Amplitude corrections for multicomponent surface seismic data
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SUMMARY
Multicomponent seismic data contain detailed information about the internal structure of the rockmass. However, interpreting this information from the data requires carefully-controlled amplitude corrections to properly preserve and recover the reflections from a target zone. Here I present techniques for such a purpose, and illustrate them using field data.

The factors which affect the target amplitudes in the multicomponent data may be divided into two groups: one related to the surface (or near-surface) and the other related to the subsurface. The surface-related group includes geometry spreading, source and receiver distortions due to interactions with the near-surface, etc. These effects may be corrected by a modified surface-consistent procedure for multicomponent seismic data. The subsurface-related group includes attenuation, scattering, anisotropy, and other undesirable wavefield properties in the overburden. These complications may be corrected by an overburden-correction scheme derived from a simplified subsurface model with the target sandwiched between the overburden and a halfspace.

A four-component seismic survey with three horizontal wells drilled nearby is selected to illustrate the techniques. The field data show that the amplitude corrections are essential for preserving and recovering the target information. Amplitude anomalies (dim spots) can be identified in the stack sections after the corrections, and can be correlated with the local fracture swarms encountered by the horizontal wells.

INTRODUCTION
Multicomponent seismic data recorded on the surface are often degraded by complicated interactions between the field recording system and the near-surface. The wavefield information of a subsurface target zone is further distorted by undesirable wavefield properties, such as attenuation, scattering and anisotropy, in the overburden. To some extent, these complications limit the applications of multicomponent data in hydrocarbon exploration. Careful corrections of these factors are essential for the success of multicomponent exploration.

Over recent years processing techniques have been developed for some of these corrections such as the layer stripping method (Winterstein and Meadows 1991; MacBeth et al. 1993) for correcting anisotropic effects in the overburden, and the multicomponent deconvolution algorithm (MacBeth et al. 1993) for correcting linear or non-linear anomalies in the near surface; satisfactory results have been obtained for multicomponent VSPs (Winterstein and Meadows 1991; MacBeth et al. 1993). However, applications of these techniques to multicomponent surface seismic data, in general, have not been very successful because of the relatively low signal to noise (S/N) ratio in surface data compared with that in VSPs. Here, I take a two-step statistical approach to implement near-surface and overburden corrections in surface data. The first step is a modified surface-consistent procedure which compensates for the surface-related factors such as source and receiver distortions. The second step is an overburden-correction scheme which compensates for the subsurface-related factors such as attenuation and anisotropy in the overburden.

FOUR-COMPONENT DATA
Consider four-component geometry in a surface seismic survey: two horizontal orthogonal sources at inline (X) and crossline (Y) directions are recorded by two horizontal orthogonal receivers also at inline and crossline directions (Alford 1986). The recorded displacements may be grouped into a two-by-two data matrix \( D \). In the frequency domain, with similar assumptions to those of Taner and Koehler (1981), \( D \) can be written as (Figure 1):

\[
D(\omega) = O(\omega) G(\omega) H(\omega) S(\omega),
\]

where

- \( O(\omega) \): a scalar representing the offset factor which is the same for all four components;
- \( G(\omega) \): a diagonal matrix, \( \text{diag}(G_x(\omega), G_y(\omega)) \), representing the receiver (geophone) responses;
- \( H(\omega) \): a two-by-two matrix representing the medium response of the subsurface;
- \( S(\omega) \): a diagonal matrix, \( \text{diag}(S_x(\omega), S_y(\omega)) \), representing the source responses.

NEAR-SURFACE AMPLITUDE CORRECTIONS
Near-surface amplitude corrections of multicomponent data compensate for the factors acting on, or near the surface. These usually include offset-related geometry spreading and source and receiver distortions, and can be corrected assuming surface-consistency. In a similar way to one-component P-wave corrections (Taner and Koehler 1981), one may not need to compute the complete frequency-dependent multicomponent surface (or near-surface) response; amplitude corrections may be implemented by multiplying the seismic trace by a scalar,
Multicomponent amplitude corrections

which is equivalent to adding a constant value to the log of
the amplitude spectrum. Statistical solutions can be
obtained, using the least-square methods, from the equation:

\[ f_{ij}^{nm} = c_0 + b_i^n + g_j^p + m_{ij}^r; \]

(2)

where

- \( f_{ij}^{nm} \) natural logarithm of rms amplitudes of trace with its
source and receiver at axes \( i \) and \( j \), and at positions
\( n \) and \( m \), respectively;
- \( c_0 \): offset scaling factor at offset \( l = m-n \);
- \( f_i^n \): source factor at axis \( i \) and position \( n \);
- \( f_j^m \): receiver factor at axis \( j \) and position \( m \);
- \( m_{ij}^r \) subsurface response at surface position \( k \), corresponding to source and receiver axes \( i \) and \( j \).

Equations (1) and (2) are extensions of the one-component
P-wave equations of Taner and Koehler (1981) to
multicomponent data. They may be implemented in two
ways: 1) directly solve for the source, receiver and offset
factors and scale the data accordingly; 2) estimate an
optimum medium response and use it as a reference level to
scale the data [this approach is similar to the robust average
scaling suggested by Li et al. (1993)].

Figure 2 shows a comparison of stacking results
before and after applying near-surface amplitude corrections,
which were implemented using the second approach. The
data are from the XX-component of a four-component
survey in south Texas. The data quality is obviously
improved. Note that Figure 2b is very different from Figure
2a not only in the continuity of events and S/N ratio but
also in frequency content. This is because the noisy
zero-offset trace has a relatively high frequency content and
high amplitude (two or three orders of magnitude larger
than other traces); the preliminary stacking results without
amplitude corrections are thus dominated by the noisy
zero-offset trace (Figure 2a).

OVERBURDEN AMPLITUDE CORRECTIONS

Consider a simplified subsurface model (Figure 1) with
the target (layer 2) sandwiched between the overburden (layer
1) and a halfspace. Following a similar approach to
MacBeth et al. (1992), the reflection from the bottom
interface of the overburden \( D_s(\omega) \) and that of the target
\( D_t(\omega) \), after surface consistent corrections, can be written
as:

\[ D_s(\omega) = M_s(\omega) = C_{13}^{-1} A_{x_1}(\omega) R_{x_1}(\omega) A_{y_1}(\omega) C_{13}; \]
\[ D_t(\omega) = C_{13}^{-1} A_{k_2}(\omega) M_s(\omega) A_{k_2}(\omega) C_1; \]

where

- \( M_i(\omega) \): the medium response of the i-layer \((i=1, 2)\);
- \( C_1 \): a coordinate transform (frequency-independent)
related to the acquisition frame and the anisotropic
symmetry direction of the overburden (an orthogonal
rotation matrix, if the medium contains uniform
anisotropy);
- \( A_{k_2}(\omega) = \text{diag}(a_{g2}(\omega), a_{g2}(\omega)) \), a one-way diagonal transfer
matrix for split shear-waves in the overburden.

Figure 1. A simplified subsurface model containing three
layers: an overburden (layer 1), a target (layer 2) and a
halfspace (layer 3). A right handed coordinate system is
used with \( X \) in the inline direction, \( Y \) in the crossline
direction and \( Z \) vertically downwards.

Figure 2. A comparison of (a) preliminary stacking results
before near-surface amplitude corrections with (b) final
stacking results with near-surface amplitude corrections.
which contains phase shift, attenuation, scattering and other wavefield properties of the overburden; \( R_2(\omega) \): the reflection matrix at the interface separating layers 1 and 2 (the bottom of the overburden).

The purpose of the overburden correction is to recover \( M_1(\omega) \) from the reflections \( D_1(\omega) \) and \( D_2(\omega) \). This requires solutions of \( C_1 \) and \( A_1(\omega) \). \( C_1 \) can be solved from equation (3) by the linear-transform technique of Li and Crampin (1993), or by rotation (Alford 1986). In a similar way to the surface-consistent approach, corrections of \( A_1(\omega) \) may also be implemented as multiplying traces by scalars, and solved from \( CD_1(\omega)C_1^{-1} \) and \( CD_2(\omega)C_2^{-1} \) by the least-square method with the assumption of subsurface consistency, that is, \( A_1(\omega) \) is consistent for all traces within a CDP gather. This procedure may also be applied to post-stack sections, and the subsurface consistent criteria can be modified such that \( A_1(\omega) \) is consistent for adjacent CDPs. Thus \( A_1(\omega) \) functions as a smoothing filter across the overburden.

Figure 3 shows a comparison of stacking results before (3a) and after (3b) the overburden correction, which is implemented in the post-stack approach. Figure 4 shows the corresponding rms amplitudes within the windowed overburden and the target. The data are the qS2-component (the slow split shear-wave), selected from the same area as in Figure 2. Amplitude variations are difficult to interpret before overburden corrections (Figure 3a and 4a). However, after the corrections, the amplitudes show systematic significant lateral variations (Figure 3b and 4b). Three zones of amplitude anomalies (dim spots) can be identified, marked by the arrows in Figure 4 and by the rectangles in Figure 3. (Note that the rectangle on the right contains two dim spots).

Figure 3. A comparison of the stacked qS2-section (a) before and (b) after overburden amplitude corrections. The grey solid lines mark two time windows representing the overburden and the target, respectively; the rectangles mark significant dim spots after overburden corrections. W1, W2 and W3 are horizontal wells; the small bars represent the azimuths of the wells; the bar in the far right indicates the crack (fracture) strike.

Figure 4. A comparison of the windowed rms amplitudes (a) before and (b) after overburden amplitude corrections. (a) and (b) are calculated from the time windows in Figure 3a and 3b, respectively. The dot-dashed line is the rms amplitude in the overburden window; the dotted line is the amplitude in the target window; the solid line through them in Figure 3a is the average amplitude representing the effects of the overburden. The long-dash straight line represent the mean amplitude; the arrows mark significant dim spots.
VERIFICATION

Here I verify the dim spots identified in the stacked qS2-section after overburden corrections (Figure 3b) by correlating them with the oil productions in the three horizontal wells (W1, W2 and W3) drilled near the survey line. All three wells yield commercial production (Table 1), which implies the presence of local fracture swarms at all three sites. Furthermore, W1 has substantially higher rates than W3, although W1 and W3 have similar azimuth and horizontal distance, in fact, W3 is more favourably oriented (Table 1); this may imply that the zone penetrated by W1 may be fractured more intensively than the zone penetrated by W3. All these implications agree with the distribution of the dim spots. As shown in Figures 3b and 4b, the three dim spots are located at CDPs 235-245, 260-275 and 345-365, respectively, while the horizontal portion of well W1 goes from CDPs 225-265, intercepting two dim spots; the horizontal portion of W3 goes from CDPs 355-395, intercepting part of the third dim spot. Note that well W2, drilled parallel to the fracture strike and at the edge of a dim spot (Figure 3b), is least productive (Table 1).

CONCLUSIONS

Multicomponent data recorded on the surface are often degraded by near-surface anomalies and overburden complications. This affects our ability to correctly interpret the vector wavefield information for subsurface properties. Factors acting on or near the surface such as offset-related geometry spreading and source and receiver distortions may be corrected by a modified surface-consistent procedure for multicomponent seismic data. Factors relating to undesirable wavefield properties in the overburden such as attenuation, scattering and anisotropy may be corrected by an overburden-correction scheme derived from a simplified subsurface model with the target sandwiched between the overburden and a halfspace. The field data show that these corrections are essential for preserving and recovering the amplitude information of the target. The amplitude anomalies (dim spots) identified in stack sections after these corrections can be correlated with the local fracture swarms encountered by the horizontal wells.

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REFERENCES

Li, X.-Y., and Crampin, S., 1993, Linear-transform techniques for processing shear-wave anisotropy in four-component seismic data: Geophysics, 58, 240-256.

Table 1: Production records of the three horizontal wells W1, W2 and W3 in Figure 3. Data are supplied by Amoco Production Company. Note that the regional fracture strike is at N40°E. Thus, wells W1 and W3 were drilled nearly perpendicular to the dominant fracture strike, while W2 was drilled parallel to the fracture strike.

<table>
<thead>
<tr>
<th>Well Name</th>
<th>Azimuth (degrees)</th>
<th>Horizontal Distance (Feet)</th>
<th>Maximum Barrels Per Day</th>
<th>Cumulative Production (BBLS)</th>
<th>Period (months)</th>
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<td>N50°W</td>
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<td>370</td>
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