Seismic Data Processing Report

Survey: MSM52 - BalTec

Location: Baltic Sea

Area: Polish Exclusive Economic Zone

Date: December 2020

Carried out by: Quang Nguyen, PhD student

Supervisor: Prof. Michal Malinowski

Contact information:

Quang Nguyen

Email: qnguyen@igf.edu.pl

Prof. Michal Malinowski

Email: michalm@igf.edu.pl

Table of Contents

64 Ksiecia Janusza St.
01-452 Warsaw, Poland
phone: (+48) 22 6915 950 fax: (+48) 22 8776 722
mail: office@igf.edu.pl

1. Introduction

The BalTec 2D seismic survey was recorded in 2016 by Federal Institute for Geosciences and Natural Resources (BGR) during the German R/V Maria S. Merian cruise MSM52 in the Baltic Sea. Around 3.500 km of multi-channel seismic data were acquired.

This report describes the analysis and processing applied to the 850 km of BalTec 2D marine seismic data, comprising of 7 profiles (BGR16-201, 202, 212, 256, 257, 258, 259), located mainly in the Polish EEZ (Fig. 1), but extending also to Danish, Swedish and German EEZ.

The processing sequence was carried out using Globe Claritas seismic processing software under the academic license from Petrosys New Zealand Ltd.

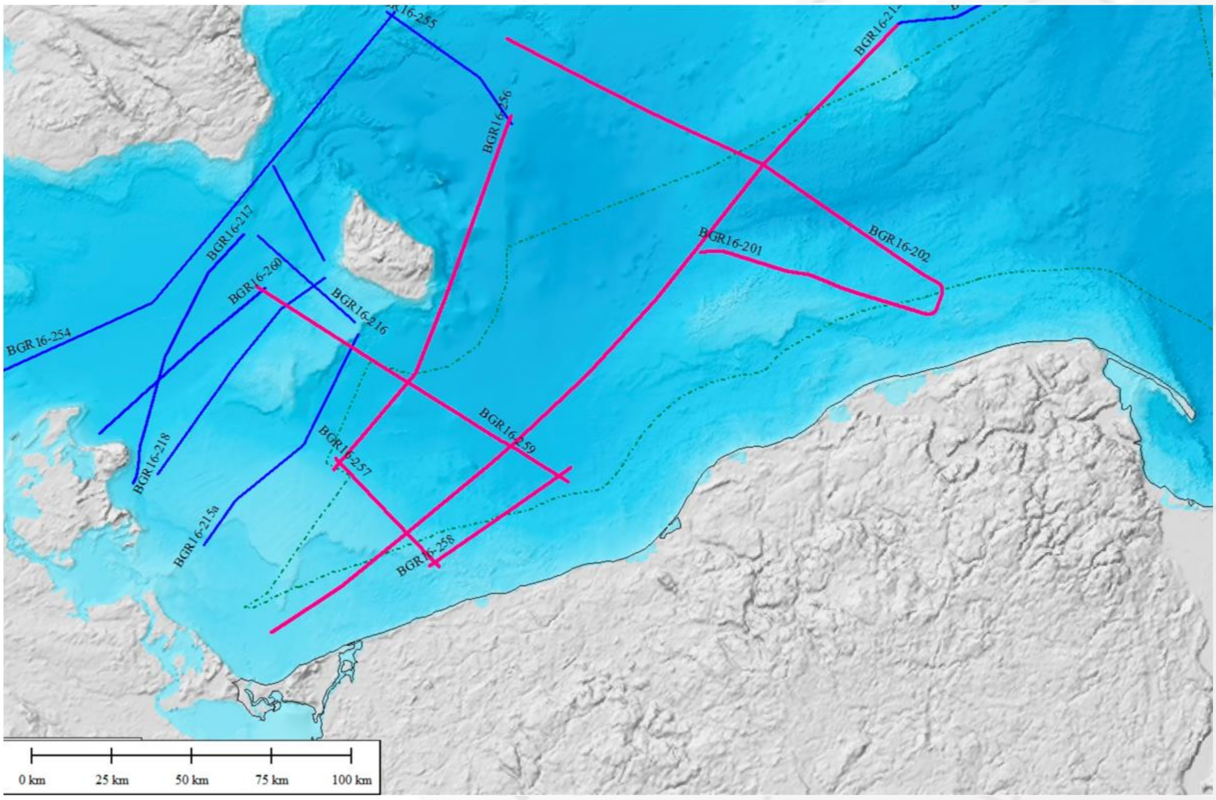


Figure 1: Layout of the acquired MSM52 (BalTec) reflection seismic data. Lines shown in magenta are processed at IG PAS.

1.1 Baltec 2D acquisition parameters

Details of the acquisition system, streamer configuration and the cruise narrative can be found in the cruise report (Huebscher et al., 2017). Table 1 summarizes most important acquisition parameters.

Table 1: Acquisition parameters of the BalTec / MSM52 cruise seismic data

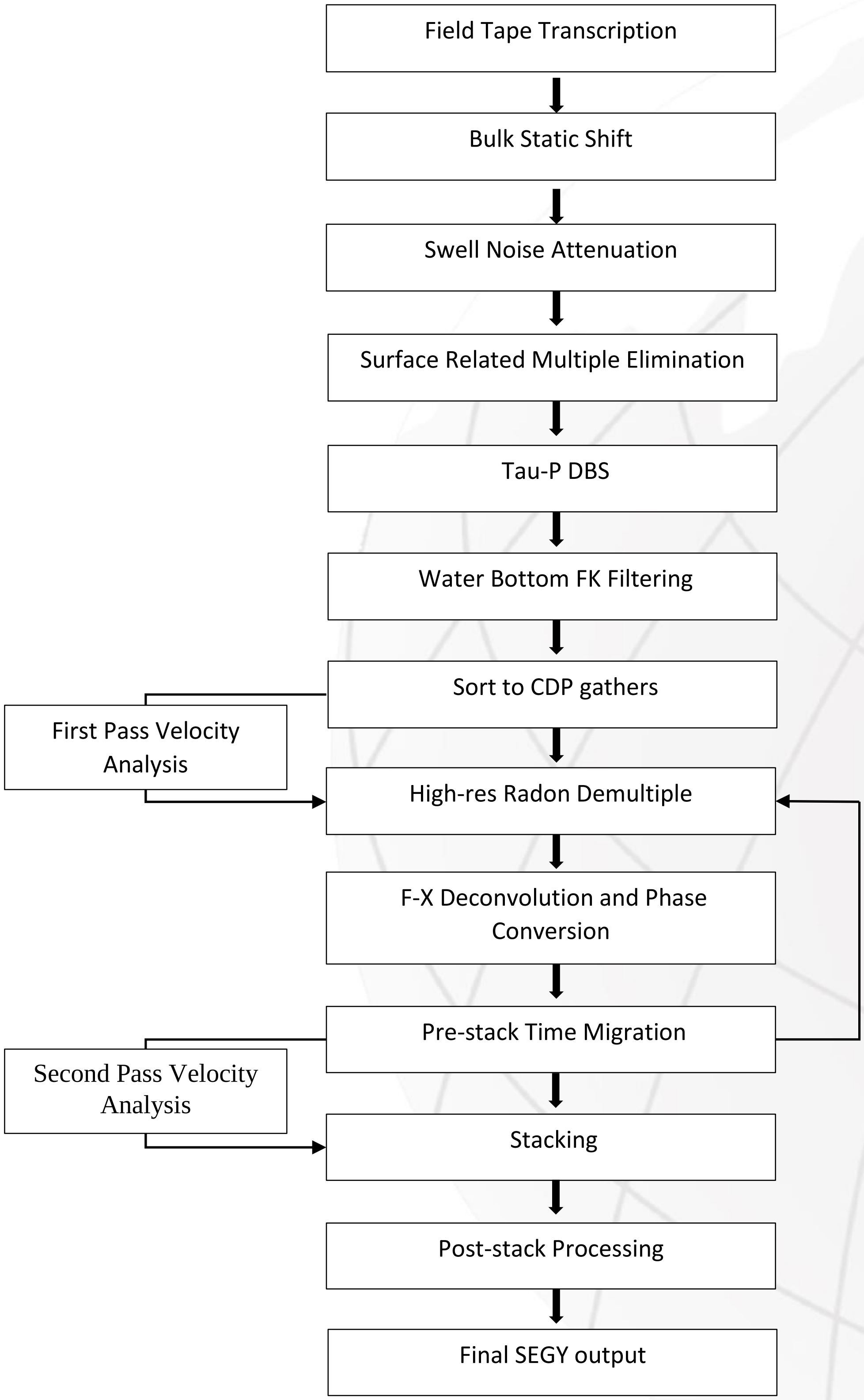
Parameters	**Value**
Number of channels	216
Receiver group interval	12.5 m
Average shot interval	25 m

www.igf.edu.pl
64 Ksiecia Janusza St.
01-452 Warsaw, Poland
phone: (+48) 22 6915 950 fax: (+48) 22 8776 722
mail: office@igf.edu.pl

Minimum offset	37.5 m
Maximum offset	2710 m
Streamer tow depth	3 m
Airgun array tow depth	2 m
Airgun array	8 x GI gun (1200 $inch^3$/ 19.7 l total volumes)
Sample interval	1 ms
Nominal record length	8.5 s (4 – 5 s usable)

64 Ksiecia Janusza St.
01-452 Warsaw, Poland
phone: (+48) 22 6915 950 fax: (+48) 22 8776 722
mail: office@igf.edu.pl

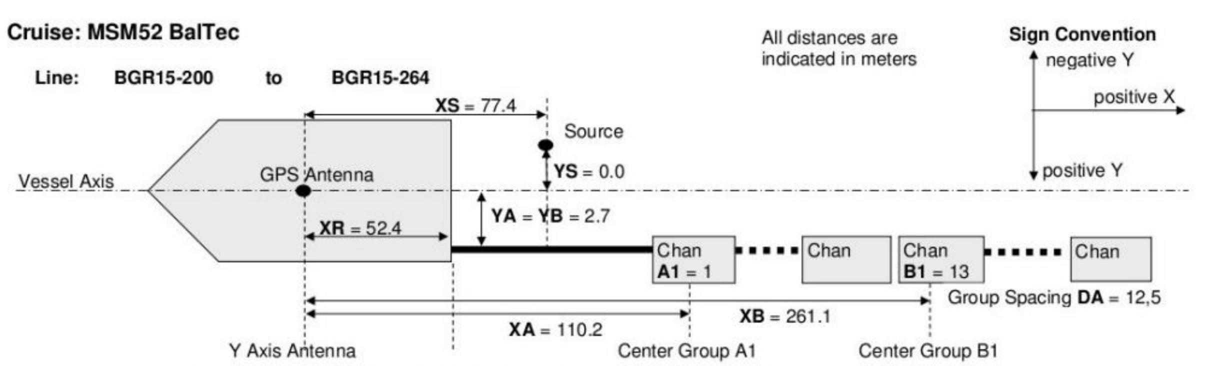
2. Processing Flow and Parameters



64 Ksiecia Janusza St.
01-452 Warsaw, Poland
phone: (+48) 22 6915 950 fax: (+48) 22 8776 722
mail: office@igf.edu.pl

3. Geometry

The streamer and airgun setup configuration is provided in Fig. 2 (BalTec MSM52 Cruise report).



Patterns Spreadsheet for 2D Marine Geometry Assignment in ProMAX

Mark Block	Min Chan	Max Chan	Chan Inc	Src Pattern	Grp Int	X Offset	Y Offset	
1	1	12	1*		12.5	XA=110.2	YA=-2.7	Streamer Patterns
2	13	24	1		12.5	XB=261.1	YB=-2.7	
...	25	36	1		12.5	412.1	-2.7	
	37	60	1		12.5	563.1	-2.7	
	61	120	1		12.5	863.5	-2.7	
	121	180	1		12.5	1613.8	-2.7	
M	181	216	1		12.5	2364.1	-2.7	
M+1				1**		XS=77.4	YS=0.0	Source Patterns
...	.							

*) -1 if A1 > AN, 1 if A1 < AN   **) The Src Pattern numbers has to be indicated in the SIN Ordered Parameter File

Remarks: All positions are referenced to MRU.

Figure 2: Sketch of the streamer and airgun geometry during MSM52 cruise (Huebscher et al., 2017).

We used simple marine geometry setup in Globe Claritas for the initial processing including swell noise removal, SRME and Tau-P deconvolution. Later on we regularized the data by interpolating shots to 12.5 m interval and stacked neighboring 2 channels forcing 12.5 m spacing between the CDP points, which increased the stacking fold.

www.igf.edu.pl
64 Ksiecia Janusza St.
01-452 Warsaw, Poland
phone: (+48) 22 6915 950 fax: (+48) 22 8776 722
mail: office@igf.edu.pl

4. Processing Description

4.1. Static Shift

The Sercel acquisition system starts registration 120 ms before releasing the airguns (BalTec MSM52 Cruise report). This delay time has been verified by the direct wave arrival on the channel groups near the source. Therefore, a 120 ms static shift (data samples will move closer to T=0) was applied to the Baltec data survey lines to compensate for the recording system delay.

To reduce processing time and data storage, surveys record lengths are reduced to 5 seconds for profiles 212, 256, 257, 258, 259 and 3 seconds for profiles 201 and 202. These new trace lengths are chosen enough to archive all geological targets in the study area. Data were also resampled from 1 to 2 ms.

Additionally, a trace editing process is applied to remove dummy or auxiliary traces in the shot gathers.

4.2. Amplitude Recovery

Spherical divergence process is applied to compensate the attenuation in seismic wave amplitude due to geometrical spreading of the wave front. Various values of scalar function are tested, and a simple T^2.0 is applied to the data.

A zero phase Butterworth low cut filter (3-5 Hz) is applied after spherical divergence.

4.3. Swell Noise Attenuation

Analysis and attenuation are performed in wavelet domain, wavelet transforms provide better localization than FFT transforms, processing one source position at a time. For analysis, the data records are transformed into wavelet space. A window run down and across the traces, size of the window defined by lateral and vertical parameters. Within each window and scale, wavelet amplitudes are normalized, then the average of the centre wavelets are compared to the centre wavelet of the window. If the centre wavelet is smaller in magnitude than the threshold times the average, it is left alone. If it is bigger than the threshold times, it is removed and interpolated back in.

The shallow portion of each shot record is muted before analysis, removing the high amplitude shallow reflections and direct arrival. This untouched shallow portion is then written to pseudo traces to merge with the portion which swell noise attenuation is applied to produce free swell noise output.

4.4. SRME

SRME or Surface Related Multiple Elimination was developed by the Delphi Consortium at TU Delft in the Netherlands (Veschuur et al., 1992). The process uses the geometry of shot recording to model all possible multiples that can generated by the surface. The surface related multiples are predicted using auto-correlation of common shot and common receivers gathers. The predicted multiples are then removed from the input gathers by a process called adaptive subtraction.

The shot point interval is 25 m while channels interval is 12.5 m. Therefore, to construct the multiples estimate, the shot point is interpolated by 2, and the record data is extrapolated to zero offset. A mute is applied to the input shot records prior to remove direct arrival energy and the first seafloor multiple. After surface related multiples is modelled by a series of convolutions and summation, the output model shot point is renumbered back to same order as the original shot gathers for subtracting process.

64 Ksiecia Janusza St.
01-452 Warsaw, Poland
phone: (+48) 22 6915 950 fax: (+48) 22 8776 722
mail: office@igf.edu.pl

For this data, a 3 pass approach for SRME adaptive subtraction including two subtraction processors based on two publications by Wang, 2003 and Monk, 1993 is applied.

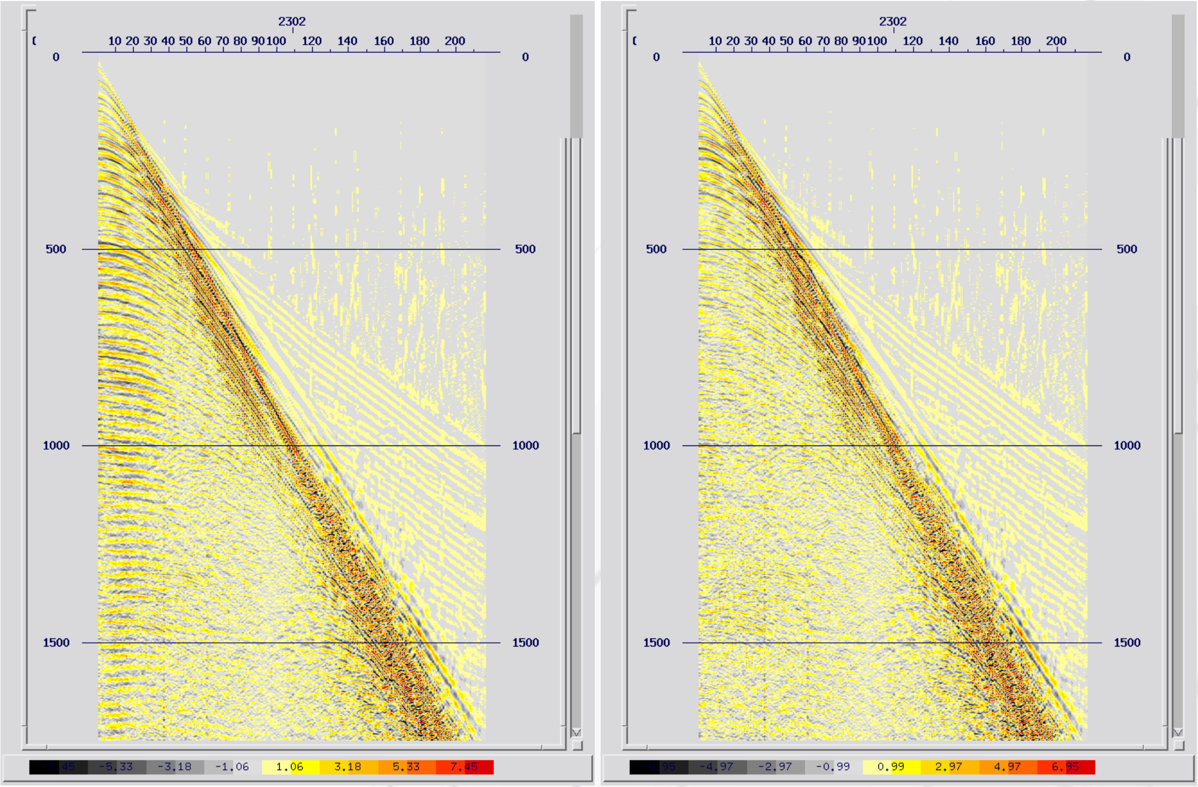


Figure 3: shot gather before and after applying SRME.

4.5. Tau-P deconvolution, linear noise removal and data regularisation

Shot records are interpolated from 216 traces to 432 traces, data is transformed to Tau-P domain using the linear transform. Predictive deconvolution in Tau-P domain consisted of a design window of 240 ms total operator length and gap length of 48 ms. Application of the deconvolution to the whole trace.

Channel	*Start time design(ms)*	*End time design(ms)*	*Start time apply(ms)*	*End time apply(ms)*
1	2250	5000	0	6500
206	2300	5000	0	6500
418	2500	6000	0	6500

To remove the linear noise and multiples from refraction energy, a “tail mute” is designed that the data below mute line will be zeroed. The mute line (green line) is shown in Figure 4.

64 Ksiecia Janusza St.
01-452 Warsaw, Poland
phone: (+48) 22 6915 950 fax: (+48) 22 8776 722
mail: office@igf.edu.pl

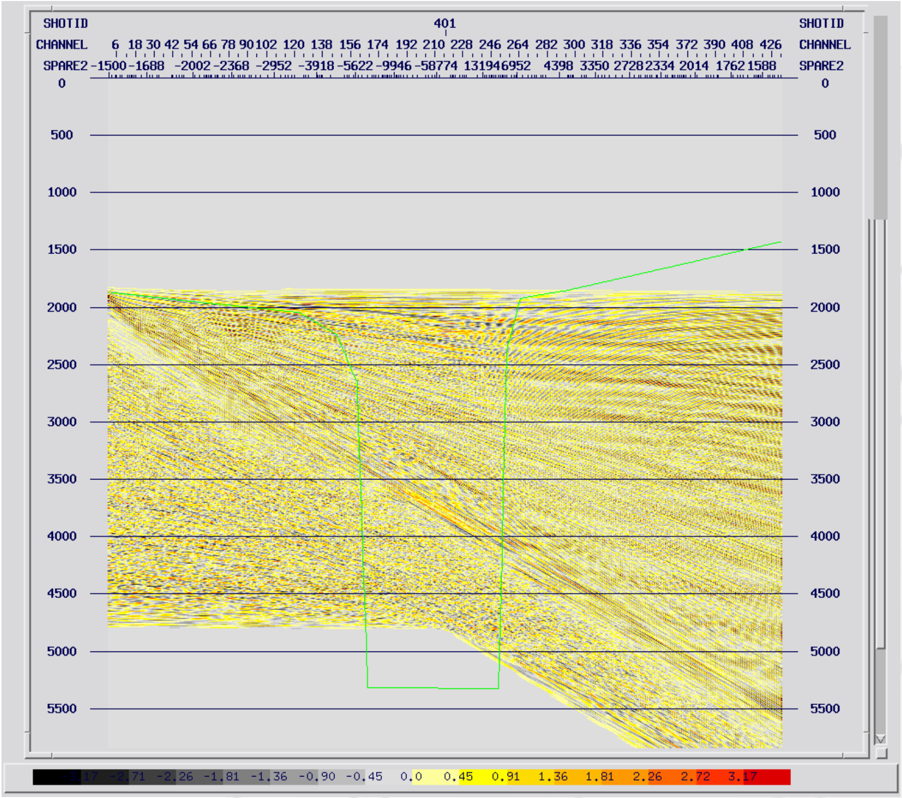


Figure 4: Mute line in Tau-P domain

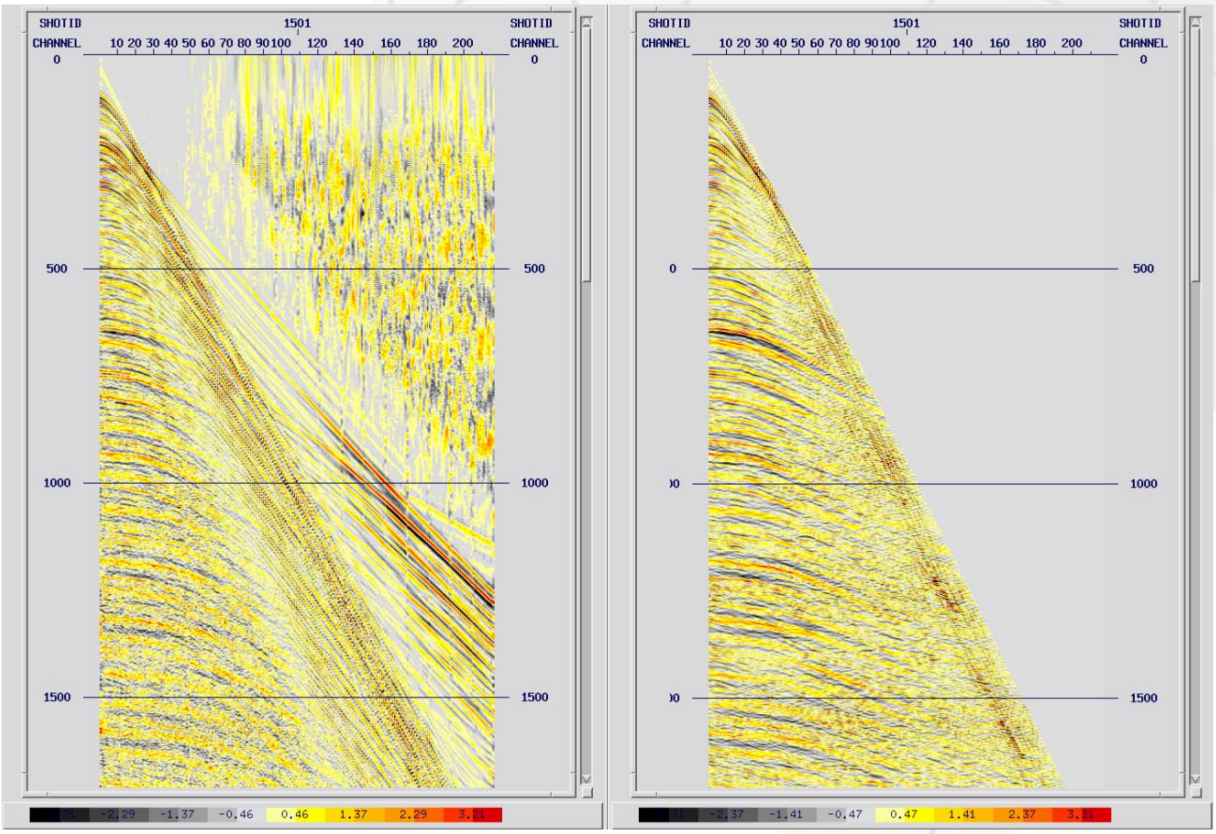


Figure 5: shot gather before and after applying Tau-P deconvolution

After Tau-P deconvolution, in order to improve signal to noise ratio and enhance deeper imaging data were regularized in 2 steps. Firstly, the shot records are interpolated to 12.5 m of shot point interval from the nominal 25 m recorded, which doubled the CDP fold. Second, decimating the fold of the shot gathers from 216 to 113 to get to a 25 m receiver interval and 12.5 m CDP interval so the spatial sampling at 12.5 m is more beneficial to image the deeper part of the sections.

A running trace mixing was applied to shot records before interpolation.

Data Regulation	
Input channels	216
Input channel interval	12.5 m
Output channels	113
Output channels interval	25 m

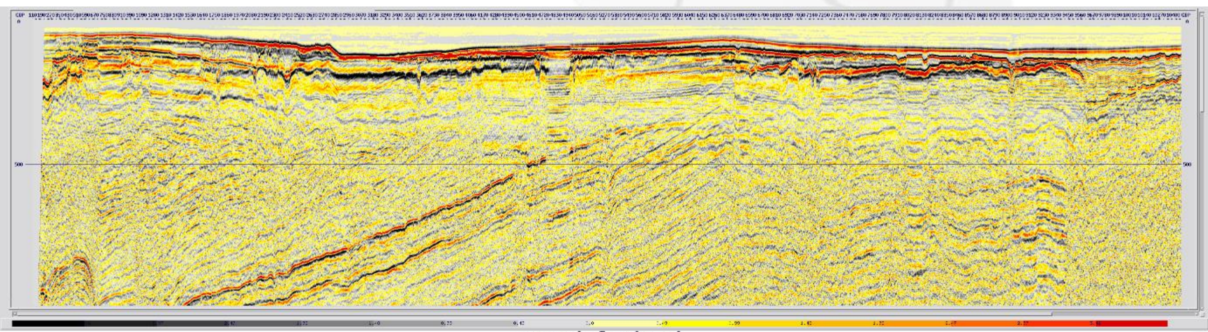
Trace Mix Details			
Time (ms)	*Trace mix*	*Time (ms)*	*Trace mix*
0	0.25 – 0.5 – 0.25	Tmax	0.25 – 0.5 – 0.25

4.6. Water bottom F-K filtering

Due to recording at very shallow water environment (water depth in some part of the sections could be less than 50 ms), the water bottom multiples are dominant in some profiles. Therefore, to remove this very shallow multiples, an approach called water bottom F-K filtering is applied. This approach includes the following steps:

- Picking water bottom on the brute stack
- Modelling the water bottom multiples by an equation reflection hodograph with water velocity
- Flattening the modelled water bottom multiples
- Applying F-K filtering within the narrow window of the flattened multiple events (zero dip rejected).

This approach is repeated for the 2^{nd}, 3^{rd} and 4^{th} of the water bottom multiple.



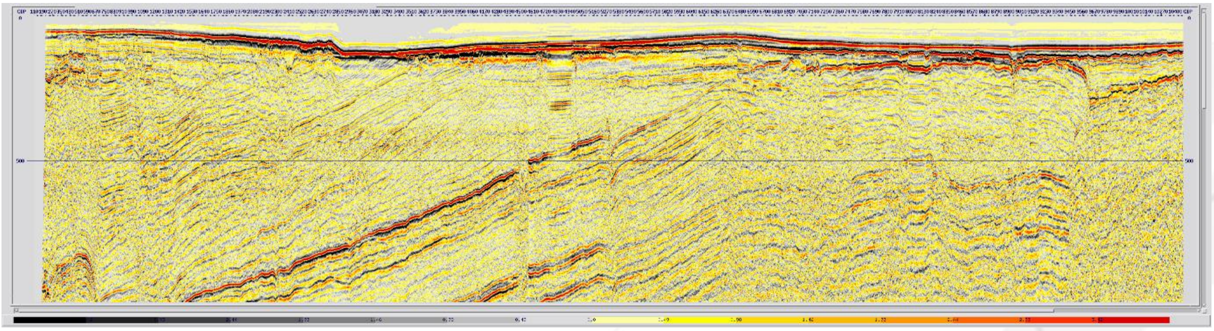


Figure 6: Brute stack of a section before (up) and after (down) applying water bottom FK filtering approach.

4.7. Velocity Analysis

The pre-processed shot records were sorted into common depth point gathers.

CDP Gather Parameters	
SP interval	12.5 m
Group interval	25 m
Number of channels	113
CDP interval	12.5 m
CDP fold	109 (up to 113)

Velocities were determined using the Global Claritas CVA interactive velocity analysis program. Velocity is picked at 250 CDPs (around 3.0 km interval). Each velocity analysis comprised a semblance, a CDP stack panel with suite of velocity functions, and central CDP gather. Generally, Velocity analysis is carried out in 3 passes: first pass velocity is picked before high-resolution Radon demultiple approach, second pass is picked and updated after pre-stack time migration, and third pass is checking and updating the second pass velocity after migration.

4.8. (High-resolution) Radon demultiple

Attenuation of multiples was achieved by modeling and subtraction using a least squares, parabolic Radon transform. Normal move-out corrections were performed using the first pass velocities, and the CDP gathers transformed into the parabolic Tau-P domain. The segment of the Tau-P domain corresponding to primary reflections is muted, leaving the multiple energy to be transformed back into the T-X domain and subtracted from the original CDP gathers.

The normal Radon demultiple has some limitations, so a HARLAN signal extraction filter (based on Harlan, W. S., 1995) is used to overcome the limitations (this approach called high-resolution Radon demultiple). This filter, provides a high-resolution Radon transform by taking the PRT of the input data, and the muted PRT of the input data with trace polarities randomly reversed and put these into Harlan's signal extraction algorithm to focus on the signal in the PR domain. The resolution in Radon space is greatly improved, the 14emultiplex is amplitude preserving and does not enhance residual multiples.

64 Ksiecia Janusza St.
01-452 Warsaw, Poland
phone: (+48) 22 6915 950 fax: (+48) 22 8776 722
mail: office@igf.edu.pl

The high-res Radon 14emultiplex is applied with start time at 500 ms as artifacts are introduced in the near surface, where move-out values are large and reflections only exist on near offsets. Optionally, this approach also is reapplied after each velocity analysis pass.

Radon Transform Parameters	
CDP fold	109
Reference offset	2707.3 m
Move-out limits (model)	-300 – 2500 ms (at reference offset)
Move-out limits (noise)	150 – 2450 ms (at reference offset)
Frequency range	3 – 80 Hz
Number of p traces	226

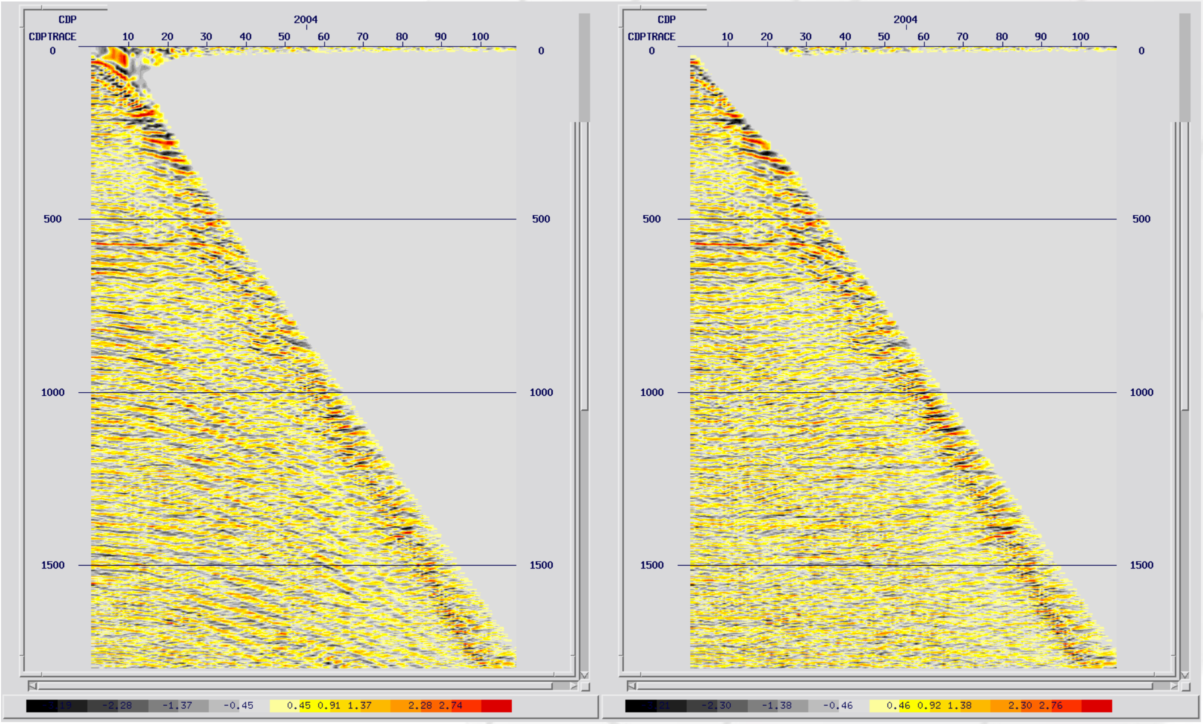


Figure 7: CDP gather (NMO corrected) before and after applying high-resolution Radon demultiple.

4.9. F-X deconvolution and minimum phase conversion

A Butterworth zero phase bandpass filter (3 – 5 – 95 – 110 Hz) is applied.

F-X deconvolution is a process deigned to effectively attenuate random noise by prediction of the non-random signal content in a seismic trace. Each input trace is transformed into the frequency domain. Groups of traces are used to design filters to predict the Fourier components of adjacent traces. The

64 Ksiecia Janusza St.
01-452 Warsaw, Poland
phone: (+48) 22 6915 950 fax: (+48) 22 8776 722
mail: office@igf.edu.pl

filtered section is finally transformed back into T-X space, and the noise component removed. Parameters for the F-X deconvolution are shown in the table below.

Due to dominance of random noises in the CDP gathers, and to improve performance of the pre-stack time migration, F-X deconvolution is applied on pre-stack CDP gathers. NMO correction is applied before and removed after FX deconvolutions is applied.

F-X Deconvolution Random Noise Attenuation Parameters	
Length of operator	19
Number of traces for design filter at a time	13
Traces overlap between panels	6
Sliding window length	100 ms
Overlap window length	20 ms

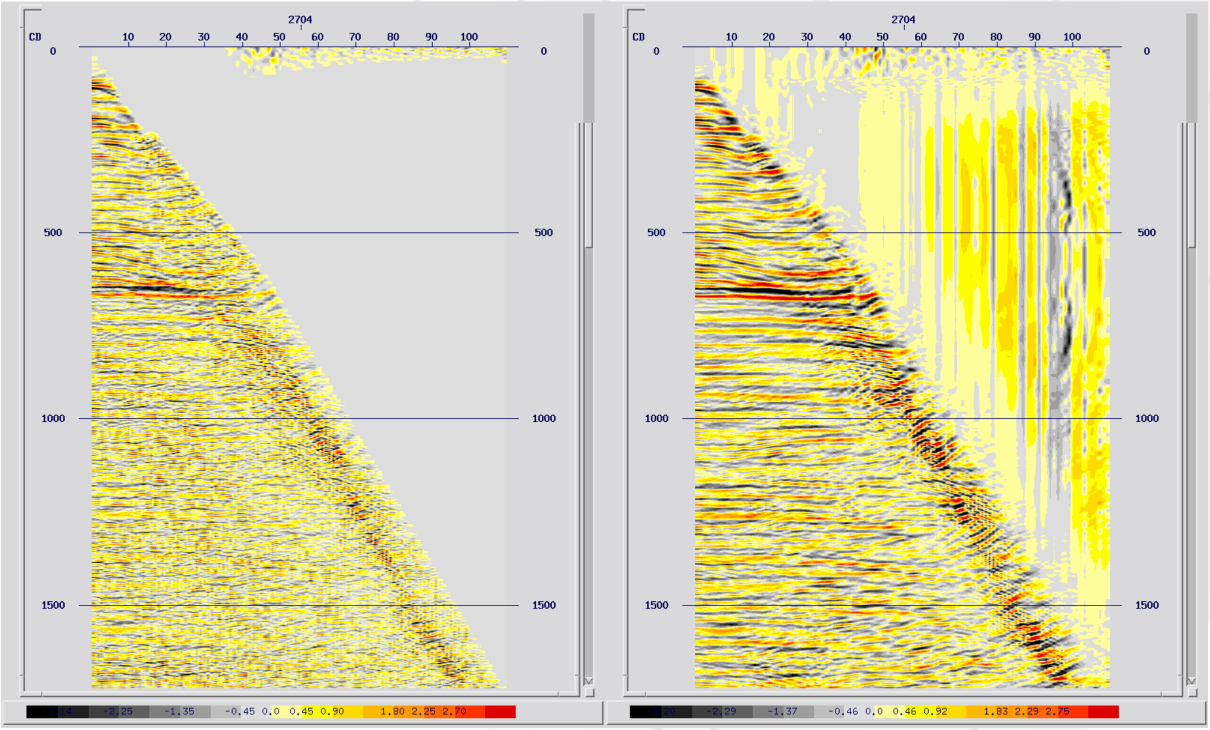


Figure 8: CDP gather (NMO corrected) before and after applying F-X Deconvolution.

After F-X deconvolution, a minimum phase conversion match filter is convolved with the CDP gathers to convert the data to minimum phase. The farfield signature source wavelet was not provided, therefore the filter is generated from a stacked wavelet created by first receiver group's direct wave recording (around 100 shots). The effect of applying this filter is to remove the phase effects of the recording instruments, and to collapse the effective source signature.

www.igf.edu.pl
64 Ksiecia Janusza St.
01-452 Warsaw, Poland
phone: (+48) 22 6915 950 fax: (+48) 22 8776 722
mail: office@igf.edu.pl

Figure 9: The match filter with its phase and frequencies spectrum.

4.10. Pre-Stack time migration

A straight-ray 2D Kirchhoff pre-stack time migration (PSTM) is performed using first pass velocities. Main input of the migration process is pre-stack seismic data with geometry applied and RMS velocity field. Pre-stack migration process is applied again when each pass of velocity field is updated.

Important pre-stack migration parameters including: Range (migration radius), which measures maximum distance to migrate from the CMP of the trace. Protect, which work together with Range parameter, measures the surface distance from the CMP of the trace, specify a bottle shape for the migration. Angle, specify the maximum dip angle to migrate, for this data, angle values from 30 to 60 degrees is tested, and 45 degrees is the most optimum. Anti-alias, this parameter specify the degree of anti-alias filter to be applied.

Migration parameters are shown in table below.

Pre-stack Time Migration Parameters	
Offset	-2707.8 : -32.8 / 25
CDPs interval	12.5 m
Migration radius	3000 m
Protect shape radius	200 m
Maximum dip angle to migrate	45 degrees
Anti-alias protection	2.0

64 Ksiecia Janusza St.
01-452 Warsaw, Poland
phone: (+48) 22 6915 950 fax: (+48) 22 8776 722
mail: office@igf.edu.pl

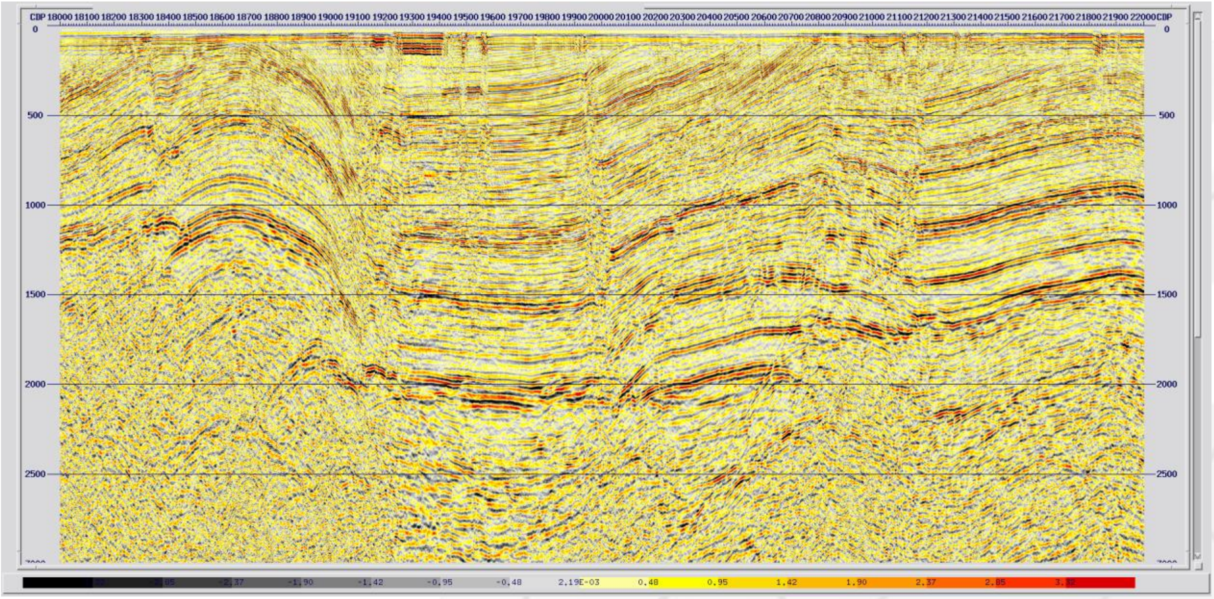


Figure 10: Unmigrated stack (part of profile 212)

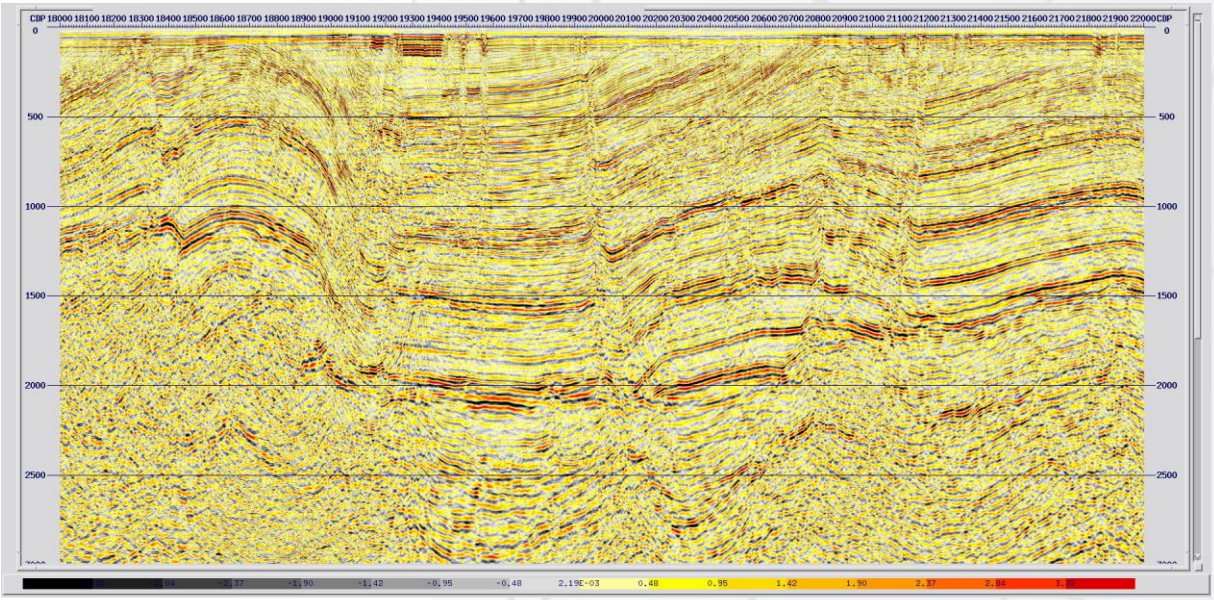


Figure 11: PSTM stack (part of profile 212)

4.11. Stacking and post-stack processing

Before stacking, an inverse scaling correction (G(t) = T^1.0) is applied to the data before stacking to compensate data amplitude losing after pre-stack migration process. A post NMO outer trace mute is applied to remove any coherent noise on the outer traces and to reduce the effect of NMO stretching on the far offsets.

To balance seismic amplitude across the section, normal 500 ms window AGC scaling process is applied before and after stacking. The traces within each common depth point gather were summed. Maximum number of traces in migrated CDP gathers is 108.

64 Ksiecia Janusza St.
01-452 Warsaw, Poland
phone: (+48) 22 6915 950 fax: (+48) 22 8776 722
mail: office@igf.edu.pl

For post-stack processing, a trace mixing process is applied to improve coherency between each seismic trace across the stacked section. Total of 5 traces to mix per window sliding across the section. Notice that other coherency processes and post-stack deconvolution are tested, however output results appear inefficient.

The final stack sections are then output to SEGY format.

64 Ksiecia Janusza St.
01-452 Warsaw, Poland
phone: (+48) 22 6915 950 fax: (+48) 22 8776 722
mail: office@igf.edu.pl

5. Polarity statement

The final desired polarity is SEG reverse (or SEG negative), where an increase in acoustic impedance is represented by a negative trough on display.

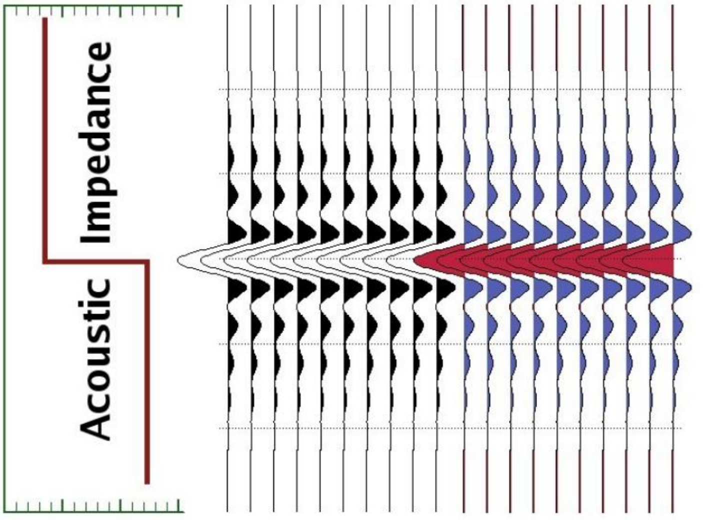


Figure 12: Desired polarity diagram. An acoustic impedance increase is represented by a trough.

6. Final Deliverables – SEGY format

1) Final PSTM stacks

2) PSTM gathers

3) Final stacking velocities – interval

4) Final stacking velocities – RMS

64 Ksiecia Janusza St.
01-452 Warsaw, Poland
phone: (+48) 22 6915 950 fax: (+48) 22 8776 722
mail: office@igf.edu.pl

7. Example Displays

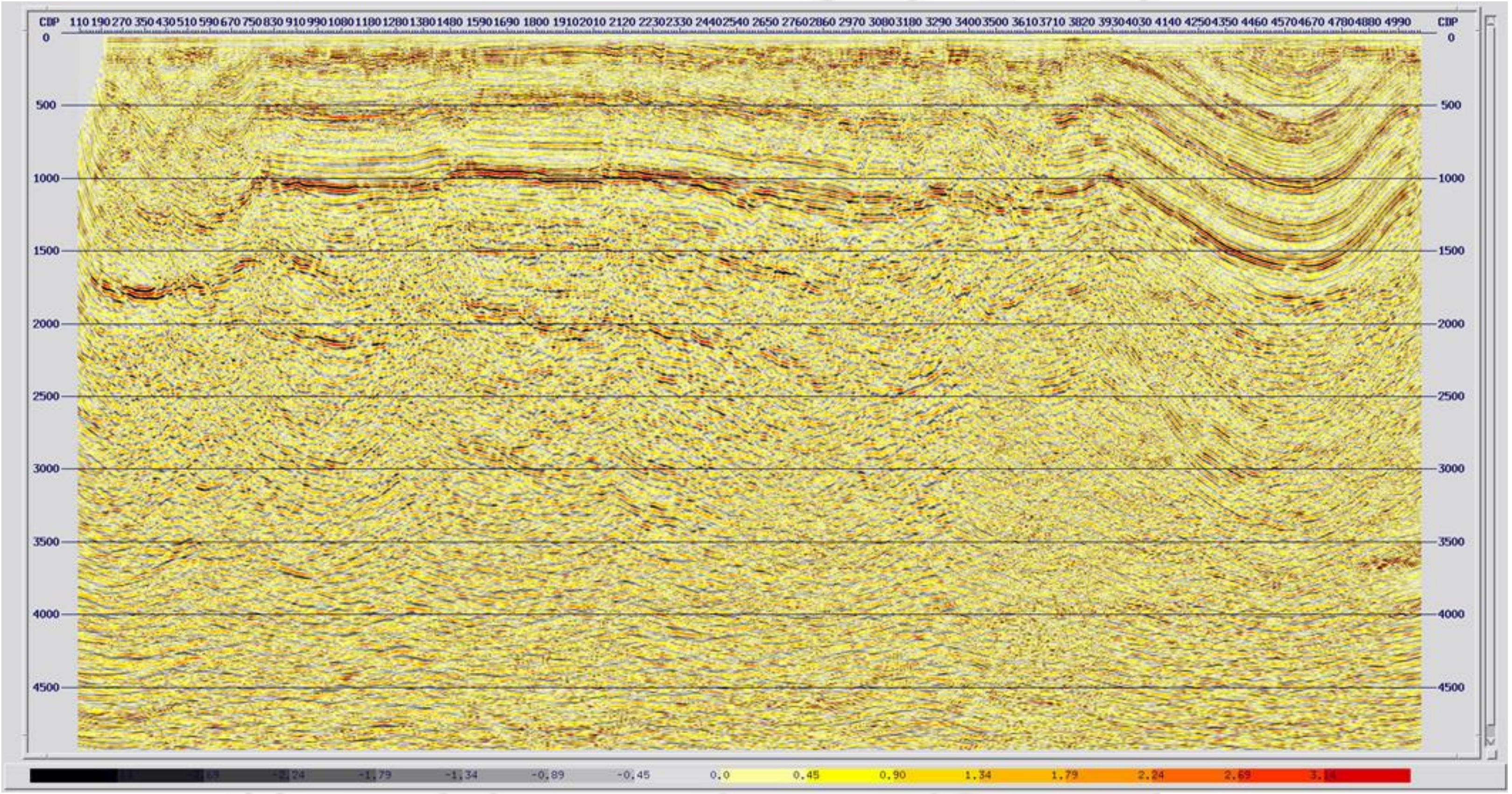


Figure 13: Line BGR16-257_PSTM_final

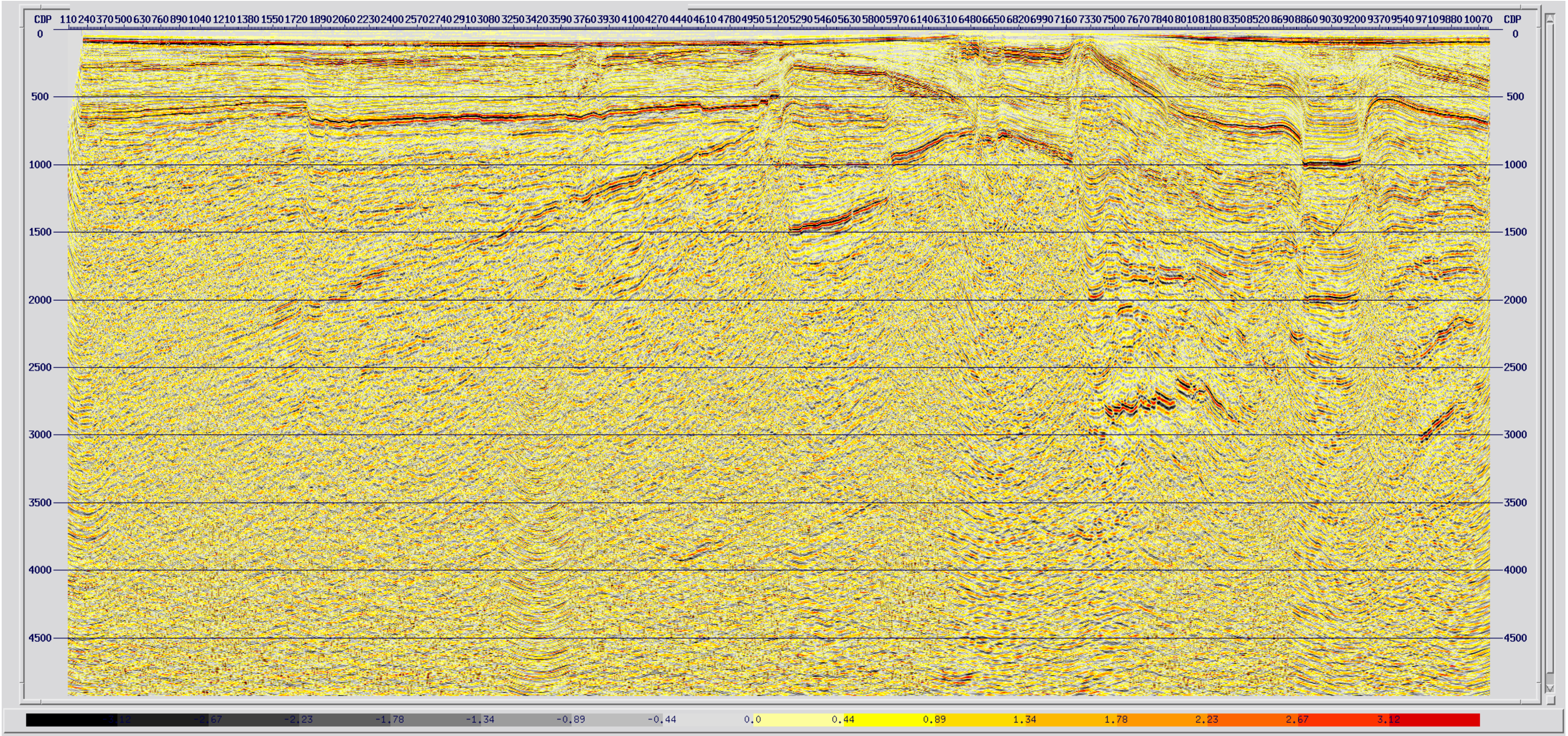


Figure 14: Line BGR16-259_PSTM_final

8. References

Harlan, W. S., 1995. Regularization by model reparameterization, assessed 22 June 1997.

Hübscher, C., Ahlrichs, H., Allum, G., Behrens, T., Bülow, J., Krawczyk, C., Damm, V., Demir, Ü, Engels, M., Frahm, L., Grzyb, G., Hahn, B., Heyde, I., Juhlin, C., Knevels, K., Lange, G., Bruun Lydersen, I., Malinowski, M., Noack, V., Preine, J., Rampersad, K., Schnabel, M., Seidel, E., Sopher, D., Stakemann, J. & Stakemann, J., 2017: BalTec - Cruise No. MSM52 – March 1 – March 28, 2016 – Rostock (Germany) – Kiel (Germany). MARIA S. MERIAN-Berichte, MSM52, 46 pp., DFG-Senatskommission für Ozeanographie, doi:10.2312/cr_msm52.

Monk, D. J., 1993. Wave-equation multiple suppression using constrained cross-equalization: Geophys. Prosp., 41, 725 -736.

Verschuur, D. J; Berkhout, A. J; Wapenaar, C. P. A (1992). Adaptive surface-related multiple elimination. Geophysics 57 (9): 1166-1177. Doi:10.1190/1.1443330.

Wang, Y., 2003. Multiple subtraction using an expanded multichannel matching filter. Geophysics 68(1), 346 - 354. Doi: 10.1190/1.1543220.

64 Ksiecia Janusza St.
01-452 Warsaw, Poland
phone: (+48) 22 6915 950 fax: (+48) 22 8776 722
mail: office@igf.edu.pl

Acknowledgement

Cruise MSM52 has been funded by German Science Foundation DFG and Federal Ministry of Education and Research (BMBF). Work reported here was funded by the Polish National Science Centre grant no UMO-2017/27/B/ST10/02316. We thank Federal Institute for Geosciences and Natural Resources (BGR) for their support during seismic data acquisition and sharing the data.

Seismic data processing was performed using Globe Claritas package under the academic license from Petrosys Ltd. Special thanks to A. Juniper for his support in designing this processing workflow.