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Abstract

This study concentrates on reprocessing a cube of post-stack 3D seismic data from offshore East Scotland to improve resolution of the data. The main application of the reprocessing is to allow for a better interpretation of the data to be made. The methodology employed was divided into 2 main parts: 1. FX prediction and Linear Noise Attenuation was carried out using Vista; 2. Seismic Interpretation using Petrel software was used to QC the dataset. The reprocessed dataset can be interpreted with a higher degree of confidence. Key results are: 1. Faults are more visible and easier to interpret and 2. Horizons can be mapped easier.

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INTRODUCTION

The objective of the project was to use and analyze a 3-D seismic dataset from a field located in the Central northern sea in order to understand the reservoir.
Many fields worldwide might have the required data, but in most of the cases this information is confidential. The data which are owned by WesternGeco-Schlumberger were processed in Western Geophysical`s Bedford office in the period of march 1998 to November 1998.The data record covers an area of 21.930 km.

The poststack datasets of this 1998 survey were merged and this data set contains a merged raw and final migrations extending only up to crossline 3155. The Quad 21 field, which fits these criteria, is described below.

Professor Robert James Brown from University of Stavanger in partnership with WesternGeco made it possible to use these 3-D poststack datasets of the Quad 21 field. The work resulted in analyzing this 3-D seismic dataset by using two softwares that are available at the University of Stavanger: the seismic processing software Vista 2D/3D by Gedco and the seismic interpretation software Petrel by Schlumberger. However, due to an incomplete description and the lack of information which are associated to the dataset report, some parts of the project remain unresolved. In addition, the mini-processing report revealed the presence of carbonates in the field which is characteristic of North Sea area.

Background of the project area

Geologic description

The Quadrant 21 field is located in offshore East Scotland in the Central North Sea. (Figure...). The field is surrounded by many other large oil and natural gas fields in the North Sea. This exploration block was drilled in some areas, but unfortunately no information is given about the productivity of the field. Late Cretaceous and early Paleocene chalk fields have been discovered in the UK Central Graben area and most of them are located in the simple structural traps. The remaining chalk discoveries have shown stratigraphic, diagenetic and hydrodynamic component of entrapment post-discovery. [**3**]

This is the consequence that very little direct exploration has been done for the stratigraphic traps since the variation in stratigraphy is the key confining element in the reservoir which traps the oil. The hydrocarbon province of the chalk play in UK Central North Sea is restricted to the Central Graben area. The UK Central North Sea Group with its main formations which are Ekofisk, Tor and Hod show extend from the Buchan basin, located mainly in the license block 21/1A and extending into block 20/5A, to the northern area of the quadrant 39.

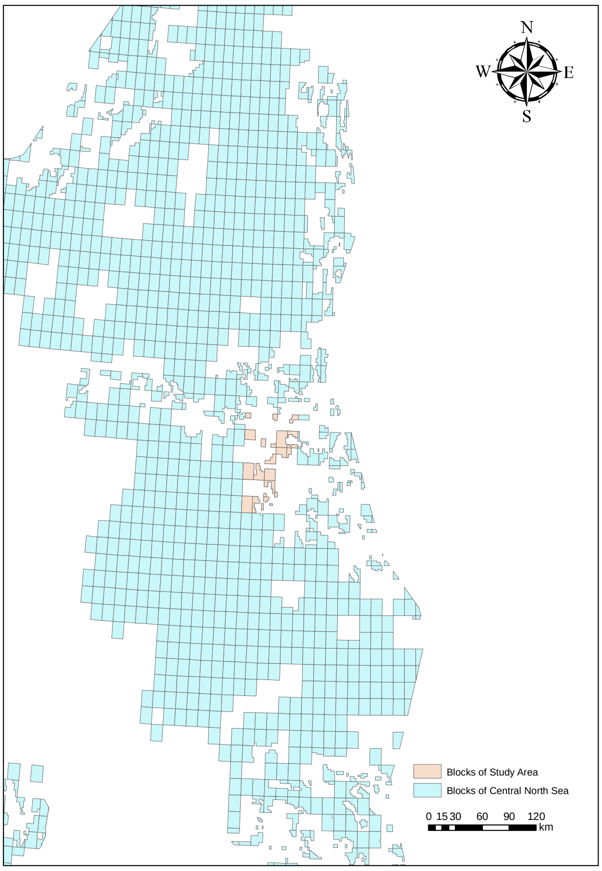


Figure Study area

Chalk reservoirs

As for many other reservoirs in the world the chalk reservoirs are highly variable in their porosity and permeability characteristics. Bramwell in his paper noted a porosity range of 0-52 % in some areas in the UK Central North Sea are due to several factors, principally: a) depth of burial, b) hydrocarbon saturation, c) original depositional facies and d) mineralogy and chalk overpressure. [1] It is also said that the chalks which were re-deposited do not have better reservoir qualities than autochthonous chalks due to destruction of early diagenetic fabric. This leads to a possibility of producing hydrocarbon from Chalk reservoir with low porosity and permeability, so that autochthonous chalks may also be viable reservoir targets. Effective permeabilities within the developed chalk fields in the North Sea range from less than 1 mD to 1000 mD.

Chalk traps

The Central North Sea which is located in a extensional system is mainly characterized by structural traps. Because structural traps consist of geologic structures in deformed strata such as fold, faults whose geometries permit retention of hydrocarbons. [2] The stratigraphic, diagenetic and hydrodynamic cannot completely trap the hydrocarbons because of the loss of reservoir quality and migration energy that can occur.
Because very little information has been given about the field and given the probability of drilling a well and losing its reservoir quality, one can say that the quadrant 21 is characterized by a stratigraphic trap.

1.1 Use of 3-D Seismic Data in Seismic Interpretation and Seismic Data Processing
The advent of 3-D seismic has transformed the upstream oil industry because it enabled exploration in areas with complex structures lying below complex overburden. An important example is sub-salt exploration. [Prof. Gerald Gardner, 3-D seismic imaging; Society of Exploration Geophysicists; Investigations in Geophysics]

The lateral variations of the reservoir properties usually cannot be deduced from measurements made at sparsely located wells. However, the integration of 3D seismic data with some petrophysical information from the wells can significantly improve the spatial characterization of the reservoir.

- Modern 3D seismic methods provide high resolution images of the reservoir geometry and also help delineate complex fault patterns
- 3D seismic data yields a dense and regular areal sampling of the acoustic properties at the reservoir interval, in contrast with the sparse well observations.

The primary use of seismic data has been traditionally for mapping subsurface structures and for identifying exploration targets. Now, by using 3D acquisition and 3D processing techniques the seismic methods can provide more detailed spatially continuous images of subsurface structures that can help the reservoir engineers construct an accurate structural model of the reservoir.

In seismic interpretation the use of 3D seismic data has several advantages in that it provides:

1) A well constrained 3D image of the reservoir volume
2) A better delineation of the faults
3) An enhanced vertical and lateral resolution of the reservoir structure and stratigraphy.[4]

There are also other important applications in 3D seismic interpretation. Several different data volumes can be viewed simultaneously to interrogate various attribute volumes at the same time. This has many applications. For example combine the lateral continuity information from a seismic attribute with the identification of the nature of the feature in the section in order to interpret a fault. Another advantage is that different time-lapse seismic volumes can be displayed so that production-related changes can be more easily seen. [M. Bacon, R.Simm, T.Redshaw;3-D seismic interpretation; Cambridge University Press; 2003]

In post-stack processing, analysis of post-stack seismic data has been effective at improving image quality and for highlighting and delineating structural and stratigraphic features in many hydrocarbon provinces. [5]
Many case studies have demonstrated how 3D seismic post-stack processing techniques are an essential step in both the verification of existing structural interpretations and the further delineation of play fairways in a fault system.[6]

Post-stack seismic data is referred to as an image that has been formed by processing or stacking a collection of pre-stack gathers also known as seismic traces. [7]

A 3D seismic post stack data comes from processing 3D raw seismic data. When the 3D raw seismic data (from the field) is demultiplexed, summed, stacked and migrated, the result is a 3D post stack dataset. [8]

In many cases poststack seismic data is the only available source of information on interwell stratigraphy and lithology. In such a situation the amount of information that can be extracted on reservoir properties such as porosity or hydrocarbon content is usually quite limited. This project had neither core nor well log, but a fully processed 3D poststack seismic data available. [9]

A range of 3D seismic post-stack post-processing techniques are widely available which can substantially aid interpretation in such circumstances. These post-processing techniques can be used for both conditioning the input data for specific interpretation tasks and highlighting or delineating features associated with specific elements of the imaged geology.

Although these post-processing techniques do not give a definitive answer regarding the imaged sub-surface geology, they do provide additional and valuable information that enables the interpreter to develop a more robust model of the imaged sub-surface geology and therefore better quantify the associated uncertainties. The added value is that an exploration team is empowered to begin constructive interpretation on an otherwise sub-optimal dataset whilst awaiting a new seismic dataset to be acquired. [10]

In the framework of seismic image processing, one is often interested in the restoration and enhancement of the quality of the seismic image. This process is carried out to attenuate degradation due to sensors during data acquisition or introduced by some preprocessing procedures. [11]

1.2 Objectives and structure of this thesis

This project focused on several techniques used to analyze a field located in Offshore East Scotland by using 3D seismic stacked dataset.

The tools within Vista 2D/3D software from Gedco were used to analyze seismic data containing chalk from Central northern sea, resulting in the development of a chalk workflow which features powerful algorithms and advanced visualization techniques especially suited for the analysis and delineation of geologic features within chalk. The visualization techniques were performed by a seismic interpretation software Petrel from Schlumberger.

This project had neither core nor well log, but a fully processed 3D poststack seismic data available.

For the seismic processing Vista 2D/3D software from Gedco the specific objectives of this thesis were as followed:

1. Noise attenuation:

    a. Random noise attenuation (FX Deconvolution,FX-Y deconvolution)
    b. Linear noise attenuation (Linear Noise Removal, Linear noise Extraction, Removal noise Adaptative Substraction…)

2. Inverse Q Filtering
3. Band-Pass Frequency Filtering
4. Time-Variant Spectrum Balancing

For the seismic interpretation software Petrel from Schlumberger the objectives were the following:

1. Visualization and interpretation of horizons picks and faults.
2. Computation of complex seismic attributes (envelope, instantaneous frequency and phase).
3. Interpretation of processing algorithms like Coherence Cube (to enhance faults and structural features)

Based on these objectives, conclusions and recommendations were made regarding the effectiveness of the different attributes (enhancement of structural features) and processing work flows (improving signal-to-noise ratio and imaging quality of seismic data) which have been used for identifying the top and bottom reservoir.

This thesis is organized as follows.

Chapter 1 gives an introduction to the geology of the area, also to the use of 3D seismic dataset in poststack processing and seismic interpretation and the detailed objectives for this thesis work.

Chapter 2 gives an overview of the 3D seismic stacked dataset (3D acquisition parameters and 3D processing parameters), Chapter 3 discusses the methodology the seismic processing and seismic interpretation with the methods, theories and their implementation for the 3D seismic stacked dataset.

Chapter 4 gives the results and discussions

Chapter 5 gives the conclusions for this thesis work and offers some suggestions for future research.

Chapter two: Literature Review

Introduction

In order to characterize and then exploit the petroleum reservoirs efficiently the reservoir engineers need realistic description of the reservoir. The process of reservoir characterization is about to tie all pieces of information regarding the reservoir from different sources (geological, petrophysical, geophysical, etc…) in a way that it assures the utilizing of all the available data in a consistent manner.

This chapter will present a brief literature of some of the approaches which are related to this project thesis.

Petrophysical Approach

The assessment in formation evaluation and reservoir development of petrophysical properties such as porosity, permeability, fluid type etc… is usually supplied by the well logs, well-tests and core data which constitute the available borehole informations.

The reservoir characterization will involve interpreting a well log, basing zones strictly on log character, averaging properties within zones, and mapping them with equally spaced contours between the wells. This approach works best for primary recovery of homogeneous reservoirs in the sense that most of the measurements give accuracy in depth direction, while in the heterogeneous reservoirs the predictions between the wells is relatively poor. This is the reason why the poor interpolation between the wells and the extrapolations from the wells might be erroneous.

The dataset of this project does not provide any available borehole informations in order to characterize the reservoir efficiently, but it is given a 3-D dataset.

An overview of the geological and geophysical approaches using the Three-dimensional seismic technology will be discussed below.

Geological and geophysical approaches of the Three-dimensional seismic technology

The three-dimensional (3D) seismic method has emerged to help reduce the uncertainty inherent in finding and recovering new petroleum reserves.

The 3D technology improves the accuracy of the subsurface information obtained from surface-recorded measurements over conventional seismic techniques by understanding the spatial or 3D nature of the problem to be solved. The increased detail and accuracy obtained from the method allow better definition and delineation of the structural (or stratigraphic) trap; hence, the reservoir management can proceed with less uncertainty (ie. more information has been used to reduce the uncertainty), enhancing the value of in-situ reserves.

The most promising role for 3D techniques lies in the area of reservoir description. The 3D seismic method is uniquely capable of providing spatially continuous estimates of rock parameters. When it is integrated with available well, and core data, areal distribution of net pay, porosity, or hydrocarbon content across the reservoir can be derived and add significantly to the quality of information provided by the integrated database input to the reservoir simulation process.

Thus the 3D seismic method offers positive leverage on the net present value of the field. Fewer dry holes, better well placement, earlier production, and greater total hydrocarbons recovered are the result.

3-D seismic now delivers not only structural details but also stratigraphic information and direct hydrocarbon indicators as well. The ability of a technology to separate good from poor prospect situations defines its efficiency and viability.[12]

The 3D data volume offers structural accuracy, high resolution, and a horizontal perspective of the subsurface by allowing the user to slice horizontally to view the total prospect area at a single depth-analogous to removing the geologic overburden to the target level and viewing the resulting subcrop map. [13]

A primary benefit of inserting the 3D seismic method into the total development plan will be the high geometric resolution and detailed information on the spatial distribution of rock parameters and content.

A three-dimensional seismic technology can help define and map the reservoir. This is discussed below in the role of three-dimensional seismic in defining and mapping of the reservoir.

Role of three-dimensional seismic in defining and mapping of the reservoir

A hydrocarbon system is composed of seven elements such as source, generation, migration, reservoir, seal, trap and time which is the overriding element. All the elements can be evaluated based on seismic data to reduce the risk associated with drilling the well. [**14**]

3D seismic surveys provide more details about the reservoir and its contents than any conventional seismic interpretation. In fact the contrasts of acoustic impedance (i.e., the product of density and seismic velocity) between the adjacent layers are the cause of seismic reflections. If it is assumed that a thick reservoir is overlain by a thick caprock, the signal reflected at the interface is a function of the contrast of the acoustic impedance. This strength of the seismic reflection can be altered by some factors such as: 1) the changes in density, velocity and lithology which are the caprock properties;
2) the changes in the reservoir properties (porosity, permeability, mineralogy, fluid content); and changes in the geometry of the interface such as faulting, fracturing and steep dips.
The use of 3-D seismic data can provide information on the reservoir and its contents because caprocks generally have constant properties over large distances, and the reservoir variation and the reservoir geometry is the cause of changes in reflection amplitude.

Seismic data can be used to correlate a source rock with seismic reflection to determine the extent and possibly the thickness of the reservoir.

Since the generation of hydrocarbons requires pressure and temperature for some length of time, the burial history of source rock is an issue, which can be assisted by mapping many seismic horizons and doing paleographic reconstructions. Once it has been determined that source rocks have generated hydrocarbons, we must find the route they took from the generation area to the trap.

The value of the seismic here is in mapping the surface along which migration takes place to determine which traps are favorably located. In order to assess the reservoir rock properties such as porosity and permeability, and the reservoir's thickness and extent, seismic methods can be used in much the same way as for the source rock determination.

3D seismic can be used to construct a very detailed amplitude map of a reflector, where the amplitude variations on these maps are interpreted from calibrations with well data, which might indicate that low amplitudes will always coincide with low porosity in the wells.

3D seismic surveys are a cost-effective tool for mapping hydrocarbon reservoirs and can have a major impact on the volume of reserves estimated. The greatest benefit, however, is gained from 3D data that are recorded in a timely manner and completely interpreted, which can be done efficiently with computer-based interpretation systems. All the intrareservoir details (i.e., porosity, pore fluids, faulting, and reservoir sedimentology) can be improved and mapped from 3D seismic data. [15]

Mapping the extent of the reservoir rock can be important nowadays, especially when it does not underlie the entire trap. With the advent of time lapse seismology, the permeability might be provided geophysically as well. All these tasks require very efficient cooperation between geophysicists, geochemists, geologists, petrophysicists and reservoir engineers.

Seismic Quality

All the disciplines involved in the search for hydrocarbons are affected by seismic data. It is important to understand that not all the seismic data are generate in the same way and the data quality does vary.

According to Greeve [14], four elements of a seismic tool need to be qualified. These are continuity, character, coverage or control and conversion to depth.

Continuity: When looking at 3-D data one first checks the horizon amplitude map to see how uniform the amplitudes are. Then one can ask if the amplitude variations are whether due to acquisition or processing effects or due to geologic effects? An observation at the cross sections is done to see the continuity of the same peak from one point to another. The number of breaks in continuity provides the measure of data quality.

Character: Character comes through the shape of the basic wavelet. The important criteria here are to know if the wavelet character does change along the mapped horizon and, if so, how the change in character does cause any uncertainty in the mapped horizon. Any change in the character means something has happened to the rock in the vicinity of the reflector. Sometimes changes in bed thickness can cause character changes due to interference.

Coverage or control: One can ask about the amount of seismic data which is available to define the prospect. In this case it is required to determine if the line spacing is too large or the entire survey is too small to allow adequate mapping of critical dips.

Conversion to depth: There are three methods to do this. One relies entirely on well control and the other entirely on velocities derived from seismic data.

For the first method, the quality control issue is to identify the location of the wells with respect to the prospect. For the second method, one must consider the number of control points. The third method is a combination of the two.

All these aspects have to be analyzed by geophysicists in order to estimate the quality of 3D seismic before it will be used by other members of the multi-disciplinary team.

Seismic Attributes

The goal of seismic exploration is to map geologic features associated with hydrocarbon deposition, generation, migration, and entrapment. The goal of seismic exploitation is to characterize the static and dynamic characteristics of subsurface reservoirs.

A seismic attribute is a quantitative measure of a seismic characteristic of interest. Good seismic attributes and attribute-analysis tools mimic a good interpreter. [**16**]

In another words, an attribute is necessarily a derivative of a basic seismic measurement. That basic information is time, amplitude, frequency and attenuation. [**17**]

Over the past decades, we have witnessed attribute developments tracking the breakthroughs in reflector acquisition and mapping, fault identification, bright-spot identification, frequency loss, thin-bed tuning, seismic stratigraphy, and geomorphology.

During 1970s and 1980s, the seismic attributes most used in petroleum exploration were amplitude-based instantaneous attributes.

However, in the 1990s, seismic attribute technology has dramatically advanced in several directions: techniques now range from single-trace instantaneous event attribute computations to more complex multi-trace windowed seismic event attribute extractions to the generation of seismic attribute volumes. What do they all mean? Seismic attributes are specific measurements of geometric, kinematic, dynamic, or statistical features derived from seismic data.

As a broad generalization of seismic attributes, time-dependent attributes provide structural information, amplitude-derived attributes provide stratigraphic and reservoir information. [**18**]

Frequency derived attributes are not yet well understood but there is a widespread optimism that they will provide additional useful reservoir information. Attenuation is not used today but there is a possibility that in the future it will yield information on permeability.

Seismic attributes describe is any calculated quantity from seismic data. They quantify specific data characteristics, and so represent subsets of the total information. In effect, attribute computations decompose seismic data into constituent attributes.

Attributes are used like filters to reveal trends or patterns, or combined to predict a seismic facies or a property such as porosity. While qualitative interpretation of individual attributes has dominated attribute analysis to date, the future belongs to quantitative multi-attribute analysis for geologic prediction.

Most attributes are derived from the normal stacked and migrated 3-D data volumes but variations of basic measurements as a function of angle of incidence (and hence source to-receiver offset) provides a further source of information.

The table below shows some methods for computing Poststack seismic attributes, with representative attributes. (19)

Method	**Representative Attributes**
Complex trace	Amplitude, phase, frequency, polarity, response phase, response frequency dip, azimuth, spacing, parallelism
Time-frequency	Dip, azimuth, average frequency, attenuation, spectral decomposition
Correlation/covariance	Discontinuity, dip, azimuth, amplitude gradient
Interval	Average amplitude, average frequency, variance, maximum, number of peaks, % above threshold, energy halftime, arc length, spectral components, waveform
Horizon	Dip, azimuth, curvature
Miscellaneous	Zero-crossing frequency, dominant frequencies, rms amplitude, principal components, signal complexity

A classification of seismic attributes and their applicability for reservoir characterization is given by Quincy Chen and Steve Sidney. Their paper says that Reservoir forecasting is the primary goal of applying seismic attribute technology.

There are several exploration challenges facing geoscience interpreters such as:

1) the discrimination of non-hydrocarbon anomalies in order to reduce dry holes or waterwet sands,

2) the repeatability of a good-luck forecasting such as in wildcatdrilling (i.e., the process of drilling for oil or natural gas in an unproven area, that has no concrete historic production records and has been unexplored as a site for potential oil and gas output)

3) a way to recover a bypassed reservoir.

A good forecasting model must tackle these challenges by pointing out the directions to develop appropriate technology in order to meet the challenges.
[*20*]

Post-stack attributes are a more manageable approach for observing large amounts of data in initial reconnaissance investigations. These attributes can also be classified by their computational characteristics:

- Instantaneous attributes which are computed sample by sample, and represent instantaneous variations of various parameters.(trace envelope is an example of instantaneous value of attribute)

- Wavelet attributes are an attribute class which comprises those instantaneous attributes computed at the peak of the trace envelope and which have a direct relationship to the Fourier transform of the wavelet in the vicinity of the envelope peak. The wavelet attributes are sub-divided on the basis of the relationship to the geology:

    1) Physical attributes which are related to physical qualities and quantities, such as the relationship between the magnitude of the trace envelope and the acoustic impedance contrast, the frequencies related to bed thickness, wave scattering and absorption.
    2) Geometrical attributes which describe the spatial and temporal relationship of all other attributes. Semblance which measures the lateral continuity is a good indicator of bedding similarity as well as discontinuity.

Most of the attributes, instantaneous or wavelet are a function of the characteristics of the reflected seismic wavelet. Since a seismic wavelet at the interface between two beds is characterized by both its reflectivity and transmissivity, two new categories of attributes can be enumerated:

- Reflective attributes which correspond to the characteristics of the interfaces. AVO (Amplitude Versus Offset) which is a pre-stack attribute is reflective attribute because of the angle dependent reflection response of an interface.

- Transmissive attributes are related to the characteristics of a bed between two interfaces. There are many transmissive attributes such as interval, RMS (i.e., Root Mean-Square) and average velocities, Q absorption and dispersion.

Some other basic attributes

The Trace Envelope is a physical attribute and it can be used as an effective discriminator for the following characteristics:

- Mainly represents the acoustic impedance contrast, hence reflectivity,
- Bright spots, possible gas accumulation,
- Sequence boundaries,
- Thin-bed tuning effects,
- Major changes in depositional environment,
- Spatial correlation to porosity and other lithologic variations,
- Indicates the group, rather than phase component of the seismic wave propagation.

There are two types of envelope derivatives:

The first derivative of the envelope which is the time rate of change of the envelope shows the variation of the energy of the reflected events; and the second derivative of the envelope provides a measure of the sharpness of the envelope peak.

The instantaneous phase attribute is a physical attribute that can be effectively used as a discriminator for geometrical shape. In a 3-D seismic dataset, the instantaneous phase is:

- A good indicator of lateral continuity,
- Is related to the phase component of wave- propagation
- Used to compute phase velocity
- Gives the visualization details of stratigraphic elements
- Devoid of amplitude information

The instantaneous frequency is a physical attribute which responds to both wave propagation effects and depositional characteristics. It is an effective discriminator in the sense that it is an indicator for hydrocarbon (by low frequency anomaly), fracture zone (by lower frequency zones) and bed thickness indicator (higher frequencies indicating sharp interfaces, and lower frequencies indicating massive bedding geometries).

Complex seismic trace attributes have become important qualitative and quantitative measures for geophysical exploration. Attributes have made it possible to define seismic data in a multidimensional form and neural network technology enables us to unravel the complex nonlinear relationships between seismic data and rock and fluid properties. [21]

The use of seismic attribute in this project thesis will try to support the interpretation part of the 3D seismic dataset.

Methodology

Background of the Project Area

3.1 3-D seismic dataset from WesternGeco

The 3D seismic stacked dataset used for this thesis is the seismic cube provided by WesternGeco and Schlumberger with the code area Quad 21 1997/98 3D and survey 7006 which covers a rectangular area of approximately 652.84750 (km^2) and has a recording length of 5 s.

This 3-D seismic stacked data consist of 1251 samples per trace, 676 inlines which are numbered from 981 to 2636 and the number of crosslines 3545 from 1 to 3519.

Besides a final scaling time section from 4 (ms) to 5004 (ms), a sampling rate of 2 (ms) and a line-spacing (or bin spacing) of 25 (m), a sampling rate were used to acquire the data. The total number of cells is 2659651020.

The longitude and latitude values for the four corners of the survey were translated to X and Y values for the offshore east Scotland in the central northern sea. Table 3.1 describes the four corners of the 3-D seismic data which were represented with the grid information 12.50 x 25.0 m.

Quad 21 1997/1998 3D (Survey ID: 7006) 651 Sq. Km

Vertice	Inline	Xline	Survey Longitude	Survey Latitude	X	Y
A	1658.0	19.0	0.146286	57.1300160	508856.00	6332010.50
B	1669.0	3165.0	0.795880	51.1300470	548181.00	6332285.50
C	996.0	3169.0	0.793476	56.9789170	548231.00	6315460.50
D	991.0	9.0	0.143642	56.9802270	508731.00	6315333.50

Table 3.1 Coordinates of the Corners of 3D Seismic Survey Area

3.2 3-D seismic data acquisition

The aim of seismic data acquisition and processing is to deliver products which will look like cross-sections through the earth. A certain amount and types of data must be acquired, and processing applied in order to remove unwanted multiples or energy, and to place the required events in the correct locations.

The field data were processed by Western Geophysical Company of America, Bedford, Great Britain. The description of the processing procedure is given as a summary in Table 3.2.

The seismic vessel used to acquire this 3D dataset is R/V Western Patriot. It is powerful and sophisticated enough to tow multiple subsurface and can connect two or more gun arrays that are shot.

This will allow the multiple subsurface lines to be collected for each pass of the boat, and this is more efficient and reduces data acquisition costs. The energy source that was used an array of air guns which were tuned to give a short energy pulse with directivity characteristics that concentrate the energy vertically downwards. The air gun is a device that discharges air under very high pressure into the water. [22] To be able to shot and process data in a correct way from a 3-D survey the boats have sophisticated navigations systems. The boat and cables are subject to currents and winds, which will often cause the cables to be pushed away from the line, meaning that the positions of shots and receivers must be continuously recorded, and this information is saved together with the trace data.

The table 3.2 below presents the general description of the 3D acquisition performed by Western Geophysical Company of America in the field data.

Survey Vessel	R/V Western Patriot
Recording System	
Seismic Recording System:	I/O System MSX Recorder
Number of Channels:	1728
Recording Filters: Freq. & amplitude attenuation Sample rate	L.C: 2Hz,12dB/Oct; H.C: 206Hz,264DB/Oct 2 milliseconds
Record Length (nominal):	5 Seconds
Recording Format:	SEGD 8058
In-line Coverage:	48
Line Spacing:	25 metres
Preamp Gain:	High

Energy Source	
Seismic Energy Source:	Tuned air gun array
Array Volume:	2250 cu. in. per array
Pressure:	2000 psi
Number of Strings per Array:	3
Number of Guns per Sub Array:	8
Array Width:	12.0 metres
Array Length:	15.1 metres
Array Separation	50.0 metres
Shotpoint Internal:	18.75 metres alternating
Array 1:	Starboard
Array 2:	Port
Gun Depth:	5 metres ± 1 metre

Gun Timing Spec:	± 1 millisecond
Source Control System:	SSS
Dedicated Computer:	Sun Sparc
Operating System:	Sun OS 5.5

Streamer	
Seismic Streamer:	Thomson Marconi Sentry Solid Streamer
Active Length:	6 x 3600 metres
Number of Groups:	1728 (6 x 288)
Crossline Separation:	100 metres
Hydrophone Group Length:	17.75 metres
Group Interval:	12.5 metres
Hydrophones per Group:	14
Group Sensitivity:	14 V/bar
Streamer Depth:	7 metres ± 1 metre
Number of Cable Levellers:	96 (6 x 16)
Number of Cable Compasses:	96 (6 x 16)
Number of Cable Acoustic Units:	6 per cable (plus 1 per tailbuoy)
Cable/Source Offsets	
Navigation Reference Point (NRP):	GPS antenna at sea level
Number of Cables:	6
Cable Separation:	100 metres
NRP to CRP (Inline):	500 metres
NRP to CRP (Inline):	377 metres
SRP to CRP (Inline):	123 metres
Quality Control Systems	
Online/Postplot Coverage QC:	Reflex
Online Navigation QC:	Spectra
Postplot Seismic QC:	Omega
Online Seismic QC:	EVP, NCU2 (SeisView)
Onboard Navigation Processing:	UNAVCHK
Onboard Seismic Processing:	Omega
Vessel Heading Control	
Gyrocompass-1 (Primary):	Sperry Mk 23
Hull Alignment Angle:	1.205 degrees
Gyrocompass-2 (Secondary):	Sperry Mk 227
Hull Alignment Angle:	0.485 degrees
Line Control System / Navigation Data Recording	
System:	Spectra
Dedicated Computer:	IBM SP2 node 5
Tape Transport:	3590 data cartridge
Packing Density:	38,000 bpi
Navigation	
Primary Navigation:	SkyFix DGPS (Spot Beam)
Secondary Navigation:	Sargas PosNet (StarFix corrections)
Tertiary Navigation:	N/A
Tailbuoy Positioning:	PosNet rGPS

	DigiRANGE Acoustics
Cable Positioning:	DigiRANGE Acoustics
	DigiCOURSE 5011 compasses
Source Positioning:	PosNet rGPS
	Fanbeam Laser
	DigiRANGE Acoustics
Geodetic Parameters	
Spheroid:	International
Semi-Major Axis:	6378388.000
Semi-Minor Axis:	6356911.946
Reciprocal of Flattening (1/F):	0. 0033670034
Geoid/Spheroid Separation:	47.47 metres
Projection Parameters	
Projection:	Transverse Mercator (UTM 31 N)
Central Meridian:	00° 0 0.00E
Latitude of Origin:	00° 0 0.00N
Scale Factor on Central Meridian:	0.9996
False Easting:	500,000.00 metres
False Northing:	0.00 metres
Magnetic Declination:	-4.58 degrees
Datum Shift (7 parameter shift in Bursa Wolfe sense)	
Datum Shift:	WGS-84 to local
Dx:	89.5 metres
Dy:	93.8 metres
Dz	123.1 metres
Rx	0 seconds
Ry	0 seconds
Rz	-0.156 arc seconds
Scale Factor:	-1.2 ppm
Echo Sounder	
Type:	Simrad EA500
Draught Compensation:	Not Applied (6.06 metres - Survey Aarhus May 1997)
Conversion Velocity:	1500 metres per second

Table 3.2 Summary of acquisition parameters of the 3D post-stack seismic data used in this dissertation.

The data processing for this project will be described in section 3.3.

3.3 3-D data processing

The processing of a 3-D seismic data is important because it ensures spatial consistency of parameters such as the velocity field. In order to run a processing sequence for 3-D several steps are required.

The first step is to reformate the operation. The data coming from the receivers are put into trace order. At this stage the data are written to tape in one of the formats used by industries so that the raw records are retained to form the basis of possible reprocessing. For this dataset, the reformatting operation was performed by converting the SEG-D format to Western internal format. In addition to that zero-phase waveform has been used for processing of the data and it has been recorded with SEG (Society of Exploration Geophysicists) standard reverse polarity.

The second step, designature, is performed by taking the wavelet which was created by the source and converting it to a more compact form. With air guns outputting a signal with a main peak and then followed by a smaller secondary peak which is due to re-expansion of the air bubble. This source signal is not desirable because every reflection is followed by a smaller repetition of itself. Designature is very useful here because it will remove the second peak, giving the input wavelet a good shape and a more compact form. In addition to that, a decision has to be made whether to have a zero-phase or minimum-phase wavelet as output. (By zero-phase wavelet, we have one of the wavelet which is symmetrical about its center, while a minimum-phase wavelet is one which starts at time zero and has as much energy near the start as physically possible.) The modeled designature which is combined with a low-cut filter and an anti-alias filter of respectively 5Hz and 93.75 Hz of frequency and 18 dB/Oct and 36 dB/Oct of magnitude attenuation in order to remove the lowest frequencies from the data (low-cut filter) and to ensure there is no aliasing. (Any higher frequencies in the near surface do not alias on to lower frequencies).

Because of the high requirements in the seismic acquisition techniques it is respectively recorded a field filter with low-cut of 2 Hz with magnitude attenuation of 12 B and high-cut of frequency 206 Hz with magnitude attenuation of 264 dB.

Marine data have a sampling interval record of about 2ms, which is enough to record frequencies up to 250 Hz, frequencies which are even higher than the ones actually recorded from the earth. The data are resampled to 4ms, which is enough to record the frequencies up to 125 Hz. The resample was from 2ms to 4ms. In order to circumvent spatial aliasing, data often are recorded twice as many numbers of channels per shot record as that would be used in processing. Before reducing other traces at the start of a processing sequence, a wavenumber filter (k-filter) is then applied to remove any wavenumber components for all the frequencies beyond the Nyquist wavenumber corresponding to the trace spacing of the data after reducing the traces which alternate from the second shot. [23] This wavenumber filter is actually a spatial high-cut anti alias filter. A resampling filter is required and in this case, we have 0.45 Nyquist, and a taper of 10% of K Nyquist. This will speed up all the later processing stages. The next step is to reduce any traces that appear excessively noisy and which lead to a poor coupling or equipment failure. The next step is the amplitude recovery. As the wavefront from the source is traveling deeper into the earth, it covers a larger area and suffers a decrease in amplitude because of transmission losses and attenuation. That is why a recovery is required in order the remove the loss in amplitude due to the expansion of the wavefront with depth. This expansion is saying that the same energy in the wavefront is spread over an increasing area as the distance travelled by the wave increases, and for this reason the wave amplitude is getting less. The next step is the merge navigation with seismic headers which consists of assigning the correct positioning information to the traces as referred to in the acquisition parameters section (see table 2.1). The inline interval is 25 m and the crossline interval is 12.5 m.

Deconvolution before stack, also called D.B.S. is applied in order to sharpen the wavelet and remove any short period of reverberations. An operator is designed for each trace which is convolved with the trace to remove the ringiness. The deconvolution used in this 3-D processing was predictive. In general it is becoming rare to apply spiking deconvolution before stack because it is assumed that the input data is minimum-phase, and a spiking deconvolution process might be variable in phase.

Every two kilometers on 48-fold common-mid-point gathers were collected to produce a multi-velocity function (MVF) stacks and velocity semblance displays.

Because in some cases the automatic mute may remove real data and it may be better to pick a mute by hand to avoid removing too many far offsets. [24]

Here an outside mute is picked at 153, 400, 600 and 3735 m for a travel-time of respectively 8,100, 450 and 3300ms. Low-cut (8 Hz and 32 dB/ oct) and high-cut filters (30 Hz and 36 dB/oct) are applied; the instantaneous gain is 512ms window.

The next step is the multiple attenuation of velocity lines. Normally there are two techniques which are used, Radon and FK demultiple. In both cases normal moveout (NMO) correction is applied to flatten either the multiple or the primary events. The data were transformed to FK domain and the unwanted events are removed by subtracting the multiple events. The methods work because multiples spend longer travelling in the near-surface and hence have a moveout velocity that is slower than the primary events arriving at the same time. The multiple attenuation in the FK space was performed by using 90% primary velocity at the time range 0-2000ms and 85% of primary velocity at 5120ms.

A single regional velocity function was used as a center function guide and 7 MVF stacks were generated based on the central function. There were three higher and three lower functions and each of these was spaced at a set percentage higher or lower than the previous function. The percentages were 4% at 4ms, 5% at 600ms, 6% at 2000ms, 8% at 4000ms and 8% at 5120ms.

A second velocity analysis is performed. Here the absence of the overcorrected events in the move-out corrected gather is convincing evidence that the velocities of the steeply dipping reflections have been corrected for the dip effect. Dip move-out correction is applied every 500 meters on multiple attenuated with 48-fold common mid-point gather. The outside mute and the different filter parameters were the same as in the first velocity analysis.

In this case 2 kilometers velocities were used as a center function guide and 7 MVF were generated based on the central function. The number of functions was the same as in the first velocity analysis and the percentages were also the same. The objective of this step was to remove the effect of dip on stacking velocities and trace positions.

Data binning is performed where every trace is assigned to midpoint locations. For this marine the bins contain a regular sampling of offsets which is highly required for seismic processing. The distribution of offsets more uniform is the flexible binning which is from 12.5m x 50 m at 0m offset to 12.5m x 100m at 3735m offset.

The 3D dip move-out (DMO) is applied for dipping move-out correction and stacking to the 3D seismic data where progressive 3D dip moveout stack of 48 offset planes is used.

The K Notch filter is performed in order to remove the pattern left caused by the acquisition. In fact what is happening here is that different common mid-points (CMPs) will contain a different combination of traces in a regular pattern so that it may be visible in the final stacked section. Any regularly repeating pattern which is visible as a strong component can be removed by a Notch filter.

An additional deconvolution is performed in order to remove the 3-D noise. The predictive is once again used for this deconvolution after stack (DAS).

The interpolation in crossline direction to infill low-fold holes in the upper section; a primary dip limitation was about 4ms per trace.

Before the pre-migration scaling two processes were applied on two surveys in order to match the phase and amplitude of two surveys with equal phase shift (+ 45 degrees) and different time shift (-2.7ms and -14ms).

The Pre-migration scaling or data conditioning is performed to remove a sudden amplitude variation between traces since these are not consistent with the behavior of waves. This causes artifacts during the migration process.

The next process is the migration velocity field. Because it is not usual to use the raw velocities as original picked, the velocities used here are smoothed both in space and in time; and various percentages of the picked velocity field are performed and the results are analyzed for evidence of over too high velocities or under too low velocities migration.

For this data set, the velocity field was smoothed over 2 kilometers radius, the scaling was 100% from 0ms to below Top Chalk and the 95% from 800-1000ms below Top Chalk to the end of the data. It is also said that in the south-western corner of the merged survey area, the scaling was 102.5% from 0ms to below Top Chalk and 95% from 800-1000ms below Top Chalk to the end of the data.

Migration in the FK domain is an important method since it is by far the quickest assuming constant velocity and is accurate to 90^{o}. [25] We apply a 3-D modified residual migration with the smoothed and scaled velocity field which is followed by a two pass residual migration. This is the final, “high-fidelity” migration process which uses the spatial varying velocity field.

A time variant filter or band-pass filter is applied to reduce the higher frequencies with time to eliminate those that are mostly noise due to their attenuation on passing through the rocks (chalk).

The final step in this 3-D processing sequence that was done by Western geophysical Company of America was to run a final scaling, which applies time-varying trace scaling to ensure a balanced-looking section with time. A Residual Amplitude Analysis Compensation (**RAAC**) is applied for the whole survey. The Automatic Gain Control (AGC) could have also been used; it applies a time-varying gain to each trace, with the gain calculated so as to keep the average absolute amplitude constant within a window that slides down the trace.

3.4 The seismic processing tool (Vista 2D/3D)

For the present project thesis the program Vista 2D/3D was used for the processing of the three-dimensional poststack data. The software is Calgary-based provider of integrated geophysical survey design software and services and has been recently the acquisition of Schlumberger which is the world`s leading supplier of technology, integrated project management and information solutions to customers working in the oil and gas industry worldwide. [26]

Vista is an industry leading software package that provides complete processing of 2D/3D seismic data acquired on land, offshore, or through VSP (i.e. Vertical Seismic Profile). Vista 2D/3D delivers algorithms for quality control to complete the seismic processing. Those algorithms and techniques are employed in order to display and/or process 3D seismic data.

The following paragraphs will present the different methods or techniques that have been used to process the 3D poststack data.

3.5 Processing of the poststack data

The final output from the main processing that described in section 3.3 is a stacked dataset which differs in the processes applied or in the choices of parameters, especially display parameters such as filtering, amplitude and polarity choices. This poststack data may be further analyze for amplitude, frequency content, apparent polarity, inverted to acoustic impedance, or synthetic-velocity traces, and so on, and displayed in many ways. [22]

Some preliminary steps which are listed below were required in order to initialize the project in Vista software:

- Create a new 3D project: The project was created by selecting the file "new project" from the Vista menu bar; the name of the file was saved as Quad_21_Papi_3D marine_Vista 11. The project data list was displayed after the 3-D survey was selected and the project units used as meters.

- The second preliminary step was to set the plotting defaults for the 3D stacked data with the SEG-Y parameters for the trace header dictionary used as SEG-Y Revision 1. This step was very important in the sense that the inline and crossline numbers were going from 1 to 1 and the SHOT and REC coordinates had the same values. The project was then saved from the Vista menu bar.

- The next step was to import the 3D SEG-Y file as stacked

- Another important preliminary step was setting up the geometry and saving that information to the headers. Without this information it would not be able to continue processing with any certainty. An accurate positioning for offsets; arrival times are required.

The figure below is the displayed traces for the 3D stacked data that has to be processed in Vista.

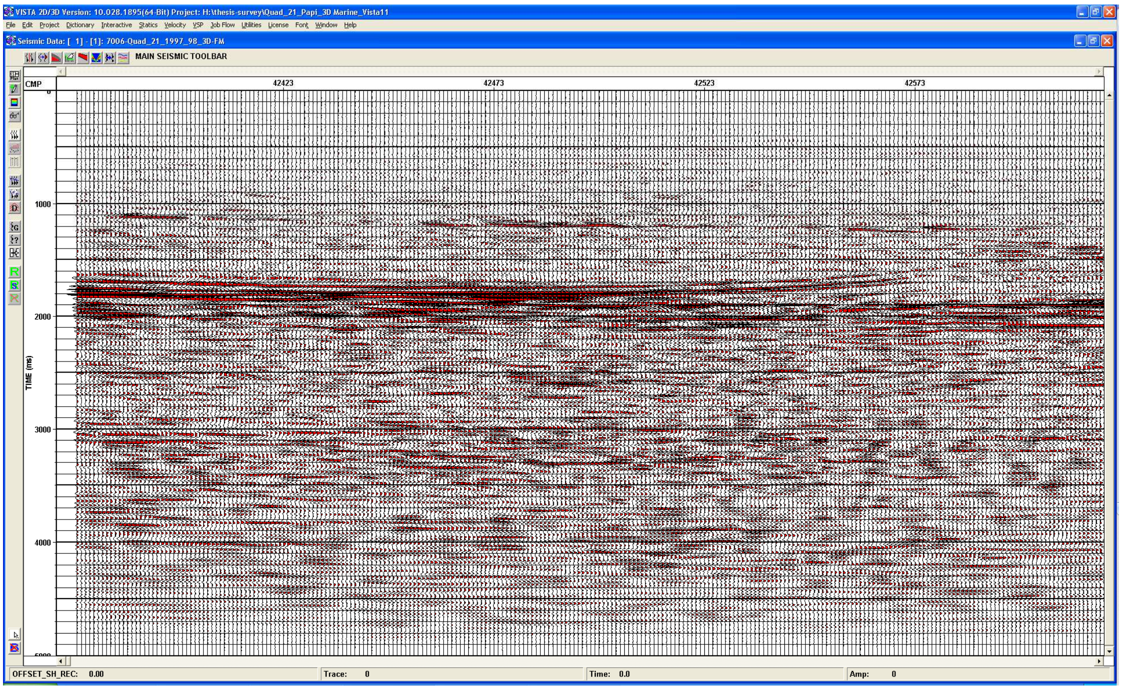


Figure 3 D raw stacked dataset to be processed in Vista.

In order to improve the quality of this 3D stacked data the objectives for this seismic data processing will be as followed:

- Noise attenuation: FX- prediction and FX-Y deconvolution
- Poststack F-X prediction random noise attenuation
- FK-FX filtering for linear noise attenuation
- Inverse Q Filtering
- Time variant spectrum balancing
- Poststack clean-up FXY noise attenuation

3.5.1 Noise attenuation

Many factors influence the reliability of the seismic data to ensure drilling success and later to provide a better understanding of the reservoir characteristics because many oil and gas companies require several methods to try and understand their reservoirs and maximize the hydrocarbon recovery.

Adequate and proper noise attenuation methods help to maximize the potential benefit and contribution of the seismic data in exploration and development. In this case there are many advantages of applying noise attenuation, but two of them are as followed:

1) When the noise is properly addressed it provides the opportunity to track amplitude anomalies and stratigraphic objectives with confidence.

2) The effective noise removal, which preserves the original amplitude and phase characteristics of the data, will provide the opportunity for advanced attribute work and inversion to better understand the reservoir.

Regardless of the source of the noise, the noise is divided into two categories:

- Coherent noise: is a noise which can typically be modeled and subtracted from the data such as ground roll, strum noise, multiples, and so on… Coherent noise such as ground roll can be measured at a specific velocity or suite of velocities. The noise can then be removed from the data based on velocity.

- Random noise is any noise spikes bursts which are not coherent in nature.[27]

The random noise can have many effects on deconvolution:

1) Field data practically contain a noise component. If this component is small, then we can ignore its effect.

2) Alternatively, the deconvolution can be delayed until the data is stacked, so that the S/N ratio is improved.

3) However, if the noise component is considerable even after stacking, a deconvolution should be applied in order to enhance the resolution of the data without destroying its interpretive content.

The filtering methods include predicted deconvolution, random transform, stacking, principal component analysis, f-k filtering and Singular value decomposition etc.
With some adjustment most methods can be applied for both coherent and random noises.
In fact random noise uncorrelated from trace to trace abounds in recorded data and remains its presence at almost all steps in a processing sequence.

In this project thesis the filtering that will emphasize are the predicted deconvolution and FXY prediction filtering.

- **Predicted deconvolution**

Predicted deconvolution is one of the most common techniques in seismic prospecting to attenuate noise. It is also known as *FX-deconvolution* or *FX-prediction*. The signal is predicted by the nearby trace and noise is the unpredicted factor.

This method is used when random noise is present or when coherent noise can be viewed in a random domain. In predicted deconvolution seismic traces are transferred to the F-X domain i.e. frequency - space domain by taking the forward Fourier transform of each trace. [28]

Noise that remains in the stacked data can have adverse effect on reflection continuity. Despite the fact that a number of multichannel signal enhancement techniques has been practiced, the one which best preserves relative amplitudes and retains the signal character without amplitude distortion. [23]

Luiz L. Canales, who invented the spatial prediction filtering, presented method to reduce incoherent noise from seismic data. The signal is defined in terms of a simple model that separates the time and space variables. [29] The prediction process involves estimating some future value of the input series defined by the prediction lag from the past values of the input series. The first step is to perform a Fourier transform over a time gate for every trace. The spatial variation of each Fourier amplitude is then examined. The signal energy in a trace amplitude will be therefore predictable in a spatial sense as a linear combination of adjacent trace amplitudes. [30]

A prediction filter, when applied to the recorded seismic trace produces an estimate of the predictable part, the multiple reflections. The error in the prediction process then represents the random reflectivity series.

In Vista software, the FX Prediction command works by first calculating the Fourier transform of every trace. The complex frequency samples are then multiplexed so that one gets a series of mono-frequency values across space (F-X transform).
In addition, VISTA calculated a two-sided complex Wiener prediction Filter for each Mono-frequency series. This filter is then applied and the inverse F-X transform calculated. This will give a smoothing effect to the data across space (X). [31]

The objective of performing this flow in Vista seismic data processing is the improvement in removal of random noise.
The F-X deconvolution flow was executed as shown in the figure below

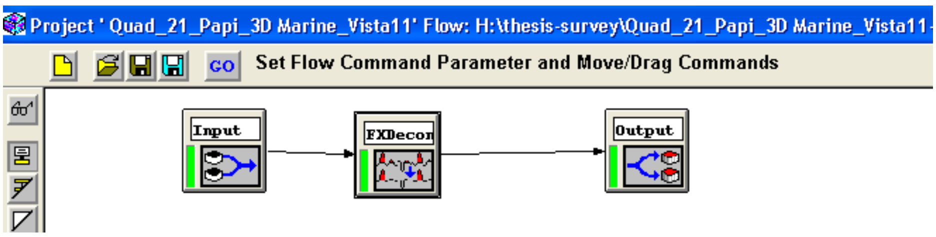


Figure F-X deconvolution flow.

The flow was executed by taking into account the following parameters:

- The input parameter of this flow was the 3D raw stacked data which was sorted by inline and crossline;
- The second parameter is the FX-Prediction flow command. Its design dialog which is shown below has several parameters which are listed below:

Filter length - the number of traces to use in design and application of the filter.

Design Window - The number of traces in the design window.

Cut–off Frequency - This value acts as a high–cut filter.

Power - Output frequency amplitudes will be increased by this exponential value. Phase will be unchanged.

Restore Trace Mutes - Restore the input trace mutes.

Design Signal Window - Define window to calculate prediction filters over. They are then applied to the entire data set.

The 3D F-X Prediction Design Parameters is shown in the figure below.

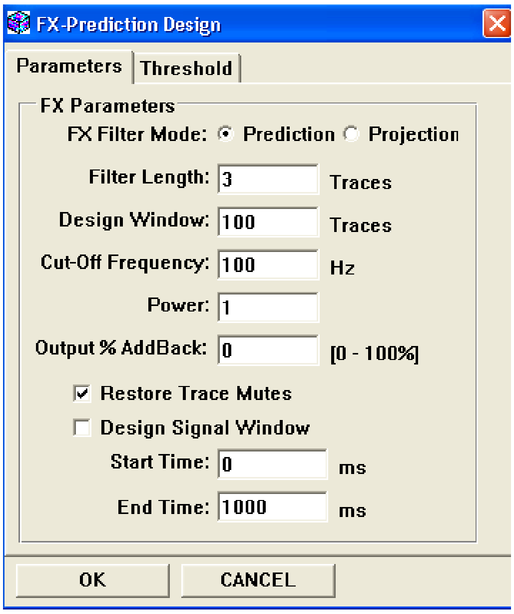


Figure: Design parameters dialog for FX-Prediction flow command.

- The output command outputs data from a flow to the Vista project data list. The output was saved as FX_Pred in the project data list.

In general the effects of F–X prediction are harsher on smaller windows meaning fewer traces and short time intervals.
It is also said that the big disadvantage of F–X prediction is the inability to handle conflicting dips, so split the data into sections each containing only consistent dips prior to inputting to F–X prediction.

This method of reducing random noise was performed by combining the given 3D dataset with the paper described by Luis Canales. [32]

One another method of applying poststack FX prediction of random noise attenuation was done using FX prediction flow command for attenuation of random noise in stacked data.

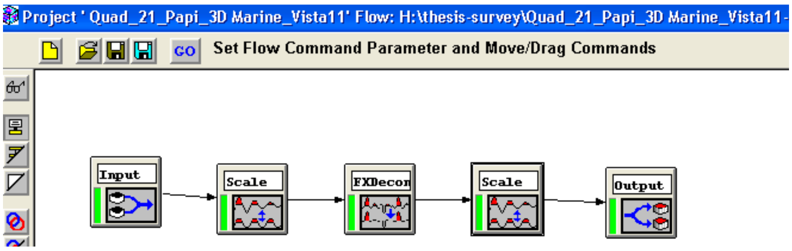


Figure Poststack random noise attenuation flow using FX decon flow command.

This flow consists of five parameters which are described as followed:

- The input data were the 3D stacked data sorted by inlines with the crosslines as secondary key.
- The scale flow command works by calculating the user define scale function of all trace samples within the scale window; and the entire trace are multiplied by scale over the average. The scale flow command is exactly the same with the second in the flow dialog window. The scale design parameters window is shown in the figure below.

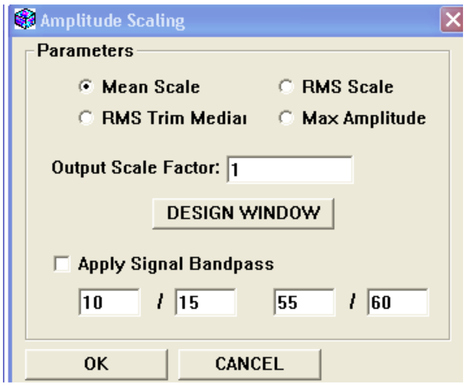


Figure Scale design parameters window.

- The FXDecon as described in the previous method is the third flow command.

- The last flow command is the Output which is saved in Vista project data list.

Another method of reducing random noise is to apply the prediction filtering in 3D.

- **FXY prediction**

FX prediction filtering for random noise reduction has been extended successfully to 3D. The advantage of using the 3D version is that there is less distortion of the geology.

Another advantage in FXY prediction over FX prediction is that in the FXY prediction the significant coefficients are spread in spatial direction, thereby reducing the severity of the smearing in any given direction.

In FXY prediction filtering the 3-D version of the algorithm described above (FX prediction filtering), the assumptions made that events are locally planar, and that therefore the Fourier amplitudes of the traces are predictable as combinations of adjacent trace amplitudes in all spatial directions.
This F-XY prediction can avoid noise amplitudes smearing to other offset by applying this process in common offset volumes. [30]

This optimum filtering significantly reduces the random noise while preserving relative amplitudes.

In Vista software, the FXY Prediction command (FXY Pred) worked by first calculating the Fourier Transform of every trace. The complex frequency samples are then multiplexed so that one gets a series of mono-frequency values across space (F-XY transform).

Then the process calculates a two-dimensional two-sided complex Wiener Prediction Filter for each Mono-frequency series. This filter is then applied and the inverse F-XY transform calculated. This gives a smoothing effect on the data across space (X-Y).

The FXY prediction flow was performed as shown in the figure below.

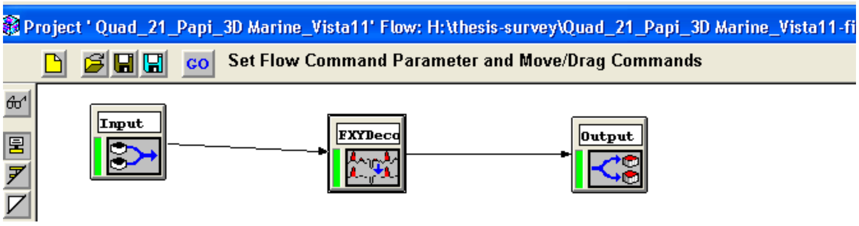


Figure FXY prediction filtering flow.

The flow was performed by setting the following parameters

- The input data used for this flow was the 3-D raw stacked dataset sorted by inline numbers.

- The second parameter is the FXY-prediction or deconvolution flow command. Its design dialog which is shown below has several parameters which are listed below:
  1) **Filter Size (N)** - The number of traces to use in the application filter.
  2) **X-Line Design** - The number of traces in the design window in the X-Line direction.
  3) **X-Line Step** - Step between designs.
  4) **In-Line Design** - The number of traces in the design window in the In-Line direction. Normally this will be equal to the X-Line Design. Unusual structure which is dominant in one direction may cause one to make these parameters different.
  5) **In-Line Step** - Step between designs. For processing adjacent subsets of a dataset, the step size is the number of traces to apply the calculated filter to
  6) **Design Window** - Define window to calculate prediction filters over. They are then applied to the entire data set. This Design Window helps to ignore noise at start or end of input traces.

The 3D F-XY Prediction Design Parameters for flow command FXY-decon is shown in the figure below.

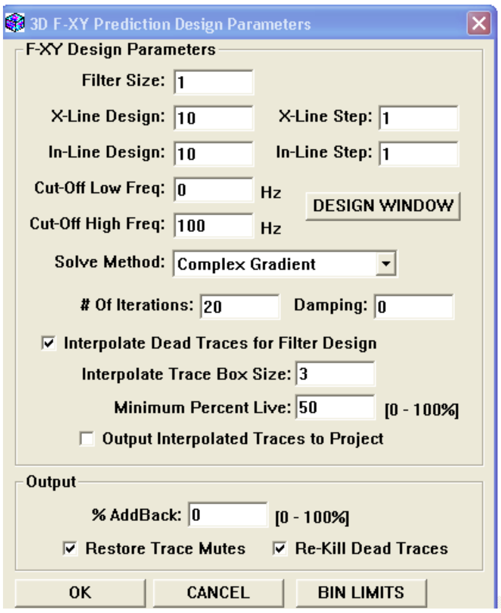


Figure: Design parameters dialog for F -XY Prediction flow command.

- The last flow command is the Output which is saved as FXY-Deconv in Vista project data list.

- **Poststack clean-up FXY noise attenuation**

The objective of this step was to perform a FXY prediction filtering by "cleaning" noise. The flow generated for this step is presented as followed:

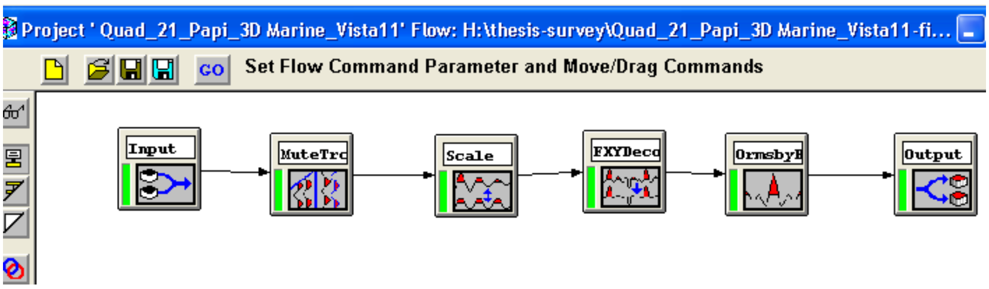


Figure: Poststack Clean-up FXY noise attenuation

- The input data used for this step was the 3D raw seismic stacked data which was sorted by inline and the crossline as secondary key.

- MuteTrc flow command is applied in order to mute the data set.

- The Scale flow command is used to calculate the user defined scale function of all trace samples within the scale window, and the entire trace is multiplied by scale over average.

- The FXY deconvolution filter is also applied to reduce random noise in the stacked data

- An Ormsby bandpass filter is also used. It works by computing the Forward Fast Fourier Transform of each trace. The frequency samples are then multiplied by a function which is specified in the Ormsby Band-Pass Filter dialog.

- The output flow command is processed data saved in the project data list.

- **Linear noise attenuation**

Elimination of coherent linear noise in seismic data has been usually carried out with either F-K filtering or by radial trace transform. Both of them involve transformation to another domain and back.

F-K filtering suffers from aliasing problems and the strict requirement of uniform source-receiver offsets while accurate trace interpolation in the x-t domain is a must for effective filtering of linear noise in the transformed radial trace domain. [33]

The objective of this method was to attenuate linear noises on this 3-D seismic stacked section through the technique and use of local radial trace median filtering, subtract directly

the noise from the sample values to give the desired filtered output and to see the effect of linear noise attenuation on the 3-D stacked section.
This linear noise attenuation will be run in four steps:

1) ***Linear noise removal*:** Filter is applied to remove or isolate linear noise. The level of noise removal is controlled by the length of the applied operator.

The job flow dialog window is shown in the figure below.

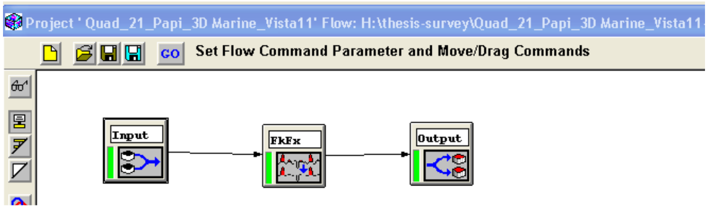


Figure: Linear noise removal job flow

- The input of this flow was the 3D raw stacked data sorted by inlines.

- The FK-FX filter is an alternate to the FK filter. It is applied to remove or isolate linear noise.

- The output of this job flow is the FK-FX data saved as linear noise removal in the Vista project data list.

2) Linear noise extraction: The objective of this flow is to subtract the filtered data from the initial data.

The job flow below is presented in the figure below.

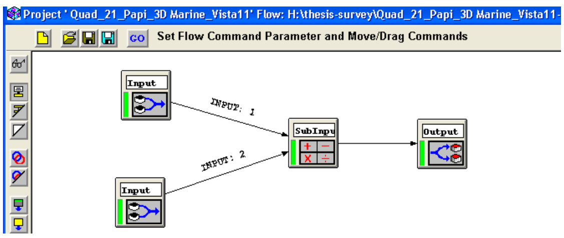


Figure: Linear noise extraction

- The first input data used was the 3D raw stacked sorted by inline

- The second input was the FK-FX data sorted by inline.

- The SubInput flow command works by subtracting the two input trace streams. The second input is subtracted from the 3D raw stacked data and is assumed to be a type of operator.

3) Band-pass Fk-Fx filter: The goal of running this flow is to apply a bandpass filter by passing a certain bandwidth that will have little or no modification on the spectrum. [23] The job flow is presented in the figure below.

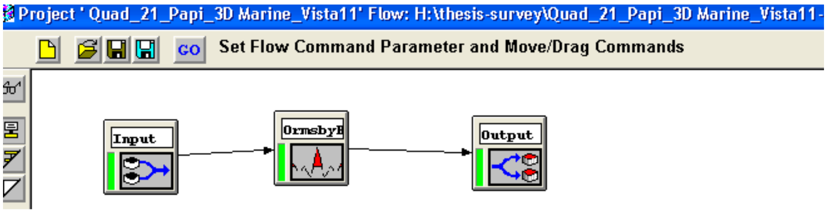


Figure Bandpass filter flow

The input used for this flow was the extracted noise sorted by inline;

The second flow command is the OrmsbyBP (Ormsby band-pass) that works by computing the Forward Fast Fourier Transform of each trace.
The frequency samples are then multiplied by a function which is specified in the Ormsby Band-Pass Filter dialog.

The output of this job flow is the filtered noise.

4) Noise removal with adaptive subtraction: The objective of running this flow is to remove noise without damaging the signal.

Below is presented the flow that was performed for this step.

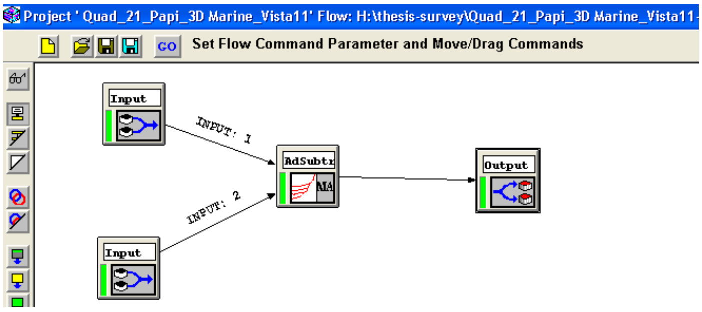


Figure: Noise removal with adaptive subtraction flow

- The first input used for this is 3D raw stacked sorted by inline
- The second input is the filtered noise from the bandpass filtering
- The output of this flow is the removed noise.

- **Time variant inverse Q Filtering**

Deconvolution has always been one of the processes to remove the effect of attenuation by modifying the amplitude spectrum of the signal, thereby making it broader.

Alternative methods to compensate for frequency attenuation are time-variant spectral whitening and inverse-Q filtering

The objective of applying inverse *Q* filtering is to eliminate the non-stationary characteristics generated by attenuation processes from the signal. Seismic waves traveling through inelastic media are attenuated by the conversion of elastic energy into heat. At being attenuated the traveling wave experiment some distortions: amplitudes are reduced, traveling waveform is changed due to high frequency content absorption, and phase is delayed. Attenuation is usually quantified through the quality factor *Q*: the ratio between the energy stored and lost in each cycle due to inelasticity. [34]

In Vista seismic data processing, the process was performed as time-variant inverse Q filtering in order to correct the effects of earth filtering.

Inelastic attenuation of seismic energy is a critical constraint upon seismic resolution because the seismic data processing is unable to fully correct for the effects of the earth filter. Because of the time variant nature of the wavelet, the spiking deconvolution that was applied before stacking could not correct fully these effects within the seismic bandwidth.

The phase and amplitude, characteristics of a seismic wavelet, are time variant in the presence of Q. Spiking deconvolution makes a fundamental assumption that the wavelet is stationary in time over the design window, and therefore cannot correct for a time variant earth filter. The seismic resolution could be improved by deterministic time variant inverse Q filtering. [35]

This process is executed for several reasons:

- The quality factor Q is directly related to the lithology

- Spiking deconvolution is incapable of treating the linear phase component and time variant nature of the earth filter.

- Time variant inverse Q filters can compensate for both the positive drift and high frequency attenuation which are evident in seismic data.

In Vista the flow was run with the different command parameters which are shown in the figure below.

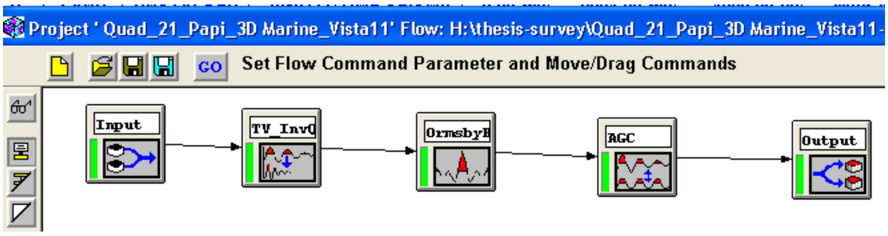


Figure Time variant inverse Q filtering

- The input for this flow was the 3D raw stacked data sorted by inline

- The TV_Inv which is the time variant inverse Q filter to calculate the quality factor q for each time - Q value pair entered in the list.

- The OrmsbyBP filter which computes the forward fast Fourier Transform of each trace. A function in the Ormsby bandpass filter will be multiplied by the frequency samples, and the result will pass through an inverse Fourier Transform to arrive at a time domain result.

- The AGC is commonly used in seismic processing to improve visibility of late-arriving events in which attenuation or wavefront divergence has caused amplitude decay. [**36**] In Vista the AGC works by calculating the average absolute amplitude of all trace sample within a moving AGC. The sample at the center of the window is then multiplied by scale / average; and the whole process will move down one sample and starts again.

- The output of this time variant inverse Q filtering is saved in the project data list.

- **Time variant spectrum balancing or whitening**

Sometimes the resolution limit of a seismic data can be a complex issue affecting the wavelet frequency, phase characteristics and the quality of the dataset. It is also known that spatial and temporal resolutions are the key to extract any stratigraphic detail from the seismic data. At the acquisition stage utmost care is required for getting greater reflection detail from seismic data. That is the reason why many attempts are made during the processing stage to enhance the spectral bandwidth.

The objective of applying time variant spectral balancing on the data was to improve its resolution. Seismic resolution is in fact the key to extraction of stratigraphic detail from the seismic data.

The objective of spectral balancing is to boost the frequencies to obtain perfect resolution, attenuate frequency and compensate it. Although the spectrum could in theory be obtained, in practice it would likely result in the boosting of noise at low and high frequencies. [**37**]
The time-variant spectral whitening has the ability to flatten the spectrum within the passband of stacked section.

The preparation of stacked input data to amplitude inversion with the broadest possible bandwidth and flattest possible spectrum is required.

The time-variant spectral whitening was done in Vista seismic processing by running a simple flow which is presented in the figure below.

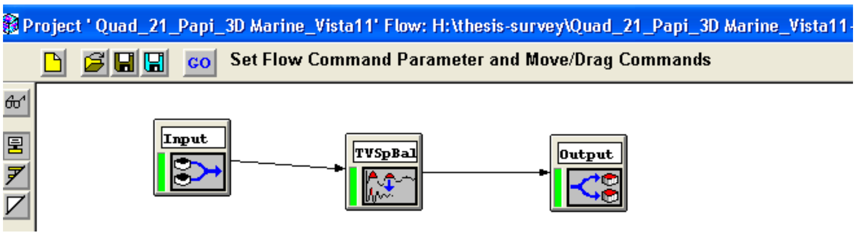


Figure Time-variant spectral whitening

- The input used was the 3-D raw stacked data sorted by inline

- The TVSpBal flow command consists of each trace which is processed independently. The trace is broken into a series of traces, each of which corresponds to a different band-pass range. Typically the trace is broken into 10Hz components. Thus the first component trace is 0 - 10Hz, the second is 10 - 20Hz and so on. Automatic Gain Control is applied on each "component trace" to improve the visibility of late-arriving events. Thus the amplitudes are equalized at all times (this is the "time variant" part of the algorithm). Finally all of the trace components are added back together to create the output trace.

The dialog box for TVSpBal command flow is shown below.

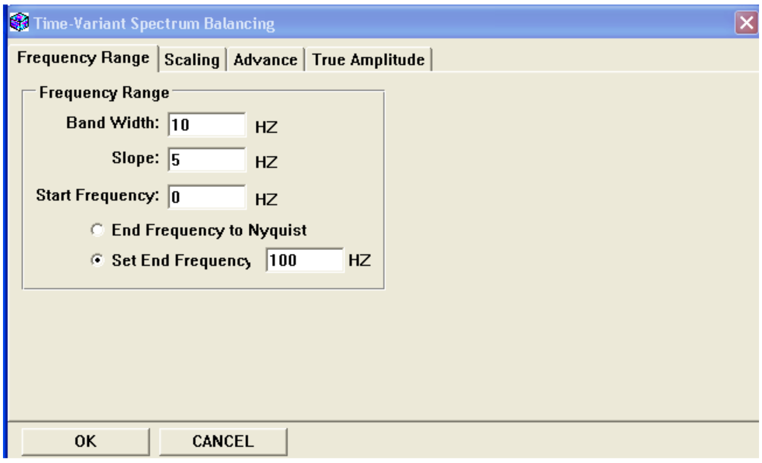


Figure Time-variant spectral whitening flow command window

Understanding the geological features can be hampered by noise in the vintage input data. The 3D seismic post-stack post-processing methods can be an essential step in the verification of existing structural interpretations.

In this study the primary objective was to apply the poststack processing methods in order to visualize the processed data in Petrel. The purposes of using the seismic interpretation software Petrel were the computation of seismic attributes, the visualization of structural features and a simple evaluation of the field.

The seismic interpretation and visualization will be discussed below.

3.5 Seismic interpretation tool (Petrel)

The literature review chapter presented previously has shown how the 3D seismic data can significantly improve the description of the reservoir. In this project thesis the seismic interpretation software used was Petrel from Schlumberger.

The main purpose of using Petrel was to visualize the data quality improvement. Since Petrel is also geophysical and seismic interpretation software the objective of project thesis was extended to an extraction of the seismic attribute and a simple seismic interpretation to enhance the structural features.

Two advantages of using Petrel for geophysical and seismic 3D interpretation are:

- Petrel geophysical software provides a full spectrum of geophysical workflows, 3D interpretation, a full set of seismic attributes including ant tracking for the identification of faults and fractures, volume interpretation (geobody detection)

- Petrel is a powerful tool in the sense that it visualizes and interprets regional 3D seismic data manually or uses advanced auto-tracking techniques. It can also create attribute maps of horizons or intervals.

The import of the 3D seismic stacked dataset into Petrel was the preliminary and fundamental task before starting any kind of work. Loading the data into the software required the coordinate parameters such as inline, crossline and the projection parameters.

The loaded 3D stacked data for this project is shown is the figure below.

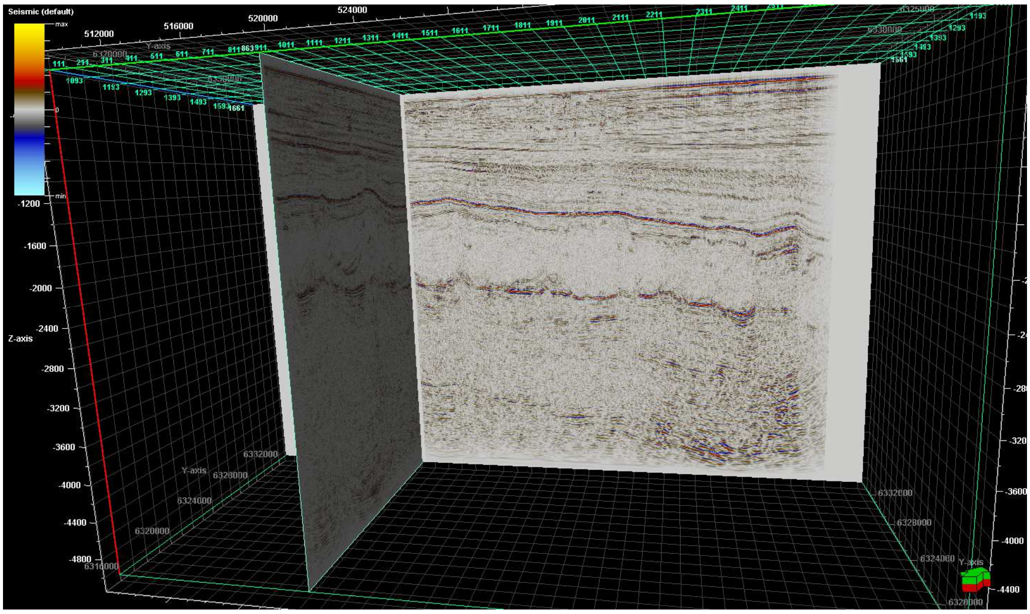


Figure: View of the 3-D loaded stacked data in Petrel software with one inline and crossline with survey grid.

3.5.1 Interpretation of 3-D seismic data

In Petrel software, the process called “seismic interpretation” can be used for the purpose of interpreting seismic horizons.

The first step in the “seismic interpretation” process is to create a seismic horizon and then to set the parameters for further interpretation. It is here essential to decide which reflector has to be interpreted.

Petrel is again a powerful tool in the sense it gives the user the option to choose between manual and automatic interpretation. For manual interpretation the user chooses freely where to interpret a horizon, while for automatic interpretation, parameters are chosen which act as guidelines. When the automatic interpretation of horizons is used, three functions can be chosen from a “guided autotracking”, 2D autotracking and 3D autotracking. For this project thesis the 3D autotracking was selected.

The second step of this seismic interpretation process was to create a fault

3.5.2 Attributes used for seismic interpretation

Seismic attributes sometimes reveal features that are not as obvious otherwise, especially lateral changes along the bedding, such as those associated with stratigraphic changes or hydrocarbon accumulations [22].

3.5.2.1 Volume based attributes

When the volume based attributes are used the properties and values are extracted from the seismic data and the result is display. Petrel software has several seismic attributes available, but only the ones that were applied in this project thesis will described.

- **Chaos:** The chaotic signal pattern contained within seismic data is a measure of the "lack of organization" in the dip and azimuth estimation method. The chaos attribute in the signal can be affected by migration of gas, salt body intrusions, and for seismic classification of chaotic texture.
- **Dip:** This attribute calculates the difference between the dip trend and the instantaneous dip. By tracking rapid changes in the orientation field, edges and subtle truncations become visible.
- **RMS amplitudes:** RMS amplitude calculates the square of the seismic amplitude values within a desired volume interval and is found by dividing the sum of the squared amplitudes with the number of live samples. Changes in the pattern of seismic amplitude both vertically as well as horizontally become apparent when using RMS amplitude. Changes might be a result of changes in lithology or fluid content.
- **Variance:** The variance cube displays the variance in the seismic signal and is a good indication of the continuity of seismic reflectors. Areas of lower continuity can be good indications of the presence of for example faults or slide deposits.

3.5.2.2 Seismic complex attributes

The complex attributes were based on the quadrature phase analysis. Those attributes are listed below:

- **Instantaneous phase**: The phase displays are helpful for showing discontinuities, faults, pinchouts, angularities, prograding beds, and events with different dips that interfere with each other.

- **Instantaneous frequency**: Variations at pinchouts and the edges of hydrocarbon/ water interface tend to change the instantaneous frequency.

Chapter 4 Results

The results are based on the seismic data processing of the 3D seismic survey Quad 21 1997/1998 (7006). This chapter presents the different results for the seismic data processing and the seismic interpretation discussed in the chapter 3.

4.1 Seismic data processing

In the seismic processing part the expectation is to look at the improvement of the image after the different poststack methods were performed. In each method the results will be presented with two figures: On the left the original raw stacked data and on the right the processed data.

4.1.1 Predicted deconvolution (FX prediction)

The objective of this method was to attenuation noise. The result below is presented with two figures where the first one is the raw stacked data (left) and the second the processed one (right).

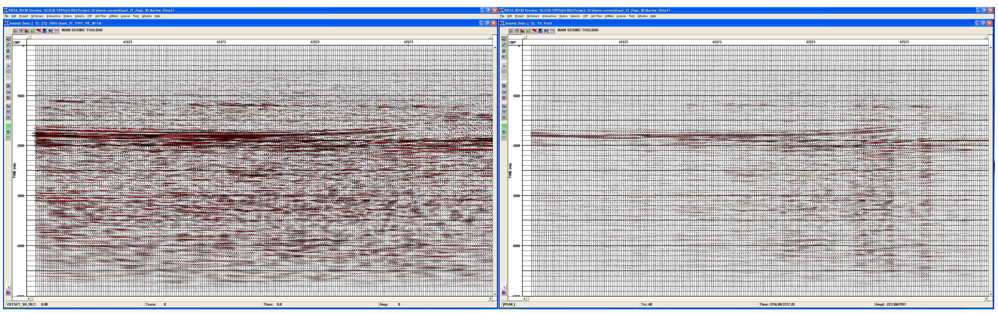


Figure: 3D stacked data before (left) and after FX prediction (right)

The unique observation is that the predicted deconvolution was quite successful in term of noise attenuation. It has removed the ringy events.

4.1.2 FXY prediction

The objective of this step was also to attenuate noise in the 3D raw stacked data. The result is presented below.

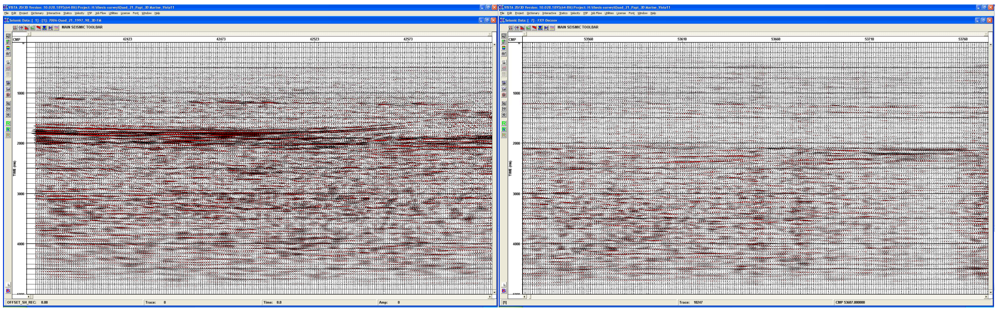


Figure 3D stacked data before (left) and after FXY prediction (right)

4.1.3 Poststack clean-up FXY noise attenuation

The objective of this step was to perform a FXY prediction filtering by "cleaning" noise. The result is shown below.

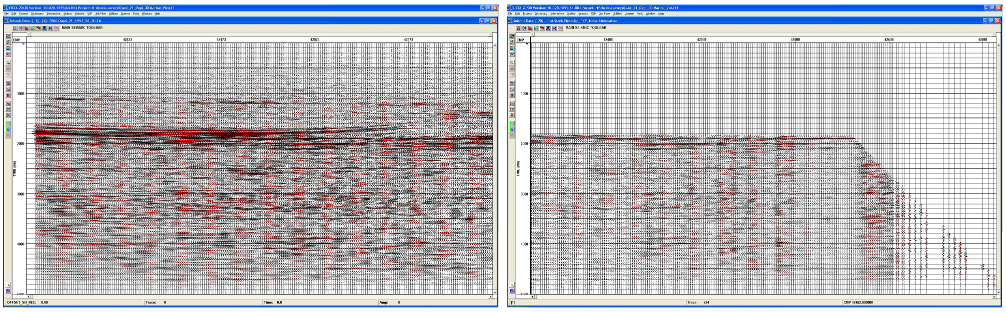


Figure 3D stacked data before (left) and after poststack clean-up FXY noise attenuation (right)

As can be seen this step was successful with removal but some problems occurred.

4.1.4 Linear noise attenuation

The objective of this step was to isolate linear noise, extract linear noise, apply a band-pass filter and remove noise without damaging the signal. The result of this step is presented with 3D raw stacked data and the final output of Noise removal with adaptive subtraction.

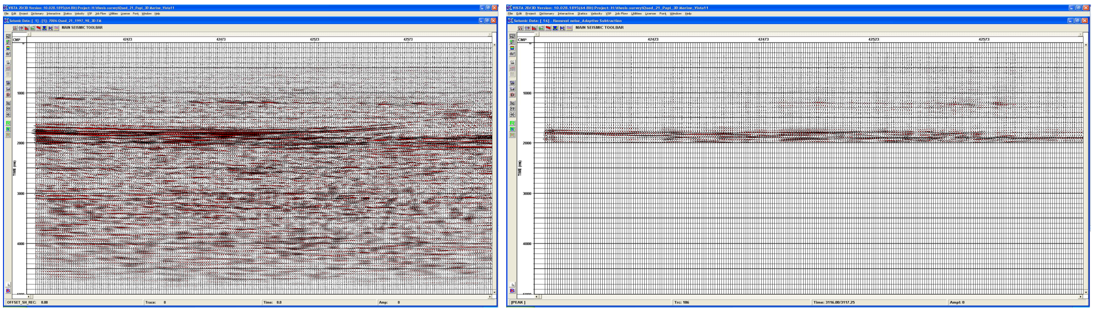


Figure: 3D stacked data before (left) and after linear noise attenuation.

4.1.5 Time variant inverse Q Filtering

The objective of this step was to improve the seismic resolution by deterministic time variant inverse Q filtering. The result is shown below.

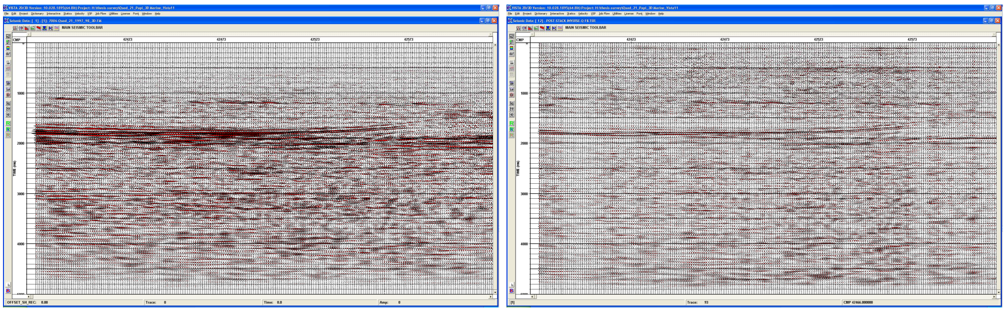
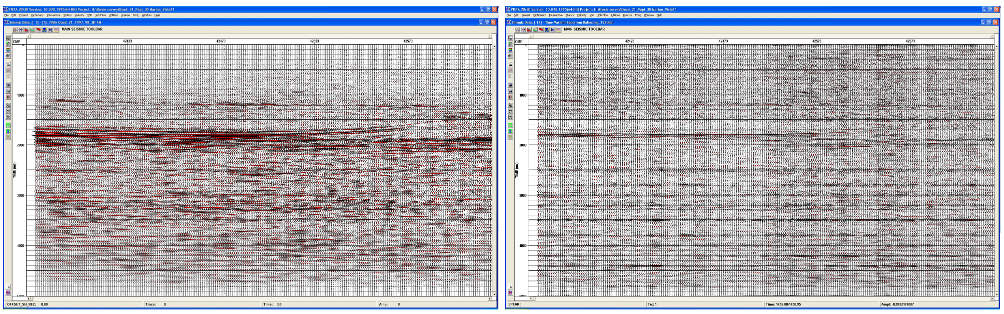


Figure: 3D stacked data before (left) and after time variant inverse Q filtering

As can be seen the time-variant inverse Q filtering gave a better resolution. It looks a bit ringy but the image is much better than the original data.

4.1.6 Time variant spectrum balancing or whitening

The objective of doing this step was to boost the frequencies to obtain perfect resolution, attenuate frequency and compensate it. The result is shown below.



As can be seen, the time variant spectrum balancing gave a better resolution. The processed image looks better than the raw stacked data.

Result summary:

The objectives of this seismic data processing were quite good and each processed data is clearer than the original. Vista showed once again that it is a very powerful tool to improve image.

Results from the seismic interpretation (from Petrel)

4.2.1 Visualization of the processed data

After the Vista seismic data processing has done its work, Petrel seismic interpretation can take over in order to:

- Check if the resolution was better in the processed data
- Estimate the noise attenuation

In this case, only two processed data will be presented here, the FX prediction and the poststack time variant inverse Q filtering. The 3D original stacked figure will on the left side and the processed data on the right.

4.2.2 Visualization of the seismic attributes

4.2.2 Visualization of the seismic attributes

Three seismic attributes were done in Petrel and they are presented in the figures below. The left figure is the seismic attribute and the right one the original data.

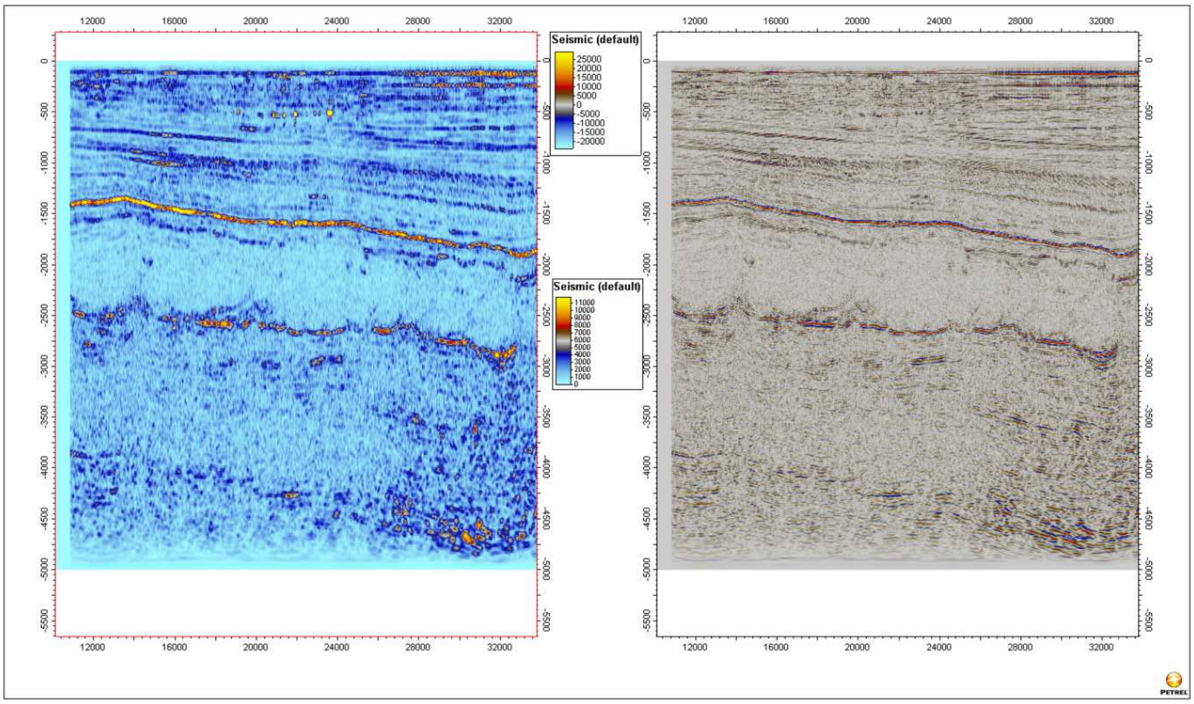


Figure: RMS amplitude attribute (left) and original stacked data (right)

We see that the highlighted changes might be a result of changes in lithology or fluid content. It could be the chalk reservoir.

The second one is the instantaneous phase and is presented below.

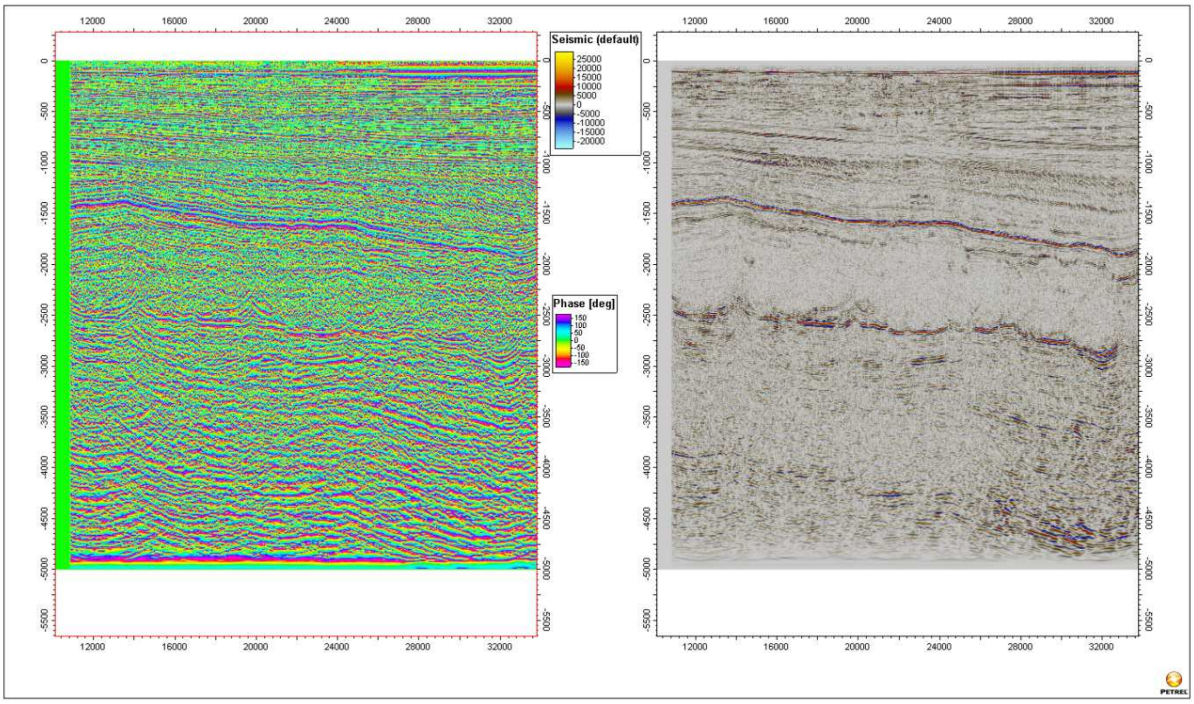


Figure: Instantaneous phase attribute (left) and original stacked data (right)

The third seismic attribute is the instantaneous frequency and the figures present it.

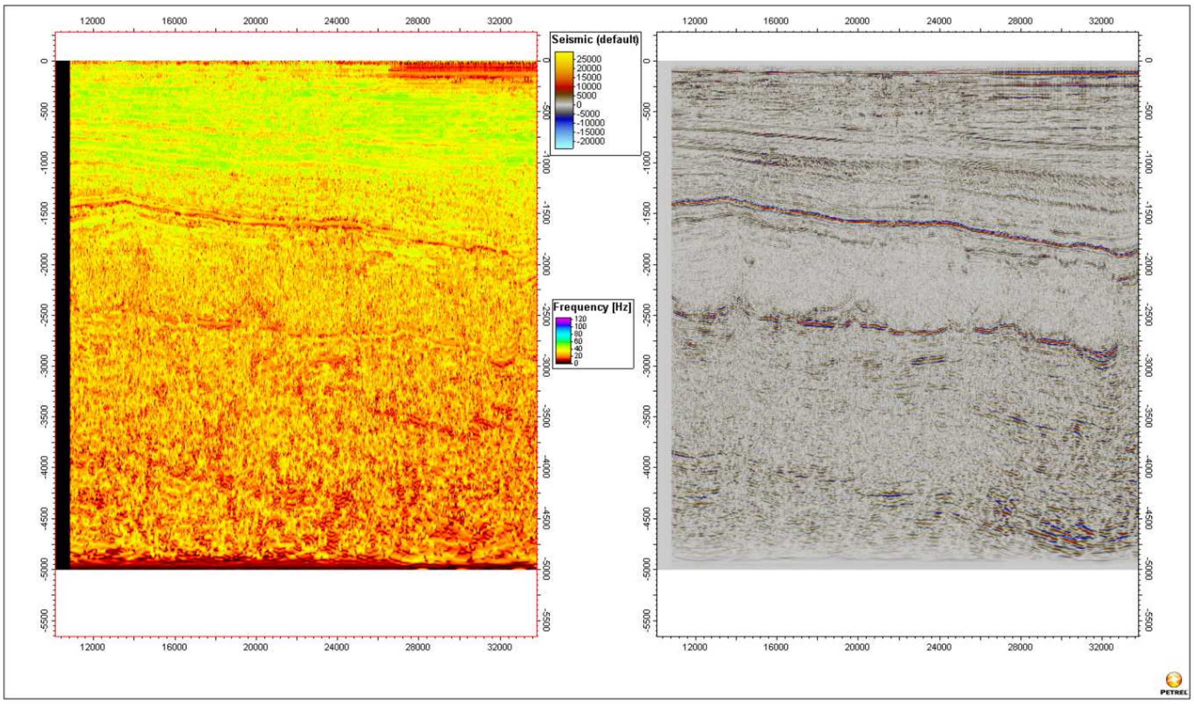


Figure: Instantaneous frequency attribute (left) and original stacked data (right).

4.2.2 Seismic interpretation

This step presents an interpretation of the dataset and the objectives here were to enhance the faults and the structural features. Some normal faults and two horizons (Top and bottom horizons) were interpreted.

The figure below shows the interpreted data with its normal faults and horizons.

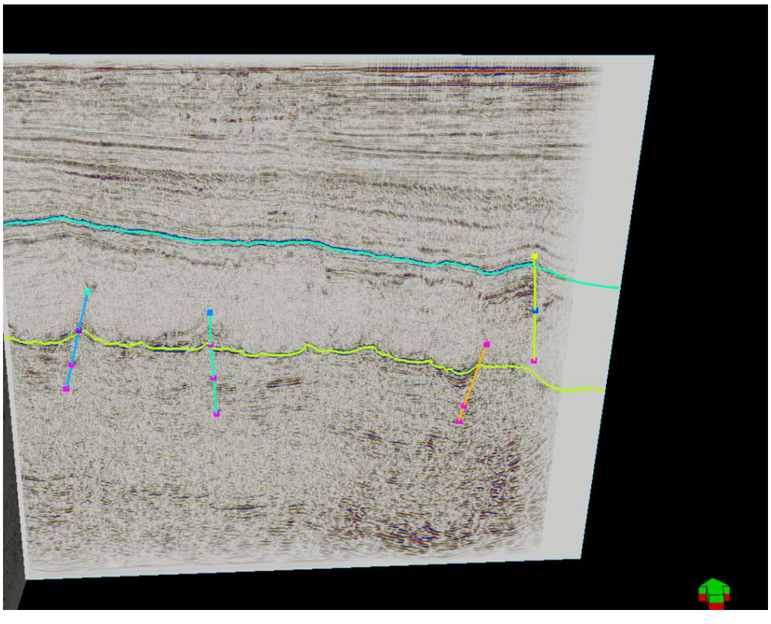


Figure: Normal faults and horizons interpretation in the 3D stacked data.

Conclusion

- 3D seismic data and the use of both Vista seismic data processing and Petrel allowed improving the quality of the data and interpreting the structural features.
- By using Vista seismic data processing the objectives which were noise attenuation, improvement of the seismic resolution were performed successfully so that the processed data could be visualized and interpreted in Petrel.
- This type of post-stack data was acceptable for structural interpretation; however, for the purposes of the extraction of seismic attributes used in this study it was very critical to ensure that the amplitude spectra were preserved at each stage of the data processing.
- However , the seismic attributes which were discussed in the previous chapters gave more

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