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3-D Seismic Gridding

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ABSTRACT

3-D Seismic Gridding is a geophysical technique that converts arbitrarily oriented 2-D seismic data in an area into a dense, evenly spaced 3-D data volume. This technique makes use of apparent dips measured on the 2-D lines and reconstructs the three-dimensional structure so that trace interpolation performed along the structure thereby avoids aliasing. Amplitude of the interpolated trace is obtained from the input data but is weighted by the distance from the input data as well as the semblance of dip measurements. Unmigrated 2-D data sets are the input, so the regridded data can be 3-D migrated.

Several examples of 3-D regridded data in the offshore Gulf of Mexico will be shown and their merits and limitations will be discussed.

INTRODUCTION

The benefits of 3-D seismic data are well known in exploration seismology. It is generally recognized that 2-D seismic processing and interpretation cannot be valid in an area where complex geology is involved; out of plane reflections, misties between inlines and crosslines as well as incorrect amplitude are problems often encountered in 2-D data. These problems arise because seismic events are reflections from 3-D geologic structure and can only be unraveled by 3-D data. From an imaging processing point of view, 3-D data allow 3-D migration in which the recorded wavefield is processed according to correct physical principles without making any spurious assumptions as in 2-D processing. Events after 3-D migration will move to their correct spatial positions and seismic amplitudes are properly imaged. The flexibility of 3-D data display and the use of a workstation for interpretation also allow fast and accurate evaluation of a large amount of data.

References and illustrations at end of paper.

Although 3-D seismic is an accurate exploration and exploitation tool, only a small number of 3-D data sets are collected each year by industry due to the high cost and time consuming procedures in acquiring and processing 3-D data. Futhermore, in many areas where much 2-D coverage exists, an additional 3-D program over the same areas may seem redundant or uneconomical. In this paper, we present a cost-effective way to utilize the existing network of 2-D lines and synthesize them into a 3-D data volume so that the benefits of 3-D processing and interpretation can be realized. The technique involves regridding or trace interpolation from the existing 2-D data.

3-D seismic interpolation has been attempted in the past. Chilcoat et al (1983) discussed the approach of space-time filtering techniques for regridding and interpolation. Recently, French et al (1987) proposed using a Common Reflection Point (CRP) stacking method for the 3-D interpolation process. The filtering technique has severe dip limitation due to spectral aliasing. On the other hand, the CRP stacking method makes use of structural dip information to compute the subsurface reflection point as the stacking bin. Our technique differs from the CRP method in how the structural dip information is utilized to reconstruct the three-dimensional structure. Dip as it appears on 2-D lines is the apparent dip and it varies as a function of azimuthal angle of seismic profile. However, the apparent dips are related to the true structure in a definite way. This relationship is programmed into our interpolation scheme, therefore synthesized traces will faithfully honor the structure as demanded by the dip data.

METHOD OF CALCULATION

The concept of dip plays a central role in our regridding process. Dip, by definition, is the change of structure over distance. The structural dip as it appears on the seismic data is time step-out per trace and it is a quantity that can be measured accurately from seismic data. Because dip changes continuously for complex geology, the structure can be accurately represented only if dip is measured locally and continuously. In our computational scheme, dip is calculated at every time sample for every trace. This is done by an automated dip search over possible time moveout using the semblance measurement for every sample. The result is a dip section for every input 2-D line.

After calculating the dip, the structural configuration that corresponds to the dip needs to be found. The way we tackle the structural problem is to fit curved surfaces to the apparent dips for each time slice. If we envision the apparent dips extracted from a single time slice as "dip outcrop", then the structures at that time would be local surfaces that fit the dip outcrop. Numerical calculation shows that curved surface fittings to dip data are at their best when curved surface patches are fitted in a localized area, preferably within a closed loop of the input seismic lines.

The precise mathematical relationship between apparent dip and azimuth angle can be simply expressed as:

$$\frac{DT}{DS} = \frac{\partial T}{\partial X} \text{ COS}\,\alpha + \frac{\partial T}{\partial Y} \text{ SIN}\,\alpha \text{............} (1)$$

Where DT/DS is the apparent dip measured in the profile orientation S with an azimuthal angle α , X and Y are an arbitrarily chosen coordinate system. If T is expressed as a polynomial function of X and Y in any arbitrary order, then the partial derivatives on the right-hand side of equation (1) can be derived explicitly. Coefficients of a polynomial surface can be inverted by solving the normal equation. The choice of order of the polynomial surface is a matter of judgement; it depends upon the complexity of the structure. Locally, a cubic surface may suffice.

It may be worthwhile to point out that our structural reconstruction is based on all the dip measurements rather than only on dip data at the line intersections as often advocated in other regridding techniques. Data which do not happen to be at the line intersections are legitimate points and should not be discriminated against. In our computational scheme, no preference is given to the spatial positions of the data points and they are all treated equally in the regridding process.

The T as obtained from equation (1) are used to calculate the time differences between the interpolated point and the surrounding input traces. The amplitude of the interpolated trace is obtained by summing the amplitudes of input traces at the times according to the calculated time surface. Also, the amplitude is weighted by the distance from the input data as well as the semblances of dip measurements. Since the interpolation is based on structural dip, so the interpolated data must honor the structure for that time slice. The fact that the surface fitting and gridding is performed in the localized line loops and for every time sample has the advantage that the gridding is capable of handling complex geology, for every change in the time slice, the structure and gridding is concurrently updated. The procedure is repeated for every time slice and finally a 3-D data grid is generated with any desired output spacing.

EXAMPLES

The gridding technique has been applied to regrid the 2-D data in the Pennzoil leased blocks offshore Gulf of Mexico where the line spacing of the 2-D grid is generally less than one-half mile. To achieve the best result, certain data requirements are recommended: (1) line misties should not exist within the individual surveys, (2) digitized navigation information is needed for all lines, (3) data should have reasonable signal to noise ratio and frequency content, (4) data should be processed using relative amplitude techniques if relative amplitude output is desired, (5) input data are post-stack and unmigrated, preferably including DMO processing, (6) maximum line spacing is one-half mile, but closer spacing is better.

Figure 1 shows 26 input 2-D lines with line spacing of one-half mile in the typical offshore Gulf of Mexico coarse 2-D shooting. Figure 2 is an outline of the output grid with grid spacing of 82 feet and Figure 3 is a time slice from the output grid after 3-D migration on the regridded data. The structural configuration as exhibited on the time slice is as accurate as one could expect from the input 2-D data because all the structural information is used in the reconstruction process. As far as the resolution of the output data is concerned, it depends upon the spacing of the input lines. Figure 4 shows the dense input grid consisting of 115 lines from 18 surveys, including the data in Figure 1. Figure 5 is the extracted time slice (at the same time as Figure 3) based on dense input. It can be seen that the structures are almost identical as in Figure 3, but the resolution is better from the dense input data as expected.

Another example to demonstrate the benefit of 3-D gridding is the "bright spot" interpretation in which the accurate position of the amplitude anomaly is crucial in locating a well. Figure 6 shows a 2-D line in the offshore Gulf of Mexico where a nice bright event can be identified at about 2.4 second. A well was drilled at the location and no hydrocarbon or anomaly was encountered at the prospective horizon. This was originally classified as "false bright spot". However, close examination of the data indicates that a cross dip component may be present at the event and the bright spot is probably sideswipe from out of plane reflection. This area was subsequently 3-D gridded, and the same line was extracted from 3-D migrated data as shown in Figure 7. The bright spot is no longer present on this line, but can be traced up-dip where it should belong.

DISCUSSION

3-D Gridding from 2-D input is a convenient technique to integrate the existing, randomly oriented 2-D data. The resulting 3-D data cube that allows fast and accurate evaluation of a large amount of data. From a structural mapping point of view, the gridding process facilitates the structural interpretation procedures by which all the modern 3-D interpretation techniques, including the workstation, are equally applicable to the 2-D data. 3-D migration is a must in the area of complex geology; it is an operation that cannot be performed easily or accurately in the conventional 2-D structural mapping.

The 3-D gridded data undoubtedly have their limitations. They are not real 3-D because the input 2-D lines may not be dense enough to meet the 3-D sampling requirement and as a consequence, the gridded data generally do not have the resolution of real 3-D. The gridded data set also does not share the benefits of prestack processing such as prestack 3-D migration, 3-D velocity analysis; techniques that have attracted much attention in recent years to improve the quality of seismic data. But based on our experience in using the 3-D Grid technique in real time exploration over the past several years, we feel the benefits of 3-D gridded data much outweigh the limitations.

CONCLUSION

The technology of 3-D Gridding involves formulating and implementing the production of continuous three-dimensional seismic coverage over an entire survey area, using existing or acquired 2-D seismic data. Although the regridded data set is not a substitution for real 3-D, this technique is a viable exploration and exploitation tool and proves to be a cost effective way to evaluate prospects.

ACKNOWLEDGEMENT

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REFERENCES

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(2) French,W.S. and Miller, M.H. Jr.: "Time Slices from 2-D Seismic Surveys" paper presented at the 57th Annual International Meeting, Soc. of Explor. Geophys., New Orleans, Louisiana, Oct. 11-15, 1987

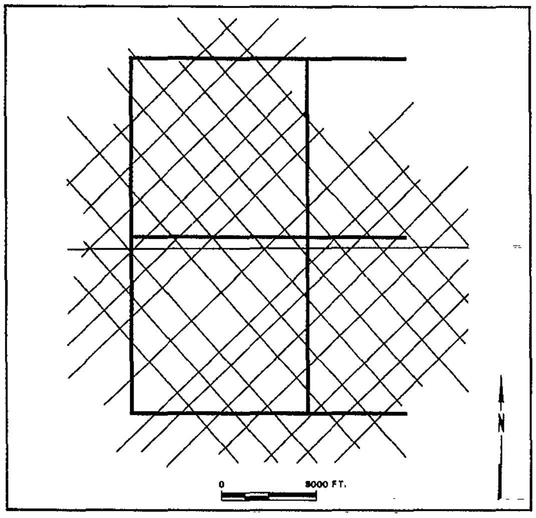

Fig. 1—One-half mile spaced input data consisting of 26 lines from one survey.

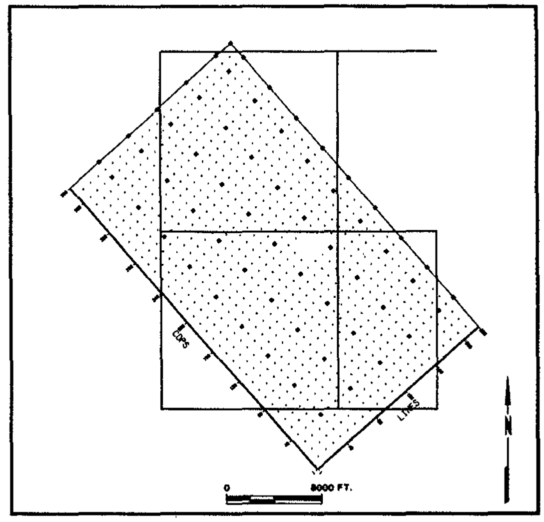

Fig. 2—Map of 3-D GRID output.

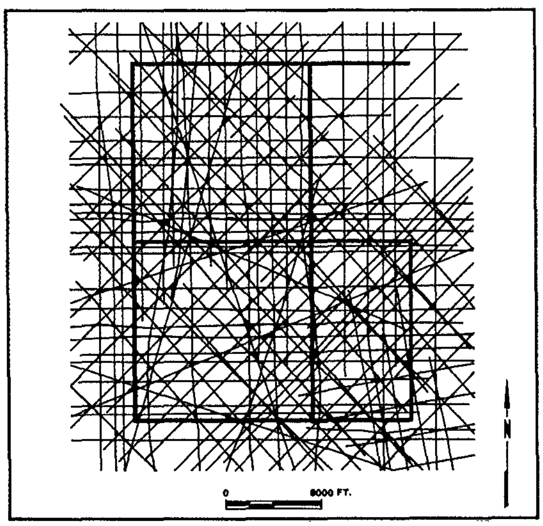

Fig. 3—Timeslice from 3-D GRID of ½-mile spaced input.

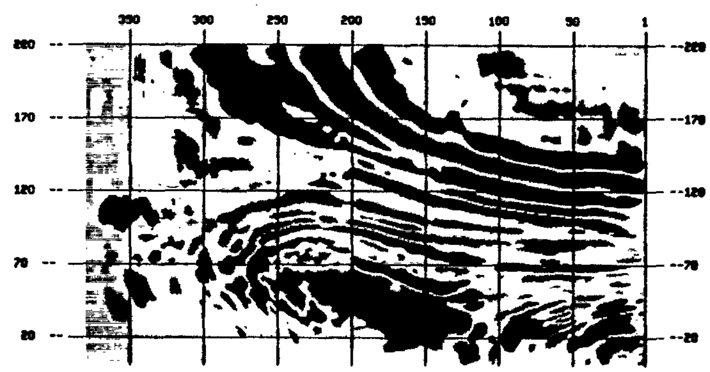

Fig. 4—Dense input grid consisting of 115 lines from 18 surveys, including the data in Fig. 1.

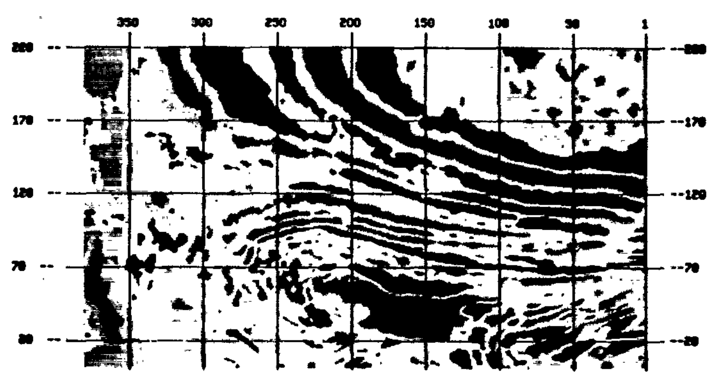

Fig. 5—Timeslice from 3-D GRID of dense input st at the same time horizon shown in Fig. 3.

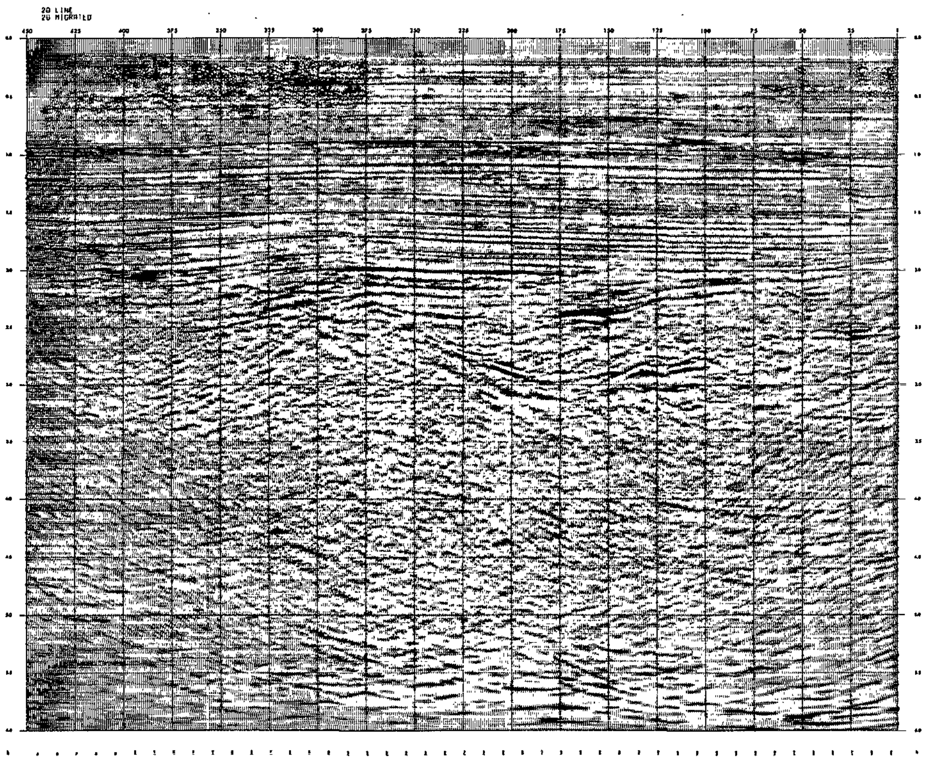

Fig. 6—Original 2-D line with bright spot anomaly.

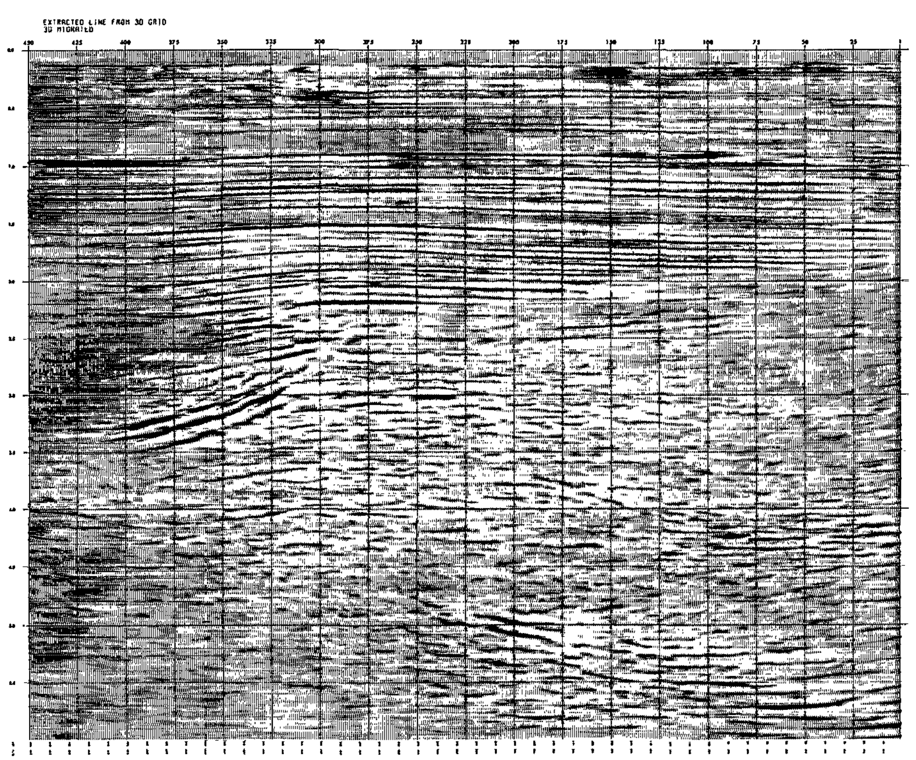

Fig. 7—Extracted line from 3-D gridded data at same location as Fig. 6.