Delft Philosophy on Inversion of Elastic Data

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SUMMARY

In the seismic industry there is an important trend towards multi-component data acquisition. Compared with conventional single-component data, multi-component data contain much additional information about the elastic parameters of the subsurface. The key-question is of course, how to resolve this additional information in a sensible way. In this paper we outline a new elastic seismic processing scheme that contains a number of distinct modules. Each module represents one seismic processing step (ranging from decomposition of the multi-component data until lithologic inversion for rock and pore parameters) and is based on physical principles. An overview of the total elastic seismic processing scheme is given in the next section; in the subsequent section, the method will be illustrated with an example.

ELASTIC SEISMIC PROCESSING SCHEME

In this section we present an overview of our approach to seismic processing of multi-component elastic data.

In ideal multi-component seismic data acquisition, not only three components of the particle velocity are measured at each geophone position, but also three different source types are used at each source position (for instance one vertical vibrator and two mutually perpendicular horizontal vibrators). Hence, an ideal multi-component seismic data set contains nine times as much data as a conventional single-component seismic data set. In order not to get drowned in the amount of data, it is important to process the multi-component data in a very well organized manner. We propose the following steps:

1. Decomposition into P and S waves
   a. Per common shot record, decompose the measured particle velocity into upgoing P^-, S_V^- and S_H^- waves at the data acquisition surface.
   b. Reorder the data from common shot records into common receiver records.
   c. Per common receiver record, decompose the source components into downgoing P^+, S_V^+ and S_H^+ waves at the data acquisition surface.

The result of this first pre-processing step is again a multi-component seismic data set in which the illuminating downgoing waves and the detected upgoing waves have been assorted with respect to their polarization direction.

2. Surface related multiple elimination

The main multiple reflections in seismic data are related to the strongly reflecting free surface. These multiple reflections are removed by a robust wave equation based multi-dimensional procedure. Also the effects of wave conversion at the free surface are removed. Hence, after this second pre-processing step, the data may be interpreted as if the free surface were replaced by a reflection-free homogeneous upper half space.

3. Macro model estimation

From the P^+-P^- data (free from surface related multiples) the macro model for the P-wave propagation velocity is estimated. From the S^+-S^- data the macro model for the S-wave propagation velocity is estimated. Optionally, anisotropy trends are estimated by comparing the S_V^+-S_V^- data with the S_H^+-S_H^- data. The found macro models can be checked for consistency with the P^+-S^- and S^+-P^- data.

4. Computation of extrapolation operators

Once the macro model is known, accurate operators are computed for extrapolation of the elastic wave fields. We propose to generate separate operators for downgoing and upgoing P and S wave extrapolation.

5. Elastic pre-stack migration

After the preparative work in steps 1 to 4 we have obtained a number of independent scalar seismic responses (P^+-P^-, P^+-S^-, S^+-P^- and S^+-S^- data), as well as independent extrapolation operators (downgoing and upgoing P and S wave extrapolation operators). By choosing the appropriate operators the different scalar seismic responses can be migrated individually with current scalar algorithms. We propose to perform true amplitude pre-stack migration per seismic shot record. The migrated output of the different responses consists of detailed reflectivity sections in terms of angle-dependent R^+_{pp}, R^+_{ps}, R^+_{sp} and R^+_{ss} information.

6. Elastic inversion

From the angle dependent reflectivity sections the detailed medium parameters in the target zone can be determined. These medium parameters are: P-wave velocity, S-wave velocity and mass density. Optionally also the crack-orientation in fractured reservoirs can be determined by incorporating the azimuthal dependency of R^+_{SH-SH} and R^+_{SV-SV} as well as effects of shear wave splitting.

7. Lithologic inversion

The last step in the elastic processing sequence involves inversion for lithologic parameters. We propose to start with the lithologic parameters (obtained from a well log) and to use the elastic parameters (obtained from elastic inversion) to extrapolate away from the well. The result is a detailed section of the target zone in terms of rock and pore parameters.

The main steps of this elastic seismic processing scheme are summarized in Figure 1. Note the interesting fact that the central step, elastic pre-stack migration, is carried out completely independent per data type by a scalar algorithm. Therefore, elastic pre-stack migration of each individual seismic response is in principle not more complicated than acoustic pre-stack migration of single component data and can be done with the same software.

Figure 2 shows the model where our multiple elimination scheme is based on. Our scheme actually transforms the surface reflectivity matrix $\mathbf{R}(z_0)$ into zero (the free surface is transformed into a reflection-free surface).

EXAMPLE

Figure 3 shows the subsurface model and figure 4 gives the V_z and V_x shot records due to a vertical (τ_{zz}) and a horizontal (τ_{zx}) vibrator. The result of decomposition is shown in figure 5, yielding P^+-P^-, P^+-S_V^-, S_V^+-P^-, S_V^+-S_V^- records. Next the multiple elimination process is applied (fig. 6). Note the simplicity of the data with respect to the original input records (fig. 4). The four records of figure 6 are input for the pre-stack migration process, yielding angle-dependent reflectivity sections in terms of $R^+_{pp}(\alpha)$, $R^+_{ps}(\alpha)$, $R^+_{sp}(\alpha)$ and $R^+_{ss}(\alpha)$.

During the presentation it will be shown how the elastic parameters can be estimated by weighted stacking of the pre-stack migrated decomposed shot records.

CONCLUSION

We have shown that multi-component seismic measurements can be successfully decomposed into one-way scalar surface data, i.e. into P^+-P^-, P^+-S_V^-, S_V^+-P^- and S_V^+-S_V^- records. This has the tremendous advantage that all existing scalar processing software can be used for elastic data as well. Results indicate that our pre-processing procedure (decomposition and subsequent multiple elimination) improves the S/N ratio of the resulting scalar shot records spectacularly. This explains the dramatic improvement of the inversion results by standard acoustic inversion software, as will be shown during the presentation.

REFERENCES

Berkhout, A.J., and Wapenaar, C.P.A., 1988, DELPHI: A three year research proposal for processing of elastic seismic data: Delft University of Technology.

ACKNOWLEDGEMENTS

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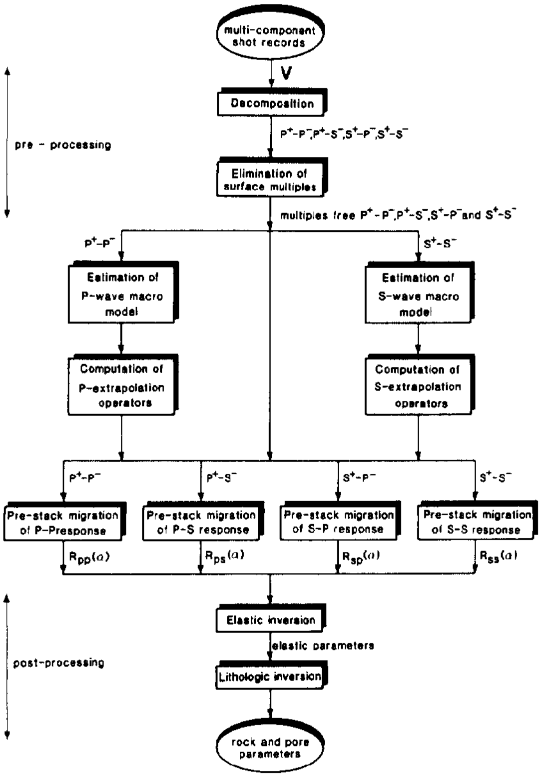

FIG. 1. Elastic seismic processing scheme.

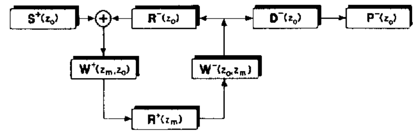

FIG. 2. Surface-related multiple elimination is based on this feed-back scheme.

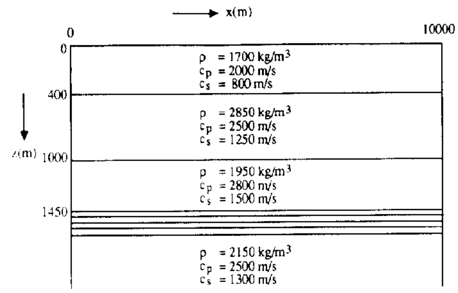

FIG. 3. Elastic subsurface model.

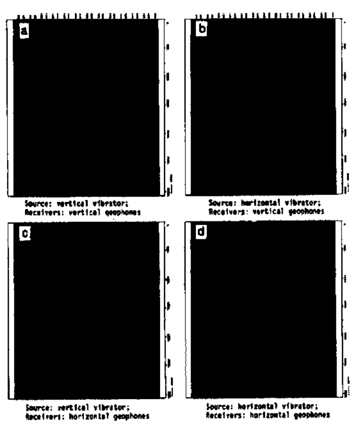

FIG. 4. Four-component data.

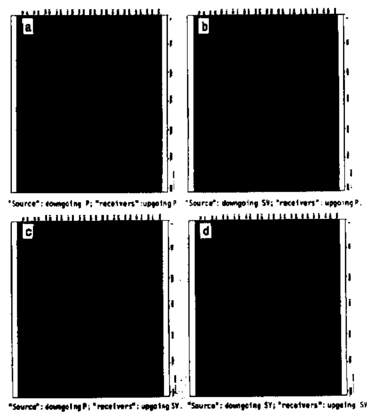

FIG. 5. Decomposed data, including surface multiples.

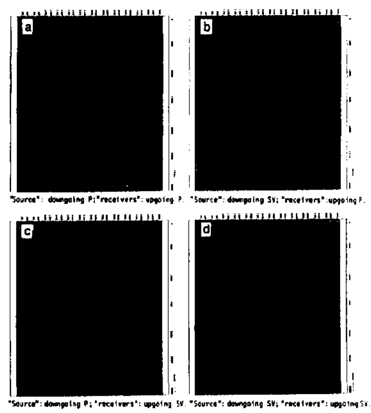

FIG. 6. Decomposed data, without surface multiples.