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2-D LITHOPROBE seismic data reprocessing for the East Coast of Canada

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Foreword

GeoVectra Ltd., based in Calgary, Alberta, performed seismic reprocessing of 2-D LITHOPROBE marine seismic data from the Labrador Sea and the Gulf of St. Lawrence, Canada, on behalf of the Geological Survey of Canada (GSC), part of the Lands & Minerals Sector (LMS) of Natural Resources Canada (NRCan). The original LITHOPROBE Geoscience Project was funded by the Natural Sciences and Engineering Research Council (NSERC) of Canada and the Geological Survey of Canada. The reprocessing was performed under a competitively awarded contract (NRCan Contract # 3000661447) and the attached Processing Report of that work was submitted on May 24, 2018.

Reprocessing of selected seismic lines in the 1992, 1990, and 1986 vintages of GSC's LITHOPROBE ("Probing the Lithosphere") regional marine seismic surveys was conducted from December 2017 to March 30, 2018.
The reprocessing was targeted to provide an emphasis on multiple suppression, improved resolution and applied pre-stack time migration. Data were provided to the contractor as digital files in SEG-Y format. Final outputs consisted of SEG-Y digital files of stack migrated (Post stack and Pre-stack) seismic sections.

The reprocessed LITHOPROBE seismic data includes the following seismic lines for each of the three areas of Eastern Canada discussed in this report (see the Final Map on following page for the location of the seismic lines) and includes the link to the "ftp" site where that data can be found and downloaded:

1) 1986 LITHOPROBE seismic lines 86-1, 86-2, 86-3, 86-4 and 86-5 in the Gulf of St. Lawrence (**FGP1986**), http://ftp.maps.canada.ca/pub/nrcan_rncan/raster/marine_geoscience/Seismic_Relection_Digital/FGP/Stack_Data/1986/GeoVectra_reproc_2018/;
2) 1990 LITHOPROBE seismic lines 90-1, 90-2 and 90-3 in the Labrador Sea (**FGP1990**), http://ftp.maps.canada.ca/pub/nrcan_rncan/raster/marine_geoscience/Seismic_Relection_Digital/FGP/Stack_Data/1990/GeoVectra_reproc_2018/; and,
3) 1992 LITHOPROBE seismic lines 92-1, 92-2, 92-3, 92-5, 92-6 and 92-7 in the Labrador Shelf and Ungava Bay (**ESCOOT**), http://ftp.maps.canada.ca/pub/nrcan_rncan/raster/marine_geoscience/Seismic_Relection_Digital/ECSOOT/ecsoot_stacks/GeoVectra_reproc_2018/.

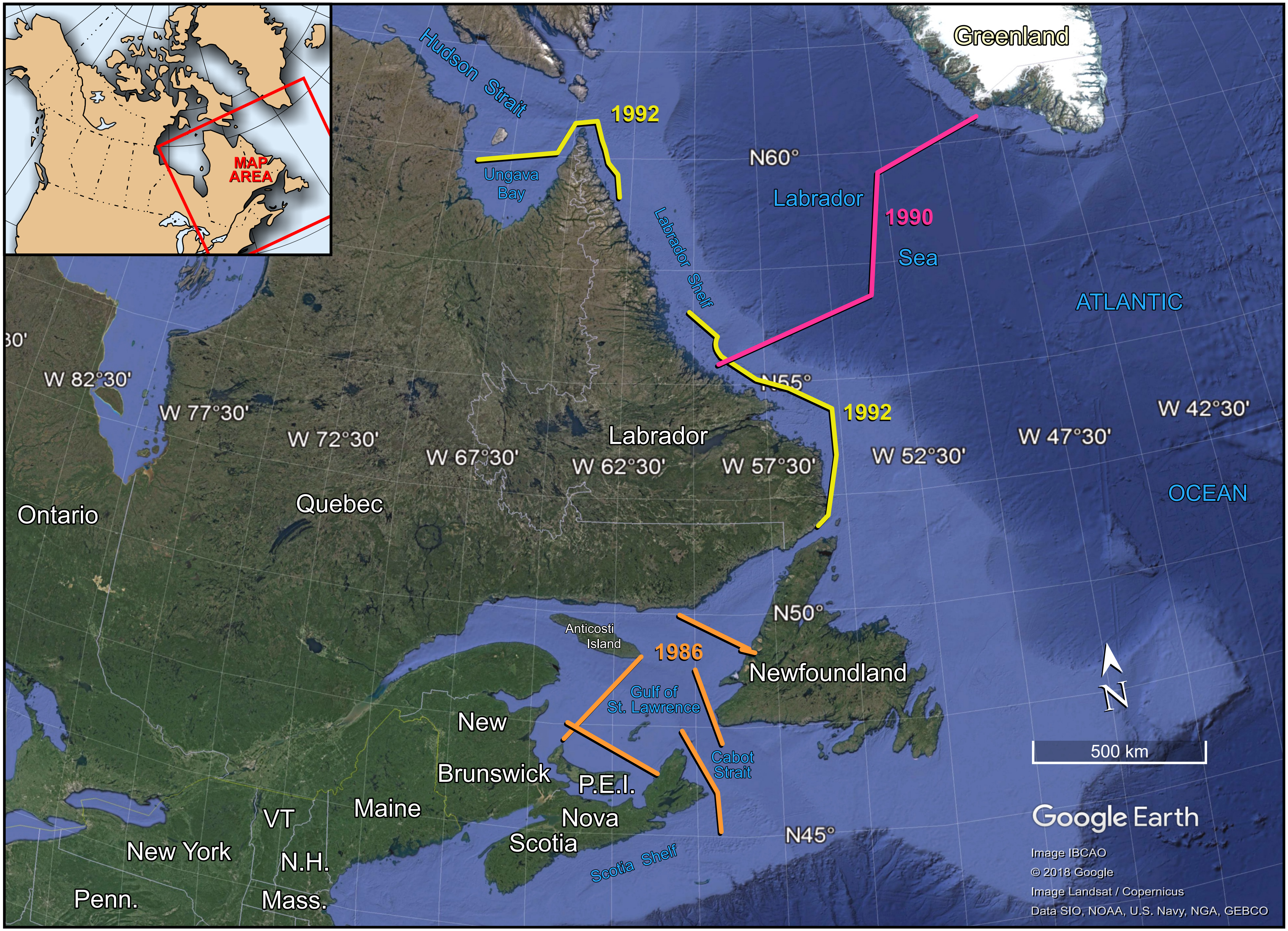
The remainder of this report comprises the final processing report supplied by GeoVectra, Ltd. to accompany the seismic lines preserved in the Open Government data repository of GSC owned seismic data.

Acknowledgements

Acknowledgement goes to all who contributed in the process for its successful completion in a compressed time. We would like to thank Mingyu Zhang and Ethan Burke, GeoVectra, Ltd.; France Bolduc, NRCan Procurement Specialist; Chris Jauer, GSC Petroleum Geophysicist; Yassir Jassim, GSC Geophysical and GIS Support Scientist; and William McCarthy, GSC Seismic Data Processor. David Sargent, GSC Geological Technician, drafted the Final Map and handled the assembly and production of this Open File. It would have been impossible to complete this work on time without their commitment to the project.

Disclaimer

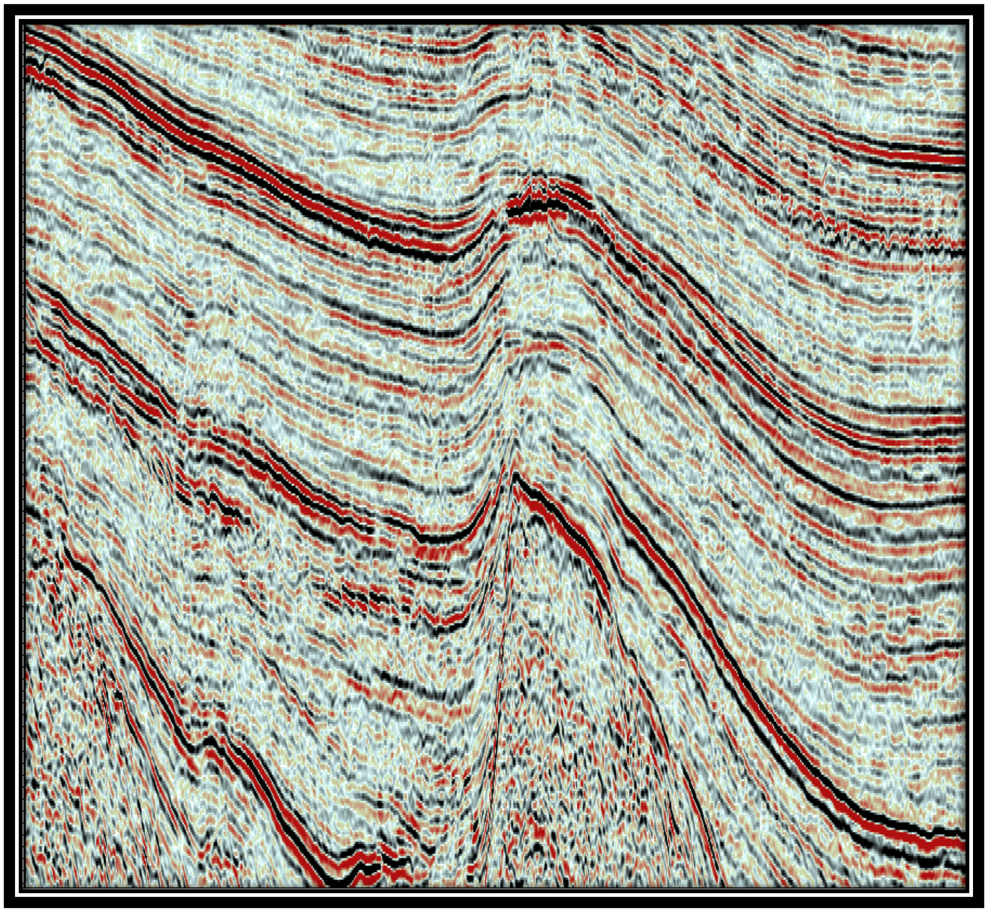
Although the GSC exercised all reasonable oversight in this work, the 2-D LITHOPROBE seismic data reprocessing output is the product of GeoVectra, Ltd. The GSC does not accept liability for any errors, omissions or inaccuracies in GeoVectra's report.



Final map showing the locations of the 2-D LITHOPROBE reprocessed marine seismic lines in Eastern Canada.

2-D Marine Seismic Processing East Coast, Canada

Processing Report



Prepared by GeoVectra

Calgary, Canada | GeoVectra Ltd. | May 24, 2018

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1.0 Overview

The objective of this project was to re-process previously processed data from East Coast Labrador Sea and Gulf of St. Lawrence. The original data were acquired as three different vintages 1986, 1990 and 1992. While the main focus of the project was concentrated around shallow and mid targeted areas, the deeper part of the section was optimized and addressed as much as tight deadlines allowed within the defined project scope.

The navigation was in a mix of survey coordinate systems. Questions were raised with regard to this and it was agreed to process the data using the NAD27 with the Lambert Conformal Conic projection. The 1992 data was already in this format so 1986 and 1990 data were translated into the same format.

The UKOOA files (equivalent to SEGP1 files) for the 1992 data required editing before they could be read by the processing system due to blanks replacing zeroes and occasional misalignment of the columns containing the coordinate information.

As part of the GeoVectra quality control routine, a thorough data integrity cross-check for the received raw data, both seismic and navigation, was performed. Given the number of the lines and different vintages, some data inconsistencies were inevitable. A summary report was issued and communicated to NRCAN at the time, that outlined the results of the data integrity check.

This step involved some extra resources and time but was necessary and vital for the success of future processing work.

It was decided to use crooked line in preference to straight line geometry as the CMP binning for many of the lines, due to the seismic vessel following a meandering course. The crooked line binning enabled a much more data consistent binning result. Only the source positions were known for these data plus notes relating to the nominal offset between the source and the first hydrophone channel, in the absence of any other information it was necessary to assume that the streamer followed straight behind the source and the vessel.

One of the significant efforts on these data was the de-multiple effort. As the multiples are complex and their character and pattern changes from vintage to vintage and from line to line, a multi-staged comprehensive multiple attenuation approach was tested and adopted, this was run in parallel and in conjunction with the velocity work.

Multiple reflection energy was particularly strong in all three vintages, especially in the shallow water and almost every line required a unique approach depending on the results of testing for the effectiveness of specific algorithms and combinations thereof.

The acquisition geometry for all vintages, with off-end shooting and the shot interval twice the receiver interval, results in a sawtooth pattern for the offsets with the shortest offset repeating every four (4) CMPs. This was particularly noticeable on the 1986 vintage lines with these having the shortest source to first hydrophone group offset and also being acquired in very shallow water. An explicit anti-alias filter was tested in an attempt to attenuate this, which it did but it can also have the effect of attenuating diffraction energy needed for an effective migration. What proved to be most effective was a post stack 9 trace mix that was applied twice. This not only attenuated the aliasing effect but also enhanced continuity. A longer trace mix was tested but the double 9 trace mix appeared to be optimal showing enhancement of the reflectors and diffractors and no detrimental effects on the steeply dipping segments of the diffractors. For most of the lines from the other vintages a 5-trace mix proved to be adequate.

Percentage velocity stacks were generated for specific lines to examine the sensitivity to velocity and hone in on optimizing the velocity. Velocities were re-picked after the attenuation of multiples as the primaries became more clearly distinguishable, enabling improvements in the image. Finally, the data were pre-conditioned for post-stack time migration to prevent energy from migrating in from the sides and bottom of the lines.

A very important aspect of preparing data for post-stack time migration was to ensure that diffraction energy from faults and discontinuities in the subsurface was preserved. This later enabled post-stack and particularly pre-stack migration to collapse this diffraction energy into complicated structural elements, faults and other geologic features.

The complexity of these data and its variability as well as various challenges made this work a dynamic and constantly evolving process, while at the same time enabled deep understanding of the data by the processing team and led to a better improved and more robust product.

To honour the reporting format, only selected lines and examples are included in the current report.

2.0 Survey Parameters

Gulf of St. Lawrence, Labrador Sea and Ungava Bay

Acquisition Parameters

Gulf of St. Lawrence (1986):
- BIN SIZE: 12.5 m
- SOURCE: Type: Air Gun
- INSTRUMENT: DFS V
- Source interval: 50 m
- Source Depth/Volume: 12 m +- 1m / 127.48 L
- Length (km): 1171.55
- Group Interval: 25 m
- Streamer Type: Analogue
- Tow Depth: 15m +/- 2m
- Record Length: 18s & 20s
- Sample interval: 4 ms
- LC/HC Filter: 5.3Hz, 18dB/oct | 64Hz, 72 dB/oct
- No. Channels: 120
- Near Offset Distance: 163.5m to 170.5m
- No. Shots: 22431

Labrador Sea (1990):
- BIN SIZE: 12.5 m
- SOURCE: Type: Air Gun
- INSTRUMENT: DFS V
- Source interval: 50 m
- Source Depth/Volume: 12 m +- 1m / 115.62 L
- Length (km): 953.75 km
- Group Interval: 25 m
- Streamer Type: Analogue
- Tow Depth: 12m +/- 2m
- Record Length: 20s
- Sample interval: 4 ms
- LC/HC Filter: 5.3Hz, 18dB/oct | 90Hz, 72 dB/oct
- No. Channels: 120
- Near Offset Distance: 245.75m
- No. Shots: 19075

Ungava Bay (1992):

- BIN SIZE: 12.5 m
- SOURCE: Type: Air Gun
- INSTRUMENT: Titan 1000
- Source interval: 50 m
- Source Depth/Volume: 10m / 191.27 L
- Length(km): 1320.775 km
- Group Interval: 25 m
- Streamer Type: Digital
- Tow Depth: 10m
- Record Length: 20s
- Sample interval: 4 ms
- LC/HC Filter: 8Hz, 18dB/oct | 90Hz, 64 dB/oct
- No. Channels: 180
- Near Offset Distance: 285m
- No. Shots: 19075

3.0 Geometry

For both the 1986 and 1990 vintage data, no shot point numbers or coordinates were included in the data headers. We were provided with a separate list of shot points, and their coordinates in NAD-27. Through examination of the observer's reports, we eliminated the missing shot-points and paired the remainder with their corresponding FFID numbers.

As signified by observers reports, conditions during acquisition were quite challenging and therefore variations in the vessel speed lead to changes in offset and tow depth of the streamers. Obstacles such as icebergs lead to significant deviations in the acquisition path. To accommodate these deviations, crooked line binning was implemented to provide a closer match to the true acquisition path. The fold and offset were then calculated and verified against the fold estimation determined previously using the fold formula.

The QC stage of geometry is essential to saving time and avoiding backtracking later in the process. As an initial step, we checked the first and last shot-points against the acquisition map to ensure they corresponded to each other. We then verified that the near offset distance matched the acquisition details provided by the acquisition and validated the number of bin points per shot interval on the processing map. Finally, we checked the fold map for any extraordinary features.

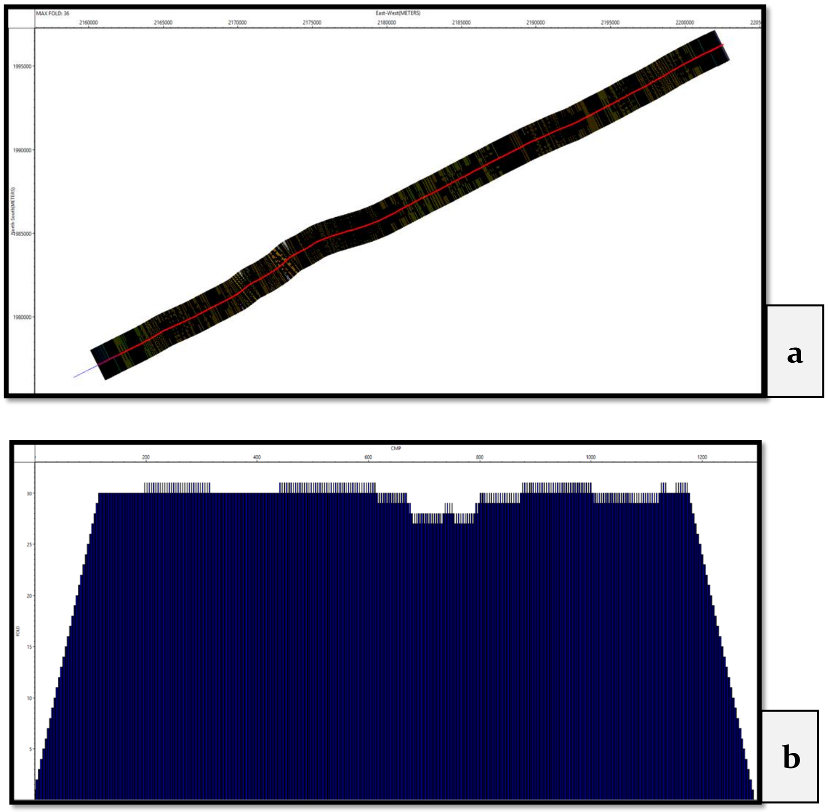

Figure 1: Geometry and Fold Maps

a) **Geometry Map**: crooked-line binning. This method of binning allows for a closer match to the true acquisition path

b) **Fold Map** shows the number of traces present in each CMP. The higher the fold, the higher the attenuation of random noise during stacking.

4.0 Noise Attenuation

Algorithms and Techniques

GeoVectra Ltd. uses the VISTA seismic processing software from Schlumberger.

To start, we approached the process of attenuating random noise on the gathers from several different directions. The challenge was to attenuate the random noise whilst preserving the energy of the diffractions to facilitate successful migration. Through the testing of several processes such as Principle Component Analysis (4DDEC), rank reduction filtering (Cadzow) and FK filtering, we decided that random noise attenuation would best be left to post stack processing. These processes had a tendency to damage diffraction energy, which would in turn produce an unsatisfactory migration result, this proved to be the case whether these processes were applied in the shot domain or the common channel (offset) domain. By leaving said noise attenuation to post stack and post migration processing, we were able to utilize the powerful random noise suppression properties of stacking and migration, while at the same time minimize the need for potentially harmful noise suppression tools. Through this sequence, we were able to preserve the integrity of the original signal.

Coherent noise attenuation in marine seismic is often primarily focused on multiple attenuation. Due to the fact that multiples don't suffer the same frequency dependent attenuation that primaries do as a result of absorption, multiples often present themselves as the strongest and highest frequency energy in the section. As many different forms of multiple energy exist, a variety of different tools must be implemented to address them. Therefore, the process of multiple attenuation is commonly iterative. As a first pass in our de-multiple sequence, we employed Surface Related Multiple Attenuation (SRME) in moderate to deep water settings to attenuate events generated by at least one reflection off the sea surface. In shallower settings, we used Model-Based Water-Layer Demultiple (MWD) instead of SRME to target multiples with at least one up-going reflection off the sea floor and one down-going reflection off the sea surface. In some cases, due to variability in the true offset, some residual multiple energy remained after SRME or MWD and was successfully attenuated using radon transform.

Due to the acquisition geometry, off-end with 50m source intervals and 25m hydrophone group intervals, strong aliasing was very prevalent in the stack, presenting as a pattern that repeated every four traces due to the way in which the near trace offset varied. Using either a 5-trace mix (1-4-6-4-1) or a 9 Trace Mix (1-8-28-56-70-56-28-8-1), we attenuated the aliased energy post stack while preserving the horizontal resolution. The trace mix operates in the wavenumber domain and therefore does not band-limit the frequency range of the data. We also used a gentle FK filter post stack to attenuate the lower frequency aliased energy allowing us to further increase the S/N ratio.

The techniques that were tested and ***applied in production processing*** for the various vintages are itemized below:

De-Signature

In marine seismic data, ghost events are generated by the down-going reflection from the surface of the water. In the ideal case, the reflection coefficient of the air/water boundary is very close to -1 (minus one) which would in theory cause massive destructive interference in the signal making the notches entirely un-recoverable. In practice however, due to the roughness of the sea surface, notches in the frequency spectrum may be recovered through deconvolution. The challenges faced in performing effective de-ghosting are due to unknown variations in streamer depth, wave height and reflectivity of the air/water boundary.

From thorough examination of the observers reports, it became clear that the acquisition conditions were very harsh:

“Heavy currents, strong tides and icebergs in the area made it very difficult to record Line 6 (1992 acquisition report)”

“The actual offset varies from time to time due to sea conditions and vessel speed. Ship speed at time of offset shots was 4.5 knots. Actual shooting speed while online was between 3.6 and 4.0 knots” (Q.C. Report line for AGC90-003F)

The consequences of these acquisition challenges cascade through the processing sequence yielding variability in the results and compromise the effectiveness of some processes. De-signature or de-ghosting was one of such processes to be affected by variable and unknown streamer depth as the time delay for the down going reflection off the surface of the water would change. This resulted in the variable success of the process and contributed to the exclusion of it altogether on the 1992 vintage data. Overall however, the process of de-signature did in fact increase the resolution of the data and resolved reflectors mired in low frequency information.

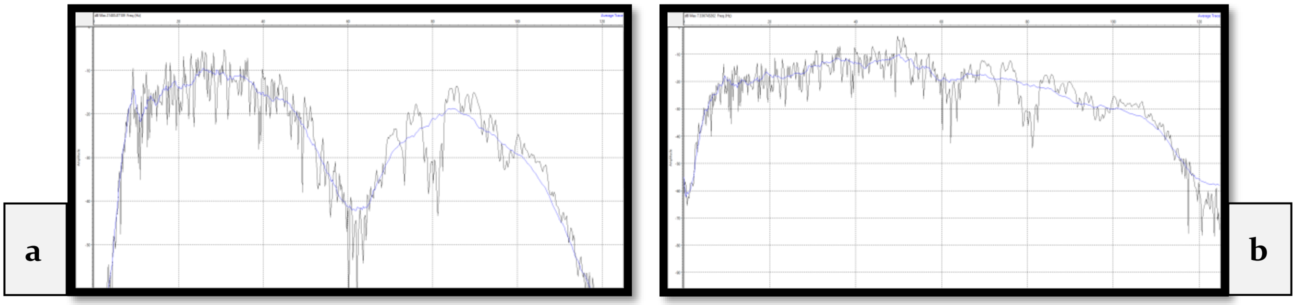

Figure 2: Spectral representation of the de-signature process

a) Initial amplitude spectrum of near offset traces
b) Amplitude spectrum of near offset traces after de-signature

Surface Related Multiple Attenuation (SRME)

In SRME, the surface related multiples are estimated by convolving the common shot gather with the common receiver gather and stacking in the common receiver domain. This yields a model of the multiple energy contribution to the section and can therefore be used in conjunction with adaptive subtraction to attenuate the multiple energy.

Model Based Water-Layer Demultiple (MWD)

MWD shares many similarities with SRME. However, while SRME is very effective in moderate to deep water, it can fail when dealing with shallow water multiples. MWD is designed to effectively attenuate multiples in shallow water. The water layer multiples are predicted by computing the cross-convolution of the water bottom Green’s function with the data. Like SRME, the model can then be subtracted from the input data using adaptive subtraction.

Radon Transform

The radon transform traditionally, is particularly successful when targeting events with large moveout differences resulting in effective separation of events in the τ-p domain. However, the software used during this project excelled in dealing with events possessing small moveout differences as the algorithm significantly reduces crosstalk for both L1 and L2 normalizations.

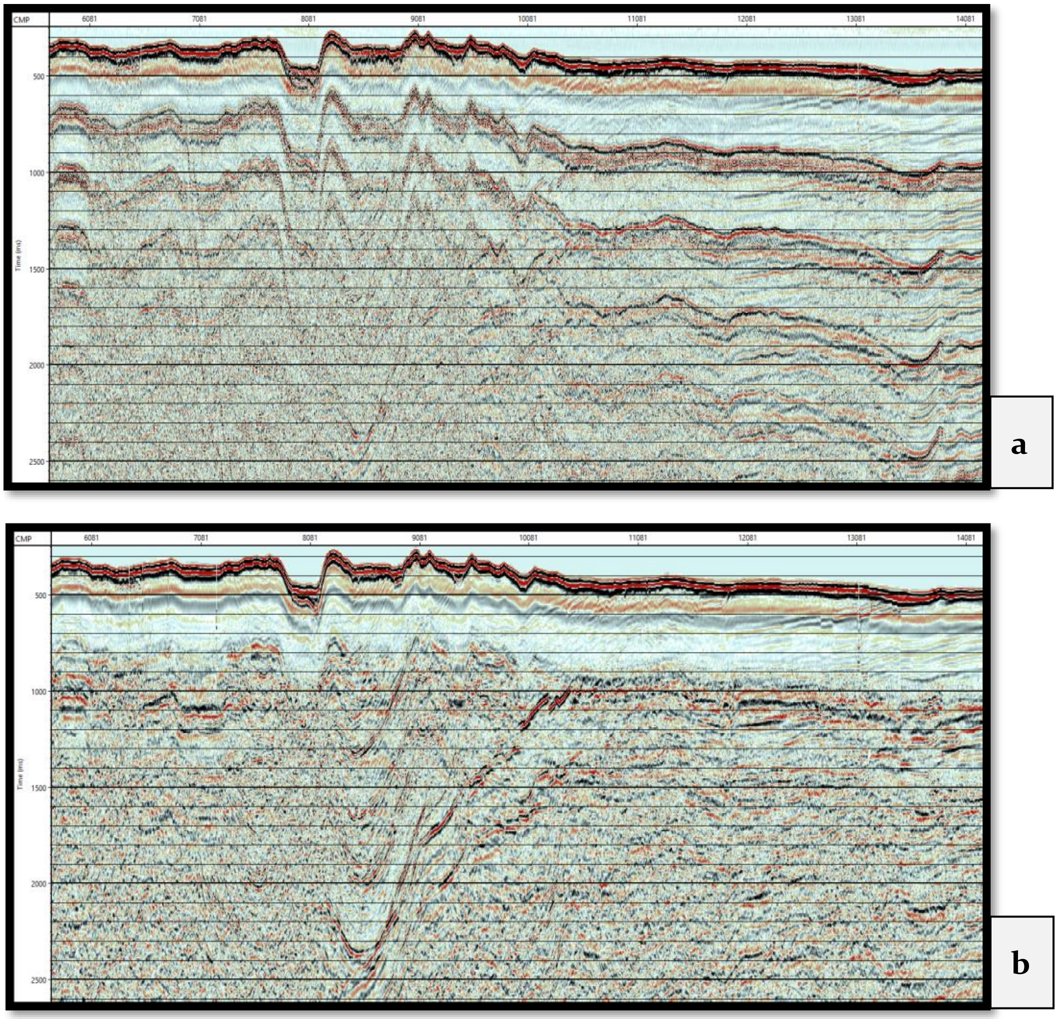

Figure 3: De-multiple results

a) Stack before de-multiple featuring stubborn reverberations. Primary reflections are almost entirely obscured

b) Stack after de-multiple and migration, revealing primary reflectors

Trace Mix

Trace mixing works by computing a weighted average of adjacent traces to attenuate aliased noise. It has the effect of drawing energy into the low-wavenumbers and attenuating at higher wavenumbers towards Nyquist.

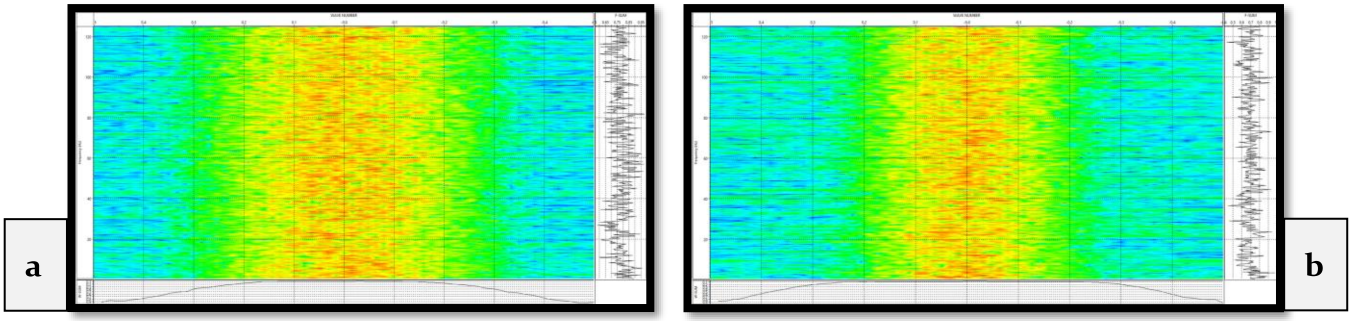

Figure 4: Representation of the effect of trace-mixing in the F-K domain

a) The F-K spectrum of a 5-trace mix applied to a white spectrum. Energy is enhanced at smaller wavenumbers and attenuated at higher wavenumbers.

b) The F-K spectrum of a 9-trace mix. Much like the 5-trace mix, however, the effect is amplified.

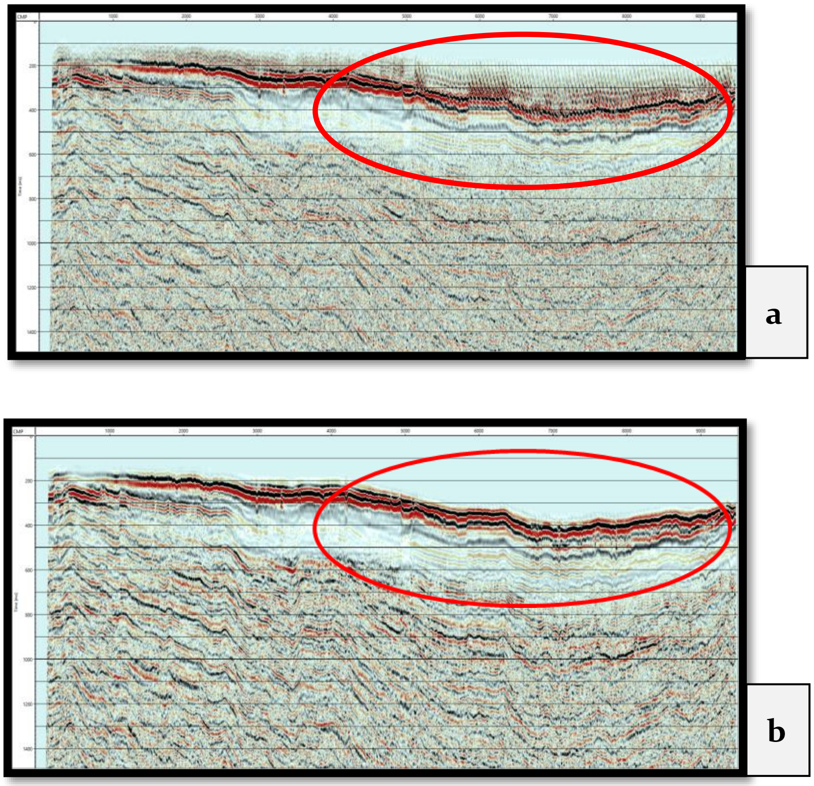

Figure 5: Trace mixing effect on horizon continuity

a) The water bottom circled in this section demonstrates strong spatial aliasing. A sawtooth pattern is characteristic of the off-end acquisition with the shot-interval being twice the receiver-interval.

b) The water bottom circled in this section shows a significant improvement in the continuity of the reflectors after trace mixing.

5.0 Velocity Work

Throughout the sequence, the velocity for each vintage was updated multiple times to resolve the structure present in the data. The first order surface multiple appears at double the time interval to the water bottom, therefore, the deeper the section, the more structure can be recorded without being masked in multiple energy. The presence of strong coherent noise provided a significant challenge to picking initial velocities in shallower sections.

Vintages 1986 and 1992 were primarily composed of shallow lines, whereas the 1990 vintage data consisted of mainly deep sections. Therefore, the 1990 data provided a lesser challenge in picking an initial velocity trend. For the shallow sections, an iterative process of velocity revision worked in conjunction with the process of multiple attenuation.

Initially a gentle trend was picked, actively avoiding the multiple energy using a series of constant velocity stacks as a guide:

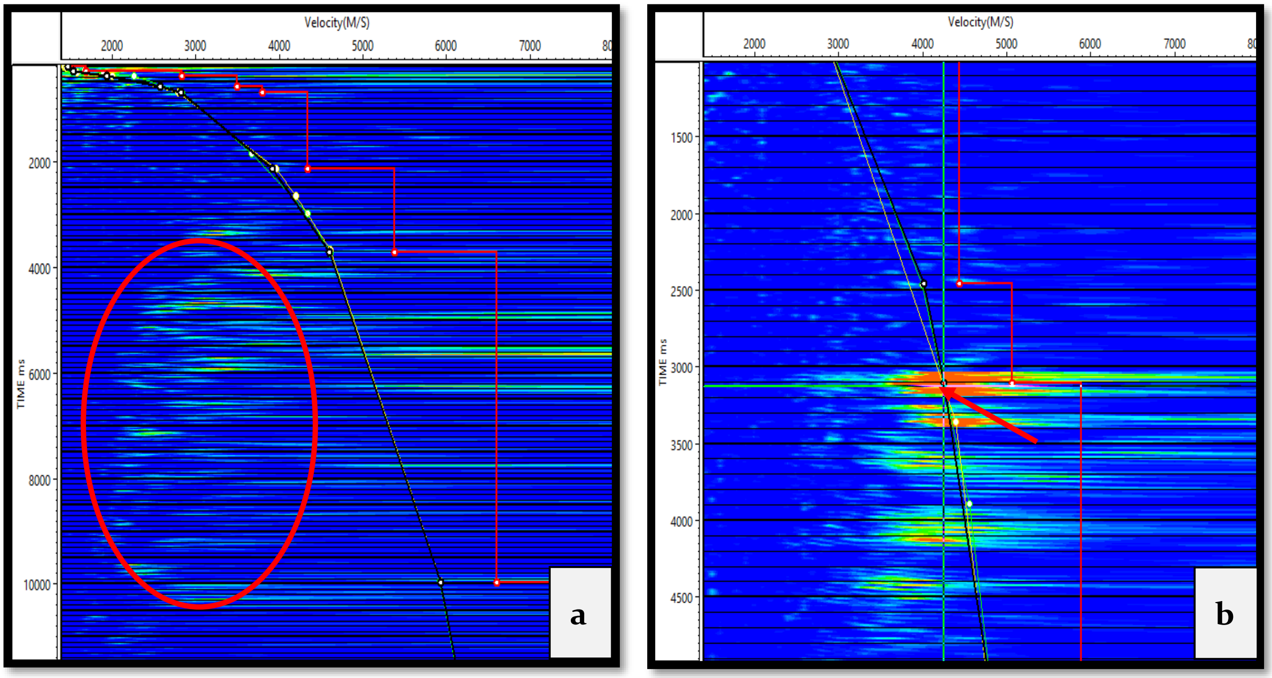

Figure 6: Semblance Plot used during velocity analysis

a) The bright-spots circled represent strong multiple energy. In picking all velocity functions, we avoided this energy and picked a general trend away from them. To the right of the RMS velocity function shown in black, we can see energy that was acquired past the reflectors critical angle. It is important to avoid this energy too.

b) This semblance cloud shows very strong primary energy that is revealed after multiple attenuation. This clearly demonstrates the necessity to run velocity analysis alongside de-multiple as an iterative process as such events were not present in the initial semblance cloud.

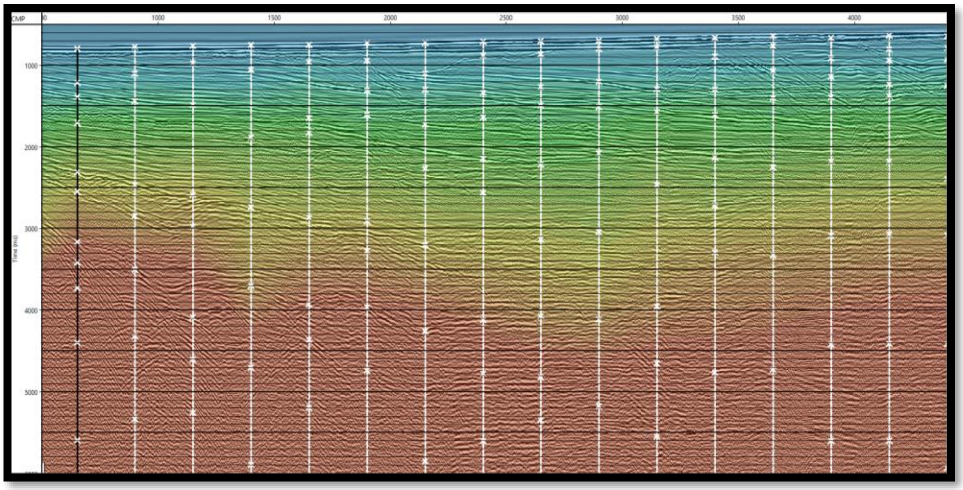

Figure 7: Velocity Field overlaid on the stack

The velocity profile overlaid on the stack. As shown velocities were picked on structural features and a smooth velocity profile was maintained to facilitate successful migration.

After SRME, the velocity was revised. Events that were once obscured were now able to be accurately picked. In some instances, performing a radon transform further revealed primary events. In such cases, the velocity was refined once again to include and improve this new information. On select lines, before post stack migration, we used residual moveout (RMO) to enhance the accuracy of our velocity functions. In some instances, RMO had the tendency to enhance the previously attenuated multiple energy and therefore, was not always included in our processing flow. RMO also tends to introduce lateral variations in the velocity function which can adversely affect migration.

In the final velocity update, we used the results of the post-stack migrated data as a velocity Q.C. The imaging velocity update was done on select lines that displayed signs of velocity inaccuracies.

To examine the accuracy of the velocity field, we ran a series of detailed velocity scans for lines in all three vintages. The complete scans were run and analyzed with a +/- 20% velocity raster and an increment of 2%. The scans were examined in conjunction with partial velocity stacks using existing velocity fields. As a result of this analysis, any velocity updates deemed necessary were performed.

In some cases, a complex and highly variable rugose water bottom leads to inconsistencies in standard velocity analysis requiring particular attention. These lines underwent several velocity updates throughout the processing sequence.

Overall, the velocity analysis on all three vintages not only significantly reduced the instances of multiple energy, but also brought out interesting, complex structures and geological features in the data.

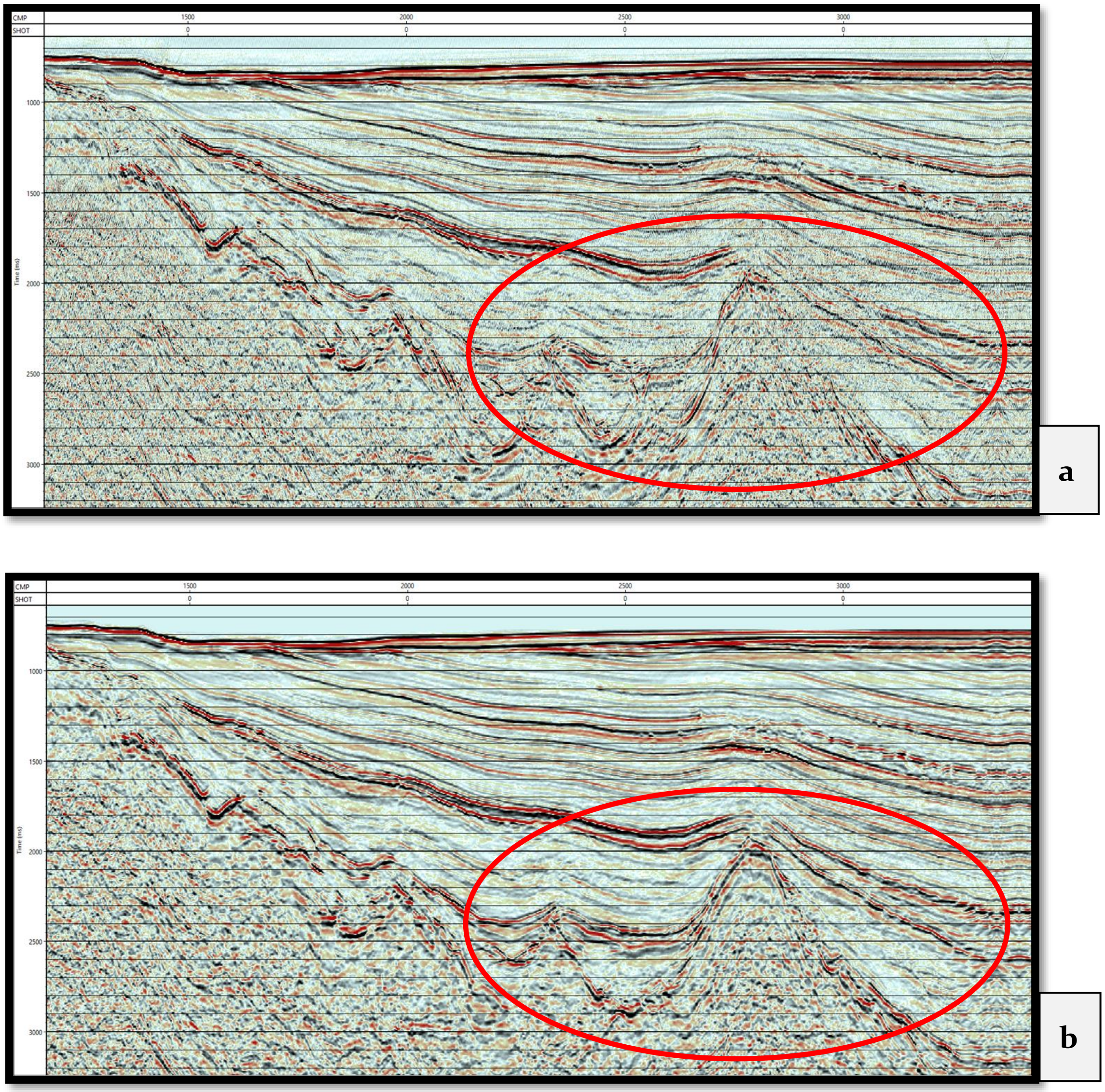

Figure 8: Effect of velocity update on pre-stack migrated data

a) The result of pre-stack time migration using the initial velocity function
b) The result of pre-stack time migration using the updated velocity function. The circled structure is much better resolved as the diffractions collapsed nicely into defined reflectors.

6.0 Post-Stack Time Migration

The post-stack migrated sections were one of the first deliverables for these data. Often nowadays, post-stack migration is omitted due to the existence of pre-stack migration. For these data set however, post-stack migration was very useful as it allowed us to observe the effect of migration and imaging on the structure, as well as better prepare for conducting pre-stack time migration.

We tested several post-stack migration algorithms on select pilot lines to optimize the production path going forward. As the data quality varies from vintage to vintage, it was important to see the response to migration before embarking on elaborate and time-consuming pre-stack time migration work.

A critical aspect to be cognisant of is the record length. As these data set had a very long record length, it was crucial to examine both shallow and deep parts of the section to locate potential migration related issues.

The importance of velocity work for any migration cannot be underestimated. As the presence of multiple energy was very strong, it was essential to ensure that no velocity update emphasised multiple energy and yet, maintained the correct trend for the main reflectors to obtain an optimal imaging result.

Running the post-stack migration earlier in the process allowed us to start testing the post-migration processing sequence that was critically important in conditioning the final migration sections.

Due to the manner in which these data was acquired, the seismic section intersected structures at various angles. The distance covered by each line varied dramatically from line to line. This resulted in some lines containing complex and interesting structure vs. some lines which contained little to no structure at all.

An important aspect of these data is the presence of well defined diffraction energy. From very early in the process, we identified numerous textbook examples of diffraction energy and therefore were very careful to preserve them to facilitate successful migration. Due to our careful preservation of diffraction energy, we were very pleased to observe the successful collapsing of the diffractions to continuous and well defined structural features as a result of migration.

The images included with this chapter are an illustration of that.

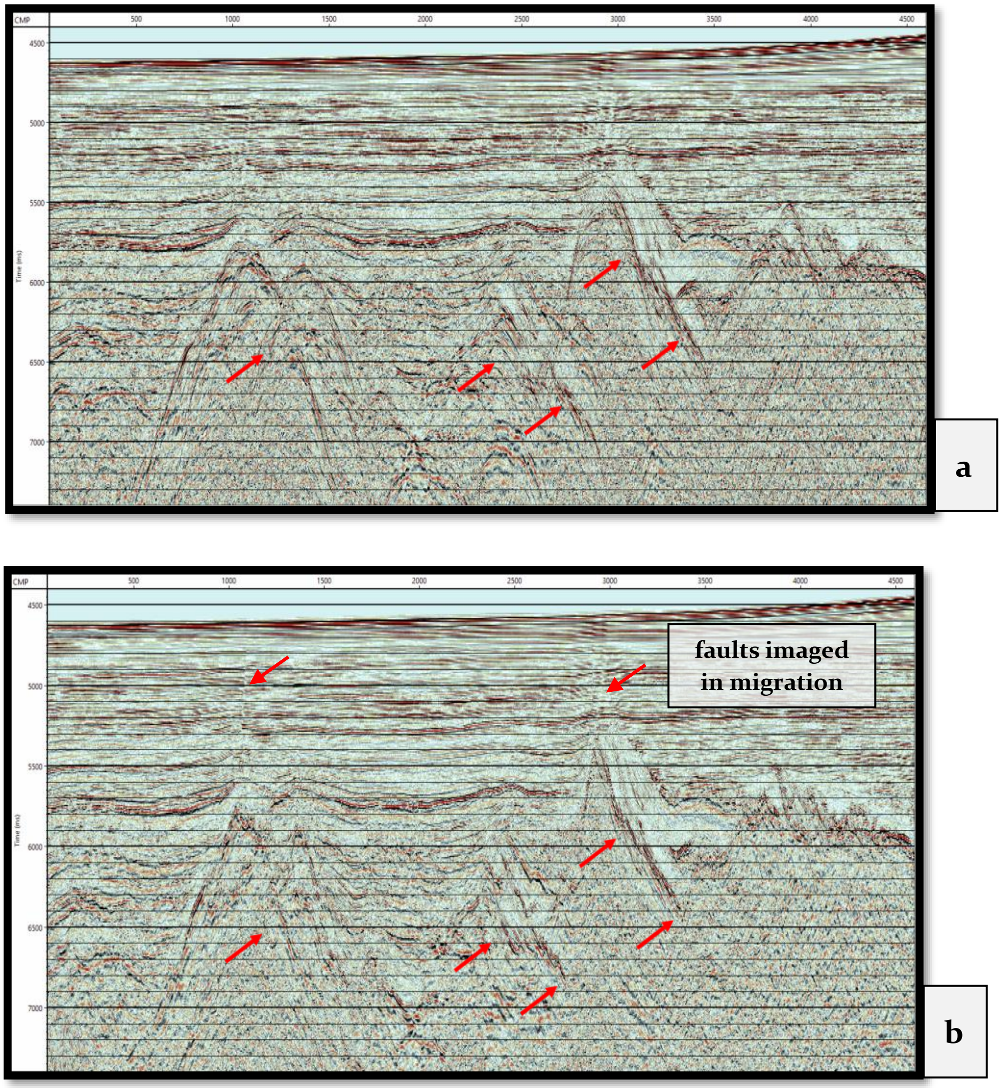

Figure 9: The collapse of diffractions into well-defined structure

a) The final structural stack which served as the input to post-stack time migration. The diffractions are clearly shown

b) The output of post-stack time migration. The diffractions collapsed nicely, and the reflectors became well defined

7.0 Pre-Stack Time Migration

2D data of this type can either greatly benefit or fall apart as a result of pre-stack migration. We were pleased to see that during preliminary testing, the data responded well to pre-stack time migration. We believe the preliminary pre-processing that was carefully preserving imaging-precious diffraction energy played a significant role in the overall success of the pre-stack imaging work.

In preparation for pre-stack time migration, we resampled the data to 6ms, which helped to increase the S/N ratio and significantly reduce run-times. As the data have a LC and HC filter applied in acquisition, little to no signal was present above 83 Hz in any vintage.

In testing various aperture angles, we chose the maximum aperture angle. Due to the long record length, a very wide migration aperture limit was tested and applied as to not affect any structure present in the data. This increased the S/N ratio in the deep portion of the section and significantly reduced the runtime, relative to having no migration aperture limit.

The application of well picked mutes had a tremendous impact on the result. Through testing, we noticed that the absence of a mute introduced strong low frequency interference into the migration, obscuring the shallow reflectors. A stretch mute was used during velocity analysis, but this proved to be inadequate for accurate imaging and mutes required to be hand-picked and spatially variable for some lines, especially those with varying water bottom depths.

Migration significantly attenuated residual noise and emphasized the reflection energy of the entire section. A series of faults were imaged throughout as well as interesting structural features in both the shallow and deep portions of the section. Even after running initial migration tests, we can observe that pre-stack time migration is very beneficial for this type of data. It focused dispersed reflection energy effectively and enhanced the coherency of the reflectors.

The velocity work that took place in parallel with migration parameter testing contributed significantly to further focusing of the migrated image.

The final migrated sections were taken through the post-processing sequence that followed the raw pre-stack time migration to further enhance the continuity of the reflections and boost post-migration S/N ratio.

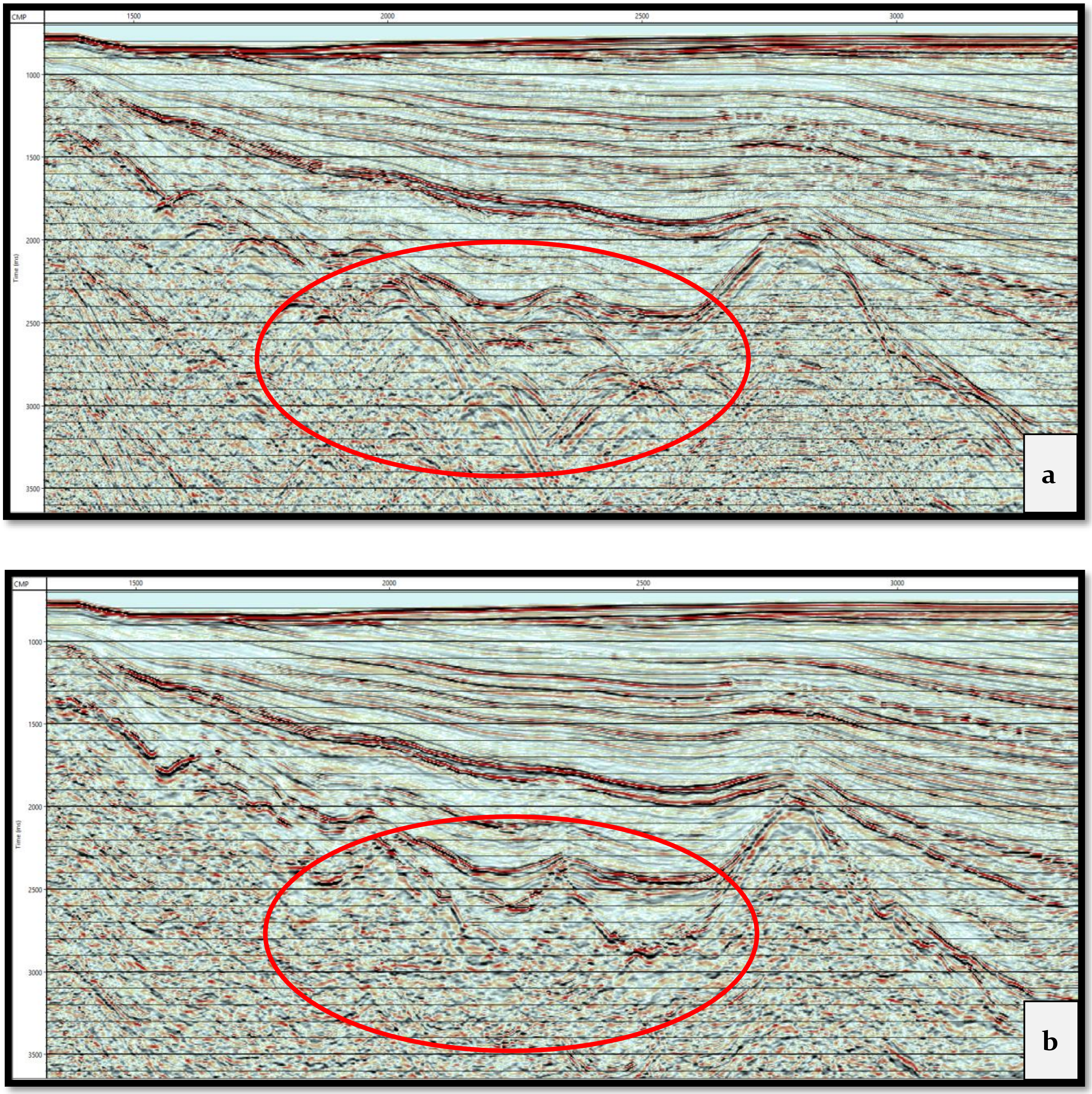

Figure 10: Collapsing diffractions during pre-stack migration

a) The un-migrated stack displaying numerous and well-defined diffractions.

b) The output of pre-stack time migration showing the collapse of the diffractions into defined structure.

8.0 Post-Processing

Post-migration processing proved very effective on these data. The process changed slightly from post-stack to pre-stack migration post-processing as the addition of a trace mix was included after pre-stack migration since no anti-aliasing was applied to the gathers. Besides trace mix, three procedures were performed on both pre-stack and post-stack migration that together significantly improved the interpretability of the seismic data image. Both migration and stacking processes improved the signal to noise ratio enabling these algorithms to work effectively with readily visible impacts on the image. As mentioned earlier, noise attenuation pre-stack was very harmful to diffraction energy and therefore, post-stack improvement of the migrated image was very important, especially in such a complex geological setting.

While working on a few select pilot lines, we tested several post-migration noise attenuation techniques and were dissatisfied with the results of many of them. The aim was to optimally preserve all structural elements and geological features brought out during the imaging process, while improving both continuity and consistency of the reflectors. Through rigorous testing, often tailored to a particular vintage or series of lines, we found the optimal post-processing sequence for this type of data.

The following steps worked well for both post-stack time migration and pre-stack time migration post-processing:

4D-DEC - This is a four-component time domain Principal Component Analysis (PCA) technique, largely utilized for addressing the issues of incoherent noise and known for good signal preservation even in the presence of highly dipping reflectors. We selected the final parameters for the production run based on the best continuity and dip enhancement and preservation criterion.

Post-stack FX – This is a signal enhancement tool designed to recover weak signal. We obtained a very satisfactory result that improved lateral resolution in the sections and continuity while attenuating residual post-migration noise.

TVF - Time Variant Filter – the TVF applied in post-processing helps to bring more definition to the seismic section. The deeper part of the section comes through well with slightly lower bands while shallow part of the section needs to keep a relatively open spectrum to preserve the fine details and steep dips. Well-designed time variant filtering helps to bring the section out as a whole throughout the entire depth of the survey

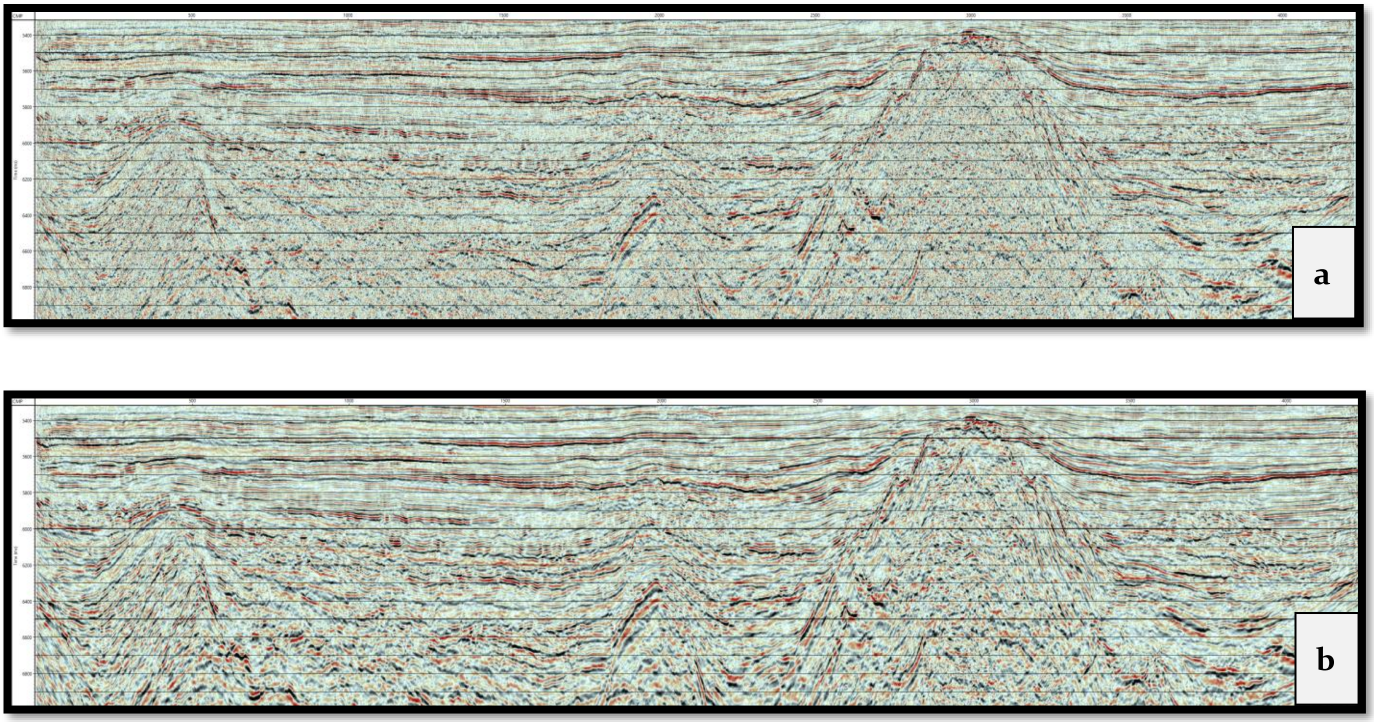

Figure 11: Effect of post-processing on pre-stack migrated result

a) The raw output from pre-stack time migration.
b) The output of pre-stack time migration with post-processing applied. The reflectors are far better resolved and much more interpretable.

9.0 Deliverables Q.C.

Both post-stack and pre-stack migrated data were included in the final deliverables. While pre-stack migration is considered to yield a superior product due to its increased resolution, we see value in both methods, particularly in 2D settings.

The final sections were output and delivered in two versions – filtered and unfiltered. The filtered version had a very open filter applied mainly to address some high frequency residual noise in the deeper part of the section.

To verify the quality and accuracy of the post processed data, we diligently reviewed all generated .segy files. A general comparison between post-stack migration and pre-stack migration was made to ensure that the presence and character of all geologic features remained, and that the resolution improved following pre-stack migration.

The final step of the QC procedure was to ensure that the seismic data was successfully exported to .segy. We output each data set to a .segy file, and then proceeded to import that file back into the program for read-write qc.

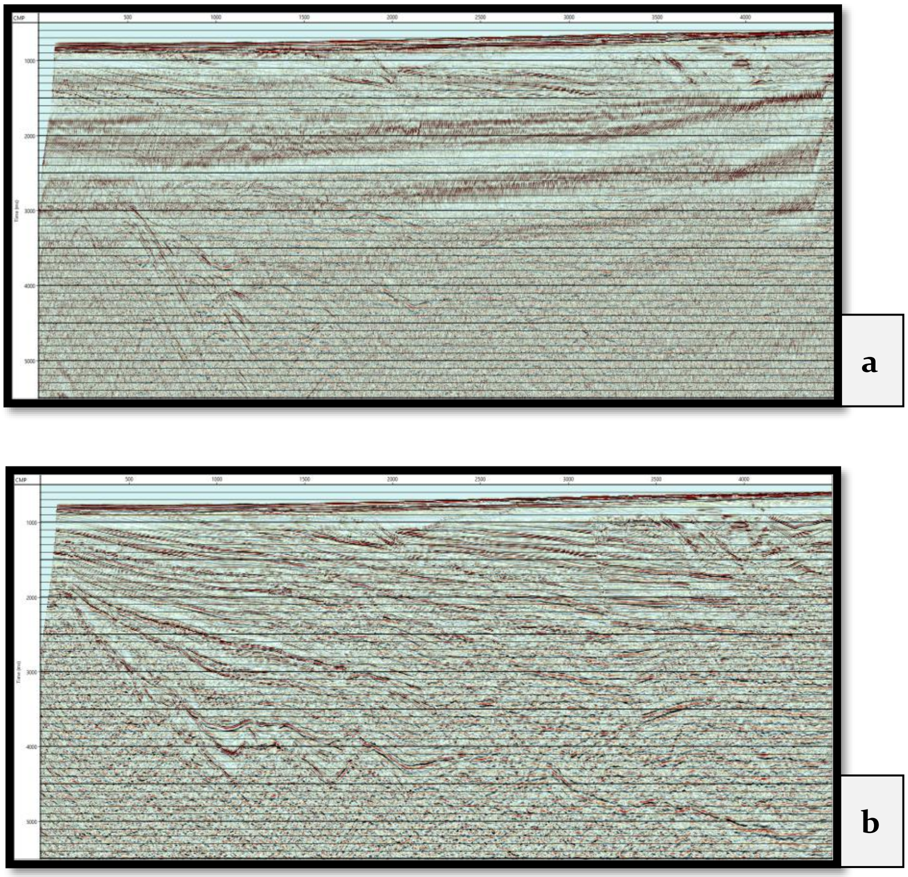

Figure 12: Raw Stack vs. Final Migrated Stack: Vintage 1990

a) **Raw Stack** - the structure in the raw stack is entirely obscured by multiples, aliasing and random noise.

b) **Final Migrated Section** - well defined structural features and fine details revealed through processing and imaging.

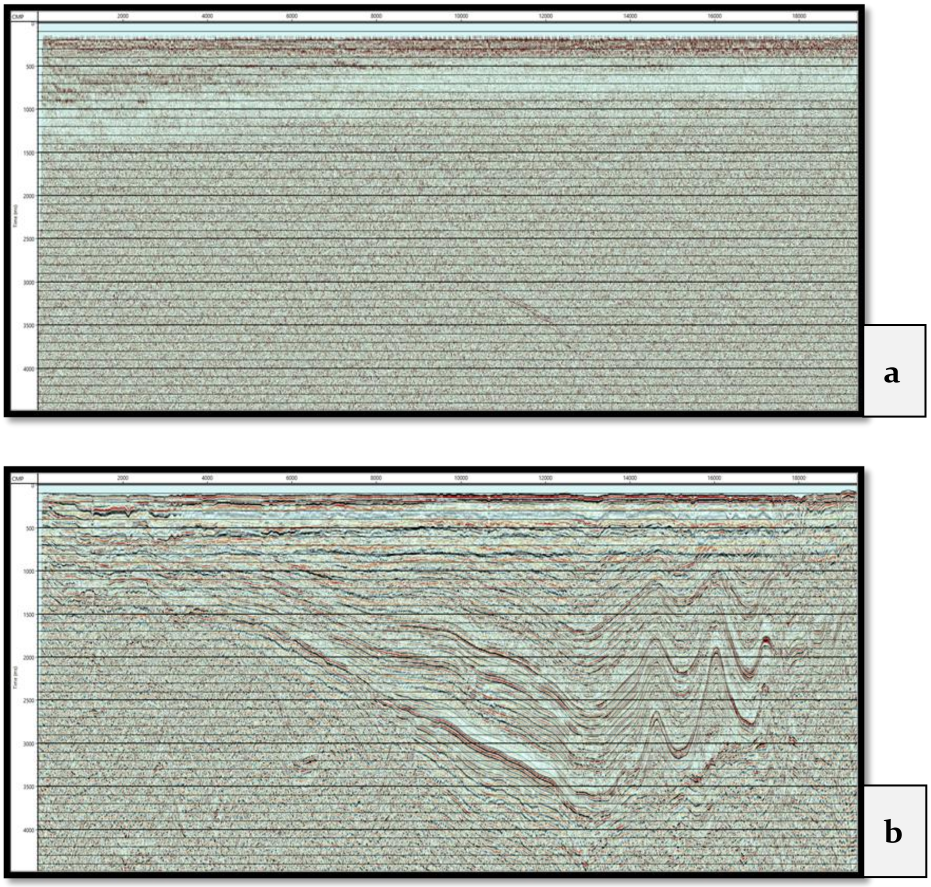

Figure 13: Raw Stack vs. Final Migrated Stack: Vintage 1986

a) **Raw Stack** - the structure in the raw stack is entirely obscured by multiples, aliasing and random noise.

b) **Final Migrated Section** - well defined structural features and fine details revealed through processing and imaging.

10.0 Special Chapter on Variability Between Vintages

In processing these three separate vintages of lines – 1986, 1990 and 1992, we recognized many differences between lines in shallower water settings versus deeper water settings. The most notable difference is when the first order surface multiple arrives. As predicted, shallower water lines often have structure masked by strong water bottom multiples whereas deeper lines often escape masking of the main structural elements, as the first order surface multiple has a longer time delay. Due to this fact, it was far more challenging to pick an initial velocity trend and produce an initial stack for shallower lines. Primary events undergo frequency dependent attenuation as they travel through the sub-surface, which manifests itself as a loss of high frequency information with increasing time. Multiples however, do not undergo this same frequency dependent attenuation and therefore maintain their high frequency information at longer time intervals. The consequence of this property is the resurgence of previously attenuated multiple energy with the application of spectral whitening processes, such as spectral balancing or predictive deconvolution utilizing shorter lag times. While both deep and shallow lines were affected by this property, structure in the shallow water lines were at a greater risk of being obscured or distorted by the recovery of multiple energy.

Different processes were necessary in attenuating multiples in deep and shallow water. While SRME was successful in deeper settings, it was not always quite as effective in shallow settings. For the SRME process to work accurately it is required for some parameters to be known very precisely. For this particular dataset the offset from the source to the first hydrophone group is not known precisely, nor is the water depth. Often the water depth is measured by sonar, or some similar apparatus, and recorded with either the navigation or seismic data. Compounding these uncertainties in time and distance is the spatial aliasing due to with data from the nearest offset only being present in every fourth CDP. This spatial aliasing is caused by the off-end acquisition with the shot interval being twice the receiver interval. In turn this makes it difficult to obtain a very precise time or velocity for the water bottom arrival when the water bottom is very shallow. These same uncertainties are identical when the water bottom is deeper but their impact is relatively very much less when the water layer is deeper and the water bottom arrival time considerably longer.

To address this challenge, we applied MWD in shallow settings. While MWD shares many similarities with SRME, the dependency on the near offset data is removed through replacement with the modelled Green's function of the water bottom. This in turn provides a more accurate prediction of the water-layer multiples.

Another way the variability between vintages played a role was the presence of stronger aliasing in lines from the 1986 vintage. This resulted in an initial stack displaying extremely poor S/N ratio and visible inconsistencies in the appearance of reflectors. The initial velocity analysis was greatly compromised by the inability to see consistent and coherent reflection energy behind this heavy aliasing. We ran numerous tests, employing different methods to address this problem. Applying a nine-trace mix post-stack provided an optimal solution, as it proved to be the most effective and safest way to address this particular challenge.

It is important to note that the seismic quality was highly dependent on the area of acquisition and orientation of the lines.

While the variability in data between vintages presented an additional challenge, it was often necessary to optimize the processing sequence on a line by line basis. While this approach is more time-consuming, it enabled us to conduct more tests and preserve the uniqueness of each line, resulting in a better tailored and more robust product.

11.0 Conclusions

In processing each of the three vintages, from East Coast Labrador Sea to the Gulf of St. Lawrence, we carefully tailored each step of the sequence to provide an optimal outcome. From the initial investigative data integrity checks, elaborate multiple attenuation, careful velocity work to the final migration, aimed to not only enhance the continuity and consistency in the data, but also to identify and eliminate processes which proved to be detrimental to the structural integrity of the data.

The combination of short deadlines with the sheer volume of unique and complex data was an exercise in balancing intellectual effort against time, however this enabled a strongly focused and more robust solution with a successful outcome in the end.

The application of a multi-staged multiple attenuation sequence brought a step-change in the execution of the entire project. The recognition and careful maintenance of the diffraction energy at the onset of the project paid off in migration.

Post-stack migration provided a chance to find solutions to unique challenges that arise during migration. In working through this step before embarking on pre-stack migration, we were able to progress much more efficiently, providing a better final result in a shorter period of time.

Each step in the processing sequence was affected in some manner by the challenges provided by the survey geometry and variability in the data. Through careful assessment and fruitful collaboration as a team, we found robust and elegant solutions to effectively address these challenges.

The data went through a dramatic transformation from the initial raw stack which presented little to no distinguishable signal to a migrated section with a lot of character, complexity and detail. Here at GeoVectra, we were very happy to be a part of this evolution.

We are grateful to NRCAN for the opportunity to work on these data and to our NRCAN colleagues for their guidance and vital input.

We truly enjoyed the experience we all gained while working on this unique data and our very productive interactions with NRCAN team. We felt great support from the NRCAN team while working on this project and it’s always truly appreciated by the processing team and everybody here at GeoVectra.

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