References

Argaud M. J. (1976), 'Geophysical interpretation at Gurubang, NSW', Unpublished Report MG690, Aquitaine Australia Minerals Pty. Ltd.

Bruvel F. J. & Sorby L. A. (1985), 'Evaluation of an airborne geophysical test survey in the Clermont Area', *Rec. Geol. Surv. Qld.* (in preparation).

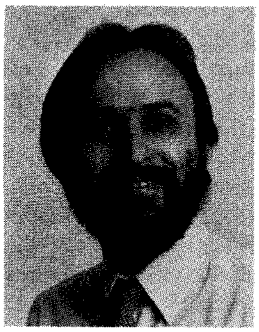
De Moully G. T. & Becker A. (1984), 'Automated interpretation of airborne electromagnetic data'. *Geophysics* **49**, 1301-1312.

Seigel H. O. & Pitcher D. H. (1978), 'Mapping earth conductivities using a multifrequency airborne electromagnetic system', *Geophysics* **43**, 563-575.

Trussell D. (1982), 'Geophysical case history of a mobile zone nickel deposit', Proceedings of 44th EAEG Meeting.

Valsardieu C. A., Harrop D. W. & Morabito J. (1981), 'Discovery of uranium mineralisation in the Manyingee Channel, Onslow Region of Western Australia', *Proc. Australas. Inst. Min. Metall.* **279** 5-17.

Whiting T. (1982), 'Surficial conductivity mapping with INPUT airborne EM system and its application to coal exploration', Proc. Fourth Internat. Coal Explor. Symp. Sydney, Australia, pp. 1-17.



Graham Butt received a BSc degree (1971) and a Graduate Diploma in Applied Geophysics (1972) from the University of NSW. From 1973 to 1984 he worked with Geoterrex on field surveys throughout Australia and in North America. Since 1977 he has been Manager, Airborne Geophysics for Geoterrex Pty Limited. He is an associate member of the ASEG and SEG.

G. Butt, Geoterrex Pty Ltd, 13 Whiting Street, Artarmon, NSW 2064.

Suppression of backscattered coherent noise by pre-stack partial migration

Ron Chambers, S. Cole, Ken Larner, Helmut Jakubowicz and Wendell Wiggins

Introduction

Linear coherent noise frequently plagues marine seismic data in areas where the reflected energy is weak. This noise may arise in a number of different ways, but it has recently been suggested that the major culprits are diffractors located near, or at, the water bottom (Larner *et al.* 1983; Newman 1984). The diffraction patterns corresponding to such scatterers have stacking velocities that increase from the water velocity at the apex to very large values out on the limbs. As a result, the stacking velocity for the diffraction tails can coincide with that of deeper events at corresponding reflection times, and the tails of the diffractions will then stack coherently together with the deeper reflections. By contrast, since the diffractors can, in general, lie out of the plane of the survey, the apexes of the corresponding diffractions will appear below the water bottom and therefore be attenuated by stacking. The result is that the diffractions manifest themselves in the stacked data as the familiar strong linear events corresponding to diffraction hyperbolas without apexes.

Aside from simply obscuring the data of interest on the stacked and migrated data, coherent noise also gives rise to two further problems: first, because the stacking velocity of the diffractions is similar to that of reflections, it can easily be mistaken for reflected energy in the velocity analysis. As a result, velocity estimation can become ambiguous. Second, the presence of the noise adversely affects any pre-stack processes, such as predictive deconvolution, that use the perceived signal in the data to determine their overall action.

In this paper we demonstrate that pre-stack partial migration (PSPM) can be an effective method for reducing coherent noise. This is suggested by the fact that PSPM followed by post-stack migration is equivalent to migration before stack. In practice, however, the noise gets suppressed for a different reason; the constant velocity formulation of PSPM fails to accurately treat media with extreme vertical velocity variations. Thus, while the near-surface diffracted energy should stack at a low velocity, the energy along the limbs of the diffraction at late times will be misstacked when the higher formation velocities are used.

Methods of eliminating coherent noise

Larner *et al.* (1983) and Newman (1984) have discussed several techniques for eliminating coherent noise. The simplest method is to dip-filter the stacked data so as to remove data with the time slope that characterizes the noise. This technique is, however, at best a cosmetic procedure that merely allows the remaining signal to be seen more easily; it cannot correct for errors introduced by incorrect choices of stacking velocities or errors incurred through the inappropriate action of any data-dependent, pre-stack processes that have been performed. It is therefore preferable to apply some form of noise-elimination procedure prior to stack.

Until now, the recognized method of attacking coherent noise prior to stack has been to dip-filter common-shot and common-receiver gathers to remove the linear events on these gathers that correspond to the diffraction tails. Some rejection can also be achieved during acquisition through the use of source and receiver arrays. These methods work well, but do have some problems associated with them. Dip filtering of common shot and receiver records is expensive and, because these gathers have limited spatial extent, problems arise in the design of the appropriate dip filters. The use of field arrays, on the other hand, is relatively economical, but often the lateral extent of the source arrays that would be required to effectively eliminate diffractions that lie out of the plane is much larger than can be achieved in practice (Lynn & Larner 1983). Furthermore, both these methods, as well as simple dip-filtering of stacked data, risk removing other dipping energy that is of interest. Thus, the use of wide source arrays in 3-D surveys can be especially dangerous since they could preclude the measurement of some of the out-of-the-plane reflections that would be required for a full 3-D migration.

Pre-stack partial migration as a method of eliminating coherent noise

In this paper we suggest that pre-stack partial migration (PSPM), also known as 'dip-moveout correction' or 'offset continuation', can be used as an effective method for reducing coherent noise. PSPM is an additional processing step that is applied after normal moveout correction. After PSPM, events stack at their migration velocities, independent of their dip, and, unlike data that have been corrected only for normal moveout, PSPM data correspond to zero-offset (Hale 1983).

PSPM applies strictly to constant velocity media. In practice, the constant velocity theory readily extends to media that have purely vertical velocity variations, provided that the gradient of the velocity variation is not too large. In the case of the transition between the water layer and the rocks beneath the water, the gradient of the velocity is usually larger than can be accurately handled by the theory. In these circumstances, when PSPM is applied to data containing coherent noise, the diffraction tails have their stacking velocities converted to values that are closer to the water velocity, while the events corresponding to reflections at depth will then stack at velocities that are closer to the root-mean-square (rms) velocity for propagation through the subsurface; the stacking velocities of horizontal events, such as the apexes of the diffractions, remaining unchanged. As a result, whereas after PSPM the diffractions would stack best at low velocities, they are stacked out by a choice of stacking velocities corresponding to the rms velocity of the medium. This elimination of the coherent noise by misstacking can be further enhanced by application of an explicit velocity filter, either during the application of PSPM or afterwards, on the common-midpoint gathers.

Strictly, the removal of coherent noise is a failure of PSPM. Ideally, PSPM would make all primary events on a given common-midpoint gather stack coherently with a single time-dependent velocity function. Because the model assumed in the theory of PSPM has a constant velocity, PSPM causes coherent noise from shallow scatterers to misstack, rather than stack coherently. This is actually the converse of what happens in conventional stacking. There, because simple normal-moveout cannot correct the diffractions at long offsets, the CMP stack suppresses the apexes but retains the troublesome diffraction tails. By contrast, PSPM attempts to make all of the diffracted energy from the shallow subsurface stack at a single velocity corresponding to its migration velocity (typically that of water); in so doing, however, it causes that energy to misstack because the migration velocity of the deeper section differs greatly from that of the shallow subsurface.

We prefer to consider the elimination of coherent noise as a benefit, rather than a failing, of PSPM. Indeed, the benefits of this method of eliminating coherent noise make it a very attractive alternative to other methods of removing coherent noise. First, while sharing the benefits of the other pre-stack methods, it is computationally more efficient than dip-filtering of common-shot and common-receiver gathers. Second, PSPM offers the advantage of an improved treatment of dipping signal while simultaneously discriminating against the dipping noise. Finally, since PSPM is not an explicit dip-filtering process, it does not suffer from the problems encountered in the application of other (overt) dip filters (whether applied before or after stack). PSPM incurs no loss of resolution through accidental removal of steeply dipping energy (in fact it actually *increases* the spatial resolution of the data) and, provided that the fold and offset range of the data are sufficient, does not suffer from artifacts arising from the limited spatial extent of the data.

Data example

Figure 1a shows a conventional common-midpoint stack from the Gulf of Mexico, and Fig. 1b shows a stack of the same data after PSPM has been applied. The data are from an area in which bedding with generally gentle dip is uplifted and interrupted by salt intrusions. Of considerable interest are the boundaries defining the flanks of the salt domes.

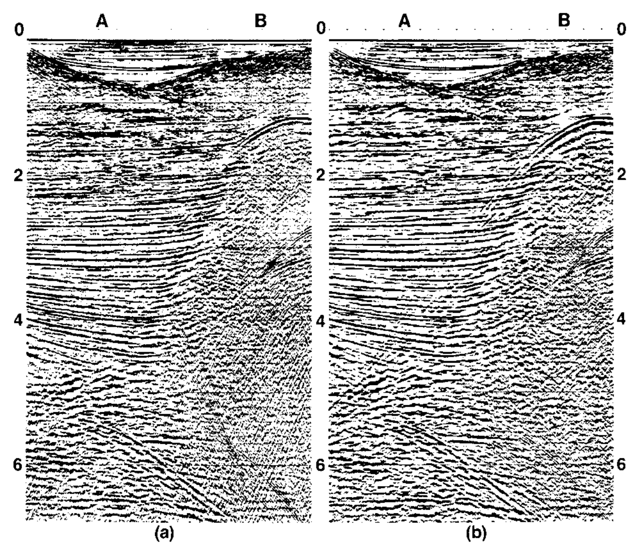


Fig 1a Conventional CMP stack of data from the Gulf of Mexico.

Fig 1b Stack of the same data after PSPM has been applied.

The two sections show significantly different treatment of steeply dipping signal. In the PSPM-processed data, reflections and the tails of diffractions from the top and flank of the salt intrusion are clearly imaged, whereas in the conventionally-processed section, only faint hints of these steep features are present. The same is true for the relative imaging of the diffraction whose apex is at Location A, at about 1.2 s.

The two sections differ as much in their treatment of the linear, coherent noise as in that of signal. In the conventionally-processed data, noise with large moveout abounds at late time (below about 4 s), particularly within the weak-signal zone inside and below the salt intrusion. That noise is virtually absent from the PSPM-processed data.

Relative to the conventionally-processed data, the PSPM-processed data show (1) comparable treatment of the gently dipping bedding, (2) general enhancement of the dipping events, and (3) suppression of the coherent noise. These desirable features of the PSPM results have been achieved without the loss in lateral resolution or the introduction of artifacts (i.e. alignments associated with the frequency-domain boundaries between the regions of rejected and preserved dips) usually found in dip-filtered data. Also, these results were achieved with substantially less effort than would be required for dip-filtering of common-shot and common-receiver gathers. This data example confirms that PSPM can provide the combined benefits of efficient enhancement of dipping signal as well as an effective suppression of dipping noise.

References

Hale D. (1983), 'Dip-moveout by Fourier transform', PhD thesis, Stanford University, May 1983.

Jakubowicz H., Beasley C. & Chambers R. (1984), 'A comprehensive solution to problems in the processing of 3-D data', Abstract for paper presented at the 1984 meeting of the Society of Exploration Geophysicists, 2–6 December, Atlanta, Georgia.

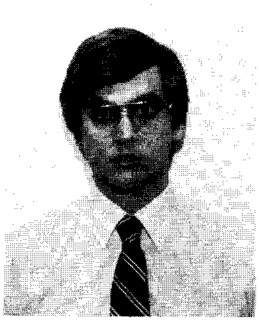
Larner K., Chambers R., Yang M., Lynn W. & Wai W. (1983), 'Coherent noise in marine seismic data', *Geophysics* **48**, 854–886.

Lynn W. & Larner K. (1983), 'Effectiveness of wide marine seismic source arrays', Paper presented at the 1983 Offshore Technology Conference, Houston, Texas.

Newman P. (1984), 'Seismic response to seafloor diffractions', *First Break* **2**, Feburary.

Ronald E. Chambers received a BS in physics from Colorado State University in 1964. He joined Western Geophysical Company in 1964 and worked with field crews as computer, chief computer and party chief in the Rocky Mountains, the Gulf Coast and in Canada. He later worked in the Houston Research and Development Department as a programmer and is presently a Technical Coordinator of Geophysics (Western Research). Ron has a special interest in design and application of geophysical software and is a member of the SEG, EAEG, and Sigma Pi Sigma.

R. Chambers, Western Geophysical, PO Box 2469, Houston, Texas 77252, USA.



Steve Cole received his SB degree in Physics from the Massachusetts Institute of Technology in 1983. He then joined Western Geophysical Company as a Research Geophysicist. His interests include seismic signal processing and data acquisition. He is a member of SEG and Sigma Pi Sigma.

S. Cole, Western Geophysical, PO Box 2469, Houston, Texas 77252, USA.

Kenneth L. Larner received the degree of Geophysical Engineer from the Colorado School of Mines in 1960 and a PhD in Geophysics from MIT in 1970. He served two years as an officer in the Army Corps of Engineers at the Lawrence Radiation Laboratory in Livermore, California and in Vietnam. During 1967–1969, he was a Senior Research Engineer for EG&G, Inc. in Boston. In 1970 he joined Western Geophysical Company as a Senior Research Geophysicist specializing in signal processing, wave propagation, and velocity studies. He received the Best Presentation Award for a paper presented at the 1975 SEG Annual Meeting in Denver; Best Paper at the 1976 CSEG Meeting in Calgary; Best Paper in *Geophysics* in 1976; outstanding OTC Geophysical Paper, 1978; and Best Presented Paper, 1981 APEA Conference in Adelaide, Australia. In 1981, he was awarded the Distinguished Achievement Medal by the Colorado School of Mines. He is currently Vice President of Research and Development at Western and previously served as First Vice President of the SEG. He is also a member of the EAEG, the SSA, and the Geophysical Society of Houston.

K. L. Larner, Western Geophysical, PO Box 2469, Houston, Texas 77252, USA.