Study on the navigation problems of deep tow seismic

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A high frequency deep-tow seismic survey was carried out in the Nankai Trough area in 1996. The objective of the survey was to obtain high resolution seismic sections and velocity profiles of the methane hydrate zone, inferred from the strong BSR events seen on conventional seismic data. A special feature of the survey is that both the source and the streamer cable are towed close to the seabed. This special acquisition geometry requires special data processing to handle the varying source and receiver depths. A CMP floating datum processing sequence was designed which led to high quality sections of the shallow geology. The processing sequence was applied to a number of lines, totaling 200 km. The quality of the final stack sections was highly variable.

It was found during the processing that the positions of source and receiver caused problems to harm the quality of the final sections. We classify the positioning problems as (1) streamer cable feathering, (2) source and cable depths, (3) relative shotpoint position and (4) absolute shotpoint position. The floating datum processing with static corrections could fix the problems (1) and (2). Post stack correction techniques are applied to fix (3) and (4) using 3D marine seismic.

We are planning to use deep-tow seismic survey for hydrothermal deposits. Hydrothermal deposit is specially limited and higher resolution is necessary than methane hydrates. The very high frequency of the data is considered to make the data processing much more sensitive to errors or approximations. In this paper the navigation problems are reviewed to design the new deep-tow seismic system.

1. INTRODUCTION

A 2D high frequency deep-towed seismic survey was carried out over part of the Nankai Trough, Offshore Japan, in 1996. The area is known to have a major accumulation of methane hydrate inferred from the strong BSR events seen on conventional seismic data and the presence of methane hydrate was confirmed by a MITI research well in 2000. The objective of the deep-towed survey was to obtain high-resolution seismic section and velocity profiles of the methane hydrate-bearing sediments down to the BSR, which occurs at around 300 msec below the sea bottom in this area. The data was acquired using the "Deep-Towed Acoustics/Geophysics System (DTAGS), developed by the Naval Research Laboratory, USA ¹). Both the source and the hydrophone cable are towed close to the seabed, allowing a "close look" at the shallow sediments, shown in Fig. 1. The source is a vibrator-type Helmholtz transducer with a 0.25 sec sweep from 250-650 Hz. The hydrophone cable has 48 channels and a maximum offset of 620m.

The data were processed by JGI, Inc. Ref (2) and ref (3) described the data processing. The key point in the processing was to handle the floating acquisition datum with source and receiver depths being maintained at typically 200-300 m above a varying seabed with the depths of 700-1400 m. A CMP floating datum processing sequence was designed which led to high quality sections of the shallow geology. The measured depths had to be corrected by residual statics derived from picks of the sea bottom reflection event.

In 2002, a 3D marine seismic survey was carried out by METI/JOGMEC over Tokai-oki for the purpose of evaluating the methane hydrates deposit and the data were processed in 2003. To obtain a more detailed evaluation of the deep-tow seismic section, it is necessary to make a precise comparison with the migrated volume of 3D survey.

![Fig.1 DTAGS acquisition configuration](image)
Fig. 2 shows the location of the processed deep-tow lines together with the outline of the Tokai-Oki 3D survey and the position of the MITI well. The color coding in the map shows the picked sea bottom times of the Tokai-Oki 3D migrated volume. This 3D survey covers most of the deep-tow lines. To compare these dataset, positioning problem of the navigation was realized. We took post-stack positioning analysis and correction by correlating the deep tow final stacks with the conventional 3D seismic volume, which was used as a fixed reference.

2. NAVIGATION DATA

The nominal shotpoint spacing was around 17.5m, corresponding to a vessel speed of 2 knots and a shot every 17 seconds. It was not possible to maintain a constant shot interval for such a deep source and a histogram of all SP intervals showed a normal distribution around the nominal 17.5 m with a standard deviation of about 5m. The accuracy of the X, Y and Z positions of the source and receivers is a key issue in the processing of the deep-tow data. In conventional marine acquisition the position of the vessel and the streamer cable can be determined with sufficient accuracy for the resolution of the data. For the DTAGS system the position of the vessel can be determined accurately but it is much more difficult to determine the position of the source and receivers, typically 1 km below the surface. The depths were determined from pressure-sensors on the source and at 4 locations along the streamer. Residual statics analysis during the processing indicated that the source and near-offset streamer depths had errors of around 2m but the longer offsets had much larger errors, up to 25m. The X-Y position of the source was determined relative to the vessel using a trackpoint transponder on the source and receiver beneath the vessel, together with heading sensor readings on the source. The position of the streamer relative to the source was determined from 4 heading sensors adjacent to the depth sensors. It was found during the data processing that the calculated positions of the receivers were unreliable; they often showed a curved streamer when the direct arrivals showed the streamer was straight. As a result, the streamer heading data and the calculated streamer positions were not used in the processing. Instead, the direct arrivals were used to determine which line segments had an almost straight cable, and these were the segments processed. The shotpoint X-Y positions from the navigation data were used in the processing. It is not so easy to verify these positions and this will be discussed with comparison to the 3D marine seismic.

3. DATA PROCESSING

The flowchart shows the main steps in the processing sequence, shown in Fig. 3. Details of each of the steps in this flow are described and relative positioning errors problems were discussed.
by ref. (2) and ref. (3). Since the deep-tow acquisition configuration has a number of special implications for the processing, we summarized them briefly here.

Geometry

The lines were not completely straight and also, there was a variable amount of feathering of the streamer. Nevertheless, the geometry was defined for a straight line, both in terms of the CMP binning and the shot-receiver offsets. The SP interval was not constant and so it was calculated from the navigation SEGP1 file information and used in the geometry definition. The depth information was present both in the SEGP1 files and in the field tape trace headers, and was used for static corrections first to a floating and later, after NMO, to a fixed datum.

Source Signature

The piezoelectric vibrator source produced a relatively narrow band of high frequencies with the range of 250 - 650 Hz. The appearance of the narrow bandwidth in the time domain is a wavelet with not one but three dominant peaks. Deconvolution cannot in principle produce a single dominant peak for such narrow band data and so even after deconvolution there will be at least three strong loops for each reflector.

Noise (Strong reflection from the sea surface)

The sea surface reflection was very much stronger than any other event and due to the complication of the varying acquisition datum it was not possible to filter it out at all. In some lines, it severely disrupts the hydrate zone reflections.

Floating Acquisition Datum

The DTAGS system was designed so that the source and streamer could be towed a few hundred meters above the seabed. It follows that the acquisition datum is not fixed as for a conventional marine survey but follows the sub-sea topography in a manner very similar to land data acquisition. The processing sequence for this data must include datum statics in the same way as land data;

1. Static correction to CMP floating datum from which velocity analysis and NMO are applied
2. Post-NMO static correction to a fixed datum with all times referenced to mean sea level (MSL).

It is noted that elevation statics corrections are only an approximation. The approximation is good enough where the depth of the source and cable is slowly changing but will become worse where there are rapid changes in the depth.

Datum Statics

The datum (elevation) statics were calculated using the measured source and receiver depths with a 1480 m/sec water velocity. In most cases the measured depths in the DTAGS shot records was used for the source and receiver depths, however there were some exceptions. In such case, sea surface reflection picking would be a better approach to the statics than sea bottom picking if the surface arrival could be reliably picked but it turns out that the sea bottom arrival is generally a much more stable wavelet and gives better results.

Residual Statics

This is a key step to obtain high quality seismic section. There are errors in the measured depths of the source and receivers and these errors must be corrected by residual statics. There are two complications that make the residual statics more difficult than for typical land data;

1. There is no receiver location consistency. The statics can be expected to be shot-consistent but at a given receiver location, the cable will have varying depths as it is dragged past.
2. The errors in the measured depths lead to static corrections much larger than the dominant wavelength of the data (~2.5 msec). This leads to severe loop-skip problems with conventional cross-correlation based residual statics techniques. In view of these problems, a new residual statics technique was developed for this data. It replaced correlation picking with sea-bottom arrival picking, and surface consistent statics with a kind of filtered CMP trim statics.

Velocity Analysis

An accurate velocity analysis in and around the hydrate zone was one of the principal objectives of the survey. In areas where the statics solution is good the RMS velocity analysis can be expected to be very accurate within 10 m/sec.

It was found necessary to sub-stack the near offset channels (1-24) to the same offset bin size, 21m, as the far offset channels, in order to obtain a sharp semblance and stacking response.

Migration

Post-stack time migration was tested on parts of the data but was not very successful for the following reasons;

1. There is a very poor ratio between horizontal and vertical sampling. The horizontal sampling is the CMP spacing, 10.5m, and the vertical sampling is 0.432 msec two-way time, corresponding to less than 0.5 m. With this ratio there are severe aliasing problems in the migration operator.
2. The type of acquisition means that floating datum migration is required, or first, wave-equation redatuming to a fixed migration datum and then conventional migration. This adds more aliased migration noise to the data.

3. The strong surface reflection often comes close to, or within, the hydrate zone. Migration will smear this noise over a wider zone. As a result, migration was not included in the main processing sequence.

4. NAVIGATION PROBLEMS

The navigation data for the lines was given in a series of SEGP1 format files. For each line there was one file containing the shot X, Y and depth coordinates, and files containing the X, Y and depth coordinates for channels 2, 12, 22 and all channels 25 – 48. The coordinates for the remaining near-offset channels were calculated by linear interpolation. The depths had also been written directly into the DTAGS field records. During the processing the lines were CMP binned as straight lines, ignoring feathering and cable bending. The information in the SEGP1 files was used to set the correct in-line SP spacing. The shot and receiver depths were set using the data in the DTAGS records as far as possible.

There are 4 basic problems of the positioning accuracy, which are discussed in this section.

4-1 Cable Feathering

It causes the shot-receiver offsets error, which are very important for the velocity analysis. The accuracy was checked using the direct arrivals.

The SEGP1 files indicated that there was considerable feathering and curvature of the cable at certain intervals along the lines. However, the receiver positions in the SEGP1 files were found to be unreliable. The distance between channels 25-48 should be fixed at 21m but there were places where it increased to as much as 80m. The shot-receiver offsets in the SEGP1 file are always equal to the straight-line distance and so it appears that the navigation data was processed with this constraint. In places where there were large azimuth deviations in the cable the receiver separation is stretched to unreasonable limits.

An independent check of the shot-receiver offset could be made using the direct arrival wave in the shot gatherings. If the offsets are correct the direct arrival should line-up with a linear moveout (LMO) correction with seawater velocity. Fig. 4 shows the concept that the direct arrivals lined-up best at 1490 m/sec and so this was used as the water velocity. For each line a QC plot was made of every 10th shot after LMO correction to check that the cable was not bending too much. Fig. 5 shows the mapped SEGP1 position of the cable for 2 shots, SP 1661 and 1701, from line D96-D, together with the LMO corrected direct arrivals for those shots. It is seen that the arrivals look almost the same but the SEGP1 positions show the cable for SP 1661 strongly curved and that for SP1701 is almost straight.

The conclusions of these QC plots and analysis are;

1. The SEGP1 receiver positions are inconsistent
2. The cable is generally very close to straight and so setting straight-line shot-receiver offsets is justified.

4-2 Shot and Receiver Depth

In the 1998 processing it was found that the raw depths in the DTAGS records gave a much better result than the processed data in the navigation files.
This was confirmed in the current processing when an attempt was made to process line D96-9 using the navigation file depths (because the long offset DTAGS depths could not be read). The resulting section was very poor. Repeating the processing with the DTAGS near-offset depths gave a much better near-offset section.

Fig. 6 shows difference between the depths in the headers vs. the SEGP1 files for line D96-9. It appears that the SEGP1 depths are smoothed versions of the “raw” header depths with a smoothing length of perhaps 20-30 shot points. It is evident that the depths do in fact vary rapidly and that smoothing is generally harmful.

A good measure of the accuracy of the measured depths is the size of the residual statics. These were found to have a very strong channel number dependency, showing that there was a systematic error in the measured and interpolated depths. Fig. 7 shows the RMS depth errors for each channel of lines D96-C, D96-9 and D96-11. The trend for line D96-C is typical for all the lines that used the DTAGS depths.

The size of the depth errors was fairly constant as a function of the CMP along each line but tended to increase at locations where the cable depth was changing rapidly. This is seen clearly along line D96-C, in fig. 8.

4-3 Relative Shotpoint Positioning
This is difficult to check during processing. During the 1998 processing the 4 line intersections showed that there were positioning errors of several hundred meters.

The only way to get some idea of the general (x,y) positioning accuracy was by matching the processed sections at the expected line intersection locations. Fig. 9 shows the how the stack sections match at the 4 line intersections. For each intersection, the figure shows the match at two locations;
1. The position of the intersection determined from the SEGP1 shot location file.
2. The position of the best cross-correlation between the sections, obtained automatically by scanning cross-correlations for all pairs of traces within 50 CMP’s from the SEGP1 intersection and selecting the highest value.

Fig. 9 Line Intersection Check,

Fig. 10 Line Intersection Map

It is can be seen that for all four intersections the best-fit cross-correlation gives an excellent match, generally much better than the SEGP1 intersection locations. Furthermore, these matches are obtained with static shifts less than 2msec, making it fairly certain that they represent the true line intersection locations.

Fig. 10 shows the map of the lines around the intersection locations. The positions of the best cross-correlations are also shown as blue crosses.

4-4 Absolute Shotpoint Positioning

This is also difficult to verify absolute SP positions using only DTAGS data and it is calibrated with comparison to the 3D marine seismic. Ref (3) discussed this problem.

It was found that when the track of the deep-tow lines was extracted from the Tokai-Oki 3D data volume the extracted 2D line profile did not always match the deep-tow profile very well. These two points demonstrate that the SP positioning of the deep-tow data has large errors, at least in some places.

Matching the deep-tow data to the Tokai-Oki 3D survey provides a method to estimate the positioning errors in the deep-tow navigation data. Due to the different spectral bandwidths it was not possible to match the data trace-by-trace and thus obtain a CMP-varying shift. The most successful approach was comparing the picked sea bottom times of the deep-tow and 3D data. This method found bulk shifts in the X-Y coordinates which gave the best match of the sea bottom profiles. The shift ranged from almost zero for lines D96-7 and D96-9, to over 350m for lines D96-D and D96-E. After applying the shifts a good match was found between events on the deep-tow and 3D sections for most of the data. Some lines could not be matched by a single shift and in these cases there must have been one or more discontinuities during the acquisition leading to variable navigation errors.

The deep-tow data after shifting to the best match location can be directly compared to the 3D to evaluate the merits and disadvantages of the deep-tow system.

Post-stack positioning analysis was run by correlating the deep-tow stacks with the Tokai-Oki 3D volume to find the best matching positions of the deep-tow stack traces, using the Tokai-Oki 3D data as a fixed reference. A simple correlation of the picked sea-bottom times was attempted. In this case, the profile of picked sea-bottom times of the deep-tow stack sections were correlated with the picked sea-bottom horizon of the migrated 3D survey. This approach was more successful and it was possible to at least find the average shift between each deep-tow line and the 3D survey. In addition, by dividing each deep-tow line into 3 parts and matching each part with the 3D survey it could be seen that some deep-tow lines need a constant shift to provide a good match with the 3D data whereas for other lines a variable shift is required.

The analysis was carried out for the 8 deep-tow lines within the 3D survey. Fig. 11 shows the
analysis displays for D96-D Line. The result of the comparison between the deep-tow lines and the Tokai-Oki 3D data is shown in Fig. 12.

Fig. 11. Sea Bottom Profile Match. D96-D vs. Tokai-Oki 3D

Fig. 12. Deep-Tow Lines. Original Navigation Tracks (Green) and Corrected Tracks (red)

5. CONCLUSION

We reviewed navigation problems of deep-tow seismic survey carried out in 1996. These problems are fixed in the data processing sequence. But some other seismic survey data are required to be calibrated. We are planning to use deep-tow seismic survey for hydrothermal deposits. Hydrothermal deposit is specially limited and higher resolution is necessary than methane hydrates. The very high frequency of the data should make the navigation problem more severe. The more accurate navigation system should be necessary for the hydrothermal deposits.

REFERENCES

