



# **HR 2D GEOPHYSICAL DATA PROCESSING - RVO-OW AREA**

Seismic Data Processing

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**SUMMARY**

DEEP B.V contracted GeoSurveys - Geophysical Consultants to support the acquisition and process sparker multi-channel seismic data. Seismic data was acquired offshore Holland for future implantation of a Wind Farm.

This document reports the processing of 76 sparker multi-channel seismic lines (approximately 654 km) performed using the ProMAX software from Landmark Graphics Corporation and Radex Pro from Deco Geophysical.

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## ABBREVIATIONS

CDP – COMMON DEPTH POINT

DESIG – DESIGNATURE

DGPS – DIFFERENTIAL GLOBAL POSITIONING SYSTEM

DPT – DEPTH CONVERTED STACK

FFID – FIELD FILE IDENTIFICATION NUMBER

FFT - FAST FOURIER TRANSFORM

GS – GEOSURVEYS

HZ – HERTZ

LAT - LOWEST ASTRONOMICAL TIDE

MIG – MIGRATED

MUL – DEMULTIPLE ATTENUATION STACK

MS – MILLISECONDS

NMO – NORMAL MOVE OUT

QC – QUALITY CONTROL

RDGPS – RADIO DIFFERENTIAL GLOBAL POSITIONING SYSTEM

RMS – ROOT MEAN SQUARE

SBET - SMOOTHED BEST ESTIMATE

SAC – SCALAR TO ALL COORDINATES

SEG-Y – CONVENTION FROM THE SOCIETY OF EXPLORATION GEOPHYSICIST (SEG) FOR PRE-STACK AND POST-STACK SEISMIC DATA

SVP - SOUND VELOCITY PROFILE

TWT – TWO WAY TIME

UHRS - ULTRA HIGH RESOLUTION SEISMIC

UTC - UNIVERSAL TIME COORDINATED

UTM – UNIVERSAL TRANSVERSE MERCATOR

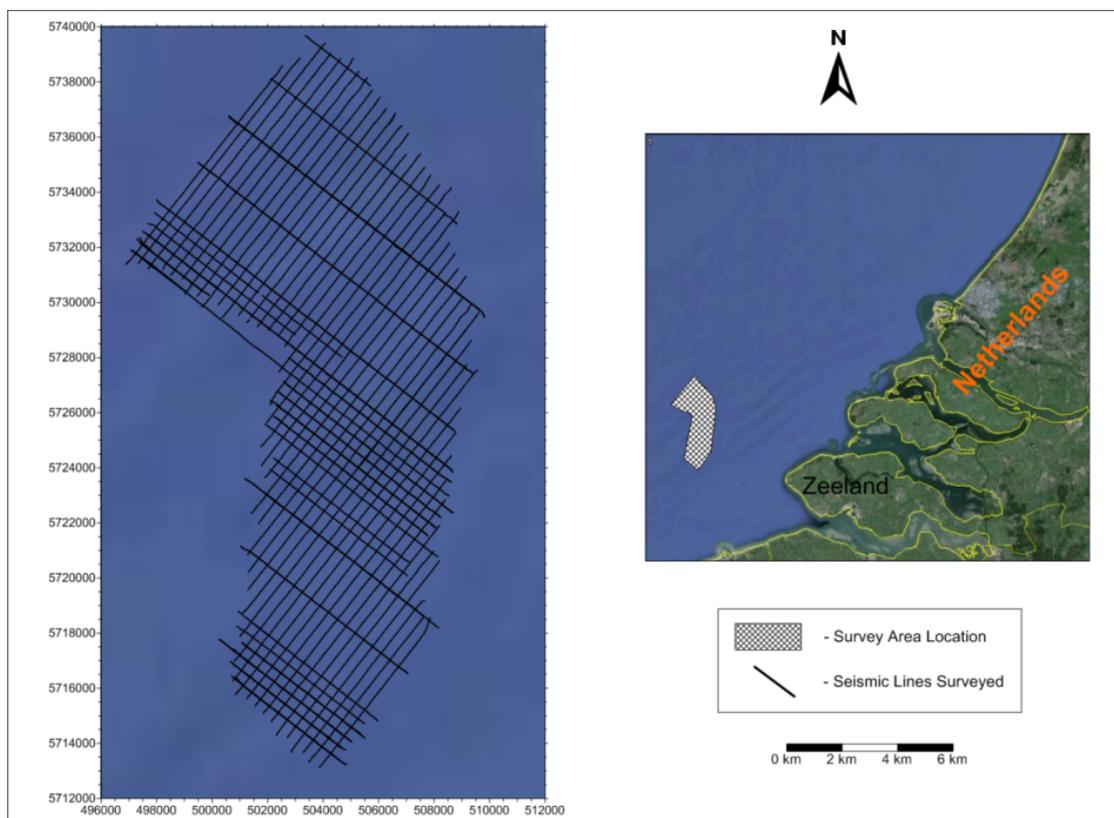
WD – WATER DEPTH

WEMR - WAVE EQUATION MULTIPLE REJECTION

## 1. INTRODUCTION

DEEP B.V contracted GeoSurveys - Geophysical Consultants, for sparker multi-channel seismic data acquisition and processing. Seismic data was acquired in an area offshore Vlissingen (Netherlands) for future implantation of Wind Farm (Figure 1). The project aims to characterize geological layers and structural elements in the survey area to a minimum depth of 80 m below seabed, and identify possible geohazards to provide information for future interested parties in the area for concession and implantation of Wind farm.

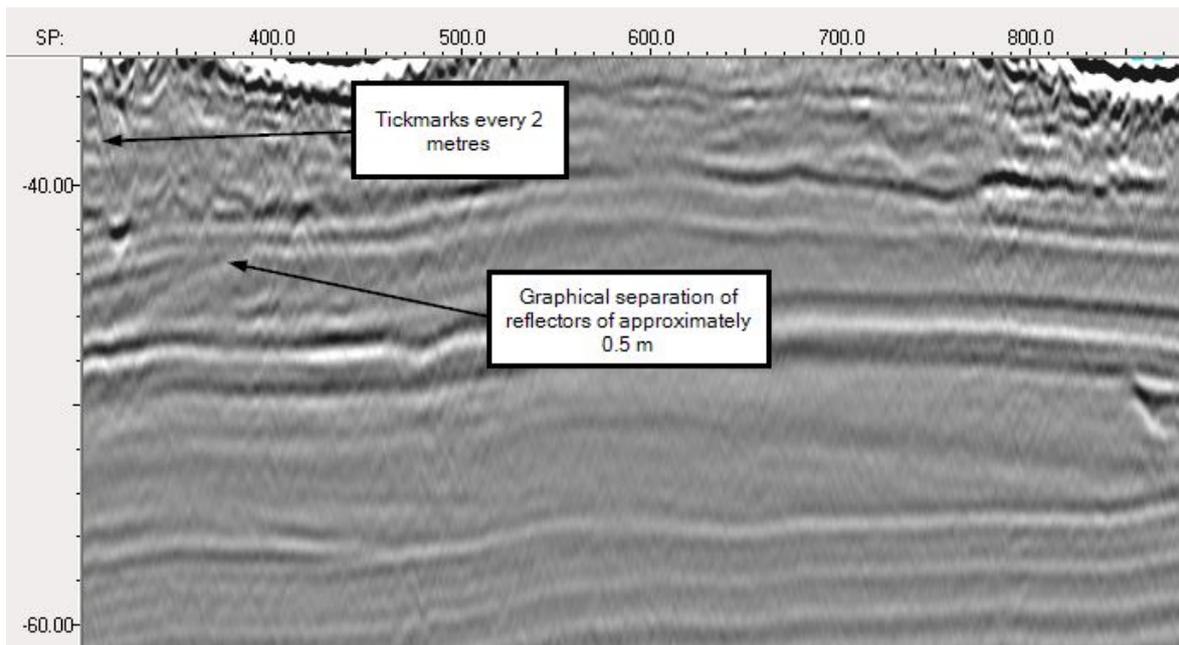
The acquisition of the seismic data was performed by DEEP B.V and Geosurveys – Geophysical Consultants (subcontractor), between 17<sup>th</sup> and 28<sup>th</sup> of January, on board of the vessel SeaZip Surveyor, in an area located on the South part of the North Sea, Dutch sector. The survey was conducted using an ultra-high resolution seismic system including a multi-channel seismic recorder, a 2000 J Geo-Spark power supply, a Geo-Source 200 sparker, a 48 channels Geomarine GeoSense analog Streamer and two AIS radio transponders for positioning of front and tail buoys of the streamer.



**Figure 1** – Survey site location, offshore Vlissingen in the south eastern North Sea, and location of seismic lines surveyed at RVO-OW. Image in UTM Z31 N, Datum ETRS89.

This document reports the processing of 76 sparker seismic profiles (approximately 654 km) that cover an area of approximately 173km<sup>2</sup>. The seismic data processing was performed using the processing software Radex Pro from Deco Geophysical and the ProMAX from Landmark Graphics Corporation.

The raw data received was of good quality, with a stable recorded wavelet across all channels, indicating the reliable behaviour of the source and a depth of the streamer varying from 0.3 m in the first channel to 1.5 – 3 m at the last channel of the streamer as previously planned during the acquisition for improvement of signal degosthing during the processing stage. Feathering was highly variable and some of the processed lines were affected by feathering in excess of 20°. The overall processed data quality was good and the maximum penetration reached in excess of 200 m (complete record length). The vertical resolution was in excess of 0.5 m due to the frequency contents higher than 1000 Hz and based on the Rayleigh Criterion - two nearby reflective interfaces are distinguished if they have about 1/4 of dominant frequency wavelength in thickness. Taking into account a frequency of 1000 Hz and a sound velocity of 1800 m/s, the wavelength of  $1/1000 \cdot 1800$  is 1.8 m, what leads to a vertical resolution of 0.45 m (1/4 wavelength). Furthermore, a detailed graphical analysis of the processed seismic data shows a minimum graphical separation between reflectors of approximately 0.5 m (see Figure 2).



**Figure 2** – Seismic profile detail showing the ability to distinguish reflective interfaces separated by approximately 0.5 m. Vertical scale in depth (meters), with tickmarks separated by 2 m, and horizontal scale in CDPs.

### 1.1. Survey area

The RVO-OW Area is located in the south eastern North Sea, Offshore Vlissingen (Zeeland), at water depths that vary between approximately 13.5 and 39.5 m. The survey area is contained within a polygon of approximately 173.8 km<sup>2</sup> with the corner coordinates (UTM, Z31N, ETRS89 datum; Figure 2):

- |             |           |            |
|-------------|-----------|------------|
| • NE corner | 503300 mE | 5739750 mN |
| • SE corner | 504500 mE | 5713250 mN |
| • SW corner | 500750 mE | 5716500 mN |
| • NW corner | 497000 mE | 5731750 mN |

The survey grid plan is shown in Figure 2 and comprises 76 seismic profiles, with lengths ranging from 1900 to 12000 m, oriented NW-SE and SW-NE. During the survey it was decided that extra cross lines were needed, especially in the South part of the survey area due to higher geological complexity. The area was surveyed with main lines parallel to the coast spaced 400 m apart. Cross lines were mostly separated by 2000 m but the extra cross lines added in the South part of the survey area are separated by 400 m.

The seabed of the survey area is mainly composed by sandy sediments and presents sand banks and sand waves on the seabed (Figure 3).

### 1.2. Purpose and objectives of the processing

The purpose of the processing is to provide ultra-high resolution seismic data for interpretation of the geological layers and structural elements to a depth of 80 m below seabed, and identification of possible geohazards.

The quality control and processing solution provided by Geosurveys was tailored to ensure processed data meet the necessary requirements to allow for:

- Production of processed seismic sections with a vertical resolution of 0.5 m or better;
- Signal penetration of 80 m or better;

- Adequately image any relevant geological features to the assessment of geological hazards for win farm construction.

The main processing steps applied to achieve these aims were the following:

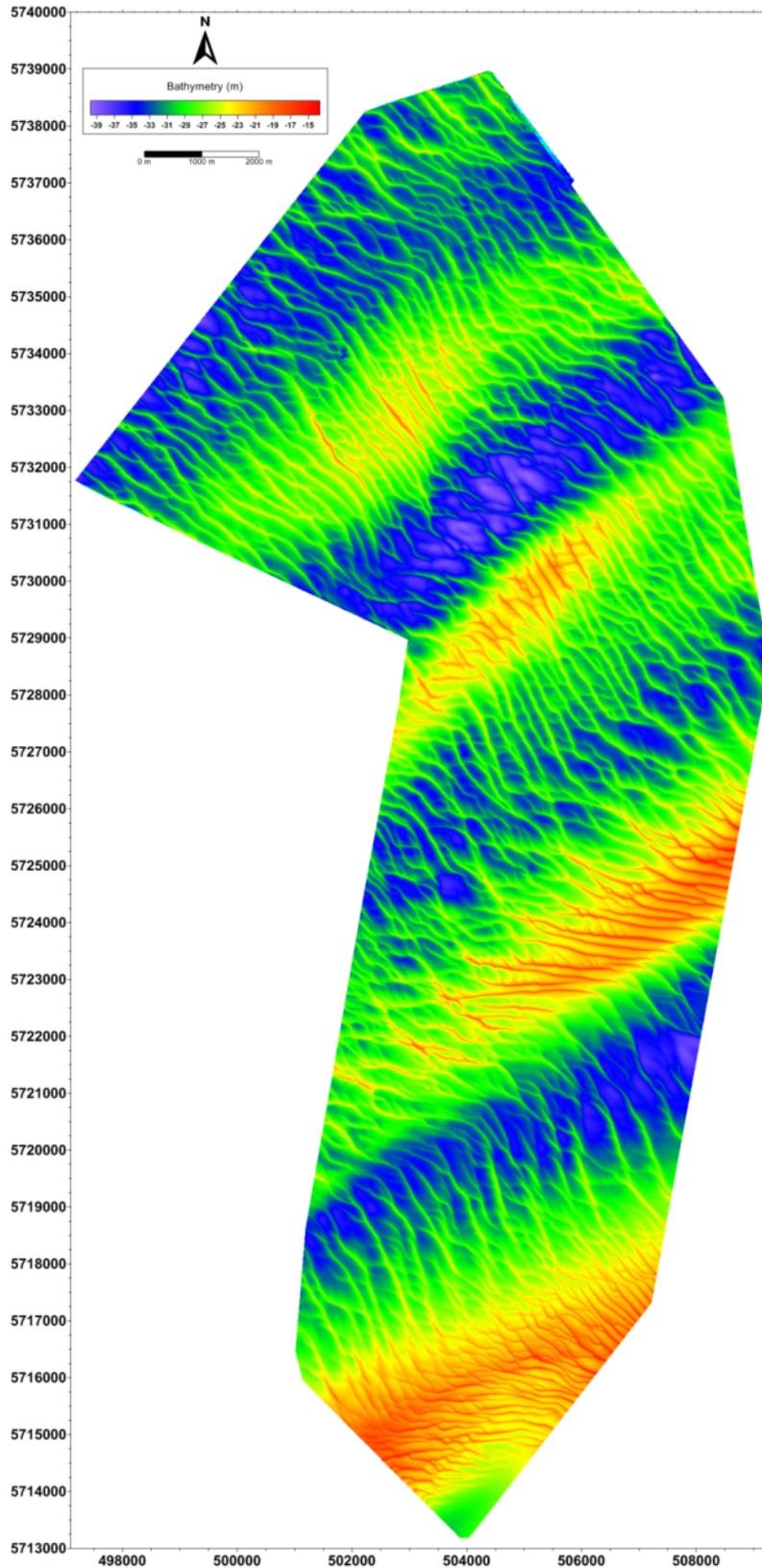
- Frequency Bandpass noise filtering and F-K Filtering;
- Source deghosting in pre-stack;
- Static corrections of the swell motion of the source and receiver groups;
- Prestack multiple attenuation, using Wave Equation Multiple Rejection - WEMR;
- Velocity analysis every 500 CDPs;
- NMO correction and CDP ensemble stacking;
- Final migration carried out at poststack, using Kirchhoff Time Migration to recover true geometry of primary reflections;
- Tide correction of the stacked sections.
- Depth conversion of the time stack using the velocity model obtained from the velocity analysis.

### **1.3. Infrastructure and personnel**

The seismic data management, processing and report were done with four workstations, using the seismic processing software *ProMAX* from Landmark Graphics Corporation and *Radex Pro* from Deco Geophysical.

The following team processed the seismic data and prepared the report:

1.	H. Duarte	Senior Geophysicist	GEOSURVEYS
2.	D. Gonçalves	Geophysicist	GEOSURVEYS
3.	J. Miranda	Geophysicist	GEOSURVEYS
4.	N. Alves	Junior Geophysicist	GEOSURVEYS
5.	B. Duarte	Junior Geophysicist	GEOSURVEYS
6.	J. Santos	Junior Geophysicist	GEOSURVEYS



**Figure 3** – Bathymetry of the survey area. A vast sand wave field is clearly visible between sand ridges that are orientated NE-SW. Image in UTM Z31 N, Datum ETRS89.

## 2. DATA ACQUISITION

The survey site sparker data acquisition was carried out on board of the vessel SeaZip Surveyor between 17<sup>th</sup> and 28<sup>th</sup> January, 2015. The multi-channel seismic spread consisted of a 200 tips Geo-Spark, powered by a 2000X Geo-source (2 kJ) and a Geomarine Geosense 48 analogue streamer (48 channels, between Ch 1 - Ch 24 group interval of 1 m and between Ch 24 - Ch 48 spacing of 2 m).

The geometry used is schematized in Figure 4 with the specific vessel layout and offset values of the seismic spread.

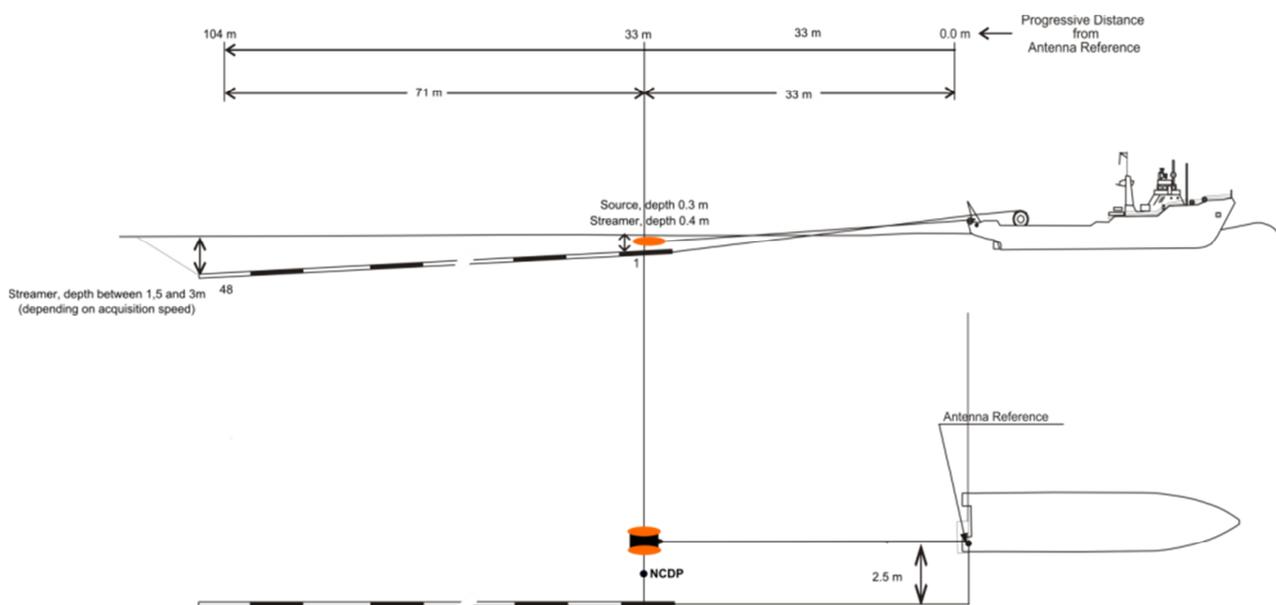


Figure 4 – Vessel Layout and offset diagram to the seismic spread for survey area (not to scale).

### 2.1. Acquisition Parameters

The streamer used had 48 channels with a single element per group, between Ch1 – Ch24 group spacing of 1 m and between Ch24 – Ch48 spacing of 2m for a total active length of 69 m. Shooting was 1 m spaced, with nominal CDP bin fold of 48. Shot points were determined with the primary positioning system Trimble RTK-DGPS and C-NAV differential corrections service as secondary backup. The coordinate system of the positioning data is UTM Zone 31N, in the datum ETRS89.

The acquisition parameters are schematized in Table 1.

**Table 1 – RVO-OW survey area acquisition parameters.**

<b>Source</b>	<i>Geo-Spark 200</i>
Source Towing Depth	≈ 0.3 m
SP Interval	1 m
Operating Power	400 J
Power Supply	Geo-source 2000X (2 kJ)
CDP Bin Coverage	48 fold
<b>Streamer</b>	<i>48 Channel GeoSense streamer (69 m active length)</i>
Streamer Depth	Variable from 0.3 m in Ch1 up to 1.5 – 3 m at Ch48
Group Interval	Variable (Ch1-Ch24 group interval of 1 m ; Ch24-Ch48 group interval 2 m)
Group Active Length	Single element
<b>Recorder</b>	<i>Multitrace 48 – Geomarine Survey Systems</i>
Sample Rate	0.1 msec
Record Length	300 ms
Format	SEG-Y

## 2.2. Line Identification

The lines were identified by the planned line number, followed by the line Kp position on the survey area (eg. 1-100)., cross lines were identified with a X after the line identification number (eg. 173-X-2000) the extra cross lines added to the original survey plan were named X-Inline plus the Kp position on the area (eg. X-Inline800).

## 2.3. Navigation and Positioning

The navigation and positioning was carried out with a Trimble RTK-DGPS as a primary positioning system and C-NAV differential corrections service as secondary backup. Streamer positioning was controlled with two AIS transponders located in the leading and tail buoy for control of streamer feather angle. The data is in UTM Zone 31 Northern Hemisphere coordinates, referred to the ETRS89 datum (Table 2).

**Table 2 – ETRS89, UTM Zone 31 Northern Hemisphere geodetic parameters.**

<b>Datum</b>	ETRS89
<i>Spheroid</i>	GRS 80
Semi-major axis	6378137.00 m
Semi-minor axis	6356752.31 m
Flattening (1/f)	298.257223563
<b>Chart Projection</b>	
Projection	Universal Transverse Mercator, Z31N
Latitude of Origin	0° N
Central Meridian	3°
Central Meridian Scale Factor	0.9996
False Easting	500 000 m
False Northing	0 m

### **3. DATA QUALITY ANALYSIS**

The seismic lines underwent thorough a quality control procedure of the signal quality and acquisition geometry, in order to ensure that the data could be successfully processed.

#### **3.1. Signal & noise analysis**

##### **3.1.1. Shot and trace gather display**

The data was inspected in the shot and trace domain to assess overall signal quality, noise types and any electrical or recording issues. Missed shots and noisy traces deemed unusable were flagged as killed traces. The following types of noise were recognised:

- Weak 50 Hz (and harmonics) electrical noise. No detrimental effect in the S/N Ratio of the records, it did not compromise meeting the requirements.
- Burst noise in the near channels when the sparker sled was towed very close to the near receiver (~1 m offset), due to the effect of cross currents. Some burst noise was also observed related with swell break, this noise only affected the near channels due to their closer proximity to the sea surface. Burst noise did not degrade the quality of the data.
- Prop wash noise (~200-300 Hz) is observed in some lines, probably more predominant in the lines run with cross surface currents. This noise overlaps the low frequency content of the source signal and was, for the majority of the lines, attenuated through stacking. Nevertheless, the S/N at depth (>100 m) was degraded by this noise. The impact of this noise on the data was judged significant enough in some lines to warrant a more aggressive Low cut filter. A residual component of the resulting prop wash noise in the stacks appeared as slanted stripping; this noise was successfully attenuated with a F-K filter.
- Sudden geometry variations during the acquisition of the lines had a negative impact during the processing stage especially during the migration process causing burst like features in the data.

##### **3.1.2. Spectral analysis**

The spectral response of the data was compared with a reference wavelet derived from a seabed reflection stack, in order to assess the recorded signal stability both in shot and trace domain (see Figure 5 & Figure 6). The recorded wavelet was very stable throughout the whole survey, signalling that the sparker source had high quality repeatability and the towed gear remained at a very stable depth throughout the survey.

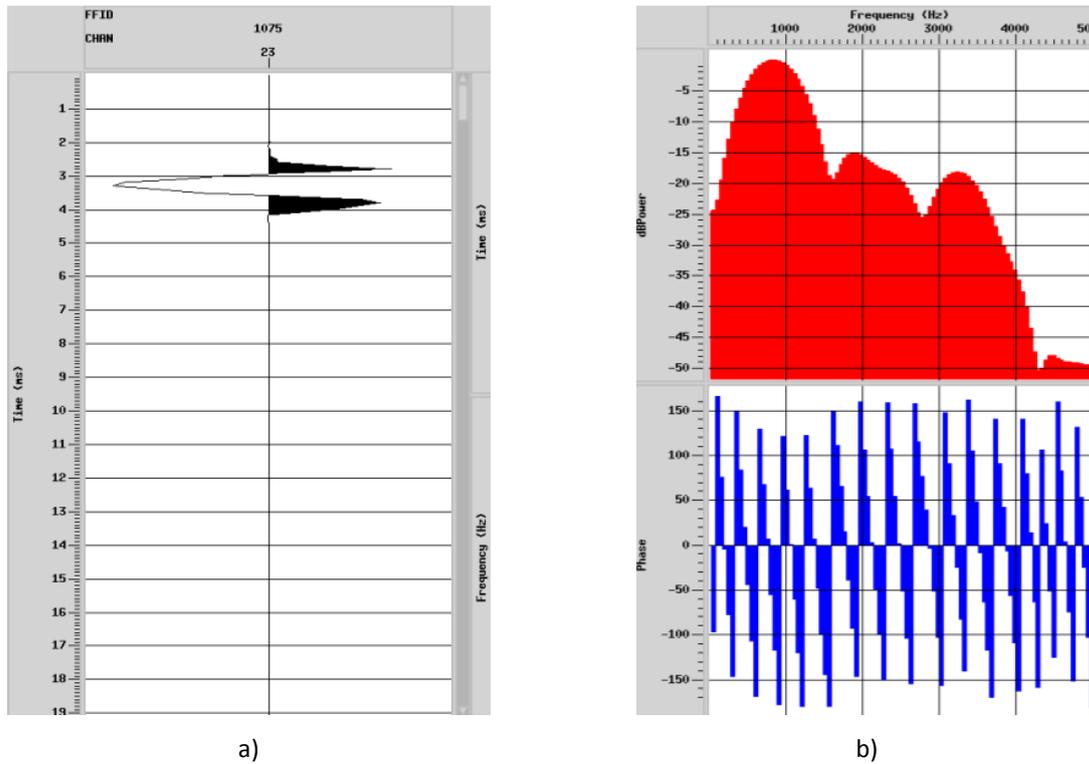


Figure 5 - Recorded sparker wavelet (a) firing at 400J and corresponding frequency spectrum (b) (in dB) for data acquired at 10 kHz.

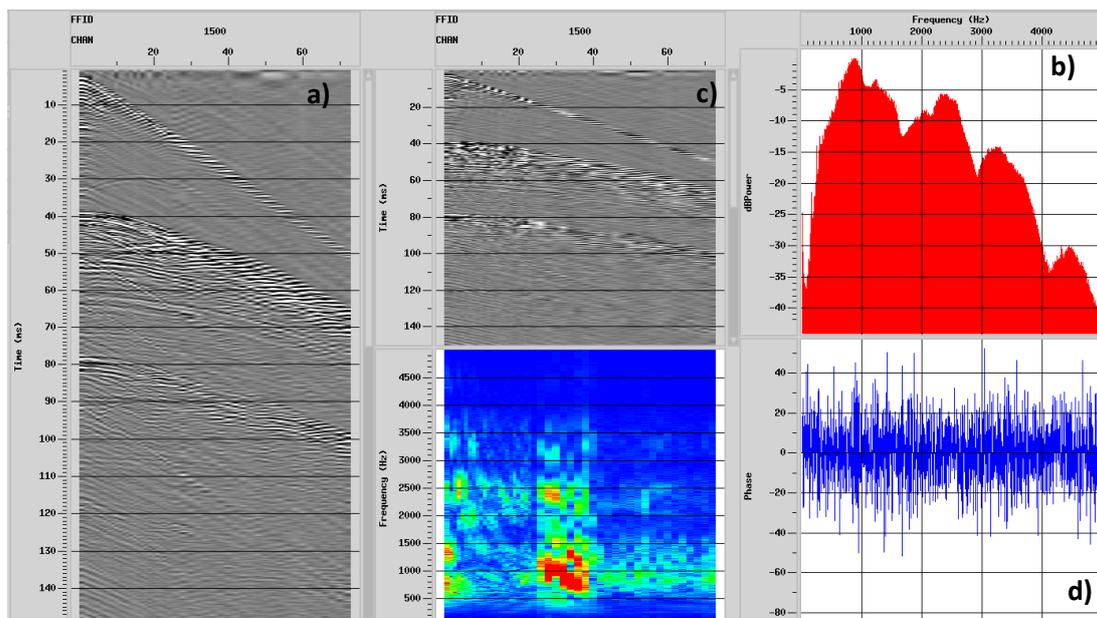
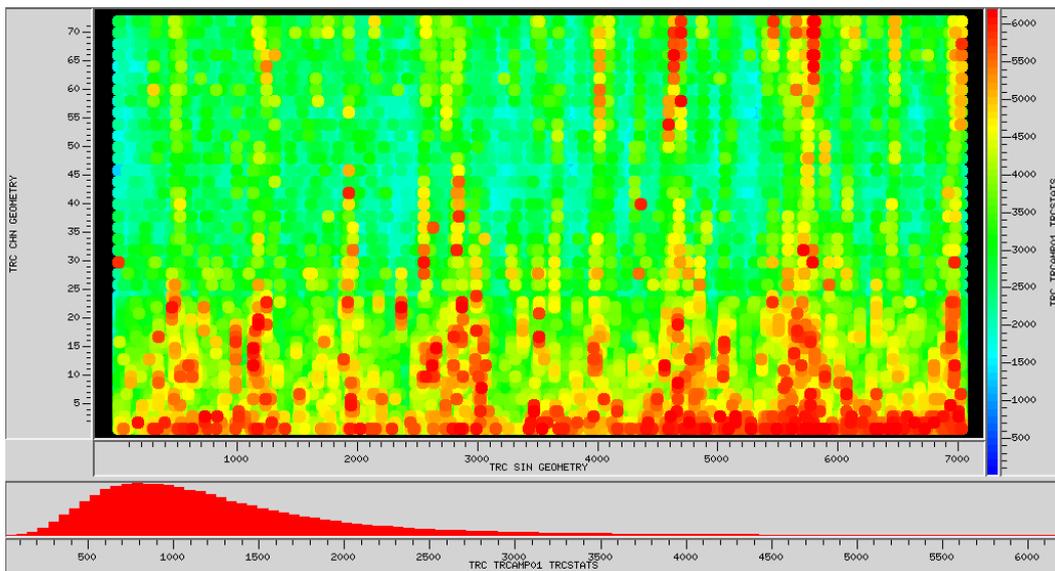


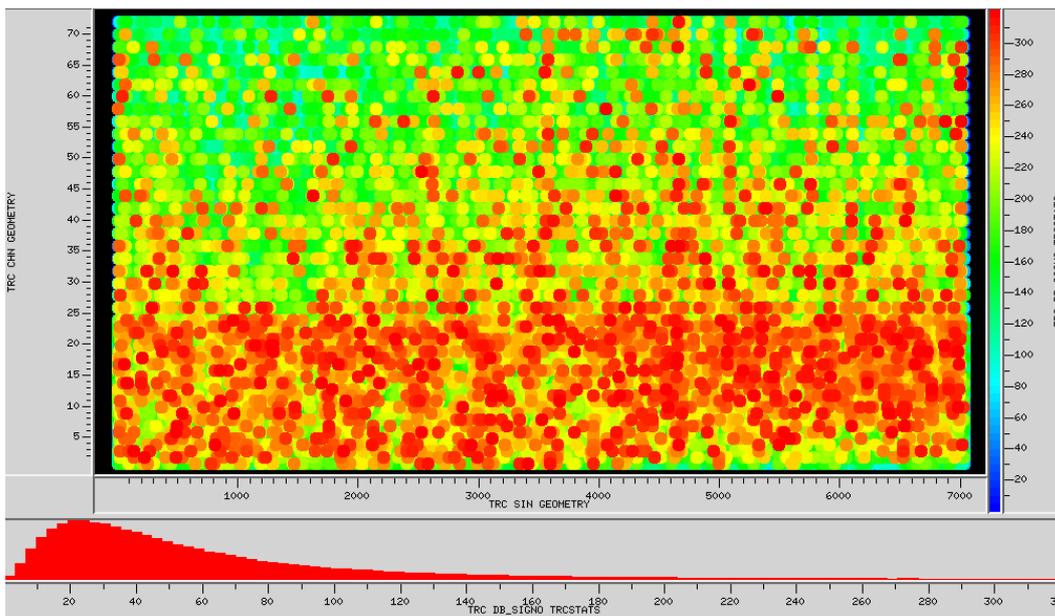
Figure 6 – Example of spectral analysis in the shot domain showing the (b) average power spectrum, (c) FX power spectrum and (d) average phase spectrum for the selected trace data shown in (a).

**3.1.3. Amplitude statistics**

The average amplitudes of selected time gates of the pre-stack data were computed to assess noise and signal to noise ratios. A 4 ms time gate, just above the seabed, was used to calculate noise amplitudes. The first 4 ms referred to the seabed were used to compute the average amplitude of the signal. Noise and signal to noise ratios were then represented in channel versus shot plots for troubleshooting and general assessment of the signal quality of the line (Figure 7 & Figure 8).



**Figure 7** – Noise plot for the line 112-11200c, as measured in average amplitudes of a 4 ms time gate.



**Figure 8** – S/N plot for the line 112-11200c. The signal average amplitudes were computed in a 4 ms time gate starting at the seabed. No noisy or dead channels were observed along all the survey.

## **3.2. Acquisition Geometry control**

### **3.2.1. Feathering**

The mode, mean, median and maximum streamer feathering were computed for all processed lines and the computed streamer feathering angles were plotted on a shot by shot basis (Figure 9). The streamer feathering mode of the processed lines ranges from 0 to 23.5°, however, most of the lines present feathering angles averaging 3 to 8°. The maximum feathering angles can be achieved 44° and are generally associated to the early start of recording during line turns. Very strong lateral currents can also produce feather angles above 20 ° in the streamer.

Streamer depth is determined offline as standard offline QC procedure. The procedure is based on the analysis of the changes across offsets of the wavelet shape and frequency spectrum. Lines that do not respect minimum requirements for towing depth are flagged for rerun.

### **3.2.2. Source receiver offsets**

In order to determine reliable source-receiver geometry for each line, the direct arrivals were measured in trace domain plots and converted to meters using measured sound velocity profile data (SVP).

In average the streamer was located inline with the source and 2.5 m starboard. However, the source-receiver relative position was changing during the survey, due probably to surface currents, more rarely due to poor steering and possibly minor modifications of the geometry during equipment recovery and deployment operations.

### **3.2.3. CDP fold track plots**

Impact of the steering and navigation on the CDP bin fold regularity was assessed with CDP fold track plots (Figure 10). All lines present a mean CDP fold of 48, however, in lines steered poorly and/or with strong streamer feathering the maximum CDP fold can reach 72. Fold coverage value is stored in header - Number of Horizontally Stacked Traces (NHST) – Bit position 33-34 in the Segy file. The trace fold header values stored in the stacked sections were used to assess the cumulative impact of steering & feathering, failed shots and missed records (i.e. bad shots) (Figure 10).

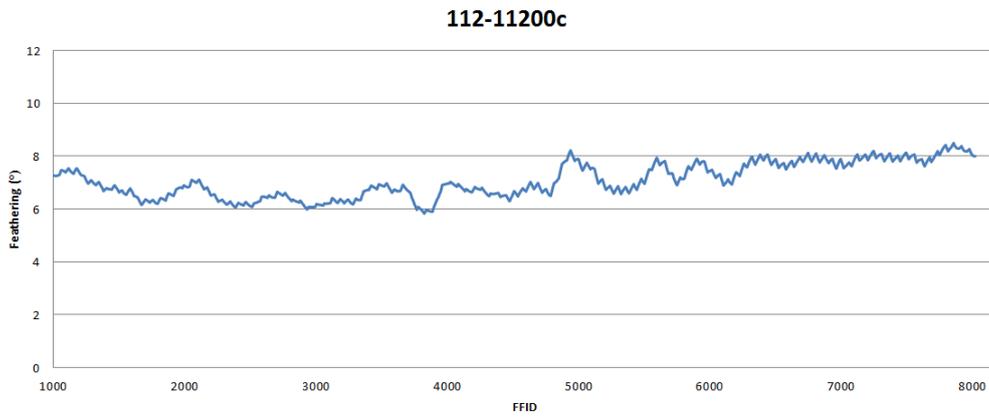


Figure 9 – Streamer feathering angle for the line 112-11200c.

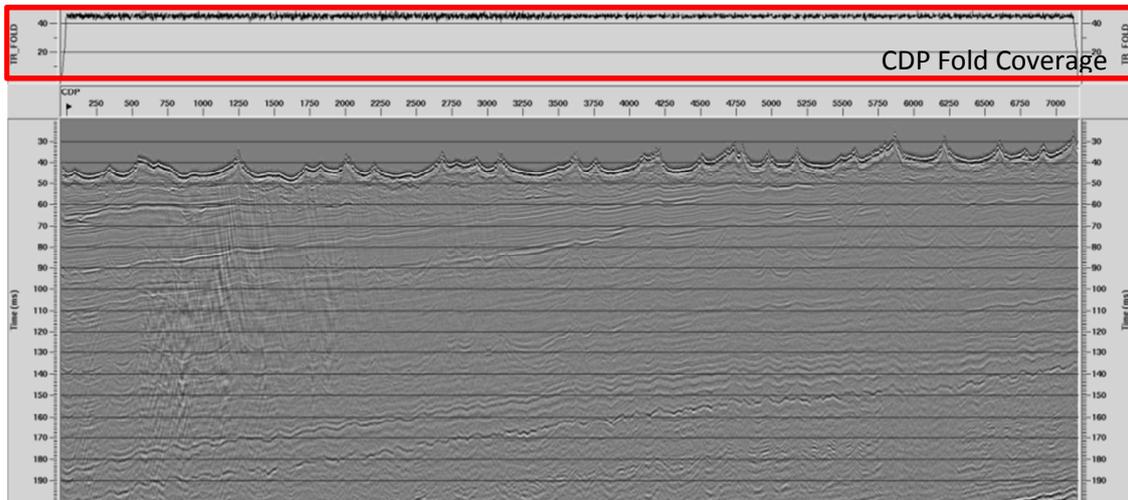


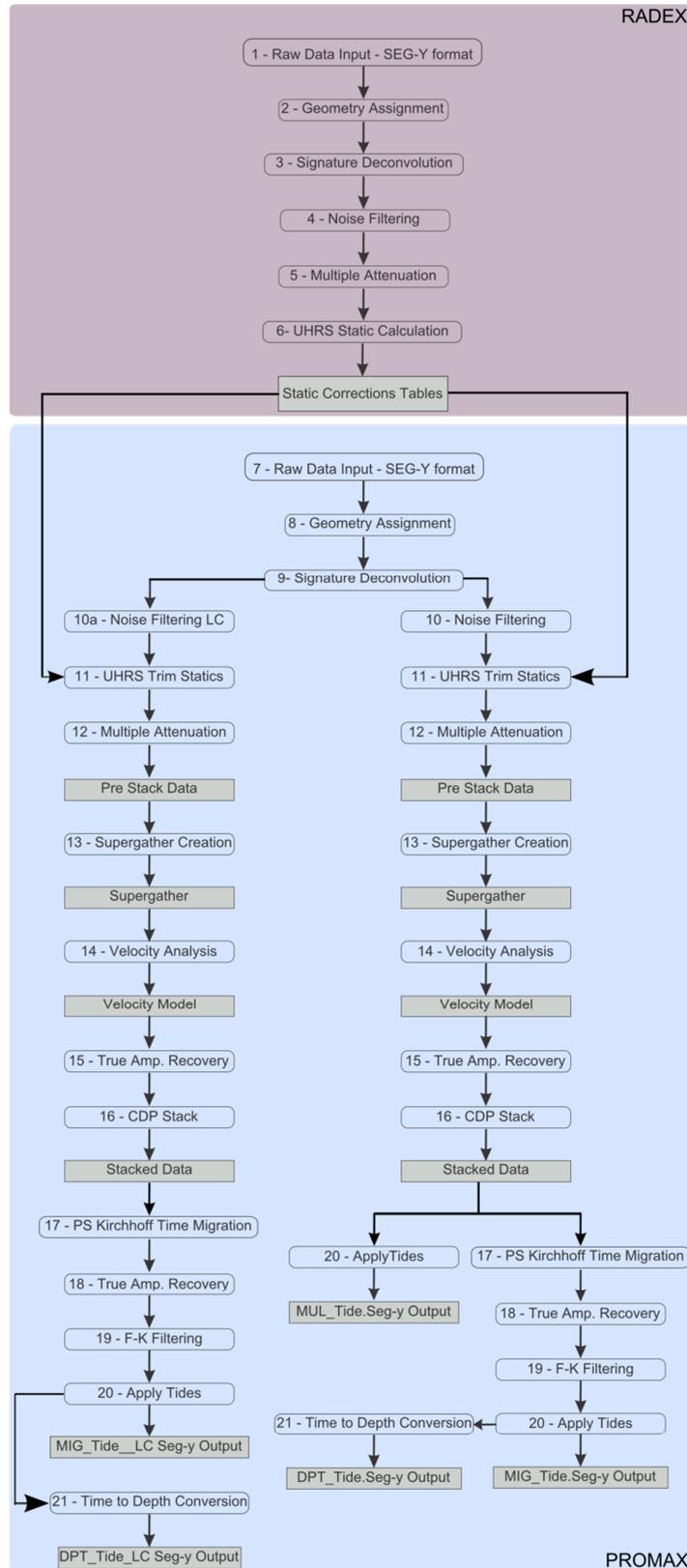
Figure 10 –Example of Migrated section of line 112-11200c with projection of CPD fold coverage along the line (red box) for QC control.

#### **4. SEISMIC DATA PROCESSING**

76 multi-channel seismic profiles (including re-runs, infills, and sectioned lines) were processed using the ProMAX and RadexPro software, making a total sail length of approximately 654 km and covering an area of approximately 173 km<sup>2</sup>. The processing was focused on improving the seismic section resolution and overall signal quality in the first 80 m below the seabed.

##### ***4.1. Processing Sequence***

The processing flow applied to the site data is schematized in Figure 11 and the processing workflow details applied to the site area are presented in Table 3.



**Figure 11** - Processing workflow applied to the seismic lines. Rounded boxes represent the processing steps and grey boxes represent the products outputs. Processes in violet and blue boxes represent the processes developed in RadexPro software and ProMax, respectively.

**Table 3 – RVO-OW UHRS data processing details.**

RadexPro PROCESSING		
<b>1</b>	<b>SEG-Y Data Input</b>	
<b>2</b>	<b>Geometry</b>	
	CDP Bin size:	1
	Nominal CDP fold:	48
<b>3</b>	<b>Pre-stack deghosting deconvolution</b>	
	Filter option:	Inverse
	Percent additive noise factor:	3%
	Type of operator:	Time domain
	Filter length:	2.4-12 ms
<b>4</b>	<b>Ormsby Bandpass Frequency Filter</b>	
	lc – lp – hp – hc:	60 – 120 – 4000 – 5000
<b>5</b>	<b>Butterworth Bandpass Frequency Filter</b>	
	lc – dB – hc – dB::	600 – 12 – 1000 – 32
<b>6</b>	<b>UHR Statics Calculations</b>	
	Receiver Statics	<i>Output of REC_STAT.dat file for ProMAX</i>
	Source Statics:	<i>Output of SOU_STAT.dat file for ProMAX</i>
	Receiver Statics_2:	<i>Output of .REC_STAT2 file for ProMAX</i>
ProMAX PROCESSING		
<b>7</b>	<b>SEG-Y Raw Data Input</b>	
<b>8</b>	<b>Geometry</b>	
	CDP Bin size:	1
	Nominal CDP fold:	48
<b>9</b>	<b>Pre-stack deghosting deconvolution</b>	
	Filter option:	Inverse
	Percent additive noise factor:	3%
	Type of operator:	Time domain
	Filter length:	50 ms
<b>10/10a</b>	<b>Butterworth Bandpass Frequency Filter</b>	
	lc – dB – hc – dB:	190 – 16 – 1000 – 24
	lc – dB – hc – dB:	600 – 12 – 1000 – 24 *LC
<b>11</b>	<b>UHRS trim statics</b>	
	Receiver Statics:	Input of REC_STAT.dat file from RadEx Pro
	Source Statics:	Input of SOU.STAT.dat file from RadEx Pro
	Receiver Statics (only applied in data acquired in bad weather conditions):	Input of REC_STAT2.dat file from RadEx Pro
<b>12</b>	<b>Wave Equation Multiple Rejection</b>	
<b>13/14</b>	<b>Interactive Velocity Analysis</b>	
	Supergather size:	1 CDP for semblance, 31 for dynamic stack
	Interval of Analysis:	500 CDPs (500 m)
	Output Model:	IVA RMS 1st pass
<b>15</b>	<b>Normal Moveout Correction</b>	
	RMS velocities:	IVA RMS 1st pass
	Mute Stretch threshold:	35%
<b>15</b>	<b>dB/sec corrections</b>	
	Start time:	Water bottom

	Constant:	35
<b>16</b>	<b>CDP ensemble stack</b>	<b>MUL.Seg-y Output</b>
	Alpha-trimmed Mean:	35%
<b>17</b>	<b>Post Stack Kirchhoff Time Migration</b>	
	Maximum migrated frequency:	3000 Hz
	Velocity (CDP:T1-V1, T2-V2, T3-V3):	1:0-1486,70-1486,300-1700
<b>18</b>	<b>Spherical Divergence correction</b>	
	Basis for spherical spreading:	1/(time*vel^2)
	Velocity parameter:	IVA RMS 1st pass
<b>18</b>	<b>dB/sec corrections</b>	
	Start time:	Water bottom
	Constant	65
<b>19</b>	<b>F-K Filter</b>	<b>MIG or MIG_LC Seg-y Output</b> (depending on initial Filter)
<b>20</b>	<b>Apply Tides</b>	<b>To all MUL and MIG Seg-y files</b>
<b>21</b>	<b>Convert time to depth</b>	<b>DPT Seg-y Output</b>
	Maximum frequency of interest:	2000 Hz
	Velocity parameter:	IVA RMS 1st pass smoothed (triangular 1500 CDPs)

## **4.2. Description of Most Relevant Processing Flows**

### **4.2.1. UHRS Statics Calculations**

Calculation of the towed equipment vertical motion was carried out in RadEx Pro. This procedure was developed in-house by Geosurveys, it includes a comprehensive review of automated picks of all shots, doubling up as a geometry and signal QC procedure of the full data set.

The trace by trace calculated residual statics to compensate the vertical motions of the towed equipment were exported from RadEx Pro for later import and application in ProMAX Software.

### **4.2.2. Geometry Assignment**

The geometry table was filled using source positions and the streamer azimuth from the navigation files. The source-near receiver offsets were computed from measured direct arrival times and near surface sound velocity in the water measured by sound velocity profile acquired during the survey. The procedure used provides a best estimate of the midpoints given the known source position and streamer azimuth and reliably assigns geometry to crooked lines. The following parameters were used:

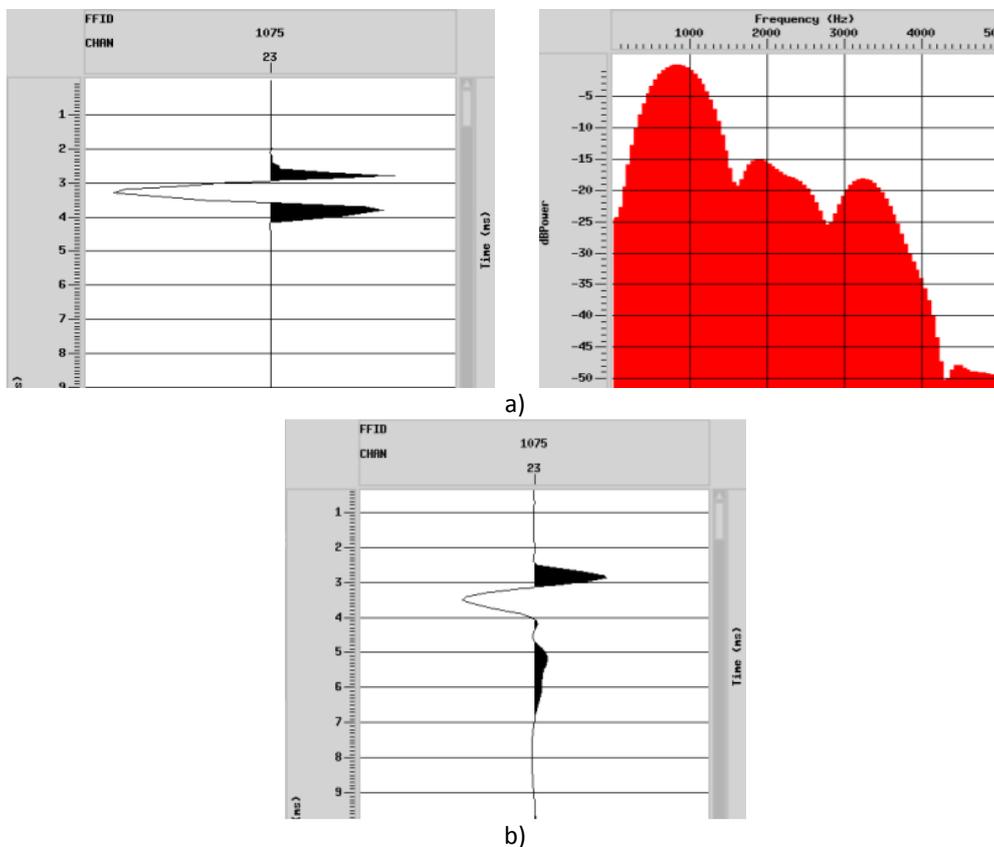
- Nominal receiver station interval: 1 m;
- Source station interval: 1 m;
- Nominal Source depth: 0.3 m;
- Nominal Receiver depth: 0.3 m.

Midpoints were computed for each trace and CDP assigned in 1 m bins.

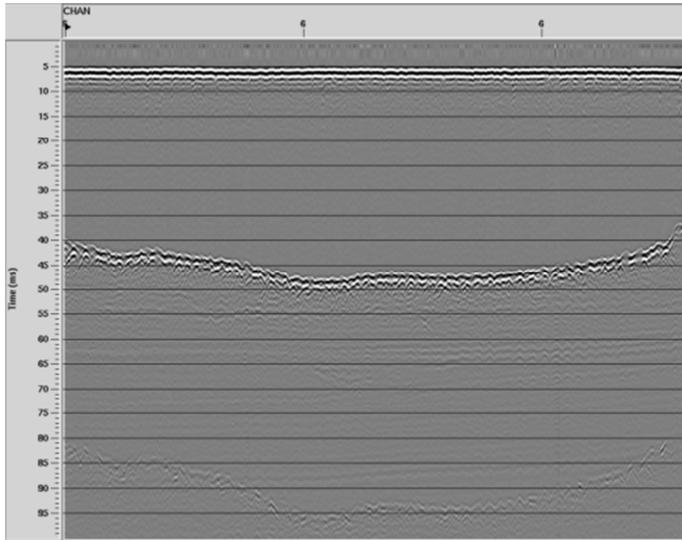
#### 4.2.3. Pre-stack signature deconvolution

The Source signature deconvolution was used to collapse the outgoing primary source pulse as well as removing both the source and receiver ghosts. The recorded source signature was modelled using an average seabed reflection resulted from a selection of traces with a good record of the seabed response. The signature model was compared with reference hydrophone records and was shown to reliably represent the record wavelet. The source was fired at 400 J and was towed at a depth of approximately 30 cm while the receiver array was towed at variable depth along the active section (0.3 m at channel 1 and 1,5 – 3 m in the last channel). A filter generation was used to derive the filter operator for the deconvolution of the recorded wavelet model (Figure 12Figure 13). An example of data deconvolution can be seen in Figure 13.

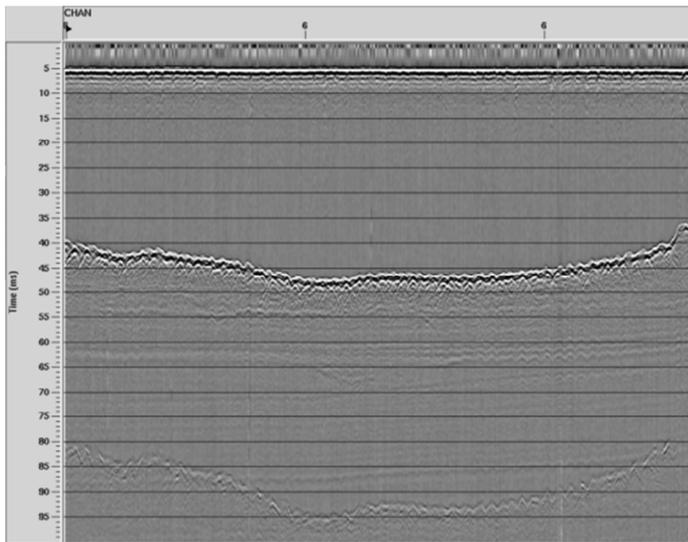
A warning should be added that the final wavelet of the stack will preserve a residual ghost energy and the have an apparent zero-phase shape.



**Figure 12-** Top a) – Source signature and FFT; Bottom b) - Deconvolved output, minimum phase, reverse polarity (i.e increase impedance marked by an increased amplitude in a minimum phase wavelet).



a)



b)

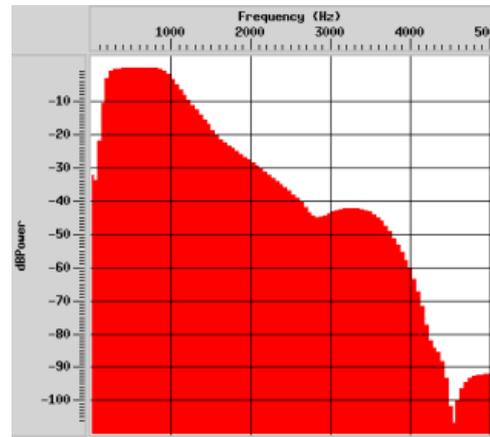


Figure 13 – Line 112-11200c before (a) and after (b) signature deconvolution (Ch 6).

#### 4.2.4. Noise Filtering

A minimum phase Butterworth bandpass filter was used in this processing for noise suppression in frequency domain. It required a percent zero padding for Fast Fourier Transform (FFT) as 25.0% and a frequency-slope values group for Butterworth filter of 190-16-1000-24:

Low Freq.: 190 Hz

Slope (Low roll-off): 16 dB/octave

High Freq.: 1000 Hz

Slope (High roll-off): 24 dB/octave

The 1000 Hz upper bandpass corner was used in order to eliminate the source ghost that appears at a frequency of about 1600 Hz, as a consequence of the chosen streamer geometry (dipping) to enable penetration to 80 m through sandwaves. Additionally, the performed automatic statics routine can only operate up to frequencies of approximately 1500 Hz, and higher frequencies require a manual statics analysis (which would increase the processing time by approximately 40%).

During the processing QC stage it was noted that in some of the lines acquired there is a higher amount of Low Frequency Noise (200-400 Hz) related with propeller wash in conjugation with high feather angles. For this reason it was decided to apply a different frequency filter for these lines. All the lines where this filter was used present the suffix `_LC` in the `seg-y` file. The alternative frequency filter used was the following:

A minimum phase Butterworth bandpass filter was used. It required a percent zero padding for Fast Fourier Transform (FFT) as 25.0% and a frequency-slope values group for Butterworth filter of 600-12-1000-24:

Low Freq.: 600 Hz

Slope (Low roll-off): 12 dB/octave

High Freq.: 1000 Hz

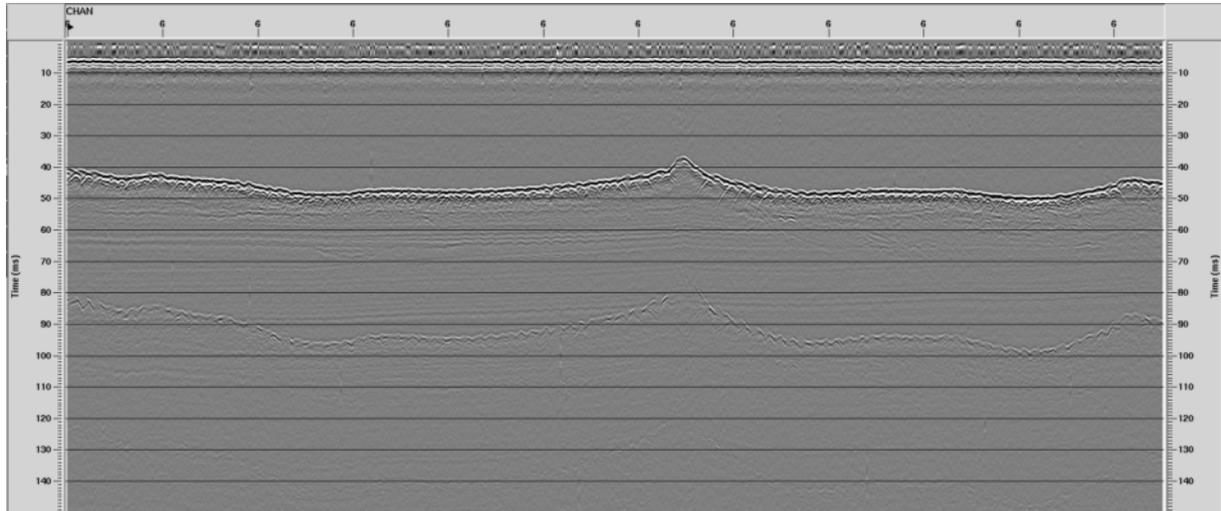
Slope (High roll-off): 24 dB/octave

#### **4.2.5. Multiple Attenuation - WEMR**

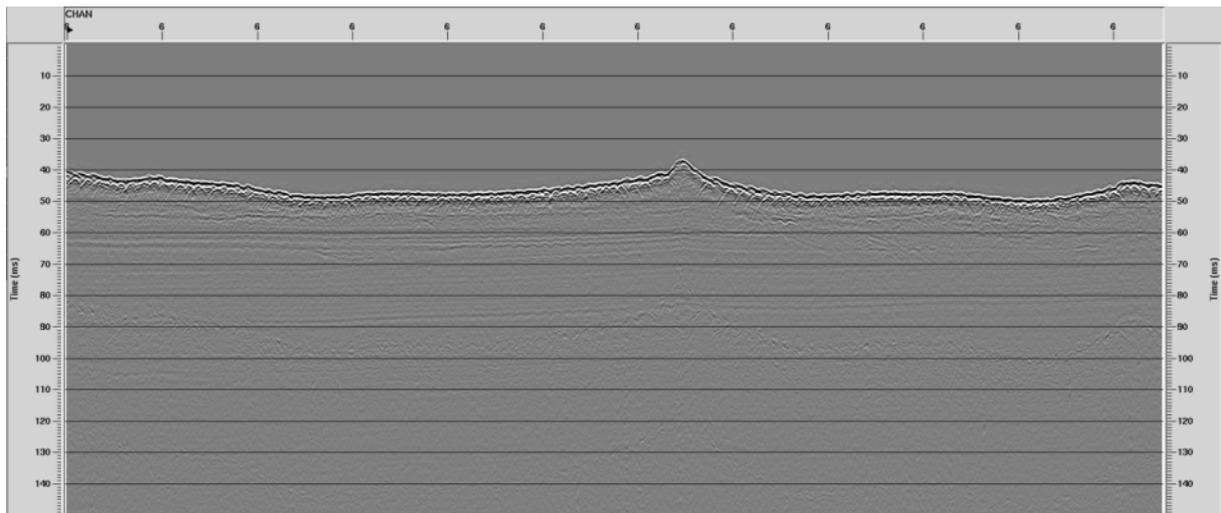
Pre-stack multiple attenuation consisted in the testing and application of a surface related multiple attenuation technique named “Wave Equation Multiple Rejection - WEMR” for improved imaging of the geology at multiple depths. This process models and attenuates the multiple energy train, through top muting 5 ms above the seabed (Figure 14).

The effectiveness of the de-multiplying was sometimes compromised due to poor weather conditions that destabilised the streamer. Even though, multiple energy still remains in the final sections, the interpretability to greater than 80 m has been achieved.

Besides WEMR, other multiple attenuation methods were taken into account, such as Radon filtering, SRME and predictive deconvolution. Radon filtering was ruled out due to the high frequency content and SRME would have been extremely time consuming. Both predictive deconvolution and WEMR were tested, however WEMR gave the best results, with less multiple energy remaining on the seismic sections.



(a)



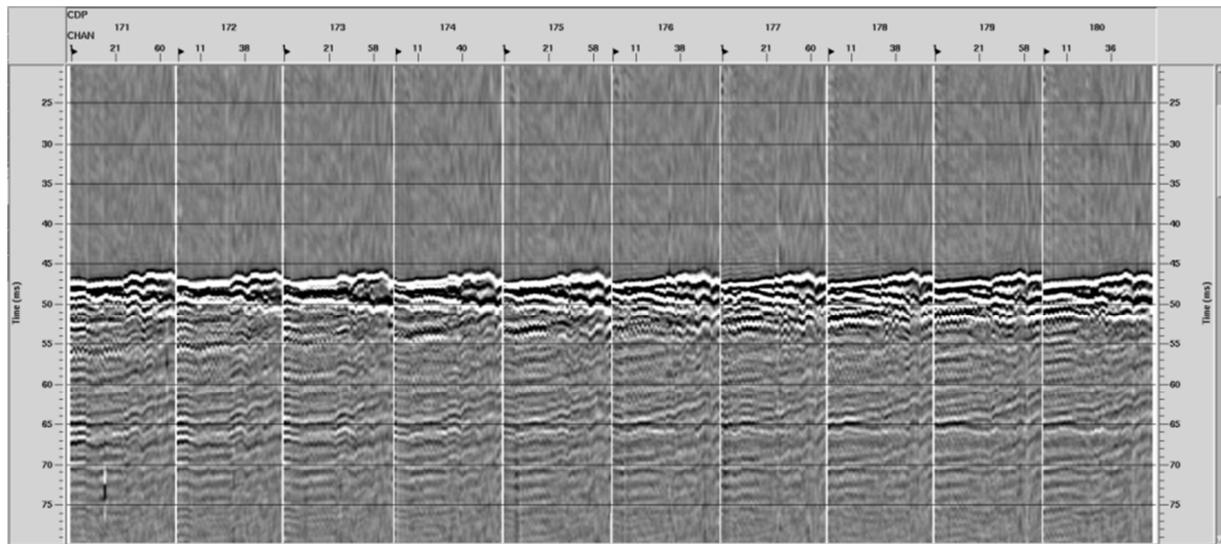
(b)

Figure 14 – Line 112-11200c before (a) and after (b) multiple attenuation.

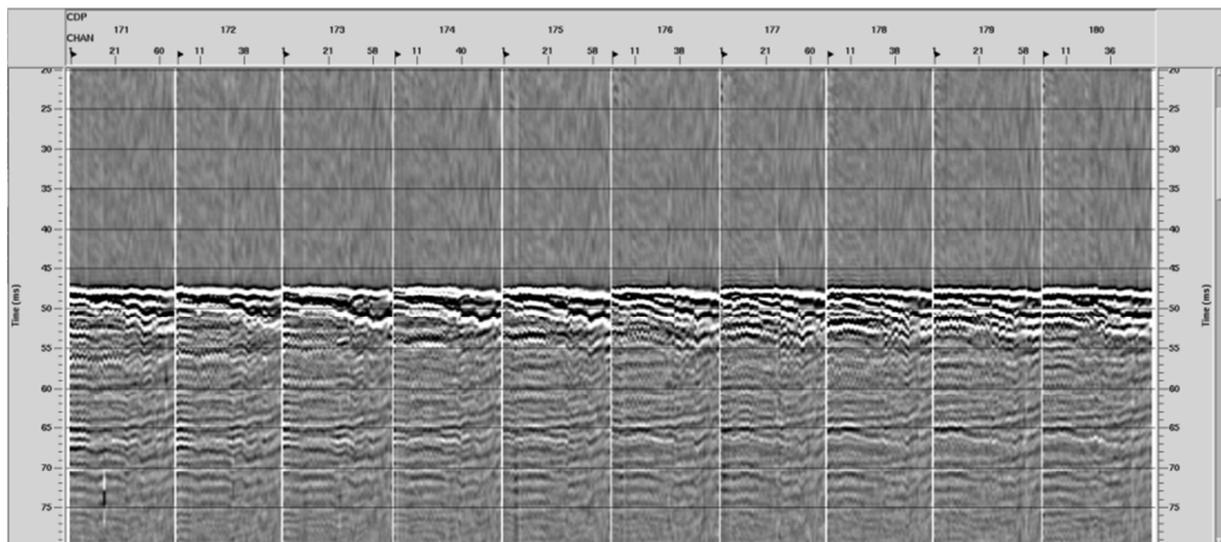
**4.2.6. UHRS trim statics**

The source and cable statics, here called trim statics, included a trace by trace residual static correction procedure to compensate for the vertical motions of the towed equipment. This procedure was developed in-house by Geosurveys, it includes a comprehensive review of automated picks of all shots, doubling up as a geometry and signal QC procedure of the full data set.

The residuals previously calculated in RadEx Pro were imported and applied in ProMax and the result can be seen in Figure 15.



(a)

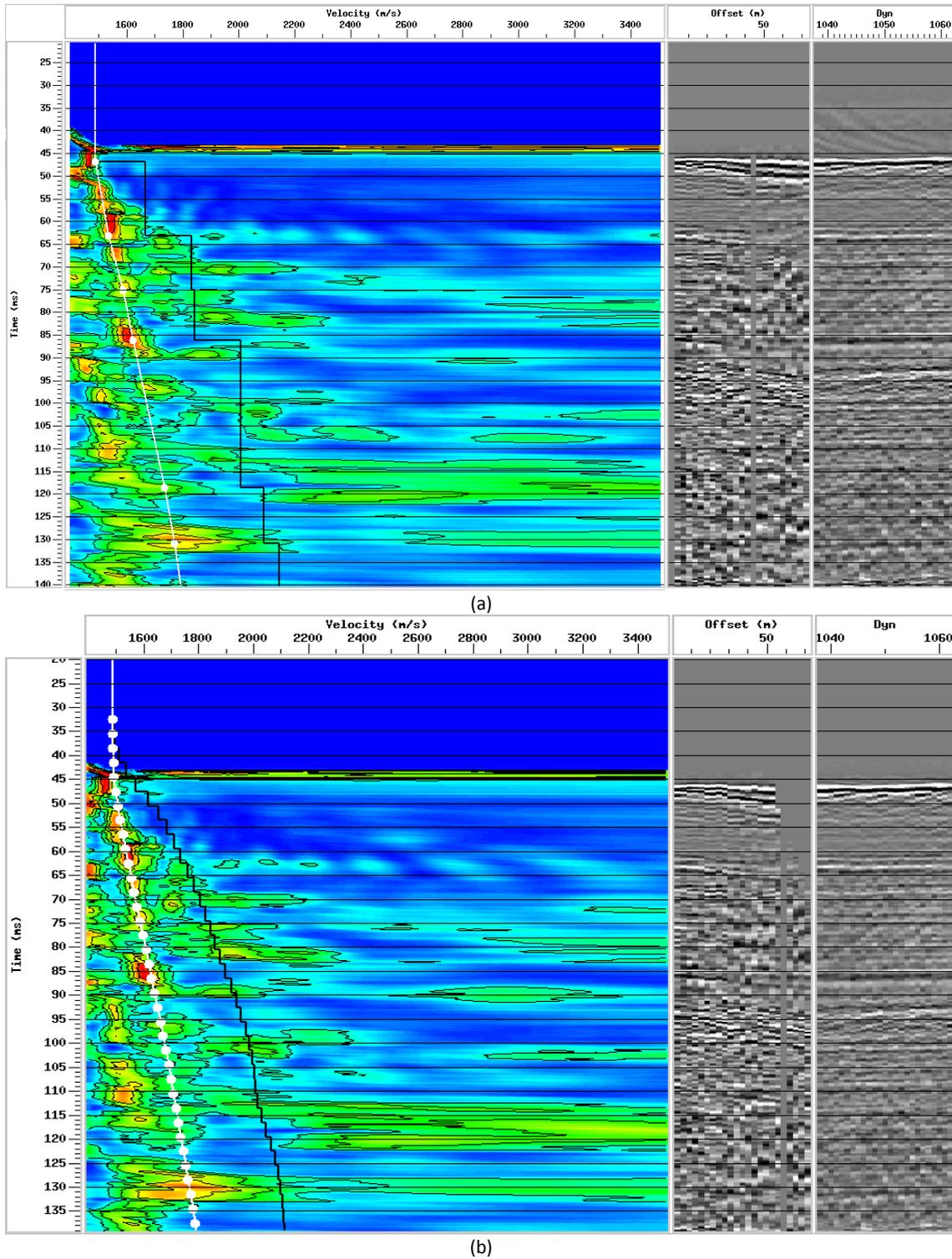


(b)

**Figure 15** – Line before (a) and after (b) residual static corrections for the line 112-11200c, data sorted by CDP, after NMO correction with sound velocity in the water.

#### 4.2.7. Supergather Creation and Velocity Analysis

Supergathers were generated every 500 CDPs comprising 31 CDPs to build the dynamic stack and the velocity analysis was performed using a semblance of 1 CDP. A RMS and interval velocity model was generated through the interactive velocity analysis, with a horizontal resolution of 500 m (see Figure 16a). The velocity model was used for both NMO and amplitude corrections. The velocity model was smoothed with an interval of 1500 m and a triangular weighting (see Figure 16b) and used in the depth conversion procedures.



**Figure 16** – Picked velocity model (a) and smoothed velocity model (b) for CDP 1050 for line 112-11200c. The white line represents the stacking (RMS) velocity and the black line shows the interval velocity. This figure illustrates an effective signal penetration >100ms.

#### 4.2.8. NMO correction

The derived velocity fields were used to apply the NMO corrections to the CDP gathers. A stretch mute threshold of 35% was applied.

#### 4.2.9. True Amplitude Recovery

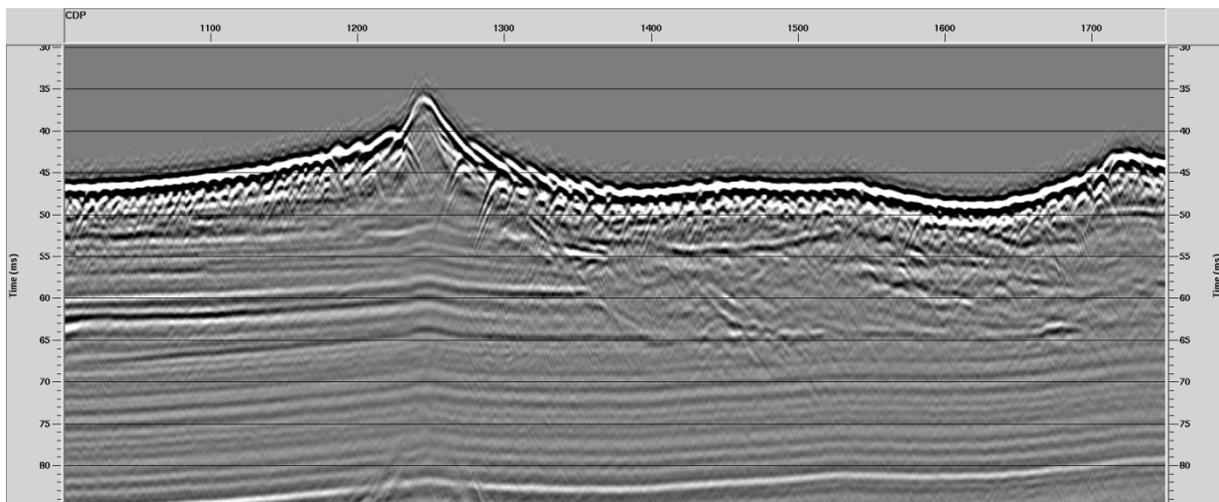
True amplitude recovery applies a time variant gain to traces to compensate for loss of amplitude due to wave front spreading and attenuation. Both, spherical divergence and dB/sec corrections were applied to the data, to compensate, respectively, for loss of amplitudes due to spherical wave front spreading and attenuation in the geological medium.

#### 4.2.10. CDP Stack

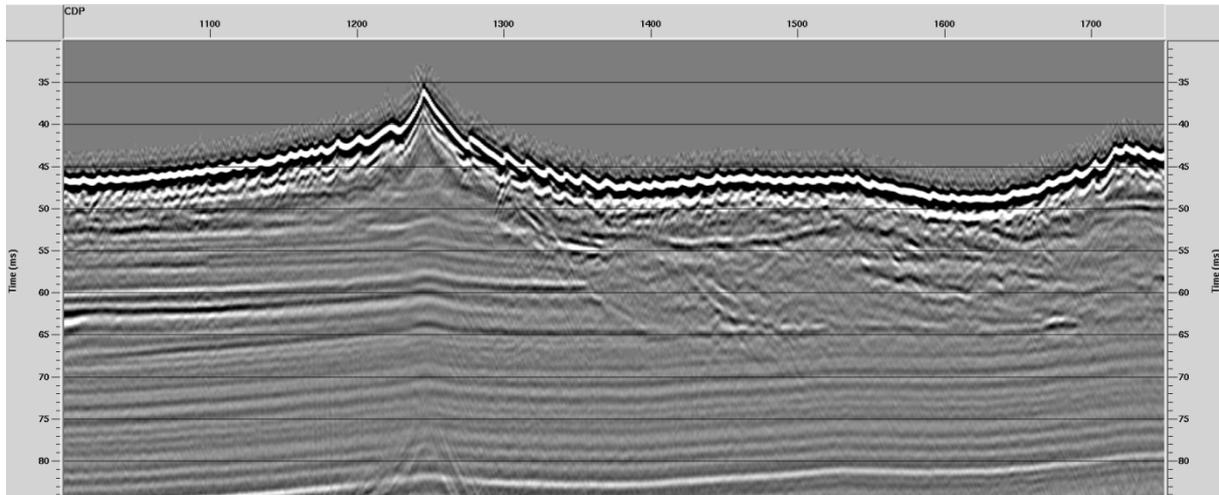
The CDP gathers were stacked using an alpha trimmed mean with a rejection of 35% of the sample outliers.

#### 4.2.11. Post Stack Kirchhoff Time Migration

This procedure performs a migration by applying a Green's function to each CDP location using an analytic RMS velocity NMO curve. The Kirchhoff migration was applied using a maximum migration frequency of 3000 Hz and the following time variant velocity function (T1-V1, T2-V2, T3-V3): 0 ms - 1486 ms<sup>-1</sup>, 70 ms - 1486 ms<sup>-1</sup>, 300 ms - 1700 ms<sup>-1</sup>.



(a)



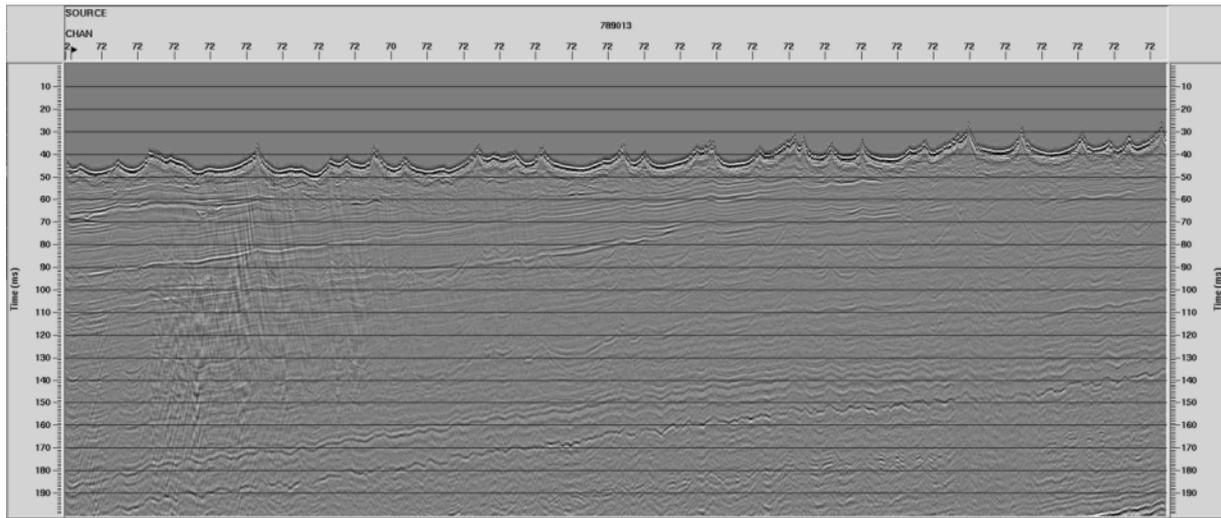
(b)

**Figure 17** – Line 112-11200c before (a) and after (b) Kirchhoff Time Migration.

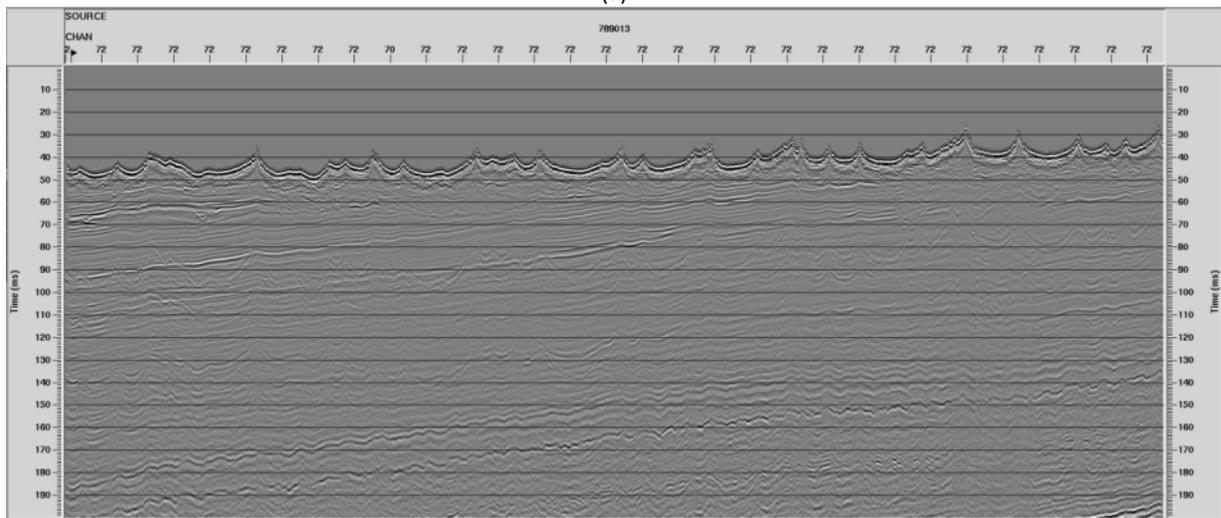
#### 4.2.12. F-K Filtering

FK Filter enhances coherent energy based upon apparent dip in the time and space data. Dip discrimination is performed in the frequency wavenumber (f-k). The filter is constructed in the f-k domain, with certain ranges in dip specified as accept or reject zones. Then the f-k filter is transformed into a time and space filter and convolved with the input data in the t-x domain. With an accept filter, coherent energy that falls within the specified dip ranges is enhanced. With a reject filter, both random noise and dipping energy that fall within the reject zone are attenuated. In either case, the effect is to enhance coherent signal energy.

In this case a polygon was picked in the F-K domain delimiting the specific area associated with the dipping noise related with propeller wash and defined for rejection. The results of the F-K filtering are shown in Figure 18.



(a)



(b)

Figure 18 – Line 112-11200c before (a) and after (b) F-K Filtering.

**4.2.13. Tide Correction**

The stacked sections (MUL, MIG and DPT) were corrected trace by trace for the tides effect by using a waterline height as measured by the RTK & MRU positioning system, which was vertically referenced to LAT. The received water line height files were created using Oasis Montaj v 5.0 software.

**4.2.14. Depth conversion**

The migrated sections were converted to depth using a smoothed stacking velocity model (Figure 19). A maximum 2000 Hz frequency was preserved in the conversion. The original stacking velocity

model was picked every 500 m and it was smoothed with an interval of 1500 m and a triangular weighting.

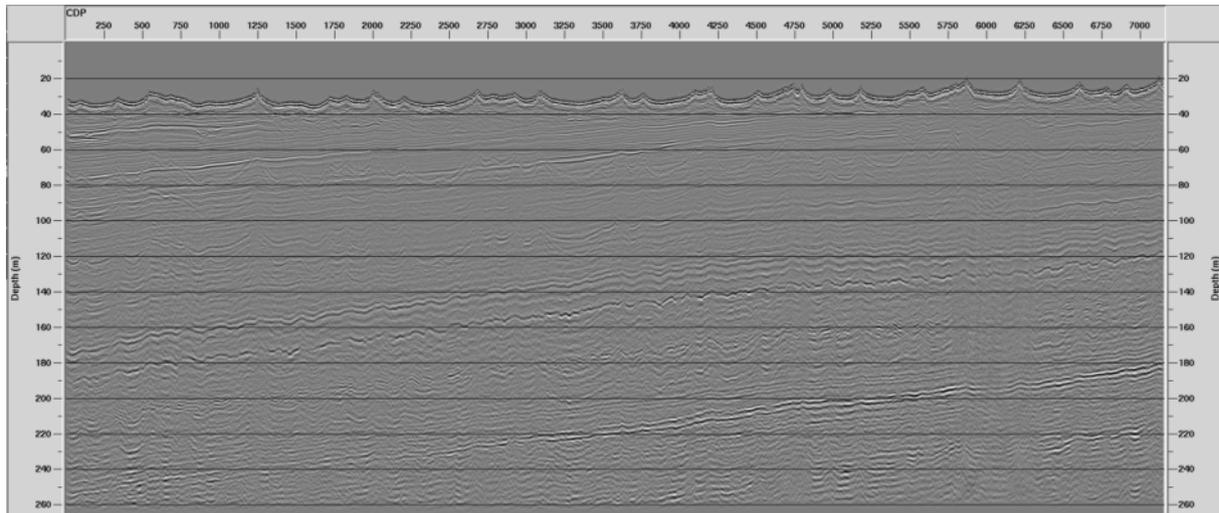
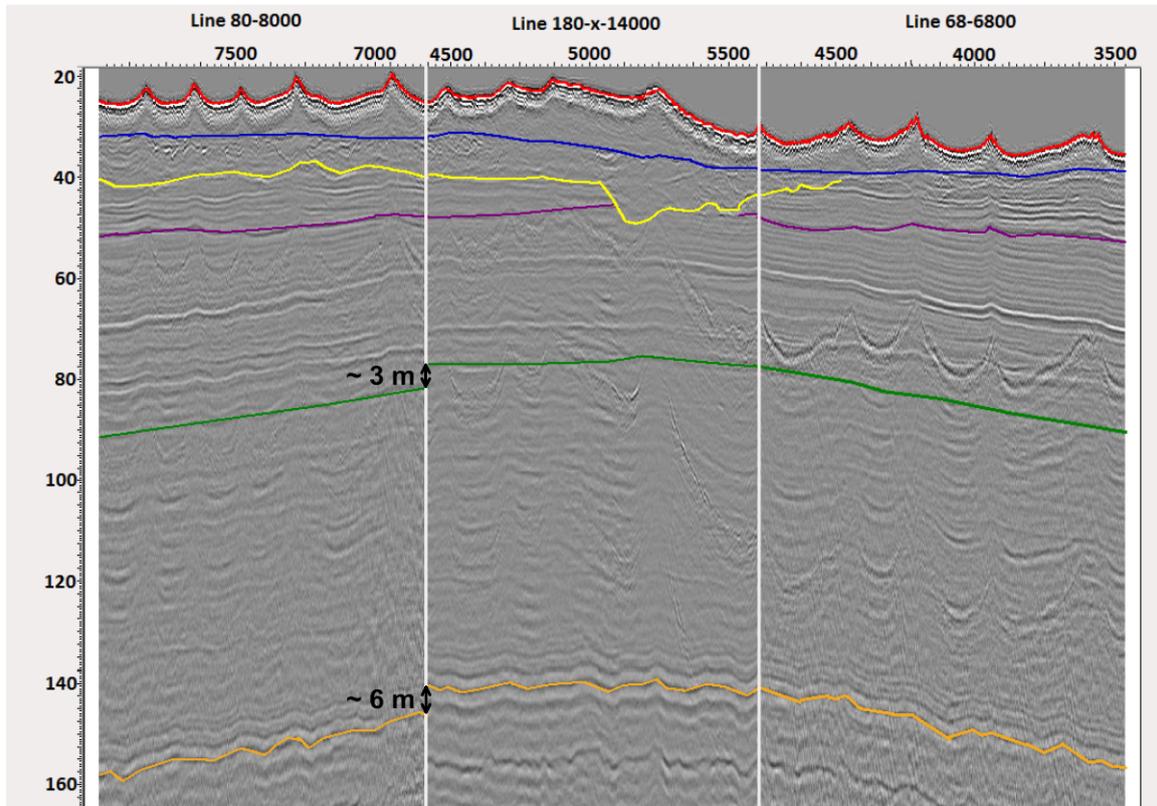


Figure 19 – Line 112-11200c after time to depth conversion.

Given that a streamer with a 71 m active length was used, it is expected that the depth conversion accuracy should be better than 1m at ~80 m below the seabed. The depth conversion accuracy decreases with increasing depth and at last knee (~300 ms) is probably around 5-10% (i.e between 10 and 25 m). The depth conversion uncertainty was estimated based on the measurement of the resultant vertical misties at different depths: 40, 80 and 120 m (see Table 5 and Figure 20). The results show an uncertainty minor than 1 m for depths up to 40 m, smaller than 5 m for depths up to 50 m (average of 0.9 m), and minor than 11 m for depths up to 120 m (average of 3.4 m).

Table 4 – Minimum, maximum and average of the vertical mistie resultant from the measurement of the inlines with two crosslines (180-X-14000 and 174-X-4000).

Vertical Misties	40 m	80 m	120 m
Minimum	<1 m	<1 m	<1 m
Maximum	<1 m	5 m	11 m
Average	<1 m	0.9 m	3.4 m



**Figure 20** – Intersection between the inlines 80-8000 and 68-6800 with the crossline 180-x-14000, showing, respectively, a poor and a good (vertical misties <1m) depth conversion example. Vertical scale in depth (m) and horizontal scale in CDPs.

## 5. DELIVERABLES

The following final deliverables were produced for every processed line:

1. Raw data with geometry loaded to the headers – Linename\_GEOM.sgy;
2. Multiple attenuation stack – Linename\_MUL\_Tide.sgy;
3. Migrated stack – Linename\_MIG\_Tide.sgy;
4. Migrated Stack (Low cut filter) – Linename\_MIG\_Tide\_LC.sgy;
5. Depth converted stack – Linename\_DPT\_Tide.sgy;
6. Depth converted stack (Low cut filter) – Linename\_DPT\_Tide\_LC;

The SEG-Y files were sent in minimum phase and SEG reverse polarity (i.e. increase in impedance marked by rising amplitudes at the top of the wavelet) with the headers populated as agreed with the client.

The relevant byte locations in the delivered sgy files are specified in Table 5.

**Table 5** – Relevant byte location on the delivered sgy files.

<b>Header Identification</b>	<b>Byte location</b>
<i>FFID</i>	<i>9</i>
<i>CDP</i>	<i>21</i>
<i>NHST</i>	<i>33</i>
<i>SAC</i>	<i>71</i>
<i>CDP_X</i>	<i>181</i>
<i>CDP_Y</i>	<i>185</i>

## 6. CONCLUSIONS

A total of 76 seismic profiles were processed, making a total sail length of approximately 654 km and covering an area of approximately 173 km<sup>2</sup>. The processing focused on improving the seismic section resolution and overall signal quality in the first 80 m below the seabed had the following major results:

- Propeller wash noise degraded the quality of approximately 15 % of the stacks, and an alternative stack was generated with an aggressive low cut filter. The overall resolution and penetration requirements are met for these profiles but signal quality and, especially, spectral band width is poorer.
- Geometry assignment and QC shows overall good CDP fold with a mean fold of 48 in all the lines (Figure 10). However, in lines steered poorly and/or with strong feathering the maximum CDP fold reached 72.
- Improved lateral continuity and resolution (see from Figure 15 to Figure 19);
- Recovery of signal at depth, down to the bottom of the record at 300 ms, more than 200 m (see from Figure 15 to Figure 19);
- Reasonable multiple attenuation (see Figure 14);
- Relative amplitudes were successfully preserved for the large majority of the lines.

16 Feb 2015

On behalf of Geosurveys, Aveiro, Portugal

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(Director of the Marine Department)