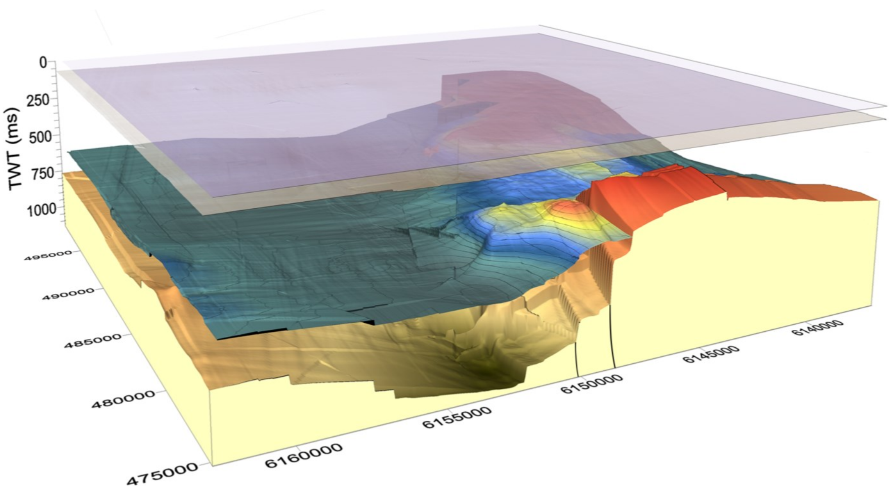
Digitization and interpretation of vintage 2D seismic reflection data from Hanö Bay, Sweden

Nikolas Benavides Höglund

Dissertations in Geology at Lund University,
Bachelor's thesis, no 470
(15 hp/ECTS credits)



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Cover Picture: 3D surface model of the interpreted area in Hanö Bay. Created by Nikolas Benavides Höglund.

Abstract

NIKOLAS BENAVIDES HÖGLUND

B, Höglund, N., 2016: Digitization and interpretation of vintage 2D seismic reflection data from Hanö Bay, Sweden. *Dissertations in Geology at Lund University*, No. 470, 18 pp. 15 hp. (15 ECTS credits)

Abstract: Seismic reflection data has been collected for more than half a century for both scientific and industrial purposes. Data sampled in modern surveys are collected, processed and stored digitally. There are, however, large quantities of vintage seismic reflection data that since its original use has been stored away and remains difficult to access in its current form. This data was acquired when it was not yet standard procedure to store seismic data digitally, but rather on vintage media formats. This study investigates the possibility of digitizing such data by presenting and reviewing a workflow model that is applicable for students and individual researchers. To demonstrate this, a grid of 2D marine seismic lines, accompanied by well data, was provided by the Geological Survey of Sweden (SGU) over the Hanö Bay area, SW Baltic Sea. This data was digitized, processed, interpreted and displayed both as contour maps and 3D surface models. This study also attempts to place what is essentially an untapped resource in a broader perspective by discussing the scientific, educational and economical benefits of transforming vintage seismic data to be preserved and shared in digital format.

Keywords: Seismic data, Digitization of seismic sections, Hanö Bay Basin, Tornquist Zone, Seismic interpretation, OPAB

Supervisor(s): Mikael Erlström

Subject: Bedrock Geology (Geophysics)

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Sammanfattning

NIKOLAS BENAVIDES HÖGLUND

B, Höglund, N., 2016: Digitalisering och tolkning av vintage 2D reflektionsseismisk data från Hanöbukten, Sverige. *Examensarbeten i geologi vid Lunds universitet*, Nr. 470, 18 sid. 15 hp.

Sammanfattning: Reflektionsseismik har använts i forsknings- och prospekteringsändamål sedan första halvan av 1900-talet. De moderna undersökningar som utförs idag behandlar hela datainsamlingsförloppet digitalt och färdigbehandlad data tillgängliggörs sedan för geologisk tolkning i moderna datorprogram. Det finns dock en stor förekomst av äldre seismisk reflektionsdata som sparats ned på numera omoderna format och som i dagsläget är svåråtkomlig för vetenskapliga studier. Den stora datamängden som insamlades under 1970- och 80-talet av Oljeprospektering AB (OPAB) är en sådan resurs som innehåller mer än 33 000 kilometer 2D reflektionsseismisk data över Sveriges sedimentära berggrund. Stora delar av denna datasamling har nu skannats till digitalt format och lagrats på SGUs servrar. Denna studie undersöker möjligheterna att digitalisera delar av detta material till så kallade SEG-Y filer, ett filformat som innehåller geofysisk data och som kan bearbetas och tolkas i moderna datorprogram. En föreslagen arbetsmodell med syfte att genomföra digitaliseringen på ett lätthanterligt och billigt sätt har utarbetats och presenteras i detta arbete. Avsikten med detta är att studenter och forskare som önskar utföra liknande arbeten ska kunna återupprepa de steg som rekommenderas för en lyckad digitalisering och användning av äldre seismisk data.

För att utföra denna undersökning har SGU i Lund bidragit med reflektionsseismisk data samt borrhålsdata över ett område i Hanöbukten i sydvästra Östersjön. Genom att digitalisera, behandla och tolka den data som SGU bidragit med presenteras i denna studie en konturkarta samt 3D-modeller över det tolkade området. Vidare förs även en diskussion kring värdet av att modernisera och bevara gammal seismisk data i digitalt format, samt hur studenter vid svenska universitet kan dra nytta av att, med svensk sedimentär berggrund som övningsmaterial, utföra seismiska övningsuppgifter digitalt i olika datorprogram.

Nyckelord: Seismisk data, Digitalisering av data, Hanöbukten, Tornquistzonen, Seismisk tolkning, OPAB

Handledare: Mikael Erlström

Ämnesinriktning: Berggrundsgeologi (Geofysik)

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1 Introduction

Knowledge of the Swedish offshore subsurface is largely based on data acquired by the Swedish Oil Prospecting Company (OPAB) during the 1970s and 1980s. The offshore part of the data collection extends geographically across the Swedish Baltic Sea as well as across the seas of Kattegat and Skagerrak and includes more than 33 000 km of 2D reflection seismic data. Since its acquisition the data has been transferred to the Geological Survey of Sweden (SGU) where most of it is stored on digital media (Sopher and Juhlin, 2013). The NA79 survey is part of the OPAB dataset collected in the search for hydrocarbons in the Hanö Bay (Fig. 1) and contains 32 reflection seismic lines. The survey grid covers the greater Hanö Bay area and partly extends over structural elements such as the Tornquist Zone, the Hanö Bay Basin and the southwestern margin of the Baltic Basin. This study will examine the possibilities of digitizing the seismic data recorded in this survey by converting scanned seismic images to processable, digital SEG-Y files and to interpret the data in a modern computer environment.

1.1 Aim of the study

This study investigates the possibility of digitizing vintage seismic reflection data for research and education purposes. To achieve a successful conversion of the scanned images to SEG-Y format a workflow model is presented and reviewed. The workflow model is created with the intention of making the conversion process as inexpensive and uncomplicated as possible,

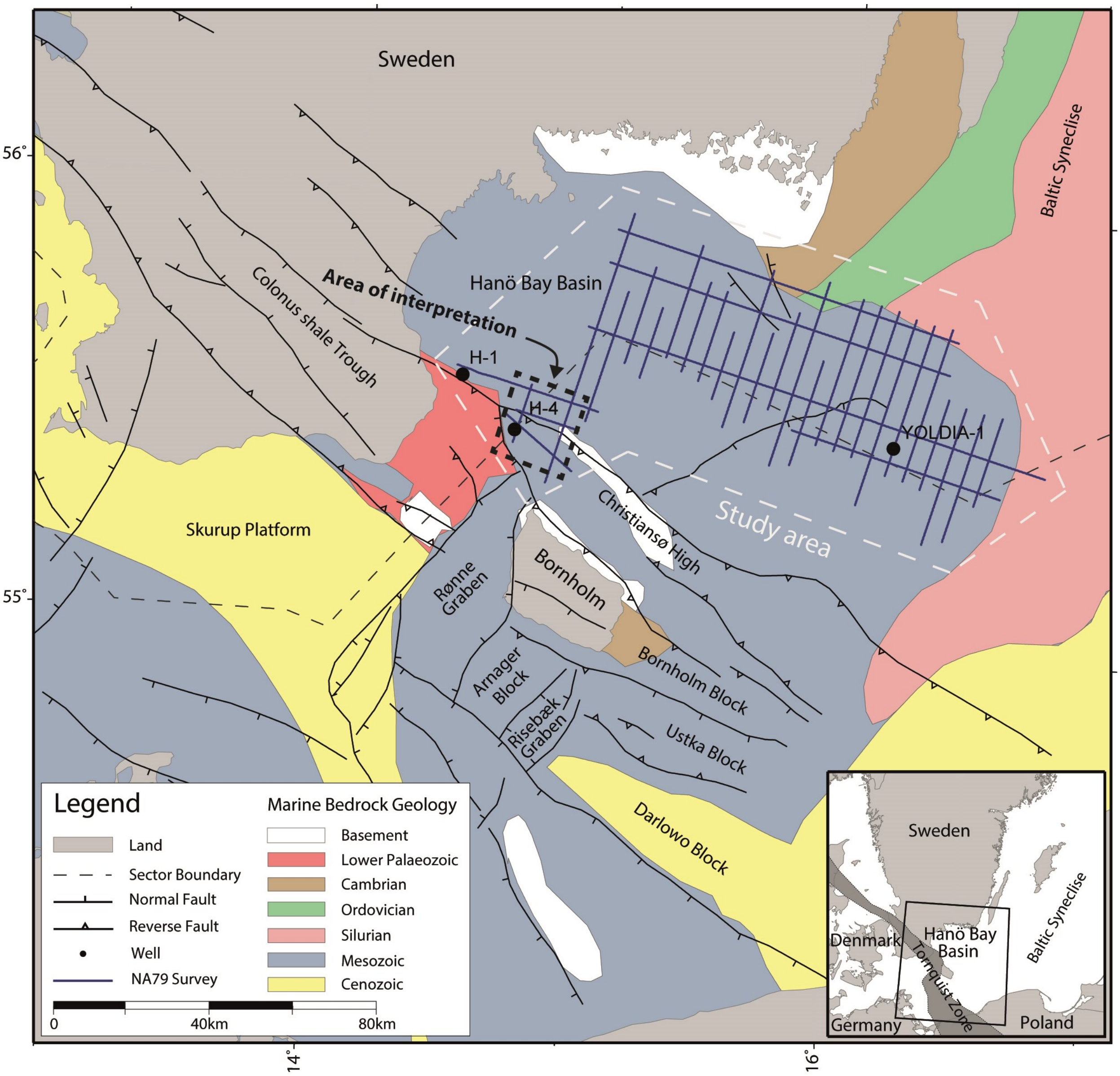

Fig. 1. Map showing marine bedrock geology and major tectonic elements of the SW Baltic Sea. The study area covers the seismic survey NA79 and three offshore wells. The area of interpretation is located in the southwestern part of the study area which extends over the Christiansø Half-Graben and Christiansø High. Based on and modified from cartographic materials in Sopher and Juhlin (2013).

thus offering a reasonable solution for students and researchers interested in expanding their knowledge of the geology in areas where vintage seismic data is available. This study also aims at directing attention towards the potentially great resource of data that at the moment remains more or less untapped. Furthermore, the aim is to encourage the implementation of digital seismic interpretation in relevant courses at Swedish universities through digitization of the OPAB dataset, either by use of the workflow model presented in this paper or one of higher quality (and higher cost).

1.2 Background

Seismology has its roots in the early 1920s, when a team of scientists performed the first recorded seismic experiment in Oklahoma, USA. The team used a dynamite charge as seismic source and the seismic waves that traveled through the subsurface were recorded with a seismograph (Dragoset, 2005). Reflection seismic surveys gained recognition during the 1930s as an established method for finding hydrocarbons (Dragoset, 2005), but it was not until the 1960s when the implementation of airgun arrays and streamer technology in marine seismic surveys that high quality data was starting to accumulate in significant quantities (Miles et al., 2007).

Before it became standard procedure to store seismic data digitally, the data was often stored on tape- or paper media (Diviacco et al., 2015). Large amounts of data have remained untouched since first being stored away, and although the data may have proven inapplicable in its original purpose, i.e. the search for petroleum, it nevertheless holds significant research value. This is true for the survey data provided by SGU for this paper, as well as for the remainder of the OPAB dataset (Sopher and Juhlin, 2013; Sopher et al., 2016). Digitizing vintage seismic data opens up new opportunities to reinterpret large amounts of data for scientific purposes in a modern and manageable way. Furthermore, it keeps the data resilient to deterioration that may affect data stored on analogue media. In fact, the European Commission research program for Marine Science and Technology funded a three-year long project (SEISCAN) dedicated to rescuing vintage seismic data and creating a seismic profile image database (Miles et al., 1997). A decade later, researchers involved in the SEISCAN project developed a computer program, SeisTrans (Miles et al., 2007), which today is one of several programs that performs conversion of scanned seismic sections to SEG-Y files.

1.3 The SEG-Y file format

SEG-Y is a digital file format that stores geophysical data acquired from reflection seismic surveys. It was developed by the Society of Exploration Geophysicists (SEG) in the early 1970's to meet the industry's demand of a standardized data exchange format (Barry et al., 1975). A SEG-Y file consists of multiple segments that operate separate functions. The Textual File Header contains information regarding the survey itself, such as the seismic acquisition parameters and which coordinate system was used in the creation of the SEG-Y file. The Binary File Header contains information that is required by a computer program to be able to process the data in the file, such as sampling interval, trace length and format code. The Trace Headers contains the seismic trace attributes and provides information that may vary from trace to trace (Barry et al., 1975; SEG, 2002).

2 Geological setting

2.1 Previous studies

Knowledge of the stratigraphic subdivision in the Hanö Bay Basin is known from exploratory wells drilled by OPAB during the 1970s and 1980s (Fig. 2). Kumpas (1980) describes the tectonic framework and development of the area based on interpretations of seismic reflection data acquired by the Department of Geology, Stockholm University, as well as seismic reflection and well data from two offshore borings performed by OPAB. The horst system of the Bornholm Gat is described in detail by Wannäs (1980) based on seismic reflection data acquired by OPAB. Wannäs and Flodén (1994), on account of SKB, presents an investigation of the area based on earlier seismic reflection data as well as seismic data not previously available and supplied to them by Dansk Boreselskab AS. Included in their material is also well data from an offshore boring performed 1987 in the Yoldia Structural Element.

2.2 The Hanö Bay area

Hanö Bay is located within the Fennoscandian Border Zone, which forms the boundary between the Baltic Shield (also known as the Fennoscandian Shield) in the NNE and the Danish-Polish Through in the SSW. The area extends over the Hanö Bay Basin, an intracratonic basin containing mainly Mesozoic deposits (Kumpas, 1980), as well as parts of the southwestern margin of the Baltic Basin, a larger, intra-cratonic basin of Paleozoic age (Sopher et al., 2016). The geological setting of the area is highly influenced by the Tornquist Zone, Europe's longest lineament with its dextral strike-slip tectonics regime (Erlström et al., 1997).

The Tornquist Zone, initiated during Carboniferous but considered a Mesozoic feature is characterized by dextral transtension during Late Permian – Early Jurassic and dextral transpression and inversion during Late Cretaceous – early Paleogene (EUGEO-S Working Group, 1988; Michelsen and Nielsen, 1993; Erlström and Sivhed, 2001). The break-up of Pangea during the Paleozoic – Mesozoic transition resulted in a transtensional stress field along the Tornquist Zone, with subsequent rifting and pull-apart basins being formed (Erlström and Sivhed, 2001). However, by the time of Late Cretaceous, a shift in the tectonic regime due to the Alpine Orogeny led to dextral transpression and inversion tectonics along the zone (Ziegler et al., 1995; Erlström and Sivhed 2001; Vejbæk and Andersen, 2002).

2.3 Tectonic framework of the Hanö Bay area and development of the Hanö Bay Basin

The Hanö Bay Basin can be divided into four structural elements: Hanö Bay Slope, Kalmarsund Slope, Yoldia Structural Element and the Christiansø Half-Graben (also known as Hanö Bay Half-Graben) (Wannäs and Flodén, 1994). The Hanö Bay Slope constitutes the continuation of the crystalline Blekinge coastal plain, sloping to the SSW. The Kalmarsund Slope is a SE dipping sedimentary unit containing Paleozoic deposits in the transitional region of the Hanö Bay Basin and the Baltic Basin southwest of Öland. The Yoldia Structural Element is a detached block of Paleozoic strata in the eastern part of the basin that has been uplifted, tilted, faulted and possibly rotated (Wannäs and Floden, 1994; Sopher et al., 2016). The Christiansø Half-Graben is situated in the central and southern parts of the area and is characterized by a thick Cretaceous sedimentary succession.

The development of Hanö Bay Basin was initiated in Late Triassic and continued over the duration of the Mesozoic through a series of tectonic events along reactivated faults in the Tornquist Zone (Wannäs and Flodén, 1994). Following the development of the sub-Mesozoic peneplain (Kumpas, 1980), the sea transgressed and flooded the area from the south, depositing Late Triassic sediments in the Christiansö Half-Graben and successively northwards into the basin. The upper Triassic deposits rest partly on the Precambrian basement and partly on a sandstone unit of debated origin, possibly Lower Cambrian (Kumpas, 1980; Sopher et al., 2016). During the Jurassic a period of erosion affected parts of the basin and it was not until the Cretaceous where subsidence and transgression of the sea affected the basin with rejuvenated force. The Christiansø Half-Graben, delimited to the south by the Christiansø High (also known as Christiansø Horst), was filled by erosional products of the adjacent block, which was affected by inversion and

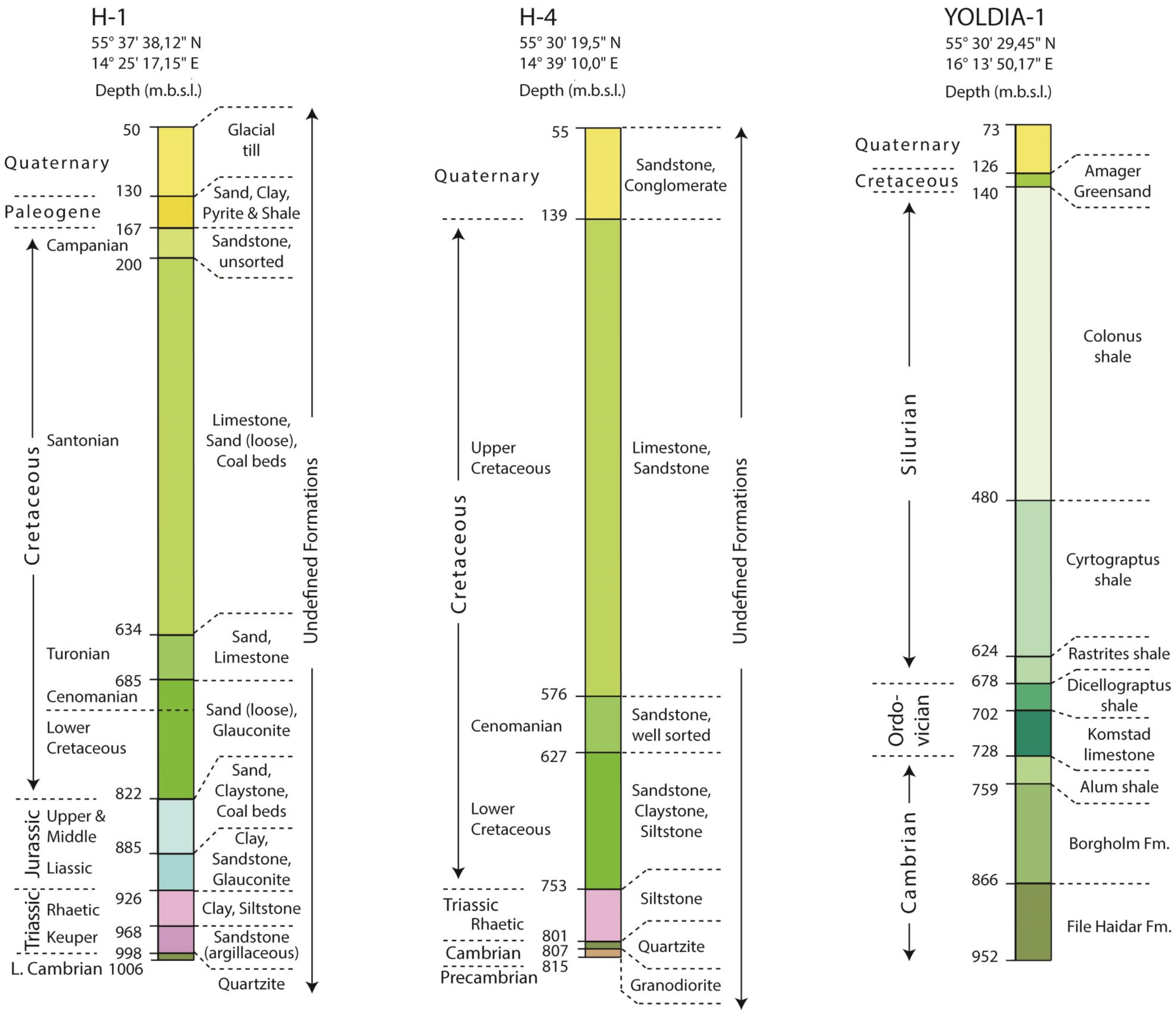

Fig. 2. Stratigraphic subdivisions of the wells in the study area.

uplift during the Late Cretaceous (Wannäs & Flodén, 1994). The latest tectonic event to affect the region was the Neogene uplift of the southwestern margin of the Baltic Shield, which, coupled with Quaternary glaciations resulted in erosion of the uppermost strata (Erlström et al., 1997).

3 Materials and methods

3.1 Well data

Final well reports from three wildcat wells located in the Hanö Bay area were provided by SGU in Lund. The wells H-1 and H-4, situated near the shores of Scania, were drilled in 1973 on behalf of OPAB, targeting Mesozoic sequences (OPAB well report, 1973a,b). Yoldia-1 was drilled in 1987, also on behalf of OPAB, targeting Lower Paleozoic sequences in the outer Hanö Bay area (OPAB well report, 1988). In addition to the final well reports, gamma-ray, sonic, resistivity and density logs were provided for Yoldia-1 in analogue and digital (LAS) formats.

3.2 Seismic data

A grid of 2D lines from the NA79 survey was selected in accordance with SGU, based on the availability of well data within the area. The survey consists of 32 lines with a total length of nearly 1 400 km. The data was acquired in 1979 by the vessel Geco Alpha on behalf of OPAB (Table 1) and covers an area of approximately 5 040 km^2 in the Hanö Bay area. The original dataset has been scanned and is now stored at SGU as high resolution TIFF-files. Coordinates for every tenth shot point was saved in the WGS84 coordinate system and were supplied by SGU in a database file.

Table. 1. Acquisition parameters of the NA79 survey.

Seismic survey	**NA79**
Recorded by	Geco International Ltd, May 1979
Processed by	Geco Stavanger, July 1979
Client	OPAB
Ship	Geco Alpha
Seismic source	Airgun array
Volume	1188 cu. in.
Gun depth	6,5 m
Shotpoint interval	25 m
Folds	24
Geophones per fold	64
Fold interval	50 m
Record length	3 sec
Sample rate	2 ms
Cable depth	8-10 m

3.3 Software

In order to effectively demonstrate the various applications of digitized seismic sections in this study a number of software products (Table 2) were used. To exemplify that the suggested workflow presented in this study can be utilized by anyone with basic knowledge in computers and geology, the listed software products were selected with the intention of keeping the workflow as inexpensive as possible. For that matter, only software available for students at the Department of Geology, Lund University, as well as freeware and open-source software available online was used.

3.4 Workflow model

The workflow presented in this study should be regarded as a suggestion as to how vintage seismic data can be digitized, interpreted and visualized. Depending on what quality the user demands of the digitized data, method and cost will vary. This specific model (Fig. 3) will not yield the highest possible data quality, but can nonetheless be utilized for research and educational purposes with minimal expense.

3.4.1 Scanning and saving sections as TIFF-files

The seismic sections supplied by SGU were originally scanned in a drum scanner at 300 dpi and saved as TIFF-files. It is, however, possible to scan seismic paper and tape sections in a regular flatbed scanner. If the section itself is too large for the glass plate, it can be scanned in multiple parts which then can be joined together in an image processing application. Since the outcome depends on the quality of the scanned image, it is recommended to set the scanner to a high quality scanning mode and saving the images as TIFF-files.

3.4.2 Adjustments and optimization

Once the sections are scanned it is a good idea to review the result in an image processing application before proceeding with the next step. When scanning there is a possibility that the image becomes unintentionally skewed or rotated. To ensure the best conditions for a successful conversion, it is recommended to rotate the image to as horizontal a position as possible. Also, if the seismic section had to be scanned in multiple parts, to give great care to detail when joining the parts back into a single image.

3.4.3 Converting TIFF to SEG-Y

Certain companies specialize in transforming scanned sections into industry quality SEG-Y data. Other companies offer software products of variable quality to which it is up to the user to perform the digitization. The more costly software products reconstructs the seismic section trace by trace and includes advanced solutions for removing artifacts and other types of distortions from the original data.

The seismic data in this study was digitized using

Table. 2. A list of the software used in this study.

Developer	Software	Comment
Adobe Systems	Illustrator CS4	Creating and editing graphics used in this report.
Adobe Systems	Photoshop CS4	Editing image parameters.
DMNG	SeiSee 2.22.5	Free SEG-Y editing tool.
ESRI	ArcMap 10.2.2	Georeferencing basemap elements.
Golden Software	Surfer 8	3D surface visualization.
MathWorks	MATLAB R2014a	Required to run Image2Segy.
Thomas M. Hansen	SegyMAT 1.5.1	Free Matlab application. Required to run Image2Segy.
Marcel Farran	Image2Segy 2.6.1	Free Matlab script. Converts raster images to georeferenced SEG-Y files.
dGB Earth Sciences	OpendTect 6.0.1	Free GPL license. Seismic interpretation and well-tie software.

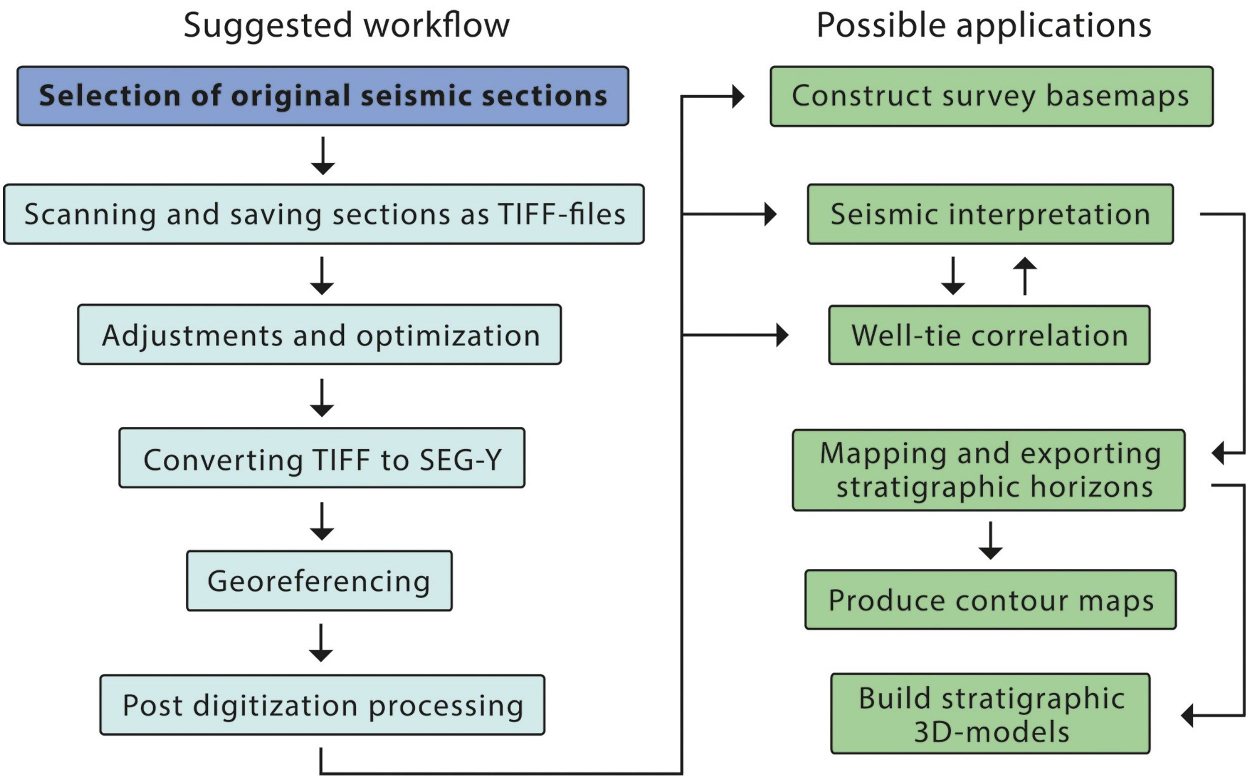

Fig. 3. Flow-chart presenting the workflow suggested and used for digitization of seismic sections in this paper. Possible applications of the digitized data are suggested in the right column.

Image2Segy, a free script for Matlab developed by Farran (2008). However, before Image2Segy can be run, SegyMAT, a free Matlab application, needs to be installed. Image2Segy does not reconstruct the section by recreating one trace at a time but rather through converting the entire scanned section and all its contents from TIFF to SEG-Y. Depending on the quality and content of the image, this method may result in artifacts and other types of distortions being included in the digitized SEG-Y file, such as printed time lines, creases and handmade notes and drawings.

3.4.4 Georeferencing

SEG-Y data needs to be georeferenced in order to be accurately displayed in interpretation software. This is especially important if working with multiple sources of data, such as well log data, which often needs to be integrated into the workspace together with seismic data. Furthermore, any information the user wishes to export, such as markers, faults and horizons will contain positioning data derived from the SEG-Y files.

When digitizing a seismic section using Image2Segy, at least two known points, the starting and ending points of a section, needs to be specified in UTM coordinates. However, because the script interpolates the position of each seismic trace between the known points, it is for accuracy purposes highly recommended to specify as many known positions along the section as possible. Therefore, to commence the conversion process, the shot point coordinates supplied by SGU were converted from WGS84 to UTM using Surfer. The UTM coordinates were then assigned to specific pixel positions in the scanned images representing their true location and saved in a text-file. When running the script in Matlab, a window prompts the user to select an image file (the scanned TIFF-image) and a control file (the text-file containing the coordinates). The output will be a georeferenced SEG-Y file.

3.4.5 Post digitization processing

In some cases the data quality can be further improved once a seismic section has been digitized. Processes altering the attributes of the seismic data can be applied in various combinations to enhance features the user wishes to interpret. A filter can be applied (Fig. 4) to reduce noise and artifacts. If reflectors have been laterally displaced due to complex geology, seismic migration can be applied to geometrically correct the reflectors to their true position.

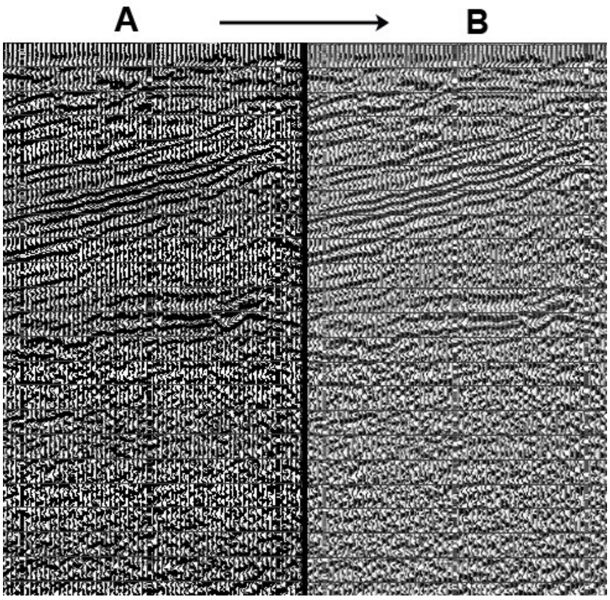

Fig. 4. Image showing the same seismic section **A.** unfiltered, and **B.** with a bandpass filter. At the expense of a lower contrast, the filter managed to remove a low frequency distortion as well as artifacts created in the scanning process.

4 Results

31 of the 32 seismic sections were successfully digitized and georeferenced. The line NA 79-174 was not included in the data supplied by SGU and could therefore not be digitized. The best conversion results were achieved using the following image parameters: 8 bit grayscale with a maximum resolution of 200 dpi.

4.1 Selecting an area to interpret

To exemplify how the digitized seismic data can be processed in a computer, a delimited area within the survey area was selected for a geological interpretation. After importing and reviewing the digitized sections in OpendTect, an area approximately 10 km north of Bornholm (Fig. 1) was selected containing geological features adequate for interpretation and display.

4.2 Geological interpretation

The section NA79-168, located within the interpreted area, was recorded adjacent to the H-4 well. It is therefore, accompanied by well data provided from the final well report, a suitable starting point for commencing the interpretation (Fig. 5).

The major part of the sedimentological sequence encountered in H-4 are of Mesozoic age, predominantly consisting of Cretaceous deposits. A core was sampled from the lowermost two meters and described as Precambrian crystalline granodiorite (OPAB well report, 1973b). The only deposit of Paleozoic age is a 8 meter thick quartzite sequence that rests on top of the basement. This sequence is also encountered in the lowermost part of H-1 and although it has not been assigned correlation with any known formation it may possibly correlate to the Lower Cambrian quartzite formations encountered in onshore Scania described in Nielsen and Schovsbo (2007).

The shearing of reflectors (Fig. 5) near the SSW part of NA79-168 indicates uplift and inversion of the Christiansø High block during the Cretaceous. This trend is consistent with reflector patterns in the sections NA79-167 and NA79-169, indicating a principal stress direction from the SSW. The source of the SSW – NNE oriented stress field could possibly originate from transpression build-up due to the Alpine orogen during the Cretaceous (Ziegler et al., 1995). Other nearby horsts follows the same SSW – NNE orientational properties and are also considered to have subjected to uplift during the Mesozoic (Wannäs, 1986).

The relatively rapid uplift of the Christiansø High during the Cretaceous probably caused a high sedimentation rate, with silt- and sandstone sequences originating from the uplifted block quickly being accumulated in the Christiansø Half-Graben (M. Erlström, Lund, personal communication 2016). Because the base of the Cenozoic rests more or less undeformed on top of the Cretaceous sequences, it is fair to suggest that the Christiansø Fault has remained inactive since the early Paleogene.

4.2.1 Digital processing

Geological interpretation software such as OpendTect allows the user to load multiple SEG-Y files into a single workspace and digitally interpret the seismic sections in three dimensions. It is also possible to load digital well log files (LAS) into the workspace, or to manually create wells with data provided from well reports. Well data and seismic data can then be correlated by using a time-depth model often included in such software.

By importing the digitized seismic sections NA79-167, 168, 169, 170 and 171, all located within the interpreted area, accompanied by well data from the H-4 well, reflectors of interest could be followed along the survey area. Using the function *track horizon*, it is

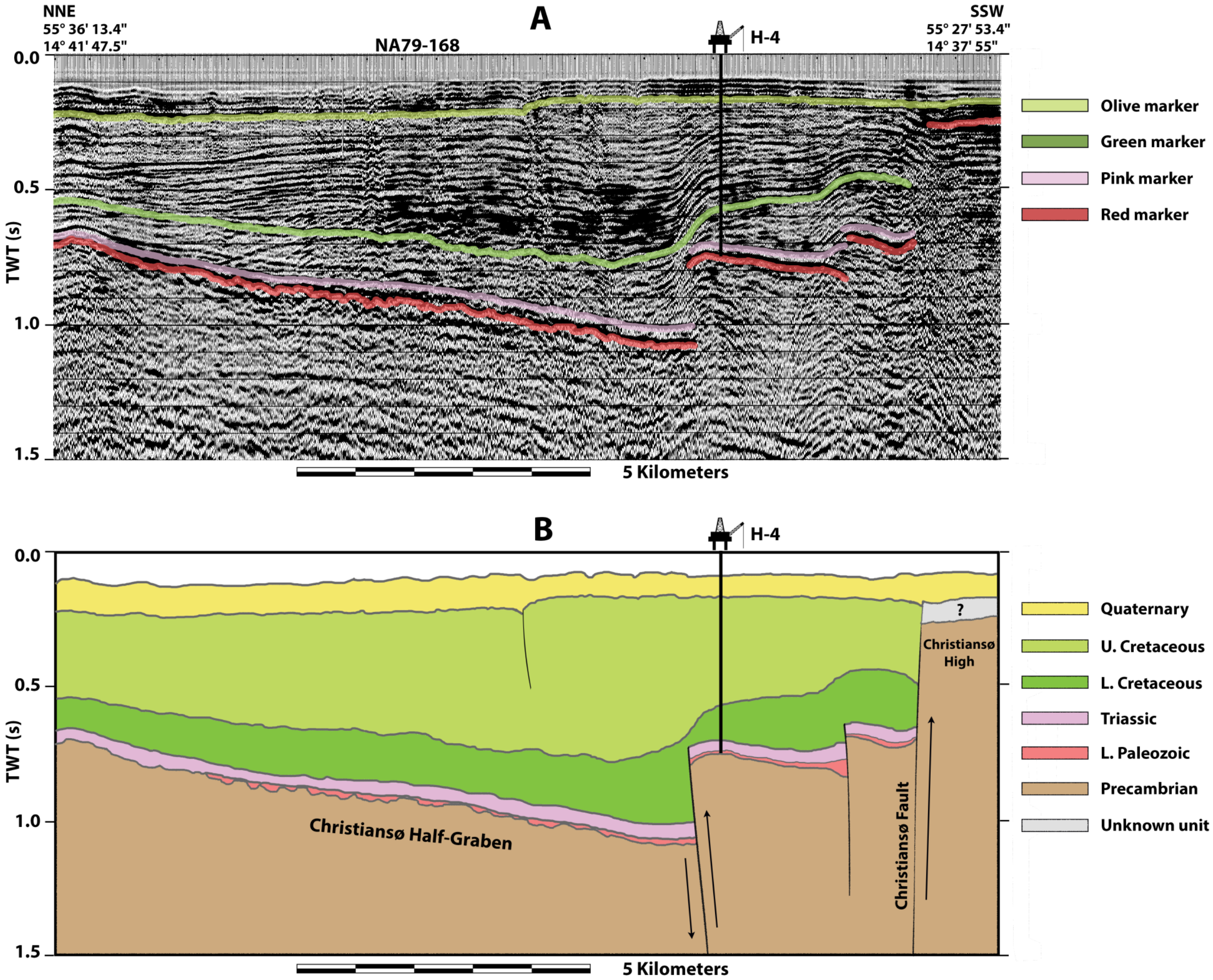

Fig. 5. **A.** Detail and **B.** interpretation of seismic section NA79-168.

possible to color-mark any reflector of choice (Fig. 6), similar to how one might commence the interpretation on seismic paper sections. It is, however, much more convenient to perform this operation digitally, especially with reflectors spanning over multiple sections. Furthermore, it is possible to create 3D surfaces between the horizons by using interpolation methods included in the software.

A more uniform way of creating and presenting 3D surfaces can be attained by exporting the horizons tracked in OpendTect. The output will be an ASCII text-file containing x, y and z data for each trace, i.e. latitude, longitude and two-way travel time (TWT) along the tracked horizon. Considering that the total number of seismic traces over a handful of seismic sections easily count over tens of thousands, the data density will be enormous along the extension of each seismic section, allowing for very detailed model-creation in software such as Surfer (Fig. 7). It is true that the contrast between areas fully populated with data, i.e. along the seismic sections, and areas with no data, such as the unsurveyed space between each section is very high, and an appropriate interpolation algorithm has to be selected and used to fill the empty space. Surfer allows the user to grid XYZ data according to a variety of interpolation algorithms. The following figures have been gridded using the *Kriging*-algorithm.

5 Discussion

As demonstrated by the results, there are many ways to process the digitized data. Although the SEG-Y quality doesn't match industry standard quality it nonetheless holds benefits for students and researchers. The ease at which the user will be able to interpret and manage data holds many perks when attempting to visualize through the creation of maps and models. In certain cases, discussion may arise whether previous decisions have been rightly motivated, and if the same conclusions had been reached had the data been available for interpretation in digital format (Fig. 8).

5.1 Conversion quality and accuracy

The certainty of any interpretation derived using digitized seismic sections is dependent of a number of factors, such as:

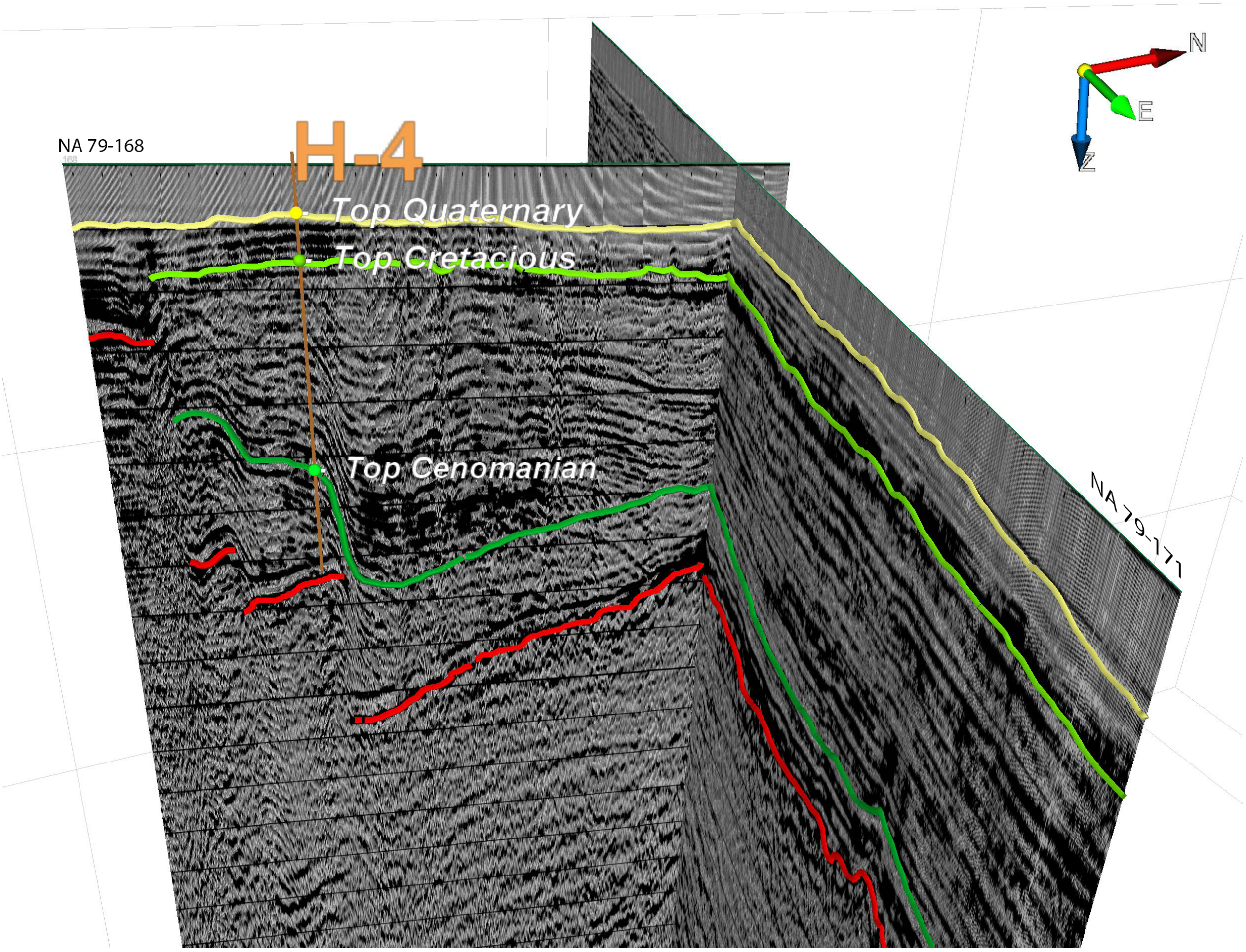

Fig. 6. Interpretation of seismic sections NA 79-168 and NA 79-171 in OpendTect. The color-marked horizons can be exported and processed to create contour maps or 3D surface models.

- Quality of original seismic section
- Conversion method and adaptability
- Navigation point density (points of known locations along a seismic line)
- Interpreter experience

Because the method and software used in this study does not include any form of adaptability in the conversion process from TIFF to SEG-Y, the converted sections will essentially be digitized copies of the scanned paper sections. This implies that any errors in the original material, such as multiples or bow-tie effects, will also be transferred onto the digitized sections and can cause problems for the interpreter. Also, since the position of each trace between specified points of known locations are interpolated, the navigation point density is an essential factor in the accuracy of the digitized sections. The more points of known locations along a line, the more confident the interpreter can be that what is observed is actually what one can expect to find in reality.

Owen et al. (2015) stated that several methods exist to digitize seismic paper sections, but that their reliability remains undocumented. Therefore, they conducted a study to test the accuracy and resolution of digitized paper sections by comparison with bathymetric and side scan sonar data over the Barra Fan, NE Atlantic Ocean. Owen et al. (2015) concluded that digitized vintage data does not match the quality of modern data acquisition but that it can be used as a valuable supplement to modern data. Furthermore, Owen et al. (2015) claims that in cases when the seismic data is of good quality and is accompanied by accurate navigation data, digitized seismic sections may prove exceedingly useful. They argue that the conversion process is extremely cheap and allows more detailed interpretations than those solely based on paper sections.

5.1 Economical aspects and research value

Research and education wise there are many benefits of having digital seismic data readily available. The data from one survey can be shared among many users, each person contributing their opinions and interpretations with the possibility of extracting and sharing data from certain areas of interest for detailed analysis. In case of the OPAB dataset, where most of the data

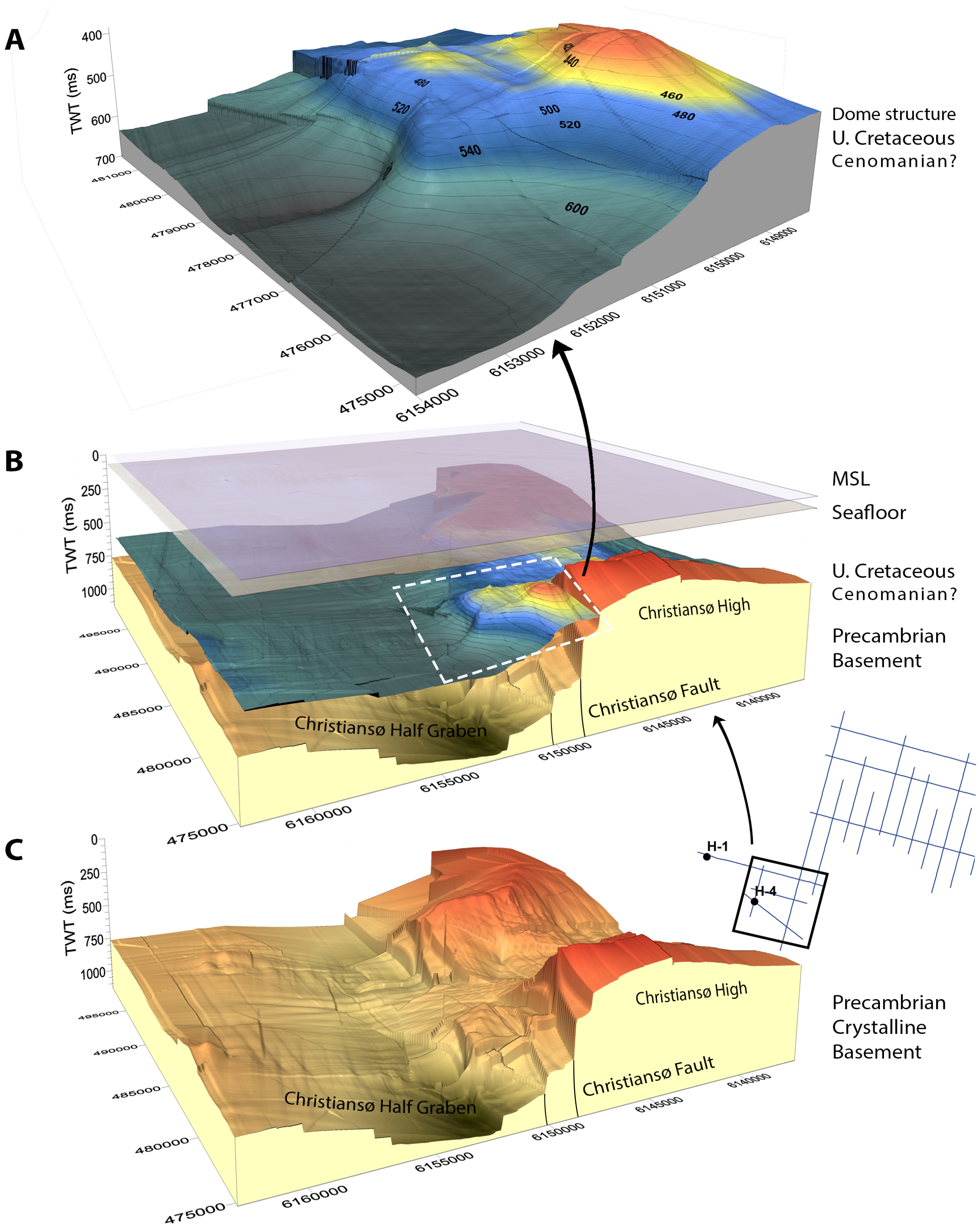

Fig. 7. 3D surface models of the interpreted area. **A.** Close-up of a dome structure found repeating within the intra-Cretaceous, here displayed in what is probably the top of the Cenomanian sedimentary sequence. **B.** Surface map of the interpreted area showing the bedrock and an upper Cretaceous reflector, as well as mean sea level and seafloor for added perspective. **C.** Surface map of the Precambrian crystalline bedrock in the interpreted area. The projections used for the models are UTM33.

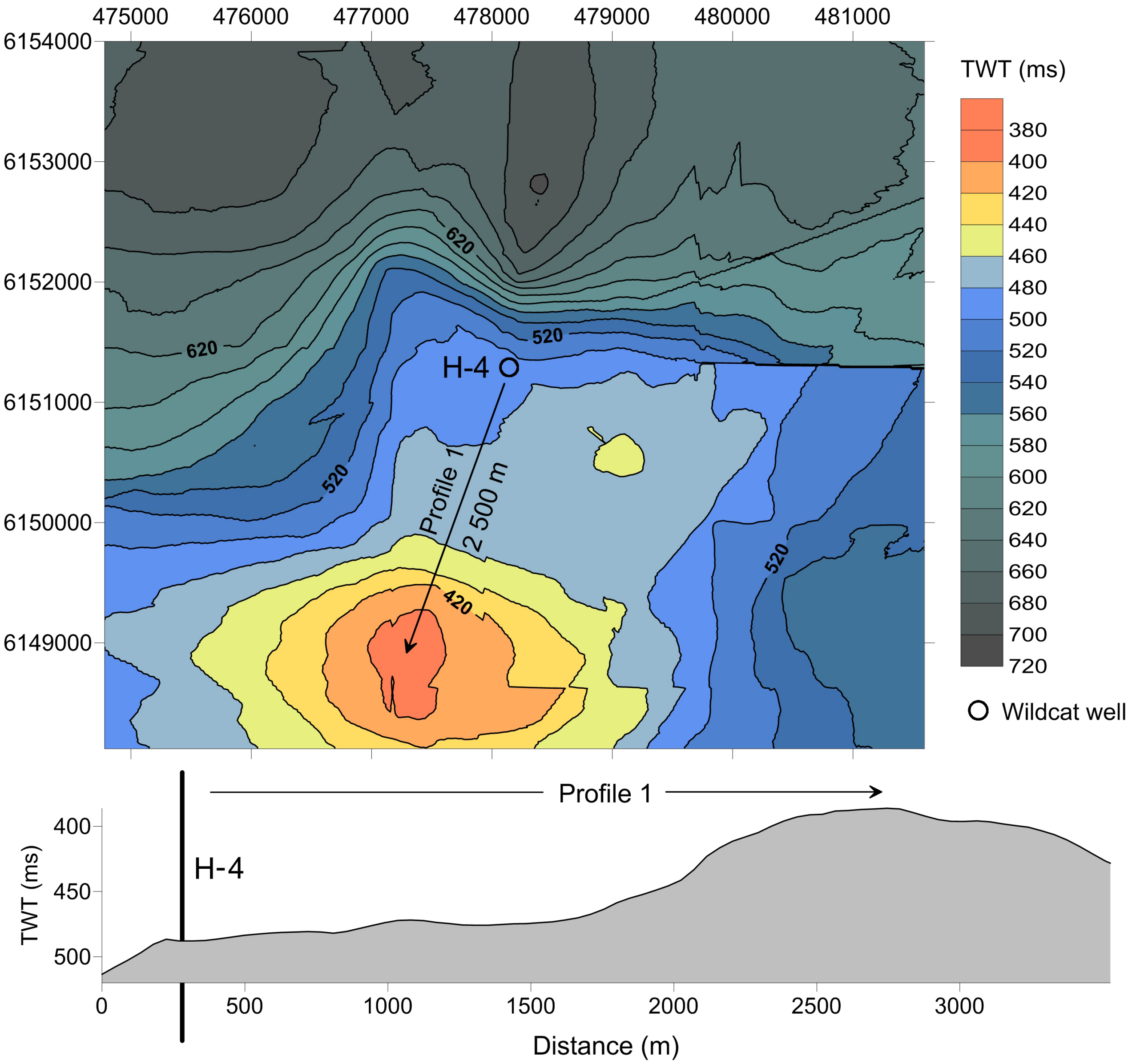

Fig. 8. Contour map showing that the position of the wildcat well H-4 lies approximately 2,5 kilometers outside the dome structure and could, perhaps, have been more smartly positioned if indeed such a structural trap was the planned target. The projections used for this map is UTM33.

has already been scanned to TIFF, the next step should be converting it to SEG-Y. Because new surveys are unlikely to be performed due to unsuccessful petroleum prospects, and because the old data still holds significant research value, digitizing and making available the old data in digital format may lead to new insights regarding the geological evolution of Sweden and southeastern Scandinavia. This argument is especially true when considering that the cost of acquisition at the time of writing falls somewhere between $5 000 and $9 000 USD per kilometer for a 2D survey (NETL, 2013; ANWR, 2014), placing the NA79 survey, used in this paper, at a price of $7 million – $12,5 million USD had the data been acquired today. Furthermore, considering that the OPAB dataset consists of more than 25 surveys containing more than 33 000 kilometers of 2D data (Sopher and Juhlin, 2013), the potential gain by digitizing and making the data available for research is enormous. Education wise, Swedish students would benefit by being introduced to seismic interpretation exercises in modern computer programs as well as from actually interpreting the Swedish offshore subsurface.

6 Summary and conclusion

- There are significant amounts of seismic data that since its acquisition and initial use has been stored away on vintage media formats. Digitizing the data not only makes it more resilient to deterioration but also makes it available to the scientific community for reprocessing and reinterpretation purposes, which can be performed in modern computer programs.

- The European Commission research program for Marine Science and Technology and SGU have, among other institutions, already scanned large numbers of seismic sections and thus ensured the survival of the seismic data. The next step should be to digitize the image files to processable SEG-Y files that can be used to expand the scientific knowledge of the subsurface, preferably using a high quality method to ensure the best possible outcome of the digitization as well as any results derived from interpreting the digitized data.

- The workflow model presented and used in this study offers an inexpensive method to modernize vintage seismic data that is applicable for individual students and researchers. Although the quality of the digitized data will largely depend on the condition of the original seismic section, as well as what program and parameters is being used in the conversion, the benefits of digital processing are substantial. Compared with interpreting a seismic paper or film section over a light table, interpretation software offers the geologist the opportunity to import multiple sections into a digital workspace and maneuver the study area in three dimensions. This, in turn, allows faster and more accurate interpretations. Furthermore, the interpreter can with ease isolate and export data within the sections to create contour maps and 3D surface models.

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8 References

Arctic National Wildlife Refuge, ANWR.org., 2014: The Value of 3D Seismic. http://anwr.org/2014/11/the-value-of-3d-seismic/ Received: 10/05/2016. Last updated: 24/11/2014.

Barry, K. M., Cavers, D. A., & Kneale, C. W., 1975: Recommended standards for digital tape formats. *Geophysics 30*, 344-352.

Diviacco, P., Wardell, N., Forlin, E., Sauli, C., Burca, M., Busato, A., Centonze, J., & Pelos, C., 2015: Data rescue to extend the value of vintage seismic data: The OGS-SNAP experience. *GeoResJ 6*, 44-52.

Dragoset, B., 2005: A historical reflection on reflections. *The Leading Edge 24*, 46-71.

Erlström, M., Thomas, S.A., Deeks, N. and Sivhed, U. 1997. Structure and tectonic evolution of the Tornquist Zone and adjacent sedimentary basins in Scania and the southern Baltic Sea area. *Tectonophysics 271*, 191-215.

Erlström, M. and Sivhed, U., 2001: Intra-cratonic dextral transtension and inversion of the southern Kattegat on the southwest margin of Baltica – Seismostratigraphy and structural development. Geological survey of Sweden. *Research paper C 832*, 33 pp.

EUGENO-S Working Group, 1988: Crustal Structural and tectonic evolution of the transition between the Baltic Shield and the North German Caledonides. *Tectonophysics 150*, 253-348.

Farran, M., 2008: IMAGE2SEGY: Una aplicación informática para la conversión de imágenes de perfiles sísmicos a ficheros en formato SEG Y. *Geo-Temas 10*, 1215-1218.

Kumpas, M., 1980: Seismic stratigraphy and tectonics in Hanö Bay, southern Baltic. *Stockholm Contributions in Geology 34*, 35-167.

Michelsen, O. & Nielsen, L.H., 1993: Structural development of the Fennoscandian Border Zone, offshore Denmark. *Marine and Petroleum Geology 10*, 124-134.

Miles, P. R., Schaming, M., Casas, A., Sachpazi, M. & Marchetti, A., 1997: Capturing a European legacy. *Eos Transactions American Geophysical Union 78*, 582.

Miles, P. R., Schaming, M. & Lovera, R., 2007: Resurrecting vintage paper seismic records. *Marine Geophysical Researches 28*, 319-329.

Nielsen, A. T. & Schovsbo, N.H., 2007: Cambrian to basal Ordovician lithostratigraphy in southern Scandinavia. *Bulletin of the Geological Society of Denmark 53*, 47-92.

Nielsen, L. H., 2003: Late Triassic – Jurassic development of the Danish Basin and the Fennoscandian Border Zone, southern Scandinavia. *Geological Survery of Denmark and Greenland Bulletin 1*, 459-526.

OPAB, 1973a: Well report Hanö Bay 1. Unpublished report, SGU archive.

OPAB, 1973b: Well report Hanö Bay 4. Unpublished report, SGU archive.

OPAB, 1988: Well report Yoldia 1. Unpublished report, SGU archive.

Owen, M. J., Maslin, M. A., Day, S. J. & Long, D., 2015: Testing the reliability of paper seismic record to SEGY conversion on the surface and shallow sub-surface geology of the Barra Fan (NE Atlantic Ocean). *Marine and Petroleum Geology 61*, 69-81.

Society of Exploration Geophysicist., 2002: SEG Y rev 1 Data Exchange format, SEG Technical Standards Committee, 48 pp.

Sopher, D. & Juhlin, C., 2013: Processing and interpretation of vintage 2D marine seismic data from the outer Hanö Bay area, Baltic Sea. *Journal of Applied Geophysics 95*, 1-15.

Sopher, D., Erlström, M., Bell, N. & Juhlin, C., 2016: The structure and stratigraphy of the sedimentary succession in the Swedish sector of the Baltic Basin: New insights from vintage 2D marine seismic data. *Tectonophysics 676*, 90-111.

Sorgenfrei, T. and Buch, A., 1964: Deep tests in Denmark, 1935-1959. *Geological Survey of Denmark, Third Series, No. 36*, pp 146.

The National Energy Technology Laboratory (NETL), U.S. Department of Energy. 2013: *Summary of Costs Associated with Seismic Data Acquisition and Processing*. NETL document number: DOE/NETL-2014/1671. Received: 10/05/2016. Last updated: 12/04/2013.

Vejbæk, O. V. & Andersen, C., 2002: Post mid-Cretaceous inversion tectonics in the Danish Central Graben – regionally synchronous tectonic events? *Bulletin of the Geological Society of Denmark 49*, 139-144.

Wannäs, K., 1986: Tectonic structures in the Bornholm Gat, Southern Baltic. *Stockholm Contributions in Geology 34*, 1-13.

Wannäs, K. & Flodén, T., 1994: *Tectonic framework of the Hanö Bay area, southern Baltic Sea*. SKB Technical Report, Stockholm, TR 94-09, pp 38.

Ziegler, P. A., Cloetingh, S. & Wees, J. D., 1995: Dynamics of intra-plate compressional deformation: the Alpine foreland and other examples. *Tectono physics 252*, 7-59.

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