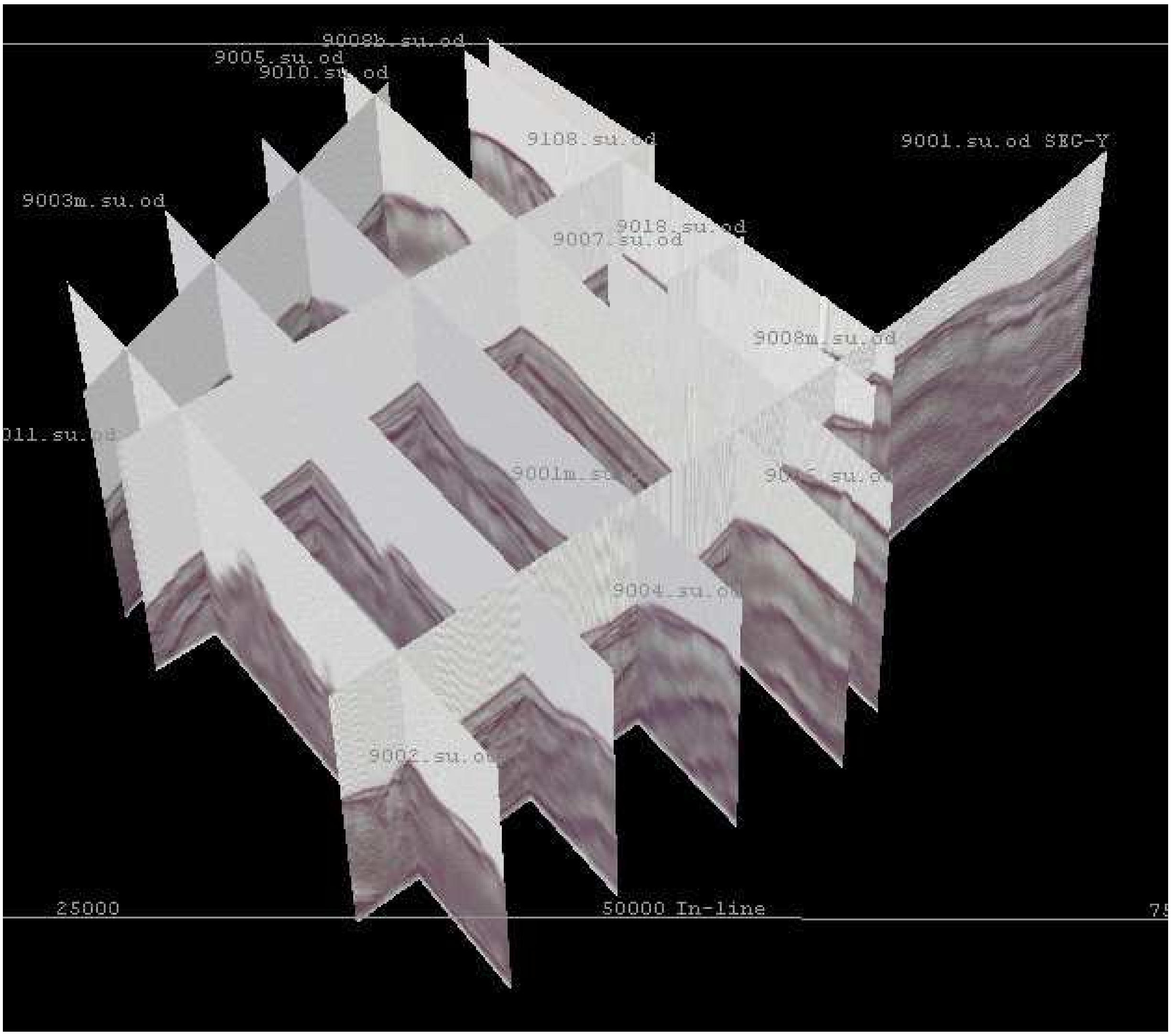
Report on Seismic Data Processing of a Reflection Seismic Survey from the Hatton Margin, West of Ireland



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Area: Hatton Basin and Rockall Plateau, West of Ireland

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Section 1: Introduction

The Hatton Continental Margin is located at the furthest Western frontier of the continental shelf, approximately 450 km off the Irish coast in both British and Irish waters. To date most of the exploration of the Hatton Continental Margin has taken place in the British sector using potential field data, a 20km grid of single channel seismic data and shallow boreholes. Seismic data has discovered "windows in the basalt" which reveal sediments of unknown age. Exploration of the Hatton Continental Margin and the Hatton Basin in the Irish sector has been carried out using wide-angle data such as the Rockall and Porcupine Irish Deep Seismic Project (RAPIDS). Less than five industry multi-channel profiles cross an area in excess of 10000km^2 and most of these are over 20 years old. The Deep Sea Drilling Programme drilled two shallow boreholes on the margin of the Hatton Basin revealing the presence of Quaternary to Tertiary sediments (Naylor & Shannon, 1982). These studies, however only reveal small amounts of information about the overall structure and stratigraphy of the area.

In 2004, a 2-D high resolution multi-channel seismic survey of the Hatton Continental Margin and the Hatton Basin in the Irish sector was undertaken by the Geological Survey of Ireland, the Rockall Consortium, and the Irish Shelf Petroleum Studies Group (ISPSG). The processing work was funded by the Petroleum Infrastructure Project (ISPSG Group). The aim of the survey was to provide a greater understanding of the structural and stratigraphical configuration of the Hatton Basin and its adjacent margins and to detect windows within basalt cover as had been revealed to the North. The survey covered the Rockall High, the Hatton Basin, and the Hatton Continental Margin in the Irish sector. The area contains sedimentary basins, such as the Hatton Basin, that are separated by basement ridges and show a NE-SW trend. This trend is believed to due to the reactivation of Caledonian faults during the development of the sedimentary basins in the Mesozoic. The sequence is comprised of lower pre-Eocene synrift sediments unconformably overlain by Eocene-Recent post-rift sediments. The basalt sills in the area are associated with the early Tertiary volcanism that occurred due to the Icelandic hotspot. From gravity data and wide-angle seismic velocities, it is believed that there is magmatic underplating under the crust of the Hatton Continental Margin (Vogt et al., 1998).

The survey comprised of approximately 3,750 line kilometres with a four second record. The data was processed onboard to brute stacks with a 4ms sampling interval. By acquiring multi-channel data seismic velocities could be used to determine the velocity, thickness and depth of any sedimentary section. Velocities, in addition to the presence of strong diffractions on stack sections, can also be used to differentiate interlayed basalt layers from sediments.

In this report we have reprocessed the seismic data and present the results from this processing. Interpretation is ongoing and will be presented elsewhere at a later date. Velocity analysis of the data will reveal information about the lithologies seen on the seismic sections and that the new knowledge of crustal structure will provide evidence of the tectonic history of this area.

Section 2: Objectives

Several difficulties were encountered processing the data onboard (see onboard processing report and cruise summary). Testing performed at Trinity College in 2005 showed that onboard data processing could be substantially improved. A new processing sequence was derived and applied to line 9002. The objectives of this study were to test and then apply this processing route (or similar) to the entire dataset. The results of this processing will be used for initial interpretation of the area as originally intended for the onboard processing. It is anticipated that smaller subsets of the data will be selected for re-processing such as depth imaging.

The HA04 survey crosses a variety of geological terrains which have different processing objectives and demand different approaches. Figure 1 displays a map showing the line numbers as acquired. The basement highs have a hard seabed (either volcanic or thin sedimentary cover) and may be as shallow as 500ms two-way-traveltime (TWT). Strong multiples are experienced in these areas, although there is little obvious deeper structure (either through lack of penetration or lack of genuine geological signal). In the Hatton Basin the water depths reach nearly 2000ms TWT and there is a thick sedimentary section, sometimes almost to the base of the section (4000ms TWT). The multiples in this area sometimes cross the principal horizons but they are readily recognisable and easy to interpret around. Volcanic features are observed throughout the dataset.

Section 3: Pre-stack Processing and Testing

Review of Acquisition and Onboard Quality Control

The data acquisition was discussed in the cruise report and onboard processing reports. While these reports have been useful, they are not sufficiently comprehensive to help resolve some of the issues which have arisen during the data processing. The observer's logs are handwritten and patchy and there is no report on onboard navigation processing or even provision of an adequate map. While we have striven to utilize all the information provided, the general poor quality and order means that some key pieces of the acquisition setup have had to be "reverse engineered". The processing has taken longer than expected because of these issues.

Data history and test line selection

Field data were recorded onto 3590 and DVD media in a pseudo SEG-D format. These data were transcribed by DPTS (Job 091785) onto DLT IV media in SEG-Y format and provided to TCD. Navigation data from the onboard UKOOA P1/90 file were merged with the field data (source positions only). The onboard UKOOA file states that coordinates are provided at CMP position. This is most unusual as the navigation position is usually the shotpoint shifted back from the antenna position. In addition the position numbers provided in the UKOOA file are clearly SP numbers not CMP numbers. It was assumed by DPTS (pers. comm.) that the navigation positions were actually SP and the merge was conducted accordingly. The maximum error resulting from this assumption would be half the near trace offset ie 35m for line 9001 and 45m for remaining lines and can be regarded as negligible. We have utilized the navigation data provided in the trace headers from DPTS.

Previous tests had been conducted on line 9002 during a preliminary study in 2005. For this report, line 9108 was chosen as the initial test line because it had a thick sedimentary sequence (target), basement high and interesting geological features. The line was also short enough to enable screen displays to compare processing tests at reasonable quality. It is very difficult to reproduce these test displays in this report at A4 size. The processing strategy was to design a single parameter set for the survey and not to spatially vary the parameters either along lines or between lines. Applying this strategy means any lateral variations in the processed data are due to lateral geological variations (or variations in data quality) and not to processing parameter variations. All test parameters were checked on every line and in some cases we adapted the global parameters to take into account varying geology. While some small spatial variations in parameters may lead to local improvements it is thought that the current parameters represent the "best overall" single parameter set for the data given the spatial variation in water depth, geology and data quality. An alternative strategy which allowed variation in data parameters would not be expected to yield significantly better results. Specific parameter improvements for specific targets e.g. volcanics will probably be discovered as part of targeted re-processing. All processing was performed used seismic-unix or TCD proprietary codes.

Field Data Transcription and Quality Control

All data at 1ms sample rate including auxiliary traces were loaded from DLT IV tape onto disk transcribing SEG-Y into Seismic Unix (SU) format. Approximately 200Gb of SU format files were archived to LTO2 media. Brute stacks were completed for all lines and part-lines using previous test processing parameters namely geometry, resample to 2ms following anti-alias filtering, gain correction, single function NMO correction, deconvolution and stack.

Several lines were shot in segments and the numbering convention's followed were non-standard, inconsistent and poorly documented. We attempted to merge line segments as much as possible using the observers logs, navigation files provided and common sense. Appendix Four details the line merges performed.

Signature Analysis and Processing Sample Rate

The data were acquired with a single Sodera GI gun at nominal 5m depth. Conventionally a modeled far-field signature would be provided which would be used for spectral shaping – for example to shape the data to minimum phase prior to deconvolution. In this case no modeled signature was provided although one could probably be obtained from the manufacturers or any quality seismic acquisition contractor (for example WesternGeco charge approximately £1000 for this service).

The signature from the gun was measured for every shot by a near field hydrophone (exact details undocumented) and was stored into the SEG-D auxiliary headers and transcribed by DPTS to SEGY format. We therefore investigated whether we could use this signature deterministically for phase correction or spectral shaping. Figure 2a shows the signature from the first 10 shots of line 9005 and Figure 2b the associated autocorrelation function. Figure 2c shows the amplitude spectrum from the first shot of line 9005 and Figure 2d the amplitude spectrum of the first 10 shots from line 9005. In the time domain (Figure 2a) the signatures have small variations in arrival time but large variations in the lower frequency bubble pulse arrivals. The autocorrelation function and amplitude spectrum show strong ringing at 50Hz – probably this is electrical pickup in the system used for signature measurement.

An ideal amplitude spectrum for seismic investigation is a white spectrum – one with constant amplitude at every frequency. Normally an array of guns of different sizes is tuned to balance the input amplitude spectrum with the lower frequencies revealing details about the deeper structures (higher frequencies being more rapidly attenuated during passage through the earth). The signature derived amplitude spectrum for the HA04 survey (Figure 2c) shows that the spectrum is very unevenly balanced in the 0-90Hz region (used for conventional reflection seismic imaging) but fairly well balanced in the mid-range between 100-250Hz and drops off in amplitude between 250-500Hz with some pronounced spectral notches. Normally the use of a gun array would fill in spectral notches except those caused by the gun depth (ghost notch). Figure 2d shows that the amplitude spectrum for the first 10 shots has most differences between 250-400Hz which is the target range for this high resolution survey.

Figure 3a shows in green the raw averaged spectrum from the source signature compared with (in red) the averaged spectrum from the actual first 10 raw shot records themselves. The real data do not seem affected by the power spike so we assume that this was caused during only the signature recording process. The real data and signature data however have very different amplitude spectra – even when making allowance for attenuation (Q) over the 4s record length.

The obvious spatial variation in source signature combined with the obvious differences from the extracted signatures make it very difficult to use the measured near field signature for any kind of deterministic deconvolution of the recorded seismic data. Further research in this area may yield improved results and different conclusions, however at this stage of the processing further use of the recorded signature was abandoned. The success of the statistical deconvolution approach determined during test processing in 2005 also supported this conclusion. Figure 3b-d reproduces tests from 2005 and show the extracted signature from line 9002, amplitude spectrum and signature after deconvolution processing including minimum phase conversion and debubble.

Figure 3a also shows potential cutoffs for aliasing at 1ms (500Hz), 2ms (250Hz) and 4ms (125 Hz) sample rate. The red curve shows maximum amplitudes in the 0-90Hz range but with a notchy spectrum. Amplitudes in the 250-400Hz range are not appreciably lower than 125-250ms range therefore there may be some small benefit to processing the data at 1ms sample rate.

For all lines we produced near offset sections and brute stacks at both 1ms and 2ms sample rates. Difference displays showed a small but consistent and significant level of signal between 250 and 500 Hz (as also shown on Figure 3a). It was therefore decided that full processing should proceed at 1ms in order to maximize resolution even though the contract required processing at 2ms. This decision had an impact on subsequent processing resources and schedule.

Spatial Sampling

Data acquired with a 25m shot interval and 12.5m group interval yields CMP gathers spaced at 6.25m. It is common to sum adjacent shot traces (or drop following K-filtering) to obtain an identical shot and receiver interval of 25m. Summation has the advantage of some noise cancellation and halves the number of CMP positions for data processing and loading. Possible data degradation may occur, however, due to spatial aliasing – especially as at 1ms very high frequencies are present. It was therefore decided to keep the original acquisition parameters. These temporal and spatial sampling decisions produce the best quality data but each line is four times larger than would have been anticipated from “conventional processing”. However final data users can opt to sub-sample the data either temporally or spatially upon data loading.

Trace edits, noise Analysis and reduction

Streamer channel 4 was dead on lines 9002, 9003, 9004, 9005, 9006, 9007, and 9008 so it was erased from these lines. Streamer channels 4 and 66 were erased from lines 9008b, 9009, 9010, 9011, 9018, and 9108 because they were dead during the survey.

Data were known from previous analysis to suffer from strong levels of swell noise in parts. Brute stacks were used to assess noise levels in the data, line 9008b was one of the noisiest lines. Onboard processing was unsuitable to assess swell noise since all frequencies below 20Hz had been removed with the filtering applied. Conventionally the onboard processing system would be used to help decide acceptable levels of swell noise for the survey. Ideally a 3 Hz 18dB/Octave filter would be applied in the field or occasionally a 5 Hz 18dB/Octave. In extreme case (e.g. for older data) 8Hz 18dB/Octave filter was sometimes applied. The HA04 survey was acquired with an 8Hz 18dB/Octave filter and with “academic quality control parameters” – basically to shoot as much data as possible rather than shutting down for large levels of swell noise. Even though the source was poor in low frequencies (these were concentrated in the bubble pulse) we still wanted to preserve as much low frequency information as possible as this would be concentrated in the deeper parts of the section.

Figure 4-1a shows 3 shot records from lines 9108 (deep water and shallow water) and line 9008b (one of the noisiest lines) with three different low-cut filters – 4a) out, 4b) 8Hz, 4c) 20Hz. The 8Hz low-cut filter appears to be adequate for removal of swell noise for the shots on line 9108 but the 20Hz filter is required for line 9008b. Since stacking also reduces (to a certain extent) low frequency swell noise Figure 4-1d-f shows three stacks from line 9008b, d) raw stack (no low cut filter) (e) after chosen low cut filter and (f) following diversity stack. Again the 8Hz lowcut filter was found to be adequate and together with the diversity stack was found to be very effective mechanism for swell noise suppression. Figure 4-2 shows an enlarged example from line 9008b showing a comparison between no swell noise suppression and a combination of 8Hz lowcut and diversity stack. Diversity stack is a noise reduction technique which works in this case using 64ms windows. For each trace, the window is scaled by the inverse of its average power before stacking. The resulting stack trace is renormalized by dividing by the sum of scalars used. The method acts to reduce isolated noise bursts within traces and to reduce the effect of scattered noise high amplitude traces in the final stack.

Bulk Static Shift

The onboard acquisition and processing reports were extremely confusing and in part contradictory regarding the time-break static which should correctly be applied to the data.

A static shift of 33msec was applied to lines 9001, 9002, 9003, 9004, and 9005 to account for the time box delay as described in the acquisition report. A static shift of 64msec was applied to lines 9006, 9007, 9008, 9009, 9010, 9018, and 9108 to account for the internal time break of the TL3 recorder since the spare firebox that replaced the original on this line did not have an internal time break. Figure 5a shows linear moveout applied to the direct arrivals of a shot record from line 9108 prior to static correction. For each line the linear moveout correction was made at 1500m/s, the shots stacked and displayed as shown in Figure 5b. This QC was used for the time-break static.

When attempting to average the source signature for minimum phase conversion it was noted that the average source signature for several lines was different from signatures observed on individual traces. Further investigation showed that there was a spatial variation in signature arrival time which was only revealed when an entire line of signatures were plotted at high spatial density next to each other (Figure 5d shows an example from Line 9004, Figure 5c the first break QC for the same line). Further, initial line tie analysis of brute stacks (see Appendix Five) showed severe misties for lines 9001,9002,9003,9004,9005. As noted above, these lines were acquired with the initial acquisition system. Lines shot with the revised system (9006 onwards) all tied with themselves and industry data and did not show a spatial variation in source signature arrival – quality control displays such as that shown in Figure 5b were consistent. The mistie lines all showed similarly variable source signature arrival characteristics. Therefore it was concluded that the initial acquisition system was somehow faulty and that the real time-break static was spatially variable and indicated as shown in Figure 5d. Since the time-break was not recorded anywhere in the signature headers we therefore picked the first break from the signature arrivals (Figure 5c shows direct arrival QC and picks). We could have used an autotracker, but the signature displays were quite noisy. The first breaks were interpolated to every shot, spatially smoothed and applied as a source static (similar to the corrections applied for land data, except that no receiver static was applied). This procedure was applied to lines 9001,9002,9003,9004,9005 and the various sub-sections of those lines. After this static procedure line ties were much improved (see Appendix Five) although misties were not completely eliminated.

True Amplitude Recovery

A t-squared gain correction was used which was found to balance the data effectively. The advantage of such an analytical function is that it can always be removed post-stack and replaced with a true spherical divergence velocity based correction if required.

Prestack Deconvolution

Deconvolution is conventionally used for three main reasons in data processing. Firstly it is used to shape the source signature to minimum phase as a prerequisite to further deconvolution processing (see Figure 3b and 3d). Secondly it is used to remove short period reverberations within the source signature and bubble pulse (equivalent to whitening the spectrum) with the objective of enhancing the resolution of the data and thirdly it is used to suppress multiples generated by the sedimentary reflections. In deep water experience shows that the benefits of source shaping are minimal as the source wavelet is approximately minimum phase by the time it has propagated through the water layer. Deconvolution is also totally ineffective at multiple suppression if the period is greater than around 150ms as is the case for the HA04 survey.

In theory we could remove the effects of source signature variation (noted above) using a shot averaged spiking deconvolution design (as would commonly be applied for example to land data). This would have a further benefit of zero-phasing the data although this can also easily be achieved post-stack. Figure 6 shows a stack section (sedimentary sequence) after three different deconvolution parameter selections (a) raw, (b) gapped (c) spiking deconvolution. Each of the panels has an autocorrelation function appended at the base – amplitude spectra are also shown. We observed no real benefits with the spiking deconvolution but a deterioration of the section due to the boosting of the low frequency bubble pulse (this is observed in other areas where the seabed reflectivity is very strong). Therefore we applied a simple gapped deconvolution in order to gently whiten the spectrum without exacerbating the bubble pulse problem and boosting the noise seen in the spectral notches due to the single gun.

Long-Period Multiple Suppression

Radon demultiple would be conventionally applied as a moveout based filter to remove more slowly traveling multiples from faster primaries. The method works well in areas of non-complex seabed topography and for multiples with a period of generally greater than 500ms. For complex topography a waveform based method is required either based on wave-equation prediction and subtraction or by prestack autoconvolution (so-called SRME methods). The former method requires the picking on the seabed and the latter requires adequate knowledge of the source signature. Both methods are elegant but computationally intensive. There are areas of the HA04 survey where these methods would be beneficial but in general it was decided that multiples were not a significant problem for interpretation and that multiple suppression was therefore not required. On the basement highs where multiples are strong there are no apparent conflicts with genuine primary reflections. If upon subsequent interpretation it is found that multiples do cause interpretation uncertainty then removal will be investigated as part of a targeted reprocessing phase. Figure 7a & b shows the results of applying radon demultiple to selected NMO corrected CMP gathers from line 9108. While the level of the multiple energy is clearly reduced in Figure 7b, there is still a lot of remnant energy in all but the deeper water gathers. Parameters were required to be quite aggressive, however it must be remembered with this limited offset that the maximum differential moveout of only 50ms or so is at the limit of effectiveness for this technique. Figures 8a,b,c show the results of the radon demultiple applied to line 9108 in deep, medium and shallow water settings. An inner trace mute of 300m was also applied since at near offsets there is no differential moveout between primary and multiple. Figures 8a,b,c show the radon demultiple to have only been partially effective and in some cases the results are noisy and primary energy has been suppressed as a result of the required overlay aggressive demultiple parameters. As noted above, since multiples did not interfere with the interpretation we elected not to apply radon demultiple to the full data volume.

Velocity Analyses

Dip corrected velocities were picked on a 1km interval using specially constructed scripts in seismic unix. We applied a mild radon demultiple to the gathers in order to be able to pick velocities from any deeper reflections in case the semblance was masked by high amplitude water bottom multiple reflections.

Velocities were picked using gather and semblance displays and quality control was provided by rms and interval velocity displays for each gather and for the entire lines. Anomalous picks were corrected. Figure 9a shows gather, NMO corrected gather, rms and interval velocity graph and semblance display. The velocity inversion in this case would be edited. Figure 9b shows rms and interval velocity displays for line 9108 (note this line is 100km long and so the displays are highly compressed. Again we tried to avoid major interval velocity inversions in the picking unless there was a clear reason to do so. Interval velocity displays were used to check velocity picks – anomalous picks (as shown by interval velocity spikes in Figure 9b) would be edited before stacking. This represents standard velocity analysis procedure for a frontier area. The width of the semblance peaks in Figure 9a-d shows that velocity resolution was fairly poor due to the limited offsets, although in general velocity analysis was straightforward.

Pre-stack Migration

Kirchhoff prestack migration tests were conducted on line 9108 and results are shown for the sedimentary section in Figure 10 where we compare the Kirchhoff prestack time migration with the post-stack migration. The Kirchhoff migration is frequency and dip limited whereas the post-stack migration is not. At smaller scale the prestack migration has a slightly better “clearer” appearance. In general at larger scale we found little to favour the prestack migration as so for the production processing we elected to use post-stack migration with no dip filtering. It is anticipated that certain areas of the survey will benefit from prestack migration during targeted reprocessing.

Section 4: Post-stack Processing

Deconvolution

Two further gapped predictive deconvolution operators were specifically designed to remove the low-frequency bubble pulse from the data and were applied post-stack prior to migration. The first operator was a 75ms gap 120ms operator predictive deconvolution and the second deconvolution was a 180ms gap 220ms operator. These operators were derived during testing on line 9002 prior to award of this processing contract. Even though the procedure is non-standard and could potentially attenuate primary energy our tests showed that they effectively removed the low frequency tail of the bubble pulse in the data (especially visible for the hard seabed areas) and did not attenuate primaries. Figure 11 shows the results of the deconvolution on a portion of line 9002 together with autocorrelation displays. In some lines where volcanic rocks crop at the seabed or close to it there is still a residual low frequency tail, however this does not significantly affect interpretation. The bubble pulse near the seabed (where it is strongest) has some similarity to a bottom simulating reflector due to gas hydrate formation. However the bubble pulse is visible throughout the data and not just beneath the seabed. True gas hydrate effects were not observed during an initial interpretation of these data.

Time-Migration

Several time and depth migration algorithms were tested at both 1ms and 2ms sampling rates. As is well known, different migration algorithms have a trade off in terms of dip response, frequency response, handling of lateral velocity variations etc. We found that the 1ms data following migration did not have appreciably more signal than the data re-sampled to 2ms. We therefore migrated the data at 2ms, also fulfilling the contract specifications and reducing the data volume for data loading. Prestack data is preserved at 1ms for future targeted prestack migrations. We found that the best algorithmic compromise for steep dip and mild lateral velocity variation was a steep –dip (~80 degree) phase-shift migration implemented in the time-wavenumber domain. Frequency domain solutions (e.g. stolt, straight phase shift) produced noise at the various notch frequencies created by the single source. The rms velocity field used for the migrations was laterally smoothed using a 1km filter and 100% was found to be the best migration percentage. In such a large dataset with laterally varying velocity field there are some areas where minor overmigration and undermigration has occurred. Nevertheless we believe these areas do not significantly affect interpretation and that our parameter choices provided the best overall compromise. When we tested migration algorithms (time and depth) which included dip filtering (e.g. Kirchoff, Finite Difference) we found at large scale an attenuation of some of the steep dips although for smaller scale displays (for example in reports) the dip filtering did reduce noise and was beneficial. Similar conclusions can be applied when we tested post-migration noise suppression techniques such as FX deconvolution, spectral whitening or trace mixing. In general we found that the simplest processing routines provided the best compromise parameters. In general our strategy was to leave noise in the data if it could be easily interpreted as such, rather than removing the noise together with genuine steeply dipping primary signal.

Post-migration processing

We applied a simple time variant zero-phase ormsby filter passing 8-12-180-220 Hz from 0-3s and 8-12-90-120Hz in the bottom 1s. A 2000ms AGC with Gaussian taper was applied to the final data to balance the scaling. Figure 12 shows the effects of the filter and two different scaling options, the 2000ms AGC was thought to represent the best compromise and does not destroy primary amplitude relationships. In some lines the AGC causes a “shadow “under volcanic horizons, however this is easily understood. In other areas the AGC brings out weak reflectivity beneath volcanic section and is therefore preferred. A simple mute was applied above the water bottom to mute out water column noise.

Figure 13a,b,c shows the results of the migrated section in deep, moderate and shallow water as represented by Line 9108. Excellent quality is observed, particularly in the sedimentary section.

Figure 14 shows an example comparison from lines 9008b and 9002 where the onboard processing is compared to the new data processing (we make the comparison at stack stage as the onboard data was not migrated). The new data processing shows much higher bandwidth, a reduction of the low frequency source tail, an elimination of areas of signal clipped above the water column and significantly more detail in the volcanic and sedimentary section including details of faulting and the volcanic plumbing. Several lines show windows in the basalt cover and sedimentary reflections, undoubtedly Mesozoic, are observed in these windows and beneath the volcanic intrusions. Overall the revised data processing strategy and parameters can be considered to have been very successful.

Data Polarity and Phase

Figure 15 shows an expanded section from the deep seabed of line 9008b in both variable area wiggle display and variable density display with colourbar showing amplitudes. The recording polarity was not stated in the acquisition report, and we have not explicitly applied any zero-phase conversion due to problems in deriving an operator from the source signature. Therefore strictly speaking the data should be interpreted as being minimum phase SEG normal polarity i.e. impedance increase is a trough. However an inspection of the seabed wavelet shown in figure 15 shows a remarkably symmetric wavelet which could be interpreted as zero-phase SEG reverse polarity. This is a common dilemma for deep water data as the wavelet often appears close to zero-phase when strictly speaking it is minimum phase. For the purposes of interpretation it does not particularly matter which convention is adopted as long as the interpretation is consistent.

An analysis of line ties in the area is carried out in the Appendix Five.

Section 5: Conclusions and Observations

Data was shot using a single airgun and 1km streamer in fairly strong swell conditions. Data are therefore quite noisy, especially in the lower frequencies (less than 50 Hz). We reprocessed the data with 1ms sampling interval to maximise resolution using a standard high resolution processing sequence was utilised involving deconvolution, detailed velocity analysis on a 1000m grid and migration.

With the revised processing route, the quality of the data was found to be much improved when compared to the original on-board processing. The new images of the sedimentary and volcanic section have higher resolution than in the original data and data reliability is higher due to the consistent processing applied. On certain lines, deeper structures were observed where they were absent in the original data. Overall there is much more geological information present in the data compared to the original data.

The higher resolution of the improved data means that a more accurate interpretation of the Hatton Continental Margin can be made, which will lead to a better understanding of the structure of the area and its tectonic history. The velocity analysis that was carried out can be used to determine the thickness of sedimentary section and potentially determine lithology directly. Several areas of interpretation uncertainty will be targeted for specific re-processing including depth imaging.

References

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Appendix One: Acquisition Parameters

Client:
Petroleum Infrastructure Project, Geological Survey of Ireland, UK Rockall Consortium.

Contractor:
Exploration Electronics Ltd. For seismic equipment and personnel.
Commissioners of Irish Lights for vessel and personnel.

Vessel: I.L.V. Granuaile

Recording Period: 29th June - 26th July 2004

Survey:
Name : GRA04_01
Area : Hatton Basin and Rockall Plateau, West of Ireland
Type : A 2-D high resolution reflection seismic survey with a 4s record length, consisting of ~3750 line kms.

Sources:
Source : Single Sodera 210 cubic inch GI
Source Parameters : Fired @ 25m. 5.0m tow depth, pressured to 2000 psi
Streamer : Teledyne 1200m Active, 96 channels, 12.5m groups
Recording : TAP TL3, 96 channels plus 5 aux. Record to 4 secs
Acquisition format : 25m CMP interval, quarter fold data set
QC Processing : ProMAX

Navigation
Vessel Positioning : Multi-reference DGPS from Fugro – SPOT
Quality Control : Starfix SEIS, QC package
Differential Stations : Shannon, Aberdeen-VBS
Navigation Software : Starfix Suite 5.2, Navigation Software

Recording Setup
Data Channels : 96
Aux channels : 4 (only Aux channel 2 was used to record the gun signature phone)
Sample rate : 1msec
Record length : 4000msec
Low cut filter : Digital 8Hz @ 18dB/Oct
Hi Cut Filter : Digital 411 @ 200db/Oct
Pre-Amp Gain : Data channels @ 48dB
: Aux channels @ 24dB
(NB all data on tape and disk is normalized to 24dB)
Data format : SEG-D 8058 revision 1
Recording formats: : IBM 3490 Tape cartridge
PC format SEG-D files provided on DVD

Appendix Two: Final Onboard UKOOA P1/90 Header

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H0100SURVEY AREA .............: Hatton Bank
H0101GENERAL SURVEY DETAILS ..: Recce seismic survey
H0102VESSEL DETAILS ..........: Granuaile                    1
H0105OTHER DETAILS ...........: CRP                          1               1
H0105OTHER DETAILS ...........: CMP                          1               2
H0105OTHER DETAILS ...........: Source                       1               3
H0105OTHER DETAILS ...........: Tailbuoy                     1               4
H0105OTHER DETAILS ...........: Towpoint                     1               5
H0200DATE OF SURVEY ..........: 30.06.2004 DD.MM.YYYY
H0201DATE OF ISSUE OF TAPE ...: 03.07.2004 DD.MM.YYYY
H0202TAPE VERSION IDENTIFIER .: UKOOA P1/90
H0300CLIENT NAME .............: PIP/BGS/GSI
H0400GEOPHYSICAL CONTRACTOR ..: DIAS/UCD
H0500POSITIONING CONTRACTOR ..: Fugro/GSI
H0600PROCESSING CONTRACTOR ...: UCD
H0700LogUKOOAP190.dll ........: V4.01.04
H0700POS./ COMPUTER SYSTEM ...: Starfix.Seis: 2.08.18
H0800COORDINATE LOCATION .....: Common Mid Point
H0900CRP to NMEA_GPS_Port.GGA :   2   -1.52    0.00
H0901CRP to NMEA_GPS_Stbd.GGA :   2   -0.28    0.72
H0902CRP to CRP               :   2    0.00    0.00
H0903CRP to Towpoint          :   2    0.00  -41.47
H0903CRP to CMP               :   2    0.00  -96.47
H1000CLOCK TIME RELATIVE GMT .: GMT +  0 hours
H1200                         :  N/A
H1300                         :  N/A
H1400GEODETIC DATUM (SURVEY) .: WGS84       WGS84        6378137.000 298.2572236
H1401TRANSFORMATION TO WGS84 .:    0.0   0.0   0.0 0.000 0.000 0.000 0.0000000
H1500GEODETIC DATUM (POSTPLOT): WGS84       WGS84        6378137.000 298.2572236
H1501TRANSFORMATION TO WGS84 .:    0.0   0.0   0.0 0.000 0.000 0.000 0.0000000
H1600DATUM TRANSFORMATIONS ...:    0.0   0.0   0.0 0.000 0.000 0.000 0.0000000
H1700VERTICAL DATUM ..........: SL
H1800PROJECTION TYPE .........: 0001UTM Northern
H1900PROJECTION ZONE .........: 28 UTM Northern
H2000DESCRIPTION GRID UNITS ..: 1INTERNATIONAL METRES     1.000000000000
H2001DESCRIPTION HEIGHT UNITS.: 1INTERNATIONAL METRES     1.000000000000
H2002DESCRIPTION ANGULAR UNITS: 1DEGREES
H2200LONG CENTRAL MERIDIAN ...:  15 0 0.000W
H0000
H0000 NB. Layback changed after line HA04_9001b as follows:
H0000
H0100SURVEY AREA .............: Hatton Bank
H0101GENERAL SURVEY DETAILS ..: Recce seismic survey
H0102VESSEL DETAILS ..........: Granuaile                    1
H0105OTHER DETAILS ...........: CRP                          1               1
H0105OTHER DETAILS ...........: CMP                          1               2
H0105OTHER DETAILS ...........: Source                       1               3
H0105OTHER DETAILS ...........: Tailbuoy                     1               4
H0105OTHER DETAILS ...........: Towpoint                     1               5
H0200DATE OF SURVEY ..........: 30.06.2004 DD.MM.YYYY
H0201DATE OF ISSUE OF TAPE ...: 03.07.2004 DD.MM.YYYY
H0202TAPE VERSION IDENTIFIER .: UKOOA P1/90
H0300CLIENT NAME .............: PIP/BGS/GSI
H0400GEOPHYSICAL CONTRACTOR ..: DIAS/UCD
```

```
H0500POSITIONING CONTRACTOR ..: Fugro/GSI
H0600PROCESSING CONTRACTOR ...: UCD
H0700LogUKOOAP190.dll ........: V4.01.04
H0700POS./ COMPUTER SYSTEM ...: Starfix.Seis: 2.08.18
H0800COORDINATE LOCATION .....: Common Mid Point
H0900CRP to NMEA_GPS_Port.GGA :   2   -1.52    0.00
H0901CRP to NMEA_GPS_Stbd.GGA :   2   -0.28    0.72
H0902CRP to CRP               :   2    0.00    0.00
H0903CRP to Towpoint          :   2    0.00  -41.47
H0903CRP to CMP               :   2    0.00 -106.47
H1000CLOCK TIME RELATIVE GMT .: GMT +  0 hours
H1200                         :  N/A
H1300                         :  N/A
H1400GEODETIC DATUM (SURVEY) .: WGS84       WGS84        6378137.000 298.2572236
H1401TRANSFORMATION TO WGS84 .:    0.0   0.0   0.0 0.000 0.000 0.000 0.0000000
H1500GEODETIC DATUM (POSTPLOT): WGS84       WGS84        6378137.000 298.2572236
H1501TRANSFORMATION TO WGS84 .:    0.0   0.0   0.0 0.000 0.000 0.000 0.0000000
H1600DATUM TRANSFORMATIONS ...:    0.0   0.0   0.0 0.000 0.000 0.000 0.0000000
H1700VERTICAL DATUM ..........: SL
H1800PROJECTION TYPE .........: 0001UTM Northern
H1900PROJECTION ZONE .........: 28 UTM Northern
H2000DESCRIPTION GRID UNITS ..: 1INTERNATIONAL METRES     1.000000000000
H2001DESCRIPTION HEIGHT UNITS.: 1INTERNATIONAL METRES     1.000000000000
H2002DESCRIPTION ANGULAR UNITS: 1DEGREES
H2200LONG CENTRAL MERIDIAN ...:  15 0 0.000W
```

Appendix Three: Final Processing EBCDIC header

```
C01    Client: PIPCO RSG LTD
C02    LINE: HA04-XXXXX
C03    SURVEY: HA04 Rockall Plateau and Hatton Bank, NW Atlantic
C04
C05    ACQUISITION: 29th June - 27th July 2004  I.L.V. Granuaile
C06    source: single 2000psi sodera 210 cu in GI gun fired @ 25m towed at 5m
C07    streamer: teledyne 1200m, 12.5m group, 96 channels, gun signature aux 2
C08    offsets: near trace offset 70m line 9001, 90m other lines
C09    recording: 4000ms @ 1ms 8Hz-18dB/Oct to 411Hz/200db/Oct
C10    field media: SEG-D 8058 revision 1 IBM 3490
C11    transcription: to SEG-Y DLT IV inc nav merge Dec 2005 DPTS Job 019785
C12
C13    Data processing: Trinity College Dublin August 2006-February 2007
C14
C15    1) Data load from DLT tape and QC.
C16    2) Edits: channel 4 (all lines) channel 66 (lines 9,10,11,18,9018)
C17    2) Apply geometry according to observers logs
C18    3) All processing at 1ms sample rate and 6.25m CDP interval
C19    4) Static shift according to observers logs for time-break static
C20    5) Pick and apply additional source time static lines 1,1m,2,3m,4,5
C21    6) Simple line merges for Lines 5 and 11 (contiguous shot numbers)
C22    7) Complex merges lines 3m,1m,8m (energy point preserves SP + 10000)
C23    8) Gain compensation: t-squared
C24    9) Deconvolution: 12ms gap, 75ms operator single trace
C25    10) Velocity analysis 1000m interval following radon demultiple
C26    11) Diversity stack 64ms window length
C27    12) Archive to SEGY format raw stack
C28    13) Deconvolution: 12ms gap, 75ms operator single trace
C29    14) Deconvolution: 18ms gap, 22ms operator single trace
C30    15) Anti-alias filter followed by resample to 2ms
C31    16) Steep dip time migration using smoothed stacking velocity field
C32    17) TVF 8,12,180,220 at 0s 8,12,90,120 at 3s 18) AGC 2s WINDOW
C33    Data Archive: SEGY format FINAL MIGRATION
C34    CMP number   BYTES 21-24 4I   Four CMP's per SP
C35    EP number    BYTES 17-20 4I   NAVIGATION DATA FROM FIELD
C36    FFID number  BYTES  9-12 4I   MERGED BY DPTS JOB 019785
C37    CMP X meters BYTES 73-76 4I   CM: 15 DEG W, ZONE UTM 28N
C38    CMP Y meters BYTES 77-80 4I
C39    TOTAL static BYTES 103-104 2I
C40   This archive: Trinity College Dublin, Dept. of Geology, February 2007
```

Appendix Four: Line merges and navigation edits

Line merges are discussed on a line by line basis. To determine line merges we used the observers logs (hand written), onboard navigation data and common sense. We constructed graphs of SP number versus shot x location in order to quality control the navigation merge. We edited out SP which had no navigation in the headers. Generally these were due to discrepancies between energy point (EP) and shotpoint (SP) number at the start of the line. DPTS had merged navigation based on EP number. In some cases it appeared there had been minor nav-merge issues. Line 9001 was the only line which required more basic editing than this – these edits are detailed below. Finally we applied a space variant source time static to lines 9001,9002,9003,9004,9005 as described in the main report. The results of this static are discussed in Appendix Five: line ties.

LINE or Part Line	EP range (header bytes 17-21)	SP range (header bytes 9-12)	Navigation file Range (P1/90)
9001	102-10070	100-10071	102-10071
9001a	100-906	100-906	100-906
9001b	100-4767	100-4770	100-4767
9002	100-11234	100-11234	100-11234
9003a	102-5942	100-5943	102-5942
9003	101-5668	100-5669	101-5668
9004	102-12142	100-12142	102-12142
9005a	102-12733	100-12733	102-13018
9005b	12734-13018	12734-13018	
9006	101-6446	100-6446	101-6446
9007	101-4119	100-4119	101-4119
9008	101-657	112-668	101-2937
9008a	101-2340	698-2937	
9008b	101-6908	101-6908	101-6908
9009	105-3450	100-3450	105-3450
9010	101-8153	100-8153	101-8153
9011a	101-9501	100-9501	102-9958
9011b	9502-9958	9502-9958	
9018	101-1633	100-1633	101-1633
9108	101-4036	100-4036	101-4036

Navigation Interpolation:

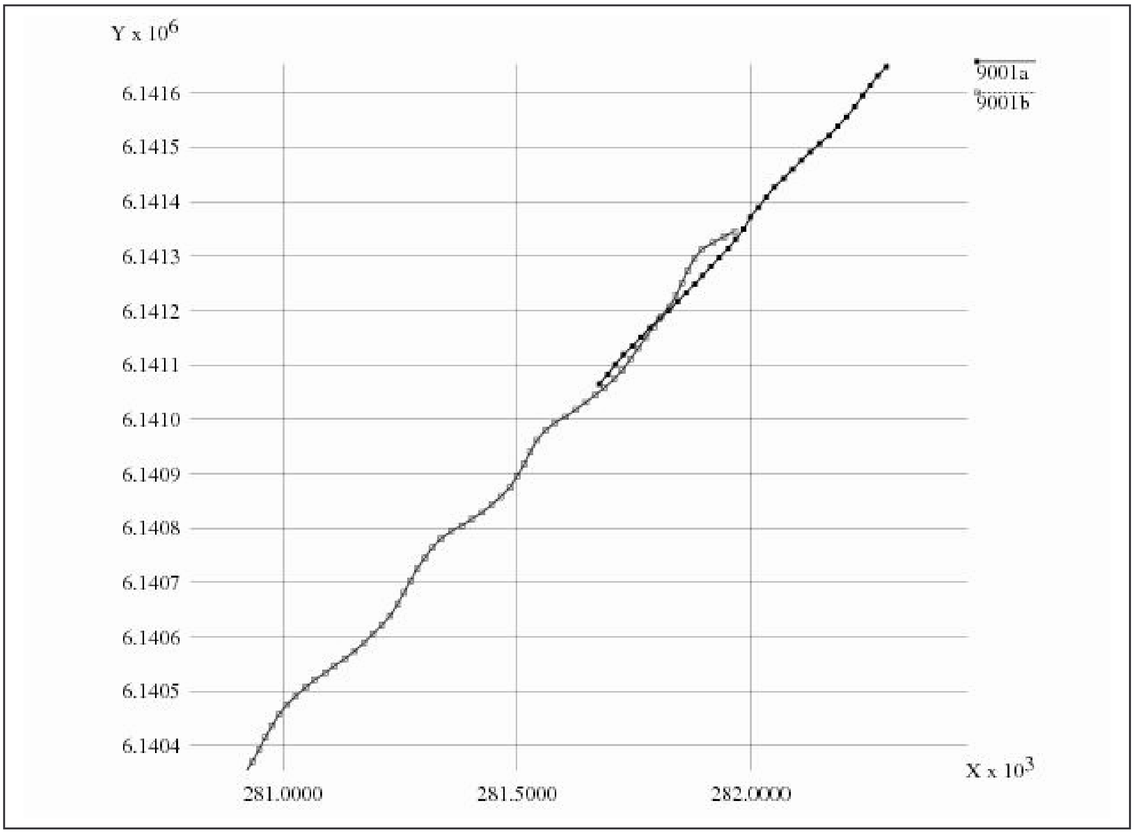
During line loading we initially deleted any shots without navigation information in the headers. However lack of contiguous SP and CDP numbers caused problems with certain data loading systems. Therefore traces with missing navigation in lines 9108 (SP 121-123) and lines 9010 (sp 119-121, 126-128, 190-217, 261-262) was subsequently interpolated rather than rejected.

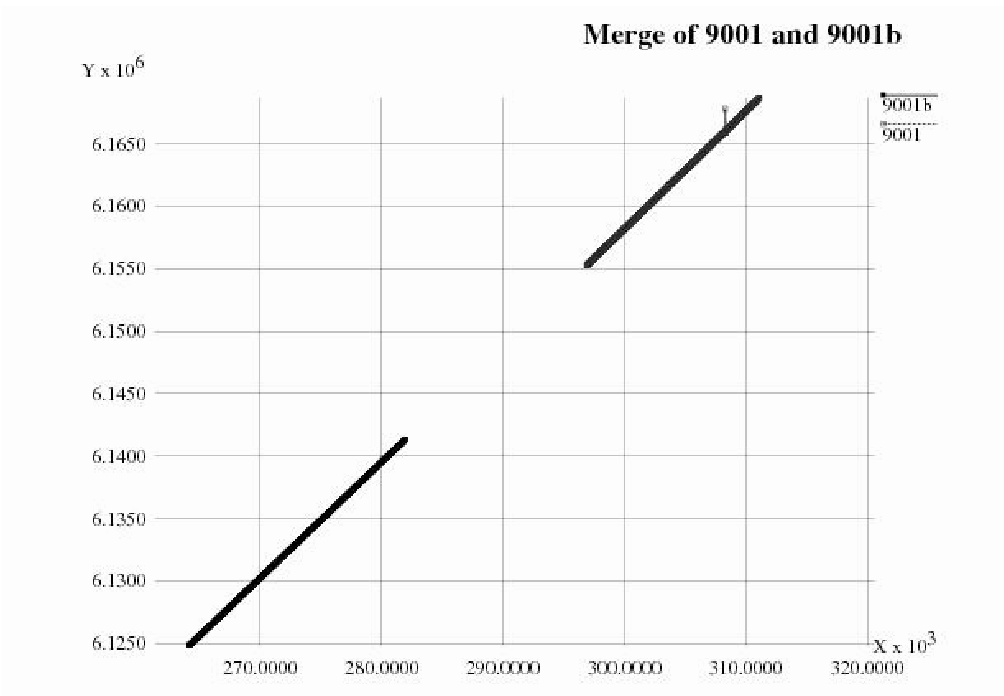
Line 9001, 9001a and 9001b

This line was shot in three parts.

9001a: sp 100-906 we selected 100-899
9001b: sp 8-4770 we selected 110-4767 and renumbered from 900-5557 adding 10000 to the ep number.

The merged line was termed 9001m with SP 100-5557 (see map below for join).

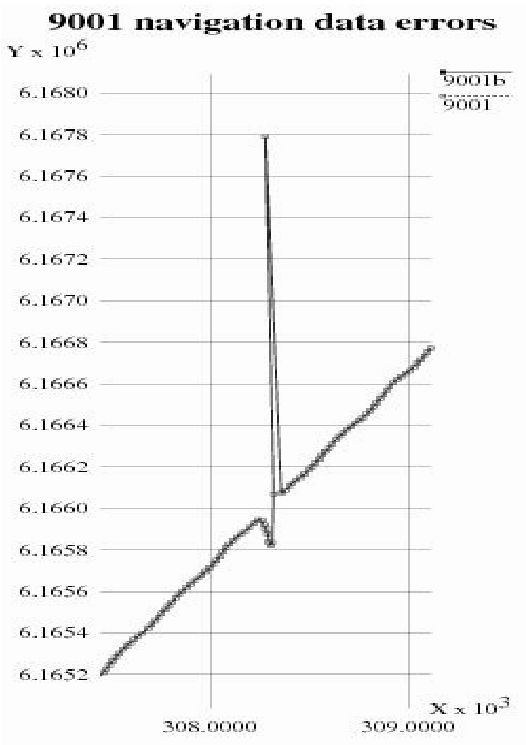




We could not merge 9001 and 9001m as there was no overlap between the lines. Infact the navigation data (see map on left) shows a gap of 600m at the supposed merge point.

Navigation editing:

Line 9001 was the first line shot and there were problems encountered with the navigation which were unique to the survey. For some errors in navigation we initially edited out the missing shots from the final migrated section (each shot error removes 4 adjacent CMP positions) but since this causes problems for landmark data loading we subsequently interpolated navigation values.



In one instance we had to interpolate a series of shotpoints 9439-9447 in order to remove spurious navigation shown in the adjacent figure.

We found that 32 shots also had spurious navigation positions although not as extreme as those shown to the left. Effectively this meant that the line "doubled back on itself" – we used trial and error in the data loading to discover these positions, which was time consuming. Possible these were due to nav-merge problems with the DPTS contract but we did not have sufficient information to verify this:

The shots interpolated were:

9607,9612,9615,9616,9620,9625,9651,9669 ,9701,9712,9730,9764,9777,9794,9798,9822,9838,9842,9 851,9860,9878,9891,9917,9925,9951,9976,9998, 10006,10029,10044,10048,10058

Additionally at a final stage we had to interpolate CMP positions:

6809,6810,6811,6812,15761,15762,15763,15764,37165, 37166,37167,37168,37685,37686,37687,37688,37657,37658,37659,37660

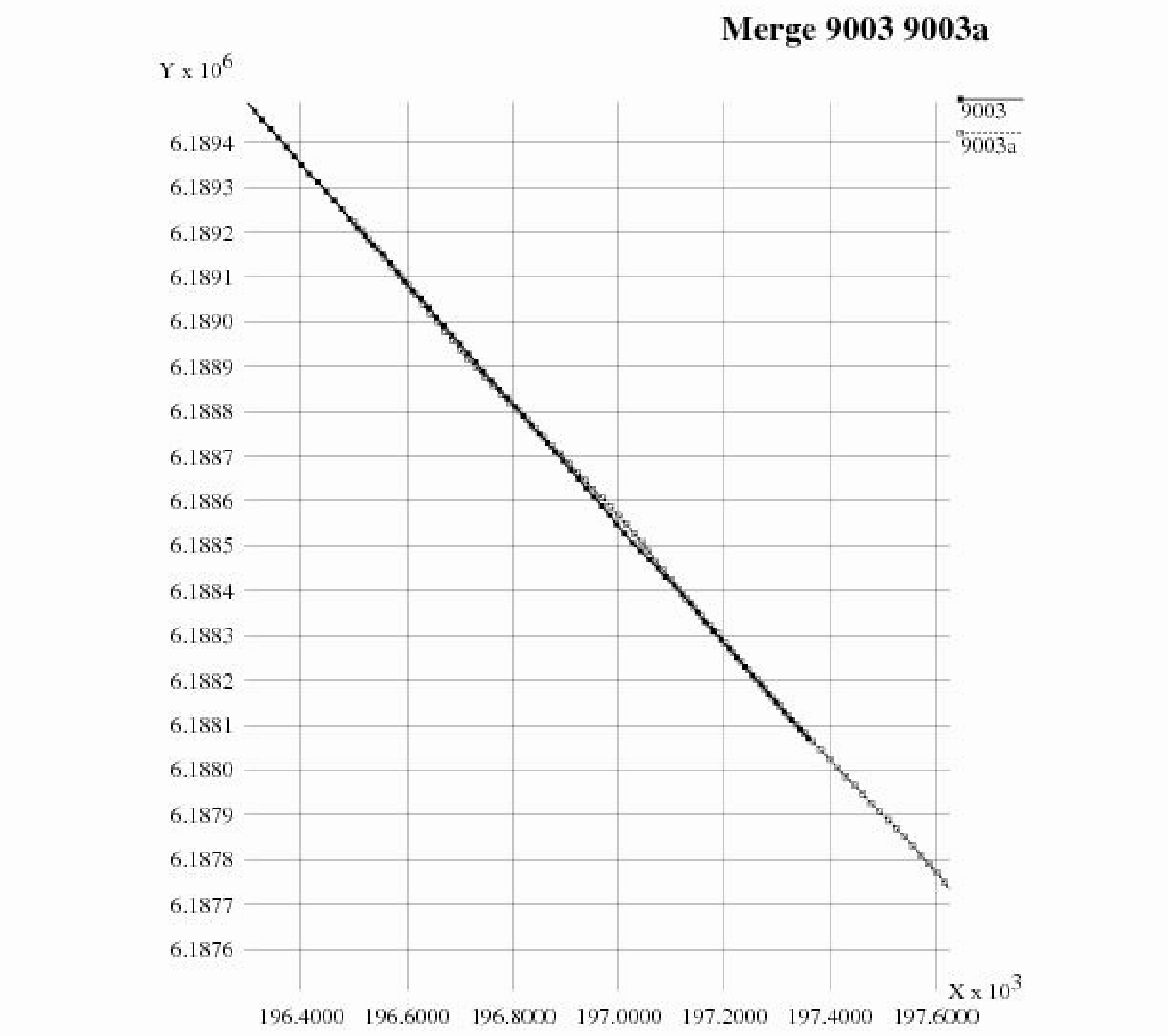
Once these edits were completed then line 9001 loaded correctly ie without navigation errors in OpenDtect or Geoframe whilst preserving the original navigation as much as possible. Editting rather than interpolation causes missing traces which may cause some loading systems to fail. To solve this problem we replaced the navigation above for the selected shots with new interpolated positions.

Line 9003 and 9003a

The line was shot in two parts with two navigation files. A merge point (SP 131 on line 9003a) was chosen from the map below (where there is good overlap). Original sp numbers from 9003a were renumbered from 5669-11452 and we added 10000 to the ep numbers. This way the ep numbers reflect the original sp + 10000 (normally during acquisition of a reshoot the sp numbers are incremented by 10000 in this manner).

Line 9003 sp 101-5669 we chose 101-5668
Line 9003a sp 101-5943 we chose 160-5943 renumbered 5669-11452

The new merged line was renamed 9003m and was QC'd on to check the veracity of the merge zone. Figure 16a shows parts of 9003 and 9003a and Figure 16b shows merged line 9003m.



Line 9011a and 9011b

The line was shot in two parts but only a single navigation file was provided.

Line 9011a has SP range 101-12733 and line 9005b has SP range 12734 to 13018. The two parts were therefore merged on SP number and treated as a single line named 9011.

Line 9005a and 9005b

The line was shot in two parts but only a single navigation file is provided.

Line 9005a has SP range 101-12733 and line 9005b has SP range 12734 to 13018. The two parts were therefore merged on SP number and treated as a single line named 9005.

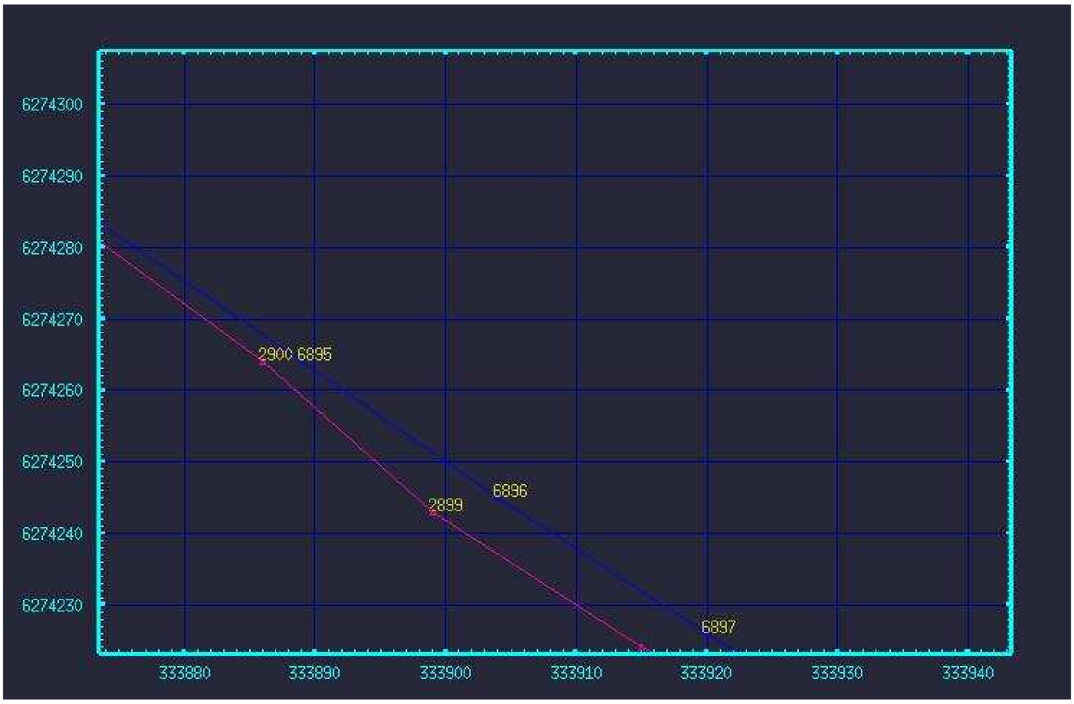
Line 9008, 8008a and 9008b

This line was shot in three parts with 9008b being shot in the opposite direction due to logistical reasons.

9008: sp 101-657 ep 112-668
9008a: sp 101-2340 ep 698-2937
9008b: sp 101-6908 ep 101-6908 (shot in opposite direction).

There are two navigation file for line 9008 and 9008b. The file for 9008 has continuous navigation values from 101-2937 and position 112 corresponds to ep 112 in the nav-merged seismic data. This indicates that files 101-111 might also be missing on the original data or a small problem with the nav-seismic merge. Therefore seismic data for ep positions 669-697 are missing. Therefore to merge the line we added dummy blank SP from ep positions 669-697 and used the correct navigation positions. We were therefore able to merge line 9008 and 9008a calling the result 9008m. The decision to merge or not to merge these lines is essentially one of "hobsons choice". Without merging each segment would be poorly migrated due to edge tapering and edge effects. With merging but including 30 SP "hole" we also get amplitude and migration smiles from the butt merge edges. In any case the geology in the merged zone is rather unspectacular being from a basement high. It was therefore decided not to spend more time on this merge.

We investigated reversing the acquisition direction of 9008m to merge with the geologically more interesting (and much longer in total) 9008b. There is sufficient overlap according to the map (following figure – line 9008b in blue and 9008 in red) however if we merged at the overlap from the navigation position we did not get overlap in geology, if we merged at the geological overlap there was no match in navigation. Ultimately we decided not to merge the lines. From a geological interpenetration 9008m is largely uninteresting.



Appendix Five: Line tie analysis

Brute stacks were loaded into the Geoframe interpretation system for analysis of line ties. Previous studies of the onboard processed data and previous brute stacks of ~ 30% of the data had indicated severe mistie problems for the data volume although the cause of these misties was unknown. In our first analysis of the brute-stacks we discovered that all the lines from 9006 onwards tied with each other reasonably well and with existing industry data. Misties were largely from the original acquisition systems employed for lines 9001,9002,9003,9004,9005 as shown in Figures 17a,b,c where misties of the order of 100ms are present. Figure 17a clearly shows misties with a black oval – good ties are shown on Figure 17c with a green oval. As previously described we picked and applied a separate shot static for these lines to correct for the variation in source arrival time.

We checked misties on the final migrated data on two interpretation systems. Geoframe/Geoviz uses a standard SP:CDP relationship to match navigation from SP to determine the CDP locations. OpenDtect loads the (x,y) locations of the CMP's directly from the trace headers.

Figures 18 indicate misties after the statics were applied as displayed in Opendtect. Figure 18a shows a perspective map of the line locations with arrows indicating the orientation of subsequent figures. Green ovals indicate good ties, yellow ovals indicate misties (but not a problem to interpret the geology) and black ovals indicate residual misties. The worst ties between 9011-9002 & 9010 & 9003m are ~ 50ms but there is steep dip at the seabed in these regions and the stacks tie better as per theory.

Figures 19a,b,c indicate a further test of line ties using the Opendtect system.

Generally it was concluded that the statics provided corrected 99% of the data misties. We also investigated data ties with available industry data in the region and bathymetry data.