Supplement of

Characterizing a decametre-scale granitic reservoir using ground-penetrating radar and seismic methods

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Supplementary material for Doetsch et al., “Characterizing a decameter-scale granitic reservoir using GPR and seismic methods”

S1. Anisotropy inversion

The basis is the Thomsen’s anisotropy formula for weak anisotropy (Thomsen, 1986)

\[ v_p \left( v_p^{\min}, \varepsilon, \delta, \theta^0 \right) = v_p^{\min} \left( 1 + \delta \sin^2 \theta \cos^2 \theta + \varepsilon \sin^4 \theta \right), \]

where \( v_p^{\min} \) is the minimum P wave velocity, \( \delta \) and \( \varepsilon \) are the Thomsen anisotropy parameters and \( \theta = \theta' - \theta^0 \) is the angle between the seismic ray (\( \theta' \)) and the direction of minimum velocity (\( \theta^0 \)). For travel time inversions it is convenient to work with slowness \( s_p \) instead of velocity \( v_p \). The corresponding equation is

\[ s_p \left( s_p^{\min}, \varepsilon, \delta, \theta^0 \right) = s_p^{\min} \left( 1 + \delta \sin^2 \theta \cos^2 \theta + \varepsilon \sin^4 \theta \right)^{-1}. \]

In the following equations the subscript \( p \) is omitted. The travel time from source \( i \) to receiver \( j \) is

\[ t_{ij} = \sum_k s_k l_k, \]

where \( s_k \) and \( l_k \) are the slownesses and ray lengths in the \( k \)th cell along the ray path connecting source \( i \) and receiver \( j \). In the isotropic case, the partial derivatives contained in the Jacobian matrix are

\[ \frac{\partial t_{ij}}{\partial s_k} = l_k. \]

In case of weak anisotropy, the corresponding derivatives are

\[ \frac{\partial t_{ij}}{\partial s_k^{\min}} = l_k a^{-1}, \]

\[ \frac{\partial t_{ij}}{\partial \varepsilon_k} = -l_k s_k^{\min} a^{-2} \sin^4 \theta, \]

\[ \frac{\partial t_{ij}}{\partial \delta_k} = -l_k s_k^{\min} a^{-2} \sin^2 \theta \cos^2 \theta, \]

and

\[ \frac{\partial t_{ij}}{\partial \theta_k^0} = l_k s_k^{\min} a^{-2} \left( 4 \varepsilon \sin^3 \theta \cos \theta + 2 \delta \sin \theta \cos \theta \left[ \cos^2 \theta - \sin^2 \theta \right] \right). \]

with \( a = \left( 1 + \delta \sin^2 \theta \cos^2 \theta + \varepsilon \sin^4 \theta \right). \)
Supposed that the ray geometry is known (e.g., computed with an isotropic ray tracer), implementation of weak anisotropy is merely a matter of adding three more columns per inversion cell to the Jacobian matrix. The isotropic case can be considered as a special case of anisotropy, where the derivatives with respect to $\varepsilon$, $\delta$, and $\theta$ are set to zero.

S2. Extra GPR Figures

Figure 6 in the main manuscript shows the unmigrated GPR data recorded from the AU tunnel and Figure 7 the migrated data acquired from the VE tunnel. Here, we show the migrated data from the AU tunnel and the unmigrated data from the VE tunnel.

![Figure S1: Fully processed and migrated GPR data acquired from the AU tunnel.](image1)

![Figure S2: GPR reflection data measured from the VE tunnel in the N-S plane, looking East. These data are processed up to step 8 (Section 3.1.2) but not migrated.](image2)

References