Amplitude versus offset: a systems approach

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Summary

The information contained in amplitude-versus-offset (AVO) effects can be extremely useful in exploration/development work. A specialized set of techniques and software, however, is needed to extract and use this information properly. A systems approach has been developed at Berrong Enterprises Ltd to accomplish this goal. The system has as major components (1) AVO feasibility studies, (2) proper AVO data processing, (3) AVO scanning, (4) detailed AVO modelling supported by well logs, and (5) elastic model inversions at prospective locations. Each of these areas is discussed from an application/results viewpoint with practical examples from actual development problems. These examples will demonstrate the degree of information that is available in proper AVO information processing. Interpretation techniques to use this information are also presented.

Introduction

Amplitude-versus-offset (AVO) phenomena in seismic data can provide substantial exploration/development information. Under good conditions, this can be as detailed as an elastic layered model of the earth in the vicinity of the exploration/development target.

In order to accomplish this goal, a systems approach to the problem is taken. The first step is to do feasibility studies to ascertain the general applicability of this technique to the problem at hand. Specialized data processing would then follow with special emphasis on maintaining and enhancing the proper amplitude relationships. We would next perform amplitude scanning operations to find anomalous amplitude regions. The detailed modelling of a well in the vicinity of the exploration target follows. This step provides base information upon which to judge and interpret the AVO study. Finally, an AVO inversion can be run at a prospective well location and results in a layered elastic model. The inversion model can then be used to identify potential reservoirs and describe them numerically prior to drilling.

Feasibility studies

The applicability of amplitude-versus-offset effects in a given environment is an often-posed problem. The explorer would like to know if the AVO phenomena that may be present will be large enough to overcome the various noises to which a seismic system is subjected. In addition, are there sufficient differences between potential geologic conditions and their seismic expressions to distinguish between them?

A solution to this problem can be had in the form of feasibility studies that are based on simple elastic models. If the models show seismic expressions that are sufficiently different for alternative geologic conditions then, assuming data quality to be adequate, the explorer has some confidence that the techniques of AVO may be applicable.

The basic information needed in order to do feasibility modelling is (1) and a depth/velocity model, (2) density and velocity trend curves, (3) porosity ranges, (4) fluid content variation, (5) Poisson's ratio trend curves, and (6) a geologic description of potential reservoirs and their encompassing environments. With this information, an elastic model can be generated showing the isolated response of the test geologic conditions. Figure 1 shows an example of this approach.

Often the explorer is also interested in the sensitivity of seismic expression to a change in a basic model parameter. Tools that can be used to accomplish this type of variational study are (1) rock physics programs, (2) reflection coefficient versus angle of incidence plots, and (3) empirical Poisson's ratio programs. With these tools, the basic model parameters can be varied and the subsequent seismic expressions generated. This allows the explorer to monitor the sensitivity of seismic data to a given parameter's variation. Figure 2 is an example of a variation of the model that generated Fig. 1.

If the above studies show that a possible exploration problem does have measurable AVO responses, then the explorer

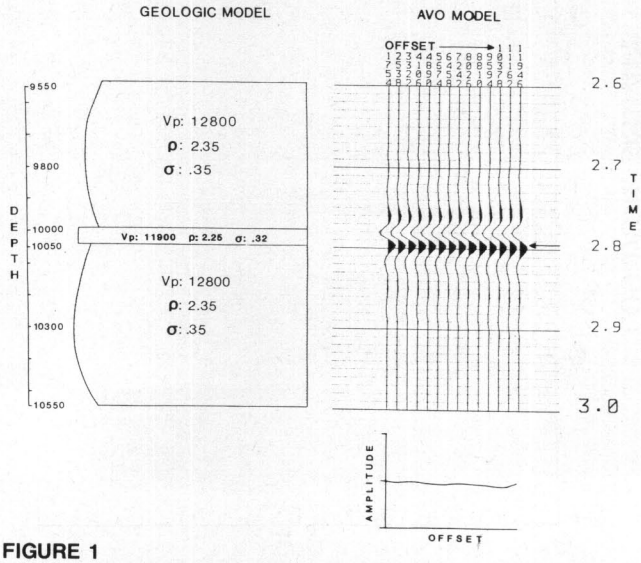

FIGURE 1
AVO feasibility study for a brine sand at a depth of 10 000 feet showing both the input geological depth model (left) and its associated seismic response (right).

knows a priori that AVO techniques will be applicable to the problem at a very early stage. If the AVO expression is too small for practical measurement, then alternative exploration techniques must be used.

AVO data processing

Seismic data processing for AVO studies is similar to that used for normal seismic projects except that a desired product is a set of CMP gathers with proper amplitude relationships. Areas of particular importance in obtaining these gathers are (1) appropriate and robust deconvolution, (2) generalized amplitude corrections, and (3) signal-to-noise ratio improvement of 100% records.

The area of generalized amplitude corrections is probably the most important aspect in extracting and restoring the proper amplitude relationships in the data set. These amplitude corrections must compensate for (1) irregular source strength, (2) source array effects, (3) inelastic attenuation, (4) transmission loss effects, (5) spherical divergence, (6) receiver array effects, (7) receiver sensitivity, and (8) receiver vertical directivity. An example of a data set processed with generalized amplitude corrections and the same data set processed with more conventional 'true amplitude' techniques is given by Fig. 3. The most pronounced differences occur for large offsets and early time.

Signal-to-noise ratio improvement of the CMP gathers can be accomplished in the common offset domain while maintaining AVO information integrity. An example of a CMP gather and the results of filtering in the common offset domain are shown in Fig. 4.

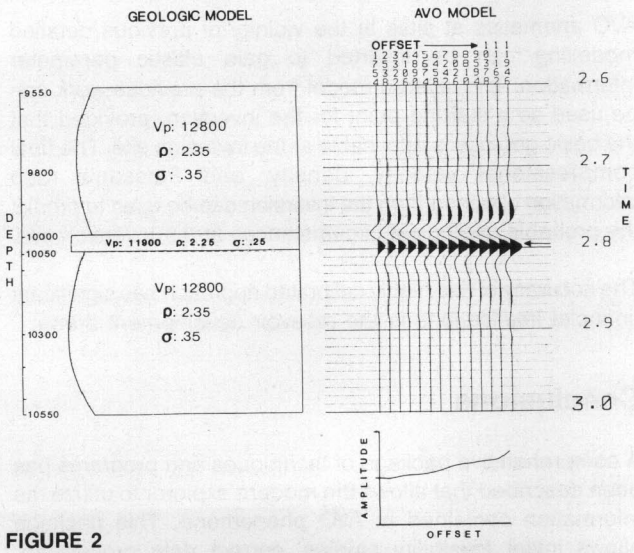

FIGURE 2
Perturbation of original AVO feasibility study in Fig. 1; the substitution of a gas sand for the brine sand results in a dramatic seismic AVO response.

AVO scanning

The large quantities of data involved in modern multifold data gathering makes it extremely time consuming to analyze 100% data records for AVO phenomena. Several techniques have been developed to help the interpreter in this regard.

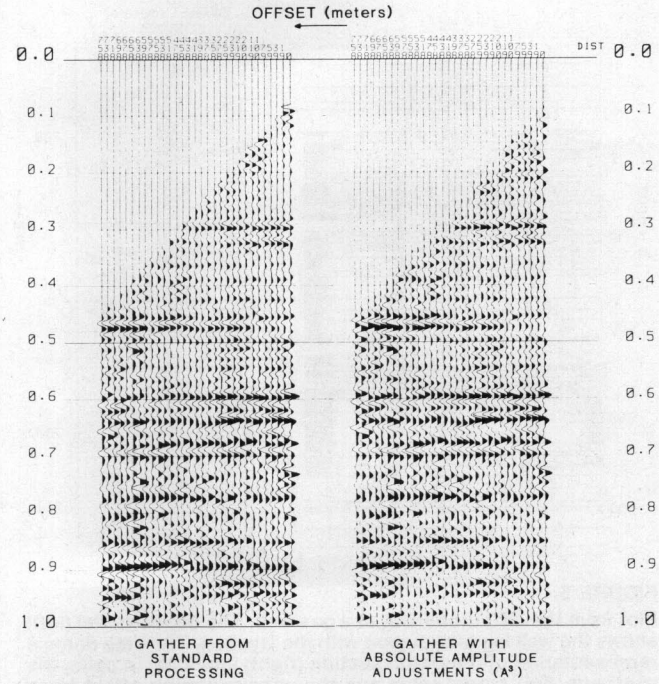

FIGURE 3
CMP gather shown with standard relative amplitude processing techniques (left) and after application of the generalized amplitude correction package (right).

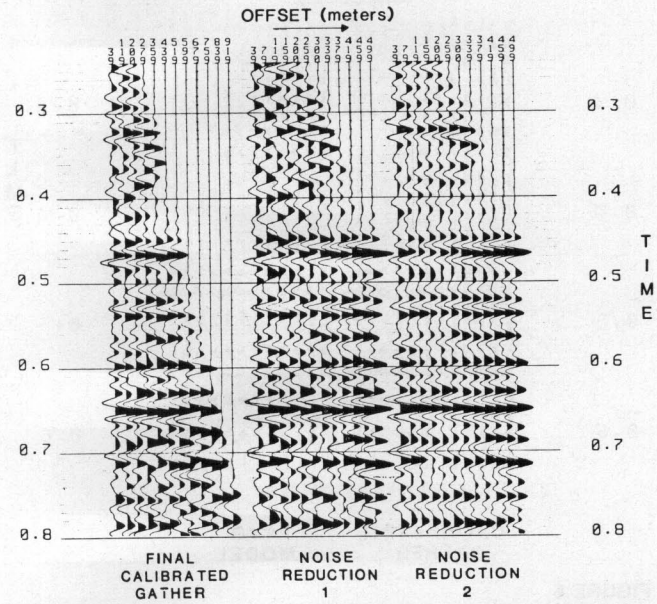

FIGURE 4
A final CMP gather showing the improvement derived from sequential common offset spatial filters.

The simplest approach is that of limited offset CMP stacks possibly followed by section subtraction to generate difference sections.

An alternative technique is that of amplitude time slice fitting. We consider this a superior approach because it has high analysis yield and is thus very cost effective for downstream efforts. In this case, the independent variable for the fit is some function of the angle of incidence. Depending on what type of limitations are placed on the maximum angle of incidence,

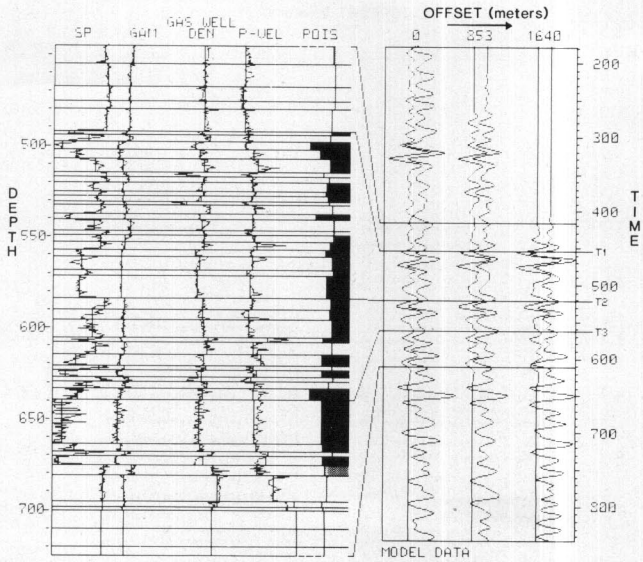

FIGURE 5
Plot from the AVO modelling of a gas well. The depth model (left) shows the well log information with the layering. The time domain representation of the depth section (right) includes, in pairs, the synthetic AVO model trace and the corresponding offset trace from the seismic CMP gather at the well site.

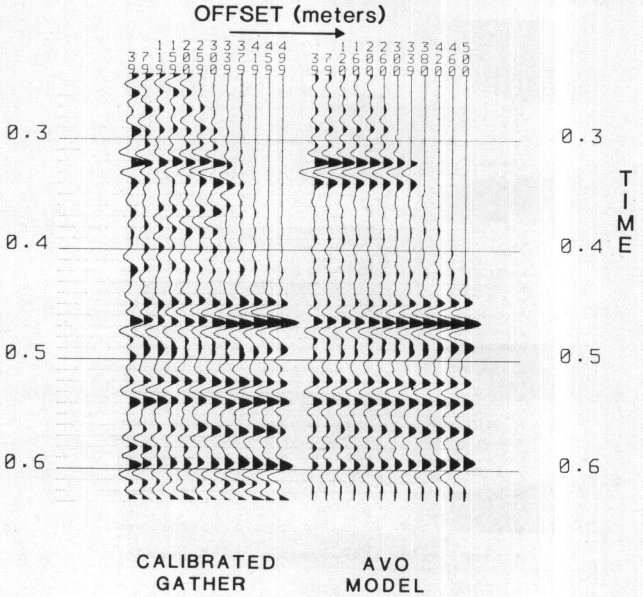

FIGURE 6
Example of the degree of match possible between the seismic CMP gather (left) and the synthetic model CMP gather (right) through the iterative AVO modelling procedure.

various approximations to the Zoeppritz equations can be made. This allows the coefficients of fit to be proportional to various combinations of physical parameters.

Whatever scanning technique one uses, the primary purpose of this phase is to identify regions of anomalous AVO behaviour and relate them to, or judge them against, known rock packages.

Detailed modelling

If well logs are available, then detailed modelling can be used in conjunction with the seismic data to provide a comprehensive understanding of the origin and nature of AVO phenomena.

The logs are blocked to provide a reasonable approximation to the geologic conditions present. Vertical incidence modelling can then be used to generate the absolute time match between the well logs and the seismic data. In addition, the seismic wavelet appropriate for the data and modelling can be extracted.

Initial Poisson's ratio estimates can be made from empirical data base programs. Elastic model inversion can then be run, generating Poisson's ratio information for the layered model.

The results of this approach applied to a gas sand problem is displayed in Fig. 5. The predicted Poisson's ratio is 0.12 for the sand at a depth of 500 m. The AVO anomaly at 460 ms is the result of this gas sand. This diagram is a product of an interactive modelling and inversion program.

An alternative display of calibrated CMP gathers and the matched AVO model for the same gas sand problem is shown by the VAR display in Fig. 6.

Inversion

AVO anomalies at sites in the vicinity of previous detailed modelling can be inverted to gain elastic parameter information. The layered model from the previous work can be used as a starting point for the inversion, provided that the basic geology is applicable at the inversion site. The final compressional velocity, density, and Poisson's ratio information obtained from the inversion can be used to predict the probable geological circumstances at the inversion site.

The accuracy of this highly calibrated approach has significant financial implications in the resevoir development arena.

Conclusions

A comprehensive package of techniques and programs has been described that allows the modern explorer to utilize the information contained in AVO phenomena. This package allows initial feasibility studies, correct data processing, anomaly scanning, detailed modelling, and inversion. All are designed to extract the maximum information available. It was shown that the final product is an elastic model of the earth at the analysis site. This model can be extremely useful in exploration/development decision making.