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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)

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

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

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

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

(3) $$t_{ij}=\sum_k s_k l_k,$$

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

(4) $$\frac{\partial t_{ij}}{\partial s_k}=l_k.$$

In case of weak anisotropy, the corresponding derivatives are

(5) $$\frac{\partial t_{ij}}{\partial s_k^{\min}}=l_k a^{-1},$$

(6) $$\frac{\partial t_{ij}}{\partial \varepsilon_k}=-l_k s_k^{\min}a^{-2}\sin^4\theta,$$

(7) $$\frac{\partial t_{ij}}{\partial \delta_k}=-l_k s_k^{\min}a^{-2}\sin^2\theta\cos^2\theta, \text{ and}$$

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

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 ε, δ and θ 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.

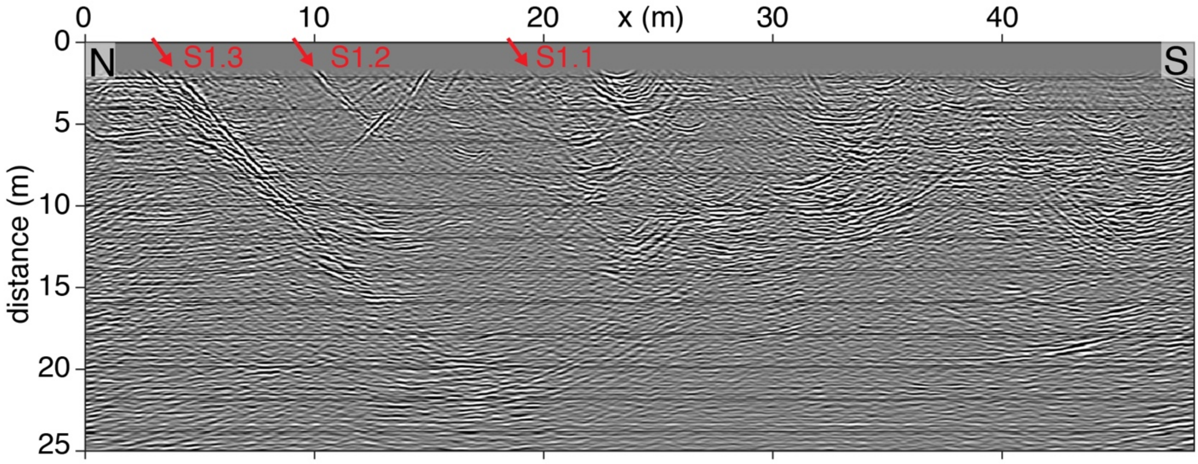

Figure S1: Fully processed and migrated GPR data acquired from the AU tunnel.

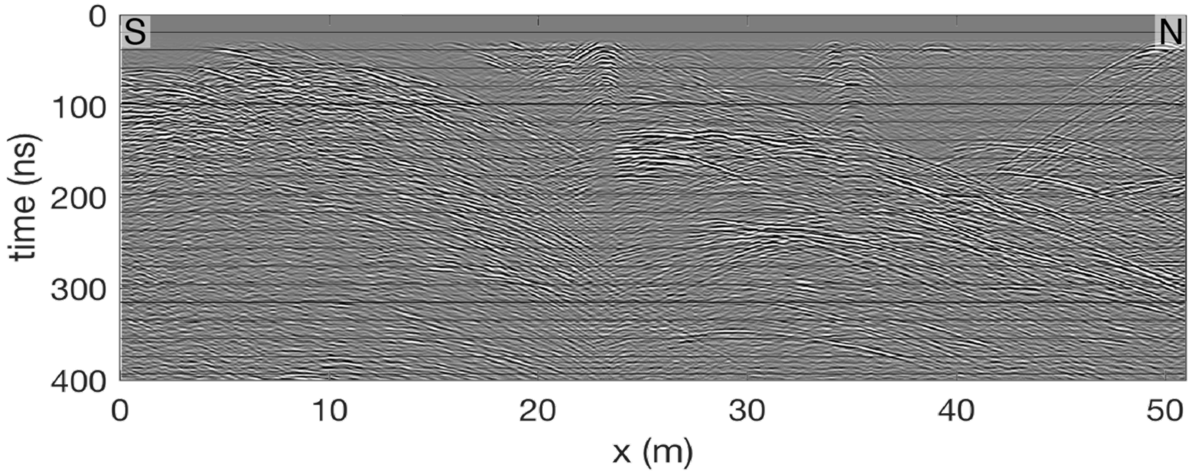

Figure S2: GPR reflection data measured from the VE tunnel in the N-S plane, looking East. These data are processed up to step 8 (Section 3.1.2) but not migrated.

References

Thomsen, L. (1986). Weak Elastic-Anisotropy. Geophysics **51**(10): 1954-1966.