The effect of texture and porosity on seismic reflection amplitude in granular sediment: Theory and examples from a high-resolution shallow seismic experiment

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INTRODUCTION

- Seismic reflection methods provide spatially continuous information about the mechanical properties of the subsurface and can be used to spatially map subsurface sedimentary properties.
INTRODUCTION

We show that theoretically the two main contributions to reflections from within a uniform, homogenously saturate sand packet are (1) changes in porosity and (2) changes in texture.
INTRODUCTION

Figure 1. Shallow seismic reflection data showing (water table) reflection (22 ms) and a reflection within a nominally homogeneous sand packet (17 ms).
\[
V_p = \sqrt{\frac{K_{\text{eff}} + \frac{2}{3}G_{\text{eff}}}{\rho_b}},\quad V_s = \sqrt{\frac{G_{\text{eff}}}{\rho_b}},
\]

\[
K_{\text{eff}} = \frac{n(1 - \phi)}{12\pi R_g} S_n,\quad G_{\text{eff}} = \frac{n(1 - \phi)}{20\pi R_g}(S_n + 1.5S_t)
\]

\[
\nu_{\text{eff}} = \frac{S_n - S_\tau}{4S_n + S_\tau}.
\]
THERORY

\[ S_n = \frac{4aG}{1 - \nu}, \quad S_t = \frac{8aG}{2 - \nu}, \]

\[ 2R_{i0}|_{\nu_{\text{eff}}} = \Delta Y_i = \underbrace{\frac{\partial Y_i}{\partial \phi}}_{\text{volumetric}} \Delta \phi + \underbrace{\frac{\partial Y_i}{\partial R_C}}_{\text{textural}} \Delta R_C. \]

\[ R_{c}^{-1} = 0.5(R_{1}^{-1} + R_{2}^{-1}). \]
Figure 2. Porosity versus coordination number (after Murphy, 1982).
Based on contact mechanics models, both P- and S- wave seismic reflection strengths ($R_{P0}$ and $R_{S0}$) in dry, unconsolidated, mineralogically uniform sediments are proportional to variations in texture.
Textural variations affect the P-wave reflection strength only at high stress (greater than 100m).

The saturated S-wave reflection strength is proportional to both porosity and texture variation.
Figure 3. Reflection coefficient as a function of depth and porosity changes $\Delta \phi$ for (a) dry sediment $R_{p0}$, (b) saturated sediment $R_{p0}$, (c) dry sediment $R_{s0}$, and (d) saturated sediment $R_{s0}$. 
Figure 4. Reflection coefficients as a function of depth and texture changes $\Delta R_C$ for (a) dry sediment $R_{PD}$, (b) saturated sediment $R_{Pd}$, (c) dry sediment $R_{SD}$, and (d) saturated sediment $R_{SD}$. 

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FIELD EXAMPLE

- We apply our theoretical result to a high-resolution, very shallow 3D seismic survey performed at the University of Kansas shallow seismic test site at Great Bend, Kansas.

- We analyze a patch of 48 shots acquired by the dense portable receiver array.
Figure 5. (a) Geometry of the survey; 72 receivers are placed with 0.25 m spacing, and 48 shots are used to generate the single supergather presented in Figure 1. (b) Field layout. Portable geophone mount makes the deployment of 72 receivers very fast.
Figure 6. (a) Supergather from all traces collected with the geometry shown in Figure 5. Two arrows mark the inner sand boundary (17 ms) and the water table reflection (22 ms). Dashed box shows traces used for zero-offset reflectivity estimation. (b) Averaged trace with the plot (blue) consists of all offsets between 0.25 m and 0.75 m overlying the amplitude envelope (red).
Figure 7. Change in zero-offset P-wave reflectivity as a function of change in contact radius $\Delta R_C$. 
Figure 8. A 3D prestacked, time-migrated image showing grain size boundary and water table reflections. Location of super-gather is marked with a square. Arrows present interpreted angular and well-sorted sands above the water table.
SUMMARY

- Well data indicate no variations in lithology, mineralogy, or clay content that might have given rise to the observed reflection within the dry sand packet above the water table.
- In the field example, acquisition using a dense receiver array provides very good seismic data at a very shallow depth.