Attenuation analysis of a cross-hole data set

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The estimated function $A(\theta)$ from Figure 4.5 (blue curve) was used to find the best-fit attenuation coefficient from the Christoffel equation (black) and from approximation (2.36) (dashed). The numbers on the perimeter indicate the phase angle with the symmetry axis.

Zhu et al., 2007
Acquisition geometry
Stage 3 microseismic

Perforation

Grechka et al., 2006
Direct P-waves, stage 3
Direct P-waves, stage 6
Attenuation

\[ |u(\omega)| = S(\omega) \mathcal{G} e^{-k_g^I R} \equiv S(\omega) \mathcal{G} e^{-\mathcal{A} \omega t} \]

\[ \mathcal{A} = \frac{k^I}{k R} = \frac{1}{2Q} \]

Behura and Tsvankin, 2009
Spectral-ratio method

\[ |u_{ij}(\omega)| = S_i(\omega) G_{ij} e^{-A_{ij} \omega t_{ij}} \]

\[ |u_{ik}(\omega)| = S_i(\omega) G_{ik} e^{-A_{ik} \omega t_{ik}} \]

\[ \ln \bar{A} = \ln \left| \frac{u_{ij}}{u_{ik}} \right| \]

\[ s_{ijk} = A_{ij} t_{ij} - A_{ik} t_{ik} \]
Spectra of two traces
Spectral ratio

\[ \ln A \]

Frequency (Hz)
Output of spectral ratio

\[ s_{ijk} = A_{ij}t_{ij} - A_{ik}t_{ik} \]

\[ 1 \leq i \leq 3, \ 1 \leq j < k \leq 10 \]
Output of spectral-ratio method

\[ s_{ijk} = A_{ij} t_{ij} - A_{ik} t_{ik} \]

\[ 1 \leq i \leq 3, \ 1 \leq j < k \leq 10 \]
Spherical coordinates

θ

φ
Orthorhombic media

\[ A_P(\theta, \phi) = A_{P0} \left[ 1 + \delta_Q(\phi) \sin^2 \theta \cos^2 \theta + \epsilon_Q(\phi) \sin^4 \theta \right] \]

\[ \delta_Q(\phi) = f(\delta_Q^{(1)}, \delta_Q^{(2)}, \phi) \]

\[ \epsilon_Q(\phi) = g(\epsilon_Q^{(1)}, \epsilon_Q^{(2)}, \delta_Q^{(3)}, \phi) \]

\[ A_{P0} = \frac{1}{2Q_{P0}} \]

Zhu and Tsvankin, 2006
Narrow aperture
Expansion of attenuation coefficient

\[ A_{ij} = A + B \tilde{\theta}_{ij} + C \tilde{\theta}_{ij}^2 + D \tilde{\phi}_{ij} + E \tilde{\phi}_{ij}^2 + F \tilde{\theta}_{ij} \tilde{\phi}_{ij} \]
Input data for each stage

\[ s_{ijk} = A_{ij} t_{ij} - A_{ik} t_{ik} \]

\[ 1 \leq i \leq 3, \quad 1 \leq j < k \leq 10 \]

\[ A_{ij} = A + B \tilde{\theta}_{ij} + C \tilde{\theta}_{ij}^2 + D \tilde{\phi}_{ij} + E \tilde{\phi}_{ij}^2 + F \tilde{\theta}_{ij} \tilde{\phi}_{ij} \]
Transition to Thomsen-style parameters

\[ A_{ij} = A + B \tilde{\theta}_{ij} + C \tilde{\theta}_{ij}^2 + D \tilde{\phi}_{ij} + E \tilde{\phi}_{ij}^2 + F \tilde{\theta}_{ij} \tilde{\phi}_{ij} \]

\[ A_P(\theta, \phi) = F( \mathcal{A}_{P0}, \delta^{(1)}_Q, \delta^{(2)}_Q, \epsilon^{(1)}_Q, \epsilon^{(2)}_Q, \delta^{(3)}_Q ) \]
P-wave attenuation

\[ A_p \]

\[ \theta (\text{deg}) \]

\[ \phi (\text{deg}) \]
P-wave attenuation

\[ \theta \text{(deg)} \]

\[ A_P \]
P-wave attenuation

![Graph showing P-wave attenuation with stages marked from 3 to 7. The x-axis represents $\phi$ (deg) and the y-axis represents $A_p$. Different stages are indicated by different markers: red stars for Stage 3, green stars for Stage 4, blue stars for Stage 5, black stars for Stage 6, and purple stars for Stage 7.]
P-wave attenuation

![Graph showing P-wave attenuation vs stage](attachment:image.png)
Stage 3 microseismic

Grechka et al., 2006
Direct S-waves, stage 3
Direct S-waves, stage 4
Direct S-waves, stage 4
S-wave attenuation

\[ A_s \]

Stage

<table>
<thead>
<tr>
<th>Stage</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
<td>0.006</td>
<td>0.008</td>
<td>0.01</td>
<td>0.012</td>
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</tbody>
</table>
P- and S-wave attenuation

\[ A_P \]

\[ A_S \]

Stage
Summary

• narrow-angle P-wave attenuation estimates for each stage
• polar P-wave attenuation anisotropy
• Thomsen-style parameters not resolved
• P-wave attenuation decreases during fracking
• S-wave attenuation complicated by noise and scattering
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