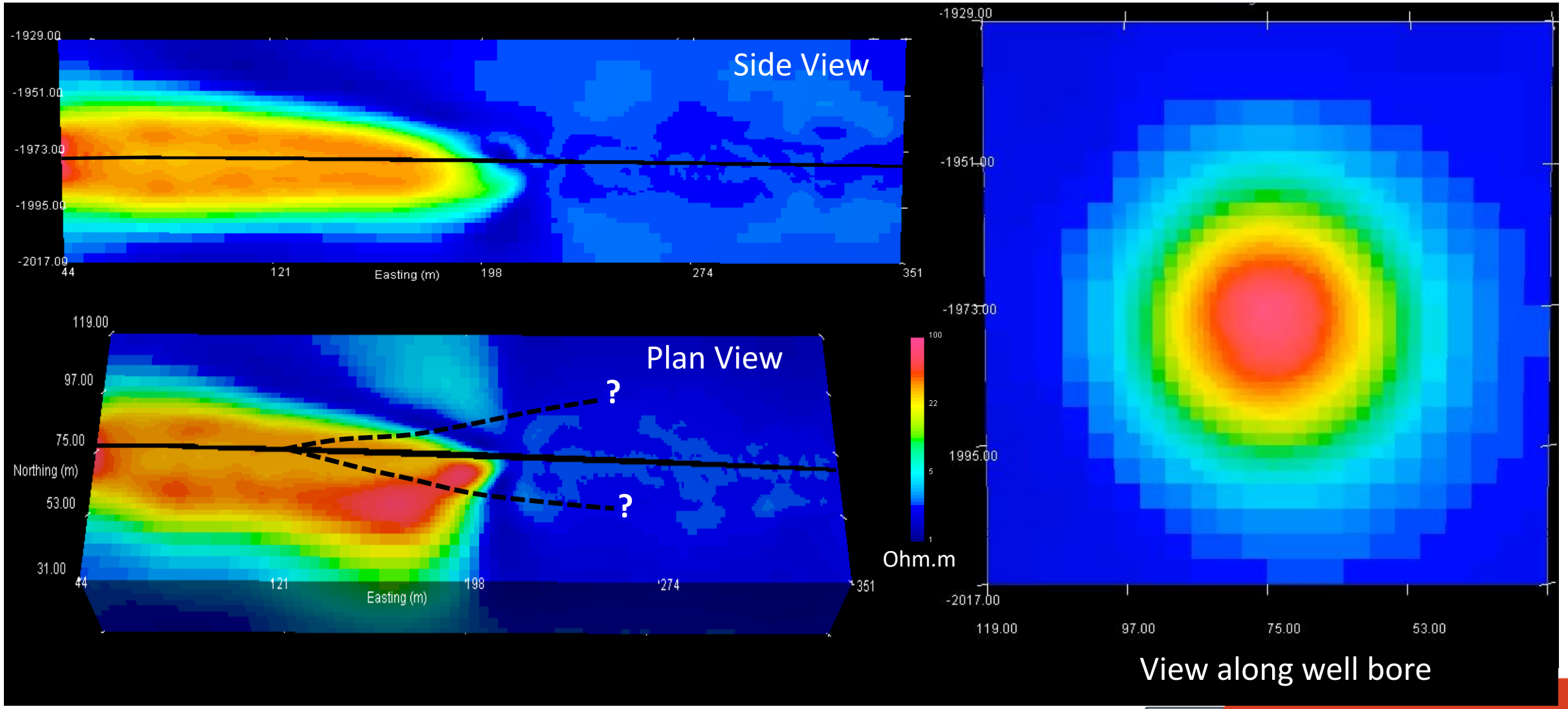
Side View
(1D)



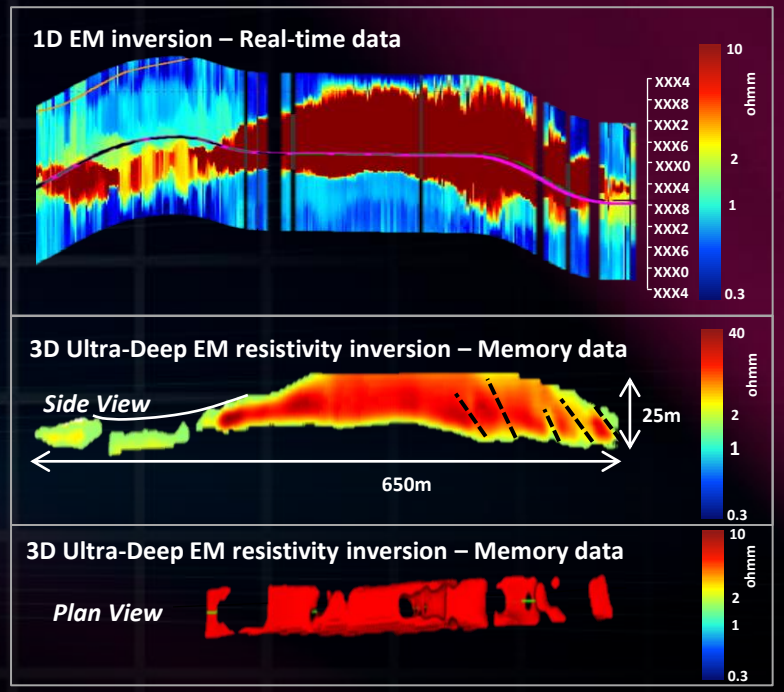
Plan View

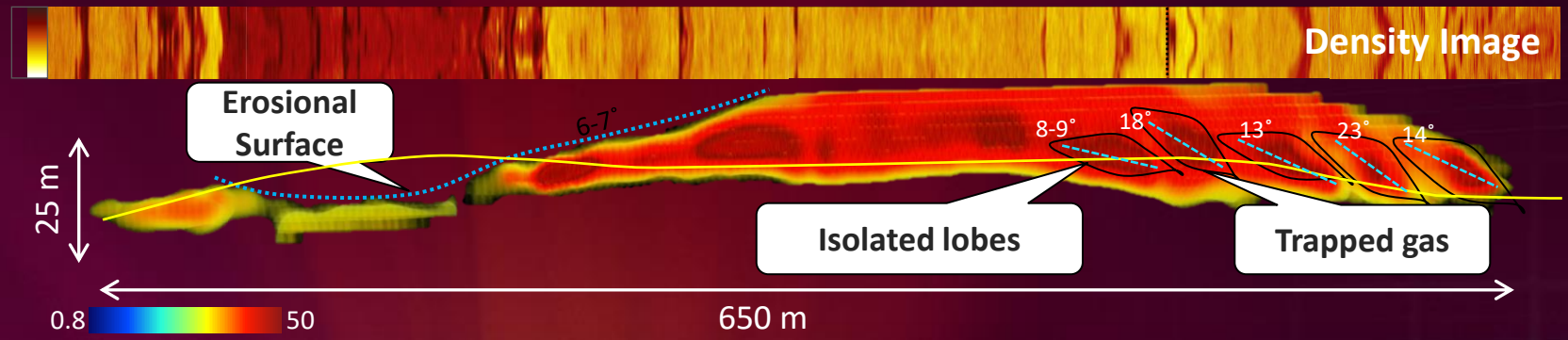


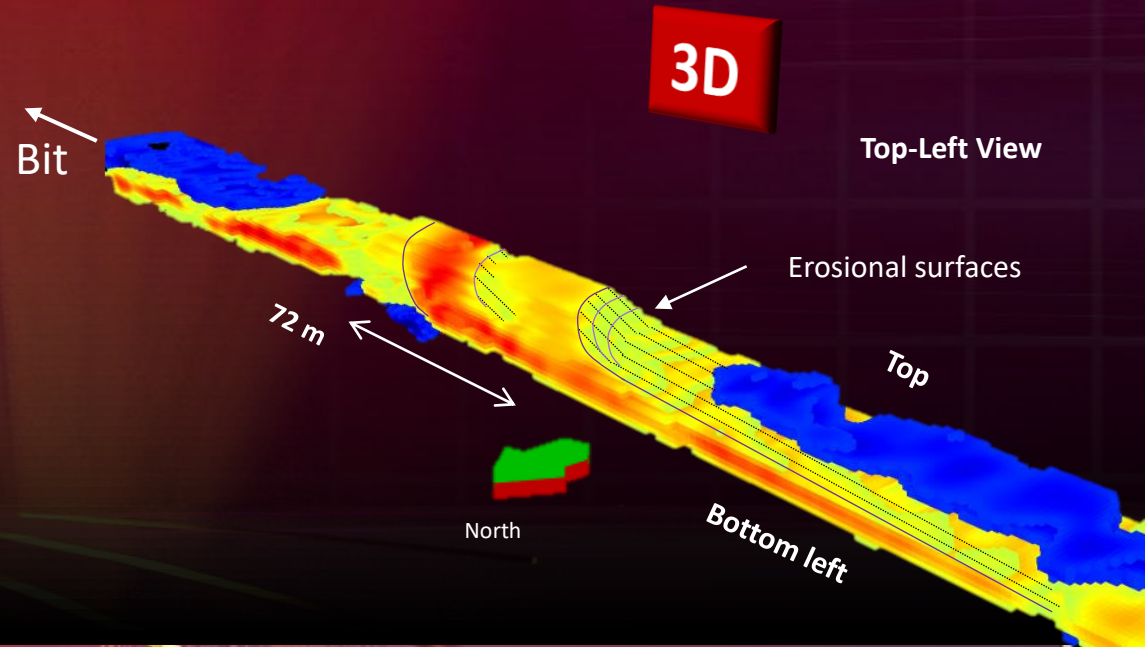
Pinch Out


Side View
-1929.00
-1951.00
-1973.00
-1995.00
-2017.00
44
121
Easting (m)
198
274
351
Plan View
119.00
97.00
75.00
Northing (m)
53.00
31.00
?
?
100
22
5
1
Ohm.m
-1929.00
-1951.00
-1973.00
1995.00
-2017.00
119.00
97.00
75.00
53.00
View along well bore

3D Ultra-deep Resistivity



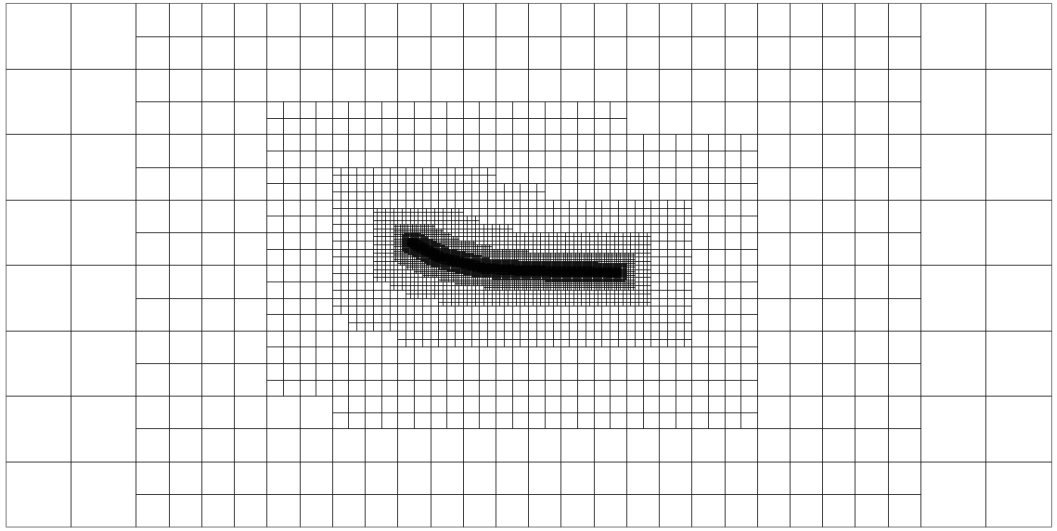


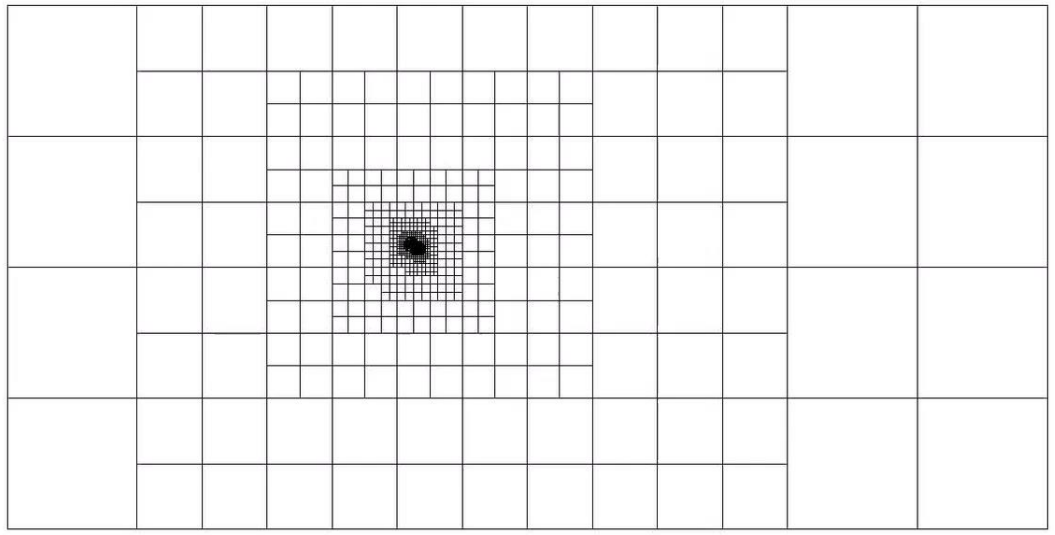


Decision-making in 3 Dimensions

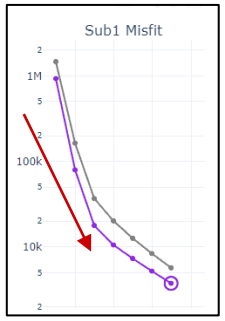
Sinha, Supriya, Riofrio, Karol, Walmsley, Arthur, Clegg, Nigel, Sviland-Østre, Stig, and Nicolas Gueze. "Real-Time 3D Imaging of Complex Turbiditic Reservoir Architecture." Paper presented at the SPWLA 62nd Annual Logging Symposium, Virtual Event, May 2021. doi: https://doi.org/10.30632/SPWLA-2021-0041

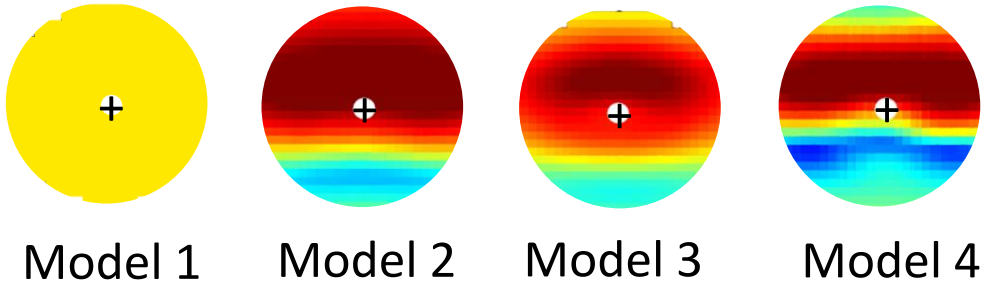
3D Inversion: OcTree Meshes

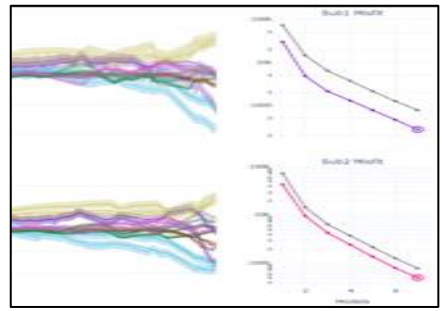


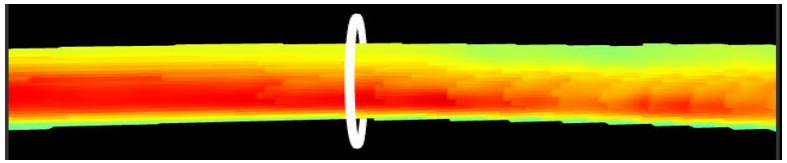


Wilson, G., Marchant, D., Haber, E., Clegg, N., Zurcher, D., Rawsthorne, L., & Kunnas, J. (2019, September 23). Real-Time 3D Inversion of Ultra-Deep Resistivity Logging-While-Drilling Data. Society of Petroleum Engineers. doi:10.2118/196141-MS









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Case Study

Ultra-deep 3D Electromagnetic Inversion for Anisotropy, a Guide to Understanding Complex Fluid Boundaries in a Turbidite Reservoir

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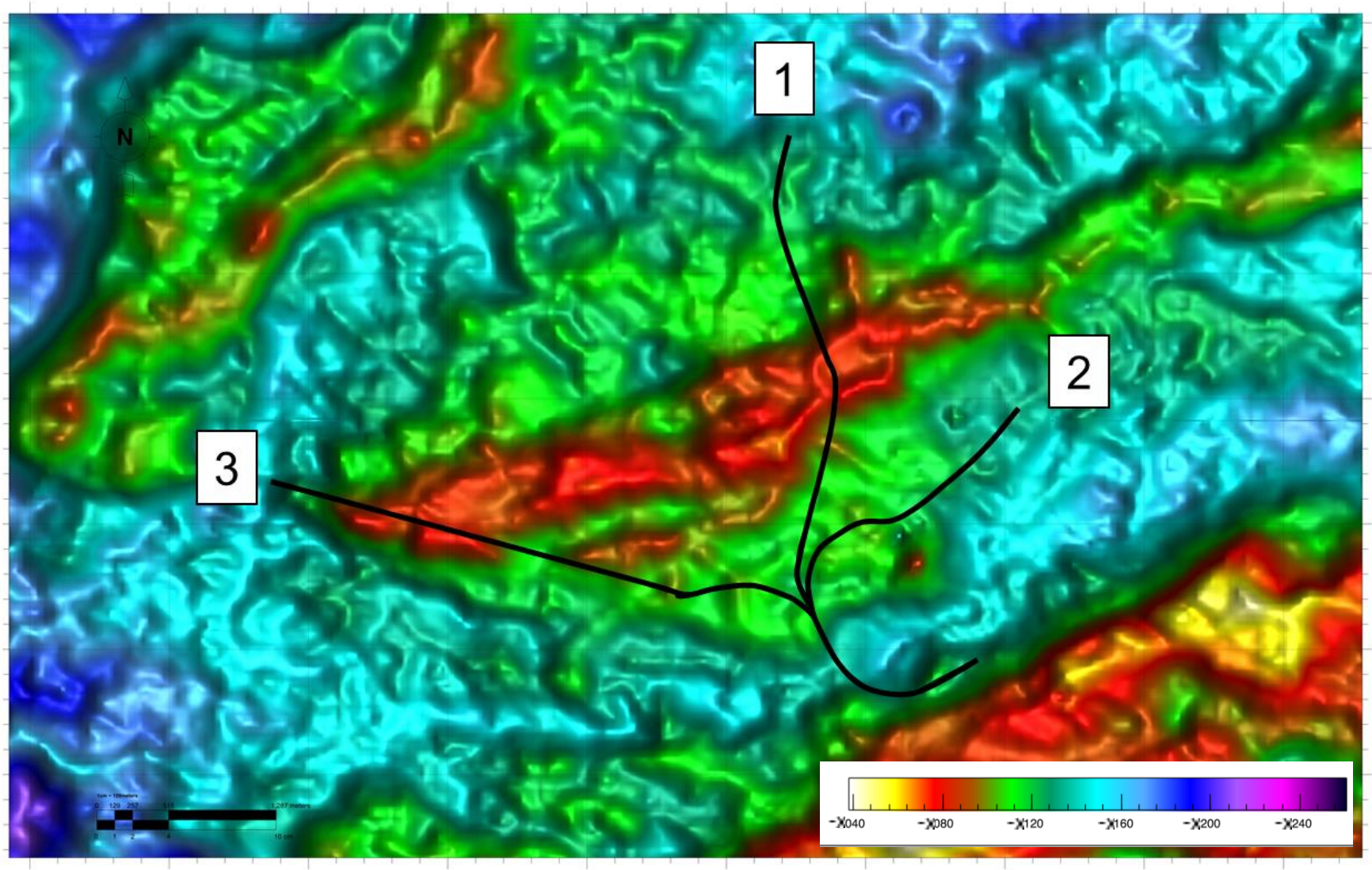
Background



- **Tri-Lateral Well**
- **Turbidite Reservoir**
- **Norwegian Continental Shelf**

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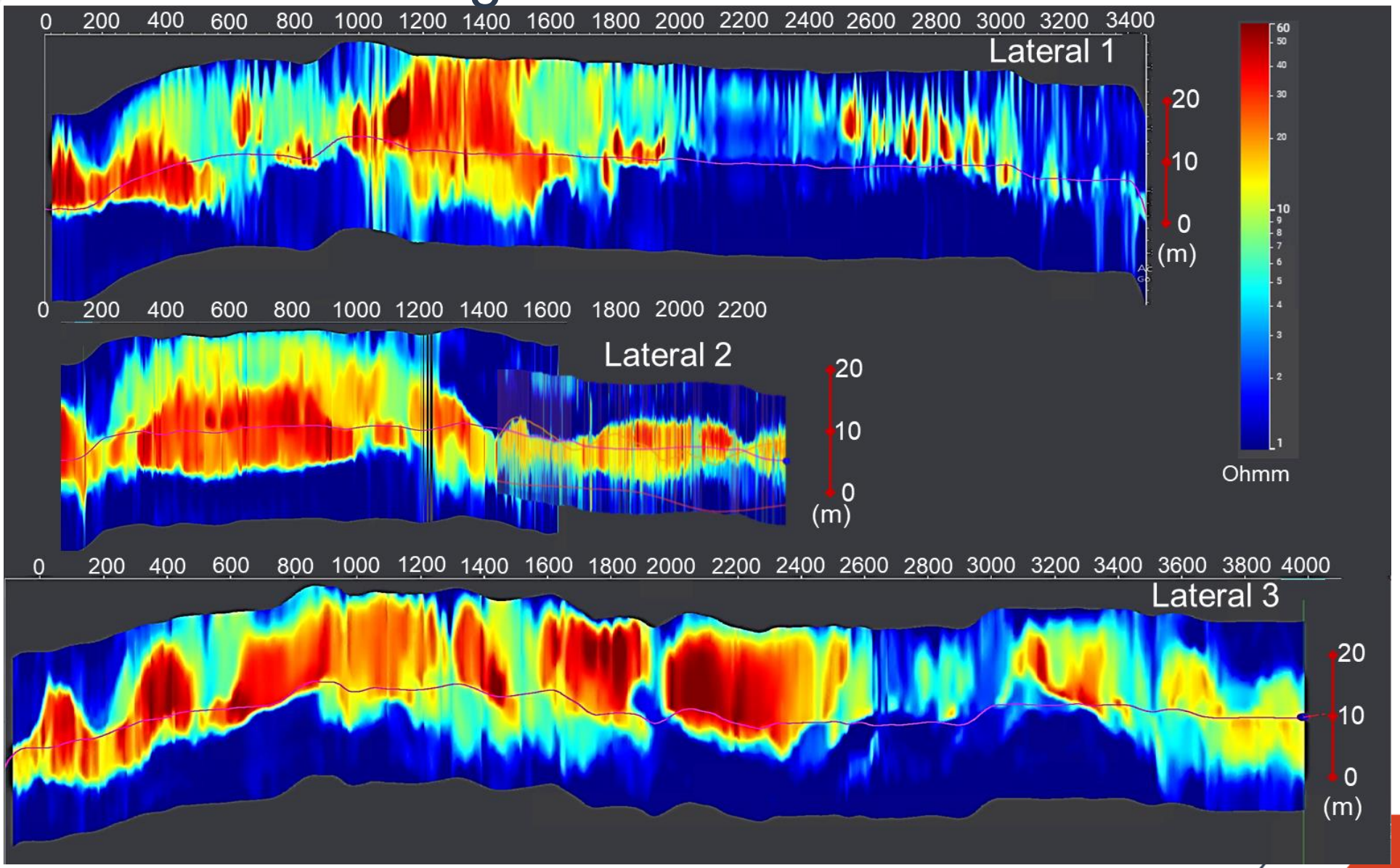
1D Electromagnetic Inversions



Low resistivity above the well is the shale cap rock

Low resistivity below the well path expected to be water.

Why the convoluted OWC?

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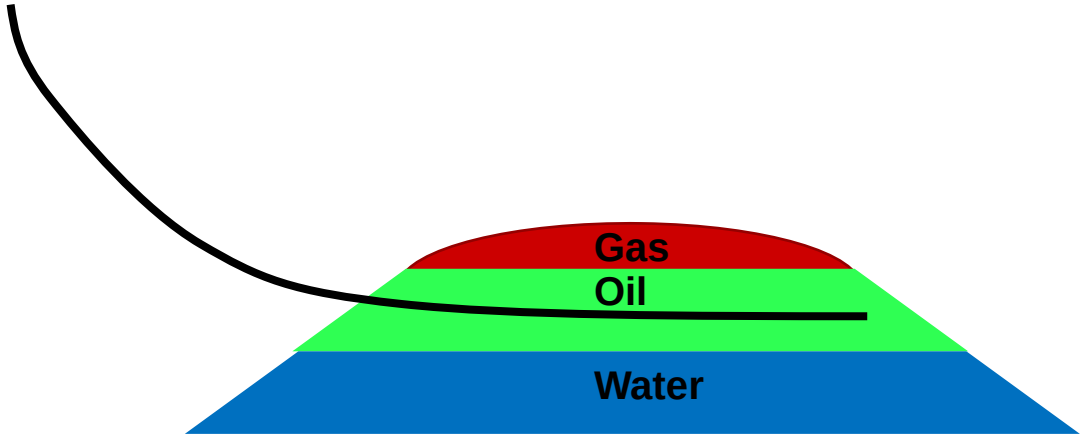
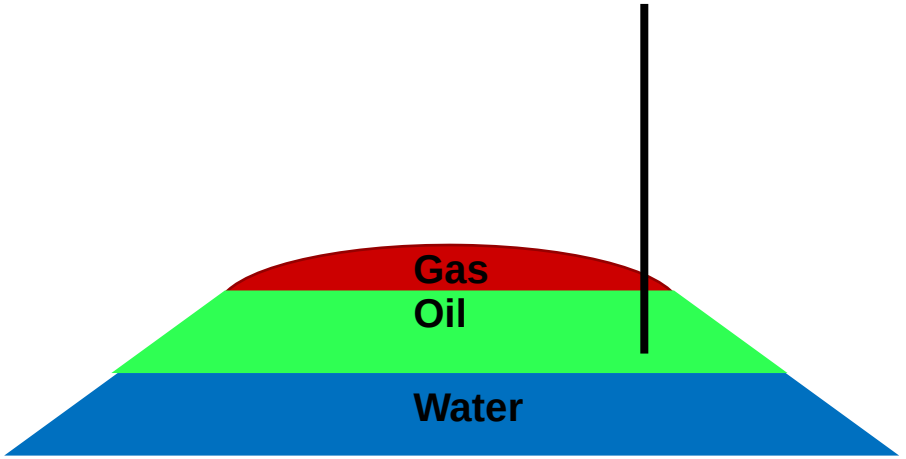
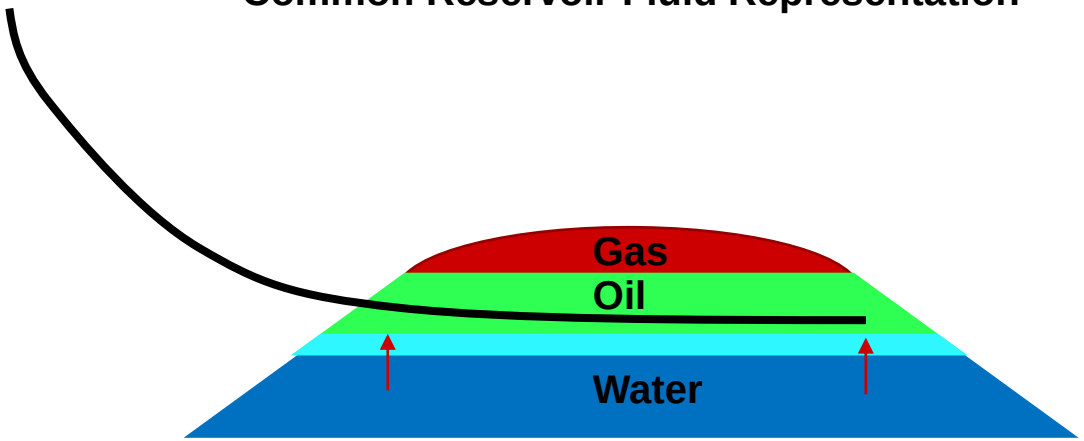
Simplistic Fluid Contacts

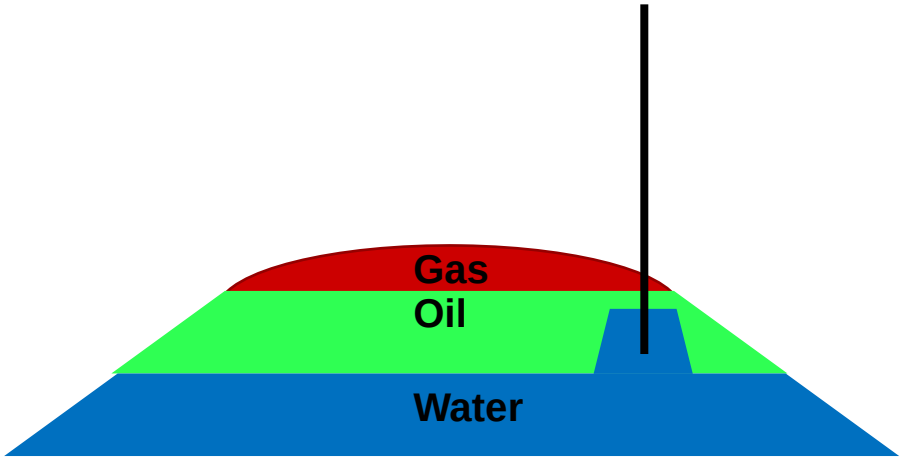


Common Reservoir Fluid Representation





Water Pulled up to balance pressure



Water Coning Caused by production

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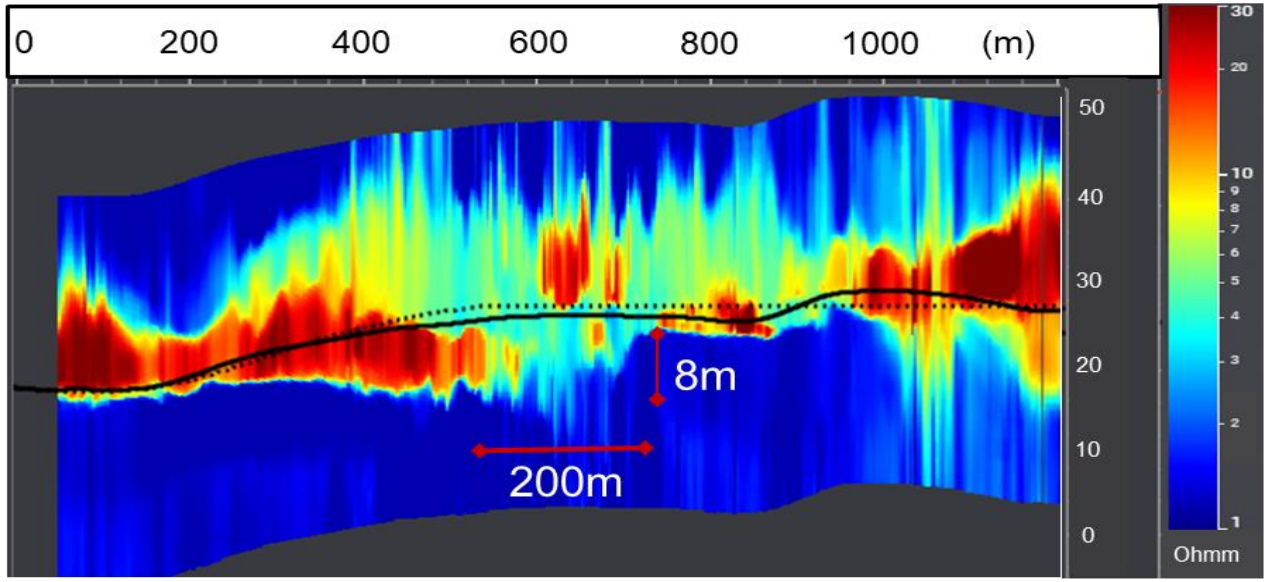
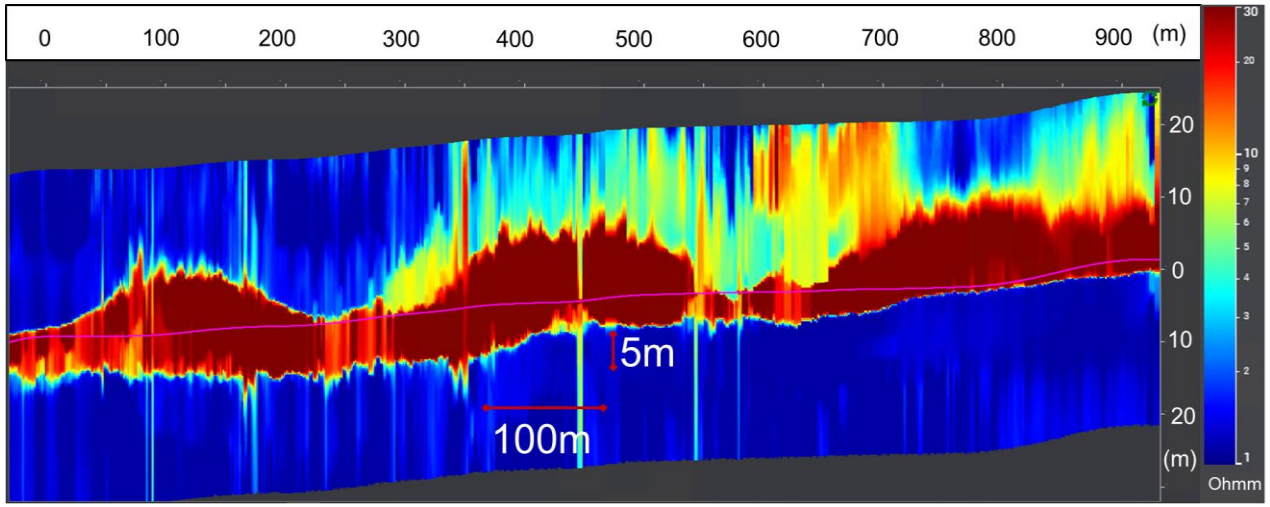
Oil/Water Contact TVD Displacement



Lateral 1



Lateral 3

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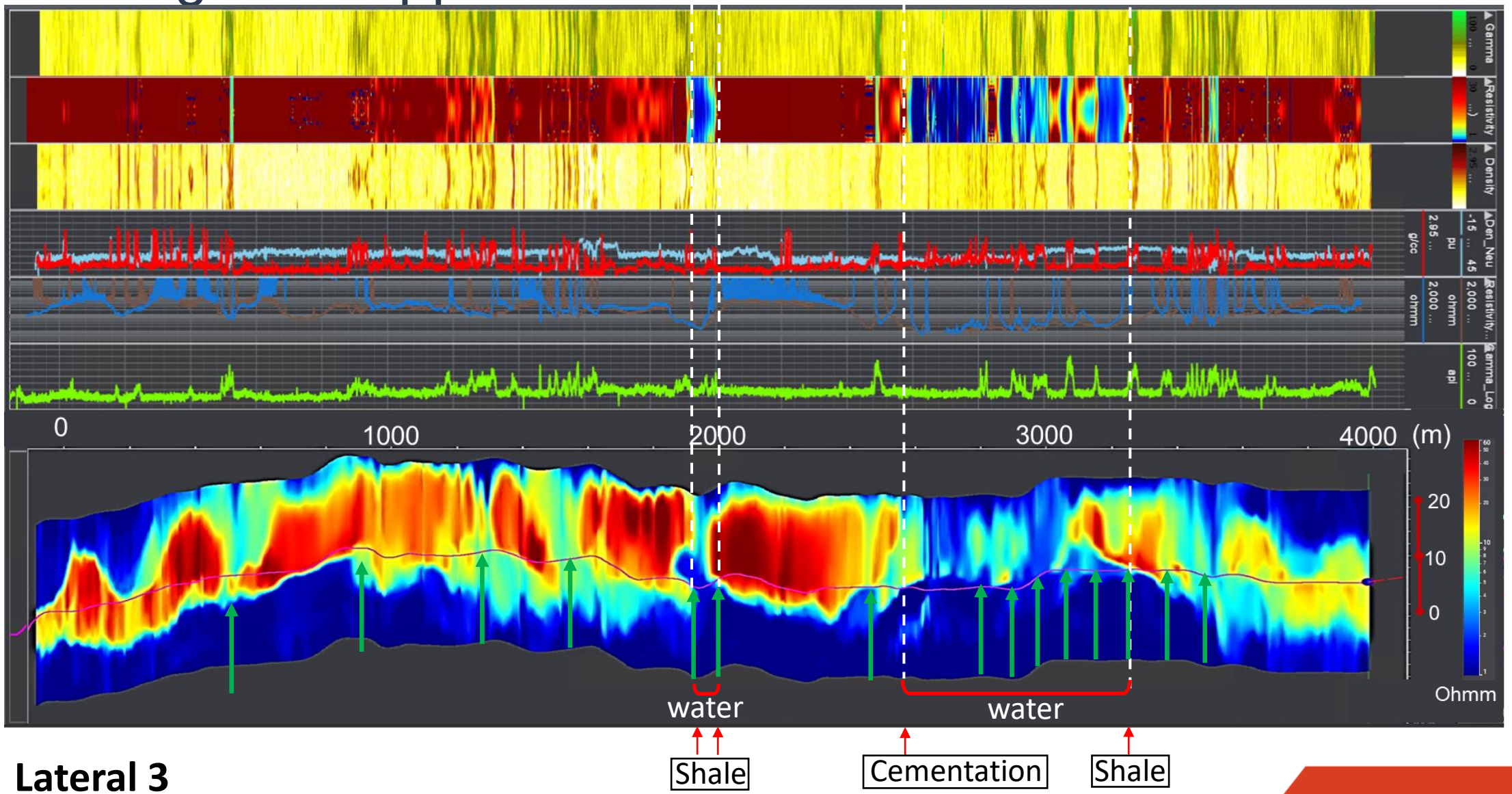
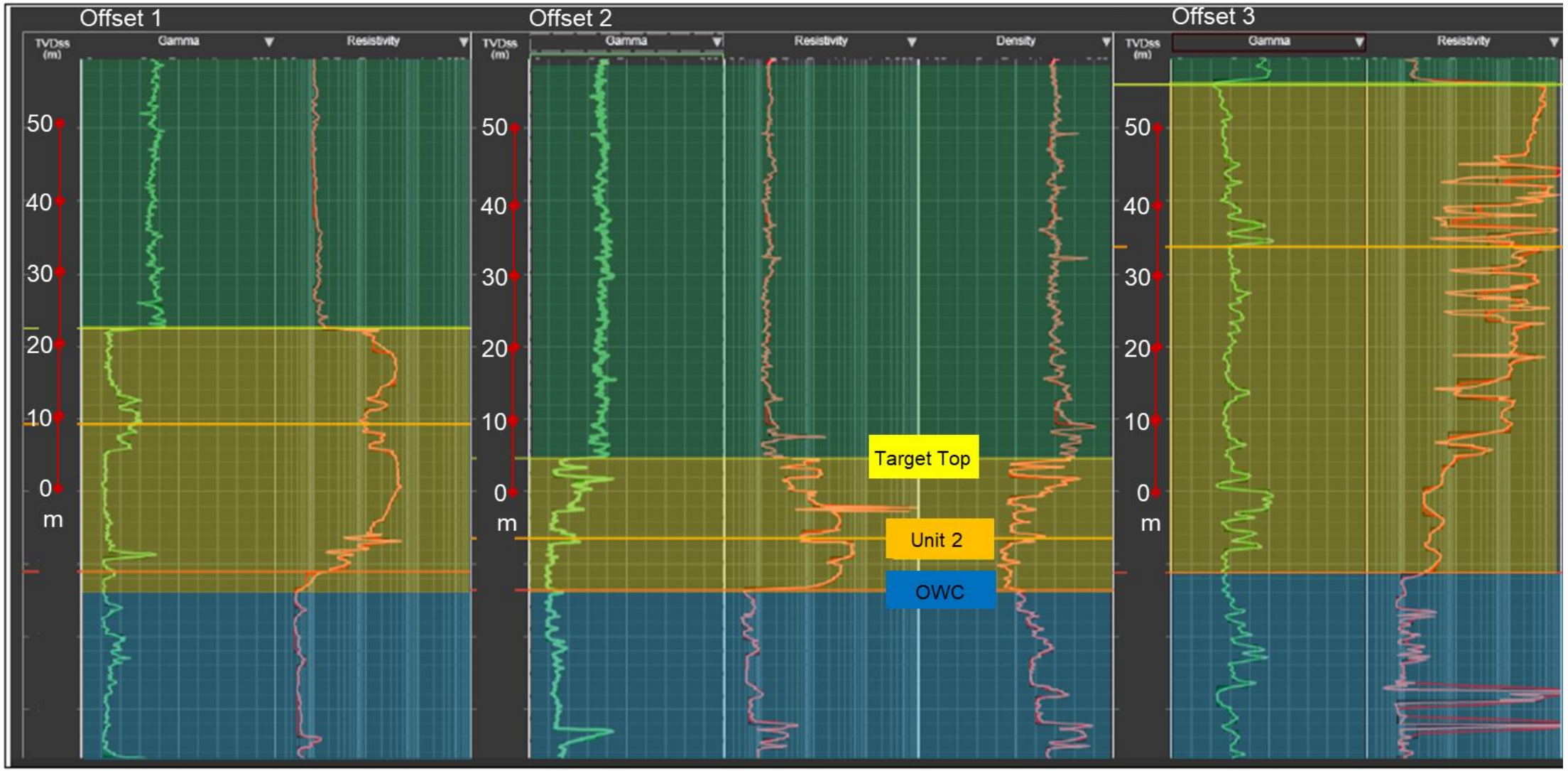
Integrated Approach



Lateral 3

Offset wells



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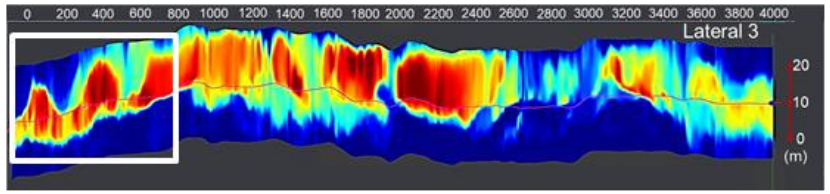
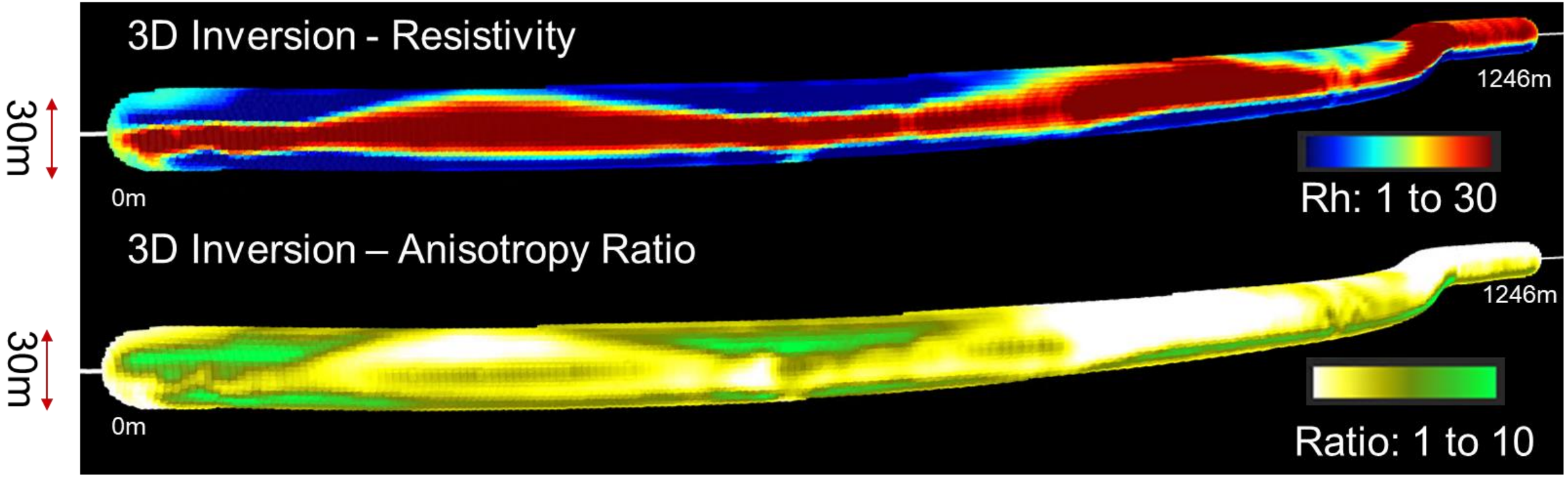
3D Inversion For Resistivity and Anisotropy



Lateral 3



Turbidite Reservoir, Norwegian Continental Shelf

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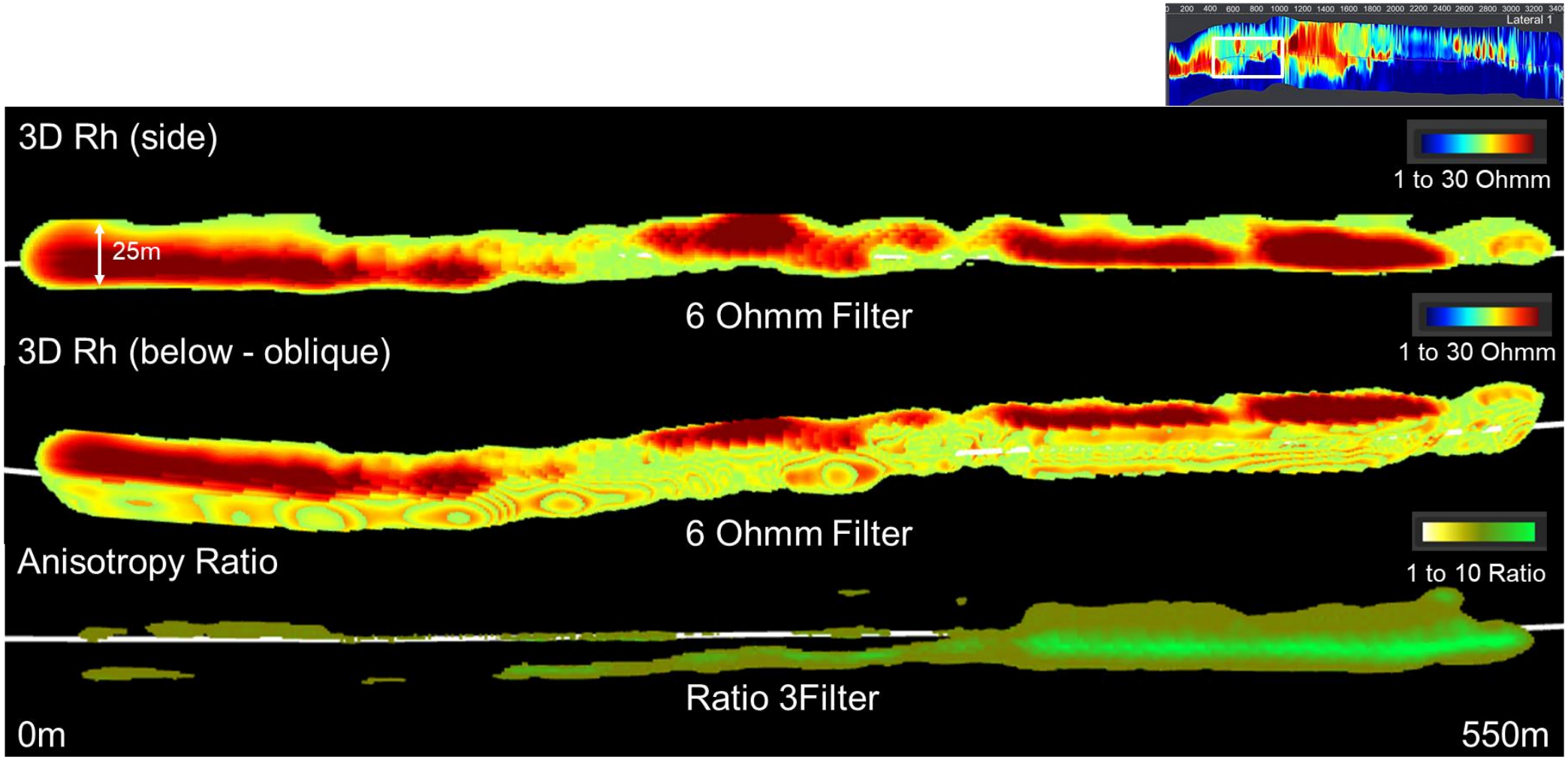
3D EM Inversion 8m Lateral 1 - 8m OWC change



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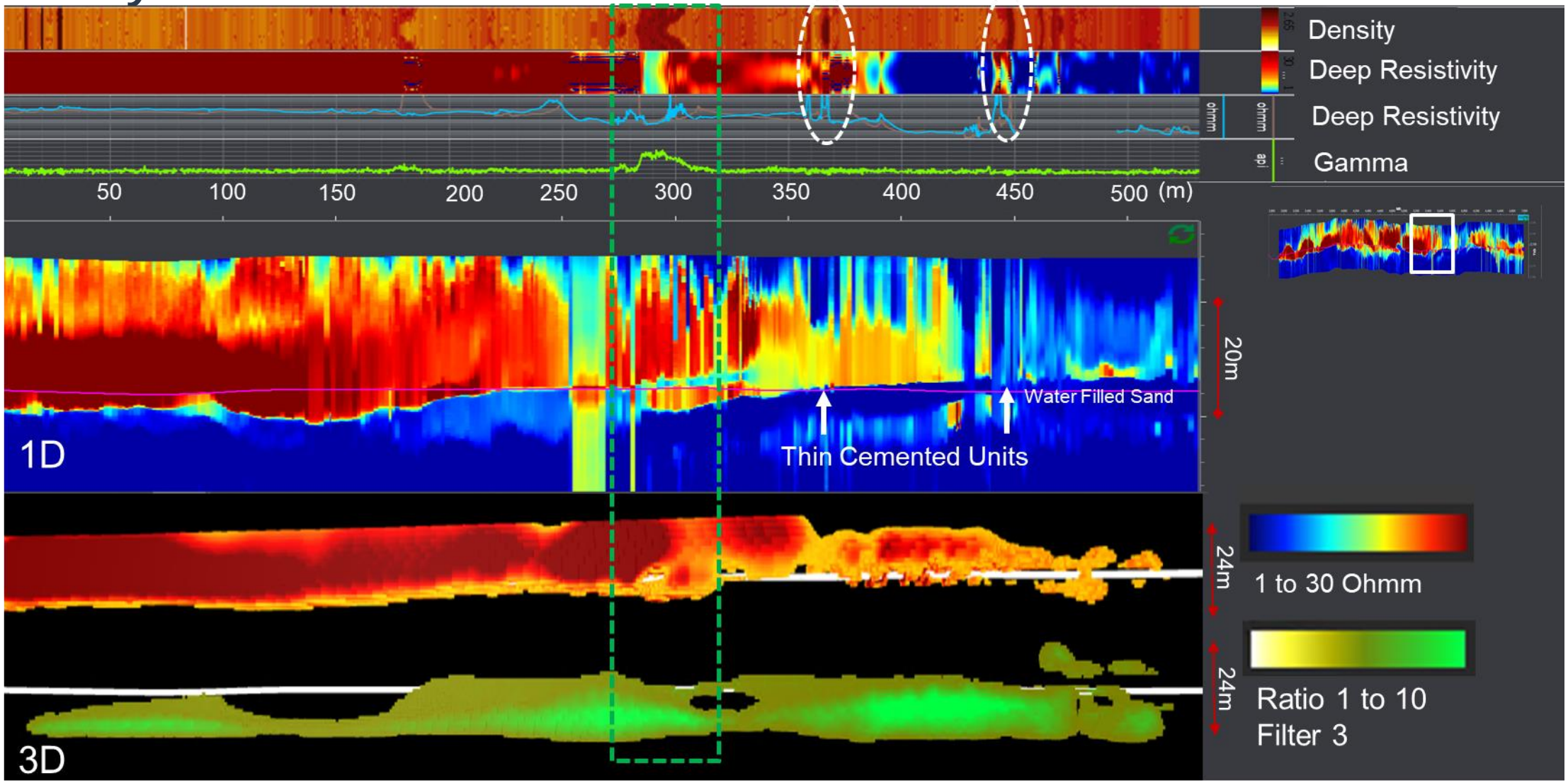
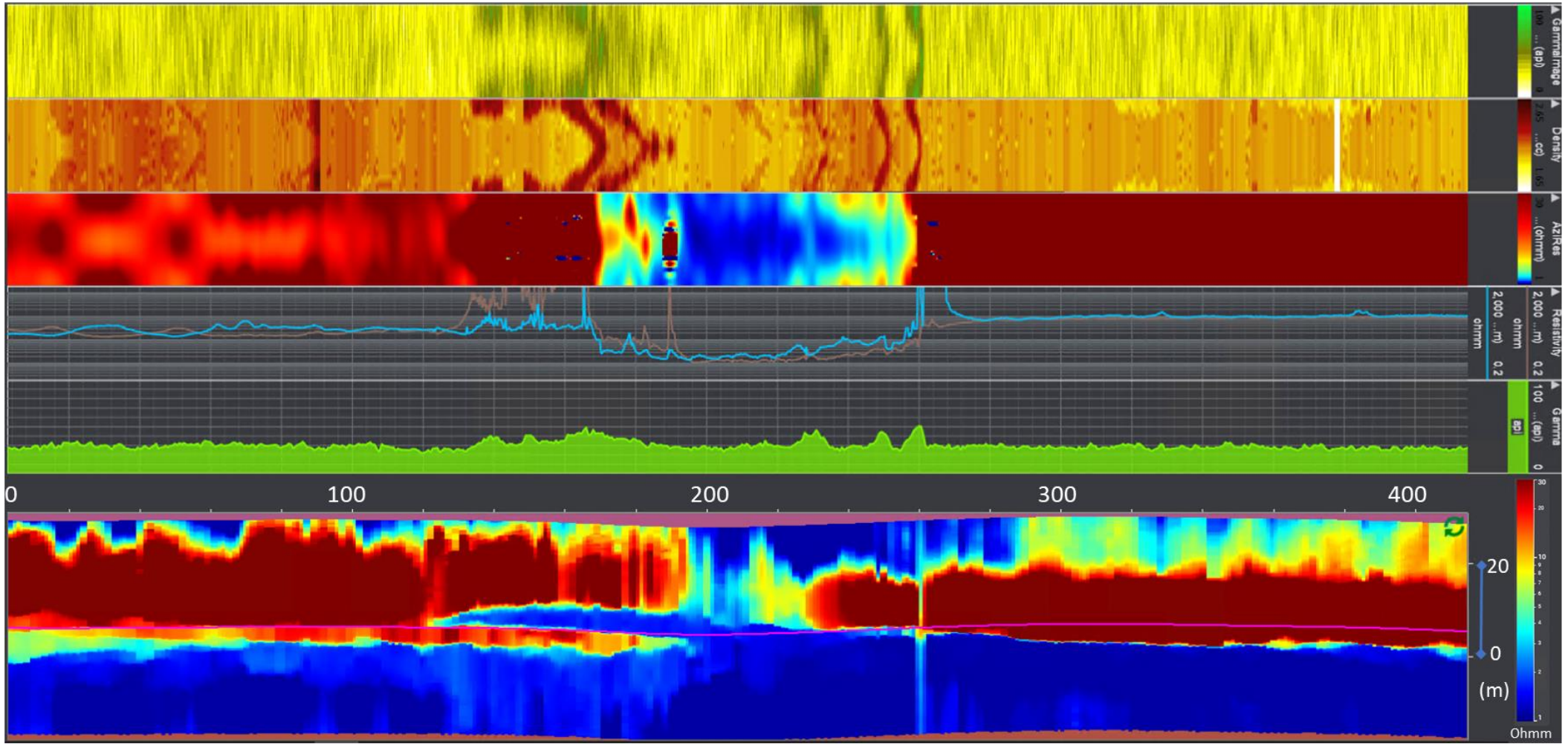
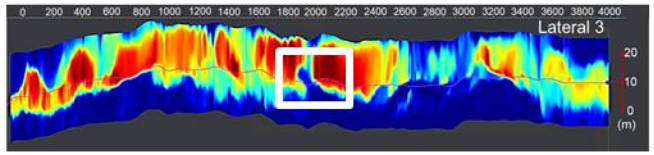
Entry to Water Zone Lateral 1



Water Intrusion Lateral 3





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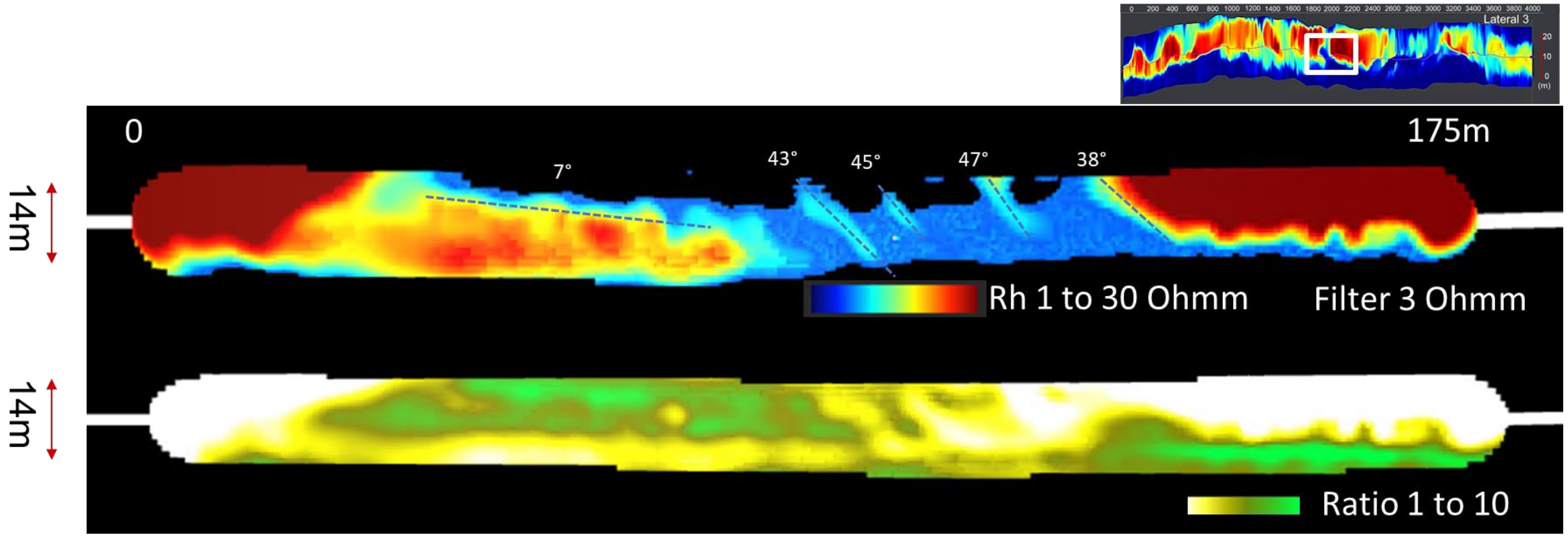
3D EM Inversion Water Intrusion



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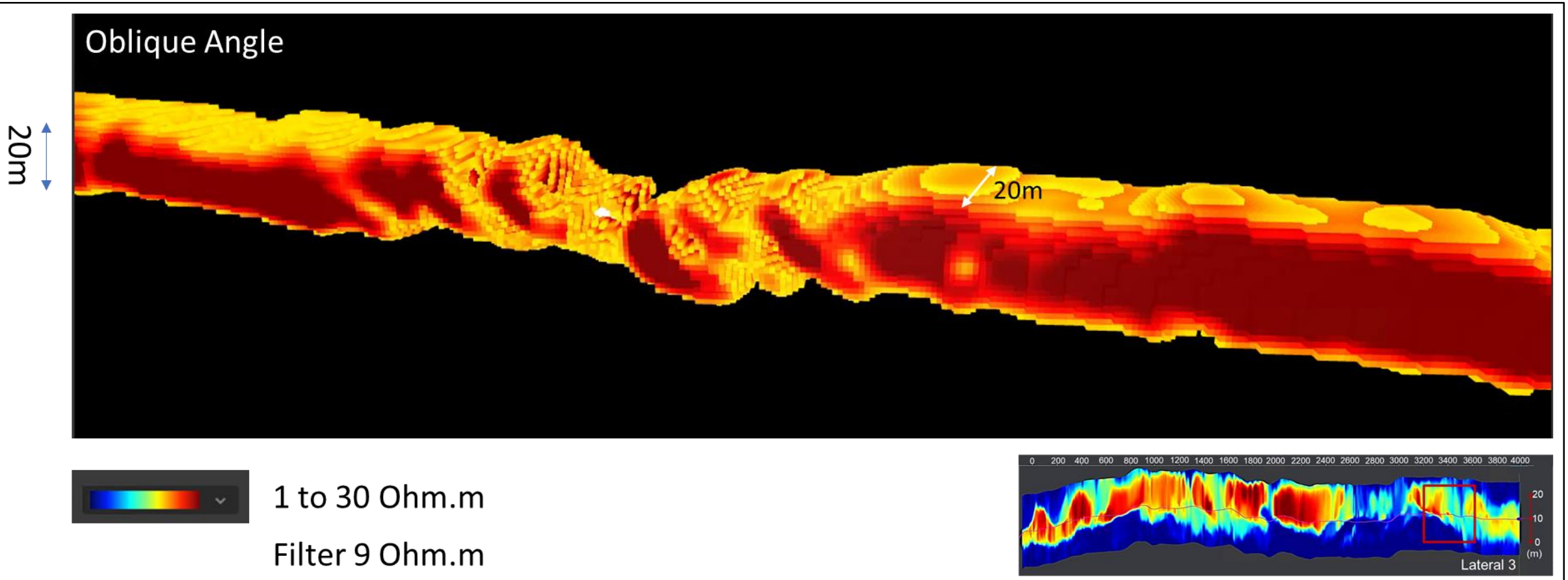
Lateral 3 Stacked Channels



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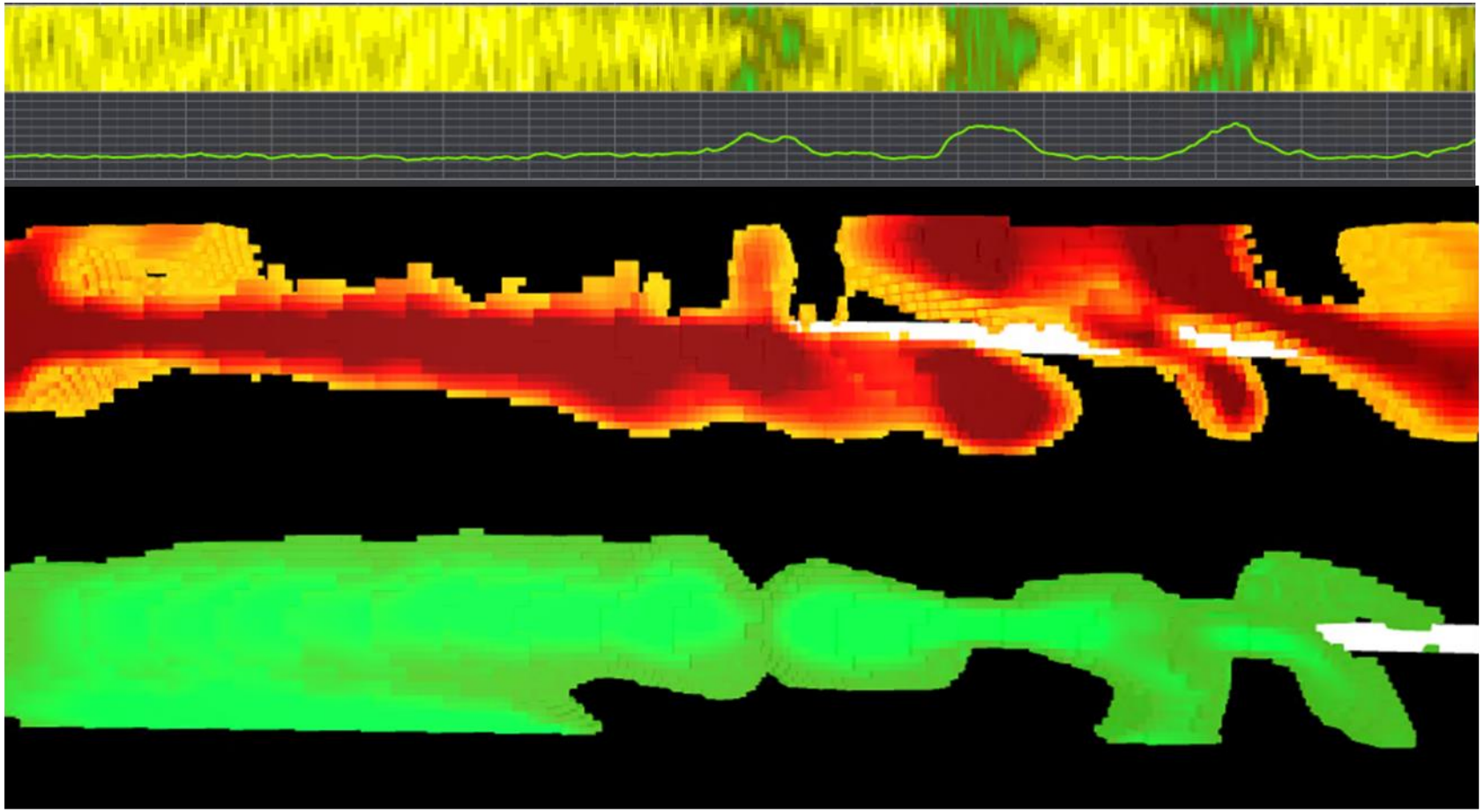
Lateral 3 Anisotropy Defining Inclined Shale Layers



1 to 100 API

Rh. 1 to 30 Ohm.m

Filter 10 Ohmm

Ratio 1 to 10

Filter 5

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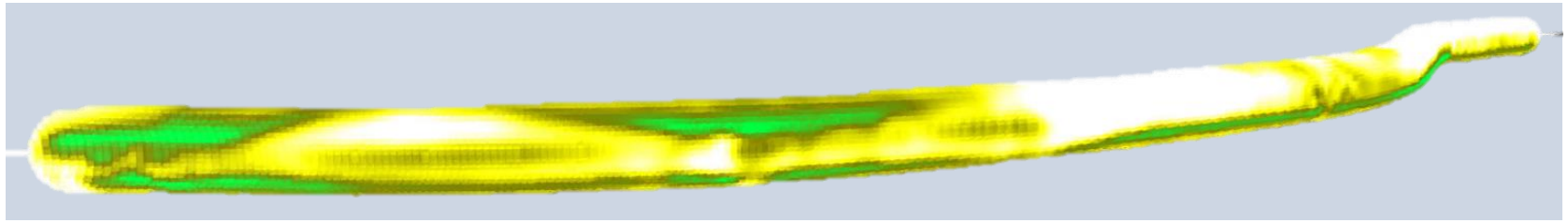
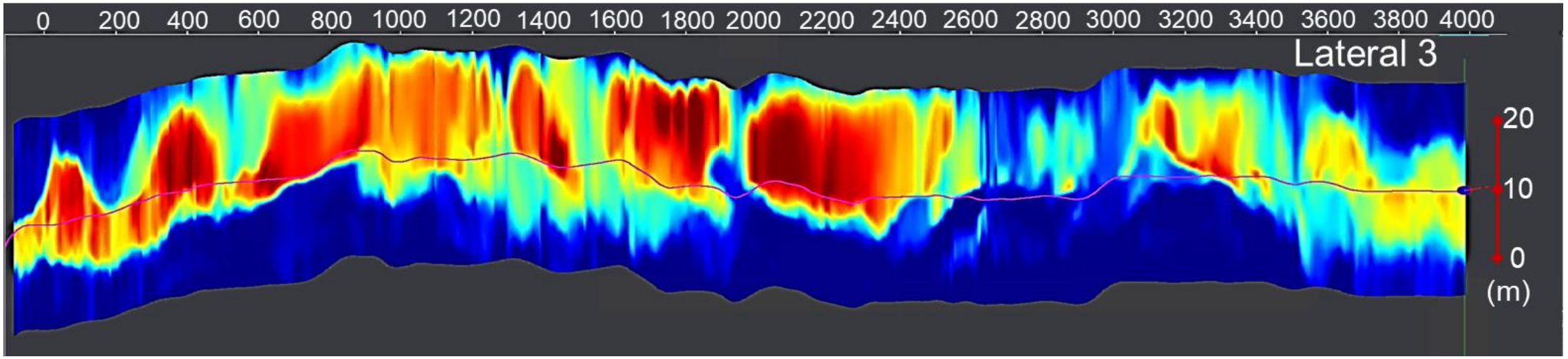
Conclusions

- The Undulating Oil/Water Contact is Difficult to Explain Given the Reservoir Properties, Unless There are Barriers to Fluid Movement.
- Inversion for Anisotropy Clearly Shows a Thin Anisotropic unit Bounding the Hydrocarbon Bearing Zone.
- Anisotropic Units Intersected by the well Show a High Gamma Signature Indicating Shale.
- Low Resistivity Isotropic Water Flooded Units Show low Gamma Indicating Sand.
- The 3D Inversion Indicates that There is an Anisotropic Shale Acting as a Baffle to Fluid Movement.
- Identifying Lithology at Distance has Implications for Completion Strategies.



Acknowledgments

- Aker BP
- ConocoPhillips
- Lundin
- Computational Geosciences Inc
- Halliburton



Thank You!

Nigel Clegg

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