Combination of surface and borehole seismic data for robust target-oriented imaging

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Joost van der Neut, Delft University of Tecnology
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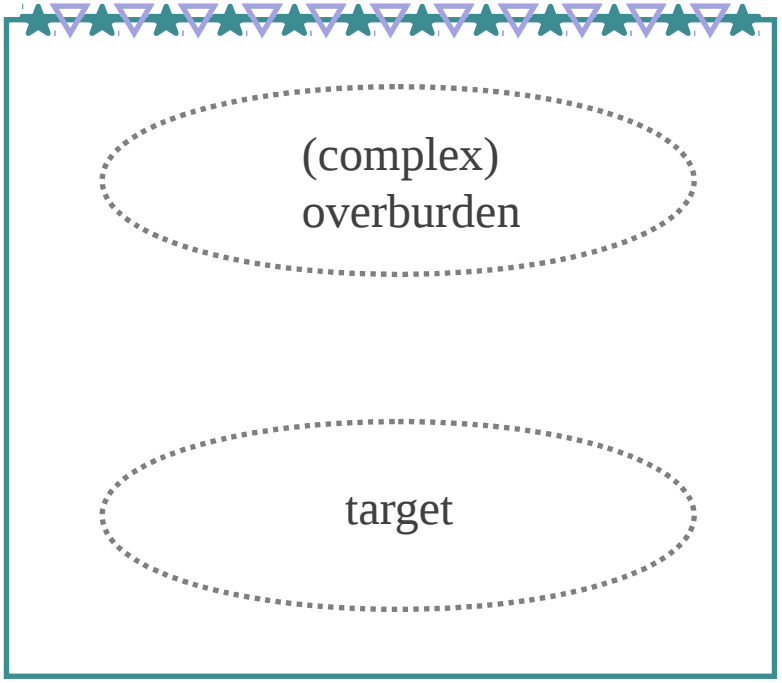
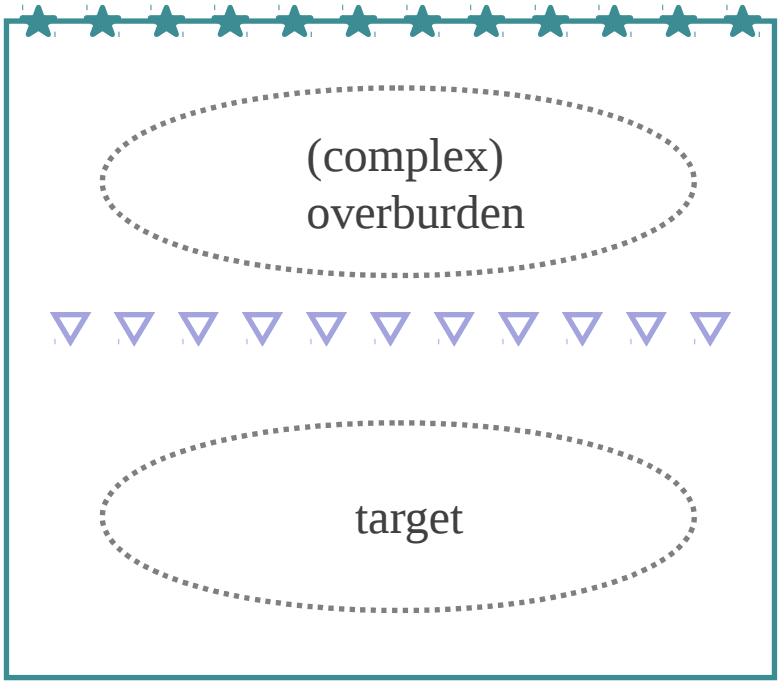
Kees Wapenaar, Delft University of Technology

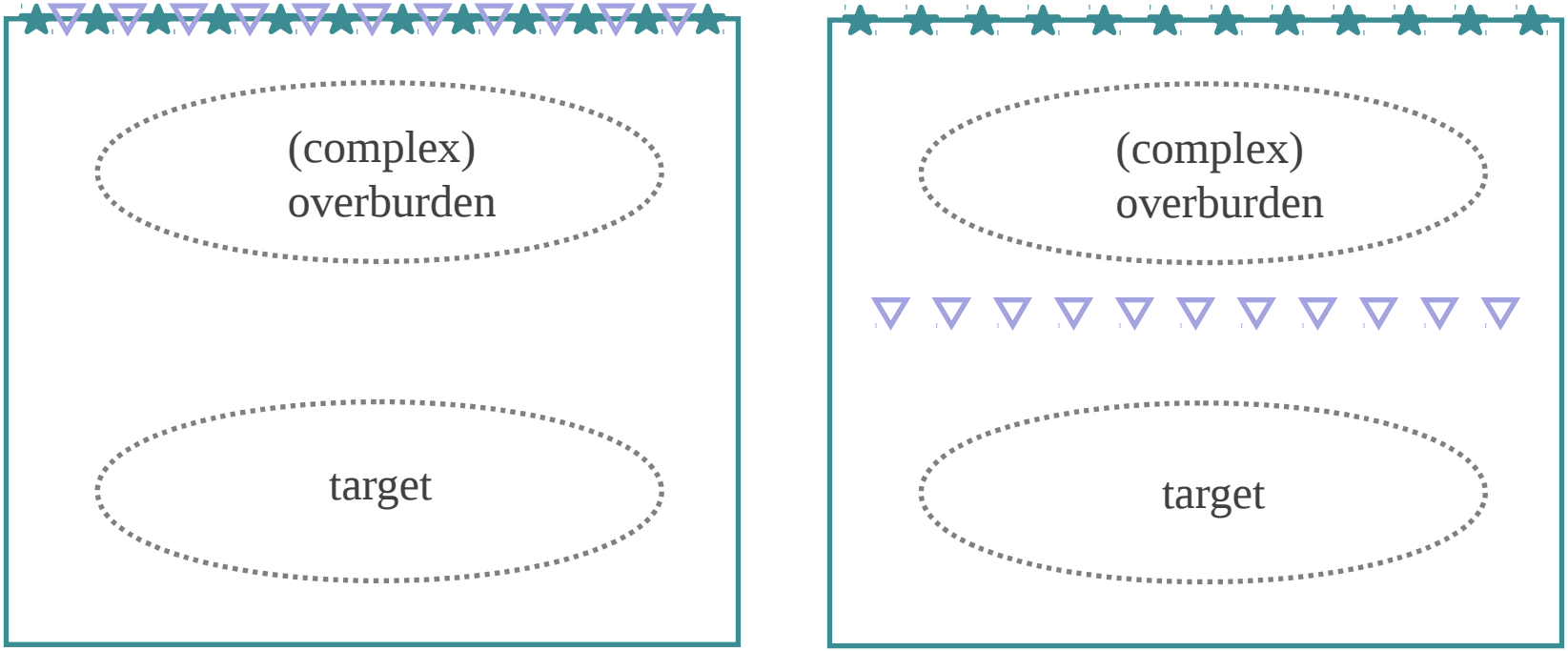
- Motivation
- Method
- Examples
- Conclusions

Motivation



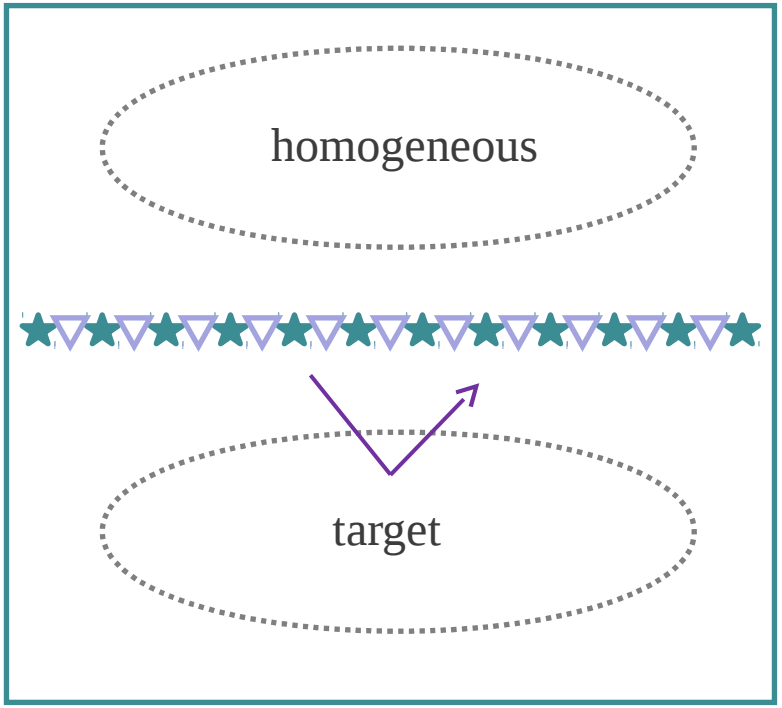


Motivation

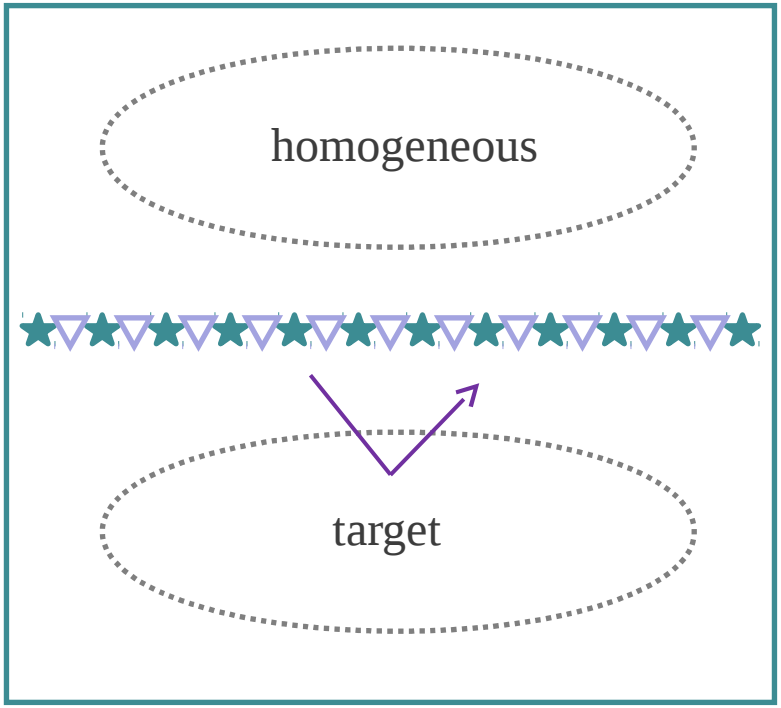


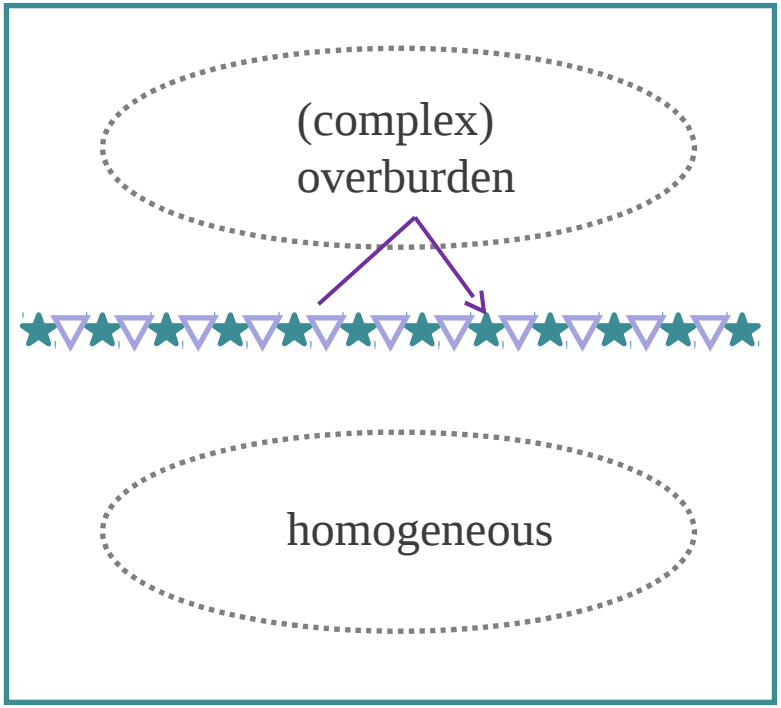
- A good velocity model of the whole area is crucial for imaging.

What if ...

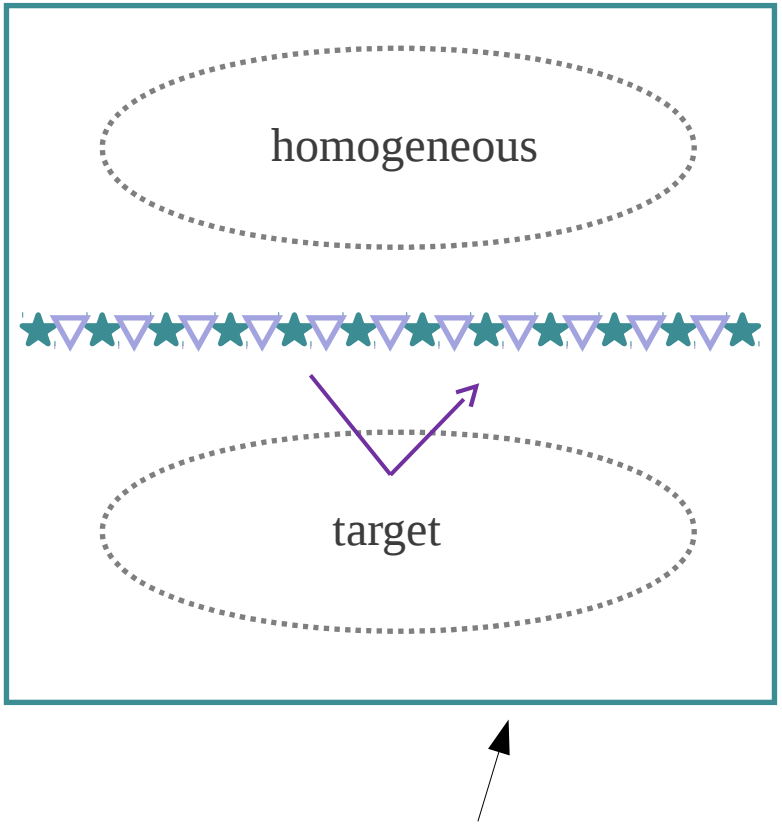


What if ...

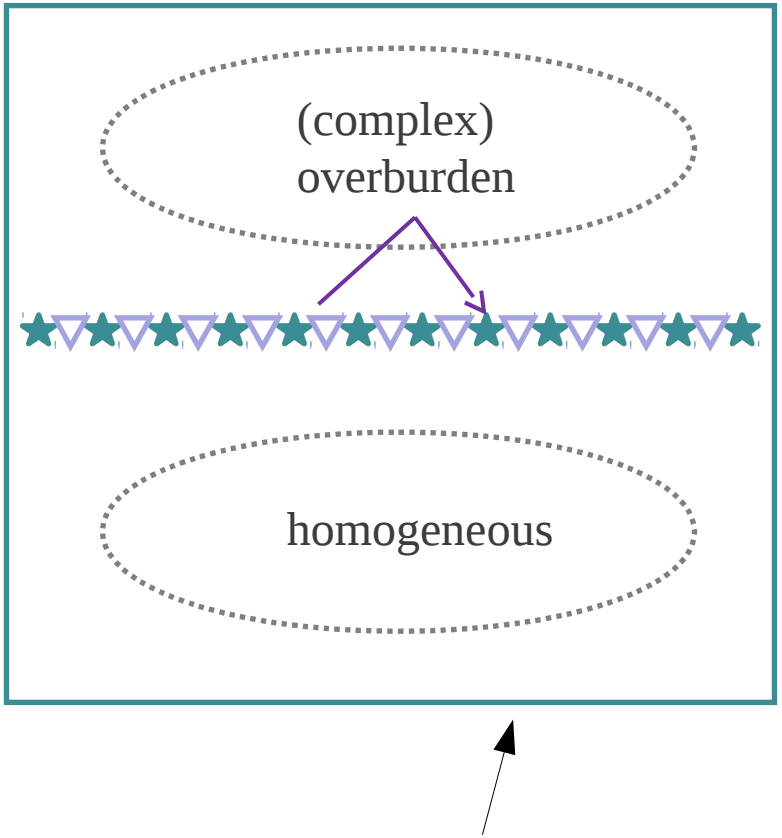




What if ...



Imaging from above

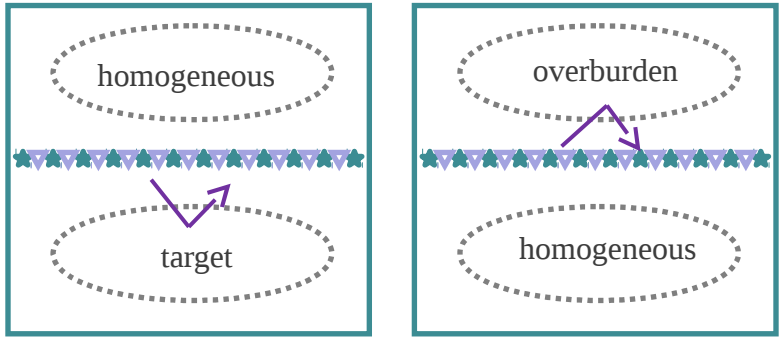


Imaging from below

Method

First redatum,

--> 2 new datasets



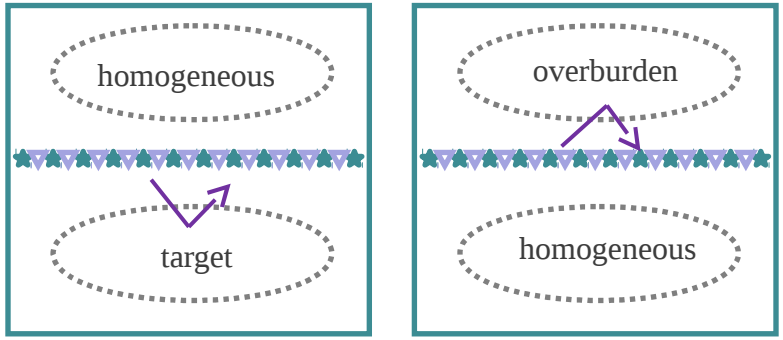
Method

First redatum,

--> 2 new datasets

then image...

--> only local velocities needed



Method

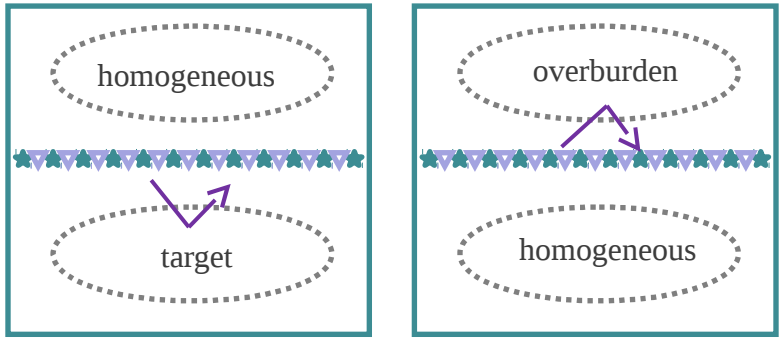
First redatum,

--> 2 new datasets

then image...

--> only local velocities needed

--> more robust to velocity errors



The two new datasets:

"R" from *above*

$$\widehat{G}^{-}(\mathbf{x}_i'|\mathbf{x}_0'') = \int_{\partial D_i} \widehat{\mathscr{R}}^{\cup}(\mathbf{x}_i'|\mathbf{x}_i)\widehat{G}^{+}(\mathbf{x}_i|\mathbf{x}_0'')d\mathbf{x}_i$$

The two new datasets:

"R" from *above*

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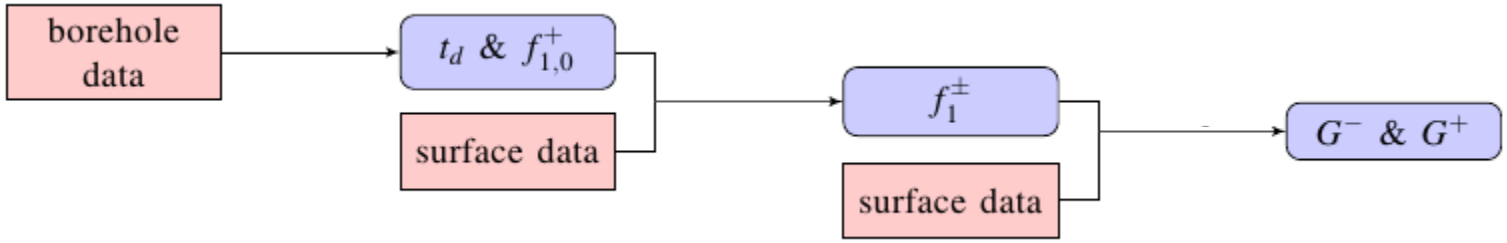

The two new datasets:

"R" from *above*

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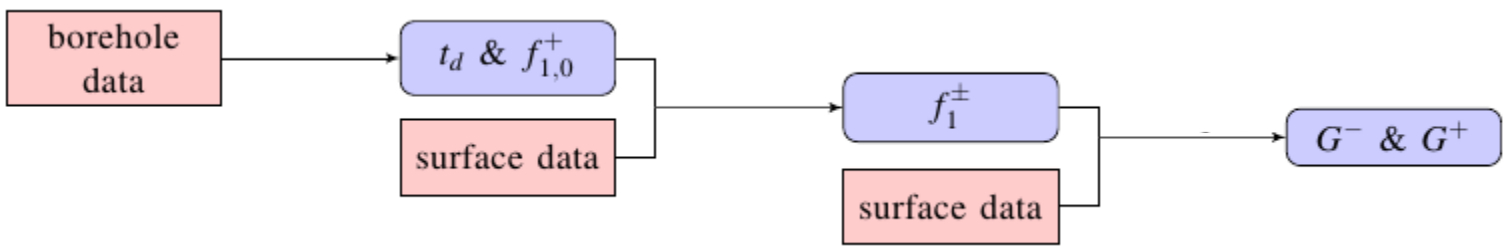


for $t < t_d(\mathbf{x}_i'|\mathbf{x}_0'')$,

$$f_1^{-}(\mathbf{x}_0''|\mathbf{x}_i', t) = \int_{\partial D_0}\int_{-\infty}^{t} \mathcal{R}^{\cup}(\mathbf{x}_0''|\mathbf{x}_0, t-t')f_1^{+}(\mathbf{x}_0|\mathbf{x}_i', t')dt'd\mathbf{x}_0;$$

for $t \geq t_d(\mathbf{x}_i'|\mathbf{x}_0'')$,

$$G^{-}(\mathbf{x}_i'|\mathbf{x}_0'', t) = \int_{\partial D_0}\int_{-\infty}^{t} \mathscr{R}^{\cup}(\mathbf{x}_0''|\mathbf{x}_0, t-t')f_1^{+}(\mathbf{x}_0|\mathbf{x}_i', t')dt'd\mathbf{x}_0;$$

$$G^{+}(\mathbf{x}_i'|\mathbf{x}_0'', t) = -\int_{\partial D_0}\int_{-\infty}^{t} \mathscr{R}^{\cup}(\mathbf{x}_0''|\mathbf{x}_0, t-t')f_1^{-}(\mathbf{x}_0|\mathbf{x}_i', -t')dt'd\mathbf{x}_0 + f_{1,0}^{+}(\mathbf{x}_0''|\mathbf{x}_i', -t).$$

The two new datasets:

"R" from *below*

$$\widehat{f}_2^{+}(\mathbf{x}_i'|\mathbf{x}_0'') = \int_{\partial D_i} \widehat{\mathscr{R}}^{\cap}(\mathbf{x}_i'|\mathbf{x}_i)\widehat{f}_2^{-}(\mathbf{x}_i|\mathbf{x}_0'')d\mathbf{x}_i$$

The two new datasets:

To image from *below*

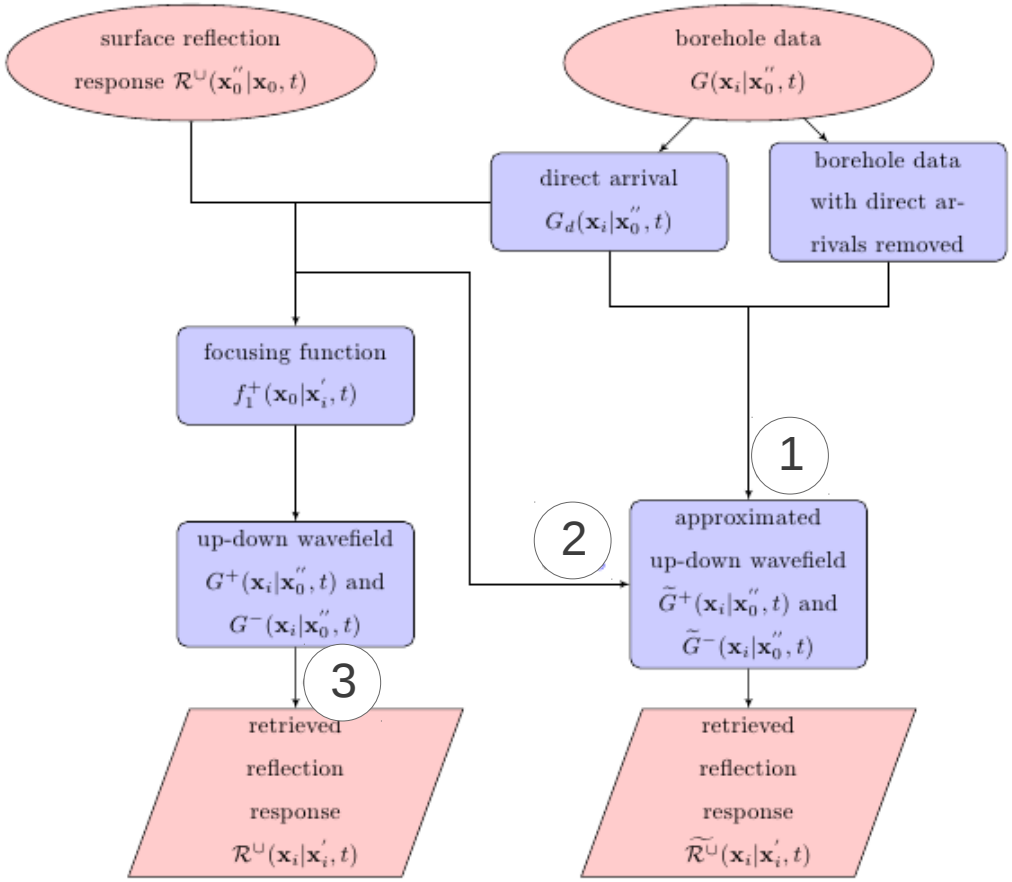
$$\widehat{f}_2^{+}(\mathbf{x}_i'|\mathbf{x}_0'') = \int_{\partial D_i} \widehat{\mathscr{R}}^{\cap}(\mathbf{x}_i'|\mathbf{x}_i)\widehat{f}_2^{-}(\mathbf{x}_i|\mathbf{x}_0'')d\mathbf{x}_i$$

$$f_1^{+}(\mathbf{x}_0''|\mathbf{x}_i', t) = f_2^{-}(\mathbf{x}_i'|\mathbf{x}_0'', t);$$

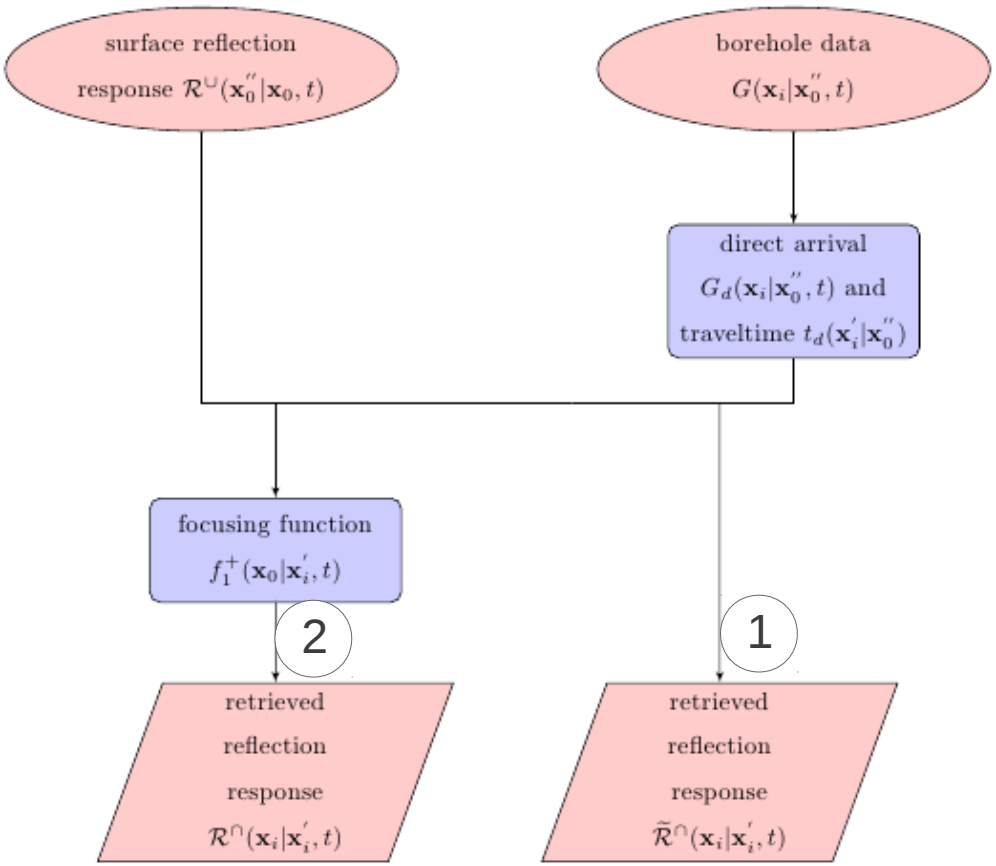
and

$$-f_1^{-}(\mathbf{x}_0''|\mathbf{x}_i', -t) = f_2^{+}(\mathbf{x}_i'|\mathbf{x}_0'', t).$$

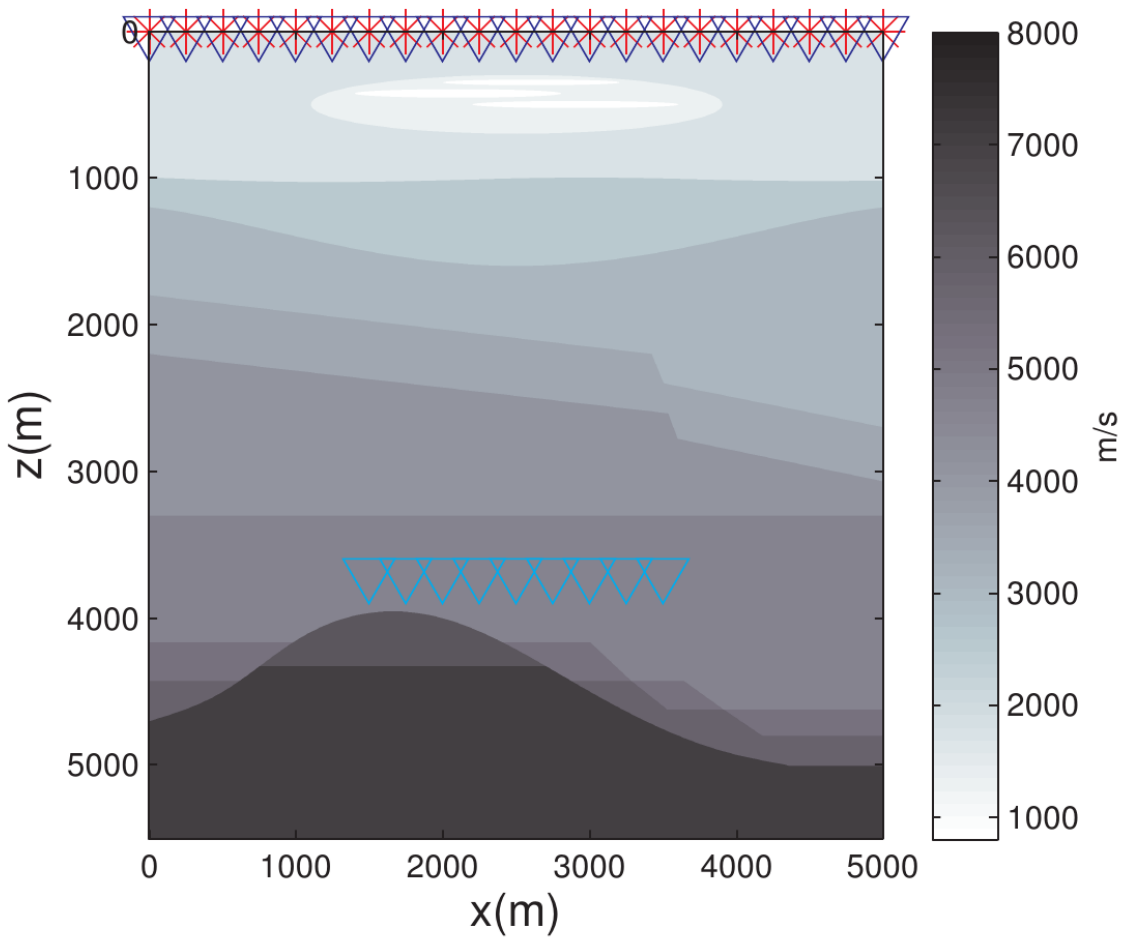
Flow chart for “R” from *above*



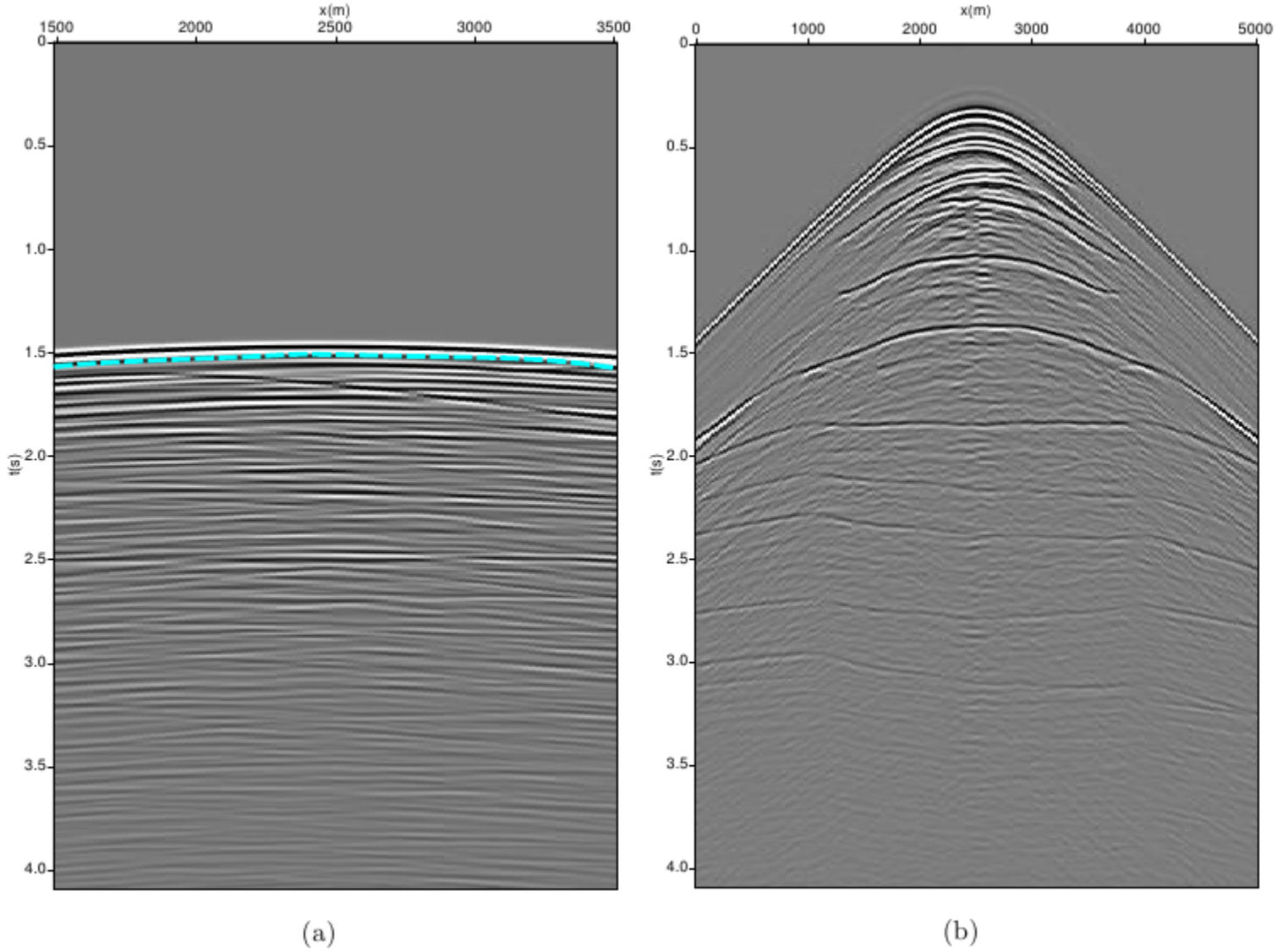
Flow chart for “R” from *below*



Example 1

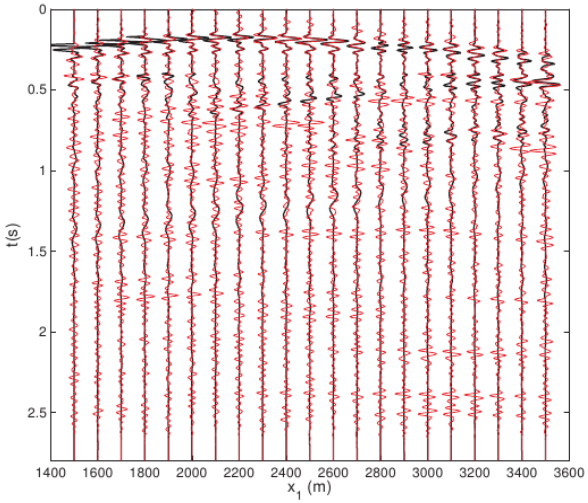

0
1000
2000
3000
4000
5000
z(m)
0
1000
2000
3000
4000
5000
x(m)
8000
7000
6000
5000
4000
3000
2000
1000
m/s

Example 1

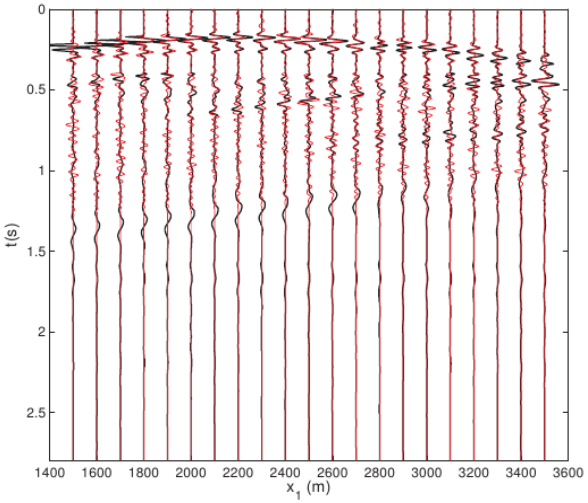


"Finite-difference modeling experiments for seismic interferometry" Thorbecke and Draganov, Geophysics, Vol. 76, no 6 (November-December); p H1--H18.

Example 1 – “R” (from *above*)



1



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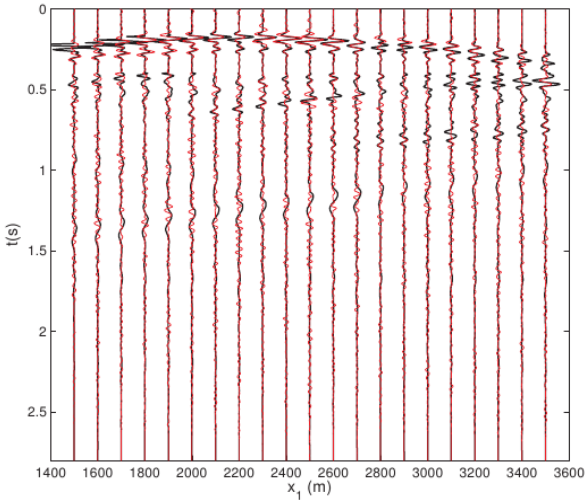

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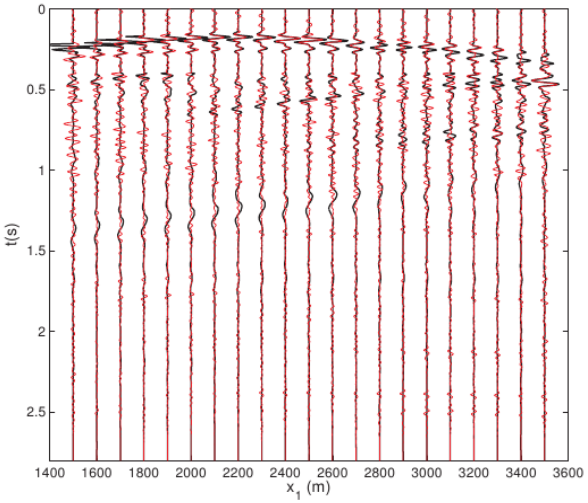
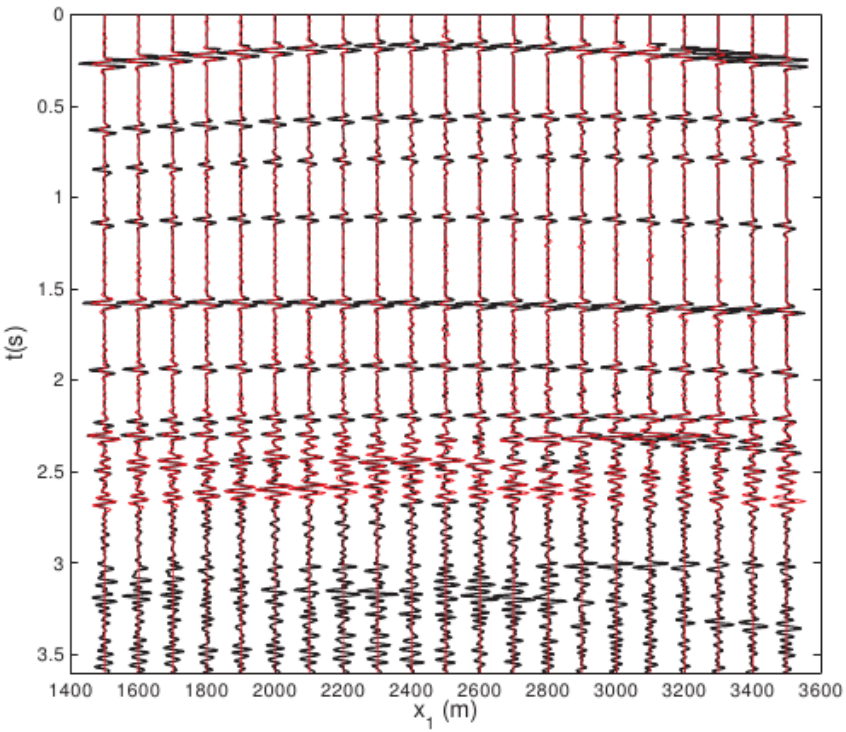
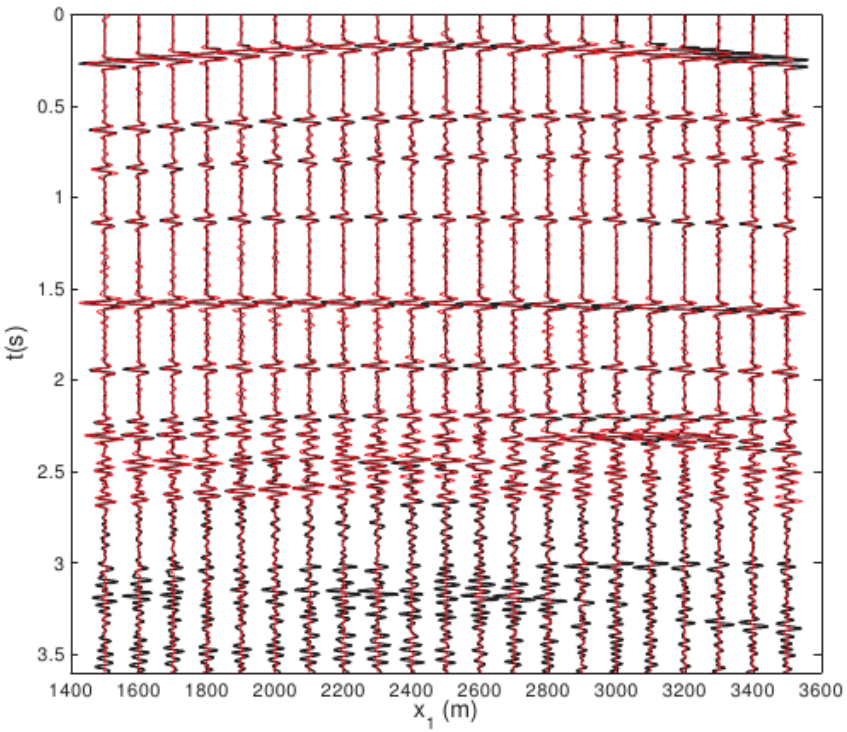


4

Example 1 – “R” (from *below*)

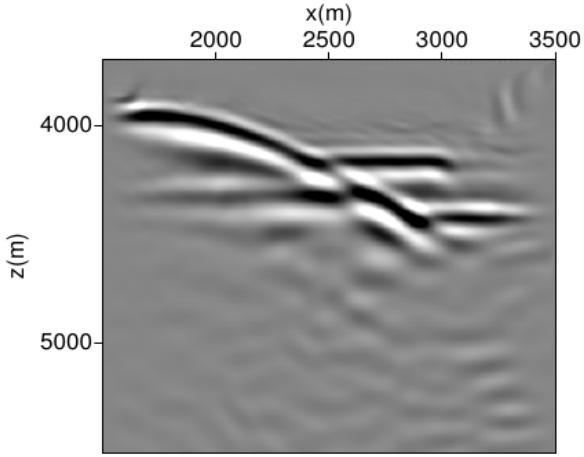


1

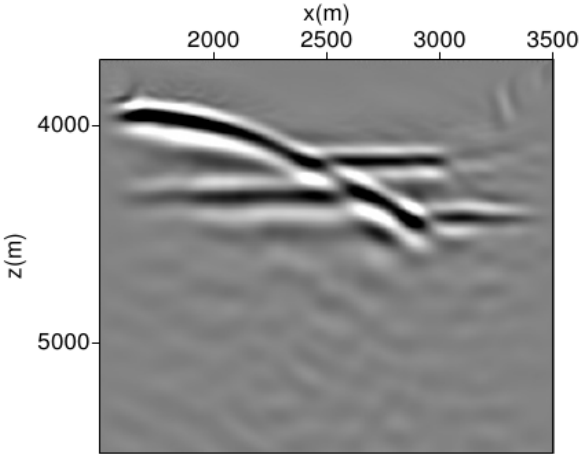


2

Example 1 – images (from *above*)



1



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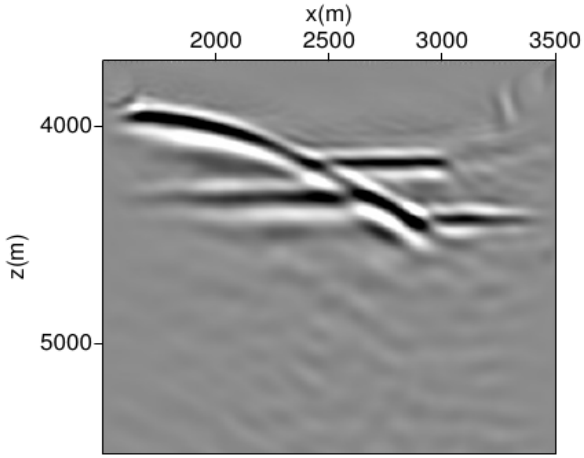

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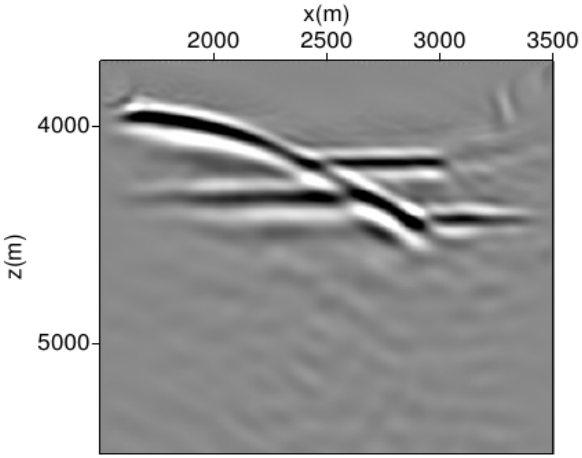
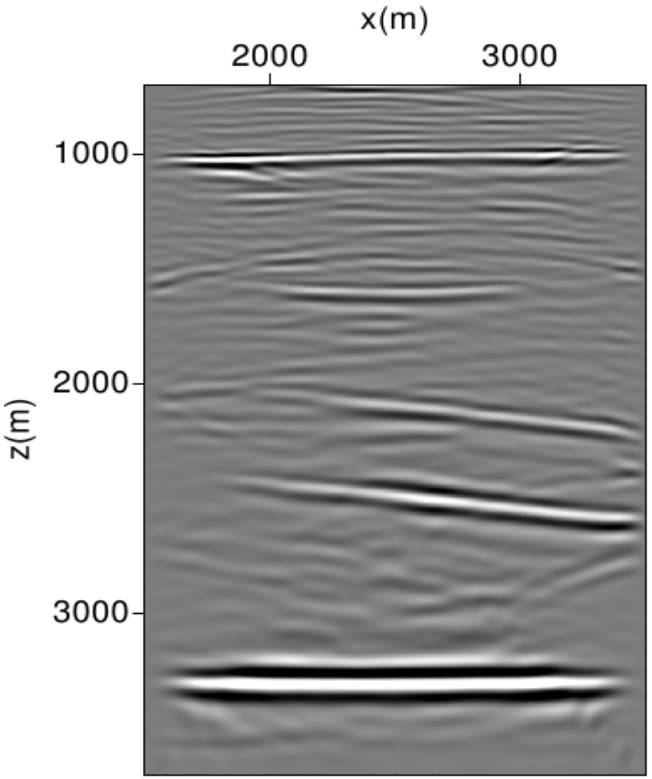
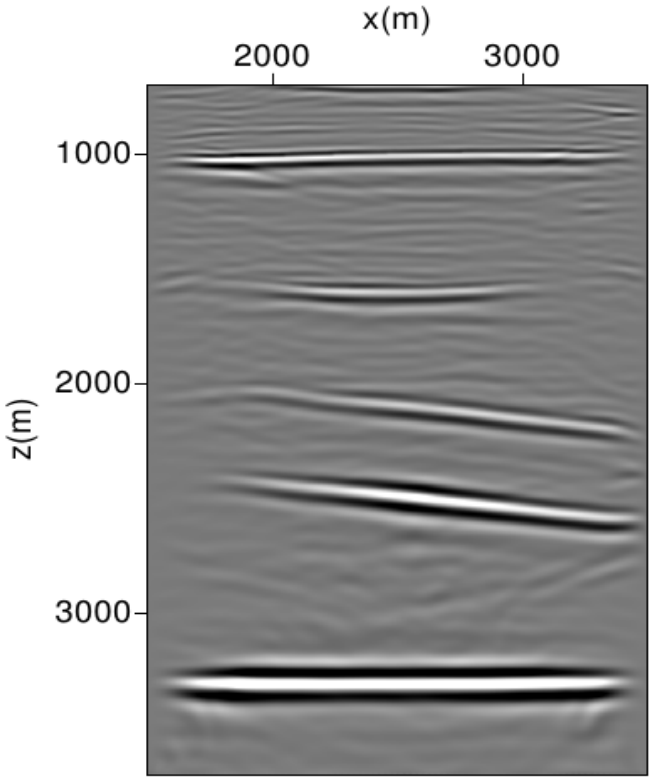


4

Example 1 – images (from *below*)

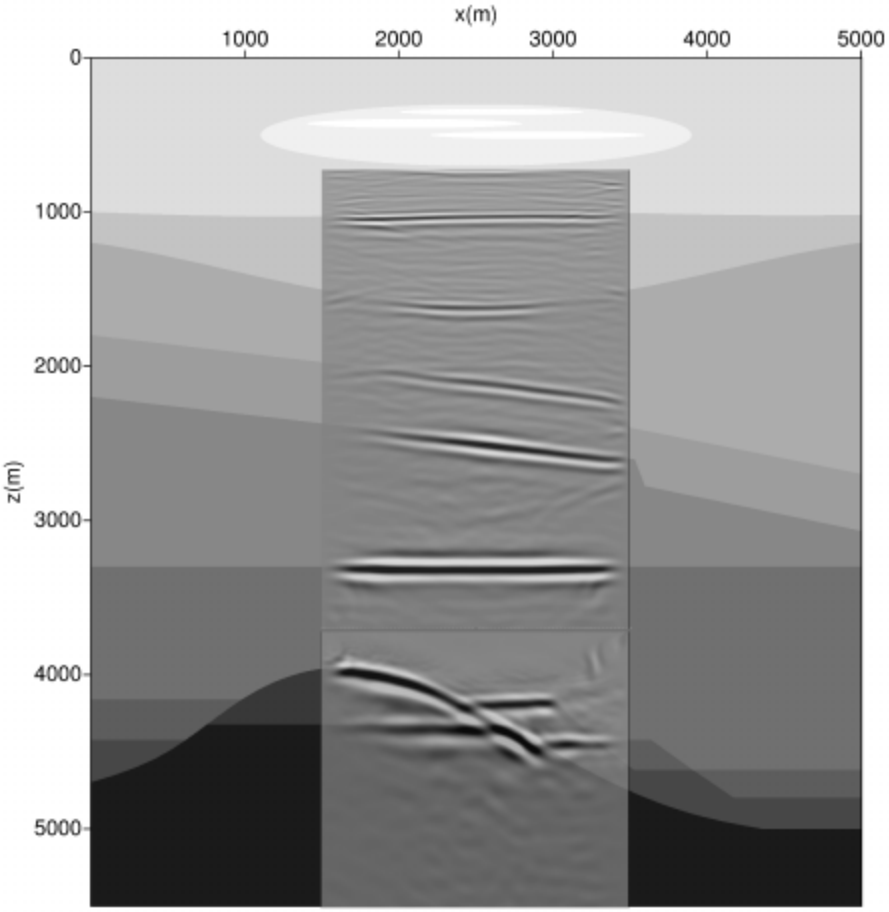


1



2

Example 1 – comparison (correct velocities)



Combined local image

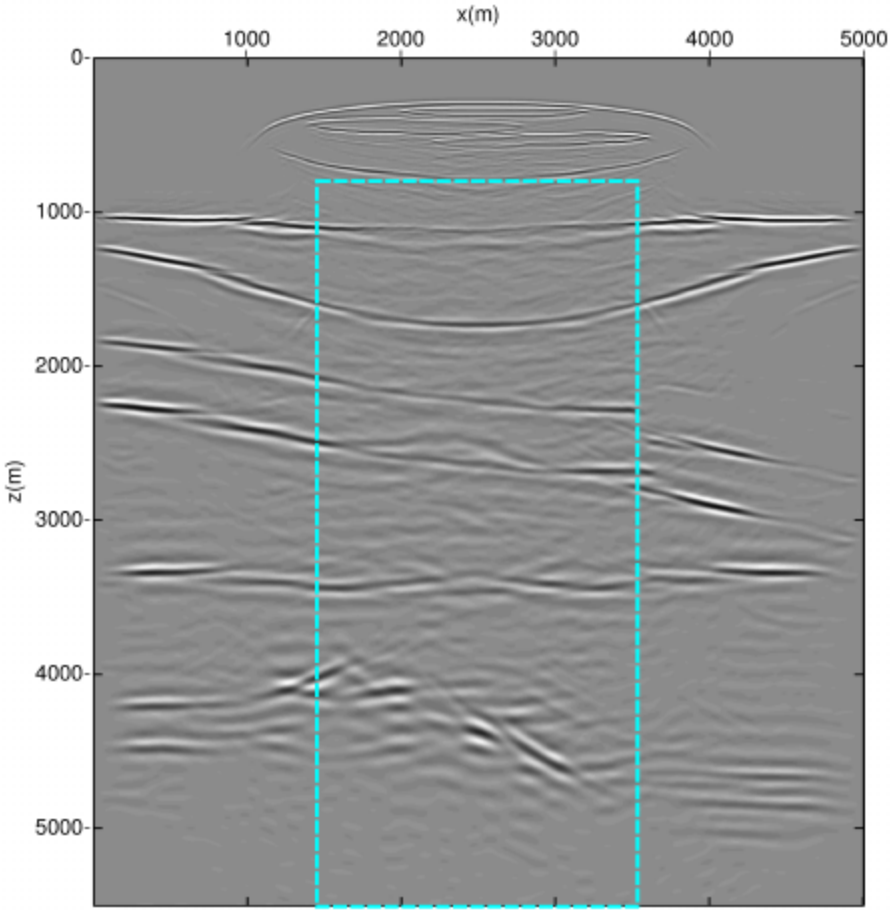
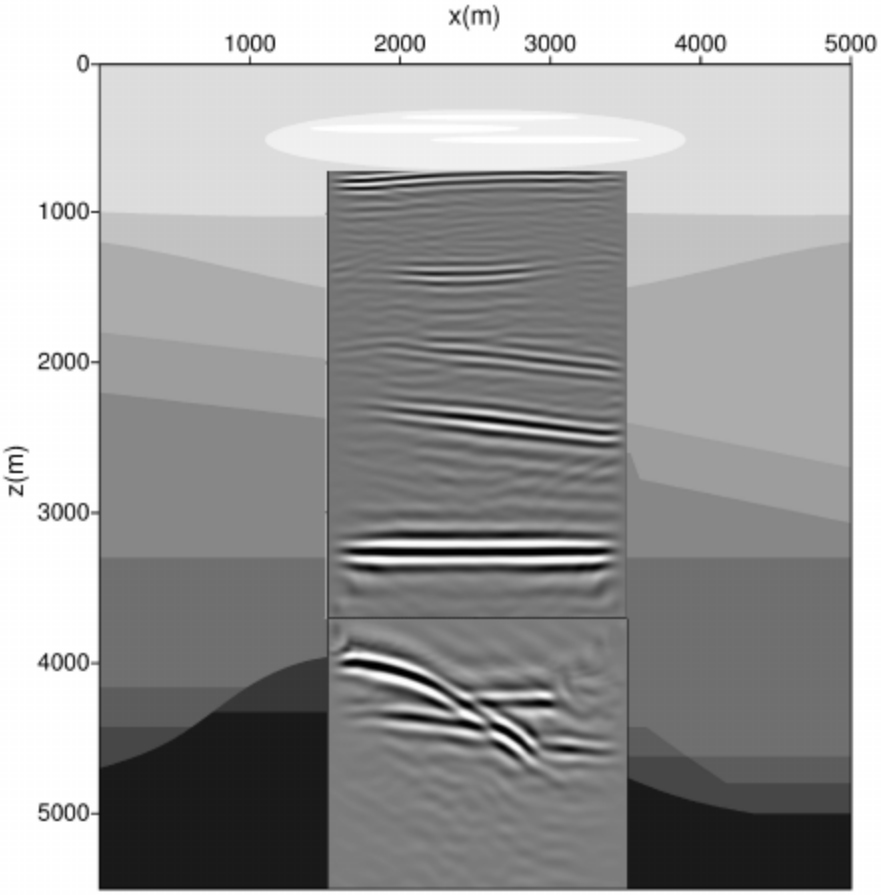


Image from the surface

Example 1 – comparison (wrong velocities)



Combined local image

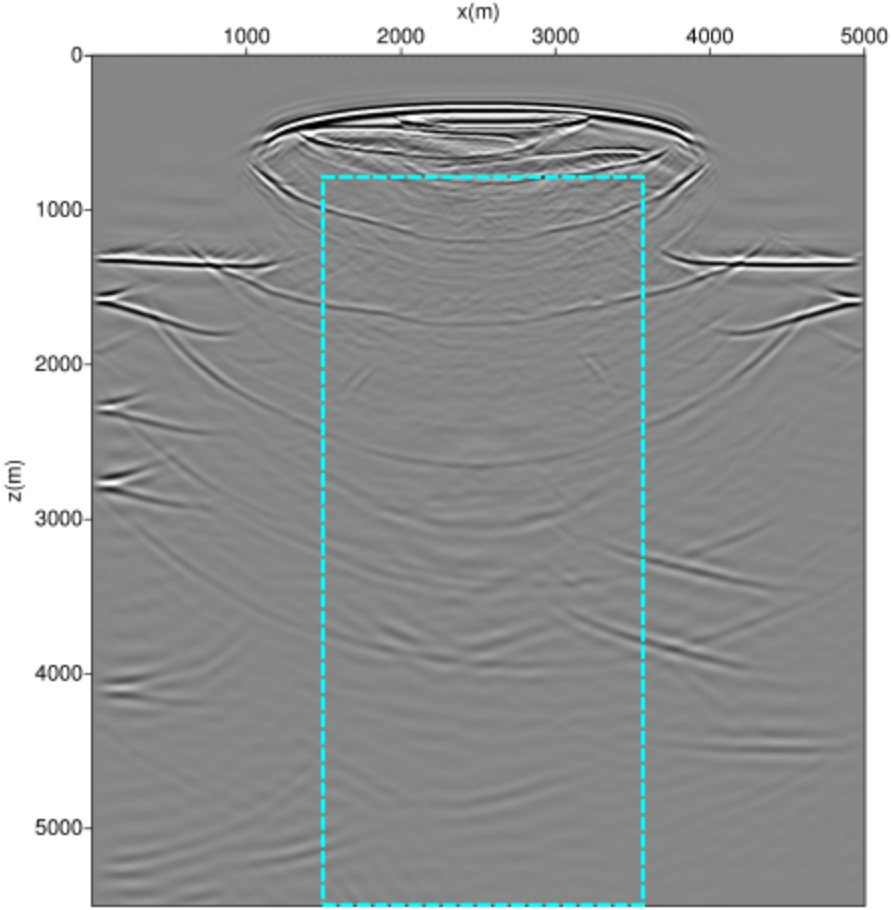
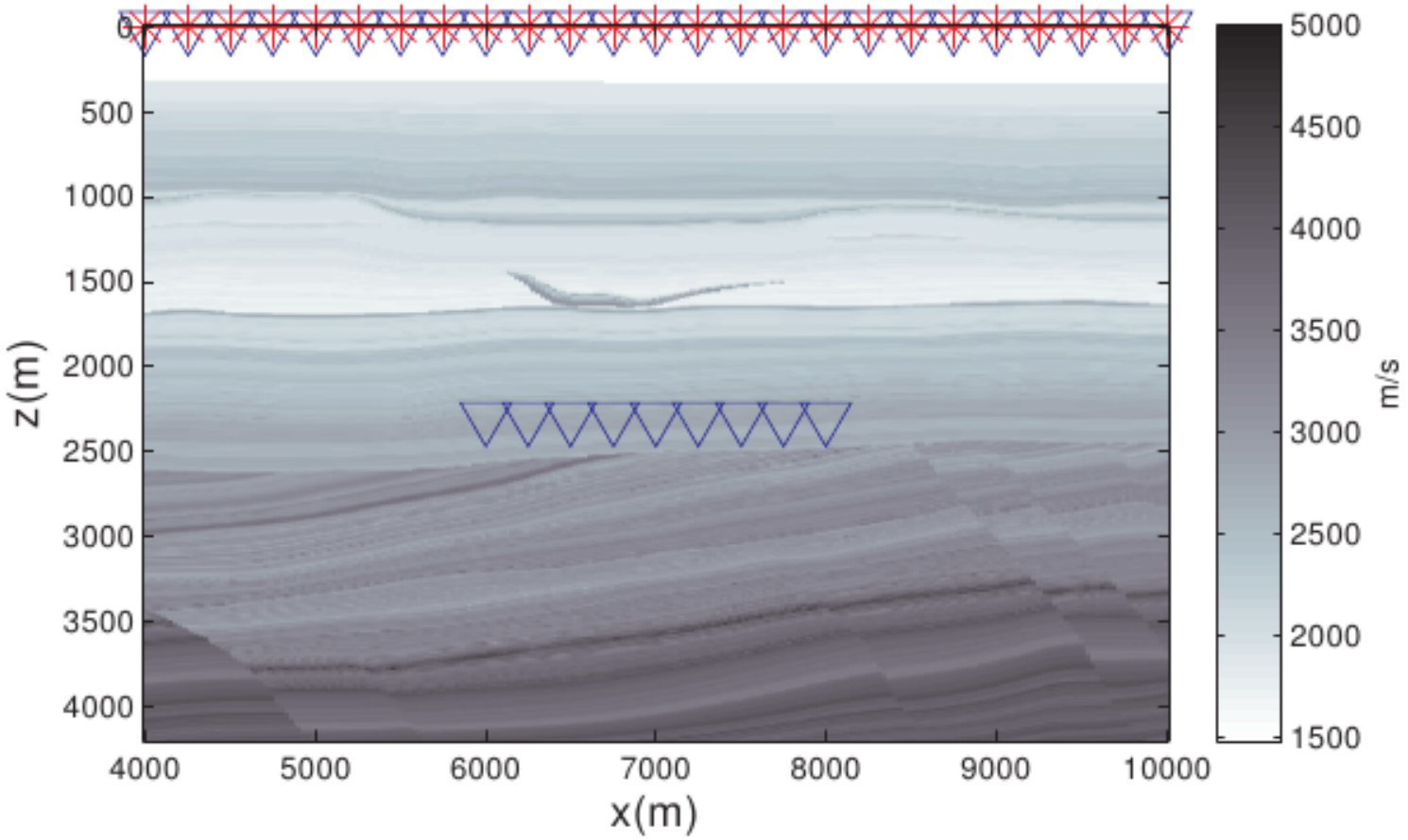
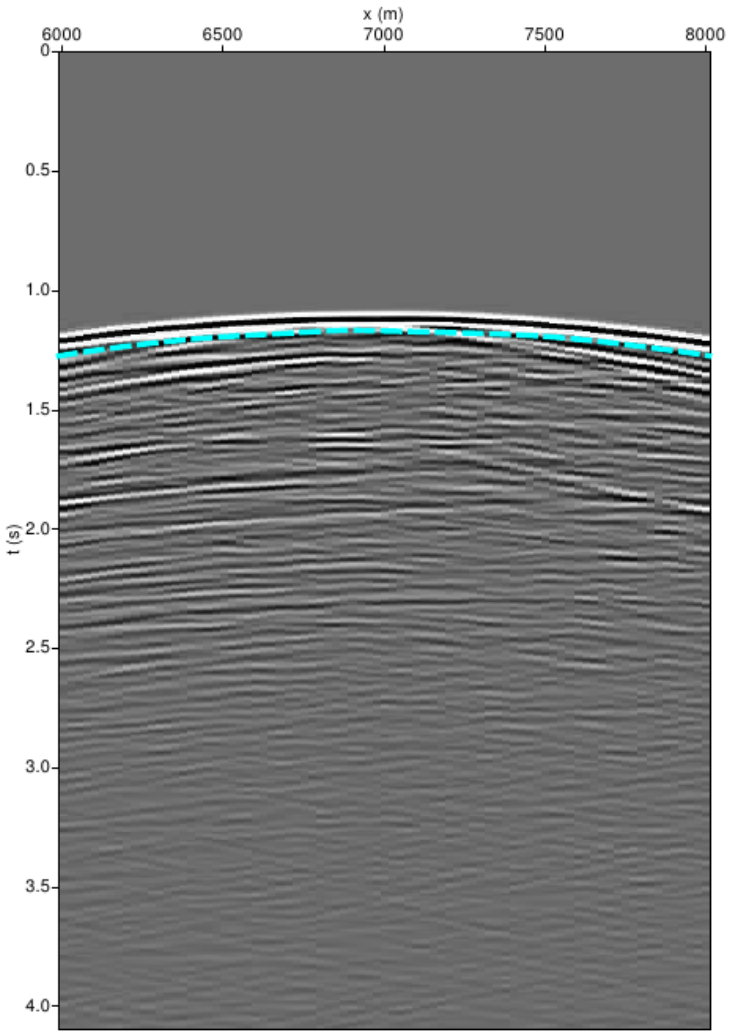


Image from the surface

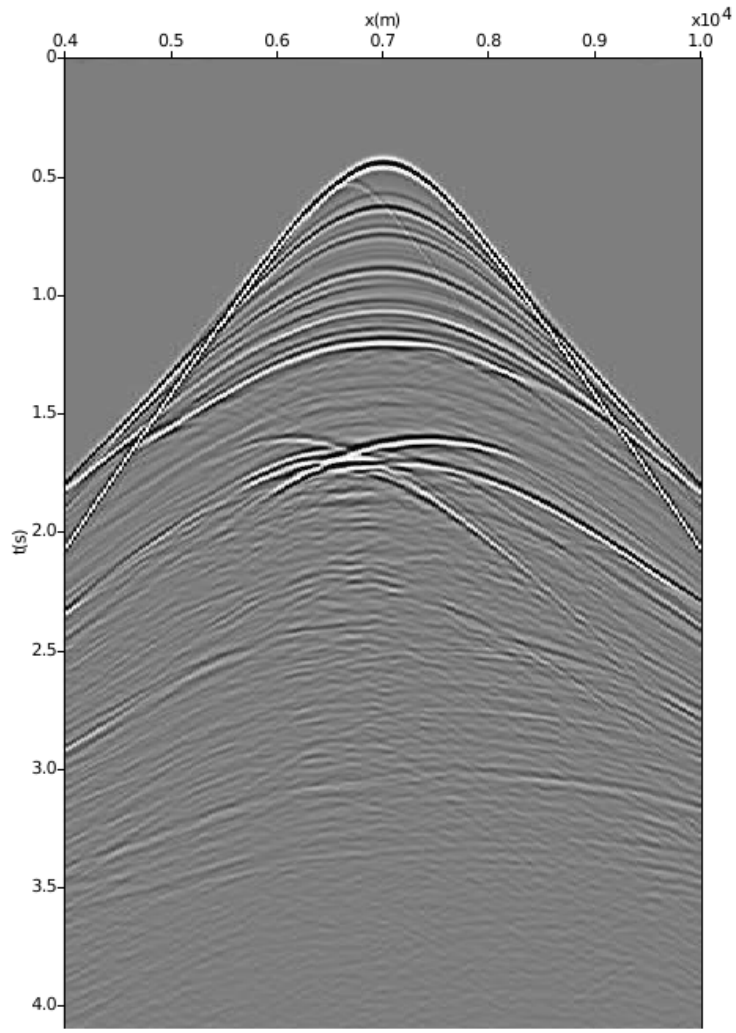
Example 2


0
500
1000
1500
2000
2500
3000
3500
4000
z(m)
4000
5000
6000
7000
8000
9000
10000
x(m)
5000
4500
4000
3500
3000
2500
2000
1500
m/s

Example 2

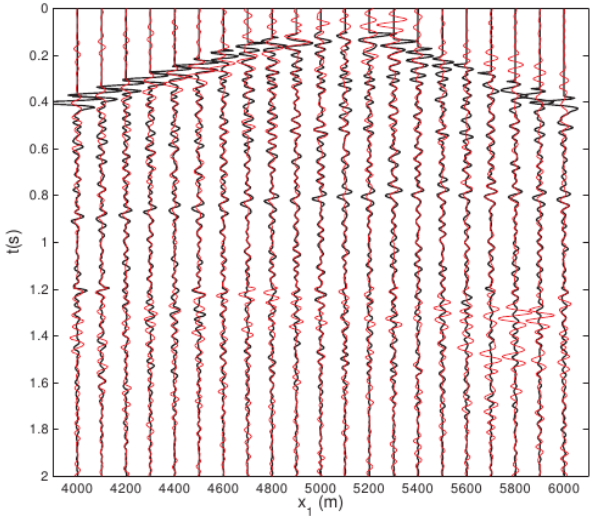

x (m)
6000
6500
7000
7500
8000
t (s)
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0

(a)

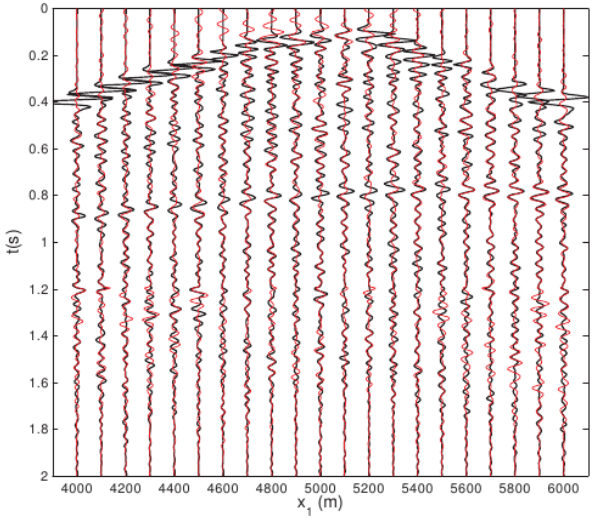

x(m)
x10^4
0.4
0.5
0.6
0.7
0.8
0.9
1.0
t(s)
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0

(b)

Example 2 – “R” from *above*



1



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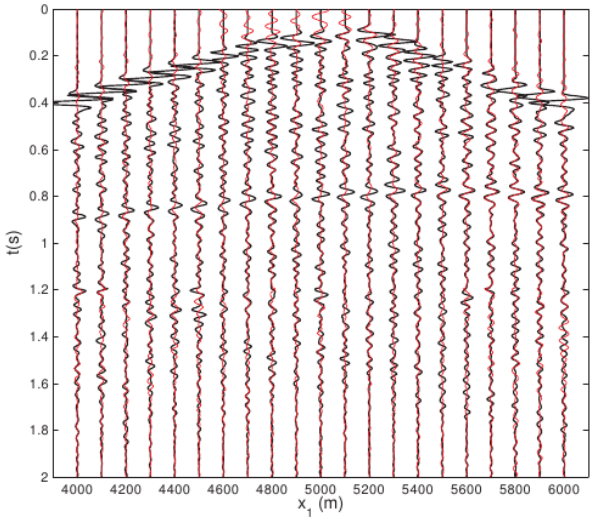

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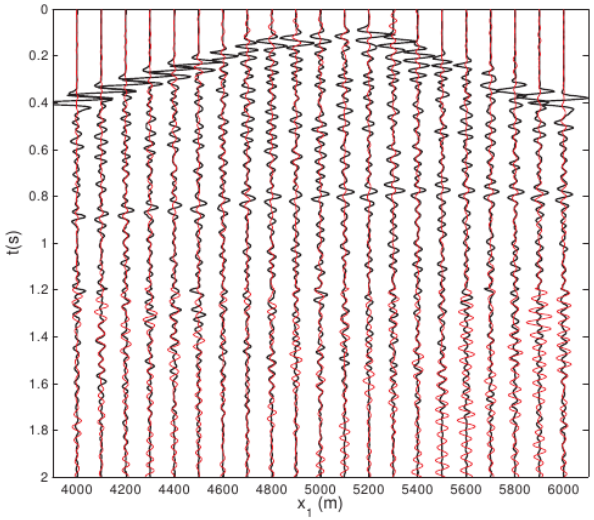
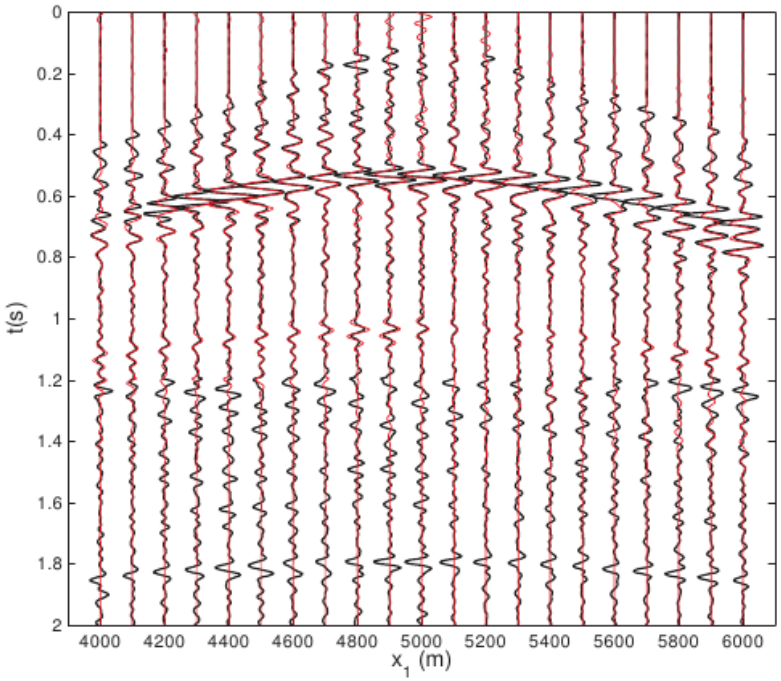
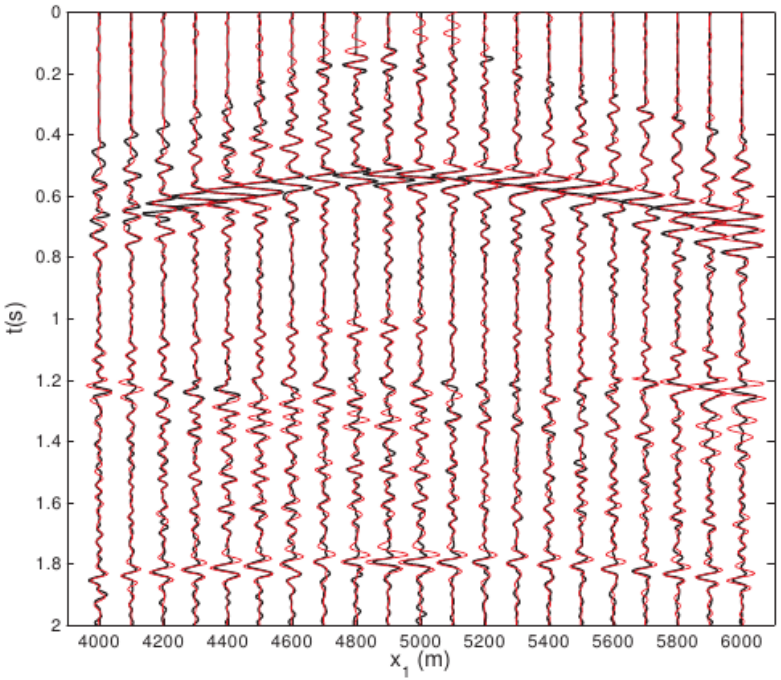


4

Example 2 – “R” from *below*

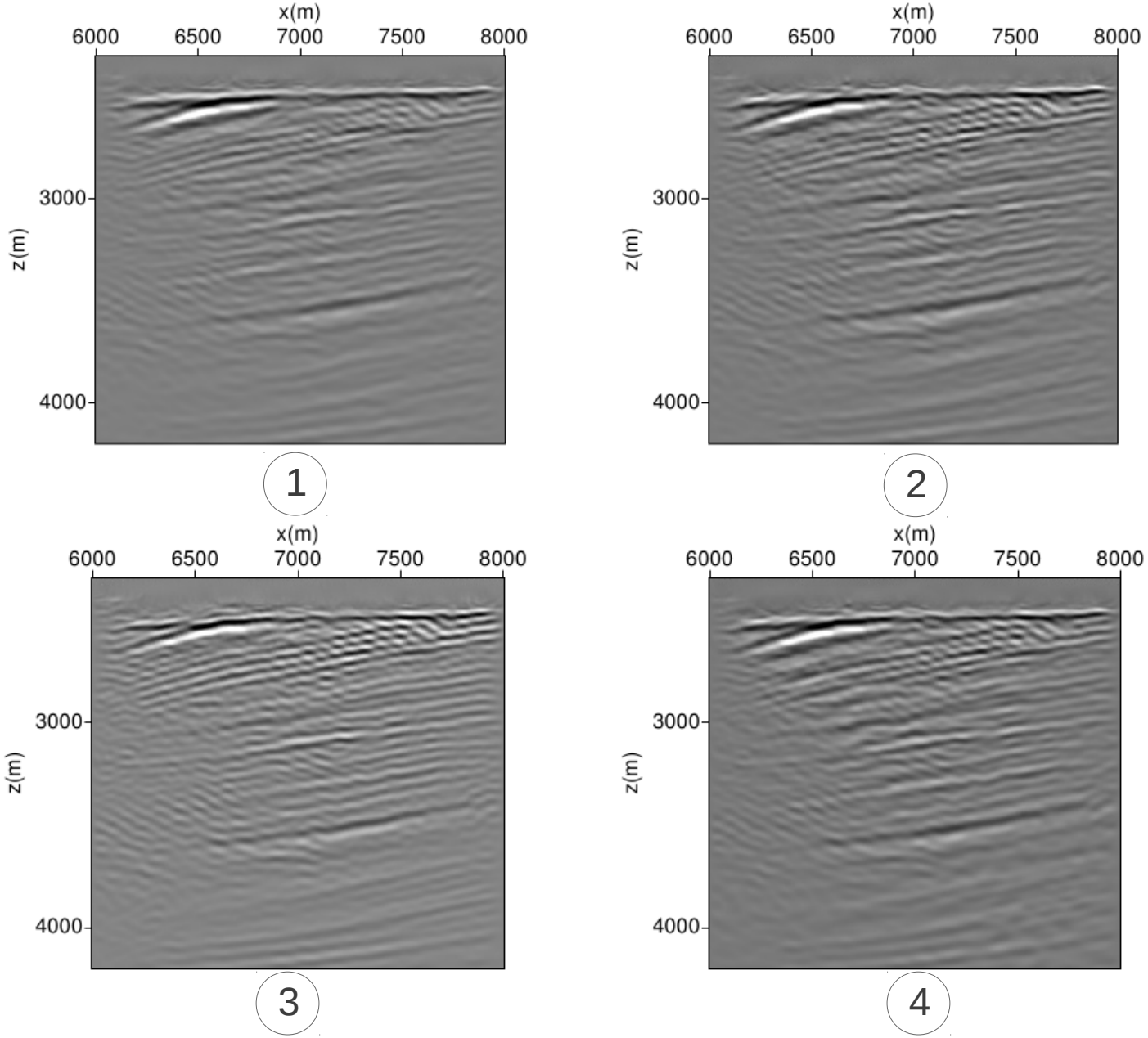


1

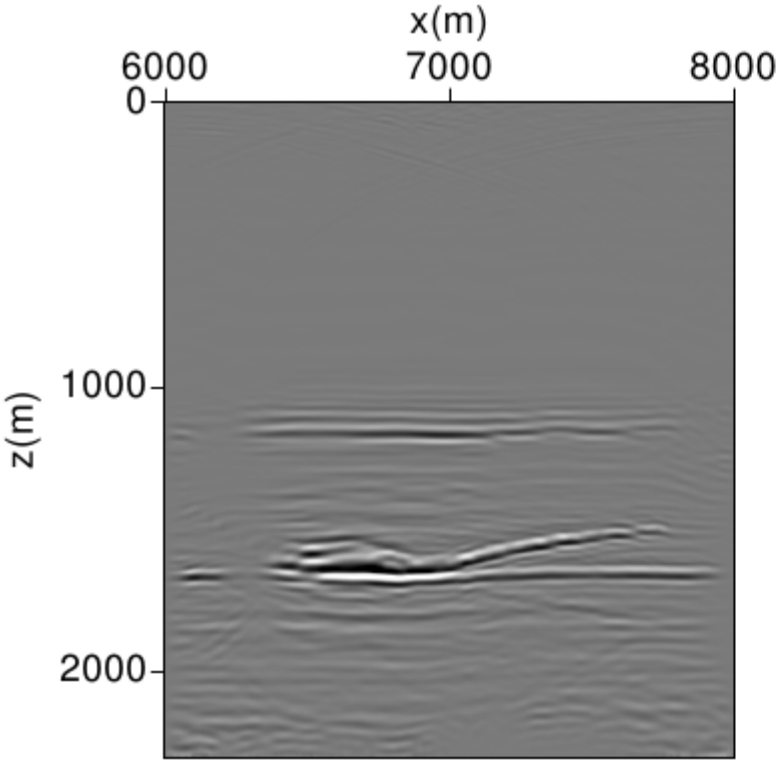


2

Example 2 – images from *above*



Example 2 – images from *below*



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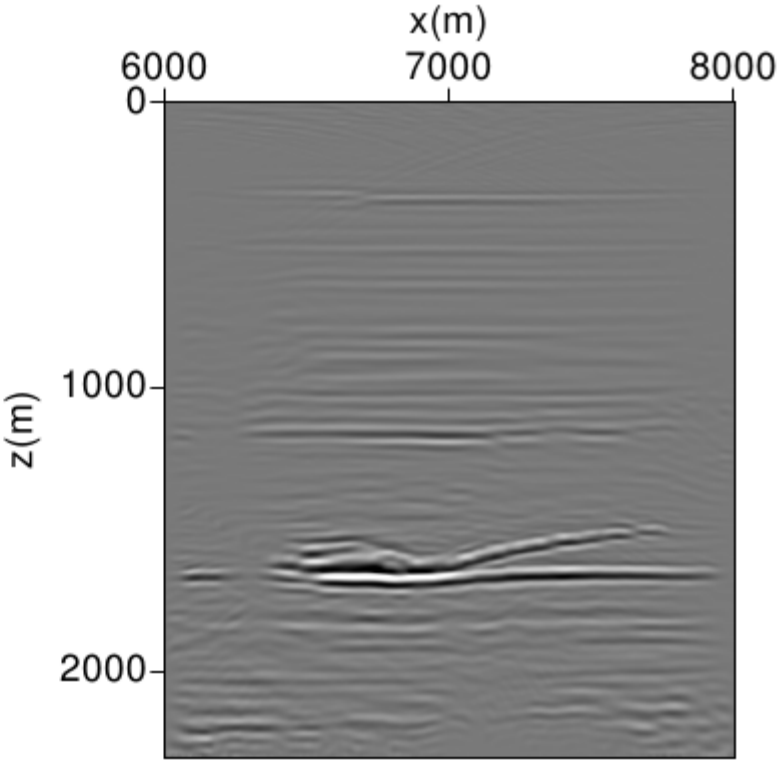
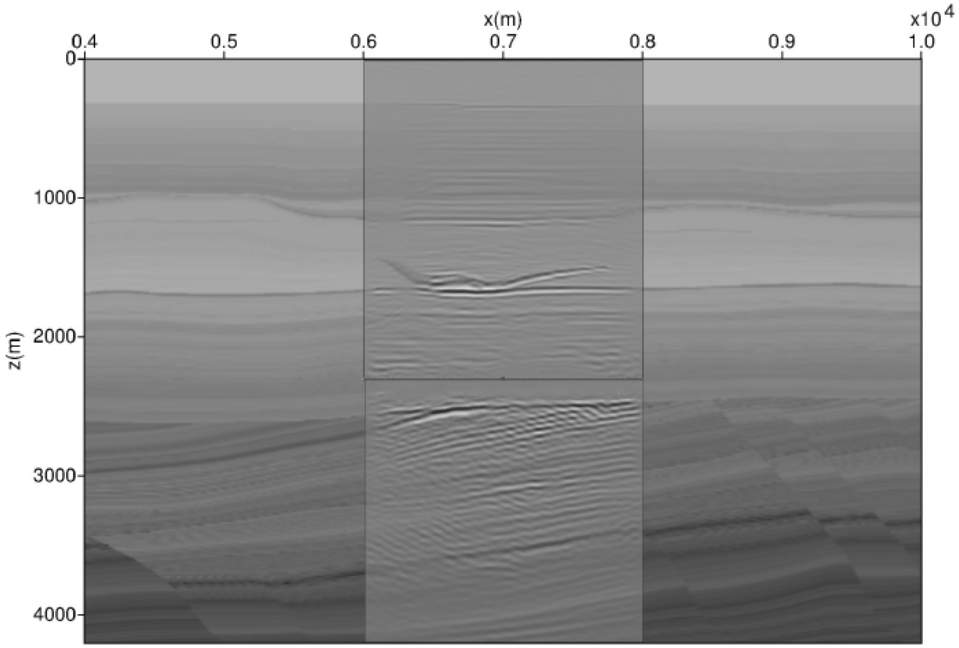


2

Example 2 – comparison (correct velocities)



Combined local image

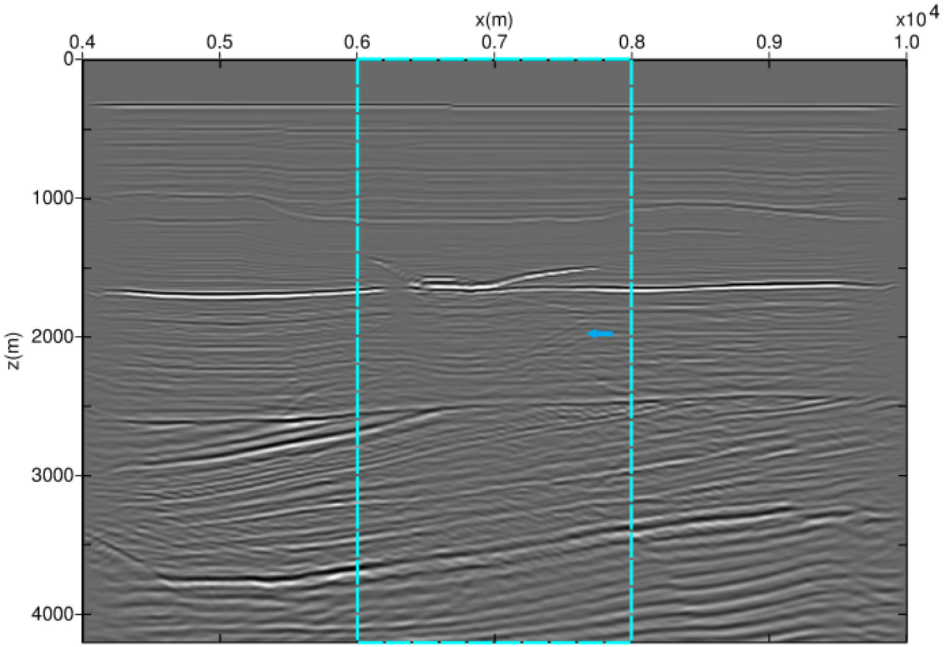
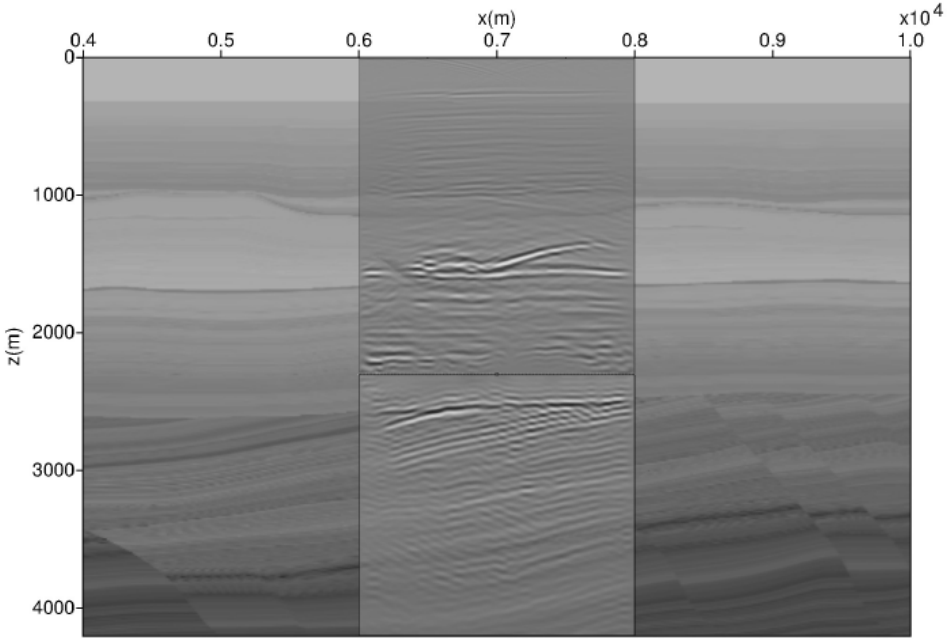


Image from the surface

Example 2 – comparison (wrong velocities)



Combined local image

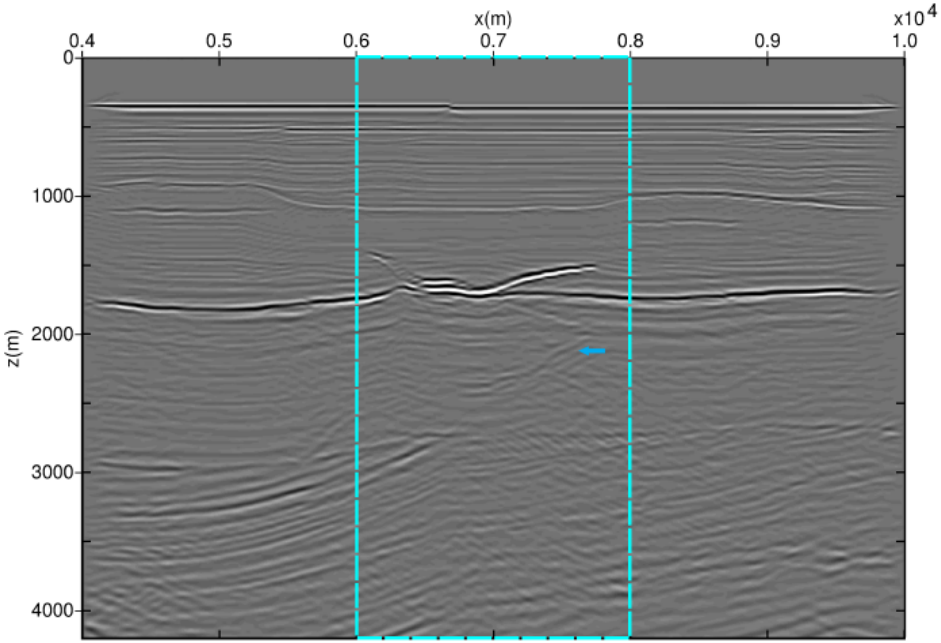


Image from the surface

Conclusions

- A new approach to deep imaging by combining surface and borehole seismic data;
- Only single-component data is needed;
- No macro-velocity model, completely data-driven;
- Robust images given wrong velocities;
- Better images without internal multiples.

Acknowledgements

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