roll with regard to the assigned numbers, the line numbering direction (high to low or vice versa), and the station numbering direction within each line.

QC monitor considerations

With a single line system, selection of a channel or group of channels for monitoring could be handled with reference to station number or system channel. The 3-D system must refer to a station with simply the line number and station number. To identify a remote unit, for QC testing or parameter checks (i.e., battery voltage), the reference is by line number, high or low side of the LIU, and count from the LIU.

Display of the line configurations is done a line at a time. For example, line 2 may be selected as the monitored line which will show the following parameters:

Look behind—Location of the last active geophone
First channel used—Ground station of first channel of the selected group (of line 2)
Gap location—First and last ground stations of the gap
Shotpoint location—Ground station at SP or next lower if off line
Recording truck location—Ground station of the recording truck
Last channel used—Last ground station of the selected group (of line 2)
Look ahead—Ground station of the farthest remote unit ahead of the recorded group (up to 72 stations may be selected)

Extended header information

A 3-D system must maintain a large record of the line configurations and current recording parameters. These data must be passed to the data processing center via the seismic data tape header. To identify the 3-D recorded data fully additional information is inserted in an extended header. Data requirements include truck flag number, SP reference number, SP location (line and channel reference), number of lines, number of Aux channels, multiplex location of the first Aux channel, Aux channel parameters (gain, notch, low cut, and alias), shorted channels (station number), and detailed data about *each* line as follows: CDP step position, number of channels, first channel, mux of first channel, flag number of first channel, gap size, gap starts after channel, flag number of first gap position, number of look-ahead channels, mux of first look-ahead channel, flag number of first look-ahead channel, and number of channel sets and parameters for channel sets.

Conclusion

Operation of a multiline 3-D system includes the requirement for identification of every line, SP, and station in the survey. With the selection of an appropriate numbering scheme, the seismic system will aid the observer by providing automated SP and line management. In addition, the fiber optic telemetry system discussed will supply all 3-D parameters to an extended tape header for use by the processing center.

The Reality of Trace Binning in 3-D Marine Surveying S21.5

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Three-dimensional marine seismic data collection involves recording swaths of subsurface reflections from a suite of closely spaced parallel lines. The method is necessarily complicated because of tides and ocean currents affecting navigation of the seismic vessel and the recording streamer. A variety of problems may arise which could seriously devalue the quality of the final product and these are discussed together with ways of compensating for them.

Two approaches to gathering marine 3-D data have emerged: "regular binning" and "dynamic binning". The development of these techniques is described and relative merits discussed. Once collection is complete, the processing geophysicist has some opportunity to minimize adverse features which have survived and may regather the data in an optimum fashion.

Introduction

In any 3-D seismic survey, subsurface reflecting horizons must be sampled spatially in two orthogonal directions. Processing of recorded data is greatly simplified if the spatial sampling interval, like the temporal sampling, is constant although the spatial interval may be different between the two orthogonal directions.

Operational problem

The marine environment is nonstationary. Tracking a line of preplot positions over the sea floor is like aiming at a moving target. The regularity of reflection points in space is dependent on the success of the navigator in compensating for the motion of tides and ocean currents. The problem is further complicated by the common-depth-point (CDP) stack process which at present is a necessary precursor to the migration operation. CDP stack is an approximation which breaks down further if the seismic cable does not track along the preplot line. In the presence of a cross current, the seismic cable streams along a track which is the resultant vector of the velocity of the towing vessel in the direction of the preplot line and of the cross current. Instead of forming a series of superimposed depth point locations, the system generates a swath of individual depth points.

An approximation to the CDP gather process is made by defining a small rectangular area called a "bin" and gathering as a CDP set all traces which fall within it. Where cable feathering is minimal, the bin gather resembles a CDP gather but where feathering is large, the density of traces within a bin is reduced, often seriously. The gather may be further complicated by the addition of traces overflowing the location from adjacent lines. Hence, techniques of binning swaths of 3-D marine data have been developed and specifications for trace assemblage requirements formulated.

Binning techniques

3-D methods and swath shooting techniques were developed on land prior to marine because of the easy solution to the navigation problem. The first marine surveys therefore used the land technique of swath shooting and gathered traces into a set of regular rectangular predefined bins, except that a single boat operation was involved for simplic-

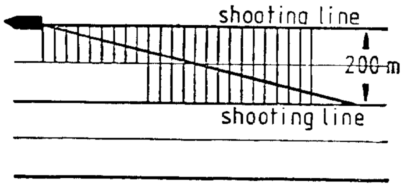

FIG. 1.

conventionally as for 2-D with the addition of magnetic compasses in the streamer, a tow point orientation device, and an electronic interface to log the output from these units and the ships gyrocompass on the navigation tape.

The line spacing was initially 200 m with the shotpoint and depthpoint interval of 25 m, although the bin dimensions were 50 m in-line and 100 m cross-line, that is, half the preplot line spacing. The term "half-line binning" is applied to reflect this relationship. These early surveys enjoyed only a qualified success. The coarse line spacing limited to low values the frequency at which data could be migrated in the cross-line direction without inducing aliasing effects. Streamer feathering angles are often inconsistent in both magnitude and direction so that the trace assemblage in any suite of bins was highly irregular leading to a very variable stack response. Occasionally, a line of bins was devoid of traces completely. The next step was to close up the line spacing and match the cross-line bin dimension exactly to this interval.

A greatly improved quality of 3-D migration results because the bins contained near traces, most if not all offsets and were dominated by traces from the "prime" line, that is, the line being processed. This "rule of three" proved to be an important requirement in 3-D migration. So far, the bins described have been static or "regular" bins which were essentially determined prior to data collection. The rule of three could be optimized if the bins were created after data collection and forced to include near traces close to one end. Then by extending the bin in the direction of feather, a continuous range of offsets from the same line would be captured. Only in cases of large feather angles would far traces be lost and these could be replaced by far traces overflowing from an adjacent line if cross currents were favorable. This form of binning is termed dynamic binning and neatly addresses the problem of binned trace assemblage since comparison to a conventional stack is significantly improved.

So far, however, line spacing has not been addressed. Each stacked trace submitted to a migration process requires an assigned pair of location coordinates. These may be derived with varying degrees of precision in numerous ways. An initial approach was to average the location coordinates of the traces within a bin and assign those means to the stacked trace. This method acknowledged unequal spacing of the bin-stacked lines (see Figure 2), and through the use of a Kirchhoff integral migration routine, maintained the integrity of lateral offsets throughout. Alternatively, if regular binning is applied, the coordinates of the bin centers could be assigned to the stacked trace positions and the regular grid of stacked data is readily amenable to migration using the finite-difference or F-K transform methods.

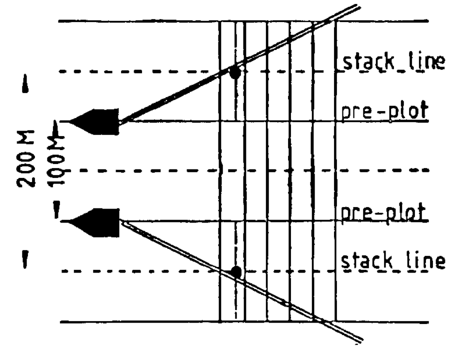

FIG. 2.

Depth-point steering

Two approaches have emerged, one based on a regular grid of bins but lacking in consistent trace assemblage, the other utilizing dynamic bins to obtain a consistent trace assemblage but lacking in a consistent and regular line spacing. The necessary improvement to both methods is achieved essentially the same way, through the introduction of real time on-board binning, and depth-point steering.

In the case of a grid of regular bins, an on-board computer keeps track of trace positions as they are created and logs changing trace content of bins. The vessel is steered to obtain a maximum trace assemblage which includes near, medium, and far offsets and involves most of the range available. Where feathering is severe, several passes are made to steer a different range of offset traces into a line of bins to achieve certain minimum specifications. A high level quality assurance display system is necessary to ensure that good coverage is being acquired and to expose areas requiring further work.

In dynamic binning, the vessel is also steered off-line in the presence of cross currents. The on-board software sets up the bin, computes the trace assemblage so contained, and determines the mean trace location. This location is displayed and the vessel steered to place it on the preplot line (see Figure 3). A regular stacked line spacing suitable for input to 3-D migration is obtained. The software also logs the trace assemblage within each bin and any traces which may overflow into the bins of adjacent lines. Ultimately, both methods produce the desired result which is a plan of evenly spaced, consistently filled bins of traces spanning a full range of offsets.

Processing problem

The data processor has no opportunity to reshoot or to correct imperfect collection. However, he does have an

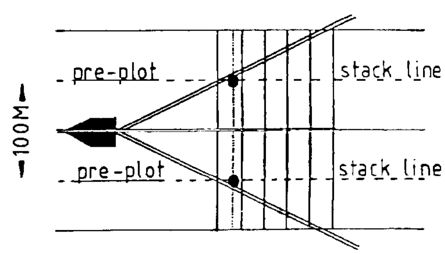

FIG. 3.

opportunity to minimize collection anomalies and an obligation to avoid processing induced anomalies. The object of the 3-D survey is the production of a valid 3-D migration supporting interpretation and lithologic analysis. It is useful to analyze some collection and processing anomalies which detract from optimum migration.

Amplitude anomalies

Unusual noise and erroneous stacking velocities may induce or fail to diminish amplitude anomalies. A 3-D prospect is susceptible to several unusual sources of amplitude anomaly. The limits on the dimension of processings bins create a situation where a regular bin structure may not have enough traces to produce respectable amplitude response. One of the realities is that an adjacent bin will usually have excess contributors, compounding the anomaly. The CDP method depends on a continuous distribution of offsets among contributing traces. One of the most damaging situations is a trace bin composed of a few near and a few far traces with nothing between. This results in a poor stack response of primaries, and aliasing of multiples. Redundant contributions from the same or similar offsets causes the same problem. A lower level anomaly may occur when the data to be stacked are from different recording lines. Differences in sea state, streamer or source configuration all lead to irregularities in the set of traces. Additionally a problem may be induced by "smear" across the collection bin.

Time anomalies

Again all the standard nemeses of the seismic processor must be comprehended by the 3-D marine processor. The realities of any binning or collection method are anomalies in the relative location of one line of to the next. A location, spacing, or navigation anomaly will manifest itself as a time discontinuity in sampled wave fields. Since the processor has control over bin placement and size, to some degree he is able to counteract some collection anomalies. Perhaps the most important consideration is the presence of near offsets within the bin. A lack will cause stacked primaries to be unusually sensitive to velocity variations, perhaps creating irreconciliable time anomalies. If the recording vessel is operating with limits on deviation from the preplanned line, near traces are usually available. The binning algorithm should then complement the binning technique employed in the field.

Another consideration in bin size and placement is "prime line precedence". A swath of depth points from the prime shooting line is preferred. The gather of traces in a processing bin should begin with the near trace from the prime line and continue selecting traces within the bin from that line until midpoint locations creep beyond bin edges. The next potential offset is selected within the bin from a secondary line if found. This process continues selecting data from continuous swaths of coverage until the maximum fold criteria is reached, or potential contributors are exhausted. Since a feathered cable implies a continuous swath of midpoint coverage, it is advantageous to place the near-trace midpoint near one edge of the bin. The reality is that it works well if there is little feathering, but may be quite poor for large, directionally variable feathering. An alternative for variable feathering situations is to place the near-trace midpoint at the center. Thus the computer process may

The width of the bin may be chosen slightly larger than the prescribed line spacing; about 20 percent. This will minimize potential gaps in wave field sampling due to cross-line adjustment of bin centers.

Field example

Figure 4 illustrates the dynamic binning procedures. The intended stacking geometry required CDP traces at 12.5 m by 75 m. Figure 4a is a map view of one processing bin. The bin was centered near the short offset midpoint due to variable feathering. The shot spacing was 25 m; therefore, every other offset is expected within a 12.5 m bin. The midpoint locations are labeled only with the original trace numbers and shooting line. Traces 95 through 79 were gathered from the prime line, 76 through 42 from the next line south, and finally 41 through 2 from the third line. Note that location irregularities due to compass and depth transducer sections affected the trace number sequence. The geometric CDP location and the bin center are also indicated. The geometric location would have been the center of a regular bin.

Figure 4b is a display following conventional NMO. There are three distinct sets of event times and differences in noise content. This is typical of binned data. Figure 4c is the same data, but with 3-D NMO including location corrections based on a 3-D time and velocity model. The event mis-ties are almost totally absent between 1 and 1.5 sec. At about 2.0 sec the correction is not as evident, attesting to inaccuracies of the model or noise content. The 3-D NMO operation incorporates variable stacking velocities due to azimuth and time variant statics to account for location. In this case the location correction moved the data to the geometric CDP location to enhance migration.

The CDP method is to some extent self-correcting. Velocity derived for stacking will automatically compensate for some smear. Therefore, shot position has a large effect on determining final event time.

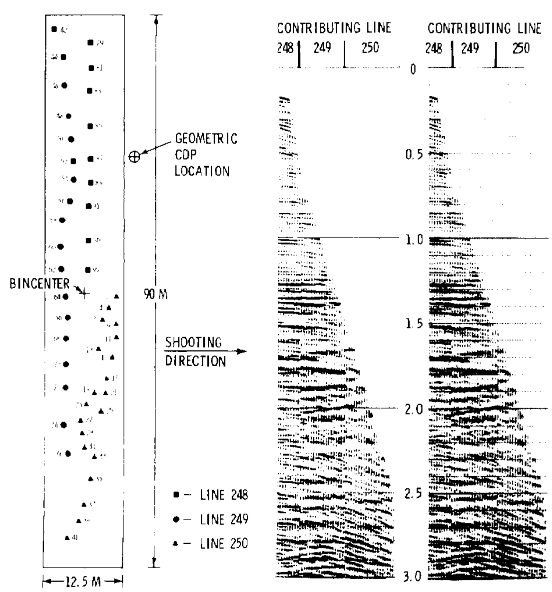

FIG. 4. (a) Trace bin for 75-m line space by 12.5-m CDP space with 3 contributing lines. (b) Binned after standard

Problems

The most common problems experienced are missing coverage (obstacles, etc.) and navigation errors. There is no perfect method for generating data where coverage is absent. Losses may be minimized using an *F-K* transform incorporating a resampling of *K*-space and an inverse transform. The operation would fill some gaps in the coverage, but at the loss of spatial bandwidth. Later methods use a subsurface time model to perform discrete location adjustments to recorded data and a weighted composition of adjusted traces adjacent to a gap. This will provide continuous sampling of the wave field, accurate to the extent of the model.

Navigation induced anomalies

The nature of a 3-D prospect requiring even, consistent sampling of the seismic wave field provides the solution to navigation errors if they should occur. Routine quality control products include cross-line displays. Ideally these should have the same appearance as the in-line displays. Undiscovered navigation errors will likely be uncovered. Further investigation may use horizontal displays which are very sensitive to time anomalies.

Conclusions

3-D marine collection procedures should be complemented by processing procedures. This is becoming increasingly important as more contractors gain 3-D capability and collection and processing contracts are divided between service companies.

Dual Vessel 3-D Marine Surveys S21.6

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Various sorts of obstacles such as production platforms may hinder the conventional acquisition of 3-D marine data. The dual vessel technique may then be applied. Continuous monitoring of the acquisition through RTB (real time binning) has been extended to this method. This paper deals with the problem of the accuracy of the relative positioning of the seismic source and the captors and its effect on the seismic quality data. The first arrivals on records resulting from one boat operation are first analyzed, so as to create maps of superficial refraction markers under the sea floor. Statistical comparisons are then made with first arrivals from 2 boat recordings, using coordinates of sources and captors deduced from radio positioning and cable drift measurements. Conclusions are drawn relating to the possible smearing effect of inaccurate binning of the data and to the maximum resolution of the method.

In offshore oil production, a logical sequence of operations would include a 3-D seismic survey after each successful exploratory well on a new structure. In real life this is not always accomplished, so that the need for a 3-D survey is often felt at a time when obstacles like production platforms are permanently installed. Furthermore, in many productive areas, the obstacles relating to producing fields other than that to be studied are close enough to present navigation problems for seismic boats towing a 2-mile long streamer.

source and recording vessels. The lateral offsetting of the source vessel allows for investigation of those CDP strips presenting obstacles. An additional advantage is due to the fact that the source vessel can safely get closer to the platforms than the cable towing vessel.

Theoretical calculations, based on statistical studies of one-boat operations, showed that the accuracy with which the relative position of the two boats and the cable is measured should be sufficient for the proper binning of each trace and for the NMO correction within the most energetic passband of the seismic spectrum.

Appropriate radio equipment must be installed on board both vessels, so as to transmit in real time the radio navigation data, as well as the shooting time and the source signature (if necessary for processing).

For continuous monitoring of operations, the RTB (real time binning) system as described in a previous paper (Regnaudin et al, 1981) was extended to dual vessel operations. Coordinates of the midpoints of each trace are calculated by the RTB minicomputer and displayed on the color RTC according to a code showing the number of traces which fill each line of bins in the grid. In some cases, if the shooting rate is not too high, the acquisition may be conducted alternately from the two vessels. The progress of the two CDP lines is visualized simultaneously on the screen.

A few 3-D surveys were conducted using this technique in the Gulf of Guinea and the Gulf of Mexico; corresponding data are being analyzed in order to check the acceptability of the above assumptions. First the water breaks and first arrivals on short traces are analyzed in order to check the accuracy of the relative positioning of the two vessels. The figures are compared to that derived from the radio positioning data. This confirms that the relative position is known with a standard deviation equal to $\sqrt{2}$ times that of each individual positioning, which with Syledis on platform in the Gulf of Mexico amounts to 2 m.

Over the entire survey area, the first breaks of single-boat records are analyzed. Several refraction markers are identified below the sea floor. Maps of velocity and delays are established for each of these markers. The first breaks of two-boat recordings are compared to what would have been their time on single-boat operations. For this purpose, the first arrivals are selected on a sample of corresponding records, depending on their offset as calculated from radio positioning data and magnetic cable drift measurements. Histograms of distance differences are established versus various parameters such as lateral offset, longitudinal offset, and regional situation on the grid. Conversely, CDP gathers are established encompassing both single and dual boat recorded traces and corrected for refraction velocities. This enables us to evaluate the smearing effect of relative positioning inaccuracy for offsets greater than those of single boat operation. The problem of the fine binning of the data is addressed in view of the above analysis, and a limit is set accordingly to the minimum size of binning, depending on the cable length.

The accuracy of the NMO corrections is discussed: here again, a limit is set to the high resolution capacity of the method. However, if the direct use of the distances measured by radio positioning and cable drift leads to a substantial fuzziness of the stack, an attempt can be made to use the variations in time of the first breaks in computing the NMO