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Illumination compensation with seismic-while-drilling plus surface seismic imaging

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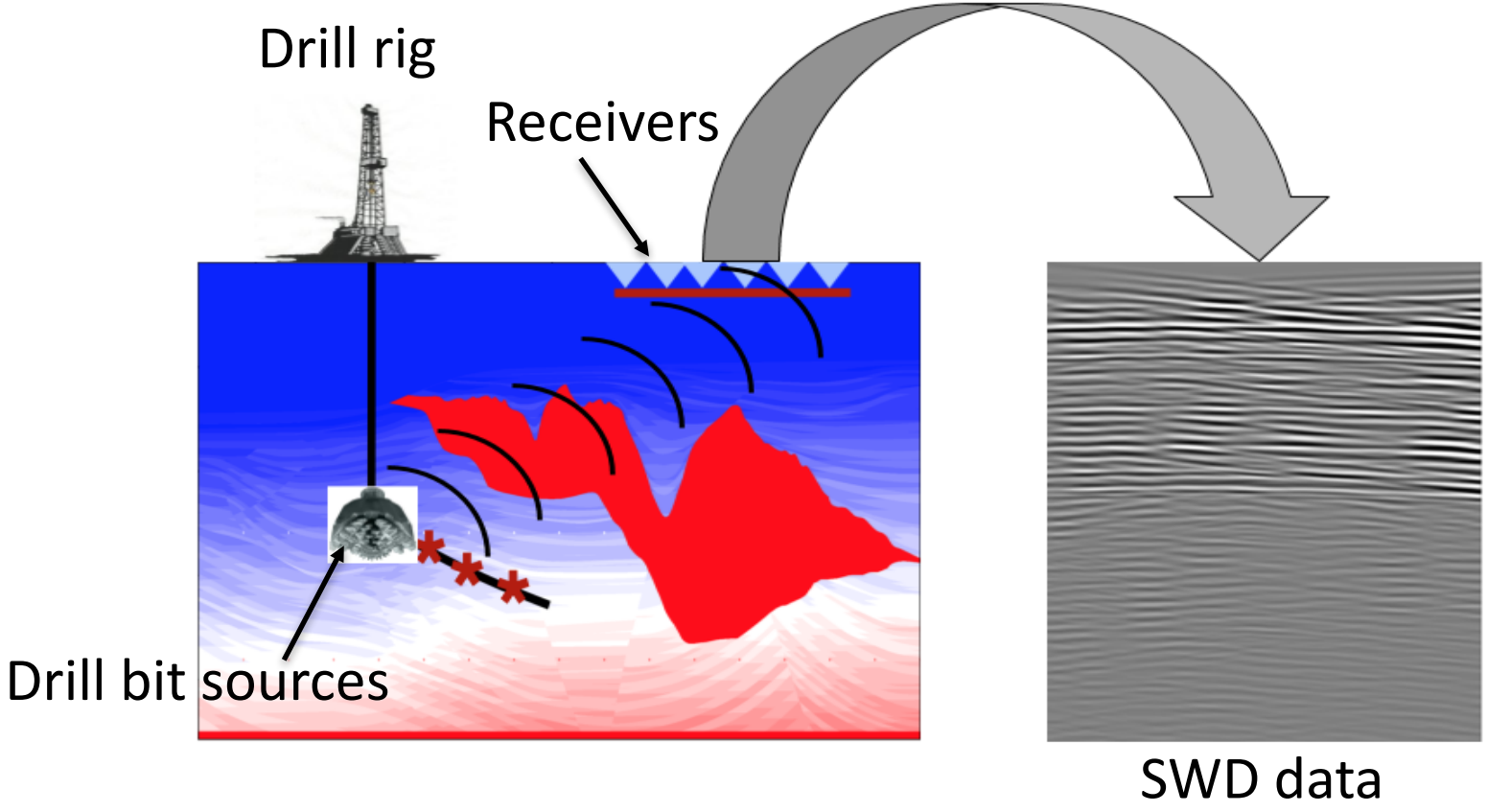
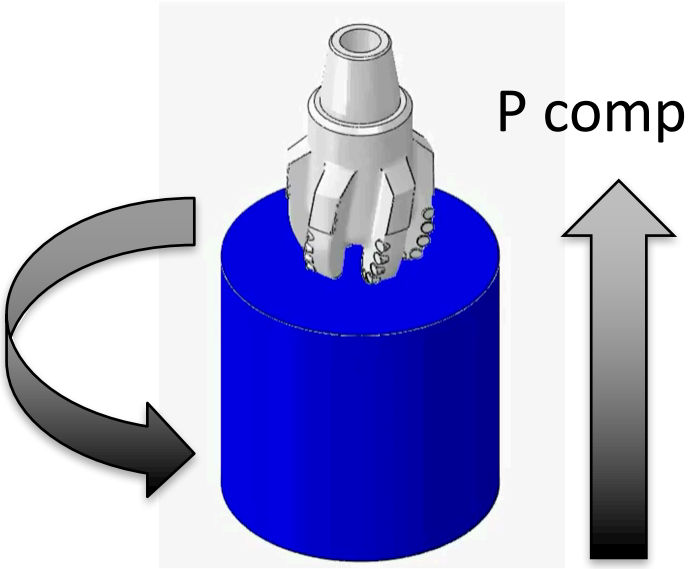
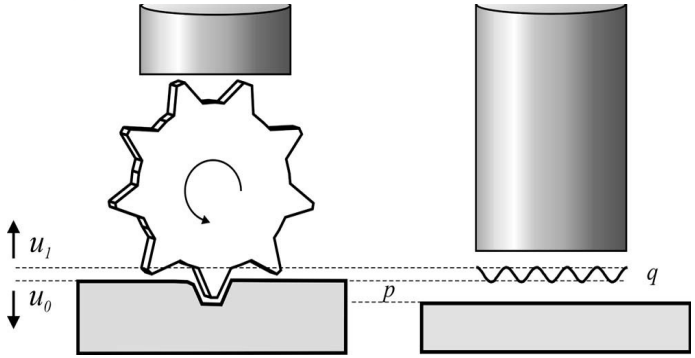
CREWES Tech Talks
January 26, 2018

SWD acquisition



Drill bit- rock interaction





Adapted from Poletto et. al., 2006

- Displacement, harmonic waves, boundary conditions: source signature.
- Drill bit source is continuous.

https://www.youtube.com/watch?v=aCksbpCQFTE

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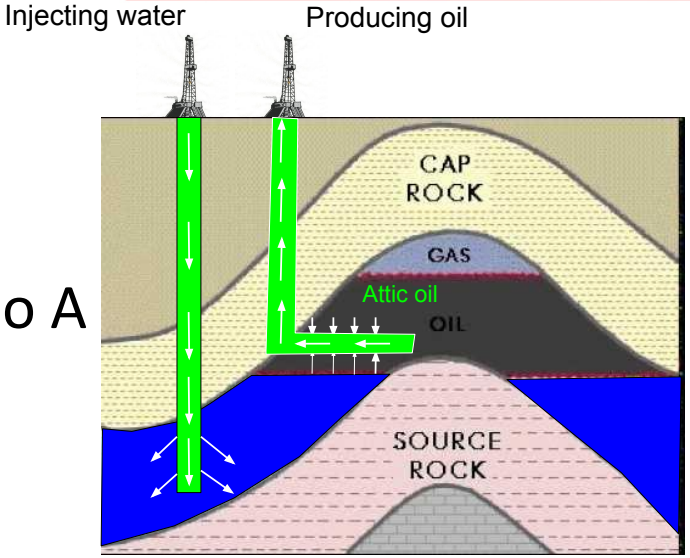
Why we use SWD?

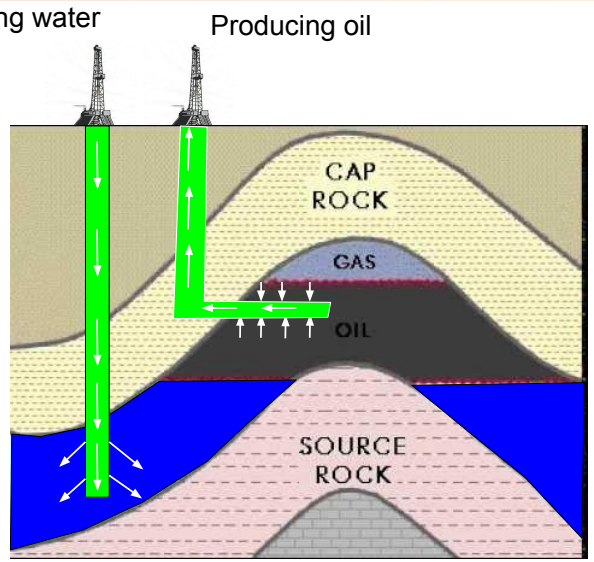
- Geosteering
- Optimized Well placement
- Interactive decision making for drilling
- Reducing the drilling risks
- Reducing uncertainties

Geosteering and Well placement issues

Scenario A



Scenario B



- Statoil Hydro Troll field: 2.4 b$ (Based on OTC-17110)
- Chevron Alba (John Hampson) 225 M$ of additional production in 3 wells

Roland Chemali, Advanced Geosteering for Optimal Exploitation of Hydrocarbon Reserves, SPE Distinguished Lecturer Program, 2011.

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Sources of uncertainties

- Geology
- Time to Depth conversion
- Sub-seismic events
- Depth imaging

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Uncertainties of depth imaging

- Migration operator falls behind the physics
- Inaccurate velocity
- Acquisition footprint
- Seismic Bandwidth
- Nonuniform illumination

Depth imaging

Linearized Born approximation

$$\mathbf{d}(\mathbf{x}_r,\omega) = -\sum_{\mathbf{x}} \mathbf{G}_0(\mathbf{x}_r,\omega;\mathbf{x})\mathbf{m}(\mathbf{x})\omega^2\mathbf{u}_0(\mathbf{x},\omega) = \mathbf{A}\mathbf{m}$$

$$\mathbf{m}_{mig}(\mathbf{x}) = -\sum_{\mathbf{x}_r}\sum_{\mathbf{x}_s}\sum_{\omega}(\omega^2\mathbf{u}_0^*(\mathbf{x},\omega,\mathbf{x}_s)\mathbf{G}_0^*(\mathbf{x}_r,\omega;\mathbf{x})\mathbf{d}(\mathbf{x}_r,\omega))$$

$$\mathbf{m}_{mig}(\mathbf{x}) = -\sum_{\mathbf{x}_r}\sum_{\mathbf{x}_s}\sum_{\omega}\mathbf{u}_s(\mathbf{x},\omega,\mathbf{x}_s)\mathbf{u}_r(\mathbf{x}_r,\omega;\mathbf{x})) = \mathbf{A}^T\mathbf{d}$$

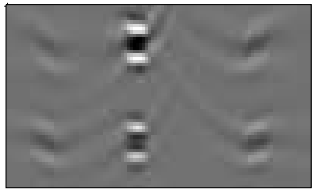
Source side wave field

Receiver side wave field

Inversion (LSM) vs Migration

$$\mathbf{m}_{mig}(\mathbf{x}) = -\sum_{\mathbf{x}_r}\sum_{\mathbf{x}_s}\sum_{\omega}(\omega^2\mathbf{u}_0^*(\mathbf{x},\omega,\mathbf{x}_s)\mathbf{G}_0^*(\mathbf{x}_r,\omega;\mathbf{x}))\sum_{\mathbf{x}'}\mathbf{G}_0(\mathbf{x}_r;\mathbf{x}')\mathbf{m}(\mathbf{x}')\mathbf{u}_0(\mathbf{x}'))$$

Migration



Inversion (LSM):

Merits:

Balanced amplitudes

Attenuated artifacts

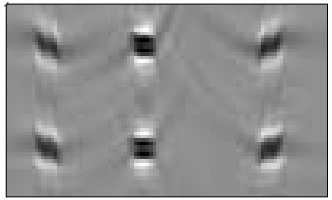
Better resolution

Reduced acquisition footprint

Demerits:

Computational time

Null space of the operator



Kazemi, N., Efficient algorithms for least squares wave equation migration and source signature estimation, PhD thesis, 2017, University of Alberta.

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SWD+ surface seismic imaging

$$\mathbf{d} = \mathbf{A}\mathbf{m}$$

$$\mathbf{m}_{mig} = \mathbf{A}^T\mathbf{A}\mathbf{m} \qquad \mathbf{A}^T\mathbf{A} \neq \mathbf{I}$$

$$\mathbf{m}_{LS} = (\mathbf{A}^T\mathbf{A})^{-1}\mathbf{A}^T\mathbf{A}\mathbf{m}$$

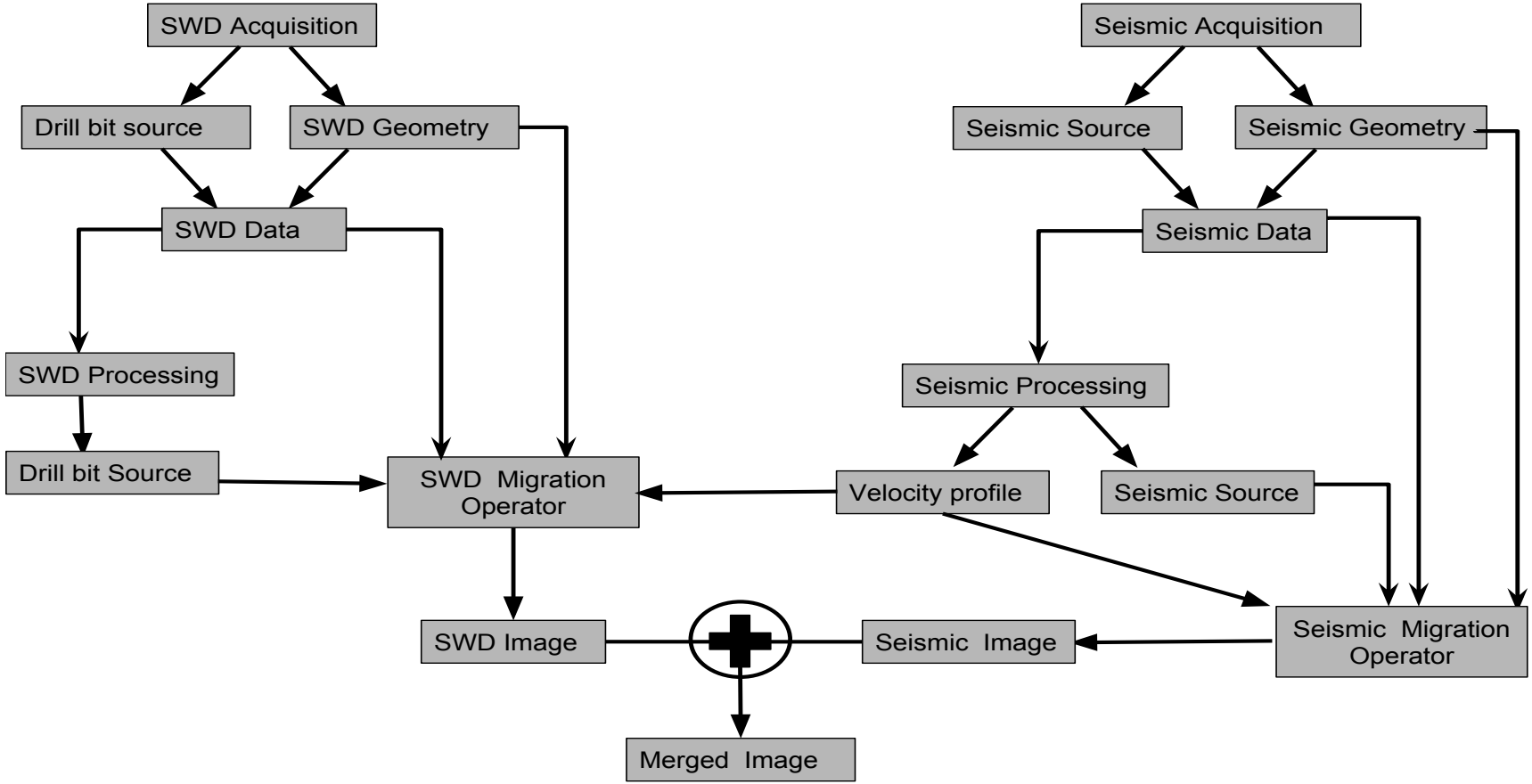
Our proposed method

$$\mathbf{m}_{merged} = \mathbf{A}^T\,\mathbf{d} + \mathbf{A}_{SWD}^T\,\mathbf{d}_{SWD}$$

$$\mathbf{m}_{merged} = [\mathbf{A}^T \quad \mathbf{A}_{SWD}^T]\,[\mathbf{d}; \mathbf{d}_{SWD}]^T = \mathbf{A}_{merged}^T\,\mathbf{d}_{merged}$$

$$\mathbf{A}_{merged}^T\mathbf{A}_{merged} \approx \mathbf{I}$$

Proposed imaging workflow



SWD source signature estimation

$$\mathbf{d}_j = \mathbf{W}\,\mathbf{r}_j + \mathbf{n}_j \qquad j = 1, \ldots J,$$

$$\mathbf{D}_p\mathbf{r}_q - \mathbf{D}_q\mathbf{r}_p = \mathbf{N}_p\mathbf{r}_q - \mathbf{N}_q\mathbf{r}_p$$

$$\mathbf{A}\,\mathbf{x} = \mathbf{e}$$

$$\mathbf{A} = \begin{pmatrix}
\mathbf{D}_2 & -\mathbf{D}_1 & & & & & \\
\mathbf{D}_3 & & -\mathbf{D}_1 & & & & \\
\mathbf{D}_4 & & & -\mathbf{D}_1 & & & \\
\vdots & & & & \ddots & & \\
 & \mathbf{D}_3 & -\mathbf{D}_2 & & & & \\
 & \mathbf{D}_4 & & -\mathbf{D}_2 & & & \\
 & \vdots & & & \ddots & & \\
 & & & & \mathbf{D}_J & & -\mathbf{D}_{J-2} \\
 & & & & & \mathbf{D}_J & -\mathbf{D}_{J-1}
\end{pmatrix} \qquad \mathbf{x} = \left[\mathbf{r}_1, \mathbf{r}_2, \mathbf{r}_3, \ldots, \mathbf{r}_J\right]^T$$

Nasser Kazemi and Mauricio D. Sacchi (2014). Sparse multichannel blind deconvolution. GEOPHYSICS, 79(5), V143-V152.

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SWD source signature estimation

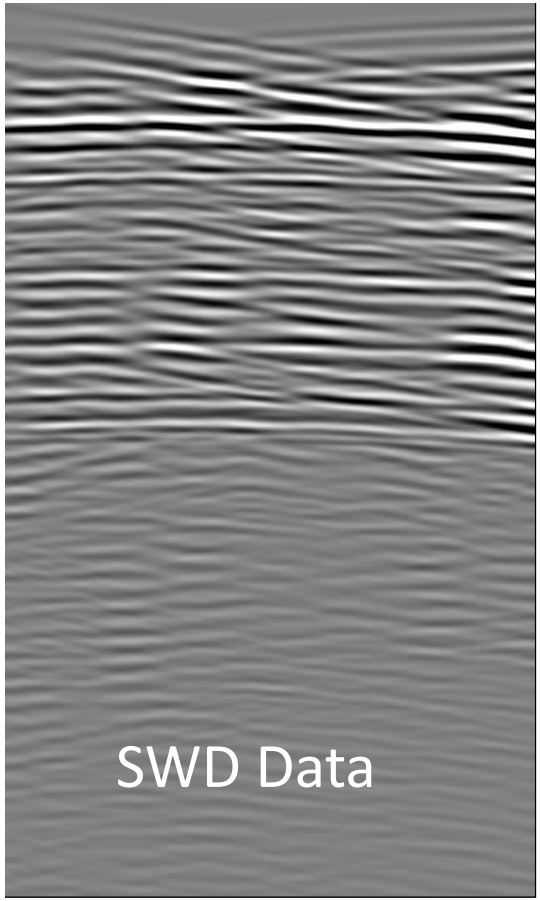
- Solve for the reflectivity: SMBD algorithm

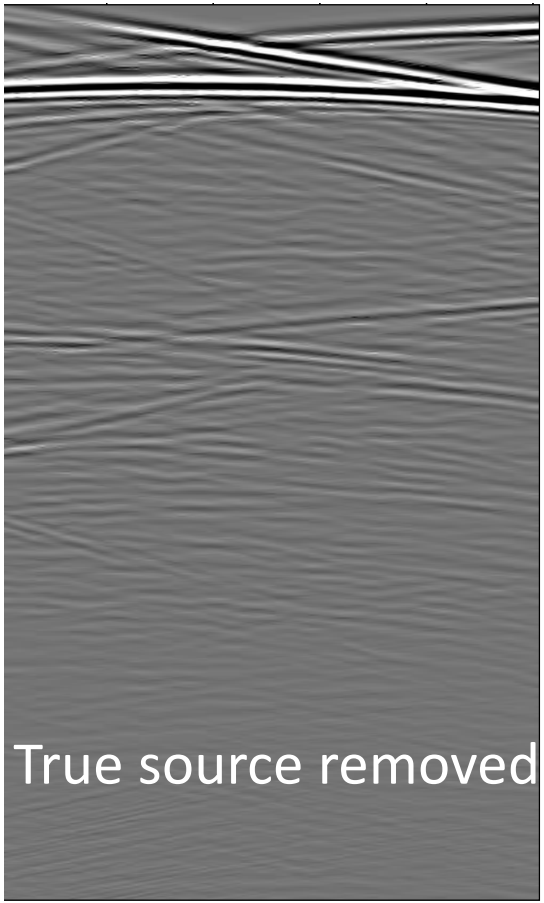
$$\hat{\mathbf{x}} = \underset{\mathbf{x}}{\operatorname{argmin}} \quad \frac{1}{2}||\mathbf{A}\,\mathbf{x}||_2^2 + \lambda \sum_i (\sqrt{x_i^2 + \epsilon^2} - \epsilon), \quad \text{subject to} \quad \mathbf{x}^T\mathbf{x} = 1$$

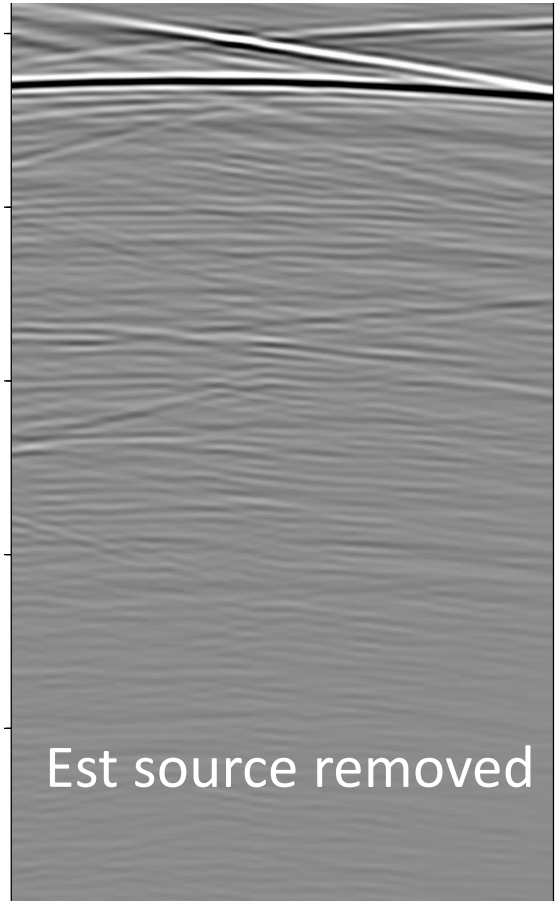
- Estimate SWD source signature: least squares estimator

$$\hat{\mathbf{w}}_{SWD} = \underset{\mathbf{w}_{SWD}}{\operatorname{argmin}} \quad \frac{1}{2}||\mathbf{X}\,\mathbf{w}_{SWD} - \mathbf{d}||_2^2$$

Drill bit- source signature estimation







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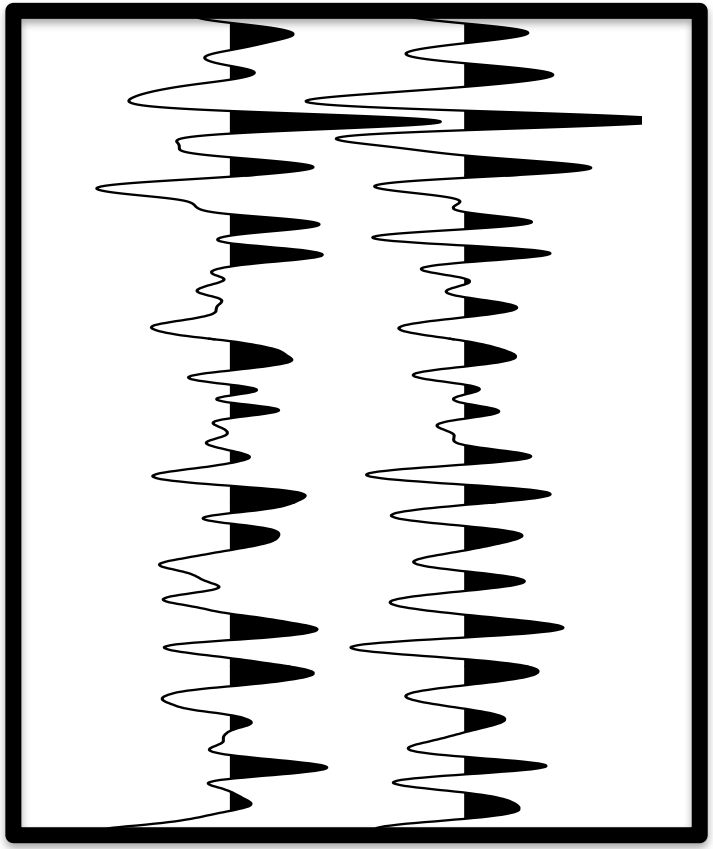
Drill bit- source signature

Original Estimated



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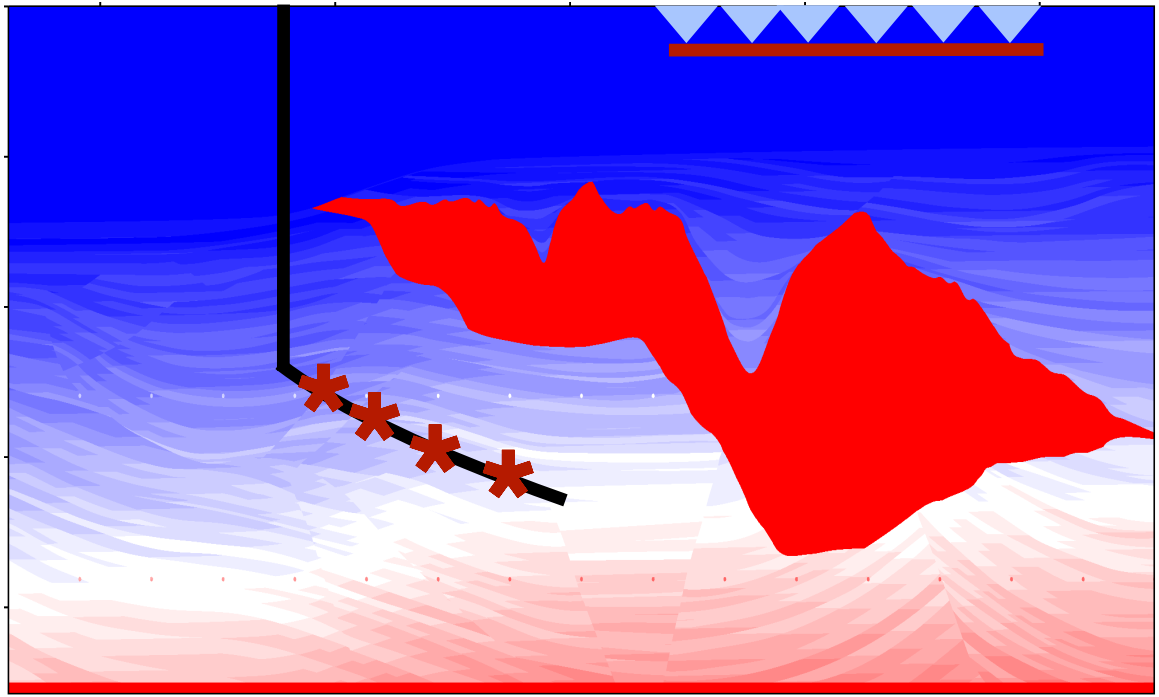
SWD imaging



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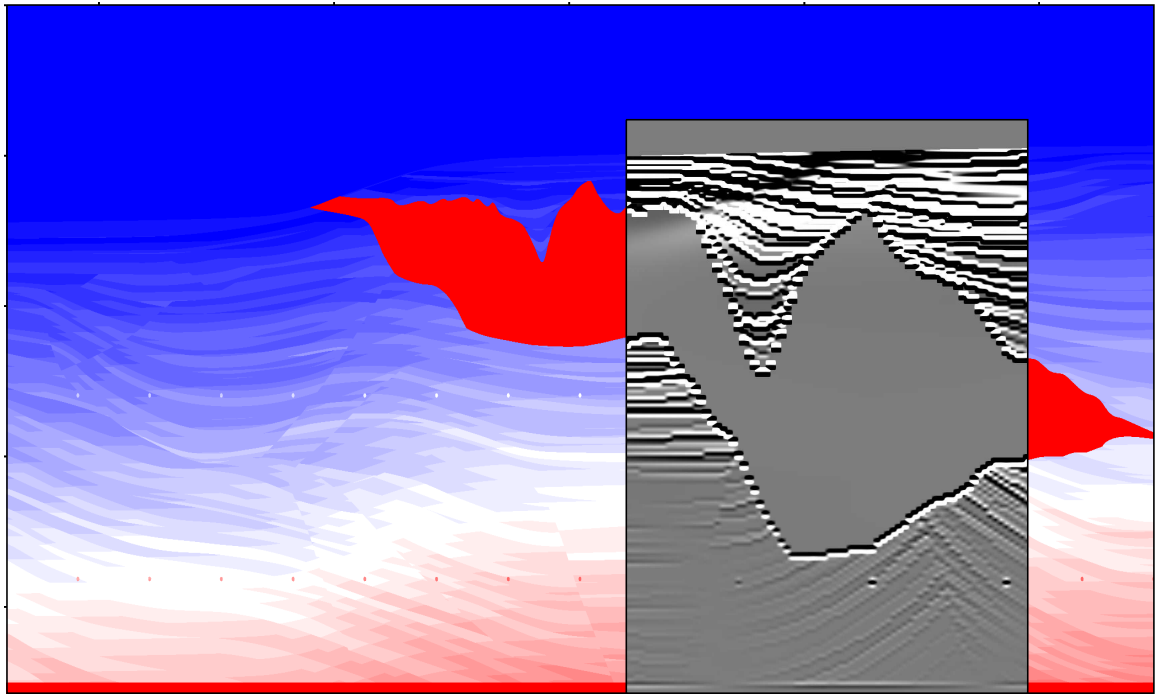
SWD imaging



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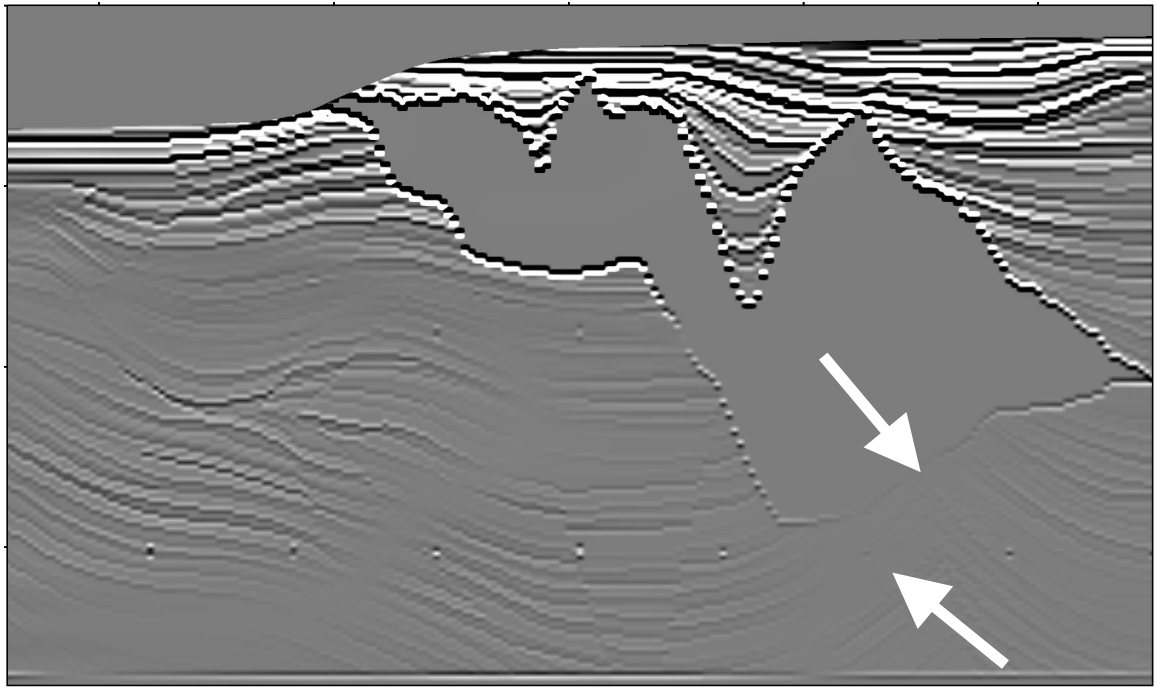
Surface seismic imaging



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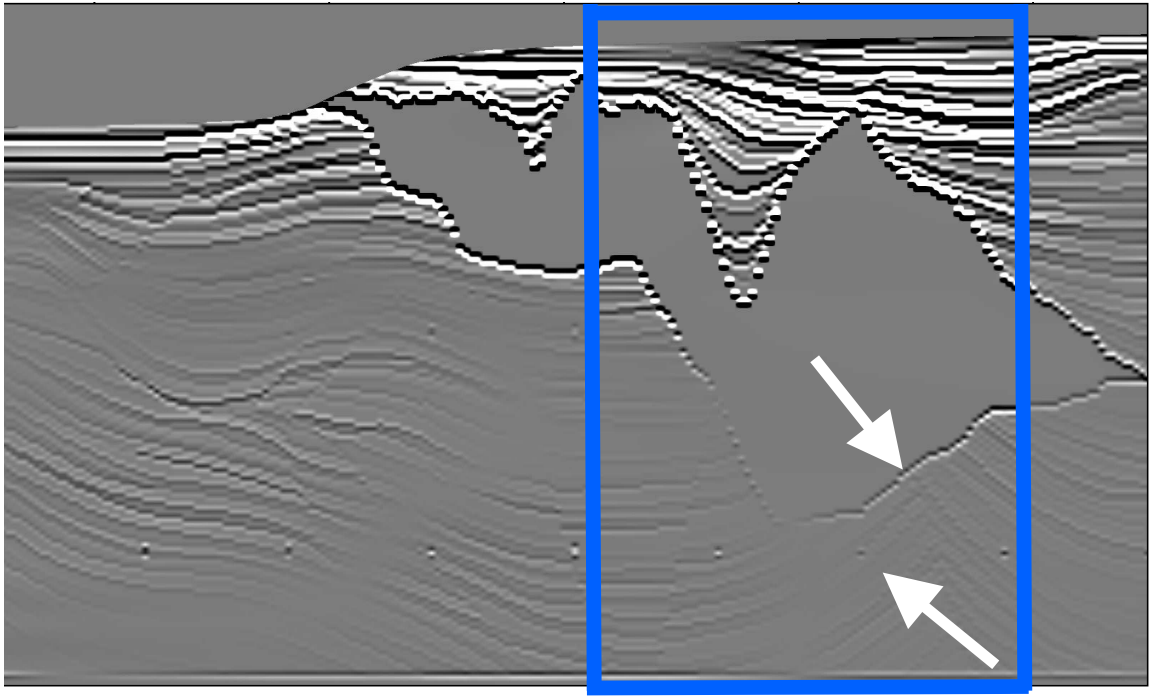
Surface seismic+ SWD imaging



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Conclusions

- Minimizing drilling uncertainties will result in better production.
- Uncertainness of depth imaging is discussed.
- Poor subsurface illumination inherent in seismic imaging is shown to be one of the major sources of uncertainties.
- Seismic-While-Drilling imaging combined with surface seismic improved subsurface illumination.

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Acknowledgments

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- I thank CREWES for the opportunity to present the results in Tech Talk series.