Seismic physical modeling of COZD and COVA surveys: AVAZ effects observed on reflections from HTI targets

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Summary

The University of Calgary Seismic Physical Modeling Facility is designed to carry out scaled-down 2D and 3D seismic surveys using ultrasonic transducers as sources and receivers (Wong et al., 2009). We used the system to investigate Amplitude Variation with Azimuth (AVAZ) phenomena associated with targets having Horizontal Transverse Isotropy (HTI) by conducting simulated 3D marine seismic surveys over Phenolic CE targets embedded in an isotropic acrylic slab. Acquisition geometries were designed to emphasize AVAZ effects of reflections from the HTI targets. Attributes based on Common Offset Zero Degree (COZD) and Common Offset Variable Azimuth (COVA) reflection amplitudes were extracted from 3D datasets to map bright spots and lamination orientations. Attribute maps clearly show locations and sizes of the simulated HTI targets.

Method

A physical model consisting of 2.54 cm (254 m equivalent) long Phenolic cylinders (pucks), with diameters varying form 1-7 cm (100-700 m) embedded in a 5.08 cm (508 m) thick slab of acrylic (isotropic) was immersed in water with its top surface at a water depth of about 13 cm (1300 m) in our physical modeling tank (Figure 1). The pucks were cut from Phenolic CE material (weakly orthorhombic anisotropy) so they exhibited HTI anisotropy in the x-y plane. Thin lines on the targets in Figure 1a represent the laminations of the pucks, while the arrows indicate the direction of the slow velocity. TX and RX denote the source and receiver piezoelectric pin transducers (Dynasen CA-1136). The active tips of the transducers were raised 3 cm (300 m) above the water-solid interface. Acrylic is a plastic material with isotropic seismic properties. This model represents a simple case of Class I AVO, since the P and S velocities of the overlying medium (water) are less than the P and S velocities of the underlying acrylic and Phenolic (Table 1).

A COZD survey was acquired along acquisition lines running in the y direction as depicted in Figure 2a with line, source, and receiver spacing to set to 0.5 cm (50 m). At every point on the 0.5 cm (50 m) grid we recorded zero-azimuth constant-offset (Δx = 1 cm, or 100 m) seismograms. A COVA survey was conducted over the same area, but with grid spacing $\Delta x = \Delta y$ = 1 cm (100 m). Each grid point was treated as the centre of a circle with a 4 cm (400 m) diameter. We recorded data for azimuths (relative to the x-axis) in the range -90° to +90° at 5° intervals (Figure 3a).

Material	V_{px}	V_{py}	V_{pz}	V_{sx}	V_{sy}	V_{sz}	Density
Water	1485	1485	1485	0	0	0	1000
Acrylic	2745	2745	2745	1380	1380	1380	1190
Phenolic	3576	3365	2925	1665	1625	1506	1680

Table 1. Seismic velocities (m/s) and densities (kg/m^3) of acrylic plastic and phenolic CE. Values for acrylic and phenolic are taken from Mahmoudian et al. (2013) and Cheadle et al. (1993), respectively.

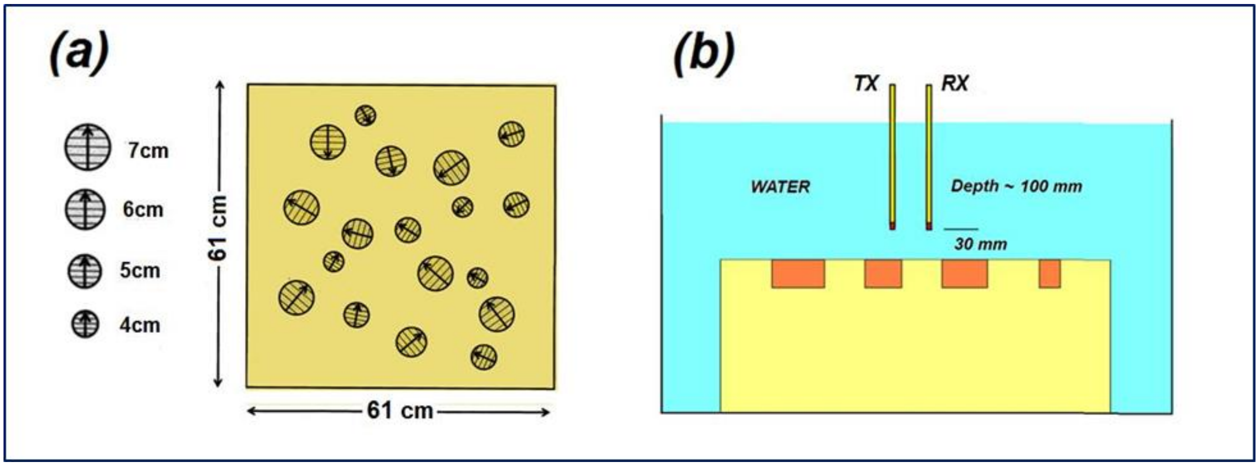

Figure 1. Schematic of physical model: cylindrical HTI targets (Phenolic “pucks”) embedded in an isotropic acrylic plastic slab immersed in water. (a) Plan view. (b) Side view. TX and RX denote source and transmitter transducers (30 cm long piezoelectric pins). Laboratory scale sizes and dimensions are shown; geological scale dimensions are obtained by multiplying by 10,000.

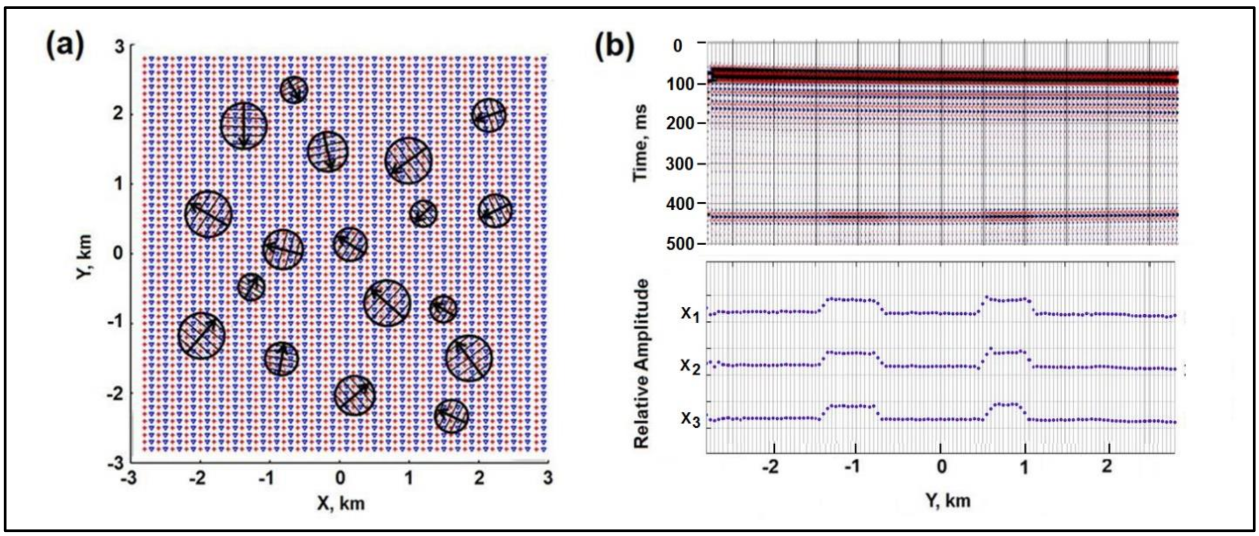

Figure 2. (a) Schematic of the common-offset-zero-degree-azimuth (COZD) survey. Red and blue symbols represent source and receiver locations. (b) Top: seismograms along line at x = 2.1 km. The direct arrivals occur at about 67 ms. The water-solid reflections occur at about 425 ms. Bottom: relative peak-to-peak reflection amplitudes for the [x1, x2, x3] = [2.10, 2.15, 2.20] km lines.

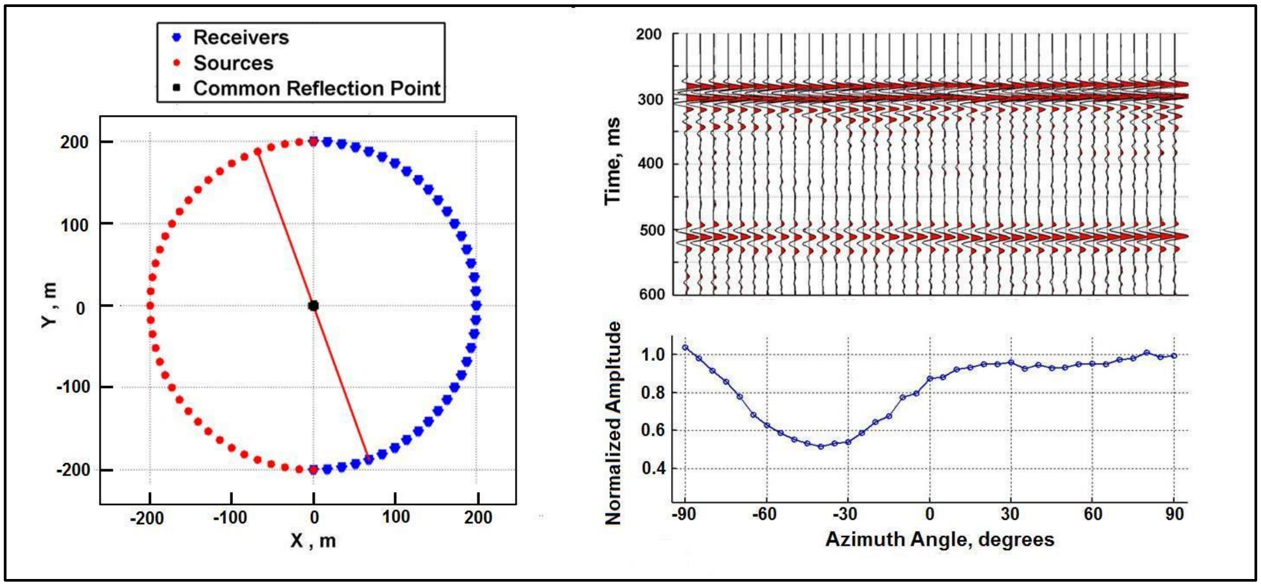

Figure 3. (a) Source (red) and receiver (blue) positions at one grid point of the COVA survey. The centre of the circle represents the x-y position of the CRP that occurs at a depth of 300m. (b) Top: seismograms at one CRP point [x, y] = [-2.00, -1.800] km. Direct arrivals occur at about 260ms. Reflections from the water-solid interface occur at about 490ms. Bottom: reflection amplitudes as a function of azimuth angle at the above CRP point, with a minimum at -40°, i.e., the direction of the slowest HTI velocity.

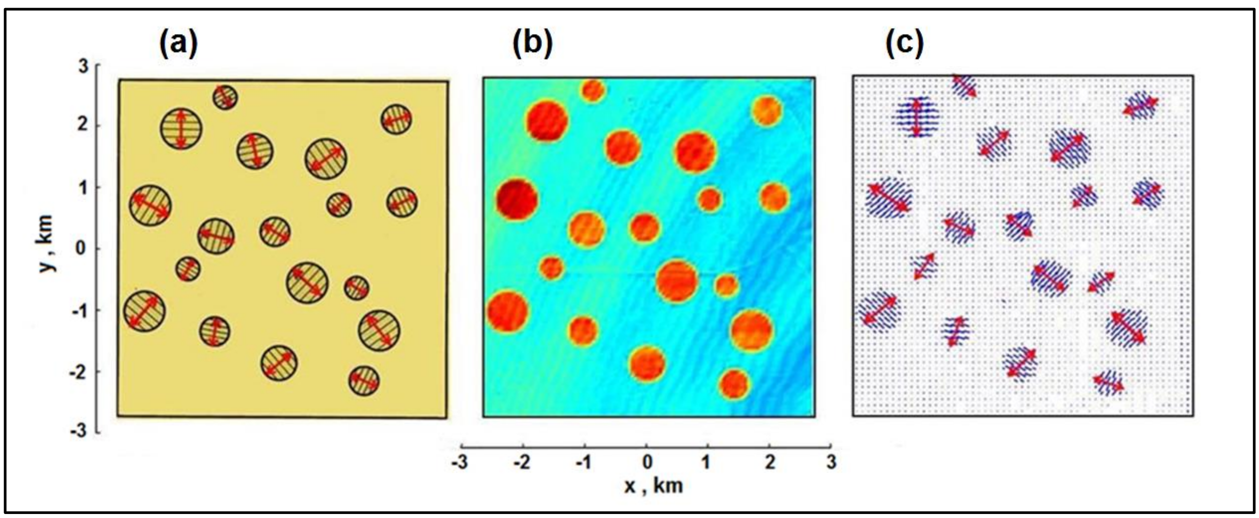

Figure 4. (a) Top view of the acrylic slab with embedded HTI pucks. (b) Color map of normalized reflection amplitudes from the COZD survey. (c) Interpreted directions from the COVA survey of HTI principal axes (red arrows) and calculated lamination directions (thin black lines) for the phenolic pucks.

Results

Figure 2b (top) shows a fixed-gain plot of seismograms acquired along one of the COZD survey lines. This line crosses two HTI targets in the physical model. P-P reflections from the water-solid interface occur at times between 400 ms and 500 ms and exhibits bright spots at the target locations due to increased impedances at the water-Phenolic interfaces compared to that at the water-acrylic interface. Figure 2b (bottom) shows amplitude anomalies for three lines that cross the same HTI targets. The lateral extent of the bright spot anomalies is related to the size of the targets. Figure 3b (top) displays a fixed-gain plot of seismograms for a single grid point in the COVA survey whose common-reflection point is on an HTI target. Figure 3b (bottom) shows a plot of reflection amplitudes as a function of azimuth angle. Reflections from the water-solid interface are seen at times of 400 ms to 600 ms. The azimuth-dependent reflection amplitudes on Figure 3b (bottom) confirm that Phenolic behaves as a solid with HTI velocity anisotropy (Rüger, 1998).

Discussion

Figure 4a shows a map view schematic of the physical model. Figure 4b shows the corresponding map of reflection amplitudes from the COZD survey. Figure 4c shows phenolic lamination directions derived from the COVA survey amplitude maxima/minima and interpreted HTI principal axis directions. We see that that, in both size and position, the correspondence of each bright spot anomaly to a HTI target is excellent. HTI principal axis and lamination directions derived from the COVA survey correspond well to the physical model with two exceptions where the schematic (Figure 4a) turned out to be in error. Our results show that COZD and COVA surveys conducted via scaled-down physical modeling can be reasonable analogues of actual surveys, provided that the real-world geological setting is not too complex (see Perz et al., 2014).

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