TNO PUBLIEK

Geologische Deinst Nederland
Princetonlaan 6
3584 CB Utrecht
P.O. Box 80015
3508 TA Utrecht
The Netherlands

www.tno.nl

T +31 88 866 42 56

TNO report

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Digitizing and reprocessing seismic archive data of the Geological Survey of the Netherlands for offshore windfarms

Date	29 April 2022
Author(s)	Vandeweijer V.P., Meijninger B.M.L., Stam J.C.

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Summary

Offshore wind farms are an important energy source in the worlds current energy transition toward a CO_2 neutral energy system. For the development of offshore windfarms in the North Sea a solid understanding of the geology and geotechnical parameters of the uppermost 150 m of the seabed sediments is essential. The Geological Survey of the Netherlands (TNO-GSN) has a significant archive with 2D high resolution seismic data. By digitization and reprocessing, these data can be used for offshore windfarm planning. Using deconvolution, weighted trace mixing, frequency / band pass filtering and swell/heave filtering, the 2D seismic data can be improved. The enhanced data quality is such that reflection signal and causative shallow structures just below the seafloor become interpretable. The reprocessed 2D high resolution seismic data provides an initial impression of subsurface conditions in the windfarm areas, this data could be valuable input for geological desk studies and geophysical site surveys. A qualitative estimation of the data quality and uncertainty has also been added. In combination with borehole data and reprocessed 3D oil and gas exploration seismic data, these data can be used to map geological structures, characterize subsurface soil conditions and identify potential hazards for wind farm developments as previous studies by TNO-GSN have shown (Meijninger et al. 2021).

Contents

Glossary

AOI	Area Of Interest
CDP	Common Depth Point
EBCDIC	Extended Binary-Coded Decimal Interchange Code
ED50	European Datum 1950
ETRS89	European Terrestrial Reference System 1989
MCS	Multi-Channel seismic
NCP	“Nederlands Continentaal Plat”, (Dutch Continental Shelf)
OFW	Offshore Windfarm
RVO	“Rijksdienst voor Ondernemend Nederland”
SBP	Sub-Bottom Profiler
SEG-Y	A standards developed by the Society of Exploration Geophysicists (SEG) for storing geophysical data
TNO-GSN	TNO- Geological Survey of the Netherlands
TWT	Two Way Travel time
UTM	Universal Transverse Mercator
WGS84	World Geodetic System 1984

1 Introduction

For planning and construction of offshore wind farms (OFW) it is important to have a solid understanding of the shallow subsurface (0 to 150 m below the seafloor). For large areas in the North Sea there is very little geological information publicly available, especially for shallow depth range between 5 m and 100 m below seafloor. Therefore, it is imperative that as much of this public information as possible is made accessible for use in preparation-phase desk studies. In 2021 RVO asked TNO-GSN to investigate a zone of interest for offshore wind farm development if reprocessing 3D oil and gas exploration geophysics and combining it with 2D high resolution seismic reflection data could close the data gap (Meijninger et al., 2021); the delivered results were very promising. This project aims to add hitherto inaccessible geological data and insights to the public domain, by reprocessing and unlocking part of the 2D geophysical archive of TNO-GSN for the zones of investigation as shown in Figure 1.

The 2D analogue seismic lines from the archive of the TNO-GSN were digitized, by converting scans of paper records into SEG-Y file format (the standard for storing geophysical data and used in seismic interpretation software). The digitized and digitally available data was subsequently reprocessed to improve the quality with focus on the first 200 milliseconds, representing a water column of about 25 to 35 m and about 150 m of sediments.

This report describes the vintage data extracted from the TNO-GSN archive, the methods used, outlines and discusses the project results. Furthermore it addresses the added value of the approach used. Since the 2D data coverage for the zone of investigation is comparable to that of the rest of the central and northern part of the Dutch continental shelf (‘Nederlands Continentaal Plat’, NCP), the results of this project can be taken as a blueprint for all sites that are considered for windfarm development in the future.

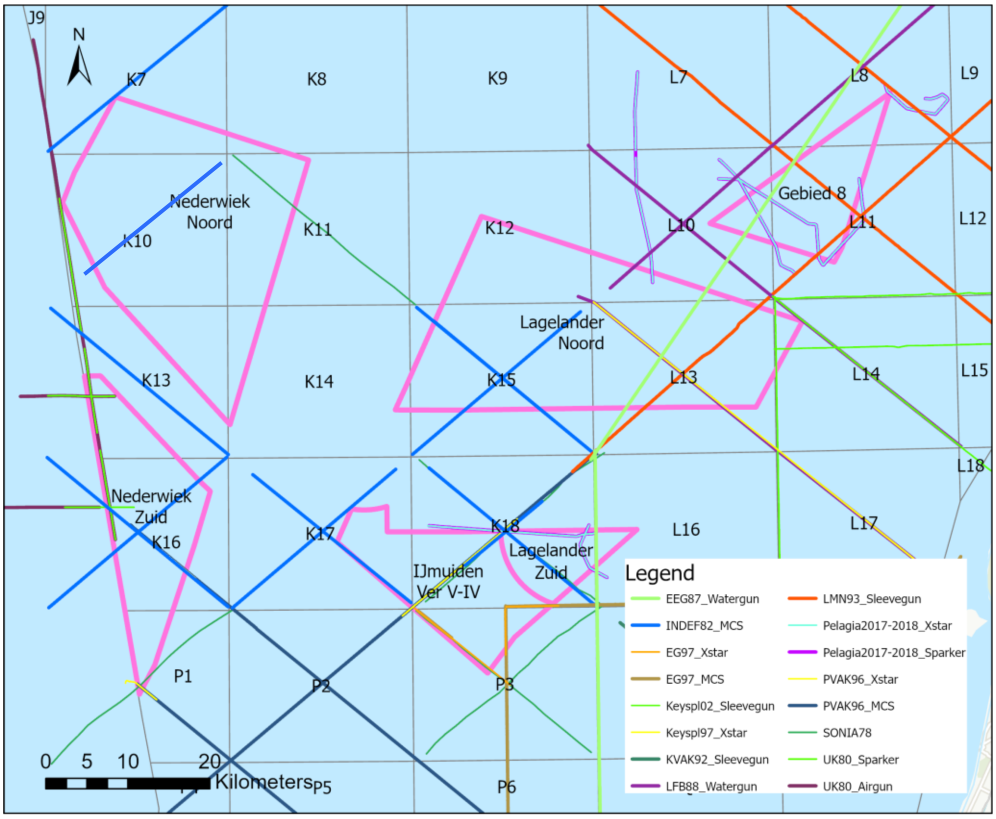


Figure 1. Potential offshore wind farm development areas Nederwiek Noord, Nederwiek Zuid, Gebied 8, Lagelander Noord, Lagelander Zuid and IJmuiden Ver V-IV (pink outlines) and the survey lines of the available digital/digitized 2D seismic reflection data, depicted in various colored lines (see legend for details). The legend shows the different 2D surveys with survey name and acquisition source as label. MCS refers to multi-channel seismic. Details are explained in the following chapters. “(All lines are included in “all_tracklines_ETRS89.shp)

2 Available Data

2.1 General Information

Figure 1 provides an overview of the locations of the 2D seismic datasets that overlap with the Areas of Interest (AOI). The major benefit of 2D seismic lines is their relatively high resolution in the shallow domain (up to 200 m depth). The 2D lines with chirp and single- and multi-channel sparker sources have frequencies up to 16 kHz, enabling resolutions of tens of centimeters, but penetrations are limited to 25 or 150 m below seafloor. The airgun, sleevegun and watergun 2D seismic data has resolutions up to meter scale and penetrations up to 1200 m below seafloor.

The majority of the 2D seismic datasets are present within the archives of TNO-GSN. These data include analogue (on paper, recently converted into scanned images) and fully digital 2D seismic profiles that were acquired in the 1970s to 2000s for Quaternary geological mapping projects in the North Sea (Cameron et al., 1984, 1986 and 1993; Laban, 1998; Perdijk, 1990) and more recent academic research projects (Busschers et al., 2019).

2.2 Data Assessment

Table 1 lists the specifics of the 2D seismic lines as shown in Figure 1, which were found in the archives of TNO-GSN.

2.2.1 Analogue and digitally recorded seismic profiles
The Sonia, UK80 and INDEF82 survey lines were shot in the 1970s and 1980s and were recorded as analogue (printed) seismic profiles. The seismic profiles have recently been scanned and are now available as bitmapped image files (tiff or jpeg). From the late 1980s onwards, seismic data were generally recorded and stored in a digital format. The X-star and multichannel data acquired since are commonly available in the standard SEG-Y format.

2.2.2 Availability of seismic survey data
Unfortunately, not all the scans of the INDEF82 and SONIA surveys could be located thus far. The paper rolls of these lines were likely lost or misplaced during the relocation of the analogue seismic archives from Haarlem to Utrecht and Zeist, about twenty years ago. Over the past ten years, all available paper rolls of seismic profiles have been scanned and stored as bitmapped image files in the archive of TNO-GSN.

Similarly, some digital records of the KVAK92 and KEYSPL97 surveys have been lost in the past. Thankfully, scans of some of the seismic profiles of these two surveys were recovered.

2.2.3 Seismic data types
The 2D seismic dataset comprises 3 types of records:

(1) Single channel high resolution sub-bottom profiler (SBP), acquired with a Sonia or chirp (X-star) recorded at high frequencies ranging from 2 to 16 kHz (SONIA, EG97, PVAK96, KEYSPL97, Pelagia surveys). For the

SONIA lines the signals were most likely recorded via a single channel system, e.g. an EPC3200 unit, and printed on (thermal) paper.

(2) Single channel seismic data, acquired with a sparker or watergun type source and a single channel streamer (e.g. Pelagia survey) or recorded via a single channel system, e.g. an EPC3200 unit, and printed on (thermal) paper (INDEF82 and UK 80 surveys).

(3) Multichannel seismic (MCS) data; acquired with an airgun, watergun or sleeve gun type source and a multichannel streamer (e.g. LFB88, LMN93, EEG87, EG97, KEYSPL97 and KVAK92 surveys).

2.2.4 Resolution and penetration of seismic data types

The high frequency Sonia and X-star seismic data have approximately a 0.5 m to 1 m vertical resolution and a maximum penetration of 25 m below seafloor. For the other seismic datasets acquired with sparker, watergun, airgun or sleeve gun source and a single or multi-channel system, much lower frequencies of the acoustic penetrating signal were used leading to higher penetrations (200 m to 1500 m below seafloor). The lower-frequency signal and corresponding longer acoustic wavelength results in lower resolutions (in the order of 2 m and higher). In digital recording, the seismic signal is sampled at a fixed rate, this is called the sample interval. The sample interval (also listed in Table 1) is chosen in relation to the seismic source and it's frequency range and can be linked to the resolving power of seismic data.

2.2.5 Locations and orientations of survey lines

Most of the surveys lines were acquired as part of a geological mapping program. In particular, the INDEF82 and UK80 surveys were part of a joined mapping effort of the British and Dutch Geological Surveys to develop the Indefatigable sheet (Cameron et al., 1984 and 1986). Survey lines were often shot diagonally across the offshore mapping "blocks" (i.e. NW-SE or NE-SW), therefor many of the SBP and MCS lines run parallel or even overlap each other, as illustrated in Figure 1 (Cameron et al., 1984 and 1986). The lines of the UK80 and EG97 surveys are an exception and follow a different orientation. The UK80 survey lines were organized by the British Geological Survey and follow a survey plan of north-south and west-east lines. The EG97 survey lines are part of a dense network of survey lines running north-south, east-west and diagonally across the P and Q blocks of the North Sea grid.

The EEG87 survey lines were acquired for a joined European cross-country geological mapping project: "The Modelling and Dynamics of the Quaternary Geology of the Southern North Sea and their Applications to Environmental Protection and Industrial Developments" (Cameron et al., 1993), connecting geologically interesting key areas across the Southern North Sea. The Pelagia survey was part of an early Holocene sea-level reconstruction program (Busschers et al., 2019) targeting specific locations with Holocene and late Pleistocene peat in the shallow subsurface of the North Sea seabed, which explains the trend and locations of these survey lines.

2.2.6 Navigation and positioning

2.2.6.1 Navigation and positioning accuracy

The positioning accuracy of navigation equipment has greatly improved over the past decades. According to Kint et al. (2021) the accuracy of the positioning of the lines shot between 1960 and 1980 varied from 10 to 50 meters, depending on the navigation system used. Usually DECCA and later the HyperFix positioning systems were used during the earlier seismic surveys across the NCP. The accuracy of the DECCA positioning system varied between 20 to 100 m and for the HyperFix positioning system between 0.5 to 10 m (personal communication with Cees Laban). The accuracy of these systems depended largely on the atmospheric conditions and the use of land based radio beacons. After the introduction of GPS in the 2000s the accuracy was enhanced to 2 meters. For most of the surveys, except the Pelagia Survey 2017-2018, it is not known for sure which navigation system was used. This information was not recorded in the data.

The vertical resolution of the vintage 2D data is largely dependent on the frequency of the seismic source and received signal (from which the latter normally decreases with depth). For the SBP lines the resolving power is typically in the order of decimeters, while for the deeper penetrating MCS this often is more in the range of 1 up to 5 m.

2.2.6.2 Sources of navigation data

For most surveys, navigation information was available either as separate navigation files (‘NAV’ file extension) or incorporated in the headers of the SEG-Y files. Table 1 lists the source of navigation per survey. Navigation information of the analogue (printed) seismic profiles was occasionally missing or incomplete. Fortunately, suitable the navigation information could be recovered from track line chart (UK 80 survey), fence diagrams (SONIA survey, see Figure 2 for example) or seismic interpretation file (INDEF82 K10 ZW). The fix locations could be digitized from the chart and fence diagrams and linked to the fix numbers on the seismic profiles to construct a navigation file. In case of the scans of the seismic profiles of KEYSPL97 and KVAK92-K15 the coordinates were noted on the profiles and were used to construct a navigation file. Normally a correction for the offset (i.e. the distance) between the antenna of the positioning system and the midpoint of the seismic acquisition system should be applied to obtain the correct coordinates of the seismic data. This information was only available for the Pelagia 2017-2018 data.

Table 1 Navigation data source

Survey	navigation data source
EEG87	embedded in SEG-Y
EG97	embedded in SEG-Y
INDEF82	fix numbers (E-numbers) and coordinates from separate navigation files and linked to fix numbers on the labels of the analogue seismic profiles. In case of INDEF82 K10 ZW, navigation information, i.e. start and end of survey line, was derived from the available seismic interpretation file.
KEYSPL02	embedded in SEG-Y
KEYSPL97	coordinates derived from the labels at the bottom of the analogue seismic profiles.
KVAK92	written coordinates of the start and end of the survey line on the scan of the analogue seismic profile.
LBF88	embedded in SEG-Y
LMN93	embedded in SEG-Y
Pelagia survey 2017-2018	embedded in SEG-Y
PVAK96	embedded in SEG-Y
SONIA78	digitized from fence diagrams
UK80	digitized from shot point map

2.2.6.3 Coordinate system

The navigation information from the 1970s to the 1990s was generally logged as geographical or projected Universal Transverse Mercator (UTM) coordinates in the European Datum 1950 coordinate system (ED50). For recent surveys, coordinates were logged in the WGS84 coordinate system (e.g. Pelagia survey).

For this project, the geographic coordinate system European Terrestrial Reference System 1989 (ETRS89) is used. The coordinates are in the UTM zone 31 North projection (UTM31N). As such, maps and navigation data in ED50 are transformed into the ETRS89 coordinate system. For the NCP, differences between coordinates in ETRS89 and WGS84 are very small and therefore negligible. As such, GIS data files and navigation data in WGS84 UTM31N coordinates are not transformed into ETRS89 UTM31N coordinates.

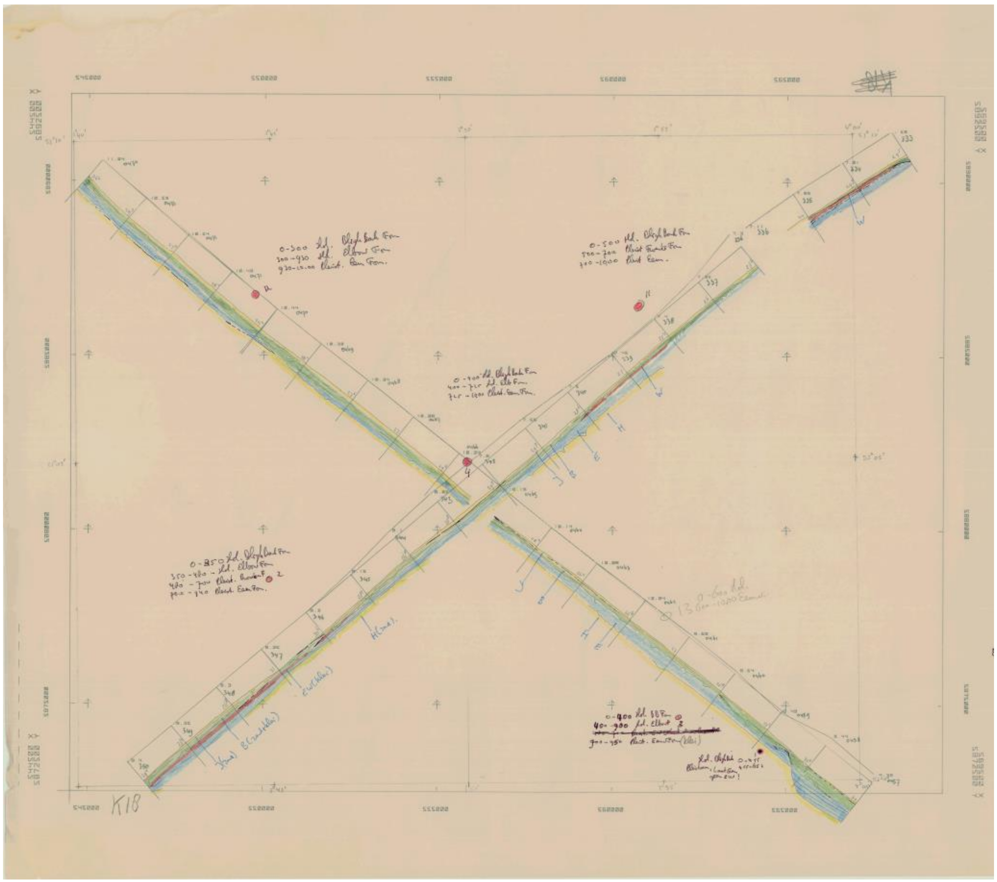


Figure 2. Example of a fence diagram (file K18_SA081-1-3_krt.jpg) showing the seismic interpretations of the SONIA profiles diagonally across K18, including litho-stratigraphic information, survey or track lines of the SONIA profiles with fix numbers, and locations of boreholes (red dots) with descriptions of depth intervals of geological units. The coordinate system on the map is ED50, with coordinates displayed both geographically and in UTM 31N.

2.2.7 Seismic interpretations

Some of the 2D seismic lines were interpreted in the 1970s to 1990s as part of the Geological Survey’s mapping program. The interpretations of the SONIA lines were captured in fence diagrams, which were used for the construction of the 1:250 000 Indefatigable map sheet. For a number of survey lines including SONIA, EEG87, INDEF82 and EG97, the fence diagrams and/or the original seismic interpretations are available in digital format (ASCII text file, with formatting: Survey Line, Reflector number, Unique ID, X and Y coordinates in_ED50_UTM31N, Fix number and Depth in meters below seafloor), including reflector IDs (see Figure 2 and Figure 3). Litho-stratigraphic labels of the reflectors are not included in the text files with the seismic interpretations. The original seismic interpretations are in depth (meters). Details are unfortunately missing, but it is believed that for the time-to-depth conversion of those interpretations a fixed velocity of 1500 m/s was used for the sub-bottom profiles (X-star of EG97 and SONIA lines), and for time-to-depth conversion of the multichannel seismic data (i.e. EEG87 and INDEF82 lines) a velocity of 1700 to 1800 m/s was used for the middle Pleistocene and younger formations and a linearly increasing velocity for the older formations (Cameron et al., 1984 and 1986).

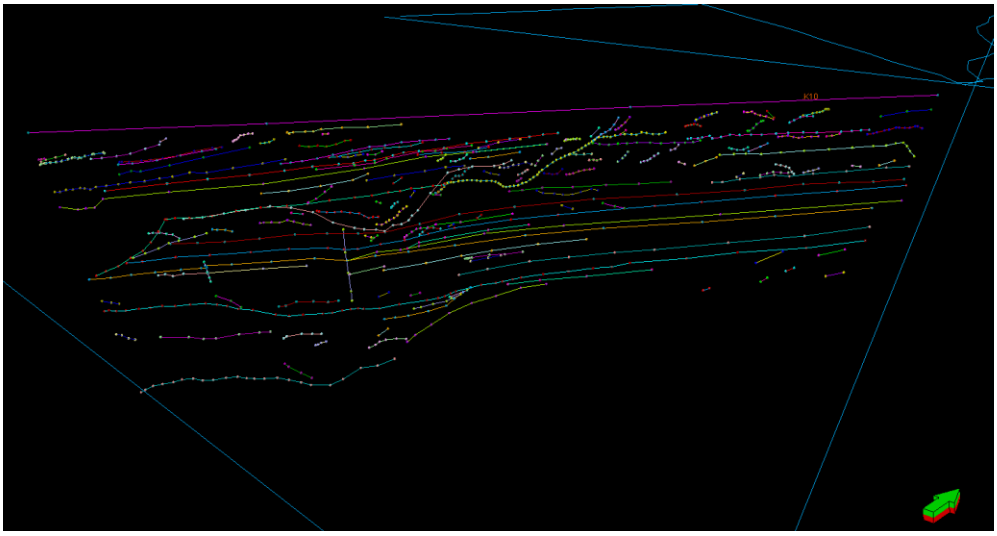


Figure 3. Screenshot of a 3D view with example of seismic interpretations of INDEF82, line K10 ZW. Multi-colored lines represent the interpreted reflectors (horizons) and faults, which were interpolated from the ASCII files with point data (light blue points). The depth range of the horizons varies from approximately 25 m for the sub-horizontal seafloor reflector to 900 m for the deepest horizon in the lower left.

2.2.8 Specifics on X-star data

The PVAK96, EG97, KEYSPL97 and Pelagia surveys contain SBP data acquired with an X-star. The X-star seismic signal is a complex trace, which in the original or raw digital seismic file is recorded as a composite signal from three channels in every first, second and third trace. Most seismic interpretation software cannot load these types of data. Generally, the amplitude of the envelope of the seismic signal from channel one, i.e. the first trace, is used for seismic interpretation. Typically, the scans of the seismic profiles portrait only information from the first channel (e.g. KEYSPL97 survey). Likewise, the SEG-Y files generally contain only the amplitude of envelope of the seismic signal extracted from the original file (e.g. PVAK96, EG97 and Pelagia survey).

2.2.9 Specifics on analogue seismic profiles UK80 and INDEF82

For the UK80 survey, for most survey lines scans of analogue (printed) seismic profiles of three types of seismic acquisition systems are available: pinger, sparker and airgun. The seismic profiles shot with the pinger acquisition system did not show much information and were therefore left out of the process, but they are available as part of the deliverables. The seismic profiles shot with the sparker and airgun acquisition systems do show useful geological information and were taken into consideration. The profiles of the airgun were available in two different vertical scale settings at 50 ms or 100 ms intervals. Unfortunately, the original analogue profiles were printed only in black and white and not in greyscale. This results in limitations on processing capabilities and usage of the seismic data because a full wave form cannot be generated from these images.

The analogue (printed) seismic profiles of the INDEF82 survey generally comprise three seismic profiles of the same line with three different vertical scale and bandpass filter settings. All three different seismic profiles, if available, were taken into consideration.

2.3 Summary

Although the quality and resolution of the data of the analogue and digital seismic profiles varies between the surveys and acquisition systems, they provide useful geological information. In particular where seismic lines of SBP and MCS run parallel, the information from these seismic profiles combined provide information for the full depth range of interest, i.e. the first 150 m below the seafloor. A combined set of these lines, including the available fence diagrams, give an initial impression of subsurface conditions and a regional overview of the geology in the potential offshore wind farm development areas.

3 Methods

3.1 2D Data reprocessing

In this project we handled 2D data of various types and multiple surveys. The data was available to us mainly in processed seismic file format but also partially merely in scanned image files (tiff and jpeg). The data was acquired using various types of survey equipment over various surveys and subsequently even storage media (seismic file format versus image files) can hardly be compared with each other. The wave types, frequency content, resolution, penetration depths and signal to noise ratios vary significantly throughout the various datasets. These variations required that each data type and survey had to have its processing flow customized and optimized for operations and parameters.

In the following section we briefly describe the workflow of the 3 main categories:

(1) Data from image files.
(2) The analogue surveys stored in a seismic file format (e.g. the single channel high resolution sub-bottom profiler surveys stored in SEG-Y).
(3) The multichannel seismic data acquired with a multichannel streamer stored in a seismic file format.

3.1.1 Data from image files

This type of data needed to be converted from scanned bitmap files, like tiff and jpeg, into usable seismic files (SEG-Y) including location data. The general workflow for conversion from paper involved the four steps listed below:

1. Loading the scanned seismic records and selecting the area of interest. Because the seismic scans were of variable layout and quality, the actual data frame selection was done by hand for every line. This was done using open source image editing software (GIMP, 2022) and saving the cropped data as an 8 bit linear grey scale tiff file with no extra data layers.
2. Acquiring coordinates for the selected section of the line. This was done in one of two ways.
    a. When shot points or fix numbers were available in table format, analogue (on paper) or digital (in some sort of readable file format) corresponding coordinates of relevant shot points or fix numbers were selected and linked to corresponding trace numbers.
    b. If merely (scanned) navigation maps exist, these would be georeferenced and “shot” or “fix” points would be digitized. The extracted coordinates would manually be linked to matching trace numbers. If not all shot or fix numbers were present an interpolation method was used to assign coordinates to the seismic traces in between known positions, or seismic lines would be cropped to the part where positioning data is available.
3. Converting the scanned seismic images to industry standard SEG-Y files, and when desirable/possible transferring that data back into the “wave domain”. This was done by a combination of Seismic Unix (https://github.com/JohnWStockwellJr/SeisUnix) and netpbm (http://netpbm.sourceforge.net/) tools. During the conversion from the Tiff’s and Jpeg’s to SEG-Y a suitable horizontal sampling rate (slow dimension)

has to be chosen to constrain horizontal resolution (the number of traces per meter in the horizontal direction). Also a suitable sampling rate (fast dimension) needs to be chosen to constrain vertical resolution (resulting in the number of samples per trace). Because the retrieved “signals” from these scanned records are converted from 8 bit grayscale values, they merely contain positive values and no real waveforms. Normally seismic data contains waveforms.

   a. Some of the data, directly after conversion, resembled that of an impedance plot, which is not very suitable for display, or interpretation in most seismic interpretation programs. To get back (realistic) waveforms that type data was convolved using a representative wavelet, with a suitable conversion method as is described in the results section.
   b. Some data was plotted as black on white only. In that case convolving the data is of no use. Lines recorded like that were not submitted to any further signal processing.

4. Merging and interpolating all coordinates from the digitized navigation maps with the SEG-Y files in such a way that every seismic trace has an x and y position. The navigation data was added using Seismic Unix and interpolating between known “fix” points.

3.1.2 Single channel “analogue” data

These data were already available in a seismic file format, mostly some sort of SEG-Y. But in all cases they could use a boost in quality (e.g. resolution, continuity and signal-to-noise ratio), especially in the shallower (up to 300 ms two-way travel time; TWT) domain. In general the processing included amplitude recovery and various frequency filtering steps. In many cases additional Wiener predictive error filtering (deconvolution) was applied, to filter out noise and suppress ringing and multiples. Occasionally trace mixing improved lateral continuity of the records by reducing refraction hyperbolae balancing amplitudes over traces and even filling dead traces.

3.1.3 Multi-channel data

These data were also already available in a seismic file format, mostly some sort of SEG-Y. Similar to the single channel “analogue” data, this data could use a boost in resolution, continuity and signal-to-noise ratio. Because we merely worked with the post-stack data, the processing performed, resembled that of the processing executed for the single channel data. These included amplitude recovery and various frequency filtering steps. In most cases additional Wiener predictive error filtering (deconvolution) was applied. Occasionally lateral trace mixing improved the record by reducing refraction hyperbolae and various multiples.

Table 2. Overview of 2D seismic data inside or in the vicinity of the areas of investigation. Note that values for time length, penetration below seafloor are only indicative values. And values between brackets are from digitised seismic profiles and may not be representative for the original seismic data. The abbreviations in the column Area of Interest (AOI) stand for 'IJmV' IJmuiden Ver V-IV, 'G8' Gebied 8, 'LLN' Lagelander Noord, 'LLZ' Lagelander Zuid, 'NWN' Nederwiek Noord and 'NWZ' Nederwiek Zuid.

Survey ID and Name	Line ID / Scan ID	Year recorded	AOI	File name(s)	Seismic acquisition system (source / receiver)	Original Format	Length (km)	Penetration / Time length (ms)	Approximate Penetration below seafloor (m)	Sample interval (µs)
EEG87, EEG Southern North Sea mapping project	8701 / mx4	1987	LLZ	dc_nov8701a, dc_nov8701b	watergun, 12-channel streamer, Prakla-Seismos streamer	digital (SEG-Y)	115	1600	1000	1000
	8702 / m13	1987	G8, LLN	dc_nov8702a, dc_nov8702b	watergun, 12-channel streamer, Prakla-Seismos streamer	digital (SEG-Y)	115	1600	1000	1000
EG97, Egmond Gronden, Franse Bank	50	1997	IJmV	dc_egmgr9750	source unknown, 12-channel streamer	digital (SEG-Y)	37	1600	1000	500
	56	1997	IJmV	dc_egmgr9756, dc_egmgr9756b	source unknown, 12-channel streamer	digital (SEG-Y)	56	1600	1000	500
	64	1997	IJmV	dc_egmgr9764	source unknown, 12-channel streamer	digital (SEG-Y)	5.3	1600	1000	500
	50	1997	IJmV	egm9703001, egm9703002	chirp (X-star)	digital (SEG-Y)	5.6	125	25	124
	64	1997	IJmV	frb9702008, frb9702009, frb9702010, frb9702011, frb9702012	chirp (X-star)	digital (SEG-Y)	15	125	25	124
	56	1997	IJmV	frb9704010, frb9704011	chirp (X-star)	digital (SEG-Y)	6.3	125	25	124
	56	1997	IJmV	frb9705027, frb9705028	chirp (X-star)	digital (SEG-Y)	5.6	125	25	124
KEYSPL, 'Keysersplaat'	1	1997	LLN	keyspl97 1a (lbf1a), keyspl97 1b (lbf1b), keyspl97 1c (lbf1c), keyspl97 1d (lbf1d), keyspl97 1e (lbf1e), keyspl97 1f (lbf1f)	Edgetech chirp (X-star), 6 kHz	analogue (jpg)	51.3	[65]	25	[84]
KEYSPL, 'Keysersplaat'	2	2002	LLN	st_keyspl02_02	sleevegun, 12-channel streamer	digital (SEG-Y)	37.5	1500	1000	500
	6	2002	LLN	st_keyspl02_06	sleevegun, 12-channel streamer	digital (SEG-Y)	43	1500	1000	500
	7	2002	LLN	st_keyspl02_07	sleevegun, 12-channel streamer	digital (SEG-Y)	40	1500	1000	500
	15	2002	LLN	st_keyspl02_15	sleevegun, 12-channel streamer	digital (SEG-Y)	36	1500	1000	500
KVAK92, 'K-vakken'	14	1992	LLZ	st_kvak9210	sleevegun, 12-channel streamer	digital (SEG-Y)	11	1600	1200	500
	7	1992	LLN	Kvak92 K15(7)	sleevegun, 12-channel streamer	analogue (jpg)	86	1000	700	[250]
LFB88, North of 53N	1	1988	LLN	dc_lfb01	watergun, 12-channel streamer	digital (SEG-Y)	53.3	1600	1000	1000
	2	1988	LLN	dc_lfb02	watergun, 12-channel streamer	digital (SEG-Y)	55	1600	1000	1000
	15	1988	LLN	dc_lfb15	watergun, 12-channel streamer	digital (SEG-Y)	58.5	1600	1000	1000
LMN93, 'L, M en N vakken' for purpose of Sheet Terschellingbank	4	1993	LLN, G8	dc_lmn04	sleevegun, 12-channel streamer	digital (SEG-Y)	150	1600	1000	1000
	11	1993	G8	dc_lmn11	sleevegun, 12-channel streamer	digital (SEG-Y)	77	1600	1000	1000
	19	1993	G8	dc_lmn19	sleevegun, 12-channel streamer	digital (SEG-Y)	87	1600	1000	1000
INDEF82, for the purpose of Sheet Indefatigable	K7 NE	1982	NWN	scans of same profile, but different scale / filter settings: indef82 K7a, indef82 K7b, indef82 K7c	Unknown	analogue (jpg)	28	1000-1600	700-1000	[250-500]
	K10 ZW	1982	NWN	scans of same profile, but different scale / filter settings: indef82 K10a, indef82 K10b, indef82 K10c	Watergun, Benthos	analogue (jpg)	23	500-2000	300-1200	[250-500]
	K13 ZO	1982	NWN, NWZ	scans of same profile, but different scale / filter settings: indef82 K13a, indef82 K13b, indef82 K13c	Sparker, Benthos	analogue (jpg)	28	500-2000	300-1200	[250-500]
	K15 NW	1982	LLN	scans of same profile, but different scale / filter settings: indef82 K15a, indef82 K15c, indef82 K15d	Sparker, Benthos	analogue (jpg)	28	500-2000	300-1200	[250-500]
	K15 ZW	1982	LLN	scans of same profile, but different scale / filter settings: indef82 K15b, indef82 K15e, indef82 K15f	Sparker, Benthos	analogue (jpg)	27	500-2000	300-1200	[250-500]
	K16 NO	1982	NWZ	scans of same profile, but different scale / filter settings: indef82 K16b, indef82 K16d	Sparker, Benthos	analogue (jpg)	28.5	1000-2000	700-1200	[250-500]
	K16 NW	1982	NWZ	scans of same profile, but different scale / filter settings: indef82 K16g, indef82 K16h	Sparker, Benthos	analogue (jpg)	28.5	500-2000	300-1200	[250-500]
	K17 ZO	1982	IJmV	scans of same profile, but different scale / filter settings: indef82 K17a, indef82 K17d, indef82 K17f	Sparker, Benthos	analogue (jpg)	25	500-2000	300-1200	[250-500]

Survey ID and Name	Line ID / Scan ID	Year recorded	AOI	File name(s)	Seismic acquisition system (source / receiver)	Original Format	Length (km)	Penetration / Time length (ms)	Approximate Penetration below seafloor (m)	Sample interval (µs)
	K17 ZW	1982	IJmV	scans of same profile, but different scale / filter settings: indef82 K17b, indef82 K17c, indef82 K17e	Sparker, Benthos	analogue (jpg)	26	500-2000	300-1200	[250-500]
	K18 NW	1982	IJmV, LLZ	scans of same profile, but different scale / filter settings: indef82 K18a, indef82 K18b, indef82 K18c	Sparker, Benthos	analogue (jpg)	26	500-2000	300-1200	[250-500]
	K18 ZW Lijn 1	1982	IJmV, LLZ	scans of same profile, but different scale / filter settings: indef82 K18e, indef82 K18f, indef82 K18h	Sparker, Benthos	analogue (jpg)	12	500-2000	300-1200	[250-500]
PVAK96, 'P-vakken'	5	1996	NWZ	st_pvak9605	source unknown, multi-channel receiver, details unknown	digital (SEG-Y)	44	1600	1200	500
	6	1996	IJmV, LLZ	st_pvak9606	source unknown, multi-channel receiver, details unknown	digital (SEG-Y)	73.5	1600	1200	500
	7	1996	NWZ	st_pvak9607	source unknown, multi-channel receiver, details unknown	digital (SEG-Y)	74.3	1600	1200	500
	7	1996	NWZ	pvak9602024, pvak9602025, pvak9602026, pvak9602027	chirp (X-star)	digital (SEG-Y)	10.3	250	25	124
	5	1996	NWZ	pvak9605035, pvak9605036	chirp (X-star)	digital (SEG-Y)	4.5	250	25	124
	5	1996	NWZ	pvak9606001	chirp (X-star)	digital (SEG-Y)	2.7	250	25	124
	6	1996	IJmV, LLZ	pvak9606034, pvak9606035, pvak9606036, pvak9606037, pvak9606038, pvak9606039, pvak9606040	chirp (X-star)	digital (SEG-Y)	18.3	250	25	124
Pelagia survey 2017, Early Holocene sealevel rise project	29	2017	LLN	S_line29, S_line29_002	sparker, single channel streamer	digital (SEG-Y)	26	250	150	50
	35	2017	G8	S_line35, S_line35_002	sparker, single channel streamer	digital (SEG-Y)	17	250	150	50
	40	2017	G8	S_line40, S_line40_002, S_line40_003	sparker, single channel streamer	digital (SEG-Y)	30	250	150	50
	42	2017	LLZ	S_line42	sparker, single channel streamer	digital (SEG-Y)	8	250	150	50
	47	2017	LLZ	S_line47, S_line47_002	sparker, single channel streamer	digital (SEG-Y)	21	250	150	50
	29	2017	LLN	X_line29, X_line29_002, X_line29_003	chirp (X-star)	digital (SEG-Y)	26	100	25	46
	35	2017	G8	X_line35, X_line35_002	chirp (X-star)	digital (SEG-Y)	17	100	25	46
	40	2017	G8	X_line40, X_line40_002, X_line40_003, X_line40_004	chirp (X-star)	digital (SEG-Y)	30	100	25	46
	42	2017	LLZ	X_line42	chirp (X-star)	digital (SEG-Y)	8	100	25	46
	47	2017	LLZ	X_line47, X_line47_002, X_line47_003	chirp (X-star)	digital (SEG-Y)	21	100	25	46
Pelagia survey 2018, Early Holocene sealevel rise project	68	2018	G8	Sline_2018_68	sparker, single channel streamer	digital (SEG-Y)	23	250	150	100
	68	2018	G8	XLine2018_68, XLine2018_68_002	chirp (X-star)	digital (SEG-Y)	23	100	25	46
SONIA	K11 ZO	1978	NWN	sonia78 K11 ZO	SONIA, sub bottom profiler system	analogue (tif)	28.7	100	25	125
	K17 ZO	1978	IJmV	sonia78 K17 ZO	SONIA, sub bottom profiler system	analogue (tif)	28.3	100	25	125
	K18 NW	1978	IJmV, LLZ	sonia78 K18 NW deel 1, sonia78 K18 NW deel 2	SONIA, sub bottom profiler system	analogue (tif)	28.5	100	25	125
	K18 ZW	1978	IJmV, LLZ	sonia78 K18 ZW	SONIA, sub bottom profiler system	analogue (tif)	28.5	100	25	125
	L11 ZO	1978	G8	sonia78 L11	SONIA, sub bottom profiler system	analogue (tif)	26.7	100	25	125
	P1 ZW	1978	NWZ	sonia78 P1 ZW_sys	SONIA, sub bottom profiler system	analogue (jpg)	29	100	25	125
	P3 NO	1978	IJmV	sonia78 P3 NO	SONIA, sub bottom profiler system	analogue (jpg)	28	100	25	125
	P3 ZO	1978	IJmV	sonia78 P3 ZO	SONIA, sub bottom profiler system	analogue (jpg)	27.5	100	25	125
UK 80, for the purpose of Sheet Indefatigable	68	1980	NWZ	UK 80.01 airgun 68 (a t/m c), 50 en 100ms	airgun, receiver unknown	analogue (tif)	42	1000	700	400
	62	1980	NWZ	UK 80.01 airgun 62, 50 en 100ms	airgun, receiver unknown	analogue (tif)	11.5	1000	700	400
	63	1980	NWZ	UK 80.01 airgun 63, 50 en 100ms	airgun, receiver unknown	analogue (tif)	15	1000	700	400

Survey ID and Name	Line ID / Scan ID	Year recorded	AOI	File name(s)	Seismic acquisition system (source / receiver)	Original Format	Length (km)	Penetration / Time length (ms)	Approximate Penetration below seafloor (m)	Sample interval (µs)
	72	1980	NWZ	UK 80.01 airgun 72, 50, 100ms	airgun, receiver unknown	analogue (tif)	21	1000	700	400
	68	1980	NWZ	UK 80.01 sparker 68 (a t/m d)	sparker, receiver unknown	analogue (tif)	42	500	350	400
	62	1980	NWZ	UK 80.01 sparker 62	sparker, receiver unknown	analogue (tif)	8	500	350	400
	63	1980	NWZ	UK 80.01 sparker 63	sparker, receiver unknown	analogue (tif)	8.5	500	350	400

4 Results

4.1 2D Seismic

4.1.1 *Data from image files*

The surveys who's data we recovered from Tiff and Jpeg files were:

1. KEYSPL (1997)
2. INDEF82 (1982)
3. KVAK92 (1992)
4. SONIA NCP (1978)
5. UK80 (1980)

For a complete overview of all data see Table 2 and Figure 1.

4.1.1.1 KEYSPL (1997)

The data and the scans (of grey scale panels) of the KEYSPL survey were of reasonable quality (example: Figure 4a).

After digitization and conversion, further processing was limited to trace mixing, which improved lateral continuity of the data. Tests to improve the data by convolution with a 750Hz ricker wavelet, frequency filtering and other means of processing were not convincingly successful. It was therefore decided to produce raw and convolved panels as output (respectively Figure 4b & c).

Sadly the original records had lots of annotations about depth, fix number, etc. very regularly printed on them. These annotations can be seen in Figure 4 as the repetitive, in a grid, oriented light spots. The annotations were plotted over the data, covering the seismic signal. Because the annotations are not really disturbing the interpretation of these records, it was decided to leave the records like this.

a.

b.

c.

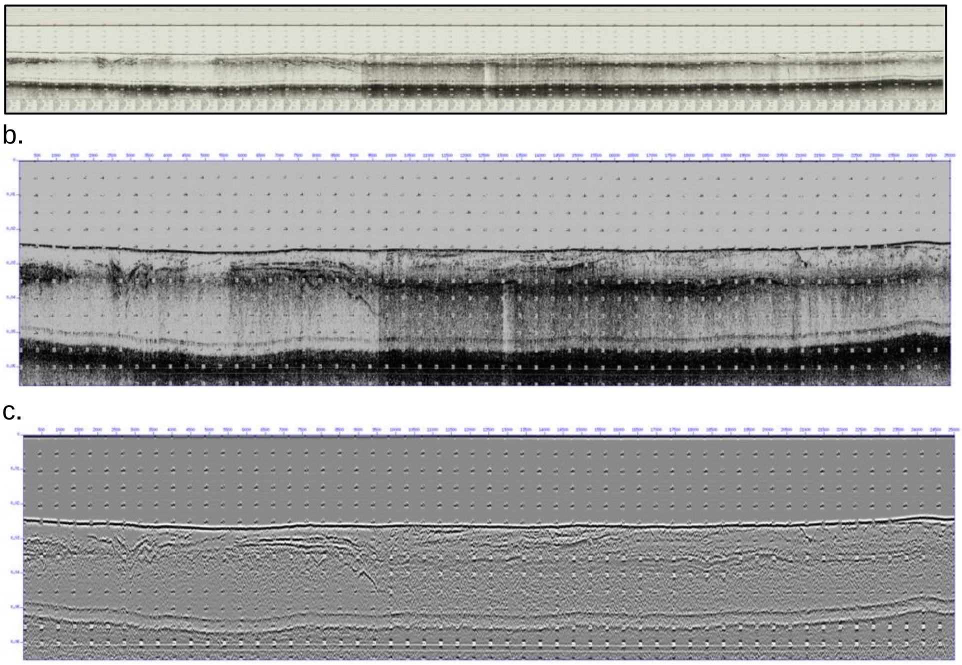


Figure 4. example of a: Scan of the original printout. b. unconvolved converted data in SEG-Y format. c. convolved and filtered data in SEG-Y format; of a typical KEYSPL line. For b & c, vertical axis is in seconds TWT, horizontal axes is trace number. Total line length on display is approximately 8 km.

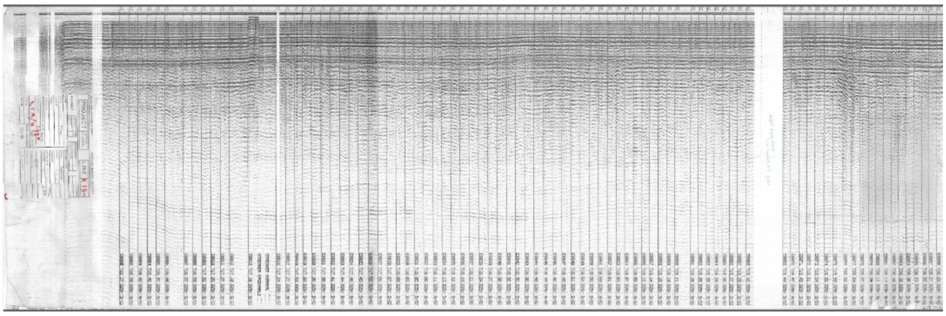
4.1.1.2 *INDEF82 (1982)*

The seismic source for this data was an X-tree Sparker. This is an old generation of sparker with sometimes only 9 electrical tips, whereas modern (multi-tip) sparkers often have in excess of hundreds of tips. The modern sparkers therefore are capable of a cleaner, more broad band and powerful signal.

The data recorded and plotted during this survey suffers from variable plotter settings by the operator. Also, the data was plotted in black on white, this means no shades of grey. The data is merely plotted as on or off (black or nothing) with a certain threshold (which was quite common in those days). See Figure 5 for an example of scanned and converted data from the INDEF82 survey.

Like the panels from the KEYSPL survey, the panels of the INDEF survey also contained many annotations like time an, fix number. But like with the panels from the KEYSPL survey interpretation is not hampered by these. It was decided not to try to remove them.

a.



b.

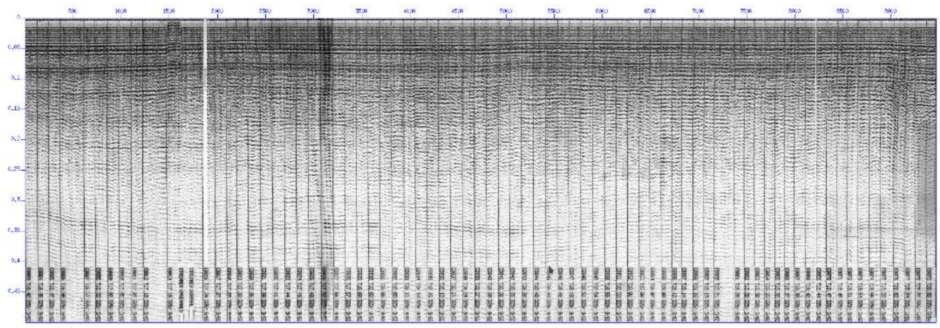
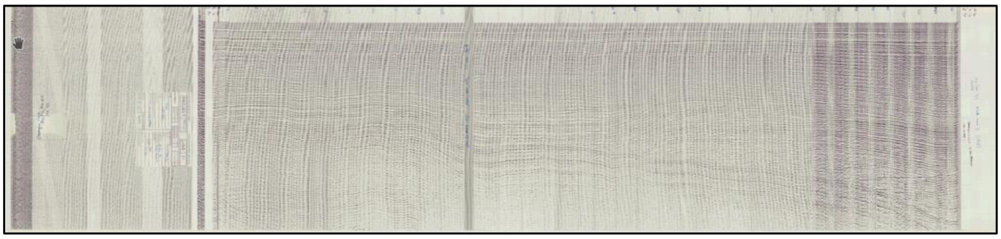


Figure 5. a. rotated image file as found in the archives. b. Data after conversion into SEG-Y format. This data has been corrected for faulty plot parts and holds navigation data. Vertical axis is in seconds TWT, horizontal axes is trace number. Total line length on display is approximately 36 km.

4.1.1.3 *KVAK92 (1992)*

The KVAK data was processed in a similar way as the INDEF82 data. The data quality from the scans was suboptimal. During recording / plotting of the original records the operator varied plot settings like gain, polarity, bandpass filter, paper speed, etc., which give an unbalanced view (Figure 6a). Furthermore the plotter used only black on white, so no shades of gray. This all severely limits any useful processing and often requires manual / surgical editing of the data. An example of the data is shown in Figure 6. But even so, the data showed good potential. The data contains quite some reverberation and multiple energy. But a seasoned interpreter should be able to look through this. Taking these factors into account the resolution and penetration depth are quite significant and pretty good within the depth of interest.

a.



b.

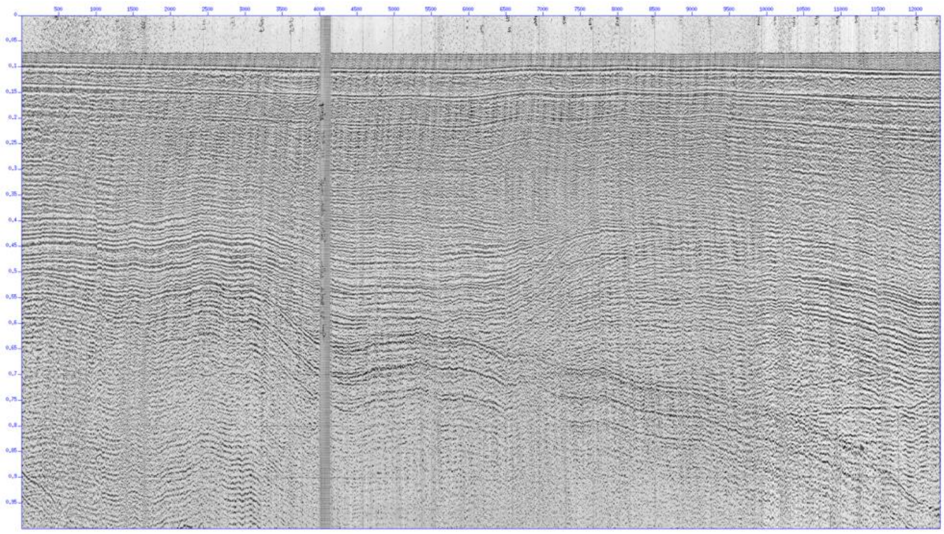


Figure 6. Example of KVAK92 line. a. scan of the original plotted profile. Note the variability in plot settings. b. the SEG-Y after surgical cleaning and editing and adding navigation data. Vertical axis is in seconds TWT, horizontal axes is trace number. Total line length on display is approximately 86 km.

4.1.1.4 SONIA NCP (1978)

The SONIA lines where the oldest ones used in this project. When these lines were recorded, digital recording equipment was rare and expensive. Especially for the shallower parts of the subsurface it was common to record “directly” on paper. This was referred to as analogue recording. Recording on paper often also included some basic analogue processing (e.g. gain control, frequency filtering) and had several advantages: Any QC could be done immediately, interpretation could start right away, and the data could easily be revisited in the office. The drawbacks mainly appeared only later. First, archiving would become cumbersome and dispersion of datasets through borrowing likely, leading to loss of records. Secondly, many records, often on thermal paper, have faded over the years, leaving barely visible reflections further masked by subjective interpretations made in red or blue pencil. Finally, integrating the original data into models proved difficult because of poor metadata recording and management. Navigation data, for example, was hardly ever integrated and normally stored separately.

Converting the “analogue” prints of the SONIA survey data incorporated 4 main steps as listed under methods in section 3.1.1. As the scans were all of different layouts and quality. Some were torn, skewed, or dark and fuzzy. The actual data frame selection was done by hand for every line.

The example scan (Figure 7) even though taken from a previous project is comparable with the data as used in this project. In this case the scan consists of over 200 million pixels in 8 bit grey scale. It contains 3 data frames (see Figure 8), where some scans in our project also only contained 2 data frames. In this example the data frames represent:

1. Upper 1/6th part of the scan contains unknown data at an unworkable (large) scale. Hardly anything can be made from this.
2. Up to the middle part, contains reasonably good data at a workable scale, with a realistic water column.
3. Lowest half contains nice signal data but has irregular time shifts and other potentially problematic attributes, like annotations and interpretations. Scale wise this portion seems to have a vertical exaggeration of 2 over the middle part.

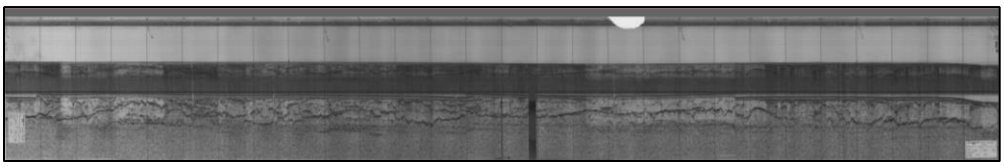


Figure 7. Overview of a scanned SONIA line. Horizontal scale measures about 26990 meters.

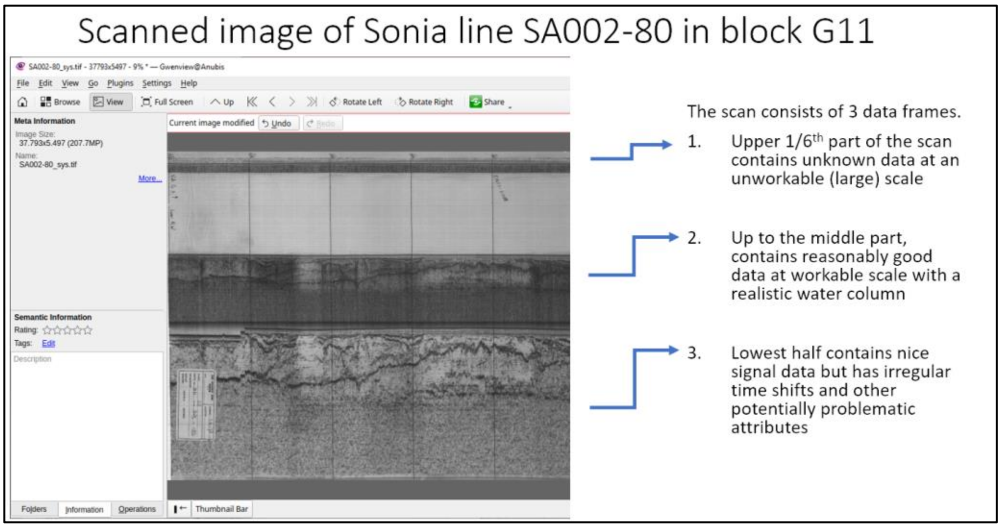


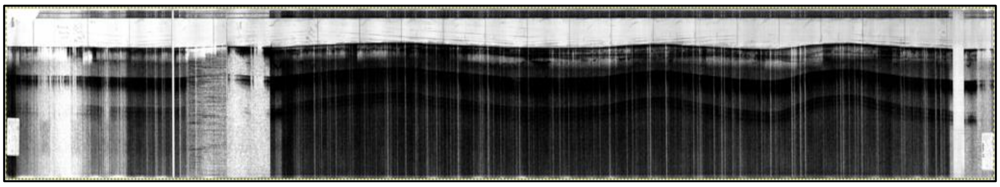
Figure 8. Example of a scanned SONIA line depicting the 3 data frames in the scans.

A best guess was performed at a trace length (based on hand written water depth and notches on the printouts). To get back realistic waveforms the resulting data were convolved, e.g. with a Ricker wavelet with a center frequency of 750 Hz. These waveforms are as close as one can get to a digitized seismic reflectivity series convolved with a representative wavelet. A straightforward interpolation algorithm was used to assign coordinates to all seismic traces lying in between the selected traces corresponding to a fix number (and thus having a coordinate assigned to it). In sections outside the first or last fix, the traces were respectively assigned to the start or end coordinate. Extrapolation was thought to be too unprecise as it showed that the vessel regularly made turns before the start or after the end of a line. Also, when the vessel had to abandon the original track during surveying, the trace numbers involved were given the coordinates of the nearest fix number.

Below a poor (Figure 9) data example and a good (Figure 10) data example from this project are displayed.

Processing of SONIA data included the convolution of the converted grey scale data with a 750Hz Ricker wavelet. Additional processing included trace mixing, FX deconvolution and frequency filtering to increase signal to noise and resolution.

a.



b.

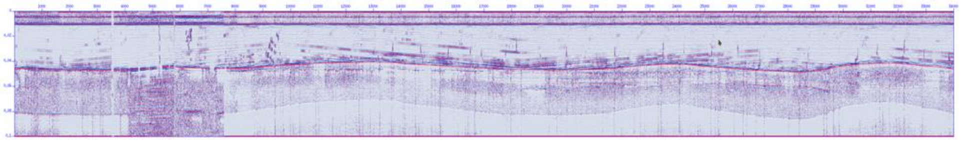


Figure 9. a. scan of the profile of SONIA78 K18 ZW. Note how the poorly plotted line is tuned into a usable (b.) and of reasonable quality SEG-Y file which can be imported into many if not all interpretation suites. The vertical axis is in seconds TWT, horizontal axes is trace number. Total line length on display is approximately 28.5 km.

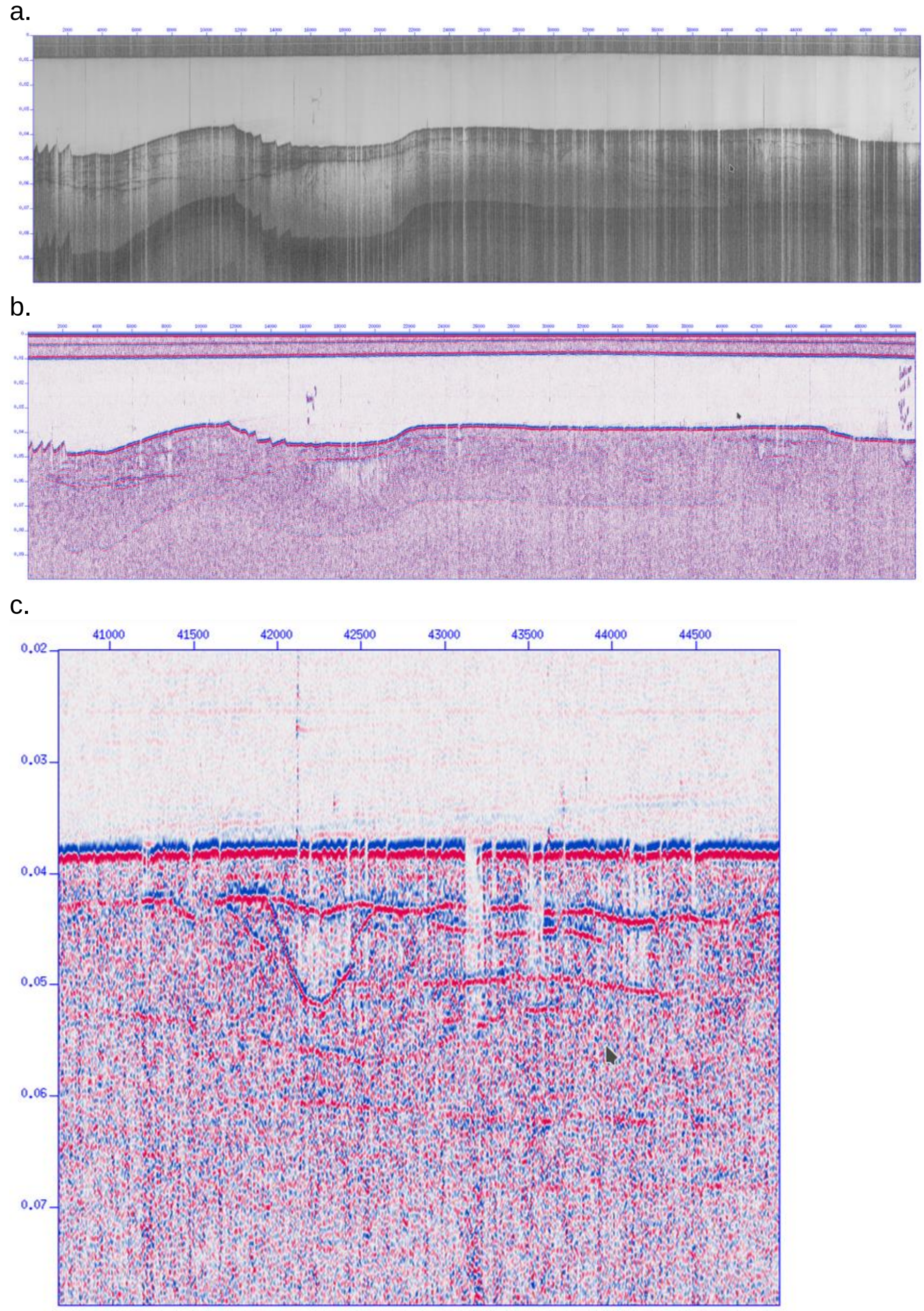


Figure 10. Data from line SONIA78 P3 NO. a. the data after conversion into SEG-Y format. b. The data after processing. c. A closeup of some shallow geological structures present in the North-Eastern part on this line. The vertical axis is in seconds TWT, horizontal axes is trace number. Total line length on display is approximately 28 km. The closeup part covers merely 1/10 of that (2.2 km)

4.1.1.5 UK80 (1980)

The UK80 survey is one of the older surveys and consisted of sparker (Figure 11) and airgun (Figure 12) data. Both were only available from poorly scanned files. The images in the files were often skewed and without visible labels. Data came in black on white (no grey scales). We managed to convert the data to SEG-Y format. This often meant first cutting, un-skewing and rotating the data as good as possible, before the conversion into the SEG-Y format could start.

The data shows some very interesting geological features like many deep tunnel valleys (Figure 12), and seems worth investigating.

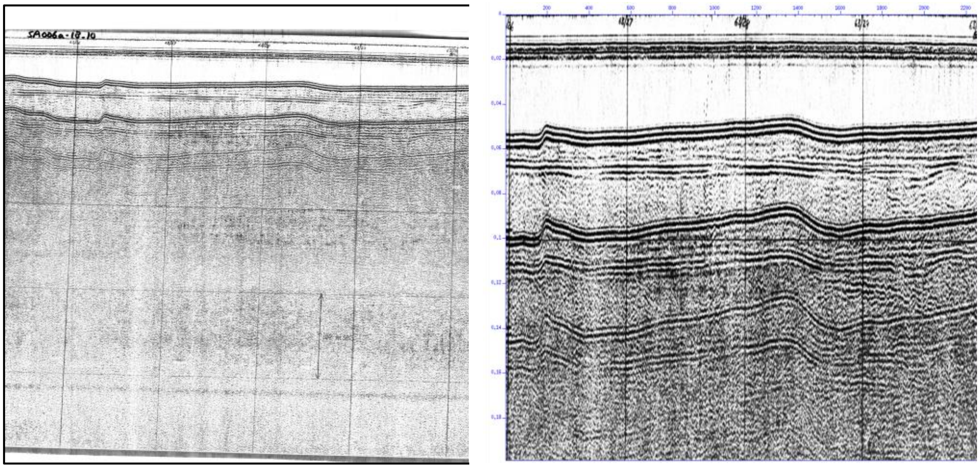


Figure 11. Sparker data from the UK80 survey. Left the scanned section. Right the SEG-Y file. Vertical axis is in seconds TWT, horizontal axes is trace number. Total line length on display is approximately 8 km.

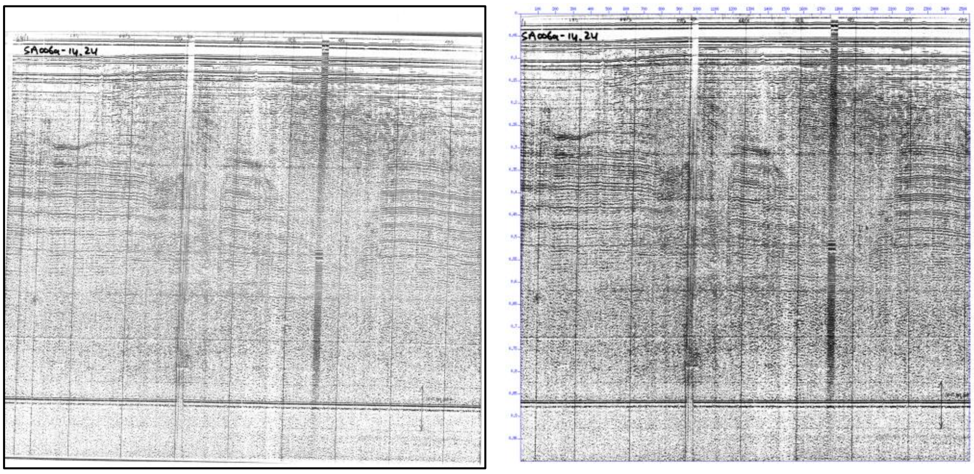


Figure 12. Airgun data from that same UK80 survey. Left the scanned section. Right the SEG-Y file. Note the massive tunnel valleys. Valleys, hundreds of meters deep, carved out during the last major glaciation event. Vertical axis is in seconds TWT, horizontal axes is trace number. Total line length on display is approximately 17 km.

4.1.2 Single channel “Analogue” data

This section describes the results from reprocessing of the single channel seismic surveys. These single channel seismic surveys are classically referred to as “analogue” surveys, because at that time their output was merely available on paper (see former section). Since the 90’s it is more common to also record digitally, hence the many SEG-Y files available for reprocessing. The data was gathered from the following surveys:

1. EG97 (1997) (Chirp)
2. PVAK96 (1996) (Chirp)
3. Pelagia_survey_2017 (2017) (Sparker)
4. Pelagia_survey_2017 (2017) (Chirp)

For a complete overview of all data see Table 2 and Figure 1.

The type of equipment used for this data was never meant to look deep into the subsurface, but instead shallow and in high vertical and lateral resolution. The depth range of the equipment is relatively limited because of the limited power output of the sources and the limited sensitivity of the single channel receivers (hydrophone/streamer). On the plus side, the higher frequency content of the source signal allows for better vertical resolution, more detail to be imaged when compared to many multi-channel surveys using more powerful seismic sources of that time (see next section). Lateral resolution is increased over multichannel seismic surveys by the decreased shot interval. So where the shot interval of a typical multichannel seismic survey would be 25m, that might be decreased during a single channel survey to merely 2m (often only measured in time between shots and not distance).

4.1.2.1 EG97 (1997) (Chirp)

The data was quite noisy, but it could be cleaned up quite well. The original signal data, which contained only positive values, and no actual wave forms, was convolved with a 750 Hz Ricker wavelet, band pass filtered, gained, swell/heave filtered and a relative light and weighted trace mixing was applied (over a moving windows of only 3 traces). Finally the data was cut at 0.125 ms, as no further reflections were witnessed beyond that depth (Figure 13).

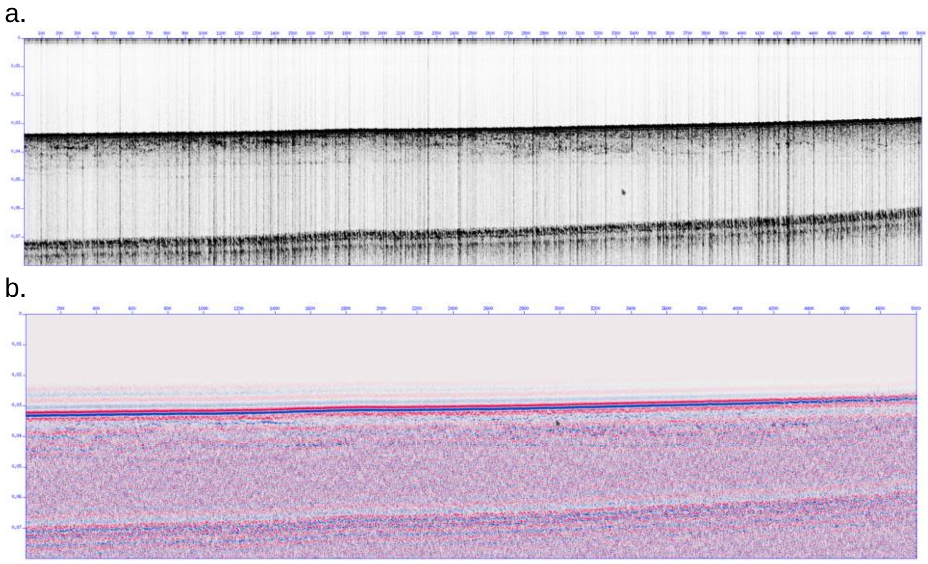
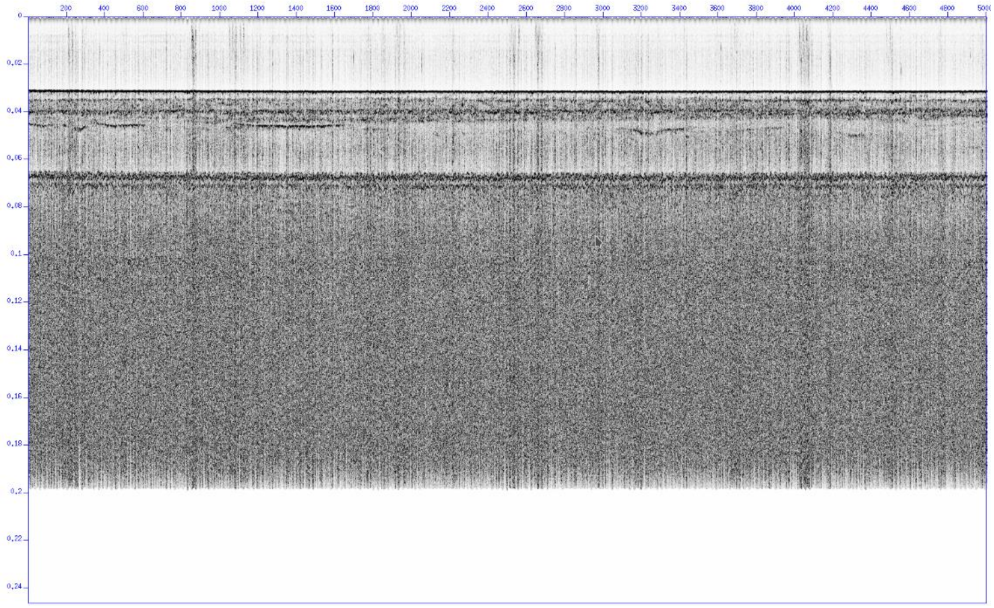


Figure 13. Chirp data from the EG97 survey. a. unprocessed. b. after processing. Vertical axis is in seconds TWT, horizontal axes is trace number. Total line length on display is approximately 3 km.

4.1.2.2 PVAK96 (1996) (Chirp)

This data is quite similar in quality as to the EG97 chirp data. The data was noisy but could be cleaned up quite well. The original signal, which contained only positive values, and no actual wave forms, was convolved with a 750 Hz Ricker wavelet, band pass filtered and gained, swell/heave filtered and a limited weighted trace mixing was applied (over only 3 traces). Finally the data was cut at 0.125 ms, as no further reflections were witnessed beyond that depth (Figure 14).

a.



b.

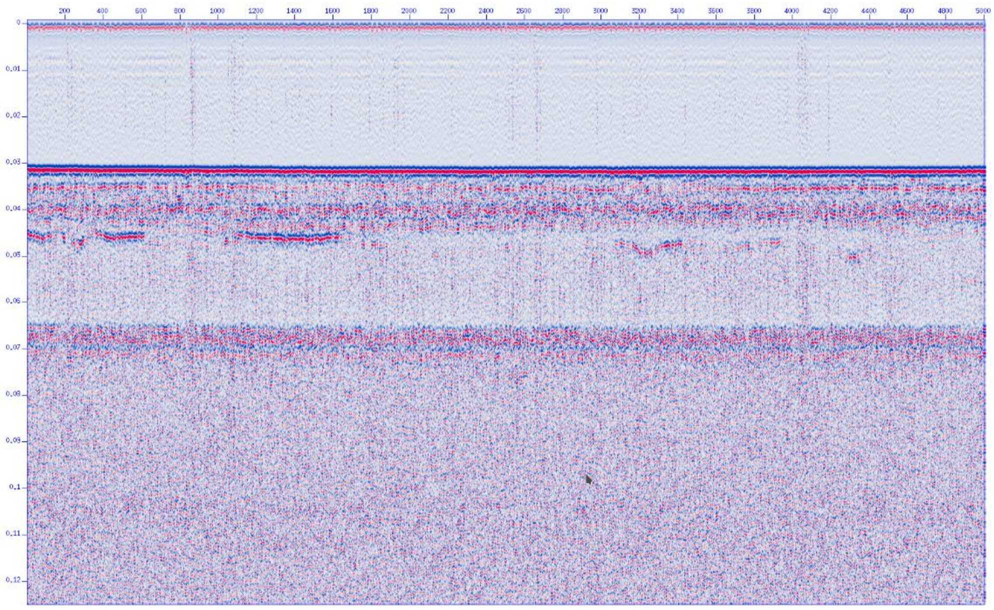


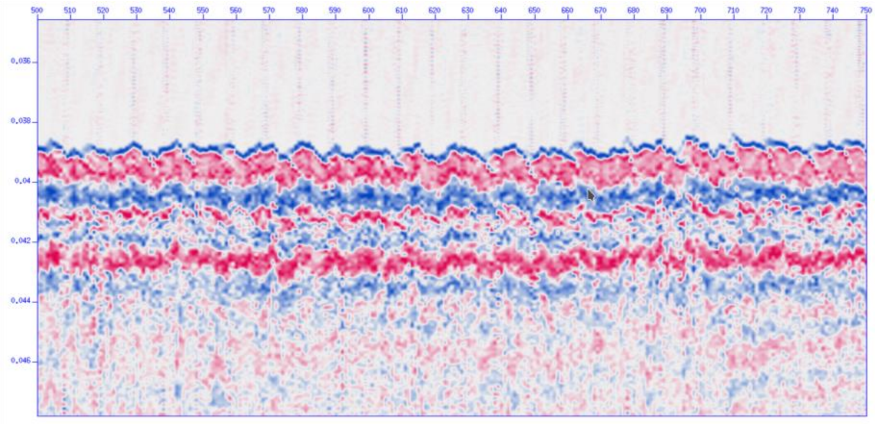
Figure 14. Chirp data from the PVAK96 survey. a. unprocessed (note the unnecessary long record). b. after processing. Vertical axis is in seconds TWT, horizontal axes is trace number. Total line length on display is approximately 2.5 km.

4.1.2.3 Pelagia_survey_2017 (2017) (Sparker)

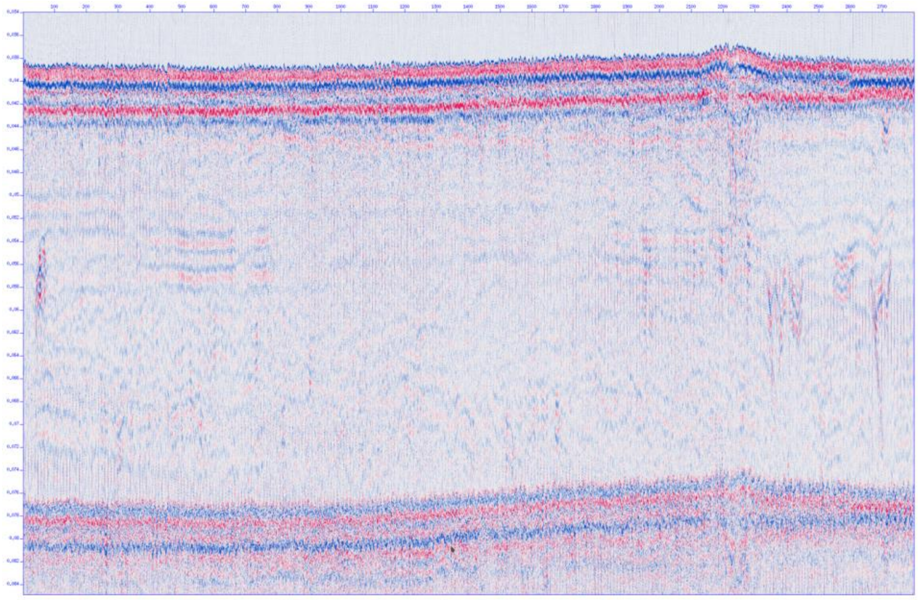
The data from the (multi-tip) sparker from the Pelagia survey was of rather poor quality. One of the most disturbing causes for that was the varying source signal (of mixed phase) which also included a lot of reverberations or ringing and possibly even a ghost reflection of the sea surface or the Pelagia itself (this is where the source signal also bounces of the hull of the towing vessel before and possibly after it traveled down into and from the subsurface). The survey was probably also shot during bad weather, as there was a lot of swell noise in the data. The combination of an non constant source signal with lots of reverberations, ringing and lots of swell noise makes filtering for removing these extra difficult. Furthermore, and probably because of the above, the resolution and penetration depth of the data was rather poor. Trials trying to spike the source signal were unsatisfactory, as were the trials to use gapped deconvolution to de-multiple the sections.

Nonetheless the sparker data, especially after processing, does reveal many structures beyond the depth range of the chirps. Seeing below the 1st sea bed multiple though proved almost impossible (which it not necessarily has to be for single channel sparker data) (Figure 15).

a.



b.



c.

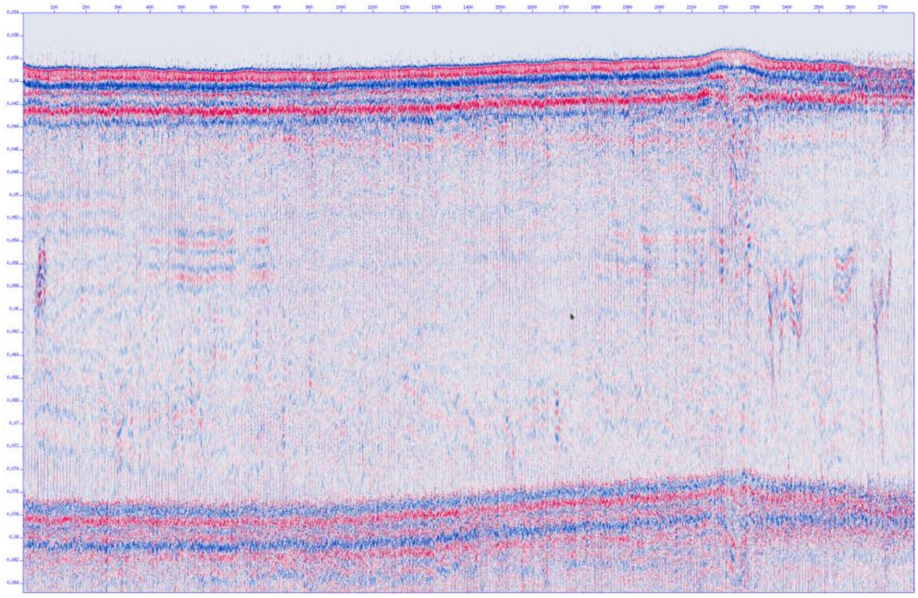


Figure 15. Example of filtering for swell movement of the equipment. a. detail of how swell can manifests itself in single channel seismic. The waves on the seabed are not real, the seabed is flat. The wavey nature is an effect of the source and streamer moving with the swell. Panels b. and c respectively show the full section before and after swell filtering. Besides the swell filtering the panels have under gone the same processing. Note the increased amplitude and continuity of the reflectors at 50ms TWT in c: the swell filtered section. This is because the whole trace is shifted back to its original location (like with static correction on land data). Vertical axis is in seconds TWT, horizontal axes is trace number. Total line length on display in b & c is approximately 3 km.

4.1.2.4 Pelagia_survey_2017 (2017) (Chirp)

The chirp data (X-star) from the Pelagia survey contained 3 channels of data per shot (Figure 16a) and subsequently the data files were large. We investigated which channel performed best, and have only output that channel in our results. The chirp is not of the best quality, since the data contained some odd types of non-random noise (e.g. a noise burst every 11th shot), and has relatively poor penetration. The non-random noise is probably generated by other equipment in the water or in the recording room. Efforts were undertaken to suppress as much as possible without making the processing flow too complicated. Next to the classical electrical and acoustic noise, the data also suffered from heave / swell noise. A routine was performed to also suppress this type of noise, which typically increases lateral continuity and vertical resolution in the seismic panels (Figure 16b & c).

a.

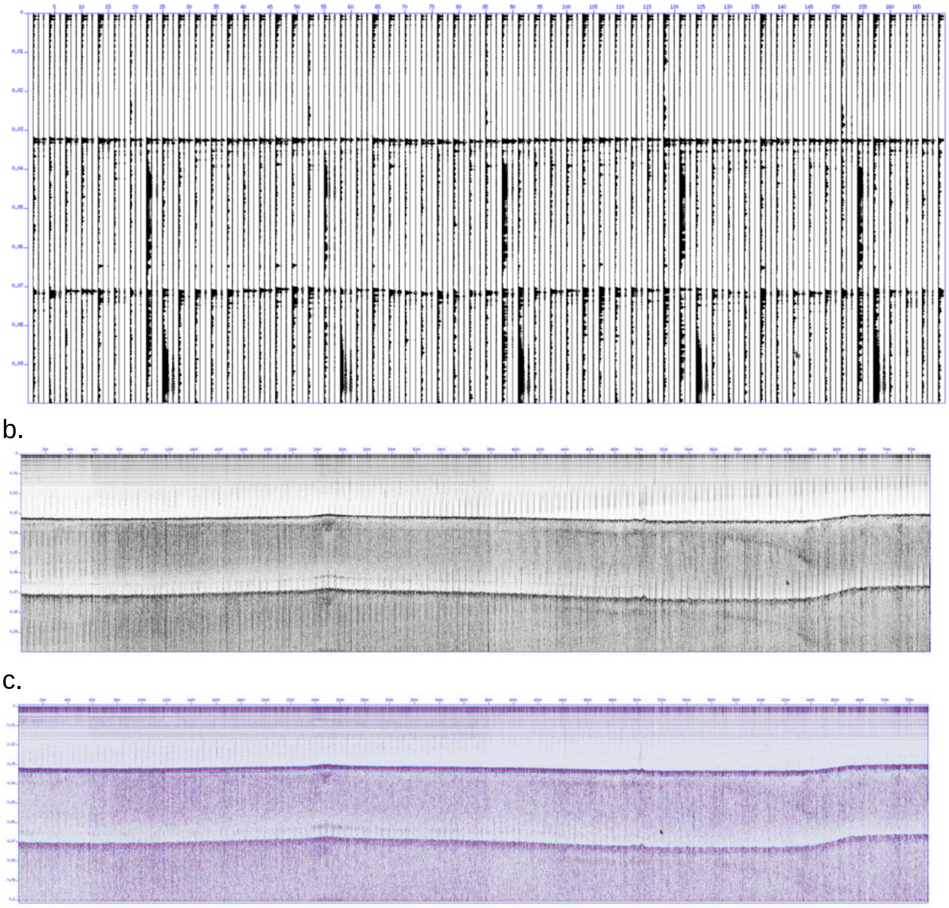


Figure 16. Chirp data from the Pelagia. a. Raw chirp data, displayed in wiggle format, b. Unfiltered Channel 1 in grey scales. c. The chirp data after processing in the classic red-white-blue color scheme. Vertical axis is in seconds TWT, horizontal axes is trace number. Total line length on display is approximately 8 km.

4.1.3 *Multi-channel data*

The multi-channel data were acquired with airgun and sleeve gun type sources and various types of multi-channel streamers. The multi-channel lines reprocessed in this project were from several surveys:
1. EEG87 (1987) (Watergun)
2. EG97 (1997) (Source unknown)
3. KEYSPL (2002) (Sleevegun)
4. KVAK92 (1992) (Sleevegun)
5. LFB88 (1988) (Watergun)
6. LMN93 (1993) (Sleevegun)
7. PVAK96 (1996) (Source unknown)

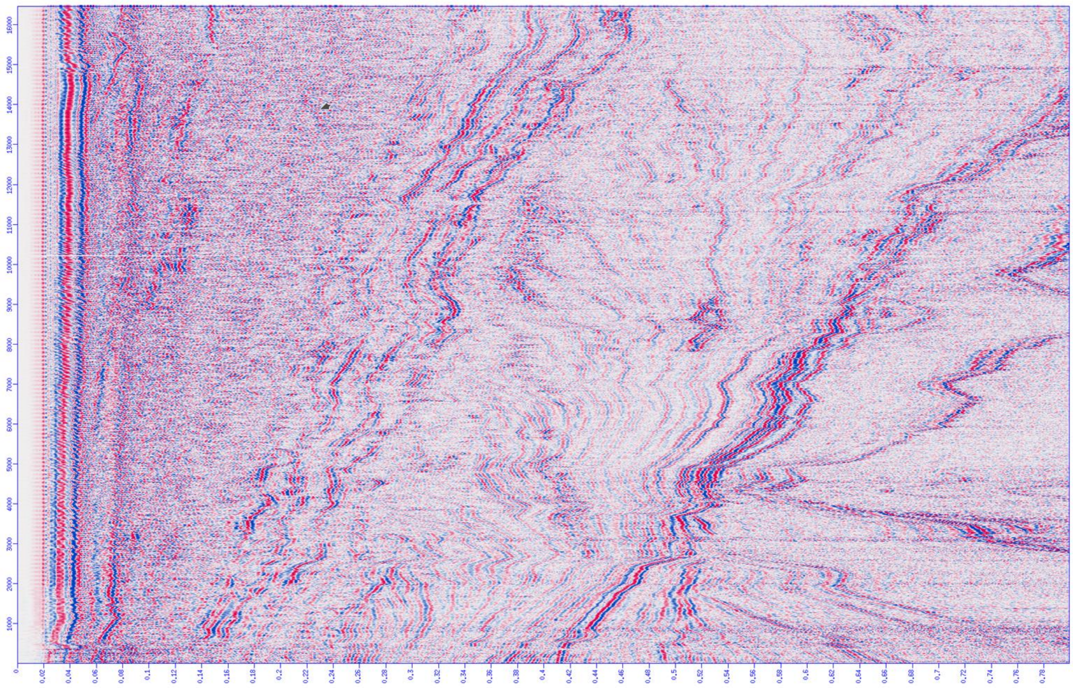
For a complete overview of all data see Table 2 and Figure 1.

Most of the time it was very apparent that the data was not shot to image the shallow subsurface with the highest fidelity. Trace length often went down to 2.0 seconds, coarsely corresponding to a depth of 1500m or more. Using relatively strong (often low frequent) seismic sources also makes it difficult to image the shallow subsurface in high detail.

In the following sections we present a brief description of the data and processing done per survey, including figures displaying examples of the data.

4.1.3.1 EEG87 (1987) (Watergun)
When this data was shot, the target was obviously located beyond the upper 200 m. The data was shot with a rather strong source, which has lots of penetration. Unfortunately the strong and broad source signal also covers up lots of the shallow geology and causes strong seabed multiples. Through spiking and gapped deconvolution the signal to noise and resolution are slightly increased. Weighted trace mixing further increases lateral continuity and suppresses random noise. Finally a bandpass filter was applied to even further clean up the data. The result show an increase in signal over the whole panel, Figure 17.

a.



b.

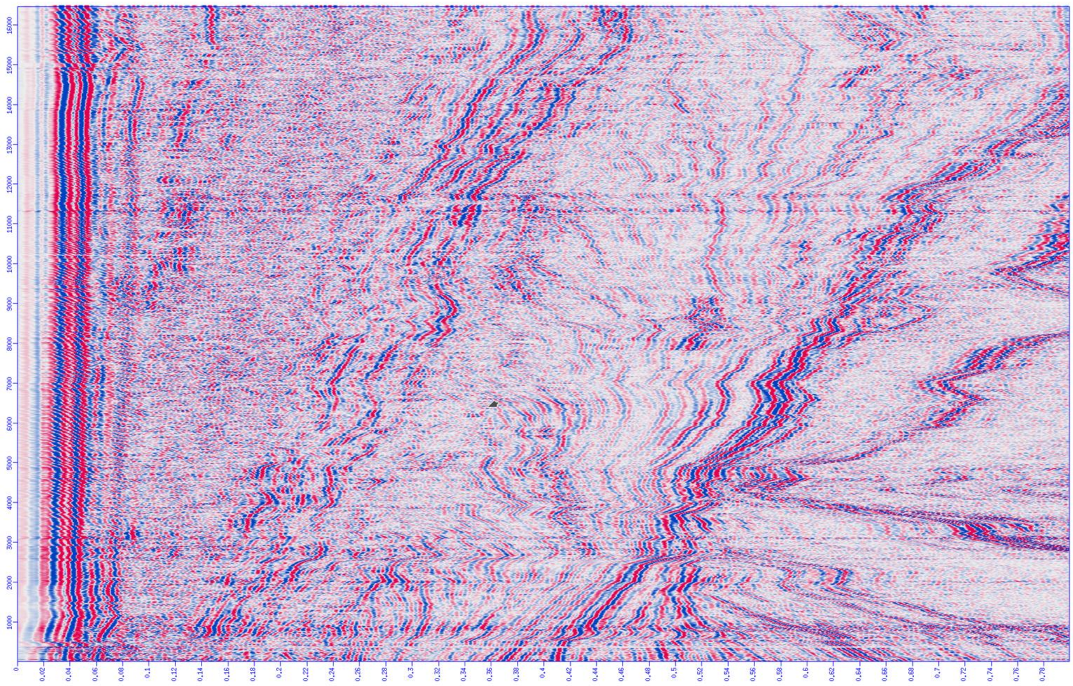


Figure 17. a and b respectively show the data before and after re-processing. The sections are rotated 90 degrees to fit on one page, which should make comparing them more easy. Vertical axis is in seconds TWT, horizontal axes is trace number. Total line length on display is approximately 115 km.

4.1.3.2 EG97 (1997)

The data from the EG97 survey was very poorly processed in the shallow domain. This manifested itself, among things, in partially muted traces (probably remnants of a faulty / too strict top mute). In some lines the seafloor was even hardly visible anymore (Figure 18). Through focusing on increasing lateral continuity, especially in the shallow domain, we were able to increase the signal over the whole panel, enabling also interpretation of the shallow subsurface.

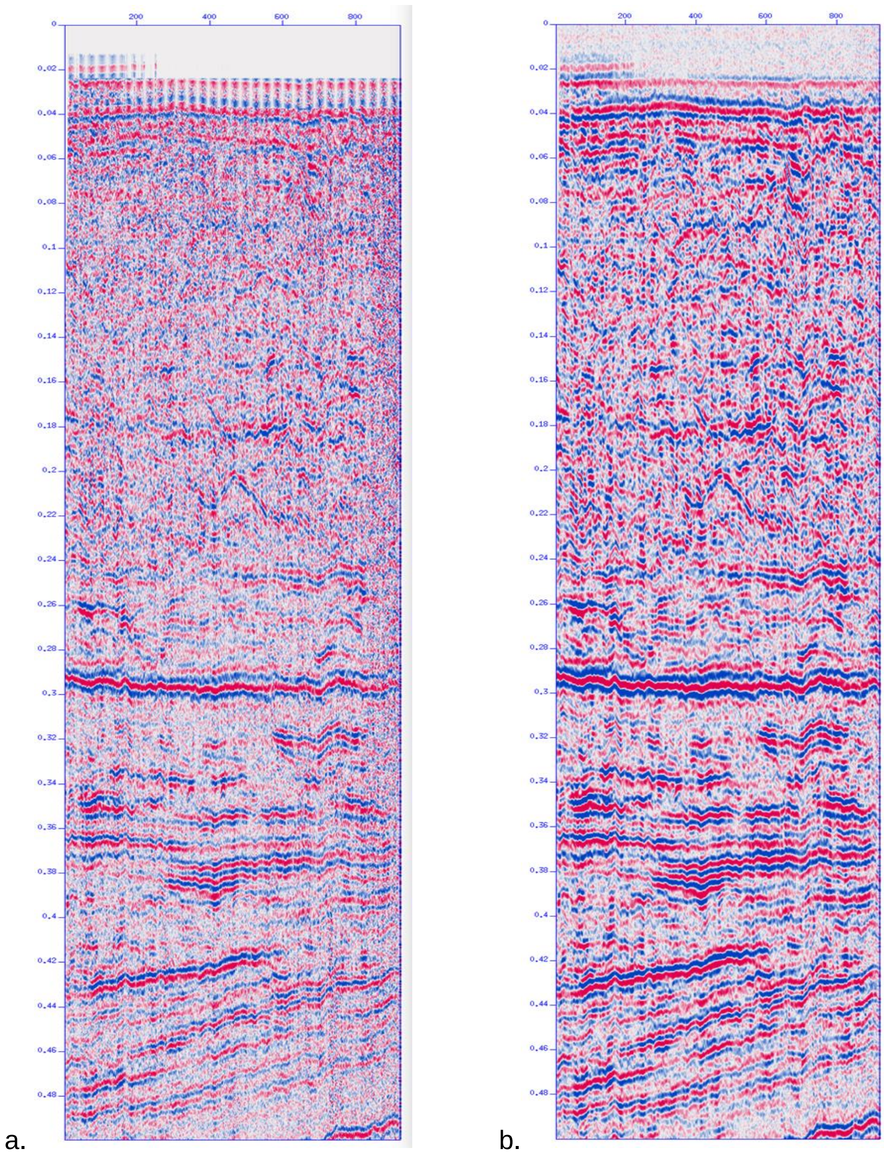


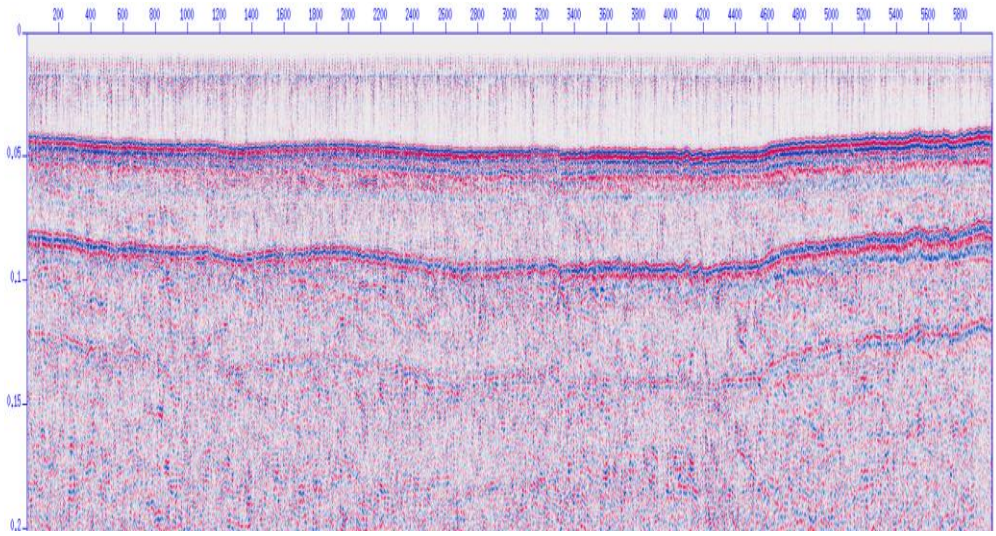
Figure 18. Before re-processing (a.) and after re-processing (b.) of a line shot during the EG97 survey. Note especially in the shallower part the increase in continuity, and even the visibility of what appears to be the seabed. Vertical axis is in seconds TWT, horizontal axes is trace number. Total line length on display is approximately 5.5 km.

4.1.3.3 KEYSPL (2002) (Sleevegun)

The data from the KEYSPL survey was of reasonable quality. It did contain some multiple energy, but the source signal was sharp enough not to cover up all the weak reflectors in the shallow overburden.

Processing involved spiking deconvolution to collapse the source signal, a gapped deconvolution to suppress the seabed multiple, weighted trace mixing to increase lateral continuity and bandpass filtering to suppress random noise. Processing sharpened reflections in the shallow subsurface, making them better visible (Figure 19 & Figure 20).

a.



b.

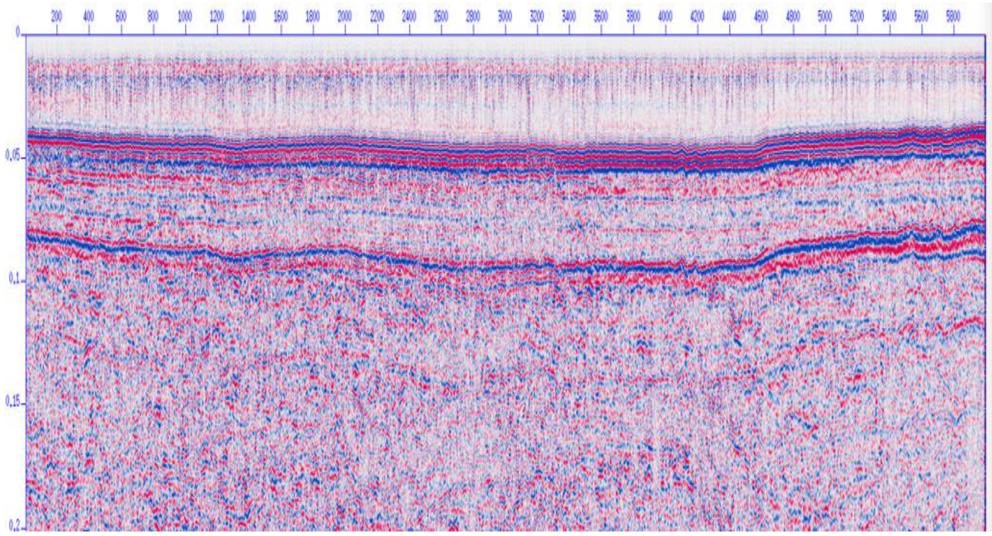


Figure 19. Zoomed (and stretched) part of Figure 20, showing the shallow subsurface in more detail. Note how reflectors between the seabed and the first seabed multiple become better visible. Vertical axis is in seconds TWT, horizontal axes is trace number. Total line length on display is approximately 37.5 km.

a.

b.

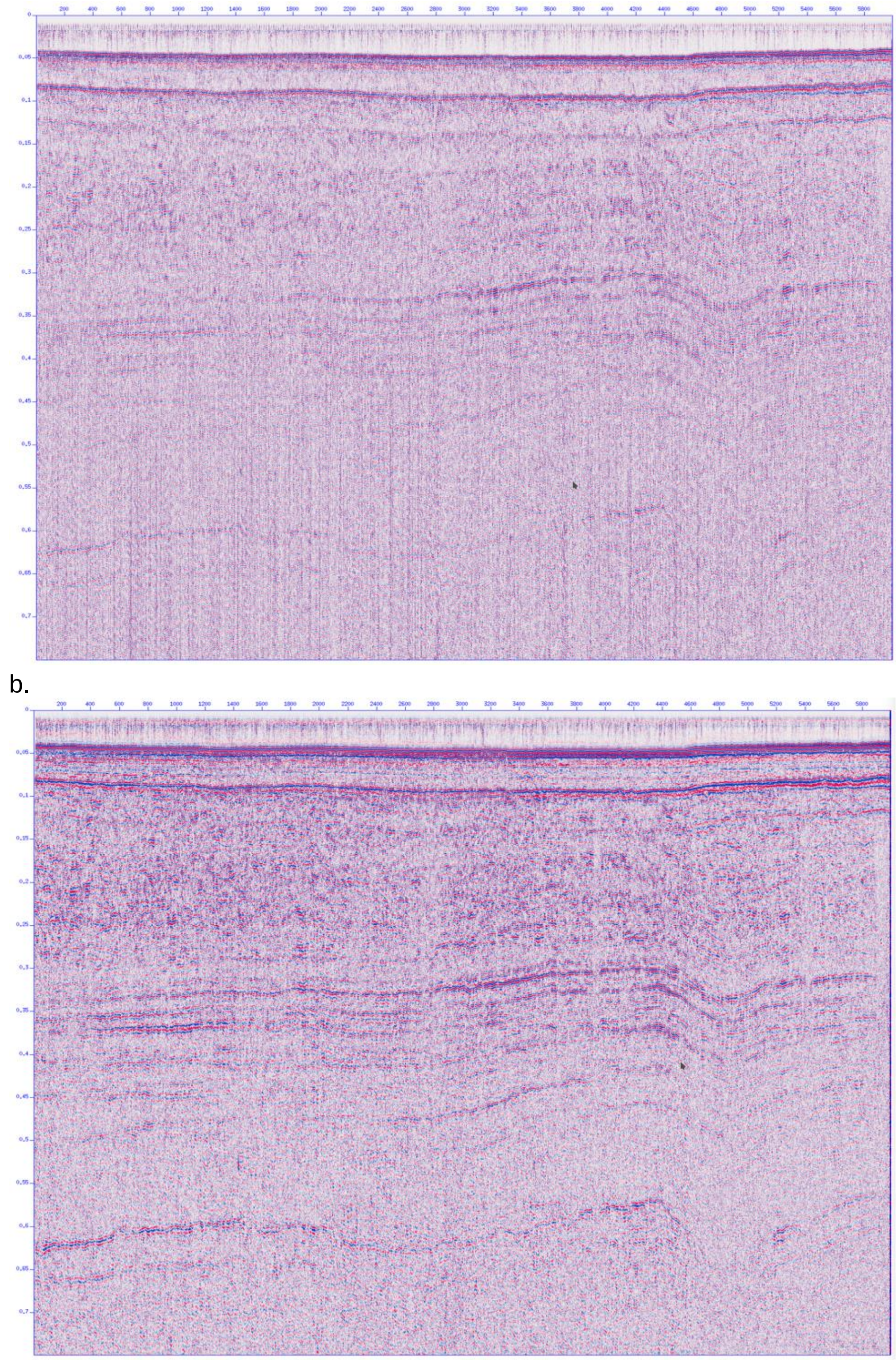


Figure 20. Before re-processing (a.) and after re-processing (b.) of a line shot during the KEYSPL survey. Note how reflectors have sharpened, especially in the shallow subsurface, and how the multiple energy has been decreased. Vertical axis is in seconds TWT, horizontal axes is trace number. Total line length on display is approximately 37.5 km.

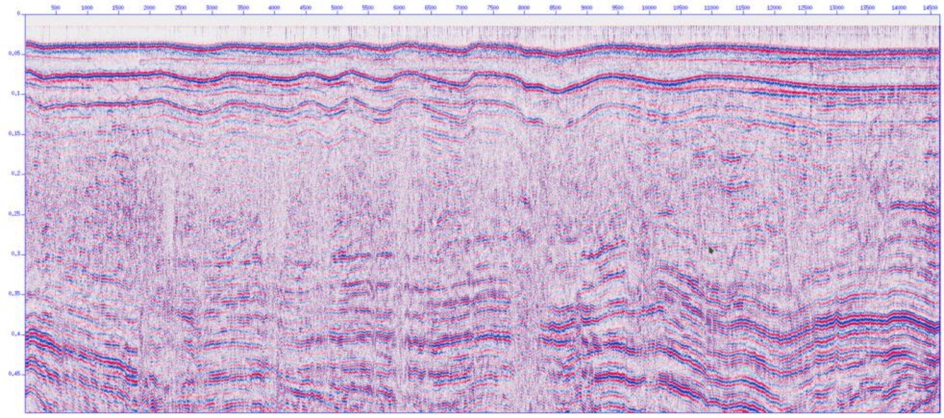
4.1.3.4 KVAK92 (1992) (Sleevegun)

The data from the KVAK92 survey was also of reasonable data quality'. It did contain a lot of multiple energy, but the source signal was sharp enough not to cover up all weak reflectors in the shallow overburden.

Final processing involved a gapped deconvolution to suppress the strong seabed multiple. Additional processing included FX deconvolution and weighted trace mixing to increase lateral continuity

Noteworthy was that this data was already the result of a reprocessing project (from pre stack) but not much attention was paid to multiple elimination. Especially when working in the pre-stack domain the best results can be achieved. Nonetheless the post-stack efforts, executed during this project, also suppressed much of the seabed multiple energy (Figure 21).

a.



b.

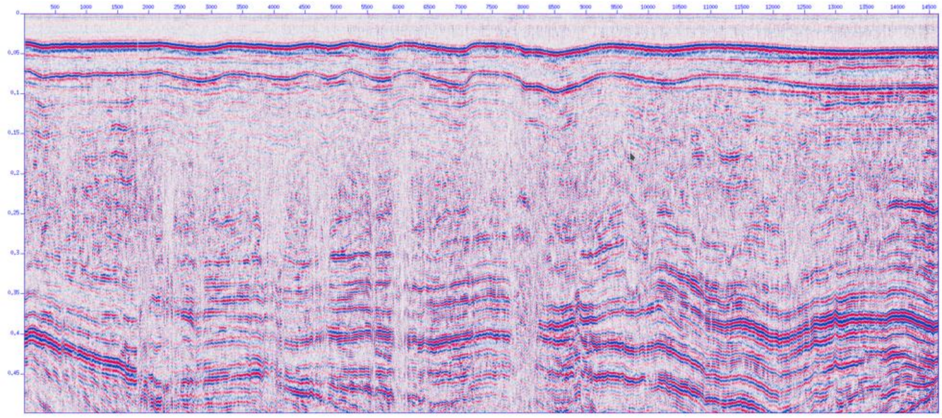


Figure 21. Before re-processing (a.) and after re-processing (b.) of a line shot during the KVAK92 survey. Note how reflectors have sharpened, random noise has been lowered and multiple energy has been decreased. Vertical axis is in seconds TWT, horizontal axes is trace number. Total line length on display is approximately 11 km.

4.1.3.5 LFB88 (1988) (Watergun)

The original data quality is quite poor, it is very noisy and even after reprocessing it is difficult to follow horizons and to interpret the seismic data. Only larger structures and reflectors with some significant amount of energy are visible (Figure 22).
The source signal seems to have a lot of reverberation and is very broad. The seabed multiple is also very strong. This causes the many weak reflection in the shallow subsurface to be overpowered by reverberations and multiple energy.
Processing involved spiking deconvolution to collapse the source signal, gapped deconvolution to suppress the seabed multiple, weighted trace mixing to increase lateral continuity and bandpass filtering to suppress temporal noise.

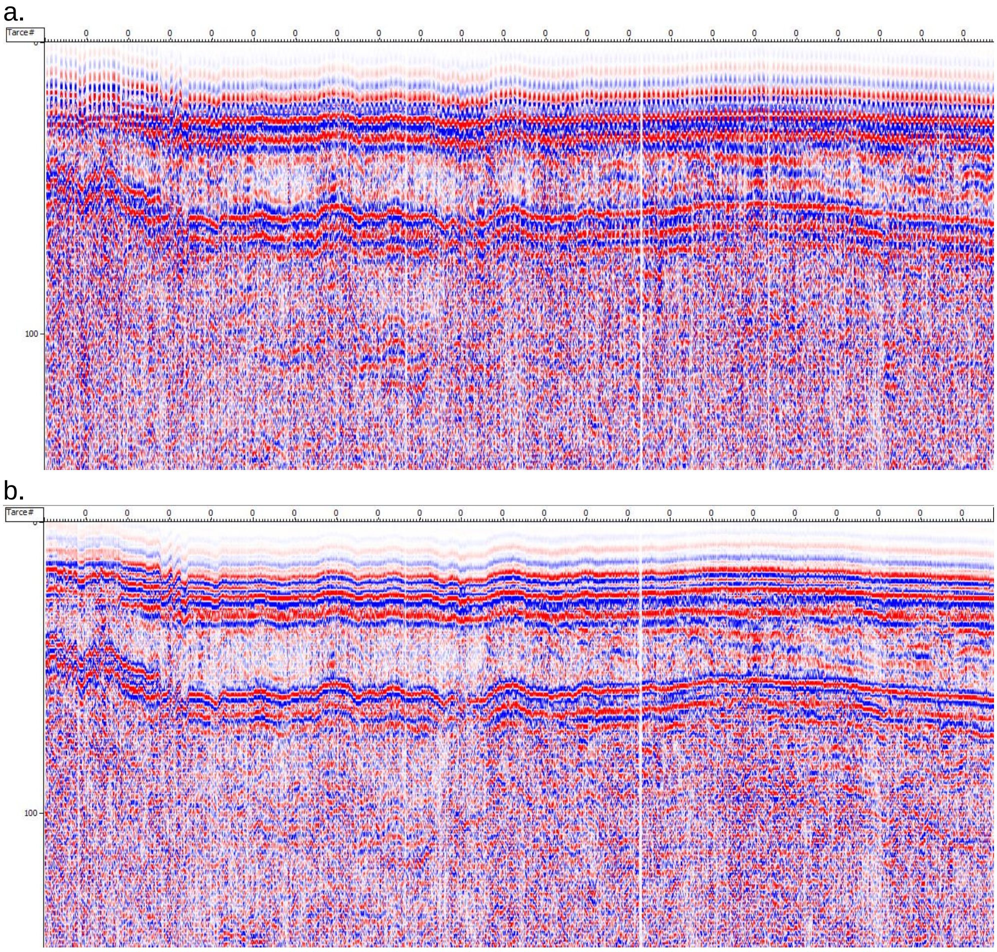


Figure 22. Zoomed in section of a line of the LFB88 survey. a. before and b. after re-processing. Horizons, especially between the seabed and the 1st seabed multiple have become clearer, to the point that they have become meaningful and are interpretable. Vertical axis is in ms TWT. Total line length on display is approximately 58.5 km.

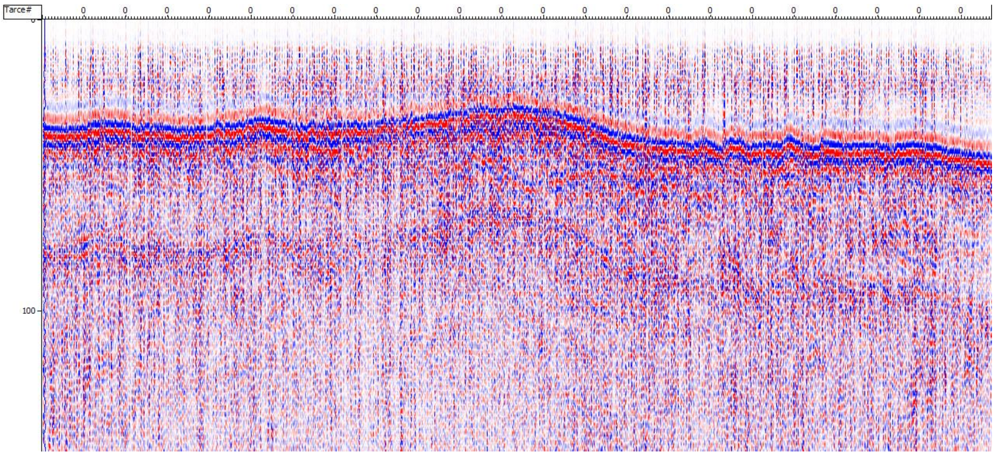
4.1.3.6 LMN93 (1993) (Sleevegun)

This data is also of poor quality, it is very noisy, even after reprocessing it is quite difficult to interpret. Mainly larger structures and reflectors with some energy are visible (Figure 23).

The source signal seems to have some reverberation, although not as bad as the data from the LFB88 survey. The seabed multiple is also a lot weaker. Because of this, even some weaker reflection become visible in the shallow subsurface. On some occasions small channels are clearly visible, above the 1st seabed multiple.

Processing involved spiking deconvolution to collapse the source signal, weighted trace mixing to increase lateral continuity, a wide bandpass filter to suppress temporal noise while trying to keep as much as possible signal in the shallow domain.

a.



b.

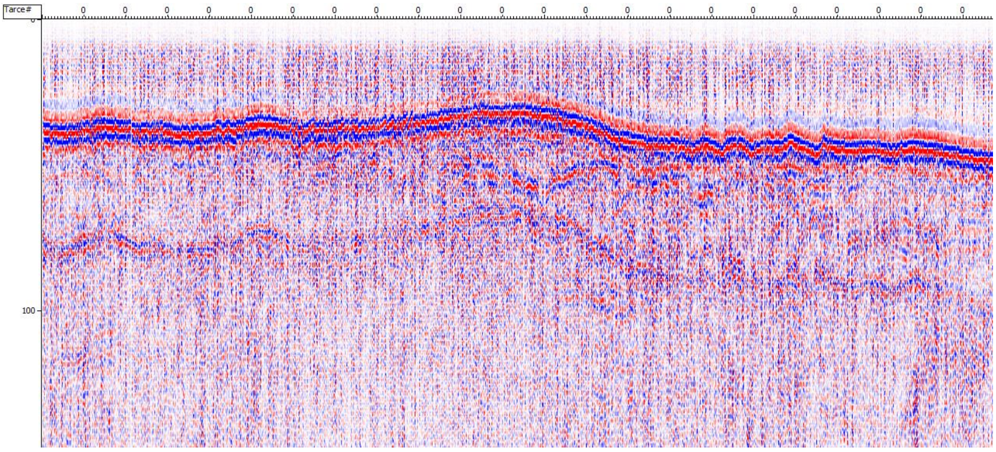
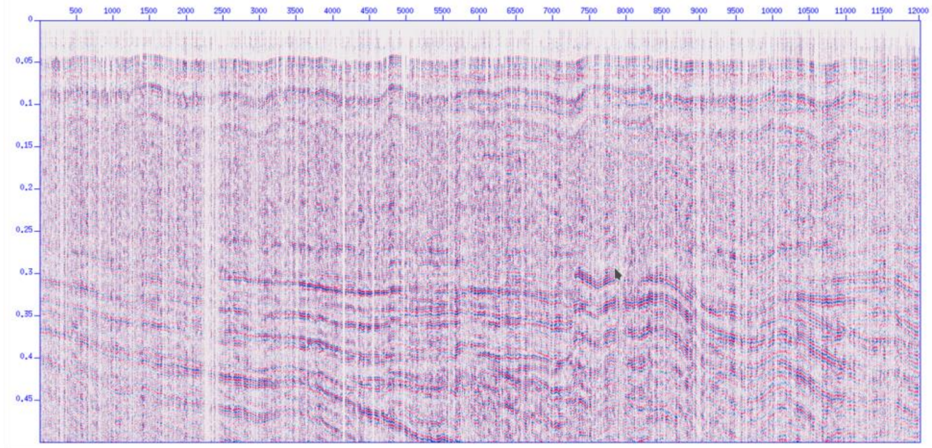


Figure 23. Zoomed in section of a line of the LMN93 survey. a. before and b. after re-processing. Some geological features are now more clear. Vertical axis is in ms TWT. Total line length on display is approximately 150 km.

4.1.3.7 PVAK96 (1996)

The processed data from the PVAK96 survey was of very bad quality. The data included empty traces, seemingly a too severe top mute was performed, etc., (see Figure 24a). Focus was on increasing lateral continuity, especially in the shallow domain. We were able to increase the signal over the whole panel through a combination of interpolation, gain and deconvolution in the time as well as in the spatial domain. Seabed multiples were also suppressed via gapped deconvolution. The results are one of the most astounding of this project (Figure 24b).

a.



b.

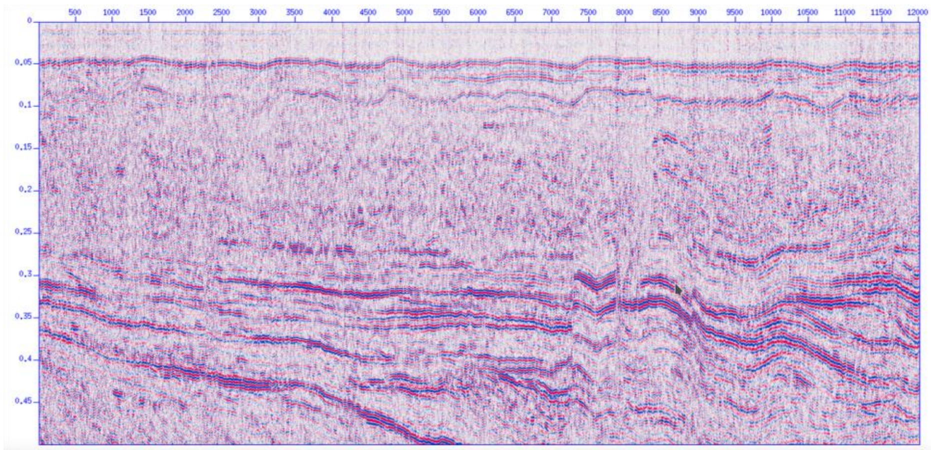


Figure 24. For (a.) and after (b.) reprocessing of a line shot during the PVAK96 survey. Note how well missing data in the weak or even dead traces is recovered, not only in the deeper, but also in the shallow domain. Vertical axis is in seconds TWT, horizontal axes is trace number. Total line length on display is approximately 74 km.

4.2 Explanatory Text files

Alongside each SEG-Y file there is an ASCII coded text file, which should be readable by any system without special software. These ascii files have the same name as the SEG-Y file, except for the .txt extension. These files hold the following information about the SEG-Y file:

1. A dump of the EBCDIC header.
2. General information on parameters in the trace header and their location.
3. The trace headers in use and the range of values in those trace headers (e.g. range of coordinates).
4. Information on the coordinate system used.

Note that the EBCDIC header is copied from the original data and modified to reflect that additional work has been done to the file. In case no (readable) EBCDIC headers was available, e.g. for some sparker lines and of course the scan converted data, a new header was created from scratch.

An example of such a file is included below.

```
----------------------------------------------------------------------------------------------------------
This file contains header information of file: dc_nov8701a-reproc.sgy

The EBDIC header:

C 1 CLIENT  MARGEO        COMPANY        CREW NO
C 2 LINE 01    AREA        MAP ID
C 3 REEL NO 1    DAY-START OF REEL   YEAR   OBSERVER
C 4 INSTRUMENT: MFG      MODEL      SERIAL NO
C 5 DATA TRACES/RECORD  0   AUXILIARY TRACES/RECORD  0   CDP FOLD   0
C 6 SAMPLE INTERVAL 0.00100 SAMPLES/TRACE  1601 BITS/IN    BYTES/SAMPLE
C 7 RECORDING FORMAT    FORMAT THIS REEL    MEASUREMENT SYSTEM
C 8 SAMPLE CODE: FLOATING PT   FIXED PT   FIXED PT-GAIN   CORRELATED
C 9 GAIN  TYPE: FIXED   BINARY   FLOATING POINT   OTHER
C10 FILTERS: ALIAS   HZ  NOTCH   HZ  BAND   -   HZ  SLOPE   -   DB/OCT
C11 SOURCE: TYPE      NUMBER/POINT     POINT INTERVAL
C12   PATTERN:            LENGTH     WIDTH
C13 SWEEP: START   HZ  END   HZ  LENGTH    MS  CHANNEL NO   TYPE
C14 TAPER: START LENGTH    MS  END LENGTH     MS  TYPE
C15 SPREAD: OFFSET    MAX DISTANCE     GROUP INTERVAL
C16 GEOPHONES: PER GROUP   SPACING   FREQUENCY   MFG      MODEL
C17   PATTERN:            LENGTH     WIDTH
C18 TRACES SORTED BY: RECORD   CDP   OTHER
C19 AMPLITUDE RECOVERY: NONE    SPHERICAL DIV    AGC   OTHER
C20 MAP PROJECTION           ZONE ID     COORDINATE UNITS
C21 FAMILY 1 DEFAULTS: DATA TRACES/RECORD     AUXILIARY TRACES/RECORD
C22          SAMPLE INTERVAL      SAMPLES/TRACE
C23 FAMILY 3 DEFAULTS: SAMPLE INTERVAL      SAMPLES/TRACE
C24
C25
C26 PROCESSED USING SKS BY MERLIN GEOPHYSICAL LTD
C27 THIS REEL CREATED ON 22/07/91  AT 14:04:58  BY JOB SEQUENCE NO. 3765
```

C28 CONTRACT NO. NOV 87

C29

C30 STACKED and post-stack decon,CDP 61-21196

C31

C32

C33

C34

C35

C36

C37

C38 REPROCESSED BY TNO, FEBRUARY 2022

C39

C40 END EBCDIC

Information on parameter location in the trace header:

tracl: byte# 1-4 tracr: byte# 5-8 fldr: byte# 9-12 tracf: byte# 13-16
cdp: byte# 21-24 cdpt: byte# 25-28 scalel: byte# 69-70 scalco: byte# 71-72
sx: byte# 73-76 sy: byte# 77-80 gx: byte# 81-84 gy: byte# 85-88 counit: byte# 89-90
ns: byte# 115-116 dt: byte# 117-118

The range from the trace headers:

16451 traces:
tracl 1
tracr 1 16451 (1 - 16451)
fldr 83 8308 (83 - 8308)
tracf 1
cdp 61 16511 (61 - 16511)
cdpt 1
trid 1 2 (1 - 1)
scalel -100
scalco -100
sx 56723424 56843790 (56843790 - 56723424)
sy 577627365 586216891 (577627365 - 586216891)
gx 56723424 56843790 (56843790 - 56723424)
gy 577627365 586216891 (577627365 - 586216891)
counit 1
wevel 1500
swevel 1500
muts 0 1600 (0 - 0)
mute 0 1600 (1600 - 1600)
ns 1601
dt 1000
gain 1
d1 0.000122
f1 -32767.998047
d2 -338984292706304756556241983349463187456.000000 337655064710519840683338176289182842880.000000 (-0.000873 - 888525654327296.000000)
mark 23875
shortpad 192

Shot coordinate limits:
North(-568438,-5.77627e+06) South(-567234,-5.86217e+06) East(-567234,-5.86217e+06) West(-568438,-5.77627e+06)

Receiver coordinate limits:
North(-568438,-5.77627e+06) South(-567234,-5.86217e+06) East(-567234,-5.86217e+06) West(-568438,-5.77627e+06)

Midpoint coordinate limits:
North(-568438,-5.77627e+06) South(-567234,-5.86217e+06) East(-567234,-5.86217e+06) West(-568438,-5.77627e+06)

Coordinates are in:

ETRS 89 / UTM zone 31N
Transverse_Mercator
latitude_of_origin: 0
central_meridian: 3
scale_factor: 0.9996
false_easting: 500000
false_northing: 0
Unit: metre

----

5 Conclusions and Recommendations

Converting the scanned images to SEG-Y and adding coordinates to the vintage data, so the data can be used in modern 2D/3D seismic interpretation software works well and significantly increases the value this data represents.

The various types of data require individual processing for optimal results when converting paper prints to SEG-Y, but also when it comes to data already available in seismic formats. This is time consuming, as it involves “manual” labour including lots of testing. But with the right tools this can be done quite efficiently.

In almost all data sets a strong seabed multiple is present, and often other multiples as well. We mainly used gapped deconvolution to suppress these multiples, with varying results. Most of the times it increased the quality of the profiles. For even better results, additional time could be spent on (further) removing the seabed (and other) multiples. This would require further testing of methods and parameters, and probably merely a hand full of lines would really benefit from the extra effort.

The resolution and fidelity of the 2D multi-channel lines could substantially be improved if we could start processing from unstacked data. This would be more time consuming and therefore a larger investment, possibly not all pre-stack data is available anymore, but this would allow to specifically process this data for high resolution in the shallow domain, which is very well possible with current processing algorithms.

Over the course of this project we have created a significant amount of reprocessed quality controlled data over the areas of interest. These data can now easily be loaded into modern 2D/3D seismic visualization and interpretation tools like OpendTect, Kingdom suite, Petrel and the likes. This will make initial investigations of these area’s significantly more easy and possibly also better than before.

There still exists a lot of data in archives (not only TNO’s archives) which might be useful to future projects at sea. We are confident that finding, cleaning up, reviewing and sharing this data will have a positive effect on future activities at sea.

Table 3 provides an overview of the seismic data that is made available and their useability for depths of interest 0-15 m and 0-100 m, which can be referred to make a choice in the seismic data. The useability is rated with qualitative indicators ‘poor’, ‘moderate’ and ‘good’, which is based on a qualitative assessment of the seismic profile including the quality of seismic data, resolution, level of noise, multiples, etc.

Similarly for the positioning accuracy, the quality of this is rated with qualitative indicators, which are largely based on the source of the original navigation data, presumed offsets, and assumptions regarding the used positioning system and related (in-)accuracies. For the quality of positioning information, the indicator ‘large’ refers to a horizontal uncertainty of more than 250 m, ‘moderate’ refers to a horizontal positioning uncertainty between 100 to 250 m, and ‘small’ refers to a positioning uncertainty of less than 100 m.

Table 3 Overview and useability of the seismic data

survey	seismic system	AOI	quality seismic profile 0-15 m	quality seismic profile 0-100 m	positioning uncertainty
EEG87	MCS	G8, LLN	poor	moderate	moderate
EG97	MCS	IJmV	poor	moderate	small
EG97	X-star	IJmV	good	Not applicable	small
KEYSPL97	X-star	LLN	good	Not applicable	small
KEYSPL02	MCS	LLN	moderate	good	moderate
KVAK92	MCS	LLN	moderate	moderate	large
LFB88	MCS	LLN	poor	moderate	moderate
LMN93	MCS	LLN, G8	poor	good	moderate
INDEF82, scale / filter settings set to top 500 ms	Sparker / Watergun	NWN, NWZ, LLN, LLZ, IJmV	moderate	good	moderate
INDEF82, scale / filter settings set to top 1000 ms	Sparker / Watergun	NWN, NWZ, LLN, LLZ, IJmV	poor	moderate	moderate
INDEF82, scale / filter settings set to top 2000 ms	Sparker / Watergun	NWN, NWZ, LLN, LLZ, IJmV	poor	poor	moderate
PVAK96	MCS	NWZ, IJmV, LLZ	moderate	good	small
PVAK96	X-star	NWZ, IJmV, LLZ	good	Not applicable	small
Pelagia survey 2017-2018	Sparker	LLN, LLZ, G8	moderate	moderate	small
Pelagia survey 2017-2018	X-star	LLN, LLZ, G8	good	Not applicable	small
SONIA	SONIA	NWN, NWZ, IJmV, LLZ, G8	good	poor	moderate
UK80	Airgun	NWZ	poor	moderate	moderate
UK80	Sparker	NWZ	moderate	good	moderate

6 References

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7 Signature

Name and signature reviewer:

ValidSigned by Bob Paap
on 2022-04-29 15:34:40

Drs. B.F. Paap

Signature:

ValidSigned by Jelte Stam
on 2022-04-29 11:30:43

MSc. J.C. Stam
Auteur

Release:

ValidSigned by Denise Maljers
on 2022-04-29 13:53:39

Drs. D. Maljers
Research Manager