RadExPro seismic software for HR/UHR marine seismic processing

10-15 years ago – processing of HR marine seismic was an easy thing to do

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demand for higher resolution => advances in hardware and acquisition

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demand for higher resolution => advances in hardware and acquisition

- **Broadband hi-freq sparkers (vert. res. up to 30 cm)**
- **UHR Boomers (vert. res. up to 10 cm)**
- **UHR multichannel streamers (receiver spacing 1 m)**
- **…**

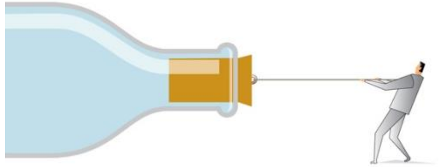
10-15 years ago – ~~processing of HR marine seismic was an easy thing to do~~

THE TIMES HAVE CHANGED…

demand for higher resolution => advances in hardware and acquisition

- Broadband hi-freq sparkers (vert. res. up to 20 cm)
- UHR Boomers (vert. res. up to 10 cm)
- UHR multichannel streamers (receiver spacing 1 m)
- …

THE BOTTLENECK IS DATA PROCESSING



RadExPro seismic software

- Broadband hi-freq sparkers (vert. res. up to 20 cm)
- UHR Boomers (vert. res. up to 10 cm)
- UHR multichannel streamers (receiver spacing 1 m)
- …

- Even small sea swelling destroys coherency at high frequencies (even more complicated with multichannel acquisition)

- Ghost waves, complicated source signatures compromise resolution

- Shallow towing, use of small vessels of opportunity result in noisier data

- Sources are powerful – multiples compromise penetration

- …

Can we borrow processing techniques from oil-and-gas seismic?

Lots of advanced processing algorithms developed

Do not address typical specific problems of HR/UHR seismic data

- Unstable towing conditions
- Statics due to sea swelling
- Short offsets
- No NFH available
- and more…

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Adequate modern HR/UHR marine seismic processing sequence = techniques from O&G seismic processing + HR/UHR data specific approaches

Noise Attenuation

Shallow towing + use of small vessels of opportunity results in noisier data

Available solutions:

Filtering (bandpass, Butterworth, TVBF)

TFD Noise attenuation

FK, Radon filtering

2D/3D Sparse FK, Sparse Radon filtering

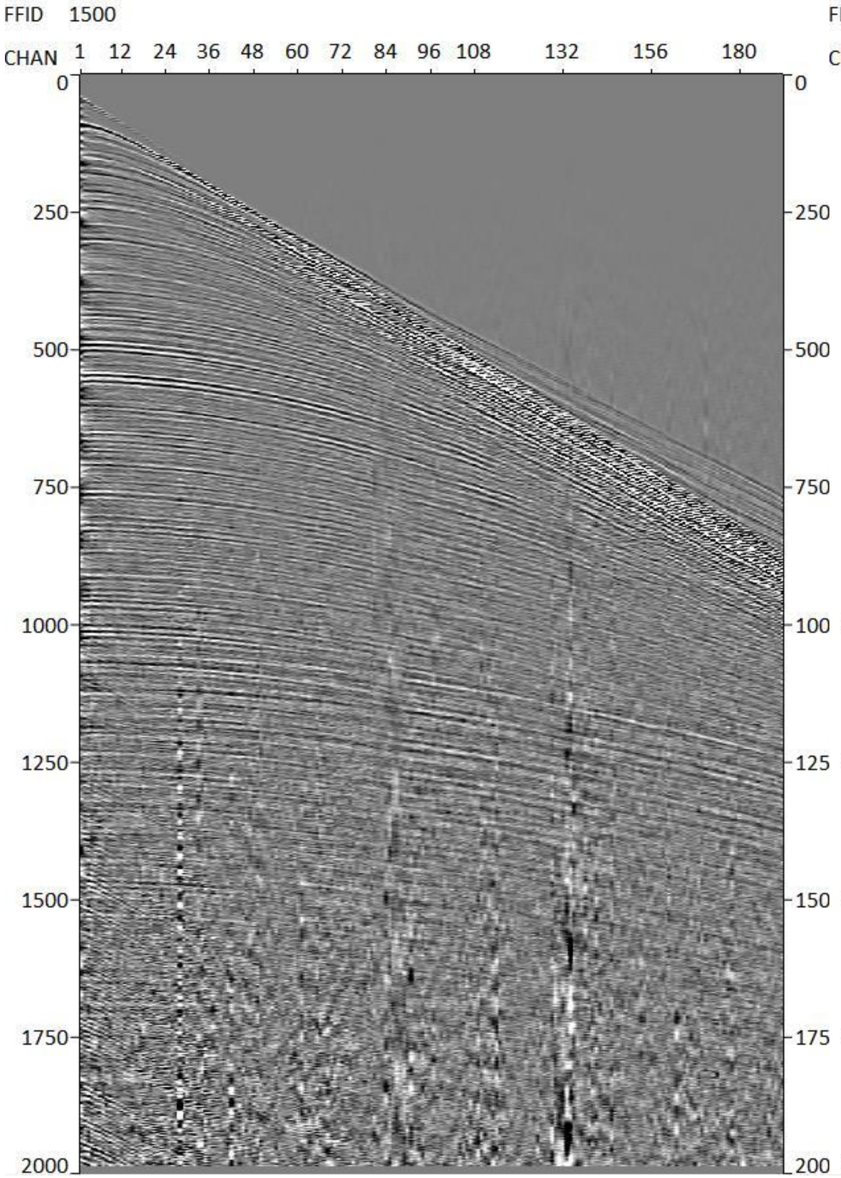
2D/3D FXY predictive filtering

Other techniques can be implemented with available algorithms

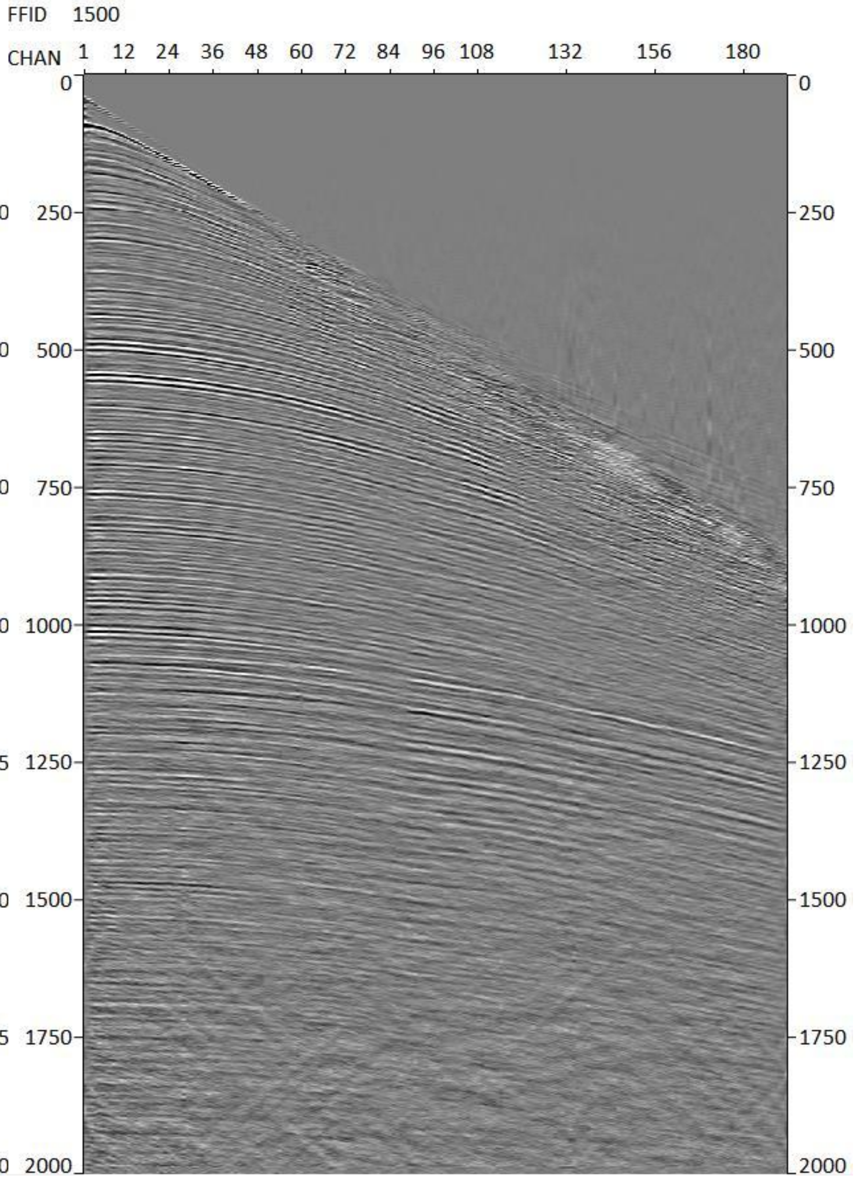
RadExPro
seismic software

Noise Attenuation

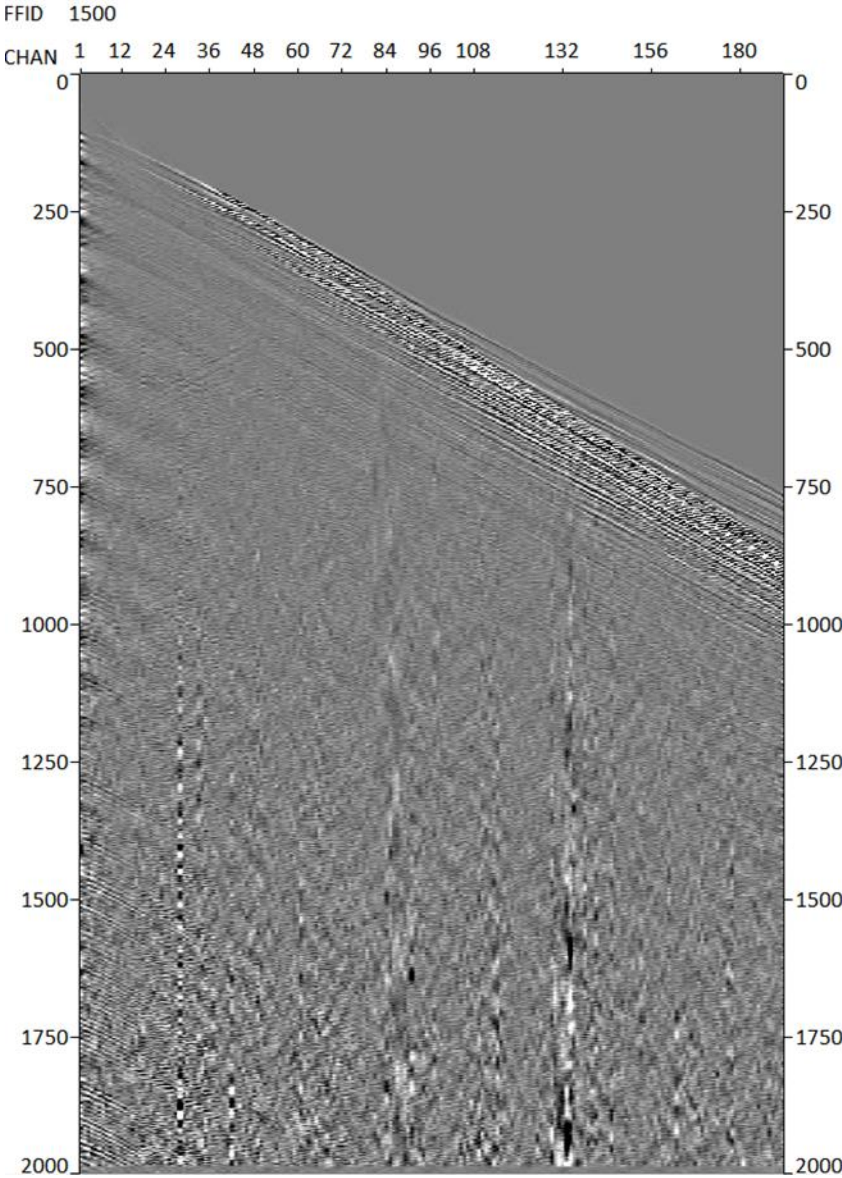
Initial shot gather



Shot gather after denoising



Difference



Static Corrections

Even small sea swelling destroy coherency at high frequencies (even more complicated with multichannel acquisition)

Available solutions:

Swell filtering

Trim statics

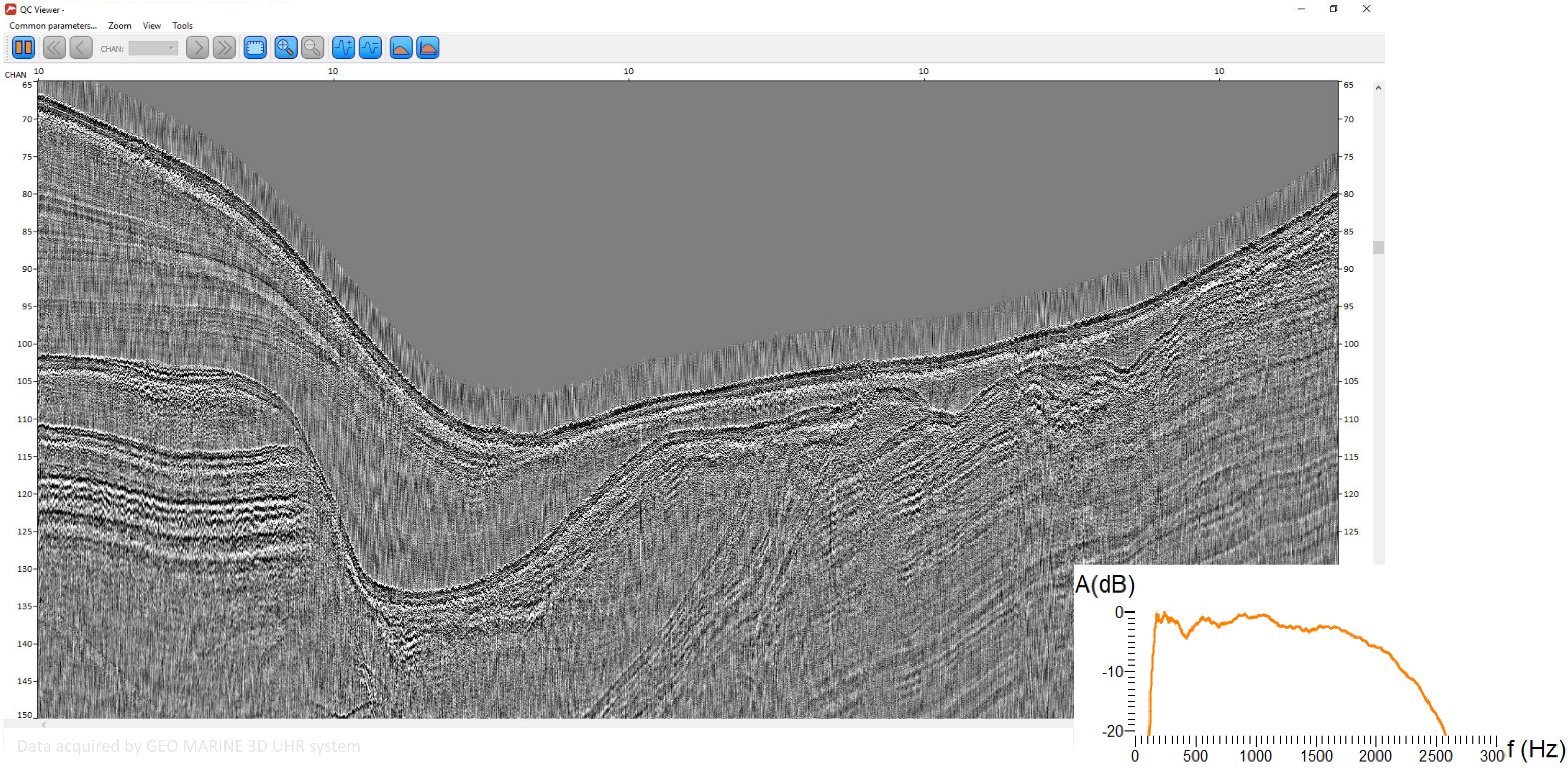
COSA * – for multichannel acquisition

Custom

*** "3D pre-processing techniques for marine VHR seismic data"**
N. Wardell, P. Diviacco, R. Sinceri - First break volume 20.7, July 2002

Static Corrections

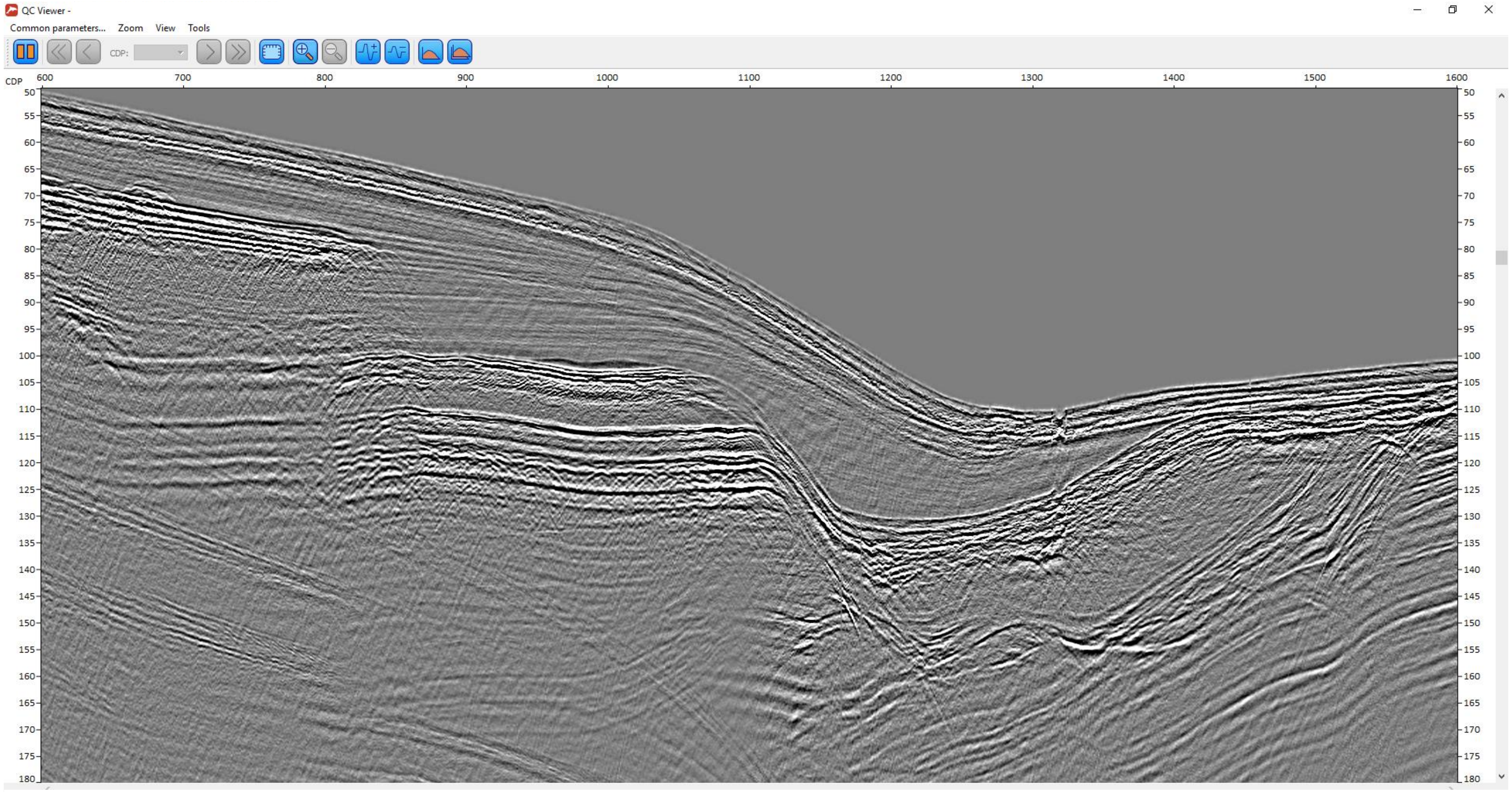
Swell Effect on Multichannel Sparker Data – Channel #10



Data acquired by GEO MARINE 3D UHR system

Static Corrections

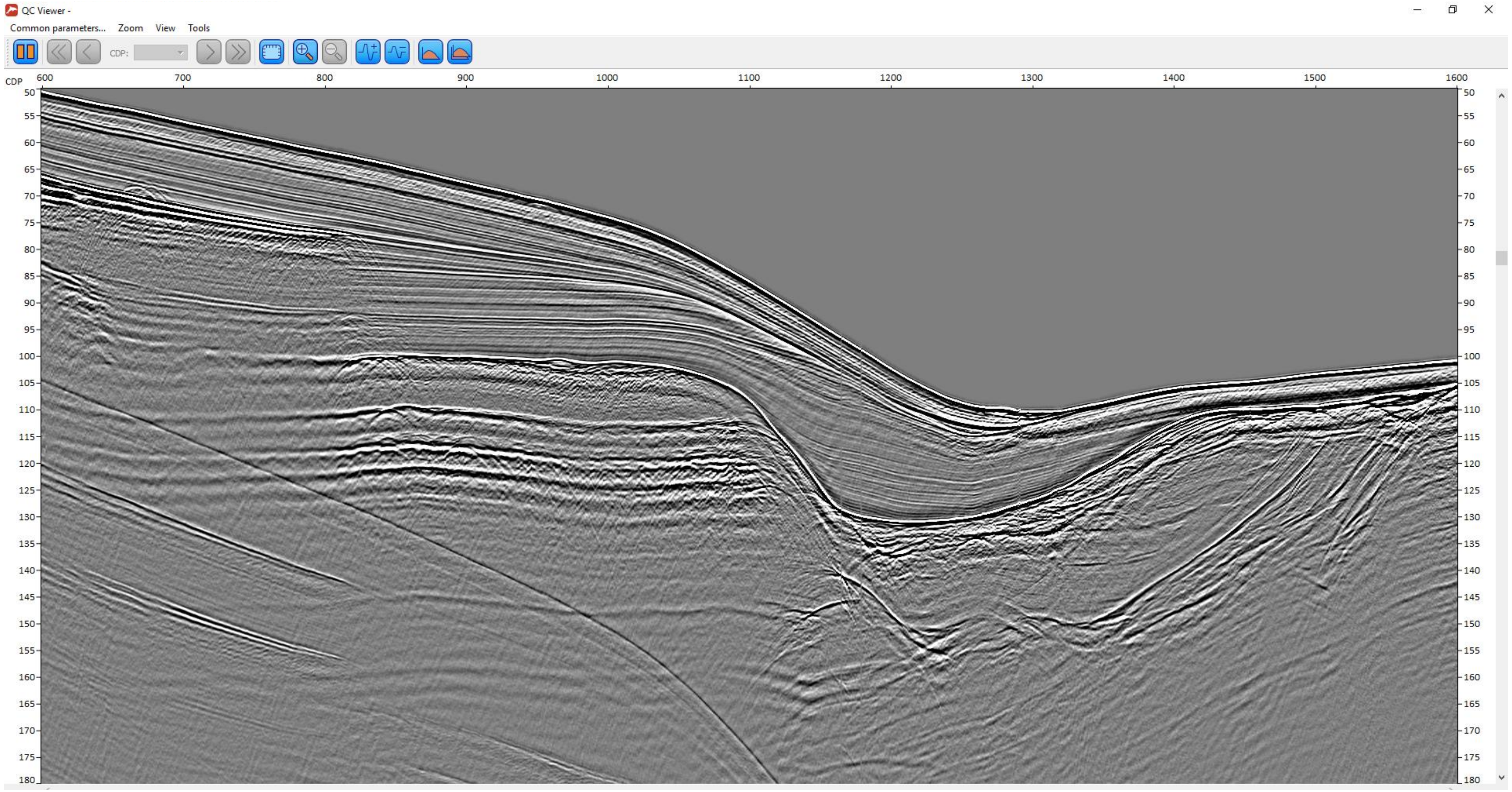
Swell Effect on Multichannel Sparker Data – Brute Stack



Data acquired by GEO MARINE 3D UHR system

Static Corrections

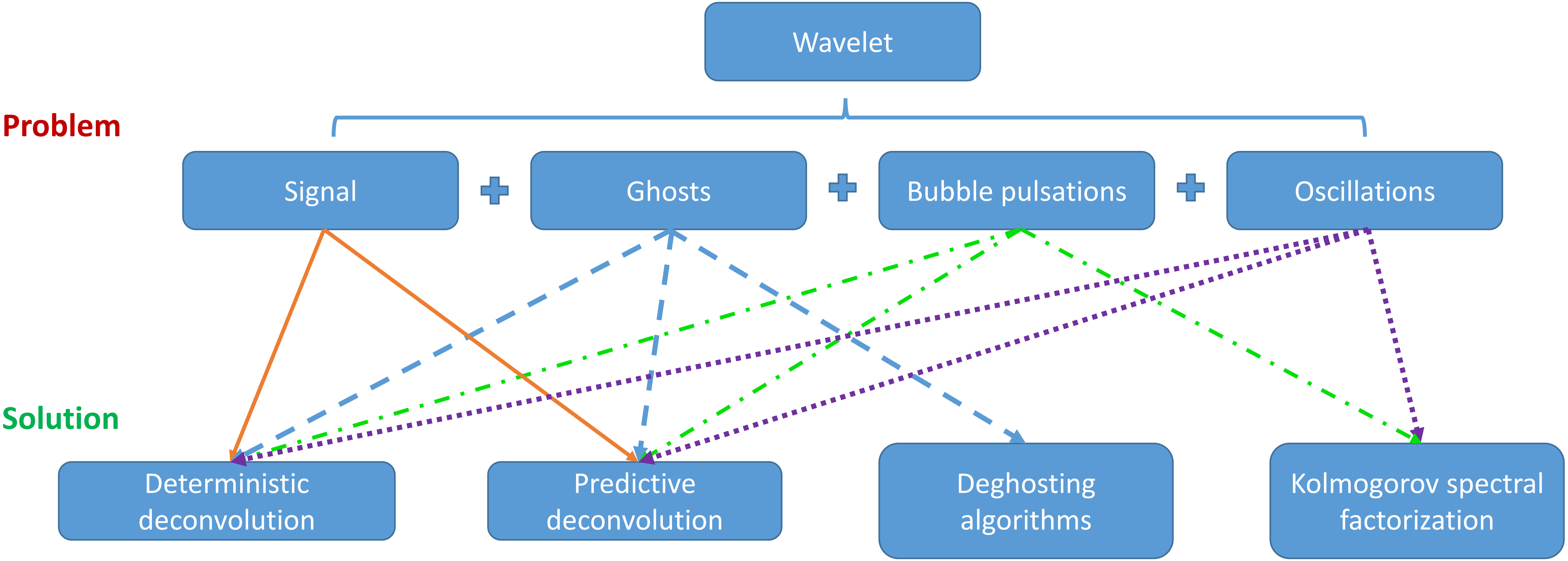
Swell Effect on Multichannel Sparker Data – after Hi-Res Marine Statics application



Data acquired by GEO MARINE 3D UHR system

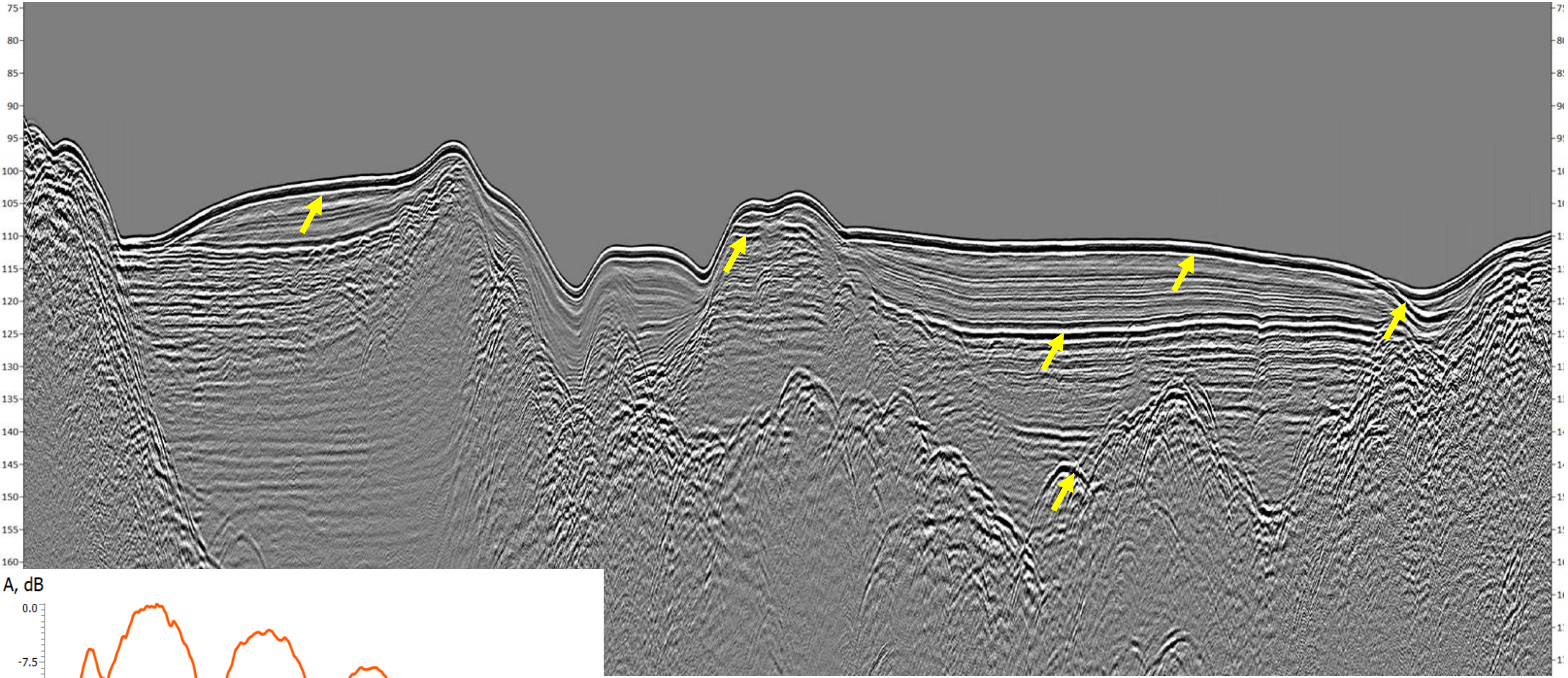
Designature

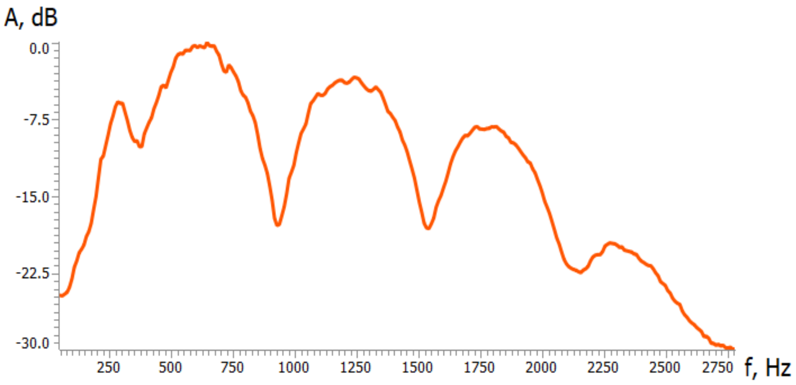
Ghost waves, complicated source signatures compromise resolution



Designature by predictive deconvolution

Multichannel HR data – stack before designature





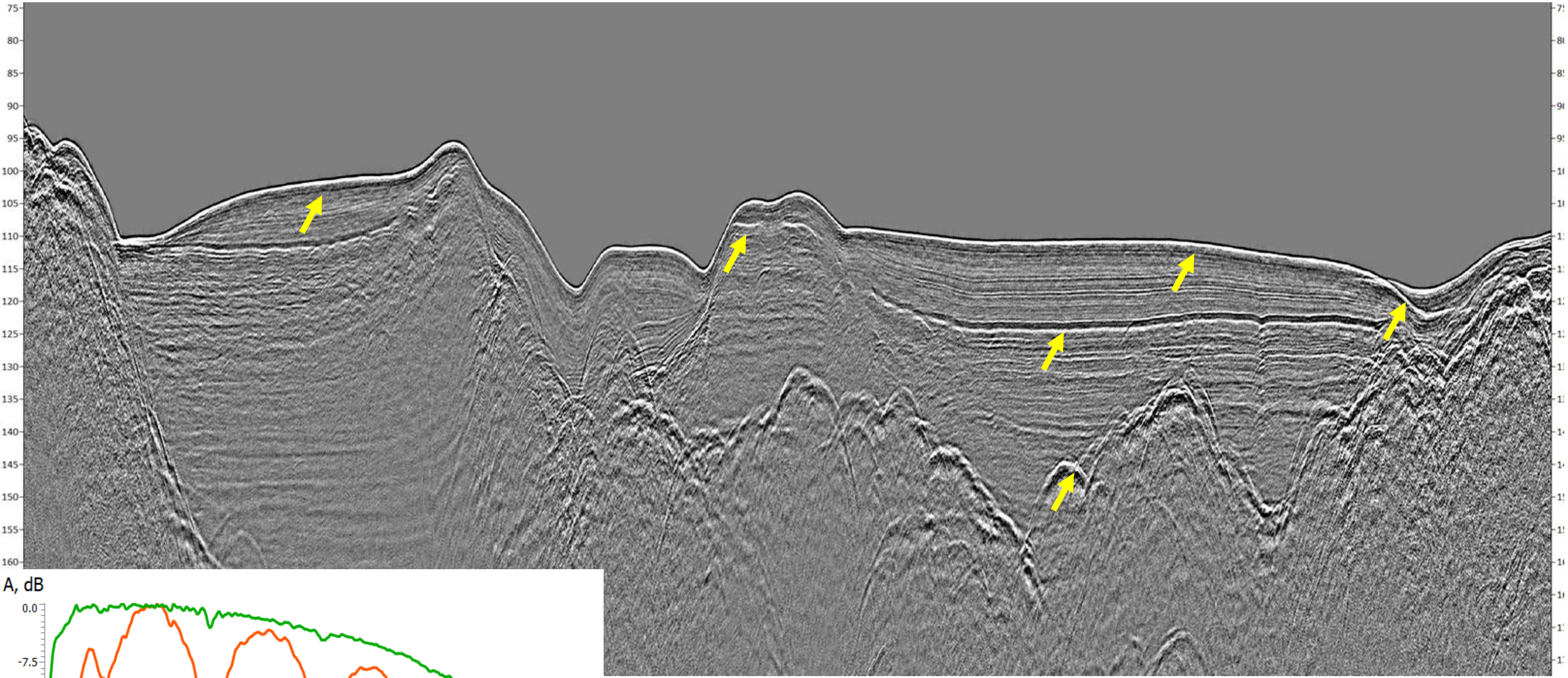
Spectrum before designature

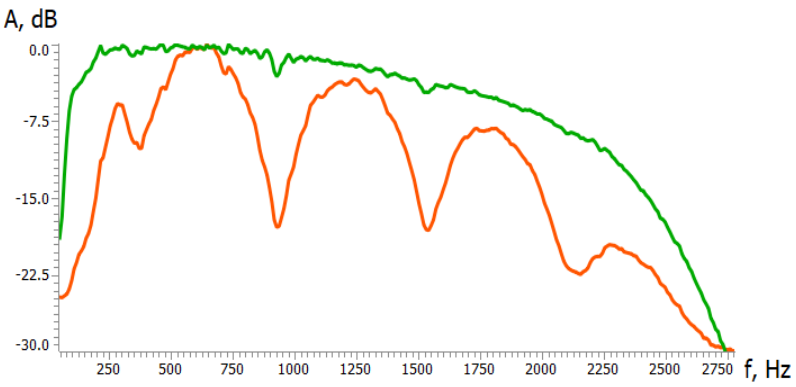
Survey parameters

Source – sparker
Streamer – 16 chans
Water Depth – 60-90 m

Designature by predictive deconvolution

Multichannel HR data – stack after designature





Spectrum before designature

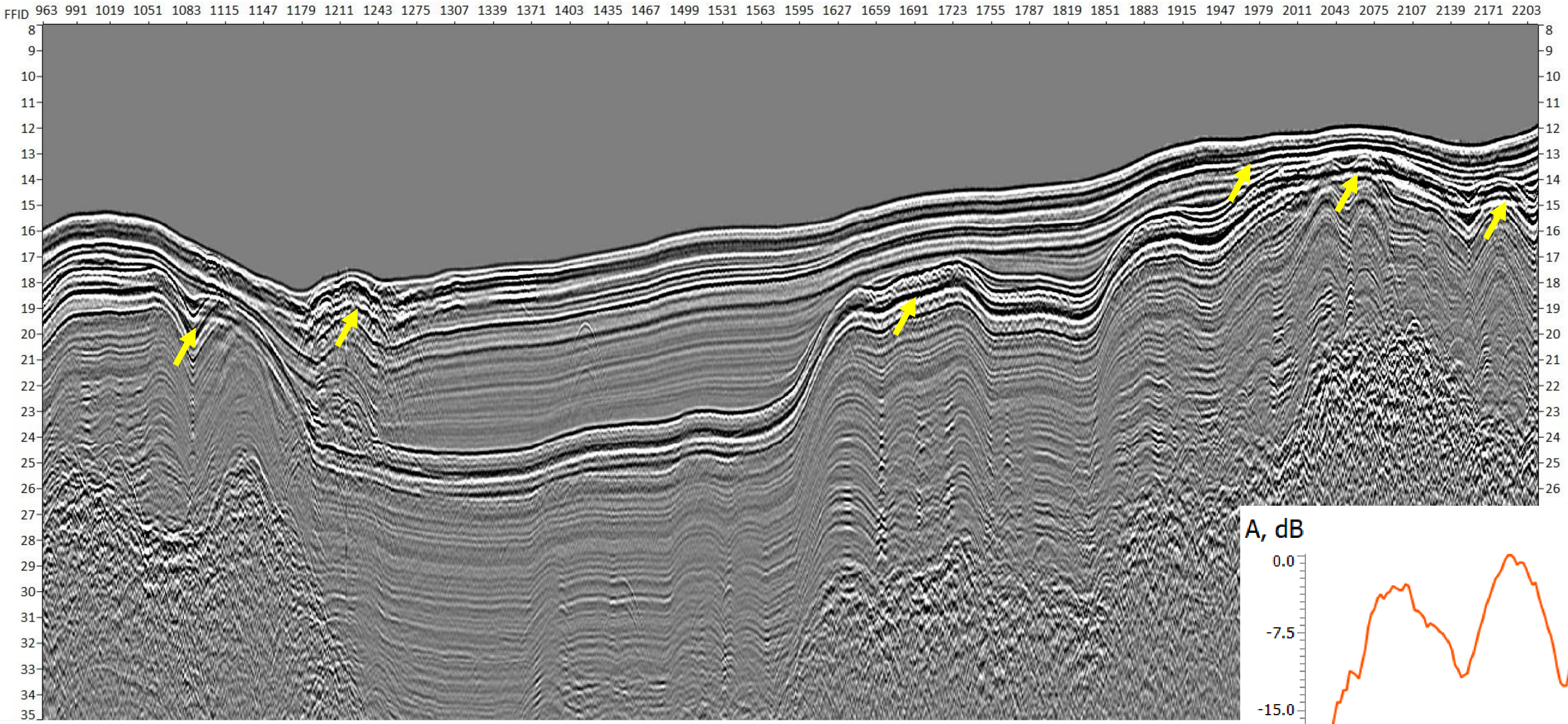
Spectrum after designature

Survey parameters

Source – sparker
Streamer – 16 chans
Water Depth – 60-90 m

Designature by statistical deconvolution

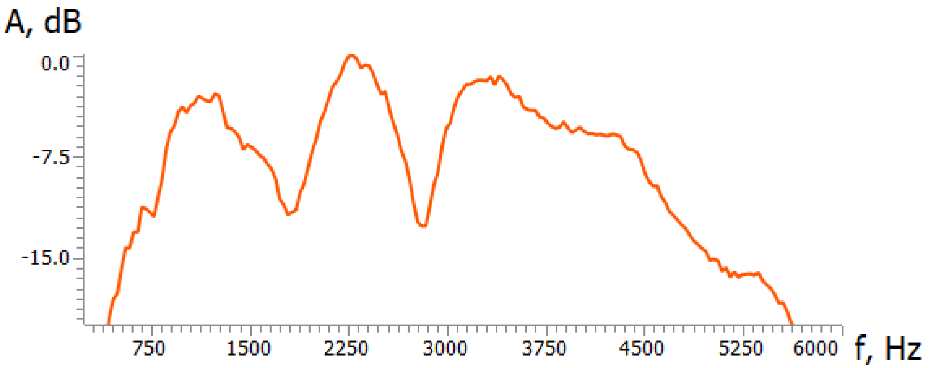
Single channel seismic section before designature



Survey parameters

Source – sparker
Streamer – 4 channels
Water Depth – 5-10 m

Data acquired by Geodevice



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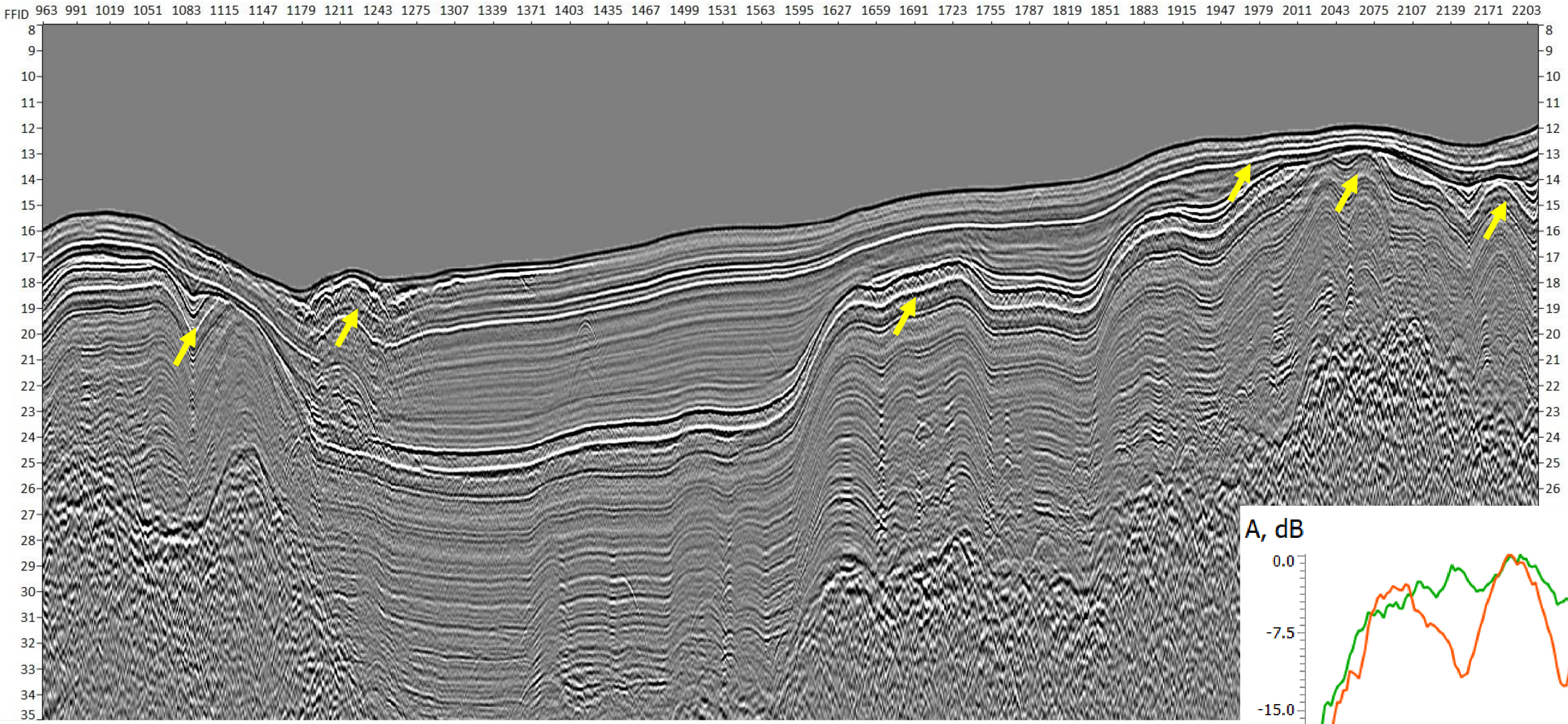
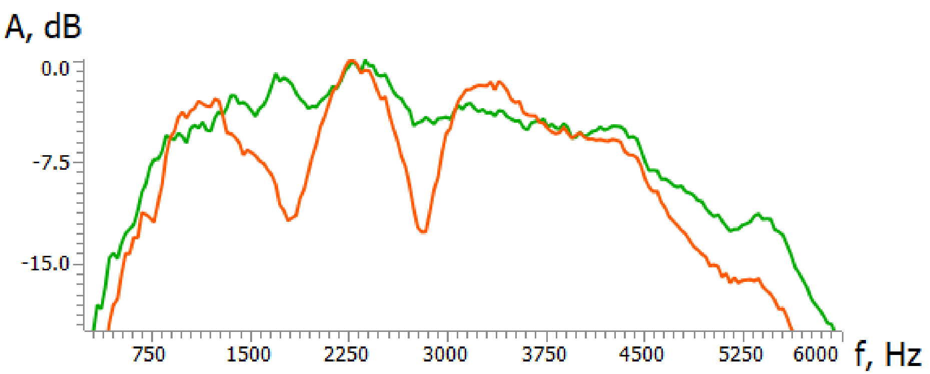
Single channel seismic section after designature



Survey parameters

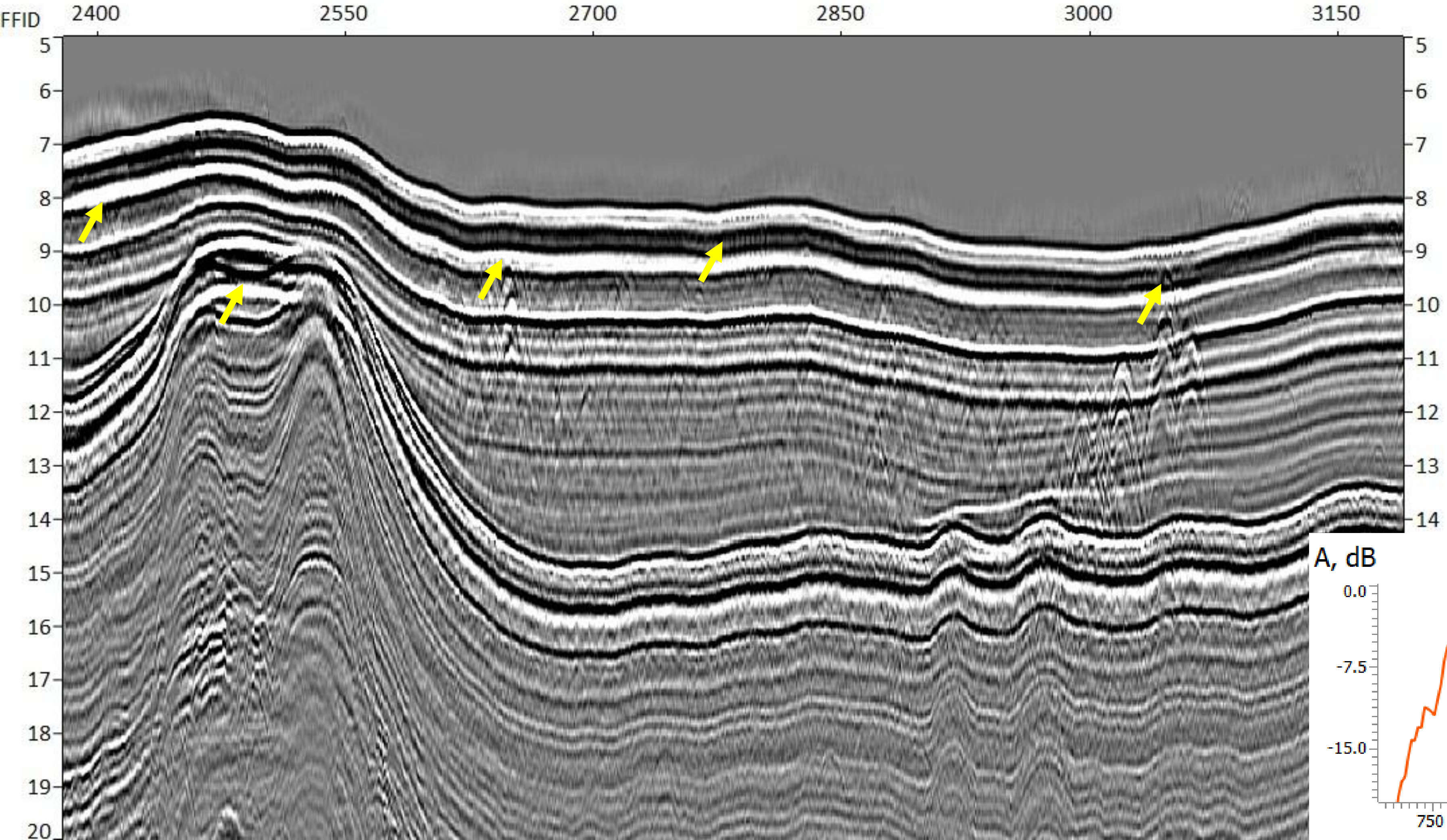
Source – sparker
Streamer – 4 channels
Water Depth – 5-10 m

Data acquired by Geodevice



Designature by statistical deconvolution

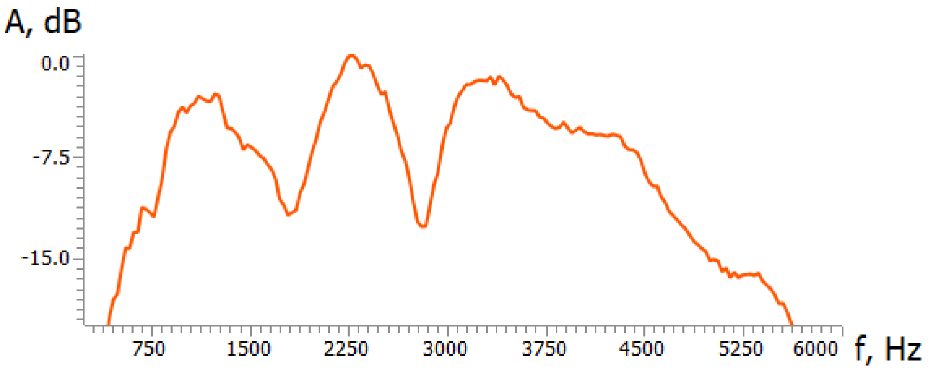
Single channel seismic section before designature



Survey parameters

Source – FWS-125 Sparker
Streamer – 4 channels
Water Depth – 5-10 m

Data acquired by Geodevice



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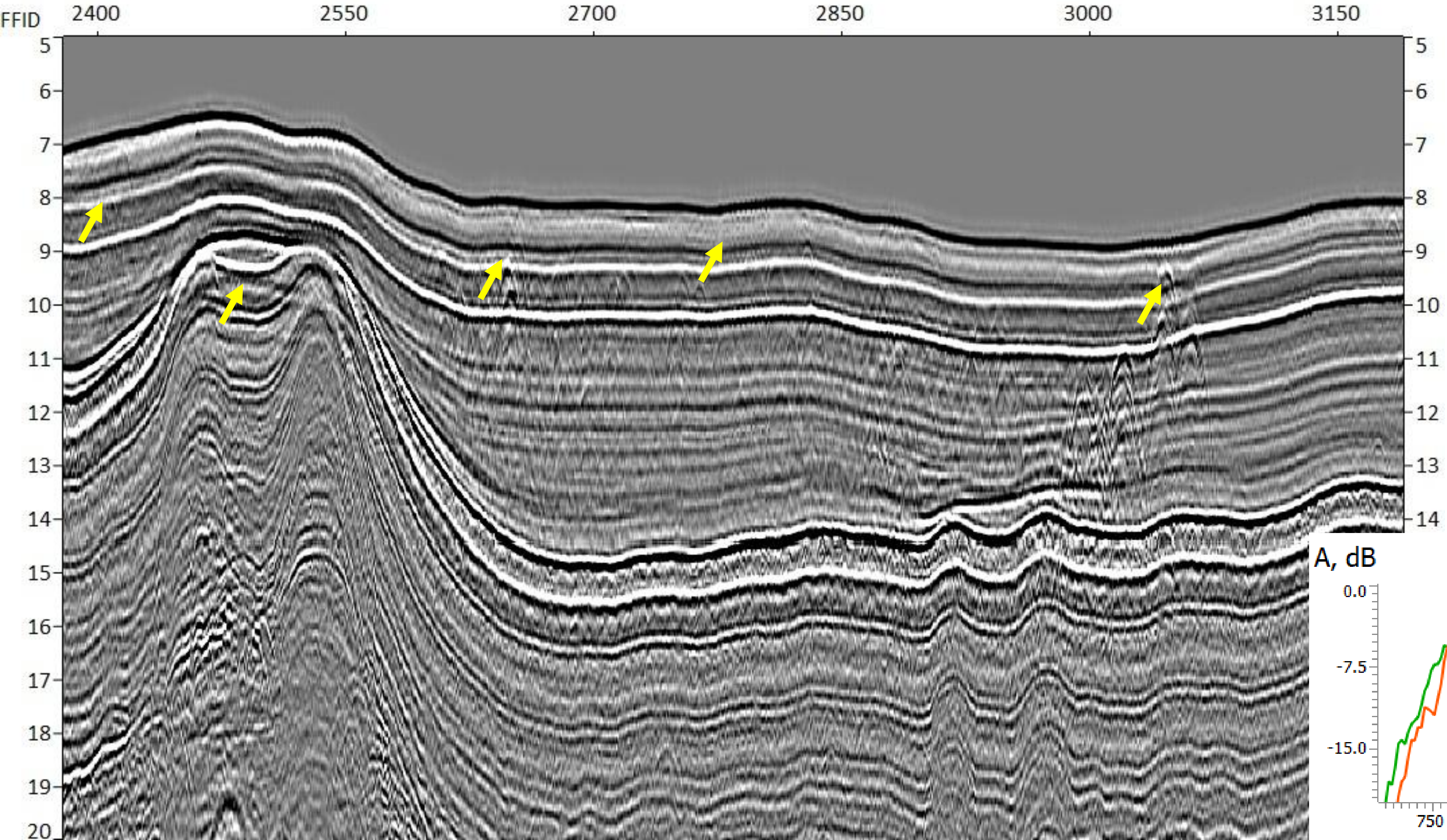
Designature by statistical deconvolution

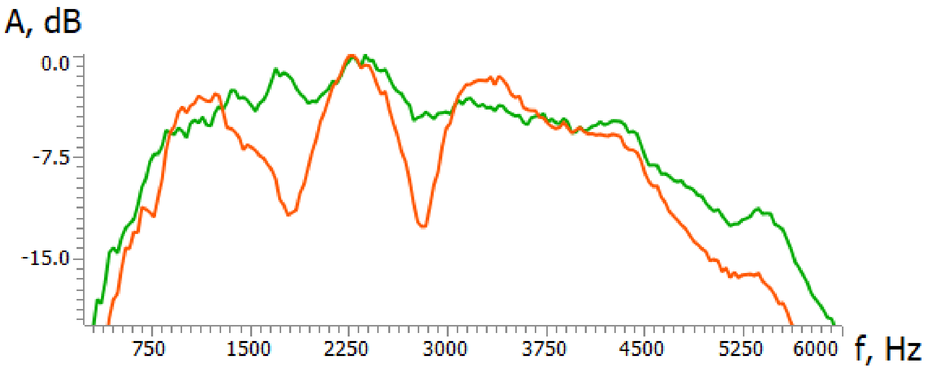
Single channel seismic section after designature



Survey parameters

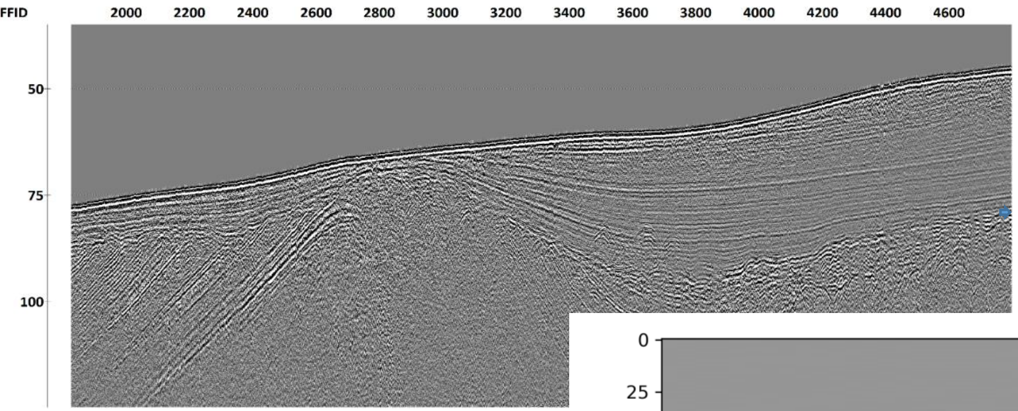
Source – FWS-125 Sparker
Streamer – 4 channels
Water Depth – 5-10 m

Data acquired by Geodevice

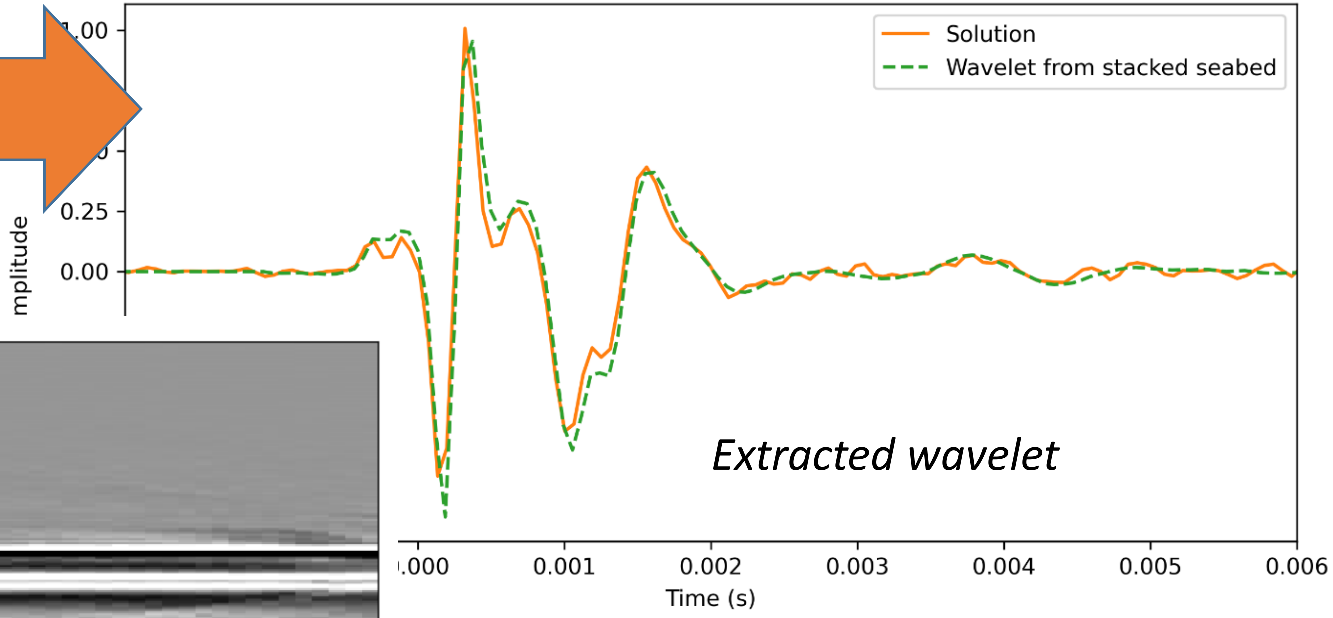


Designature by statistical deconvolution

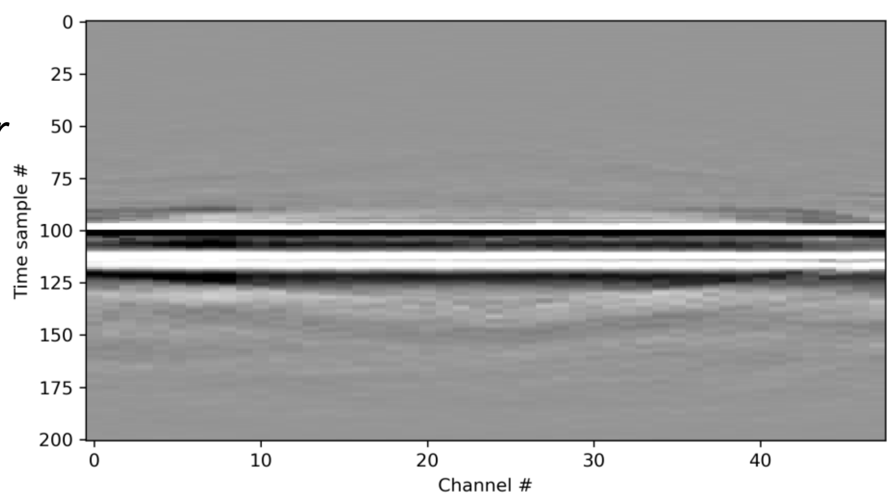
Automatic wavelet extraction – amplitude and phase match*



Common channel gather



Extracted wavelet

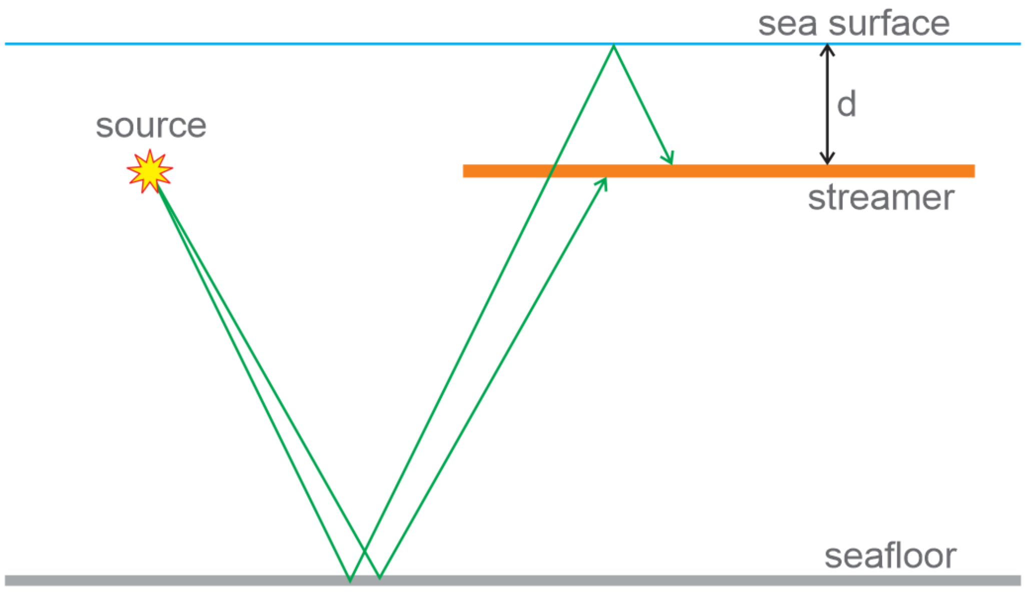


Automatically extracted wavelets for 48 channels

”Fast and accurate cumulant-based mixed-phase wavelet estimation for high-resolution seismic data” -
A. Egorov (RadExPro Seismic Software LLC) -- EAGE Annual 2025, Tuesday, June 3, 9:00

SharpSeis - dedicated algorithm for ghosts removal

Principle scheme of marine towed acquisition



Ghost time delay: $\tau = 2d\cos\theta / V$

V – water velocity

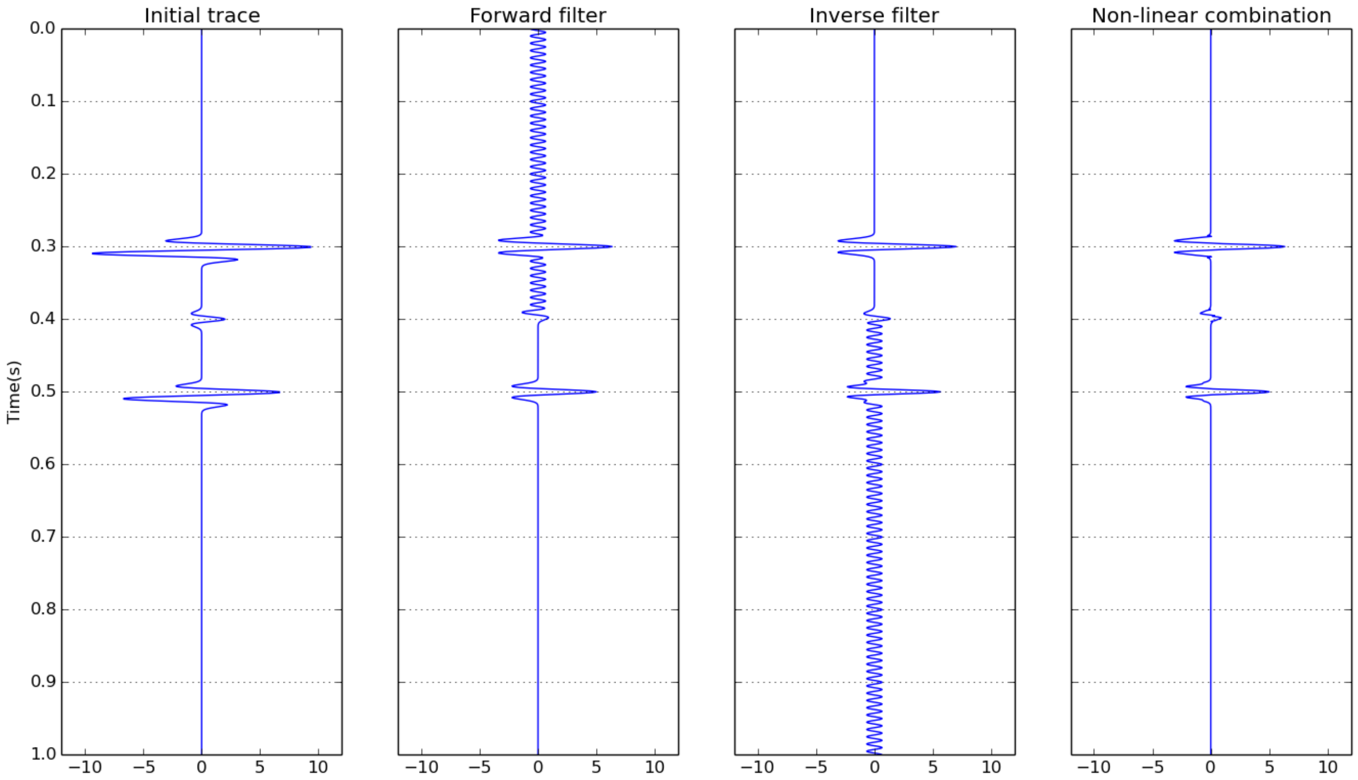
d – streamer depth

θ – angle of incidence

SharpSeis Deghosting

Solution: Adaptive Recursive Filtering *

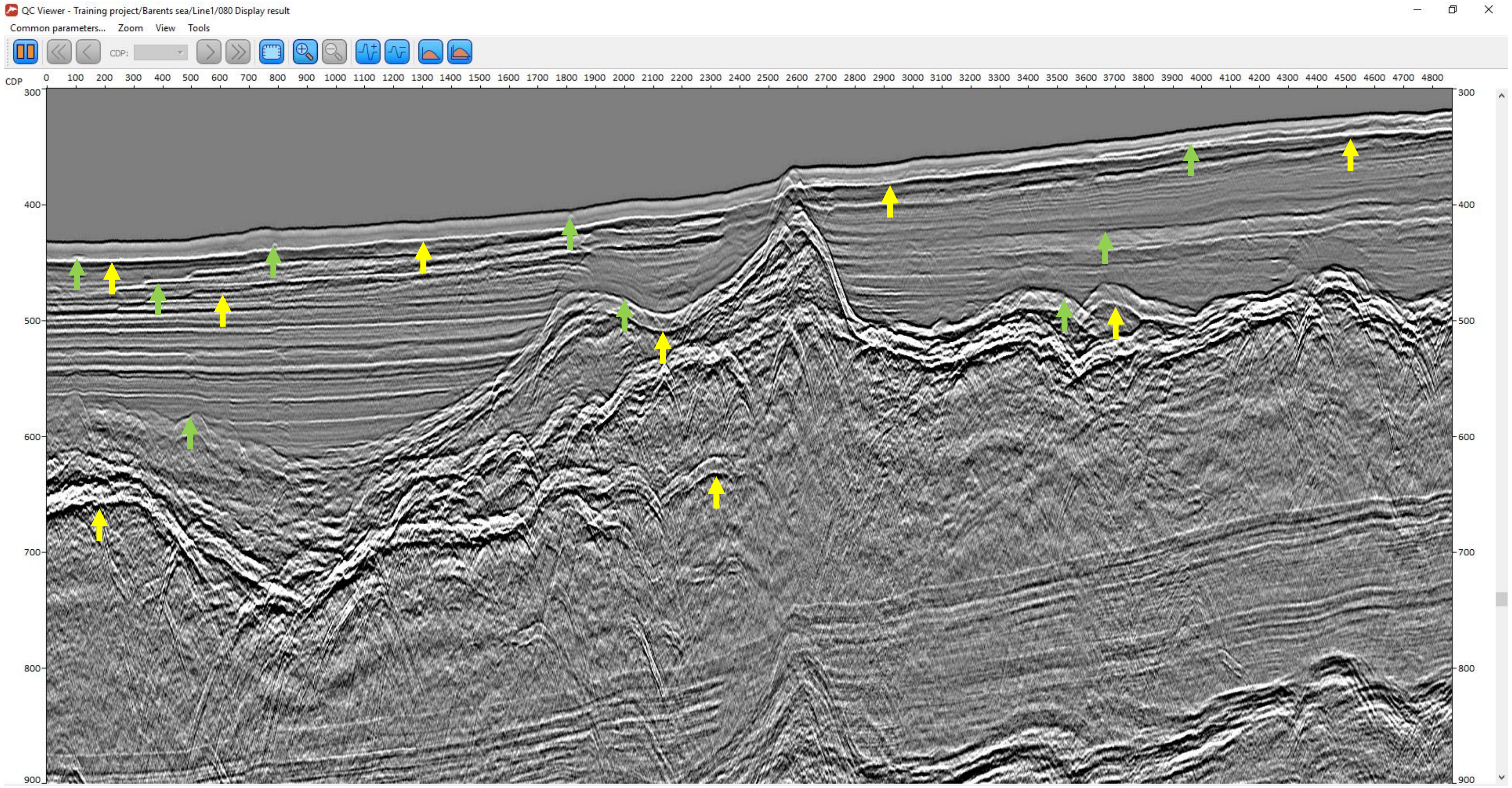
1. Recursive filtering
2. Filtering in forward and reverse time
3. Nonlinear combination of forward and reverse filters
4. Regularization of the solution
5. **Adaptive selection of filter parameters (time delay and q)**



* Vakulenko S.A., Buryak S.V., Gofman P.A. and Finikov D.B., 2014, **Deghosting of High Resolution Marine Seismic Data by Adaptive Filtering Algorithm**, Near Surface Geoscience 2014 - 20th European Meeting of Environmental and Engineering Geophysics pp 1

SharpSeis Deghosting

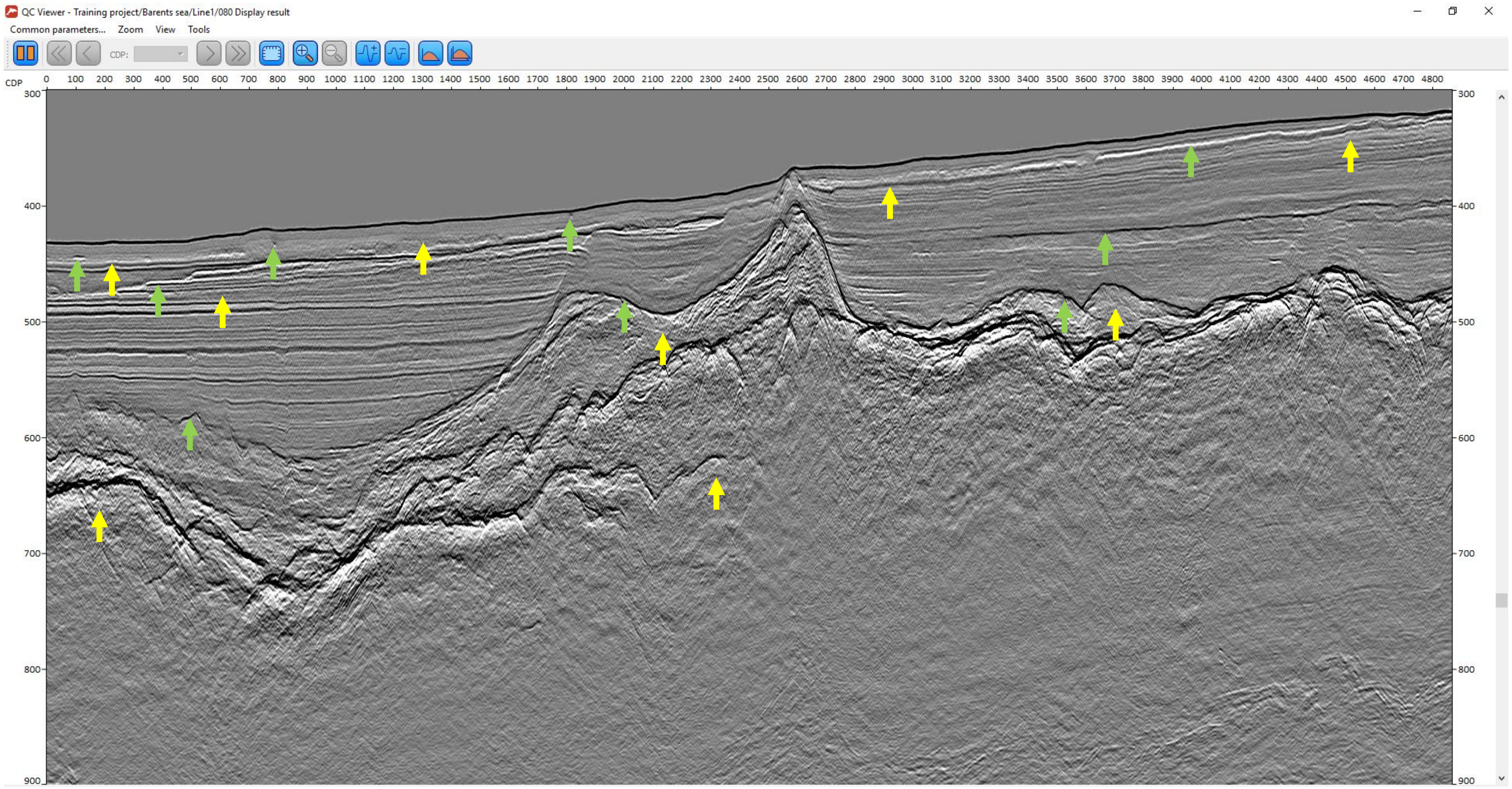
Deep towed streamer, small volume airgun, before deghosting



Data courtesy of The University of Tromsø and UiT Centre of Excellence, Acquired with P-Cable 3D System

SharpSeis Deghosting

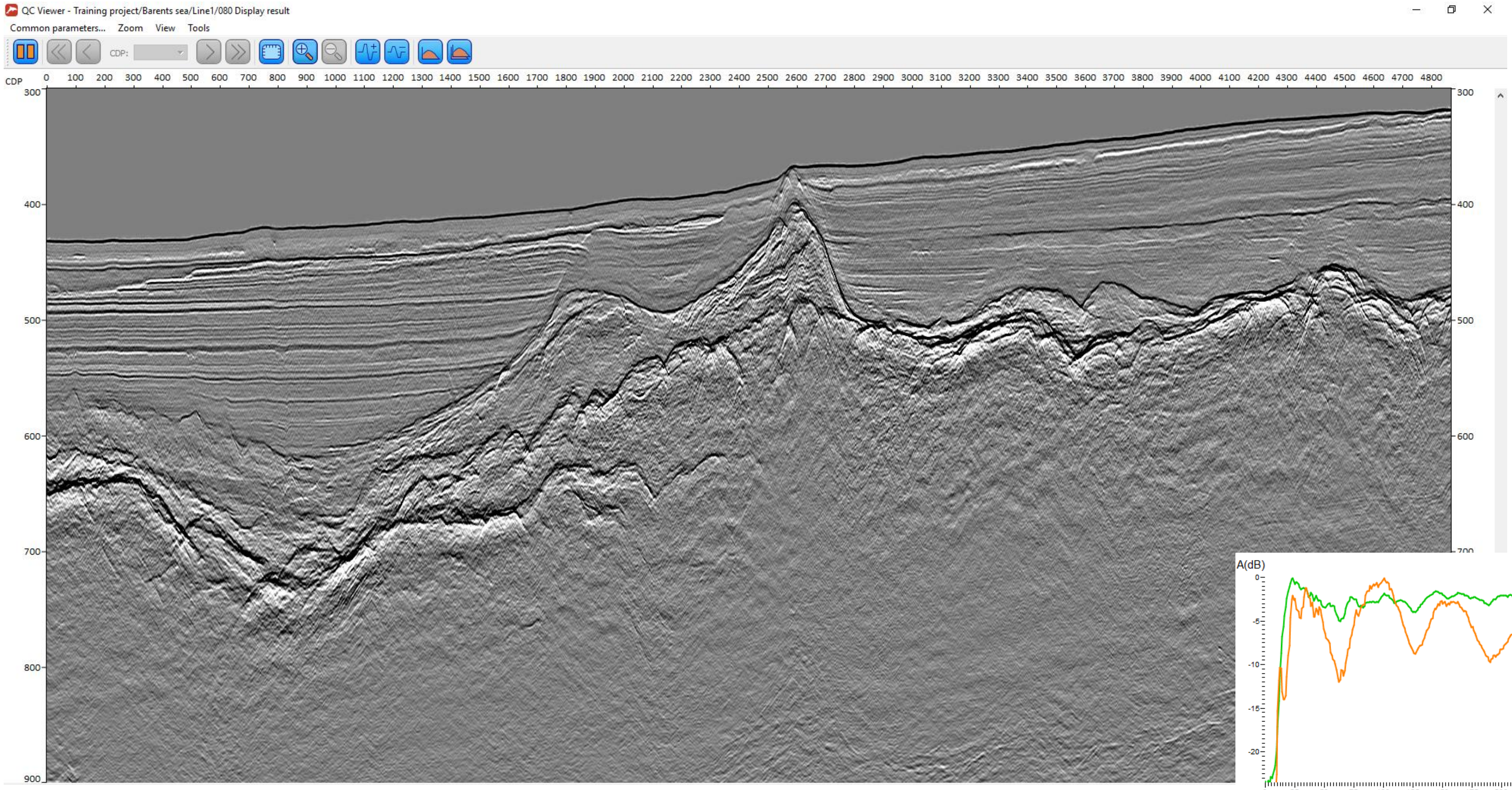
Deep towed streamer, small volume airgun, after deghosting



Data courtesy of The University of Tromsø and UiT Centre of Excellence, Acquired with P-Cable 3D System

SharpSeis Deghosting

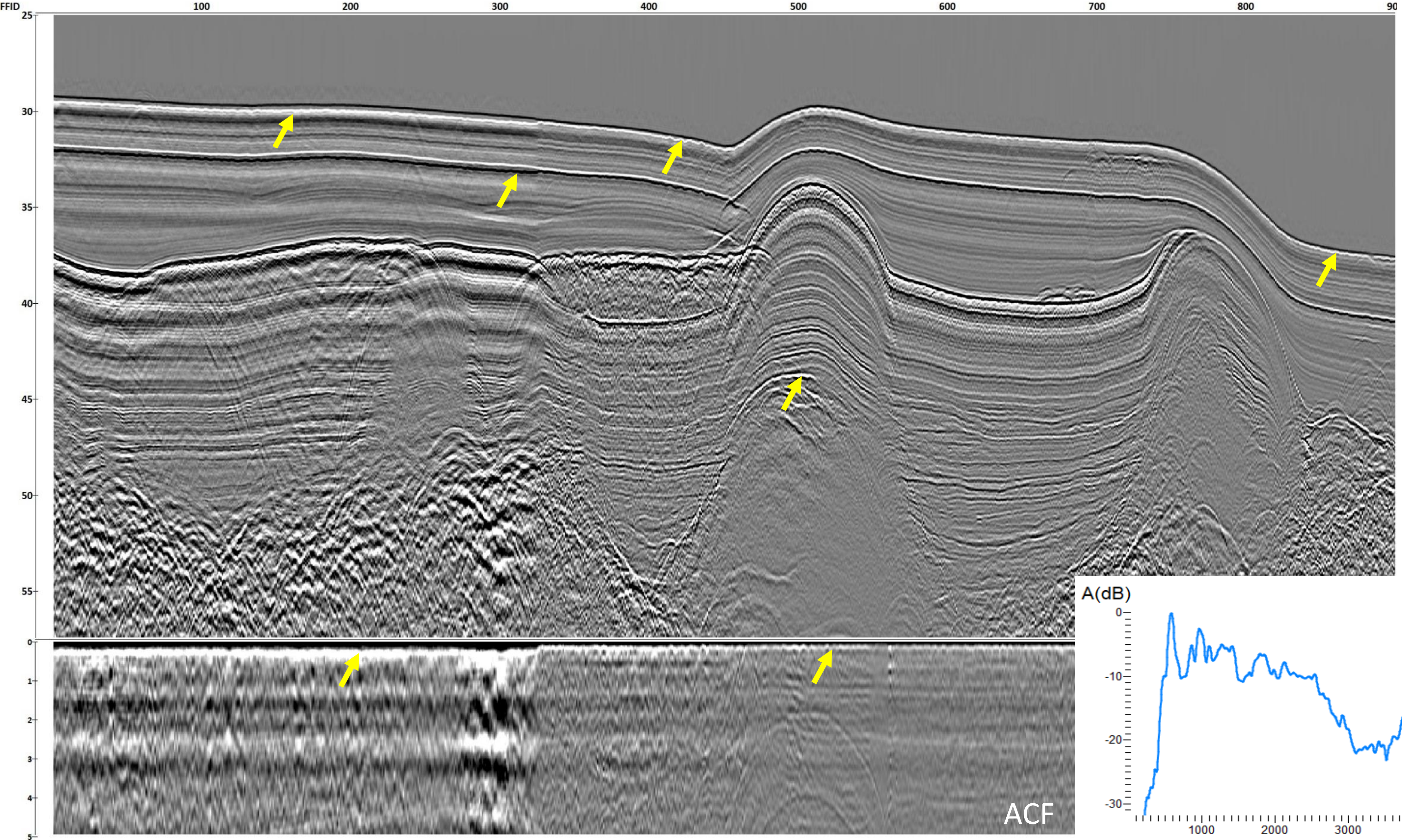
Deep towed streamer, small volume airgun, after deghosting, spectra comparison



Data courtesy of The University of Tromsø and UiT Centre of Excellence, Acquired with P-Cable 3D System

SharpSeis Deghosting

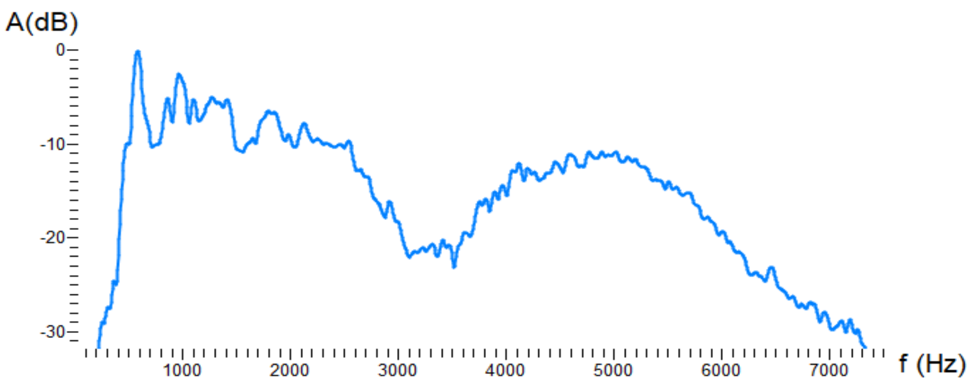
Seismic section before deghosting



Survey parameters

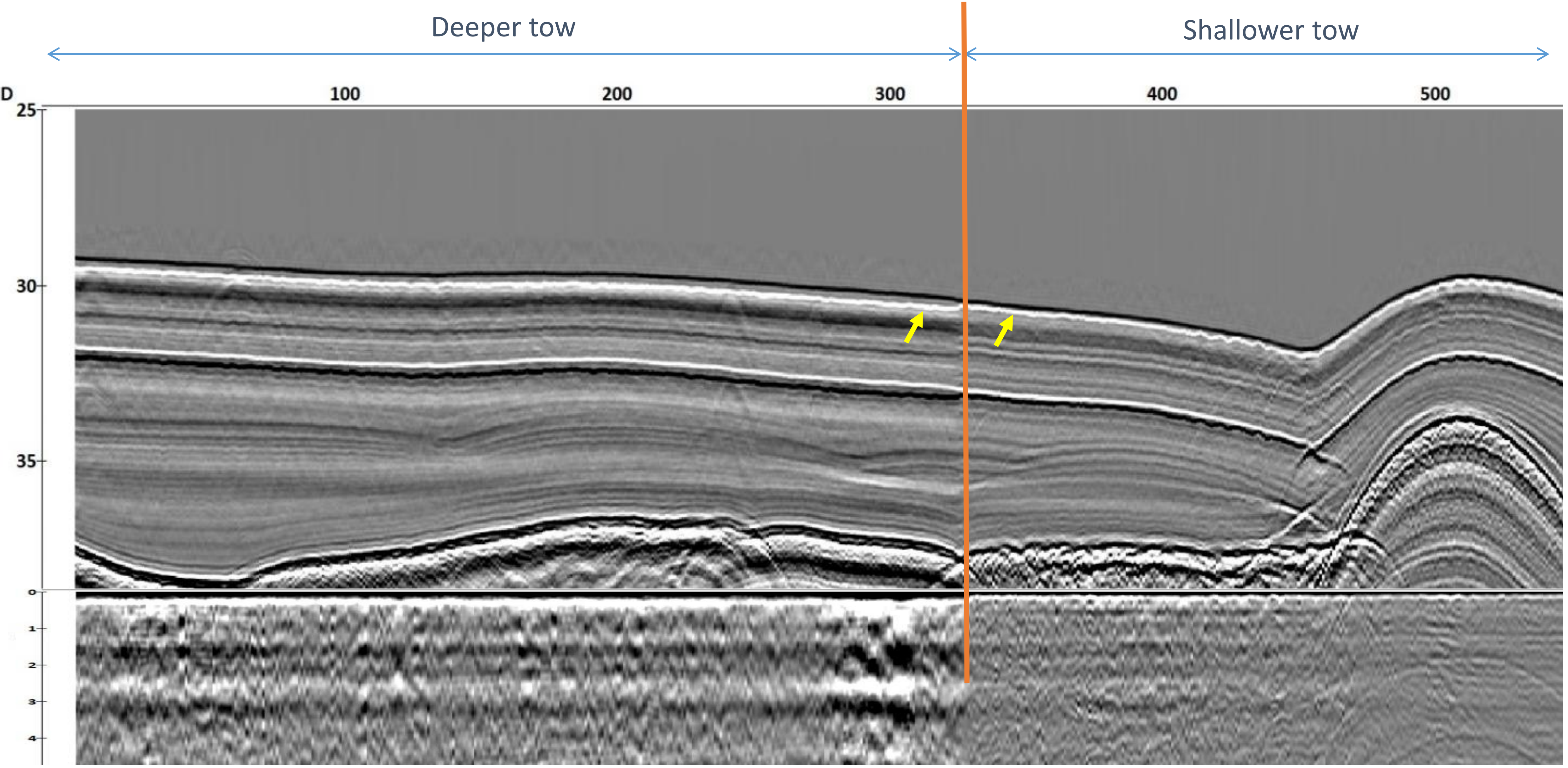
Source – G-Boomer
Streamer – 1 channel
Water Depth – 20-30 m

Data acquired by Geodevice



SharpSeis Deghosting

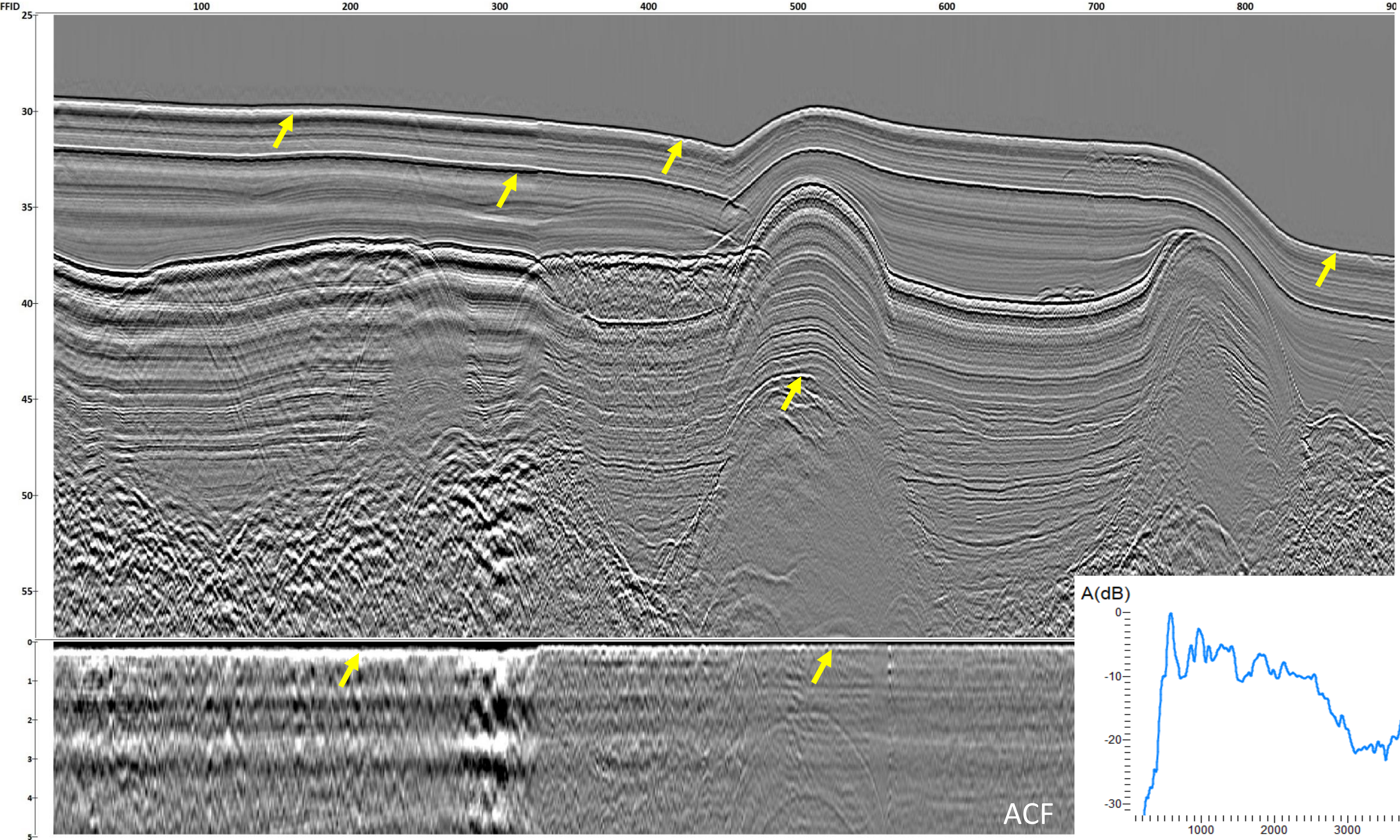
Seismic section before deghosting, zoomed



SharpSeis Deghosting

RadExPro seismic software

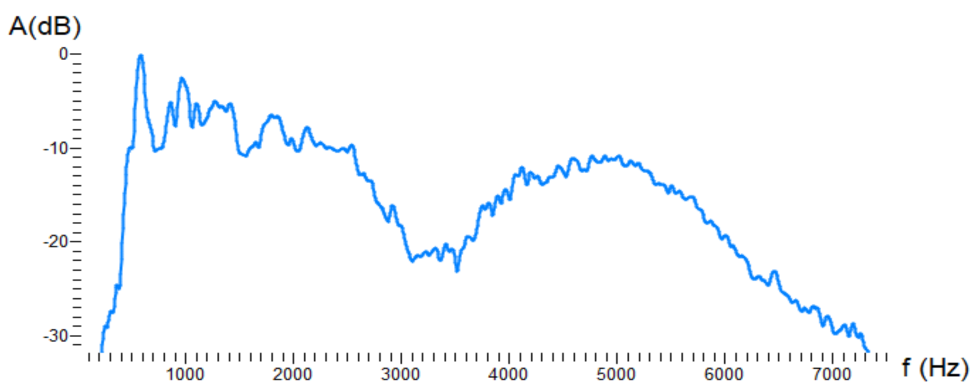
Seismic section before deghosting



Survey parameters

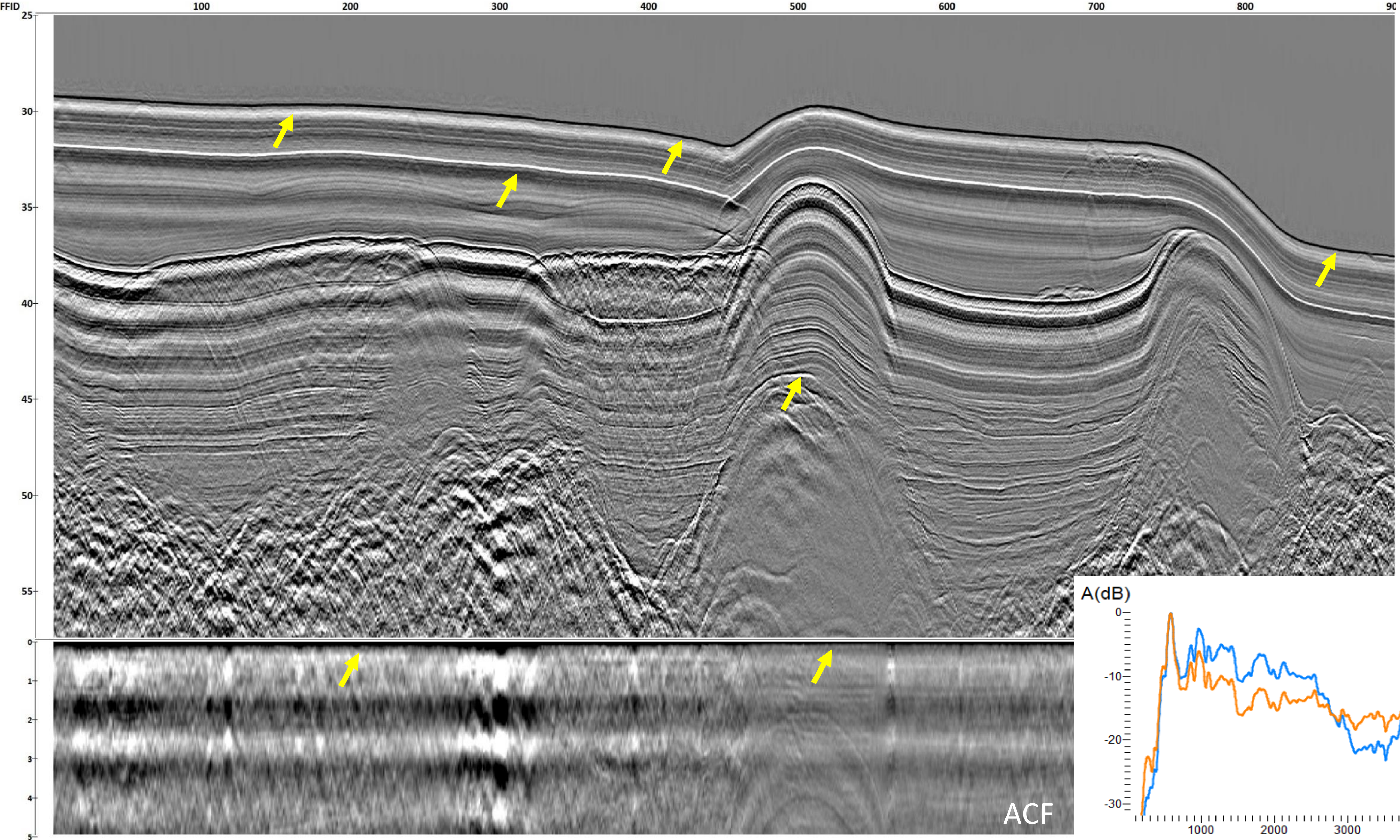
Source – G-Boomer
Streamer – 1 channel
Water Depth – 20-30 m

Data acquired by Geodevice



SharpSeis Deghosting

Seismic section after deghosting



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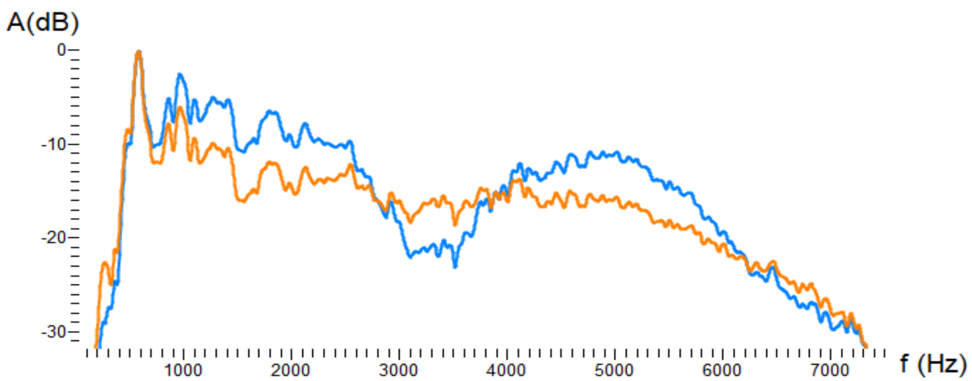
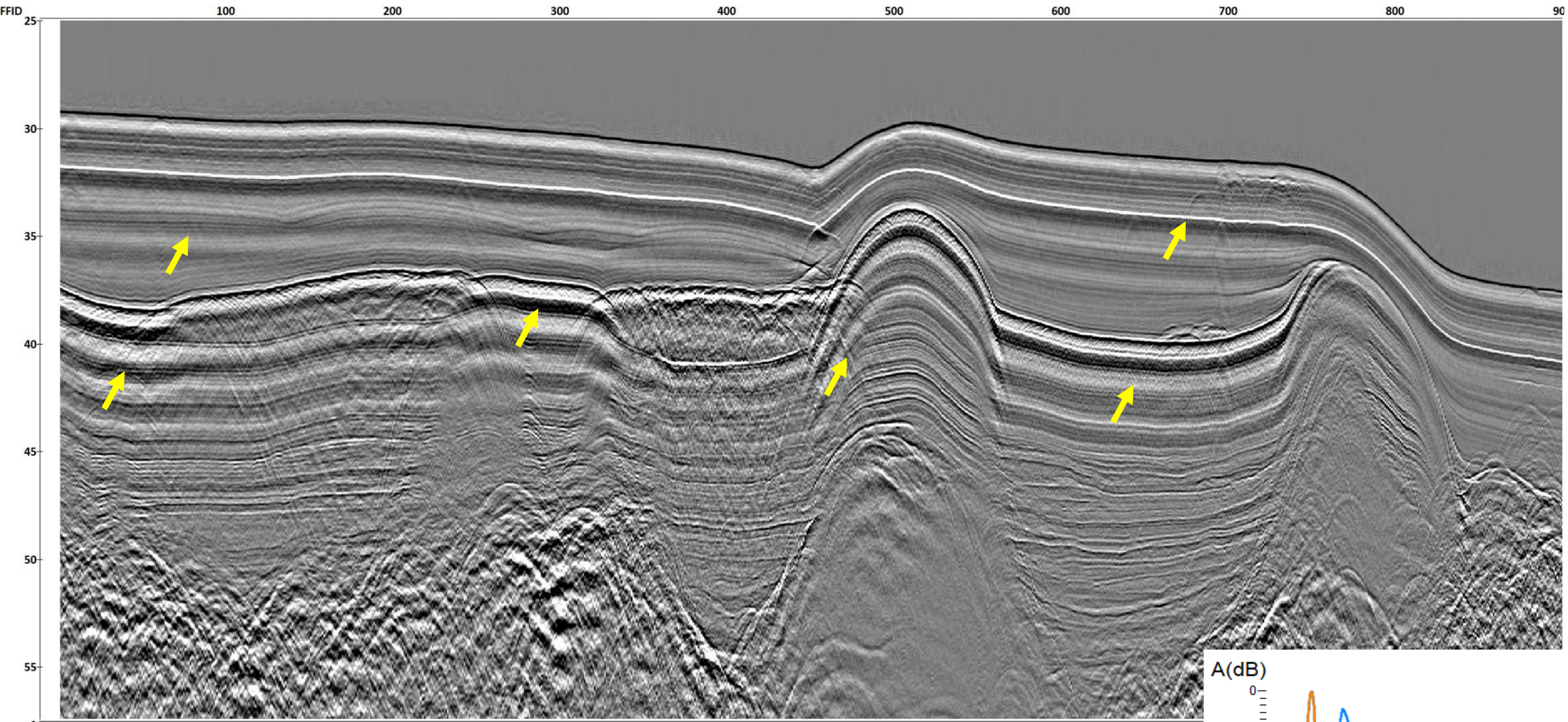
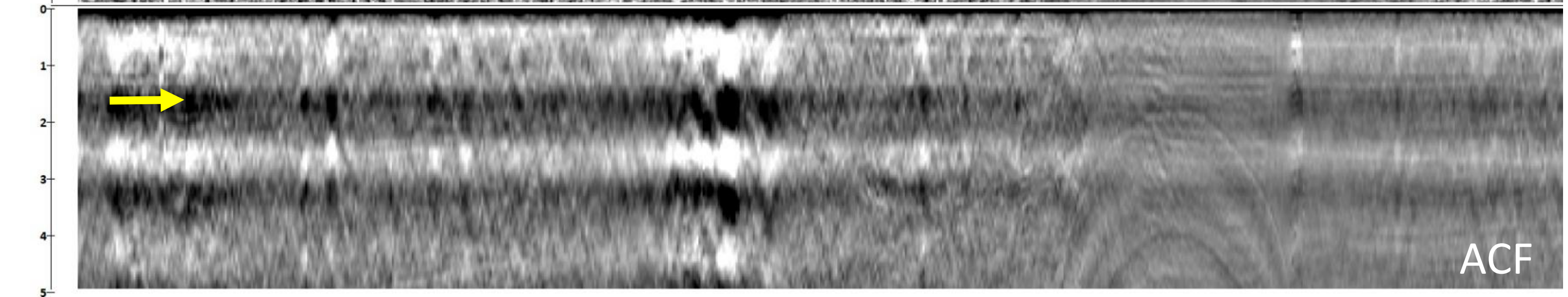


Bubble oscillations removal

Seismic section before debubbling





Survey parameters

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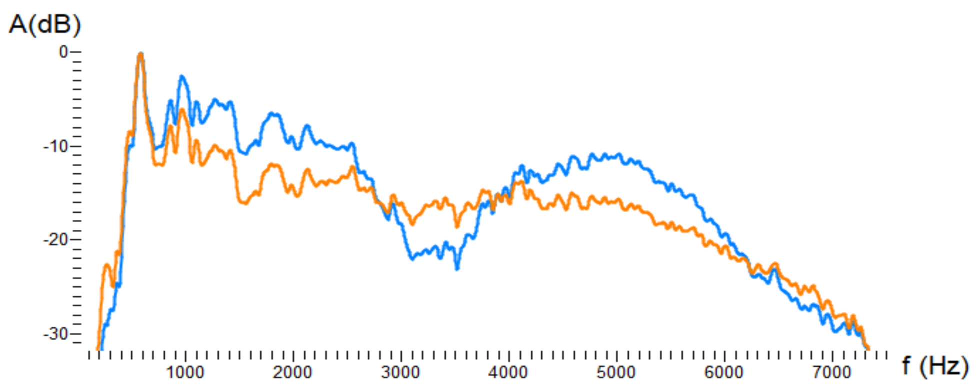


Bubble oscillation removal

Oil and gas industry typical solutions:

1. Estimation from NFH (Ziolkowski, A., 1982) + source array modeling

Available solutions for HR data:

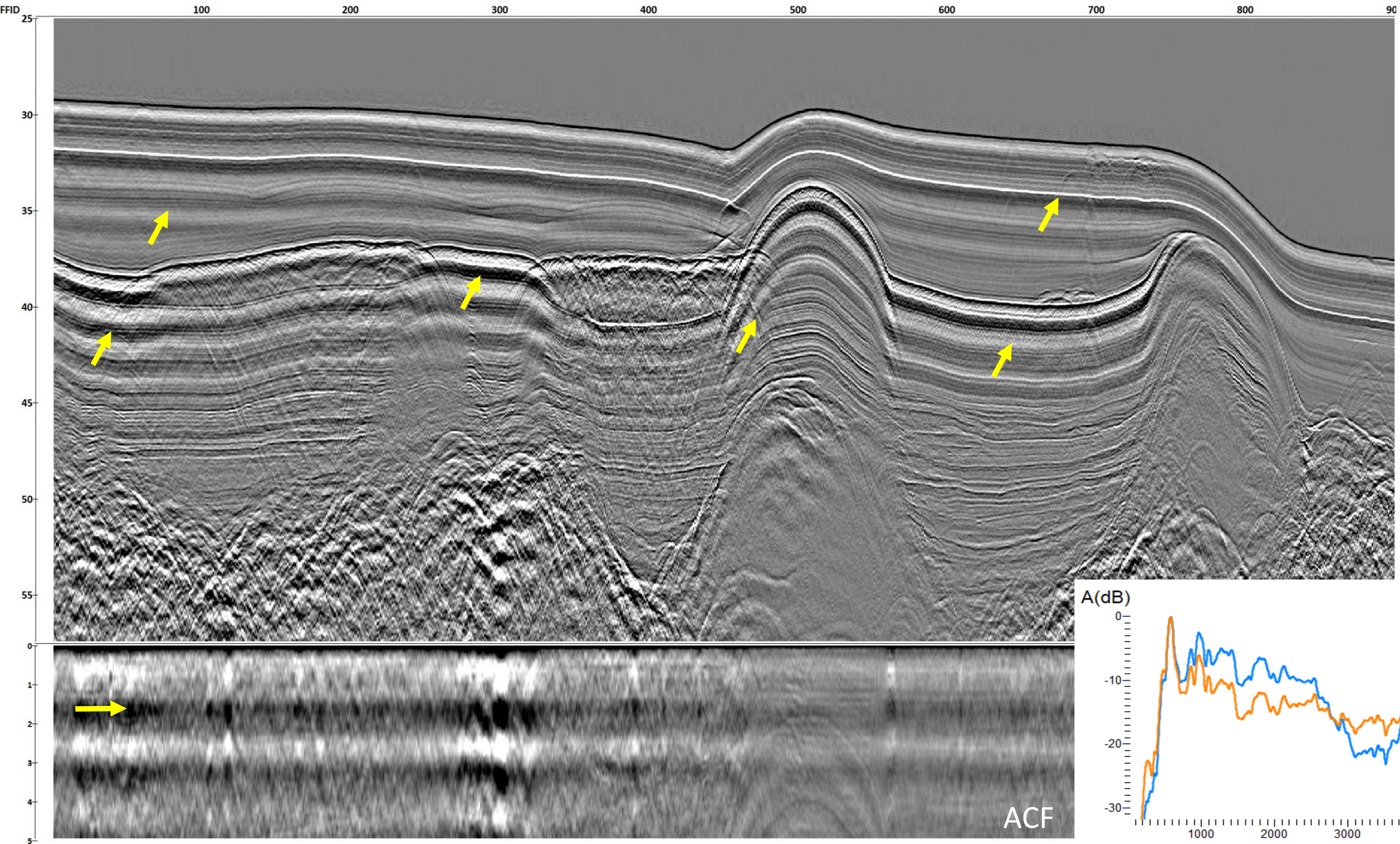
1. Wavelet extraction and inverse filter application
2. Bubble prediction filter
3. Modification of Kolmogorov Spectral Factorization *

* Claerbout, J., Guitton, A., 2015, **Ricker-Compliant Deconvolution**: Geophysical Prospecting, Volume 63, Issue 3, pages 615-625

Vakulenko S.A., Poluboyarinov M.A. and Buryak S.V., 2016, **Implementation and Application of Debbubling Algorithm, Based on Kolmogorov Spectral Factorization**, Near Surface Geoscience 2016 - Second Applied Shallow Marine Geophysics Conference pp 1

Bubble oscillations removal

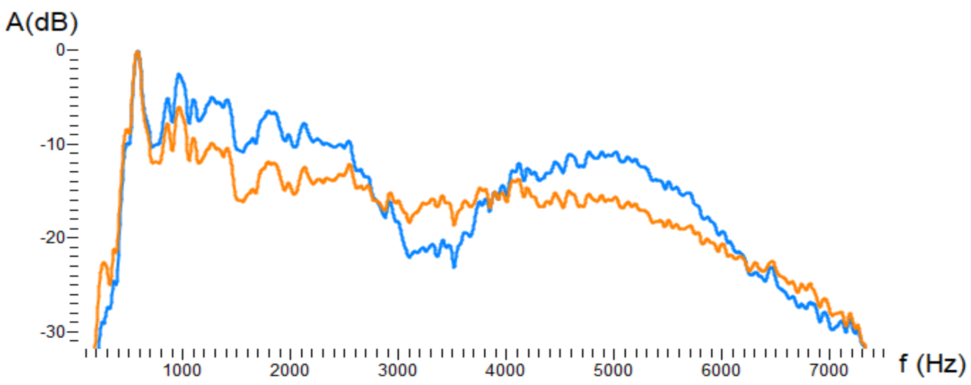
Seismic section before debubbling



Survey parameters

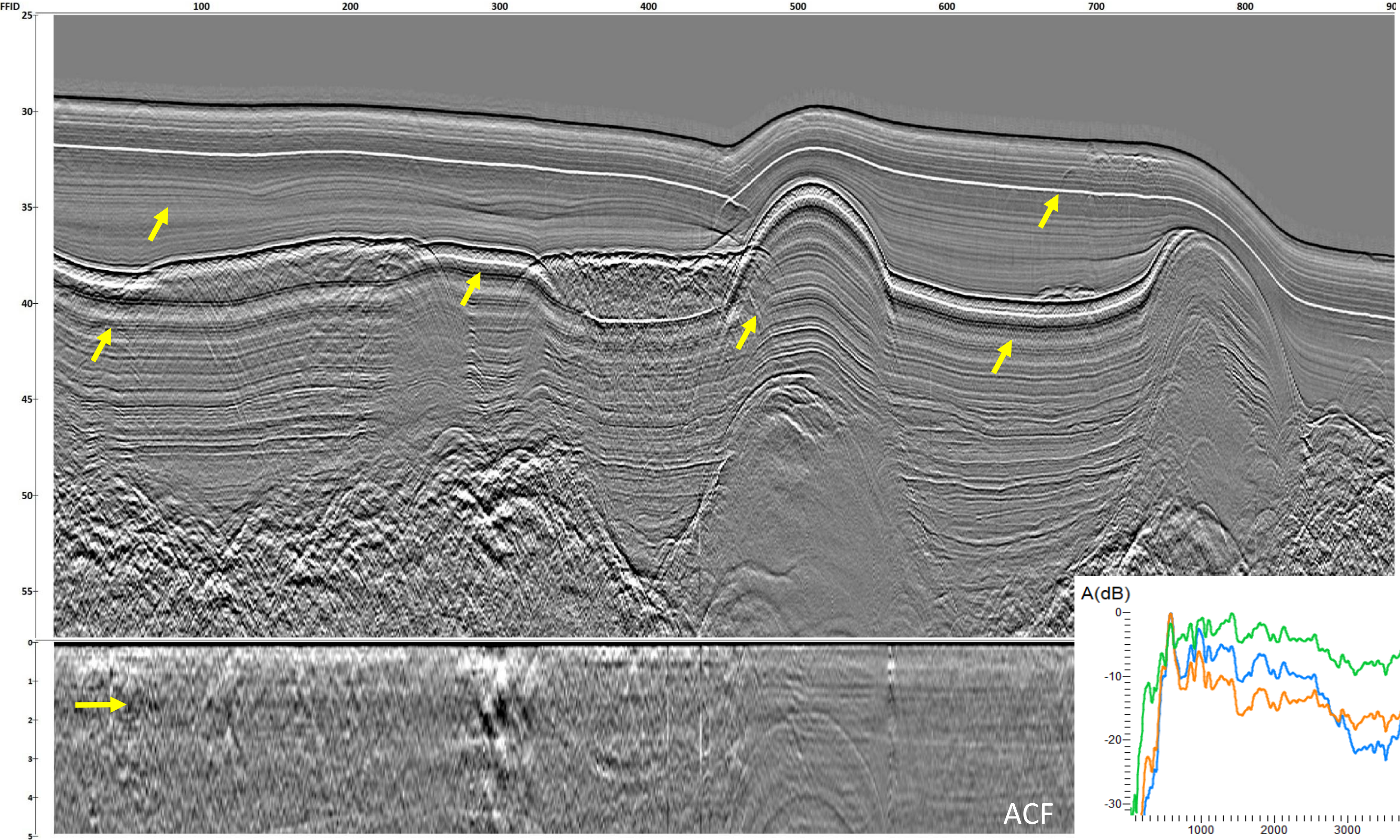
Source – G-Boomer
Streamer – HRStreamer, single channel
Water Depth – 20-30 m

Data acquired by Geodevice



Bubble oscillations removal

Seismic section after debubbling



Survey parameters

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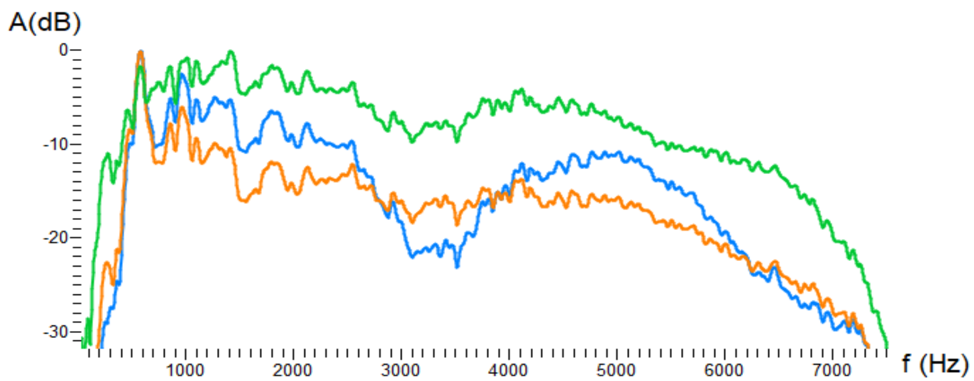
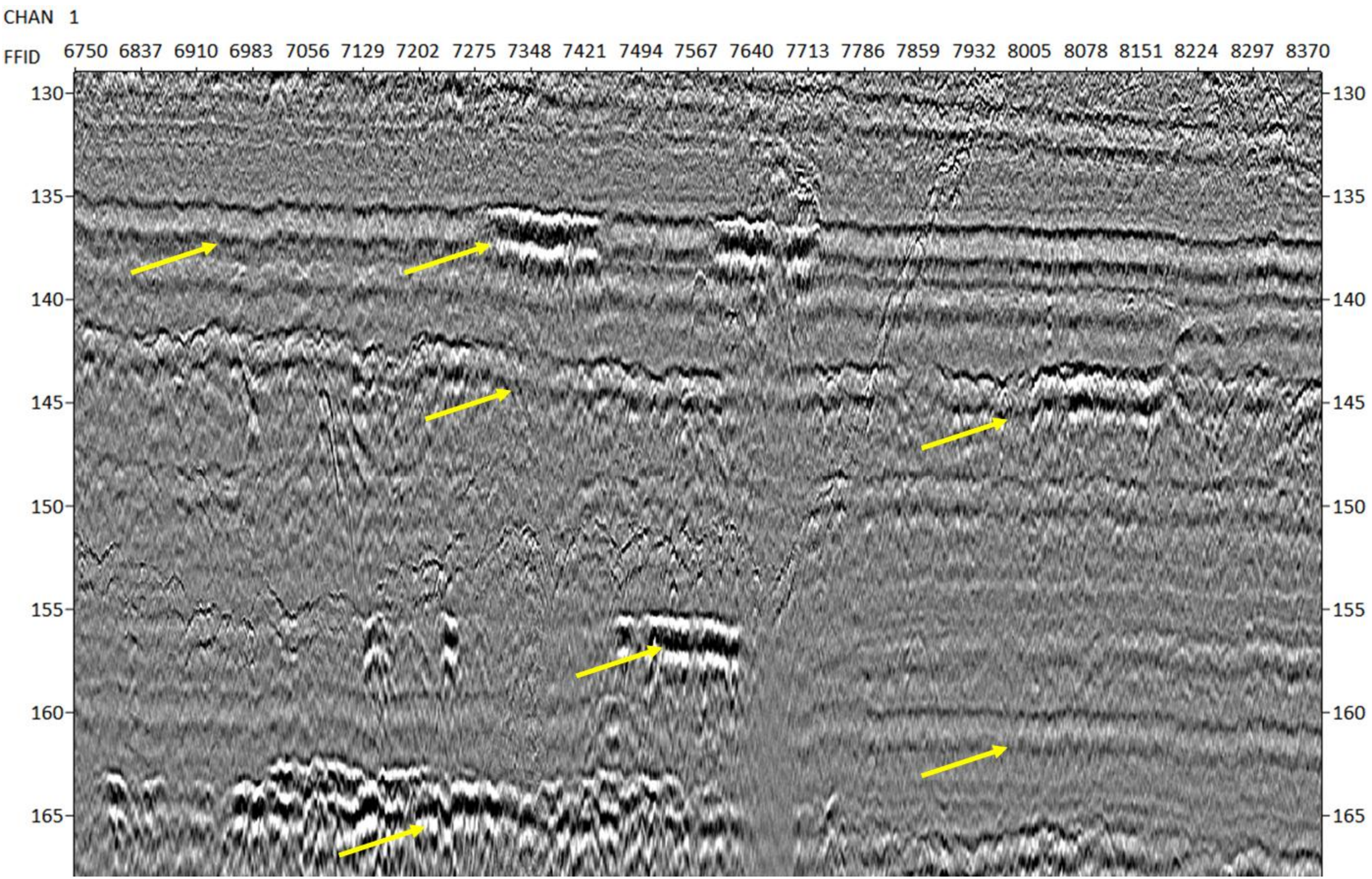
Data acquired by Geodevice



Bubble oscillations removal

Seismic section before debubbling

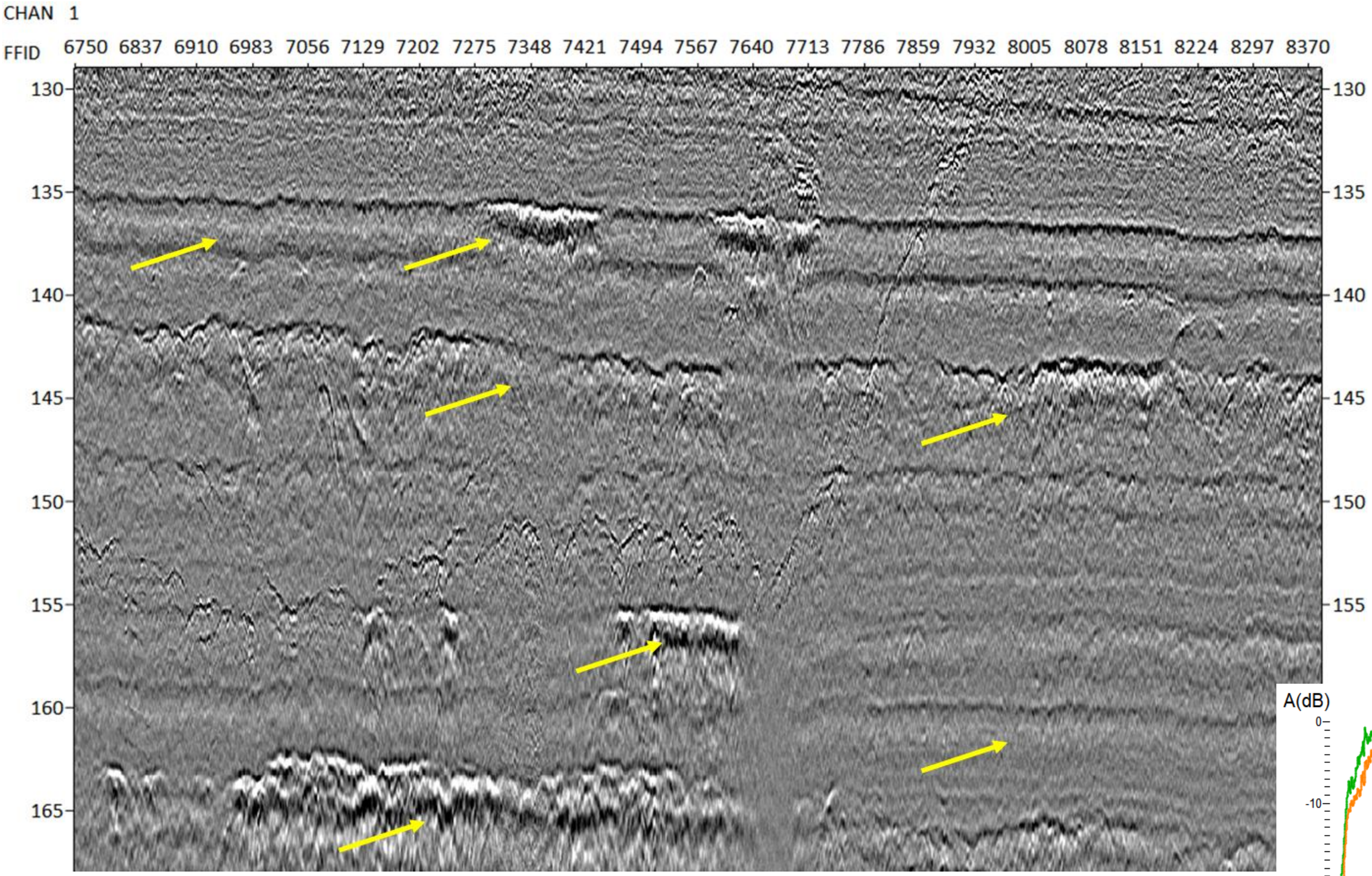


Survey parameters

Source – Fresh Water Sparker (FWS-250)
Streamer – HRStreamer, 4 channels
Water Depth – 40-60 m

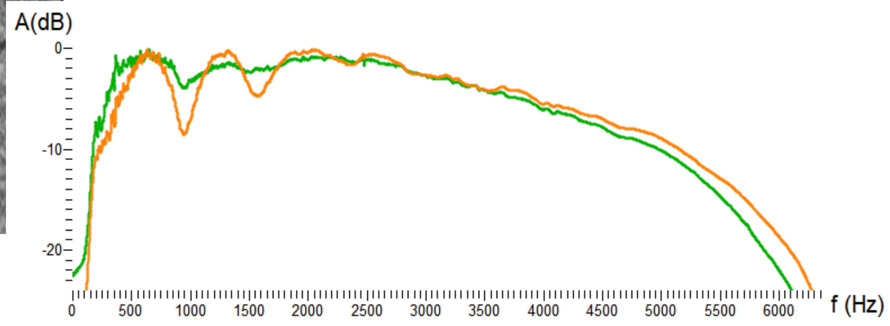
Bubble oscillations removal

Seismic section after debubbling



Survey parameters

Source – Fresh Water Sparker (FWS-250)
Streamer – HRStreamer, 4 channels
Water Depth – 40-60 m



Designature outline

- Modern HR marine seismic acquisitions use various sources for signal generation. Depending on the source type and its parameters, source signature may significantly vary.
- Resulting complicated wavelet, when convolved with the reflectivity series, significantly reduces resolution of the final image and needs to be eliminated.
- **RadExPro provides various algorithms for designature of HR seismic data to achieve high resolution of the resulting image.**

Multiple Elimination

- Sources are powerful – multiples compromise penetration

High frequencies, presented in the data result in large static differences between modelled multiple and multiple itself

Adaptive subtraction and adjusted static parameter provides good demultiple results

Available solutions:

SRME (multichannel pre-stack, adaptive subtraction in time and curvlet domains)

Zero-Offset Demultiple (single channel, post-stack)

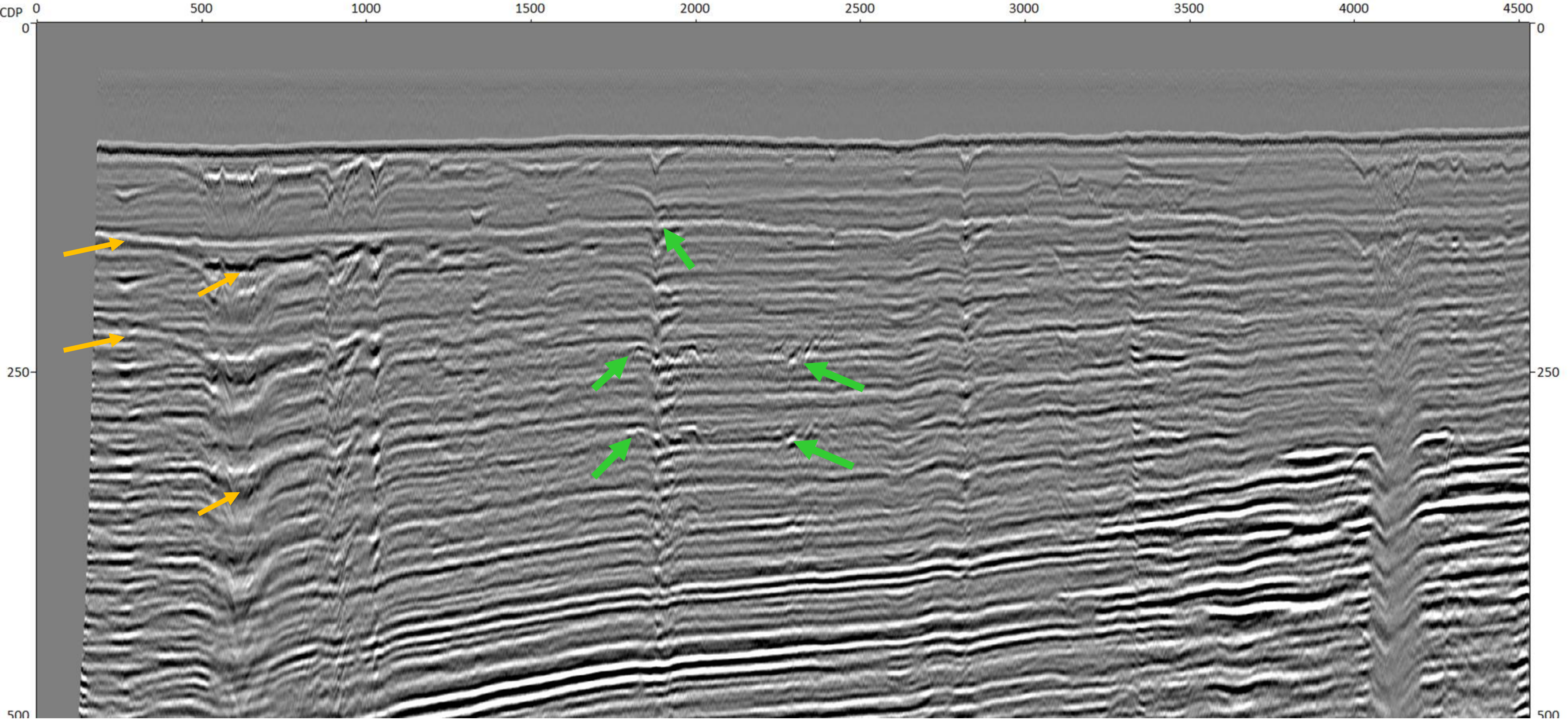
Tau-pi deconvolution

Radon demultiple

Custom algorithms (modelling and adaptive subtraction)

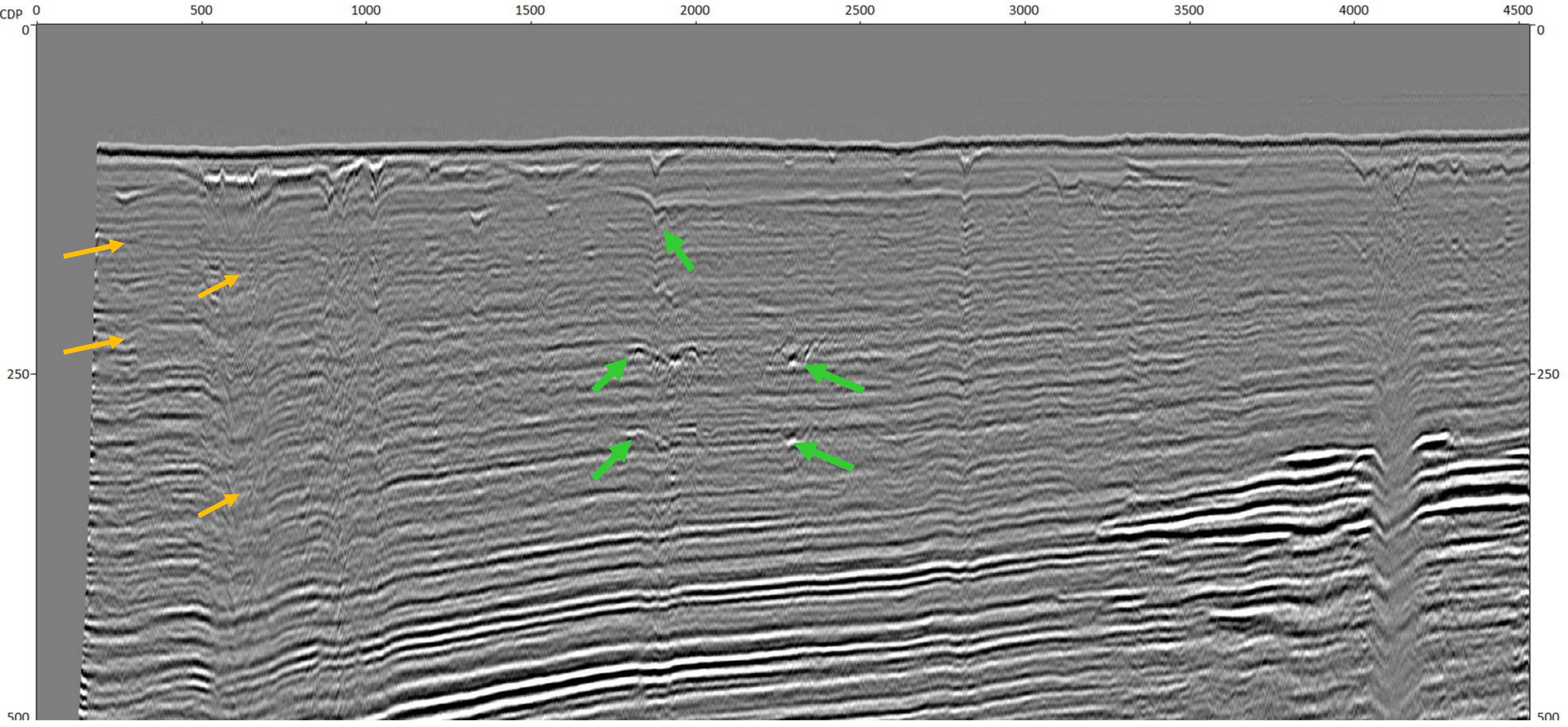
Pre-stack demultiple: SRME

Stacked seismic section – before multiple elimination



Pre-stack demultiple: SRME

Stacked seismic section – after multiple elimination



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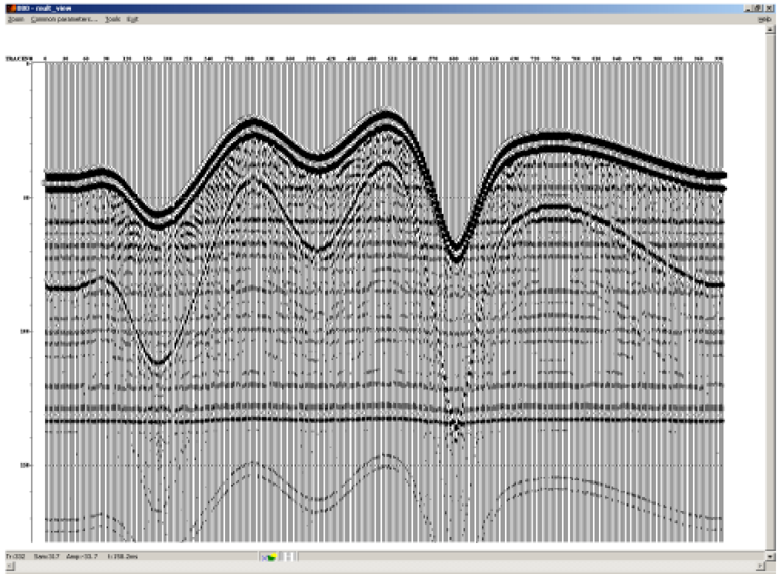
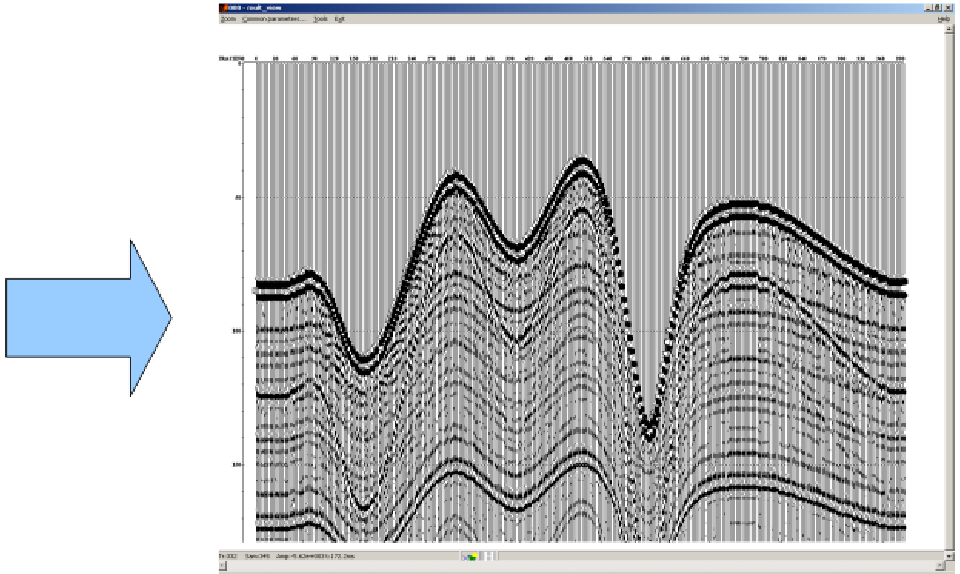
Zero-offset demultiple

A simplified SRME for zero-offset data.

1. An approximate model of multiples is generated from the data itself:
    - Static shift
    - Autoconvolution

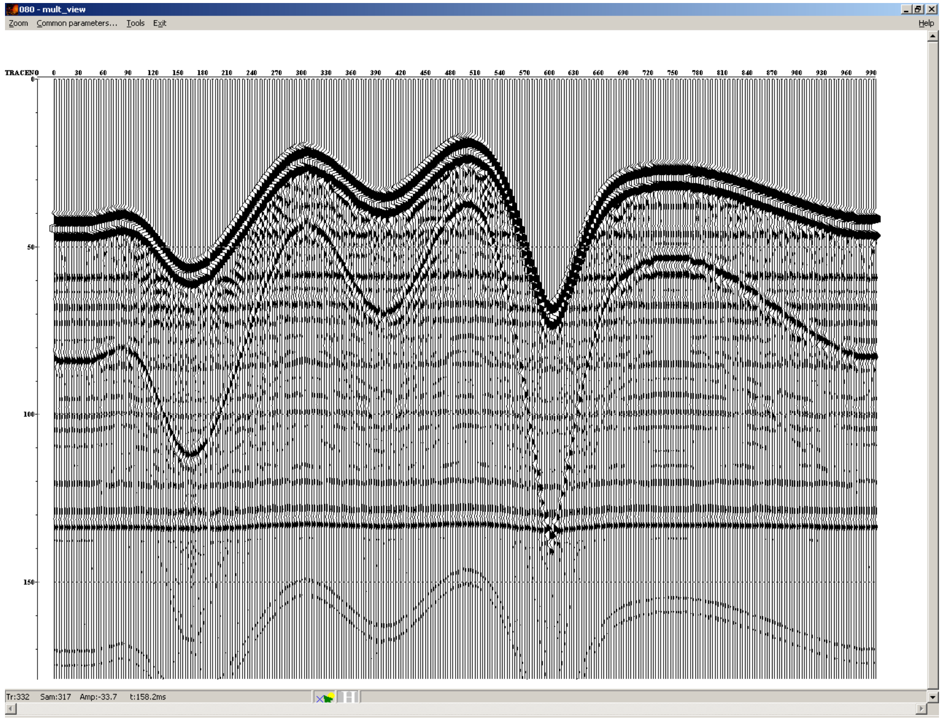


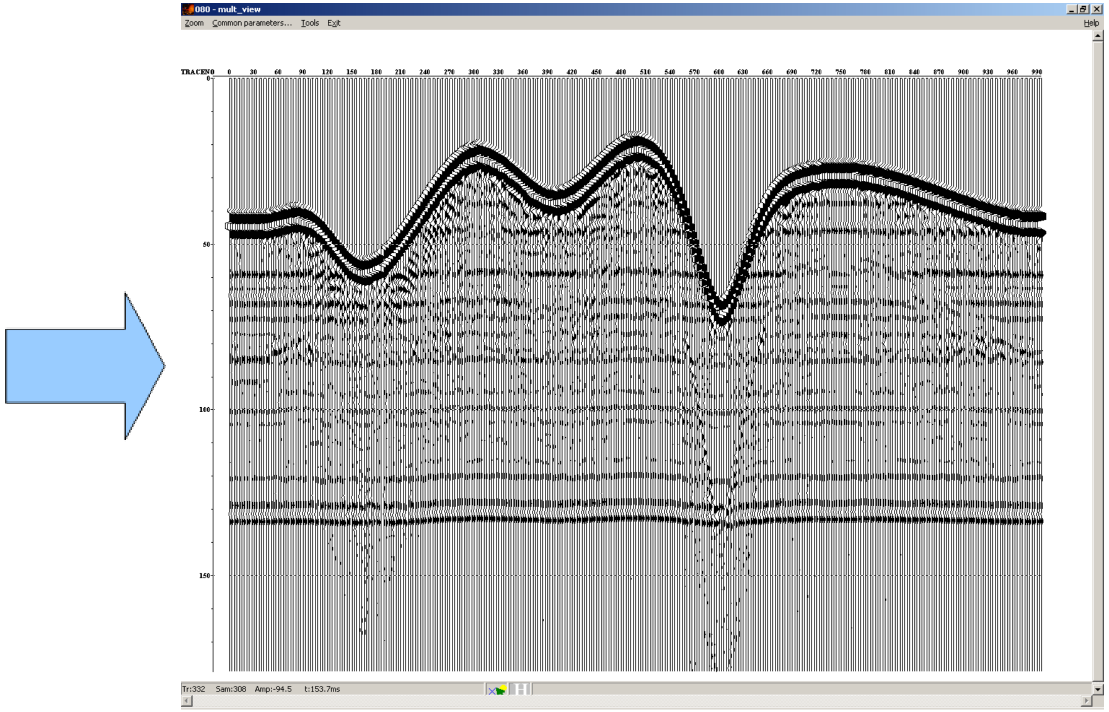


Zero-offset demultiple

A simplified SRME for zero-offset data.

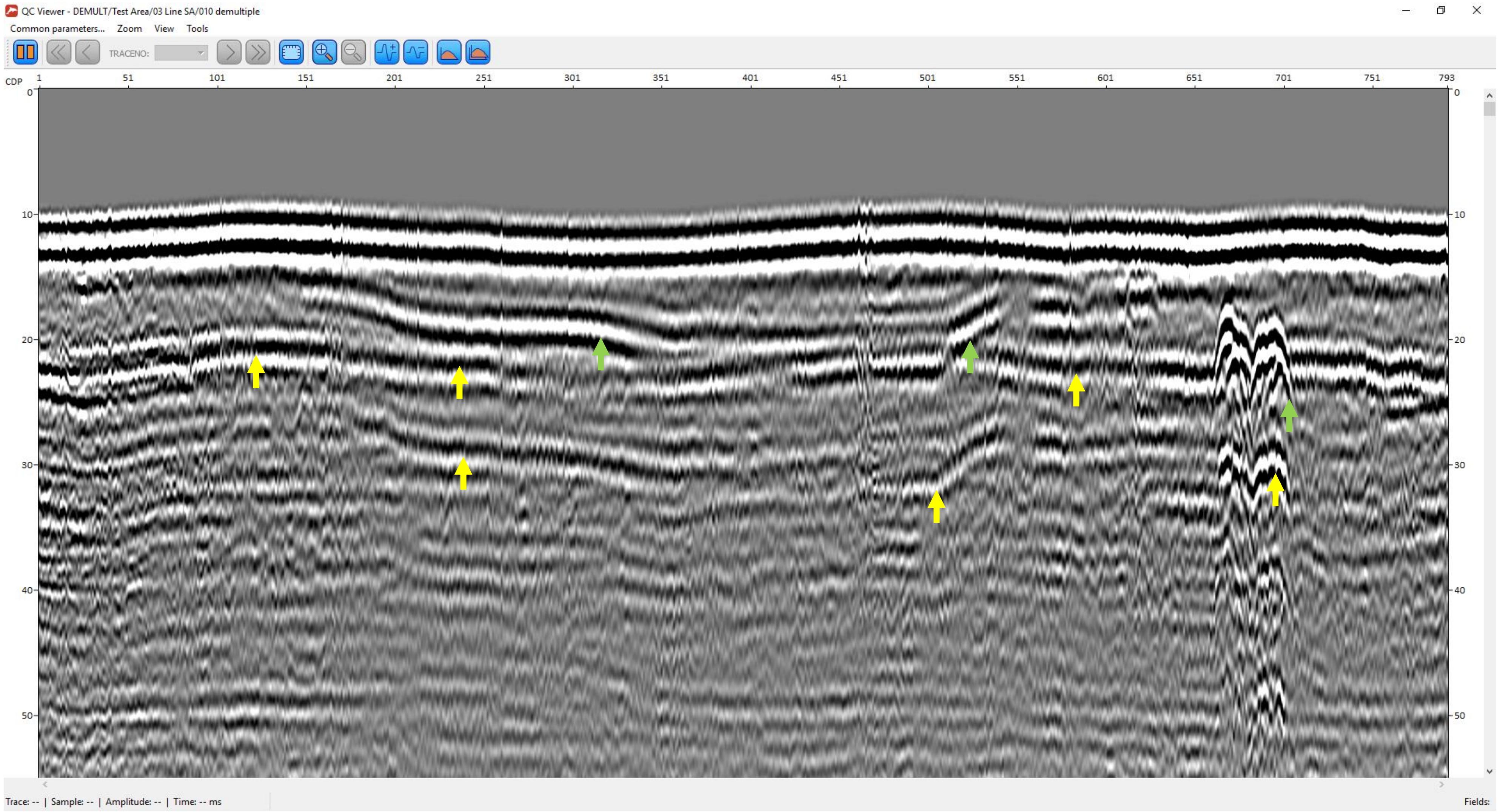
2. Model is subtracted adaptively from the data:





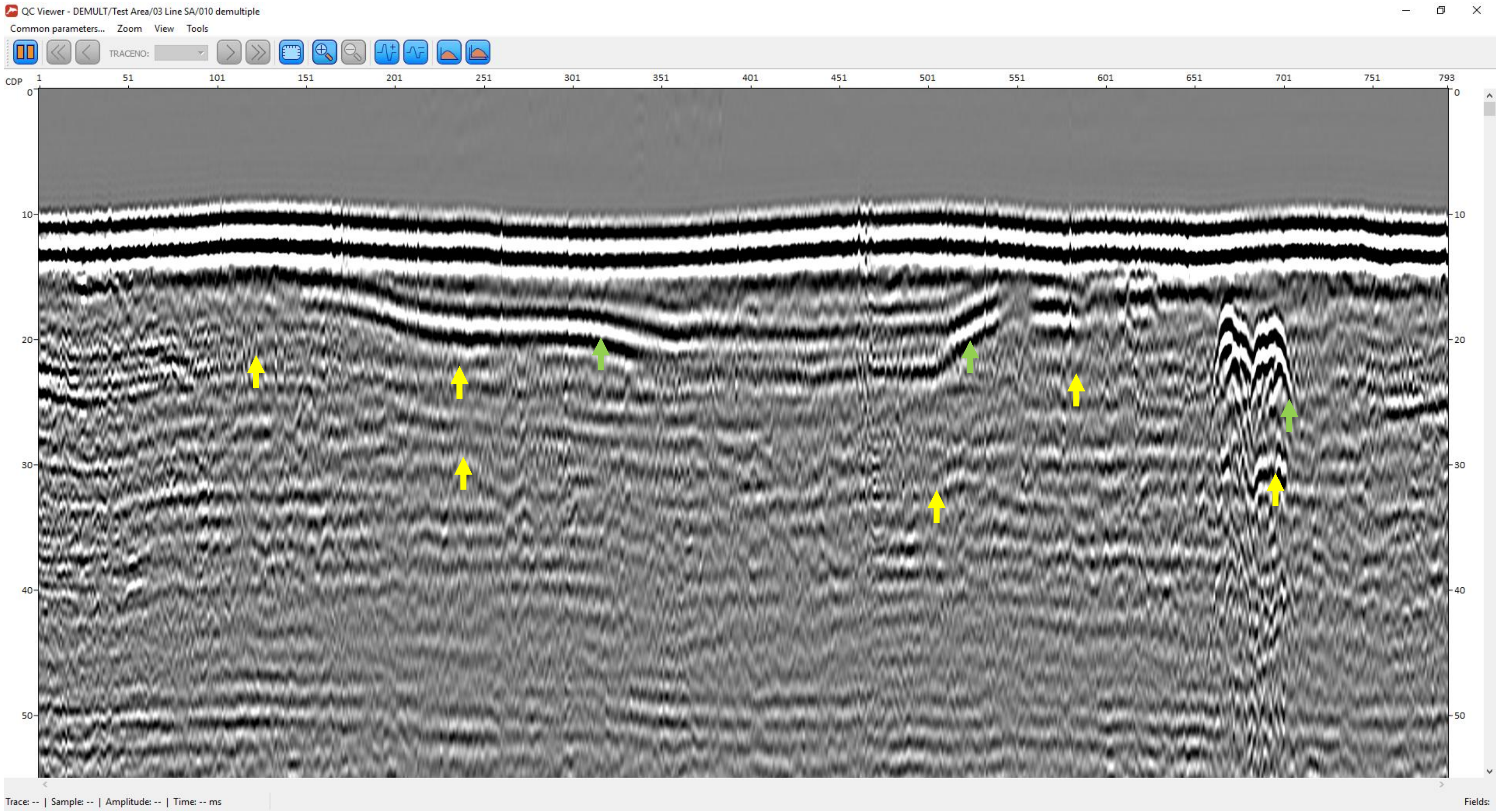
Zero-offset demultiple

Single channel boomer data – before multiple elimination



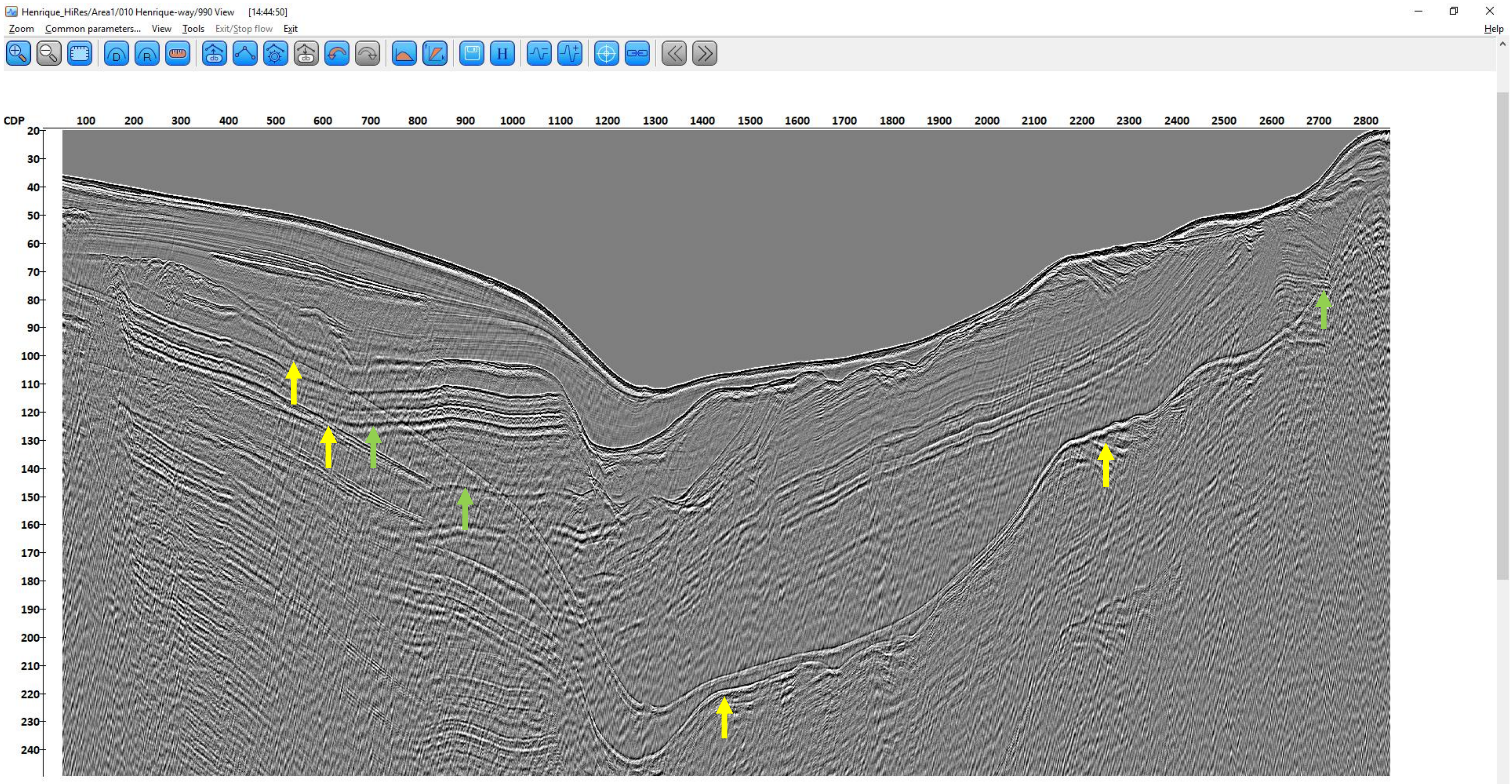
Zero-offset demultiple

Single channel boomer data – after multiple elimination



Post-stack demultiple

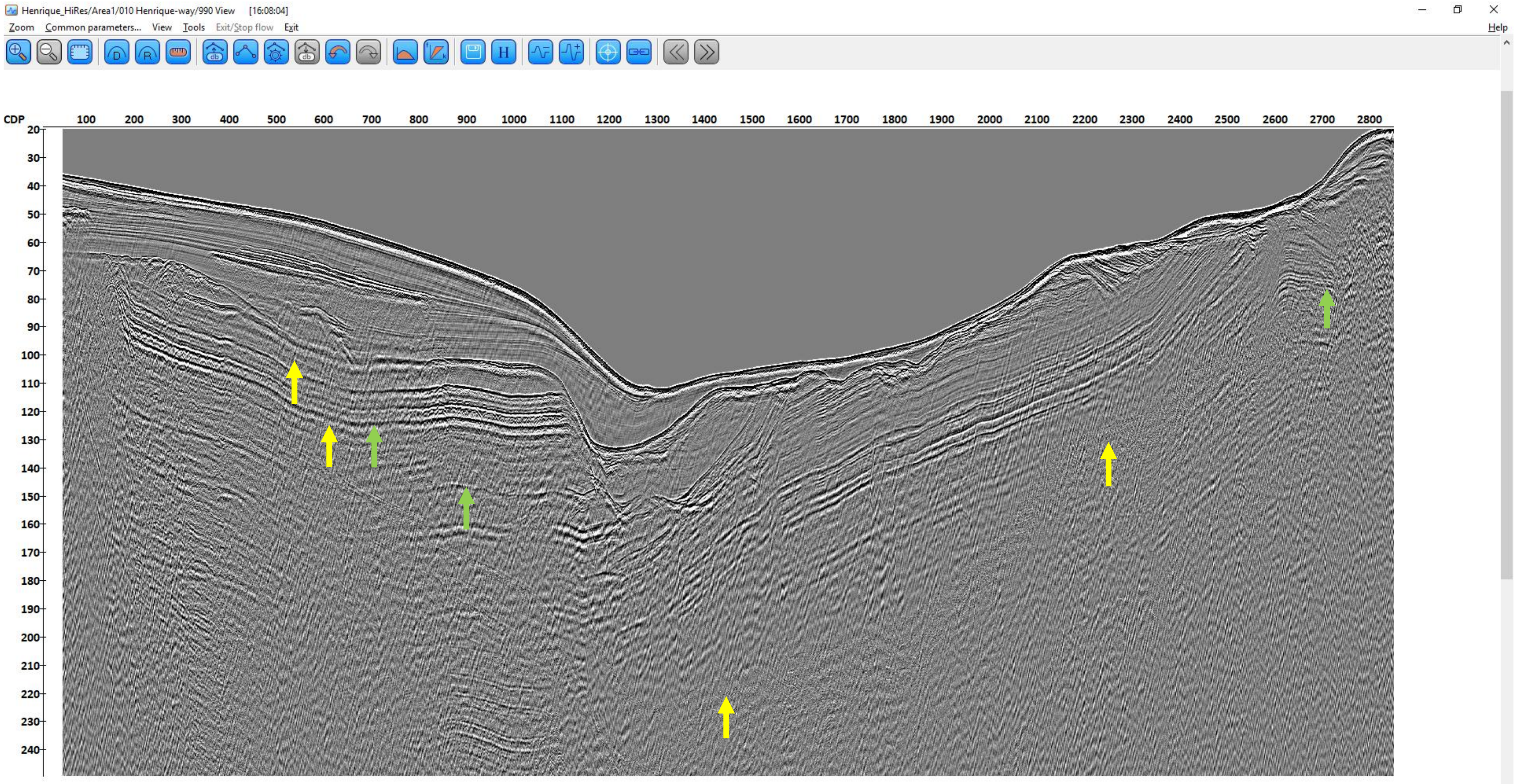
Stacked data (16 channels) – before post-stack multiple elimination



Data acquired by GEO MARINE 3D UHR system

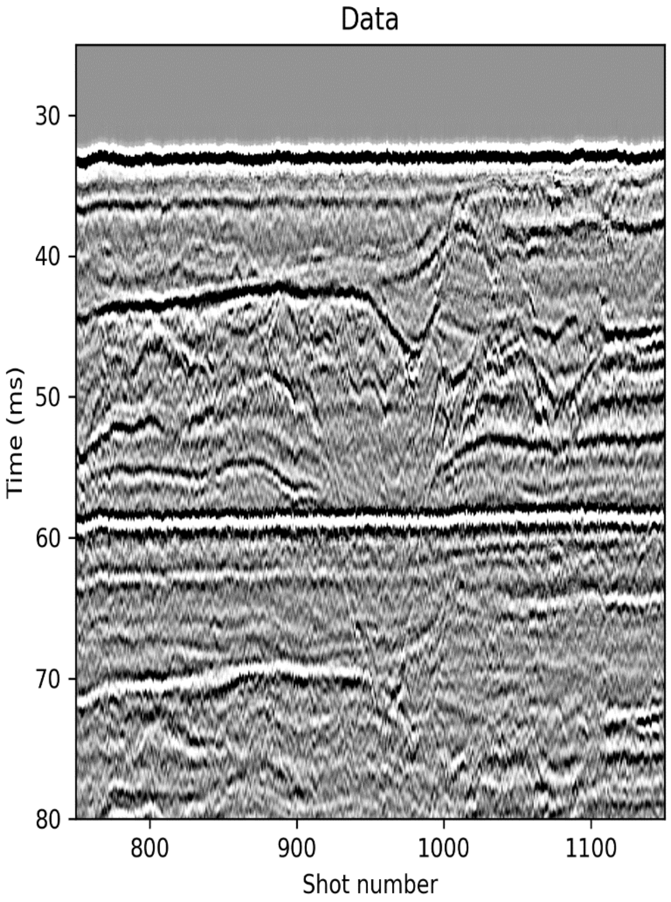
Post-stack demultiple

Stacked data (16 channels) – after post-stack multiple elimination

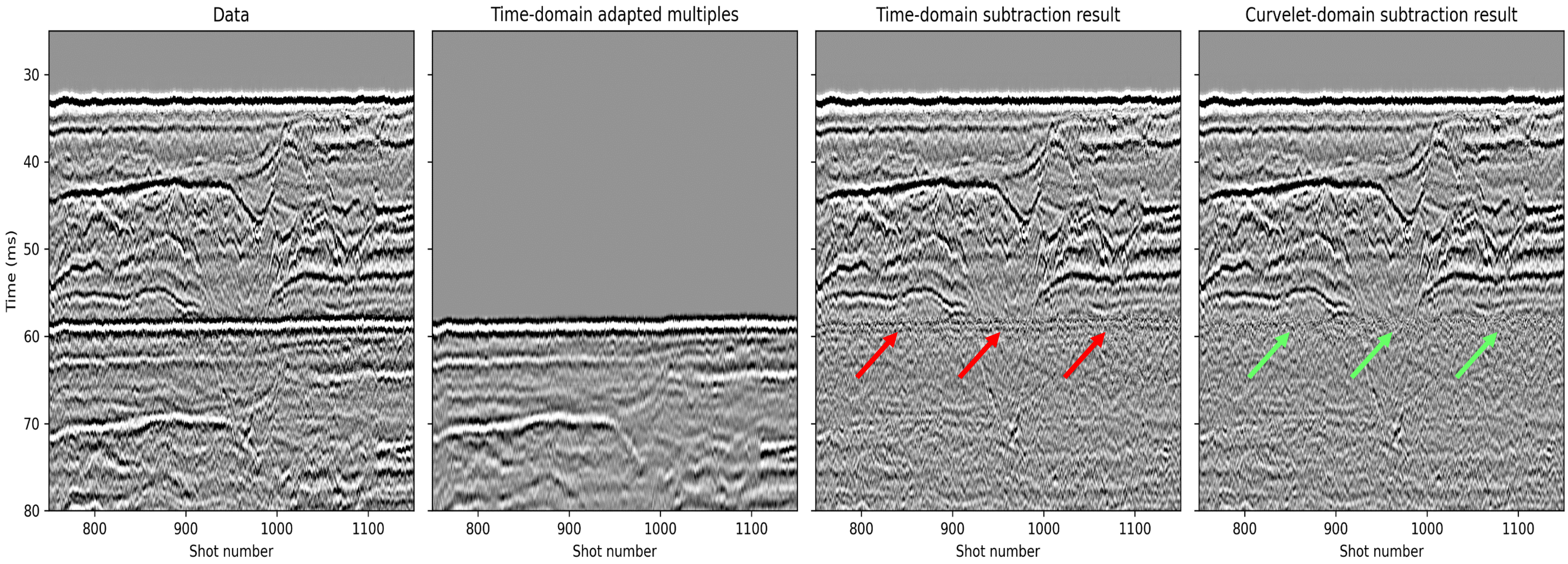


Data acquired by GEO MARINE 3D UHR system

Adaptive subtraction of multiples in time and curvlet domains



Adaptive subtraction of multiples in time and curvlet domains



3D Regularization

- Difficulty maintaining a stable course at slow towing speeds – irregular CMP coverage in 3D acquisition

Sea and ocean currents as well as other obstacles (GPS positioning) often result in gaps in CDP coverage

Non-equal offset distribution results in footprints on time slices

Available solutions:

3D Regularization

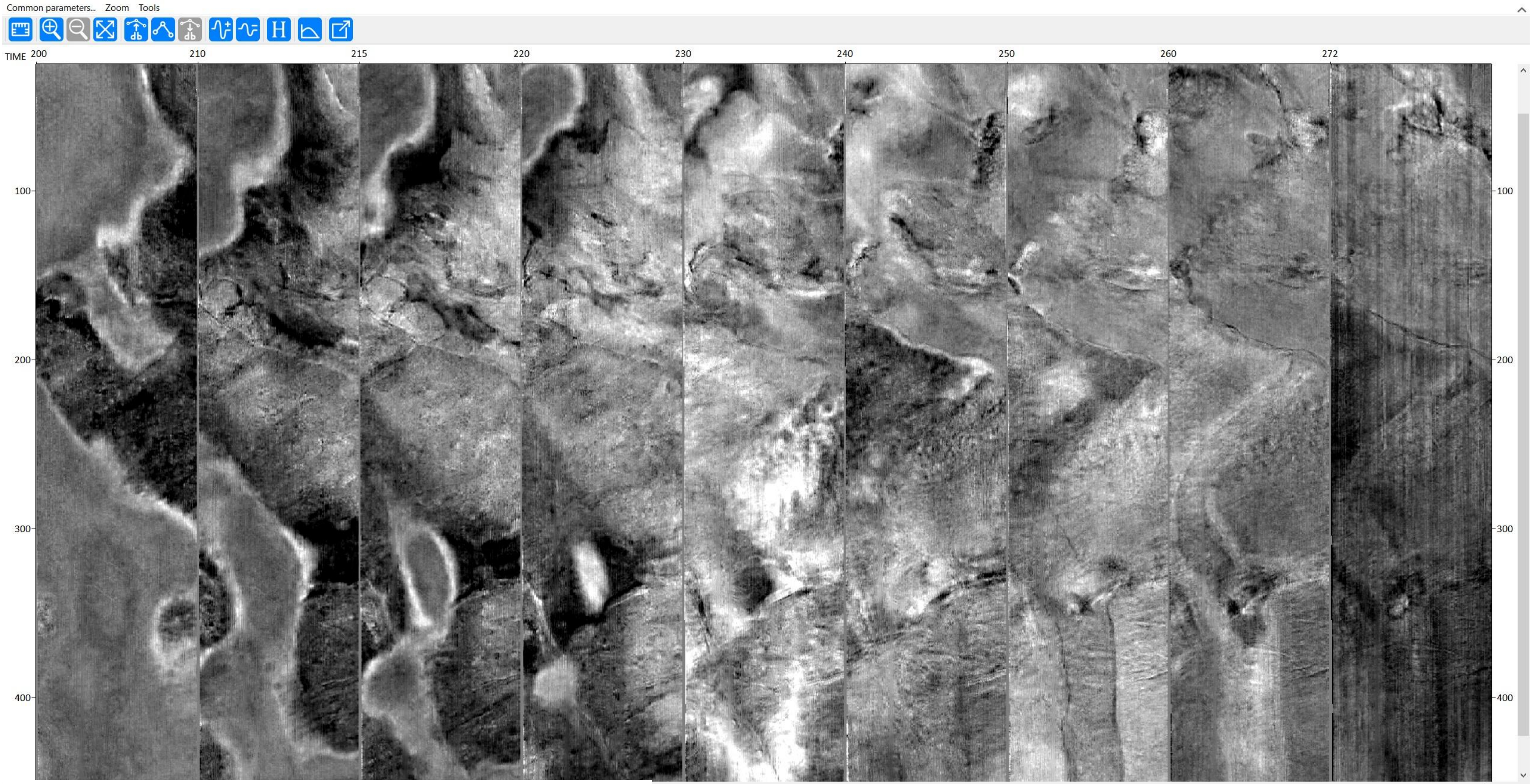
3D Regularization

Time slices before regularization

3D survey, flip-flop airguns + slanted streamers

3D Regularization

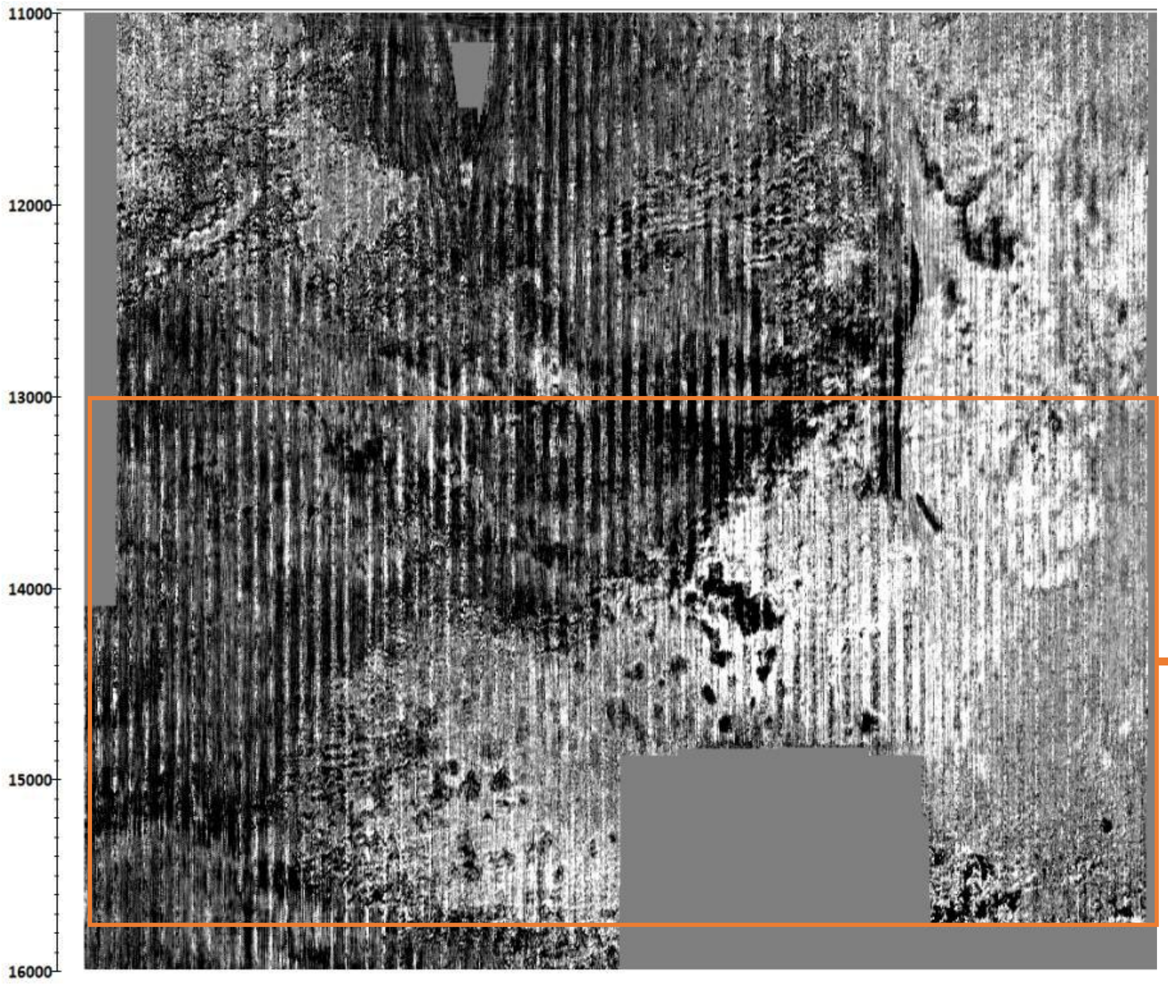
Time slices after regularization

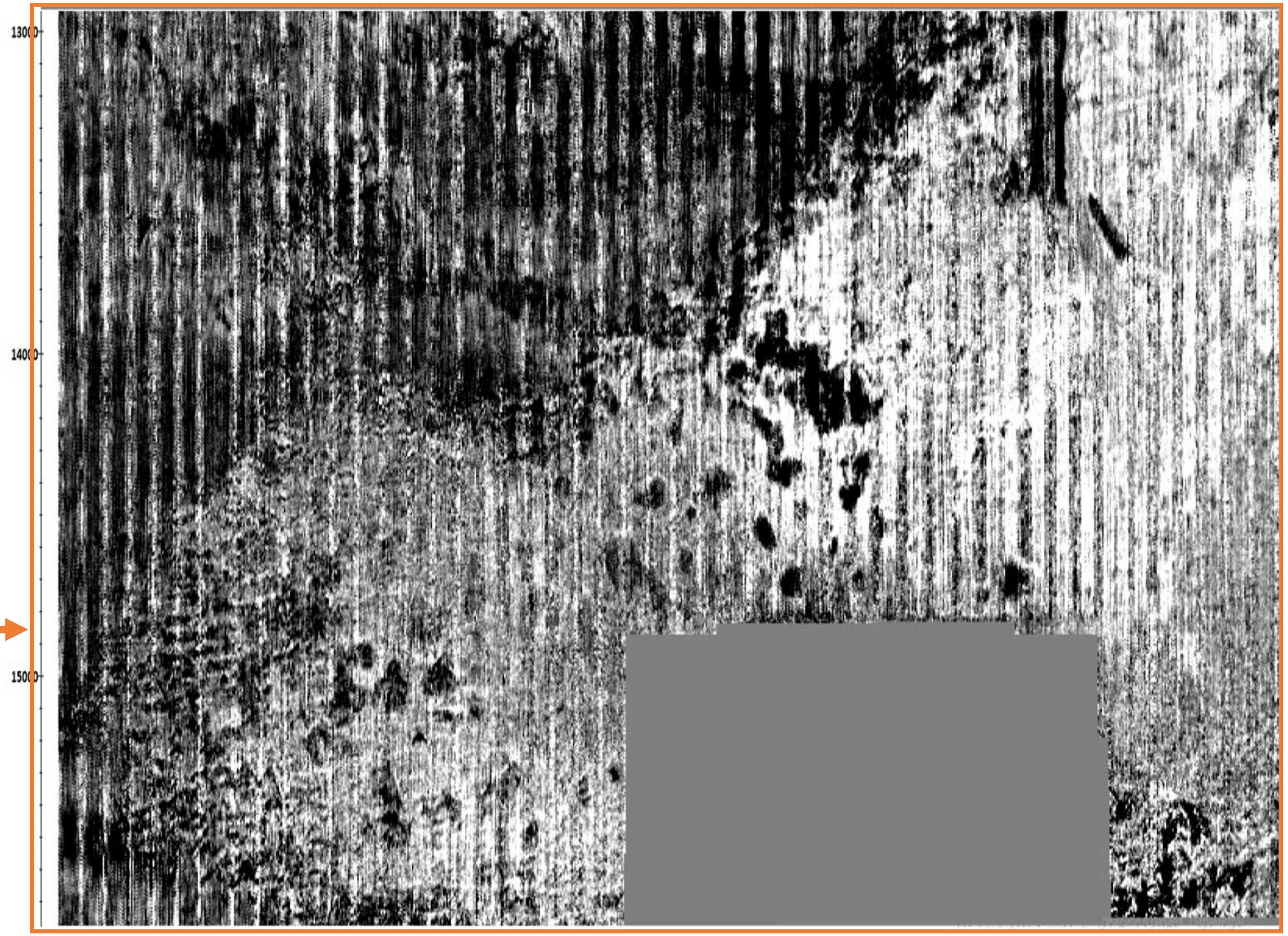


3D survey, flip-flop airguns + slanted streamers

Footprints attenuation

Time slices (100 ms) – before FPA

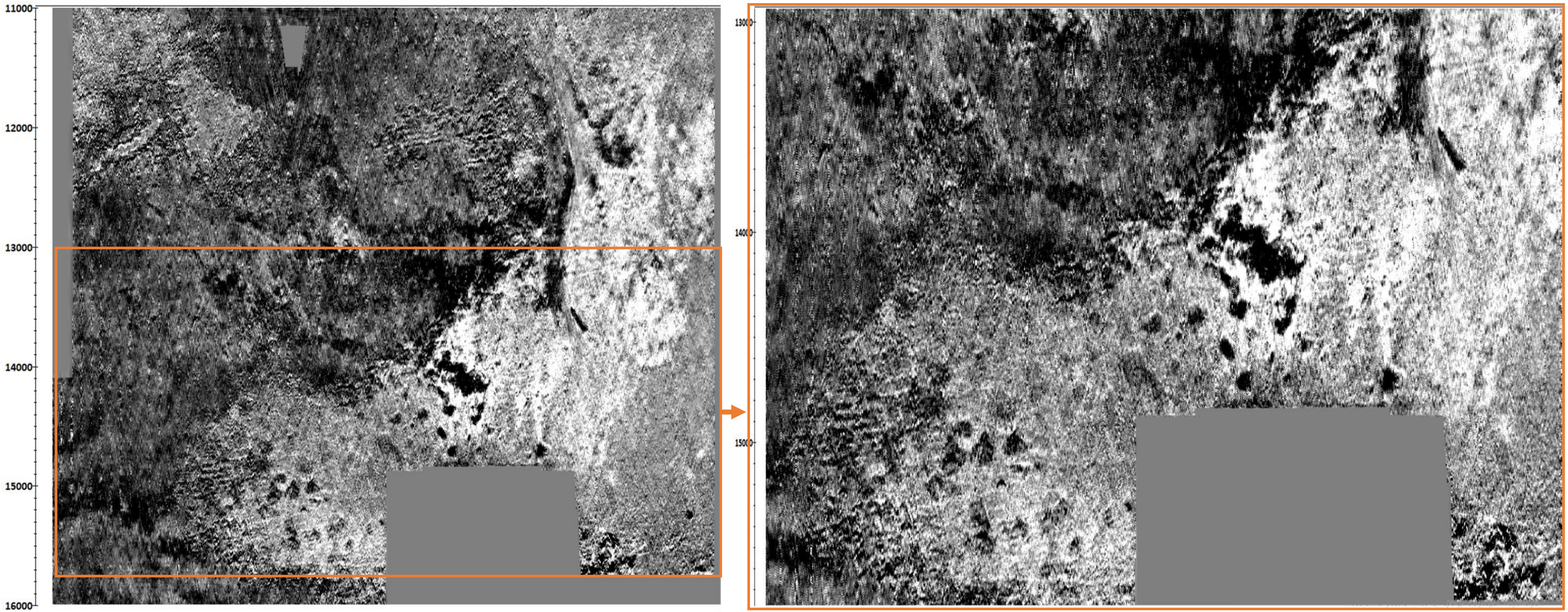




Large scale seismic for shallow imaging purposes

Footprints attenuation

Time slices (100 ms) – after FPA



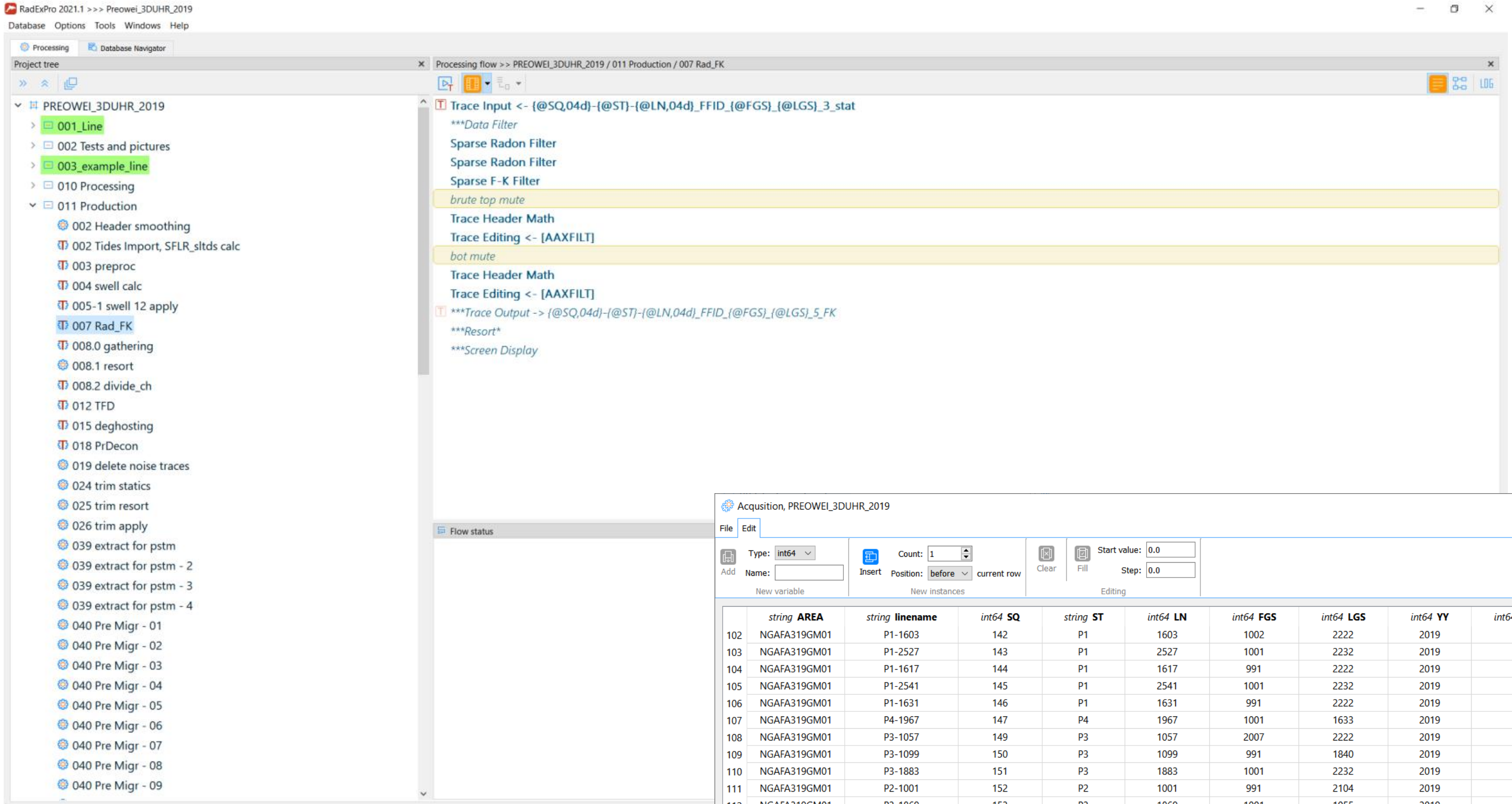
Large scale seismic for shallow imaging purposes

User-friendly interface, replica tables and queues for efficient production mode processing

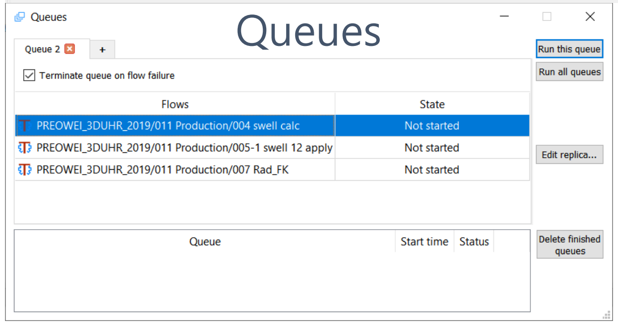
Replica tables – increased productivity

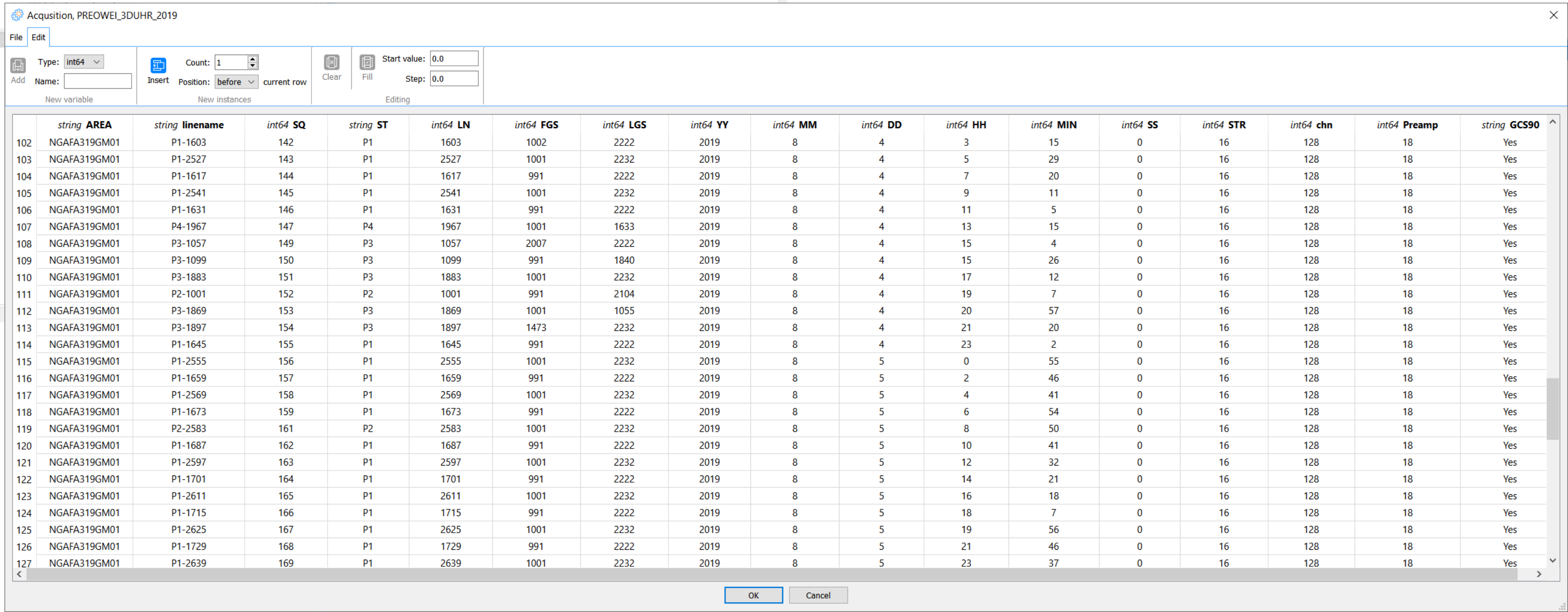
Reduces time

Reduces man-made errors



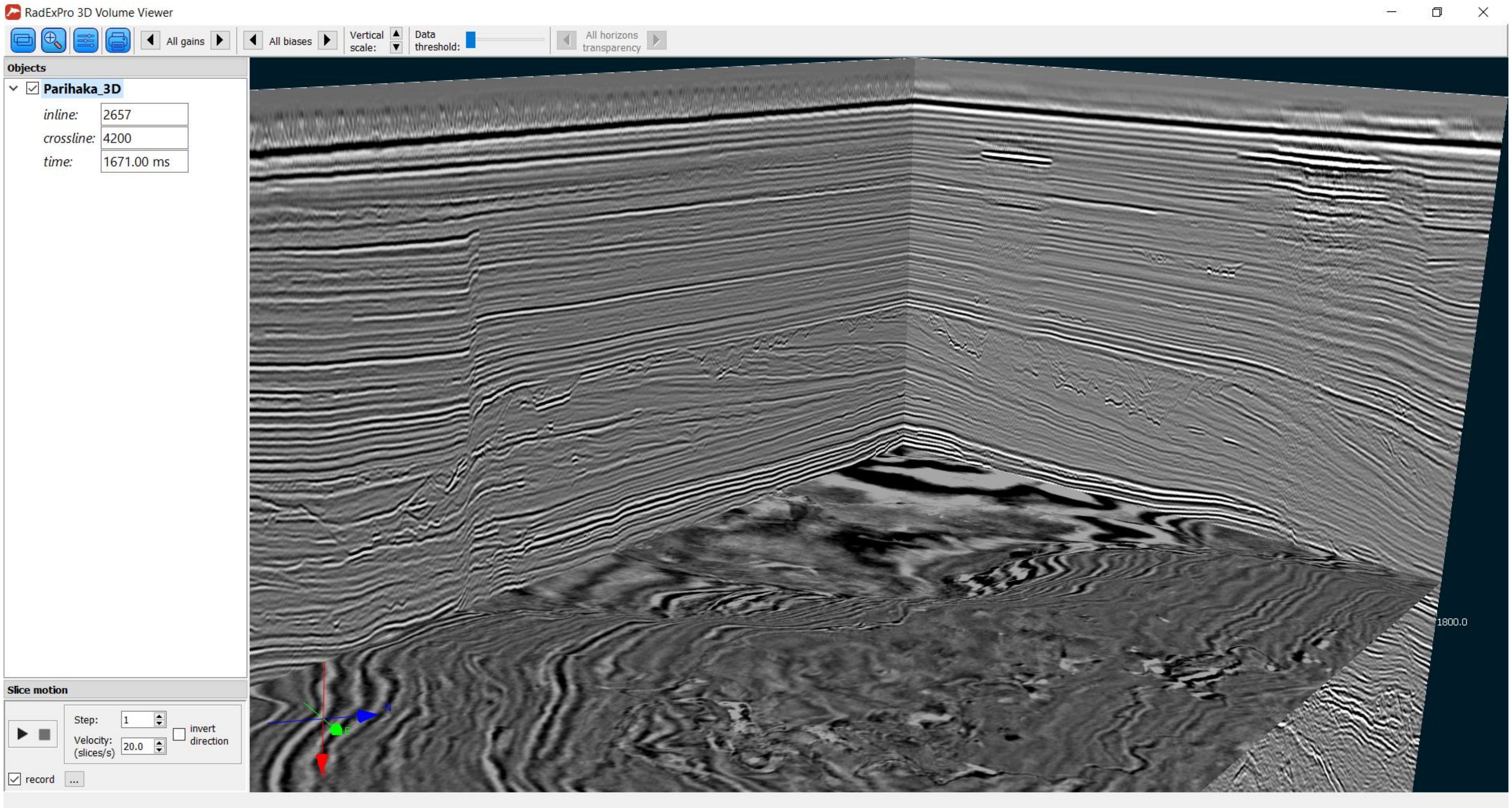
Queues





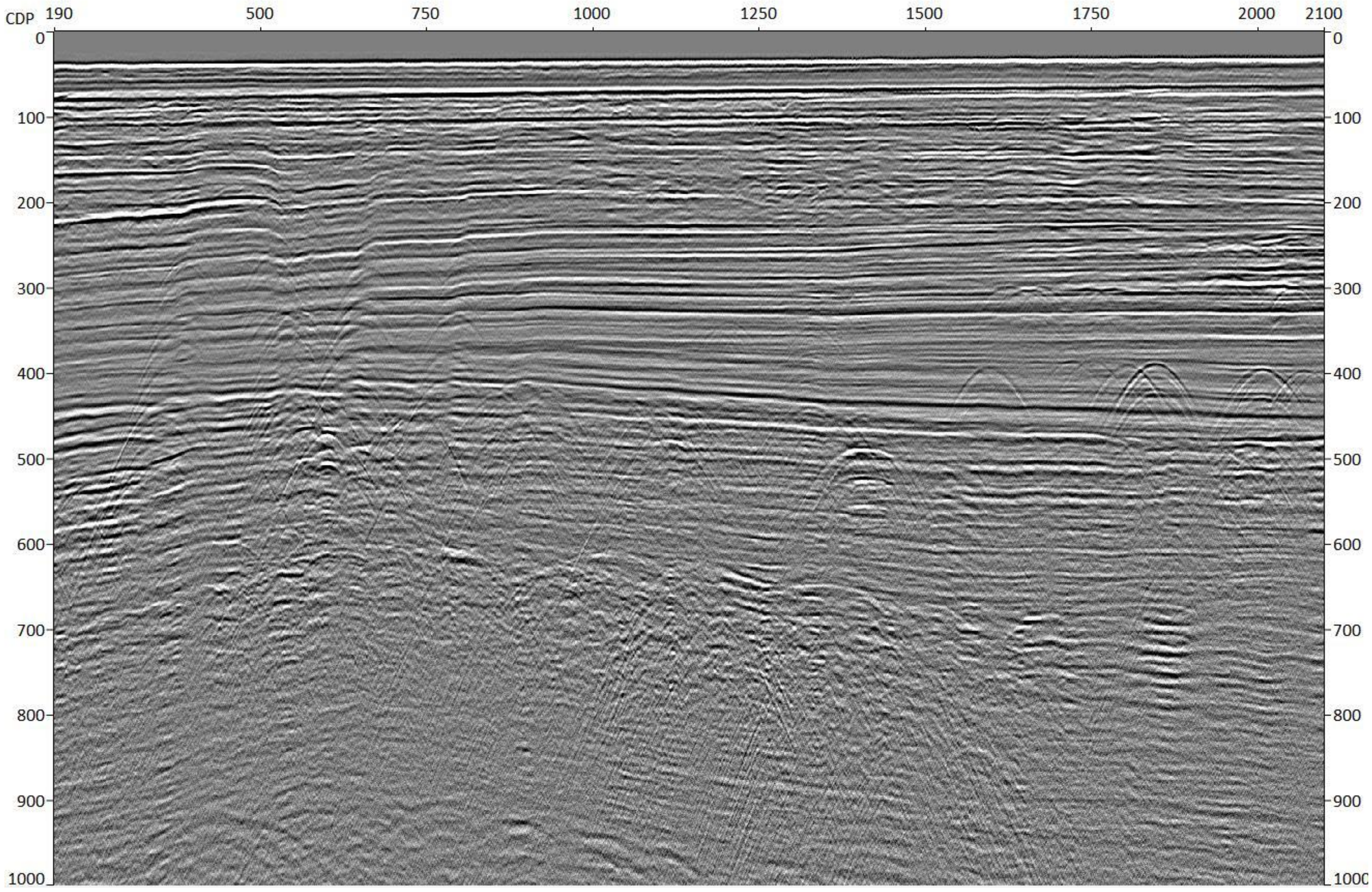
	string AREA	string linename	int64 SQ	string ST	int64 LN	int64 FGS	int64 LGS	int64 YY	int64 MM	int64 DD	int64 HH	int64 MIN	int64 SS	int64 STR	int64 chn	int64 Preamp	string GCS90
102	NGAFA319GM01	P1-1603	142	P1	1603	1002	2222	2019	8	4	3	15	0	16	128	18	Yes
103	NGAFA319GM01	P1-2527	143	P1	2527	1001	2232	2019	8	4	5	29	0	16	128	18	Yes
104	NGAFA319GM01	P1-1617	144	P1	1617	991	2222	2019	8	4	7	20	0	16	128	18	Yes
105	NGAFA319GM01	P1-2541	145	P1	2541	1001	2232	2019	8	4	9	11	0	16	128	18	Yes
106	NGAFA319GM01	P1-1631	146	P1	1631	991	2222	2019	8	4	11	5	0	16	128	18	Yes
107	NGAFA319GM01	P4-1967	147	P4	1967	1001	1633	2019	8	4	13	15	0	16	128	18	Yes
108	NGAFA319GM01	P3-1057	149	P3	1057	2007	2222	2019	8	4	15	4	0	16	128	18	Yes
109	NGAFA319GM01	P3-1099	150	P3	1099	991	1840	2019	8	4	15	26	0	16	128	18	Yes
110	NGAFA319GM01	P3-1883	151	P3	1883	1001	2232	2019	8	4	17	12	0	16	128	18	Yes
111	NGAFA319GM01	P2-1001	152	P2	1001	991	2104	2019	8	4	19	7	0	16	128	18	Yes
112	NGAFA319GM01	P3-1869	153	P3	1869	1001	1055	2019	8	4	20	57	0	16	128	18	Yes
113	NGAFA319GM01	P3-1897	154	P3	1897	1473	2232	2019	8	4	21	20	0	16	128	18	Yes
114	NGAFA319GM01	P1-1645	155	P1	1645	991	2222	2019	8	4	23	2	0	16	128	18	Yes
115	NGAFA319GM01	P1-2555	156	P1	2555	1001	2232	2019	8	5	0	55	0	16	128	18	Yes
116	NGAFA319GM01	P1-1659	157	P1	1659	991	2222	2019	8	5	2	46	0	16	128	18	Yes
117	NGAFA319GM01	P1-2569	158	P1	2569	1001	2232	2019	8	5	4	41	0	16	128	18	Yes
118	NGAFA319GM01	P1-1673	159	P1	1673	991	2222	2019	8	5	6	54	0	16	128	18	Yes
119	NGAFA319GM01	P2-2583	161	P2	2583	1001	2232	2019	8	5	8	50	0	16	128	18	Yes
120	NGAFA319GM01	P1-1687	162	P1	1687	991	2222	2019	8	5	10	41	0	16	128	18	Yes
121	NGAFA319GM01	P1-2597	163	P1	2597	1001	2232	2019	8	5	12	32	0	16	128	18	Yes
122	NGAFA319GM01	P1-1701	164	P1	1701	991	2222	2019	8	5	14	21	0	16	128	18	Yes
123	NGAFA319GM01	P1-2611	165	P1	2611	1001	2232	2019	8	5	16	18	0	16	128	18	Yes
124	NGAFA319GM01	P1-1715	166	P1	1715	991	2222	2019	8	5	18	7	0	16	128	18	Yes
125	NGAFA319GM01	P1-2625	167	P1	2625	1001	2232	2019	8	5	19	56	0	16	128	18	Yes
126	NGAFA319GM01	P1-1729	168	P1	1729	991	2222	2019	8	5	21	46	0	16	128	18	Yes
127	NGAFA319GM01	P1-2639	169	P1	2639	1001	2232	2019	8	5	23	37	0	16	128	18	Yes

3D visualization

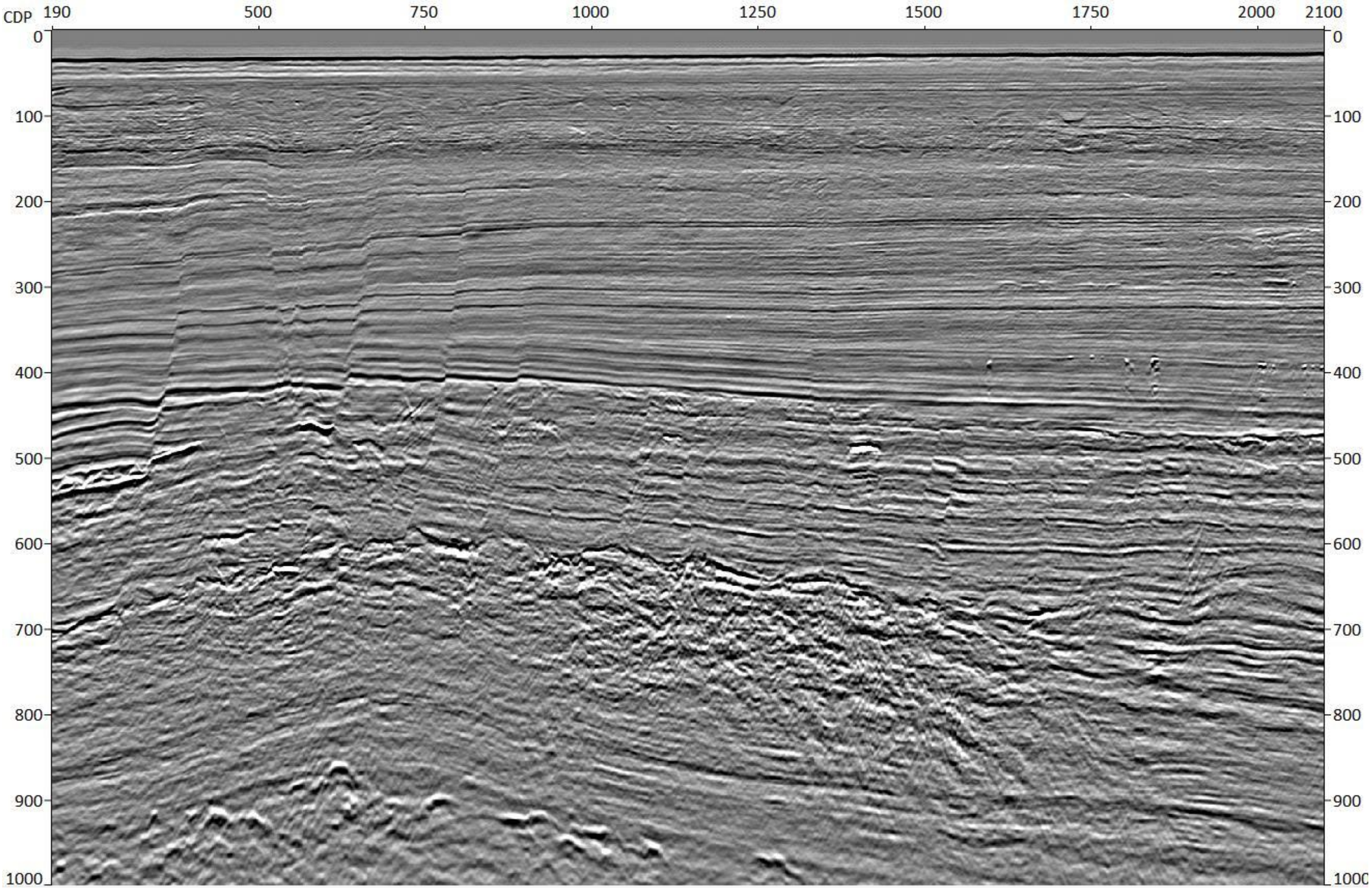


Some other examples

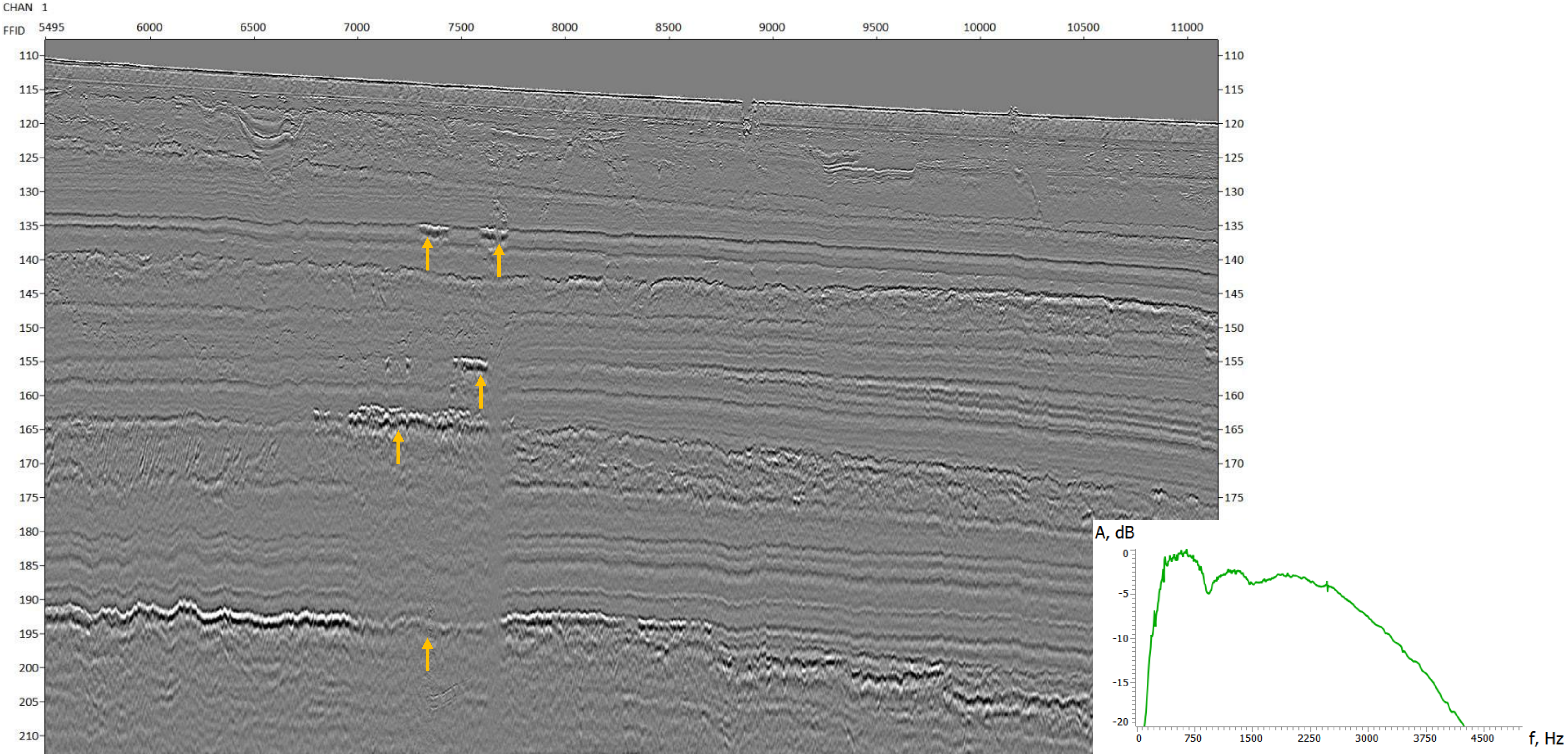
Stacked seismic section after denoising



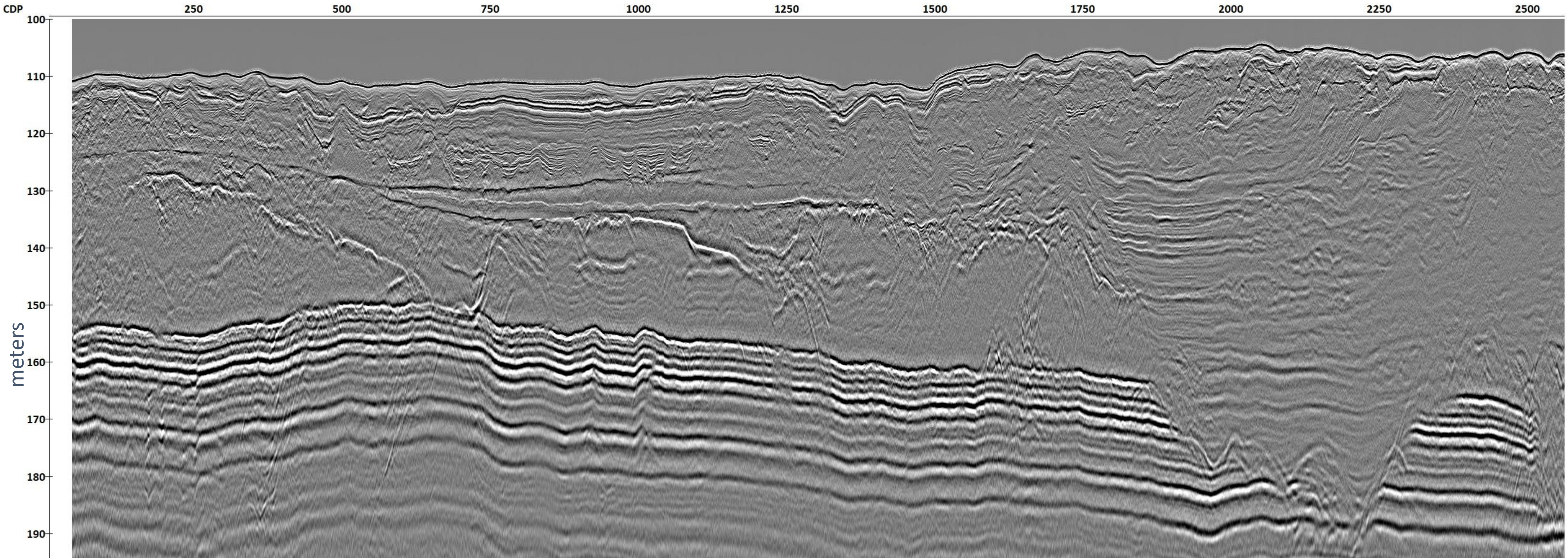
Stacked seismic section – after SRME+deghosting+PSTKM

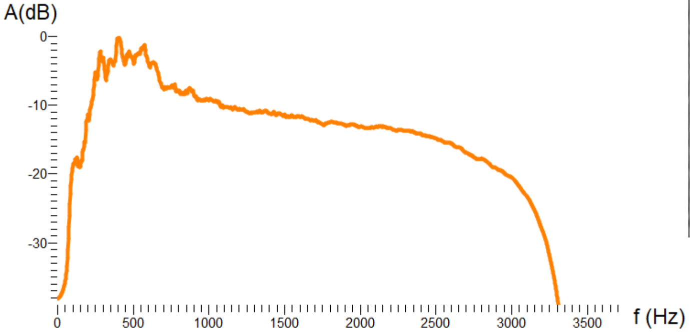


Geohazard assessment – shallow gas zones



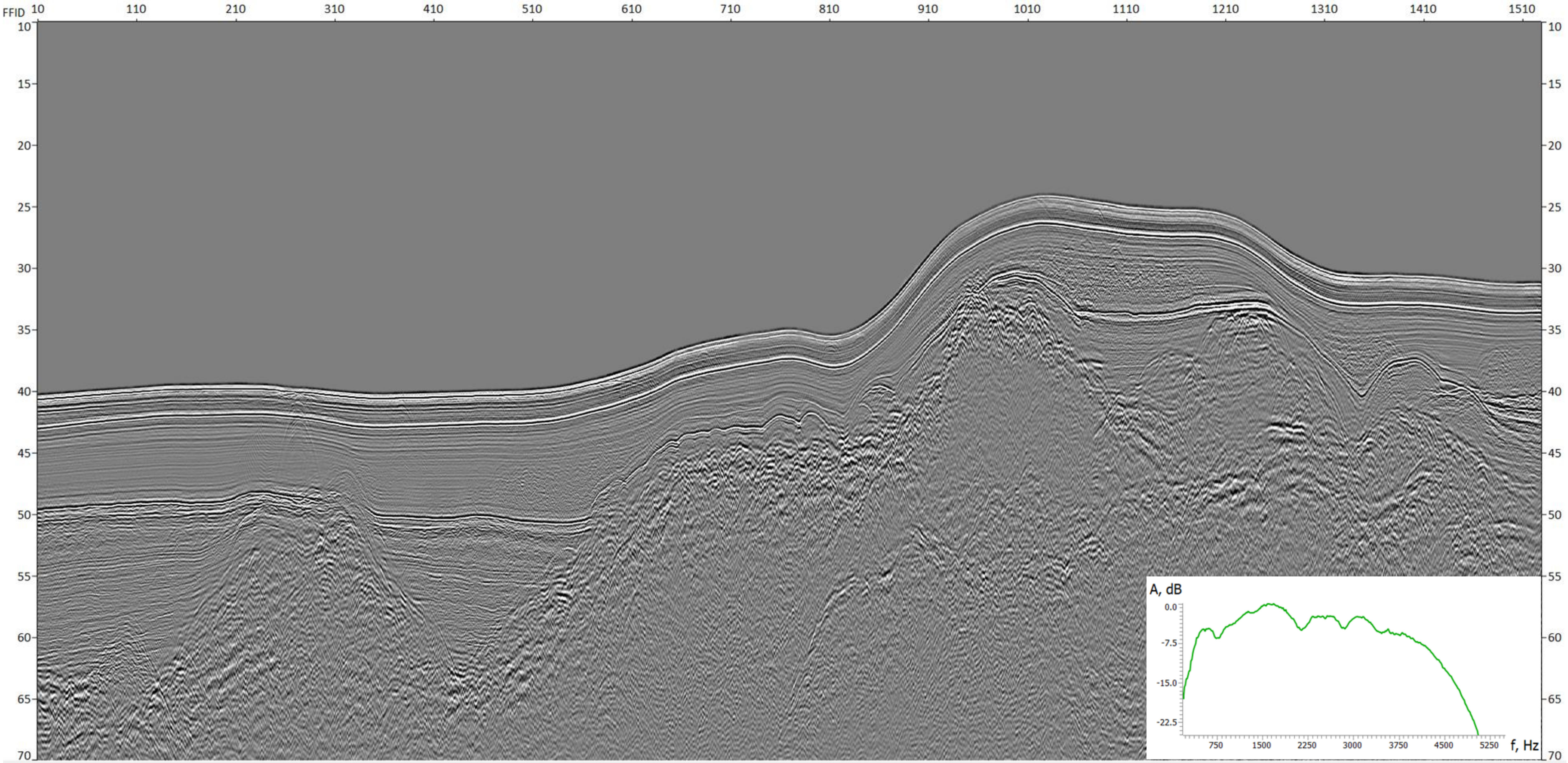
Geohazard assessment – paleo channels in the Kara Sea





Source – multilevel sparker, developed by Geodevice, processed in RadExPro Seismic software

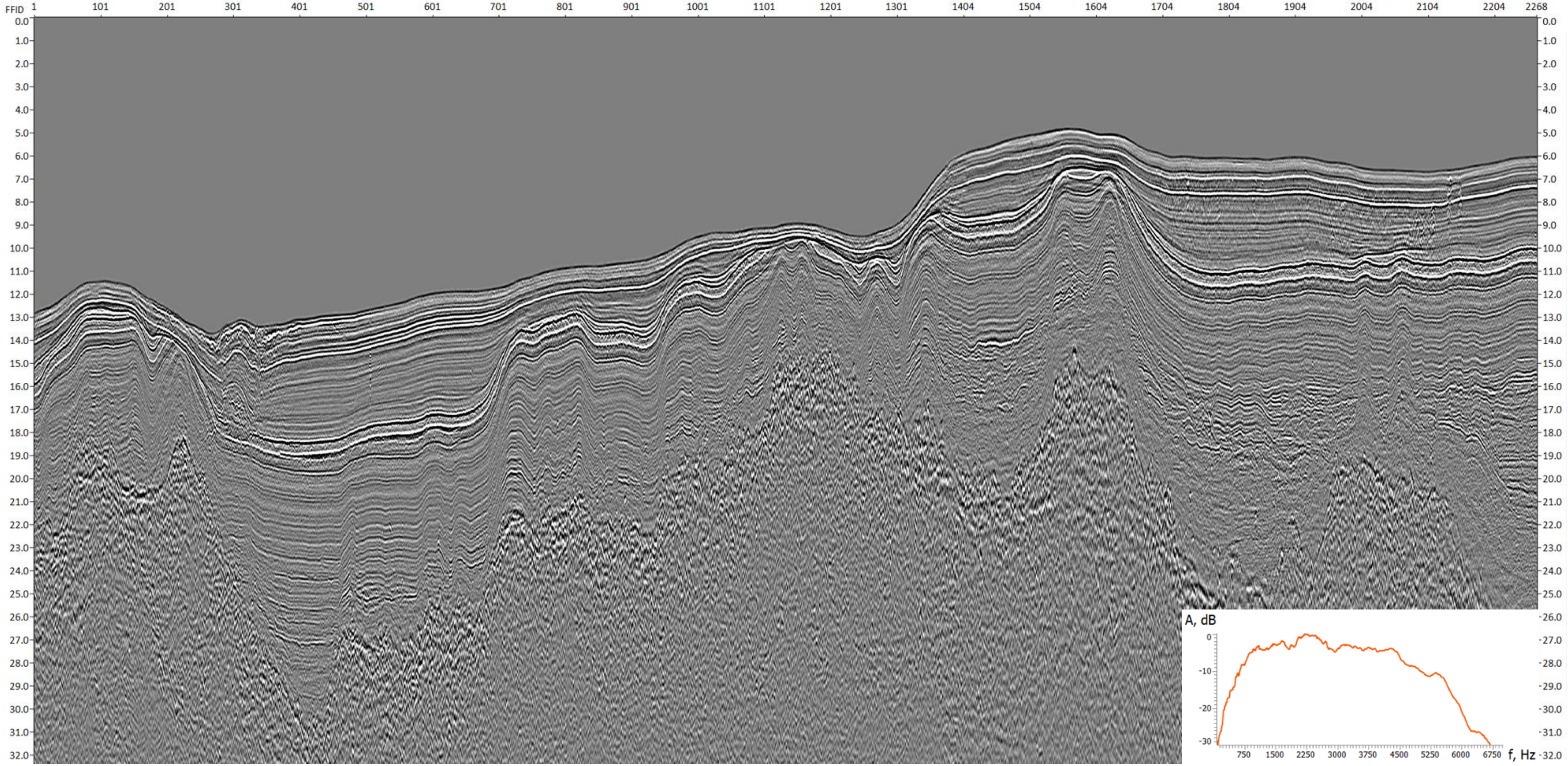
Ladoga Lake – sea trials



Data acquired by Geodevice with FWS-125 Sparker and 4-channel streamer, processed in RadExPro Seismic software

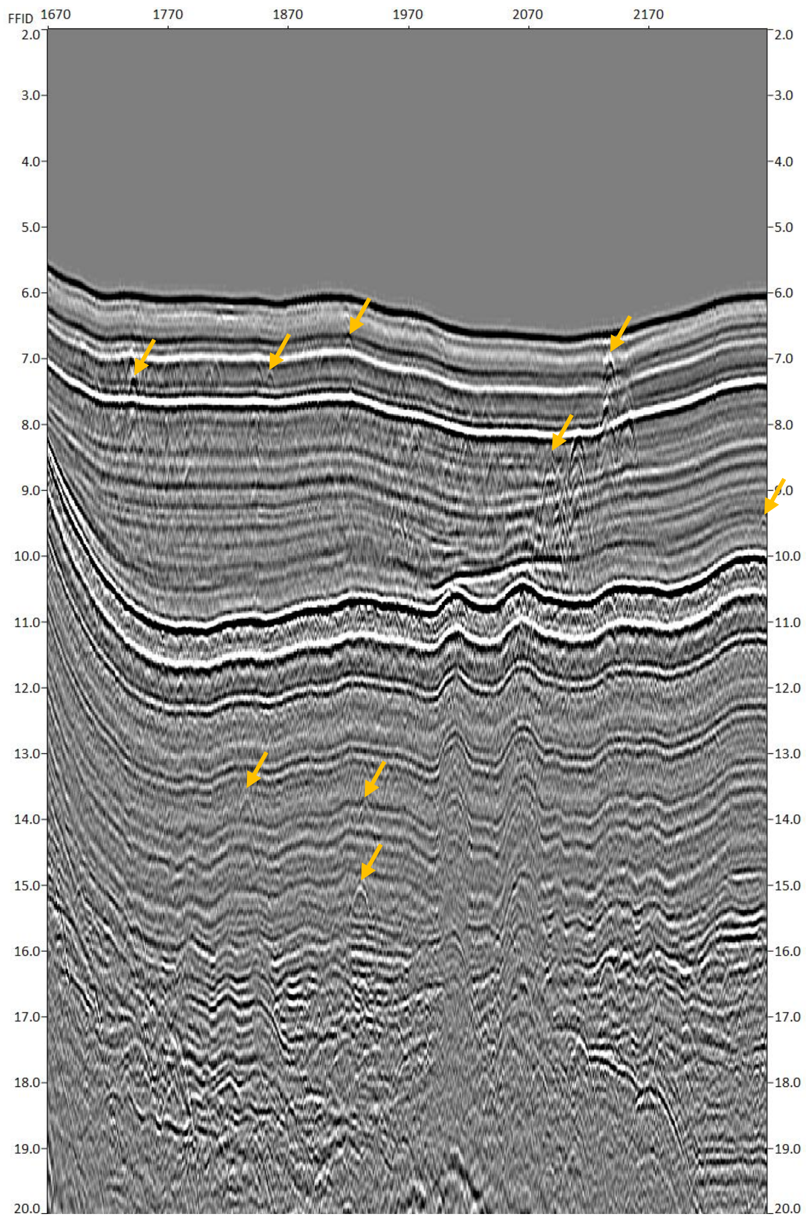
RadExPro seismic software

Ladoga Lake – boulders detection



Data acquired by Geodevice with FWS-125 Sparker, processed in RadExPro Seismic software

Post-glacier boulders detection with less than 0.5 m size

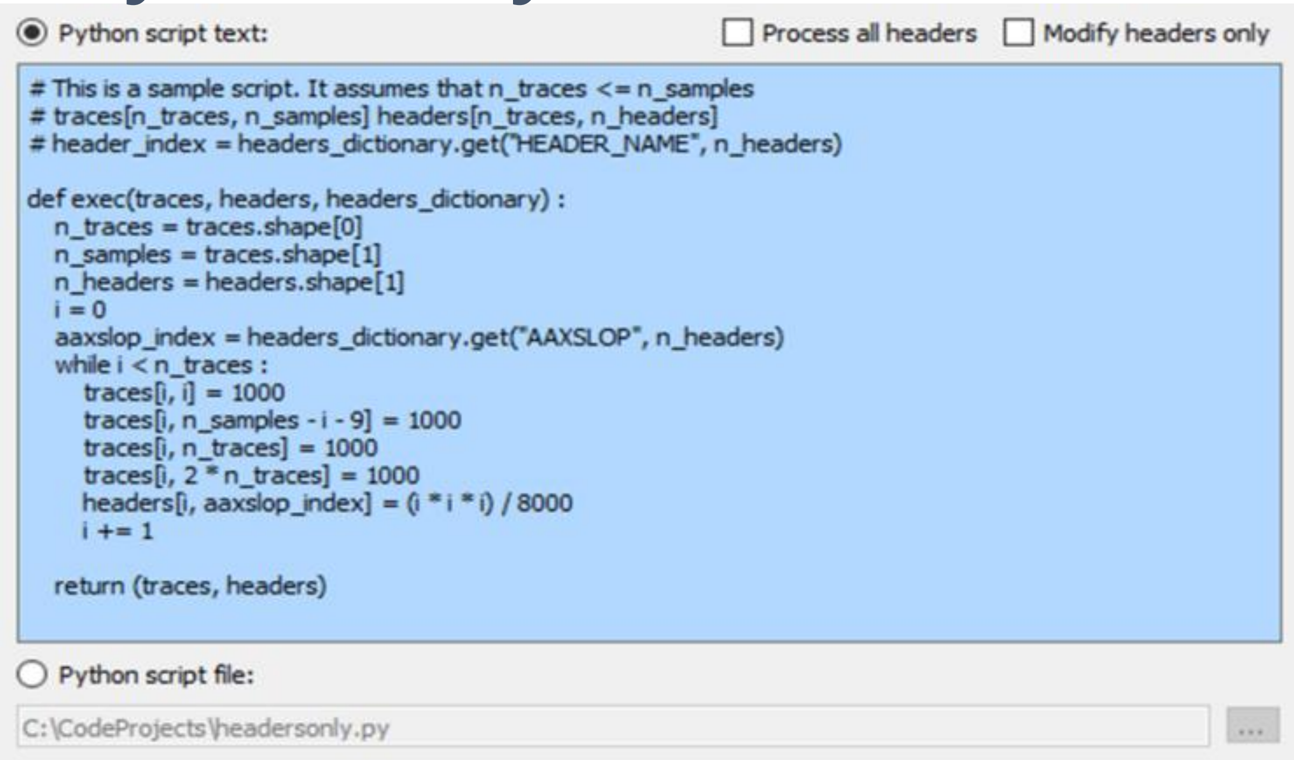


Lots of diffraction hyperbolas can be seen on non-migrated image. Some of them are marked by arrows. Diffractions are caused by post-glacier boulders.

Processing

Missing some specific algorithm?
Code it yourself and get it integrated into the system!

- **Python Proxy** module



- **Open API** for developing your own modules on **C++**

RadExPro
seismic software

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FUGRO
TGS
GeoSurveys geophysical consultants
EGS EARTH SCIENCES & SURVEYING
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TERRASOND PRECISION GEOSPATIAL SOLUTIONS
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