

Physical modeling of reflections off low-Q media

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Summary

Theoretical considerations predict that reflections with significant amplitude should occur on boundaries between media with different attenuation characteristics, even if the velocity-density contrasts are small (Lines et al., 2007). Nearly zero offset ultrasonic seismograms acquired in a physical modeling experiment over aluminum and Crisco blocks immersed in water confirmed this prediction. Aluminum is a high-Q material whose acoustic impedance is large compared to that of water. Crisco is a low-Q material whose impedance is very similar to that of water. In our data, reflection amplitudes from aluminum and Crisco were large and almost equal, even though one expects the water-Crisco reflection to be weak because of the small impedance contrast. These results are consistent with observations made previously by Carl Sondergeld. Melting and re-solidification changed Crisco from a low-Q material to a higher-Q material while the density and P-wave velocity remained practically the same. Reflections from altered Crisco in water were weaker than those for unaltered Crisco, but were still much stronger than predicted by the negligible impedance contrast with water.

Introduction

Sondergeld (personal communication) observed ultrasonic reflections arising from water-aluminum and water-Crisco boundaries. His experimental results are summarized on Figure 1. Crisco is the brand name of a vegetable shortening product commonly used in baking, and its density and acoustic velocity are almost identical to those of water. Therefore, one expects that the amplitude of normal incident reflections from the water-Crisco boundary would be very weak.

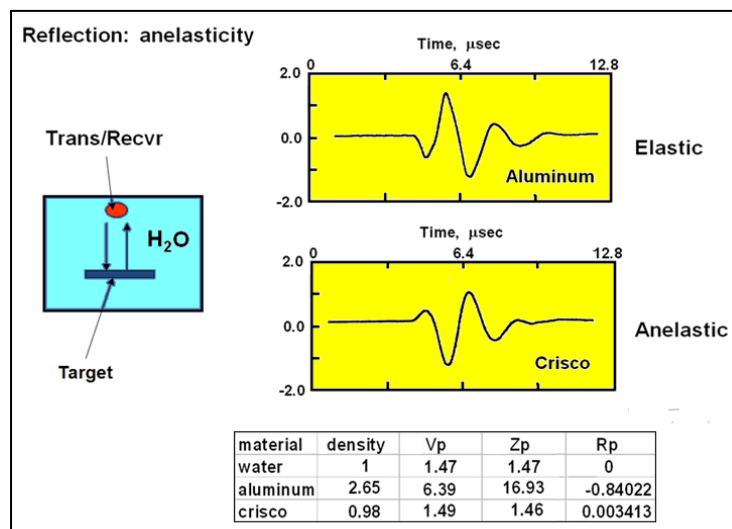


FIG. 1. Reflections off water-aluminum and water-Crisco interfaces (courtesy Carl Sondergeld).

However, the traces displayed on Figure 1 show that reflected amplitudes from the water-aluminum and water-Crisco interfaces are almost equally strong. Crisco, unaltered and straight out of its store-shelf packaging, is a highly attenuating material, that is, its acoustic Q is very low. Water, however, has very low attenuation at all acoustic frequencies (in oceanographic tomography, sound waves are transmitted and received over distances of thousands of kilometers). According to Toksöz and Johnston (1981; page 124), the Q of fresh water for signals at 100 kHz is 210,000. The Q at similar frequencies for aluminum is also very high, with a value on the order of 200,000. Since the only strongly-contrasted acoustic property between water and Crisco is the attenuation, we conclude that the large reflection amplitude from the water-Crisco boundary must be due to the attenuation contrast.

We have measured the P-wave velocities and densities of blocks of aluminum and Crisco. The measured velocity and density values and the calculated acoustic impedances of the samples are shown on Table I. Our values differ slightly from Sondergeld's values shown on Figure 1; small differences are not unexpected for different samples measured using slightly different techniques.

TABLE I. Measured velocity and density values.

Material	V_p , m/s	ρ , kg/m ³	Impedance, ρV_p	R_{pp}
Aluminum	6300	2650	16.7×10^6	.837
Unaltered Crisco	1630	970	1.581×10^6	0.031
Altered Crisco	1540	970	1.494×10^6	0.003
Water	1485	1000	1.485×10^6	0

Data Acquisition

We conducted measurements to replicate Sondergeld's results using the University of Calgary Seismic Physical Modeling Facility (Wong et al., 2009). Figure 2 shows the experimental setup for these measurements. An aluminum block and a block of unaltered Crisco were immersed in water.

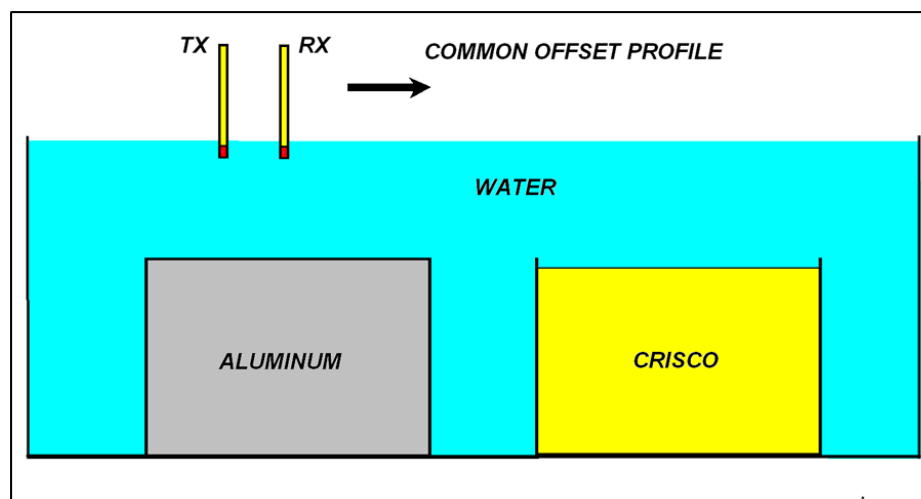


FIG. 2. Acquisition of ultrasonic seismograms over aluminum and Crisco blocks immersed in water. Transmitting and receiving piezopin transducers (labeled TX and RX) produce dominant frequencies of about 500 kHz.

Common offset gathers were acquired in lines over the centres of the blocks using piezopin transducers with their active tips located just below the surface of the water. Ultrasonic seismograms were recorded with a source-receiver offset fixed at 10 mm. The piezopin transducers in water produce acoustic signals with dominant frequencies near 500 kHz.

We repeated the measurements using melted and re-solidified Crisco in place of the original unaltered Crisco. The velocities and densities of the unaltered and altered Crisco were quite similar (see Table I). The dimensions of the aluminum block were 101.6 mm by 101.6 mm by 50.8 mm in the depth dimension. For the block of unaltered Crisco, the dimensions were approximately 130 mm by 60 mm by 60 mm deep. The block of altered Crisco was somewhat larger, with dimensions of about 135 mm by 135 mm by 40 mm deep. Figure 1: Description of chart, graphic, equation, etc.

Results

Figure 3 displays in gray-scale format the gathers over aluminum, unaltered Crisco, and altered Crisco. Events A and A' are reflections off the top of the aluminum. Events B and B' are reflections off the tops of the unaltered and altered Crisco. Events C and C' are reflections from the surface on which both blocks rest. Events D and D' are the reflection off the bottom of the aluminum block; they are relatively weak because most of the down-going energy has been reflected by the top surface. No similar reflection Event E from the bottom of the unaltered Crisco block can be seen; it seems that any acoustic energy that has entered the unaltered Crisco has been highly attenuated.

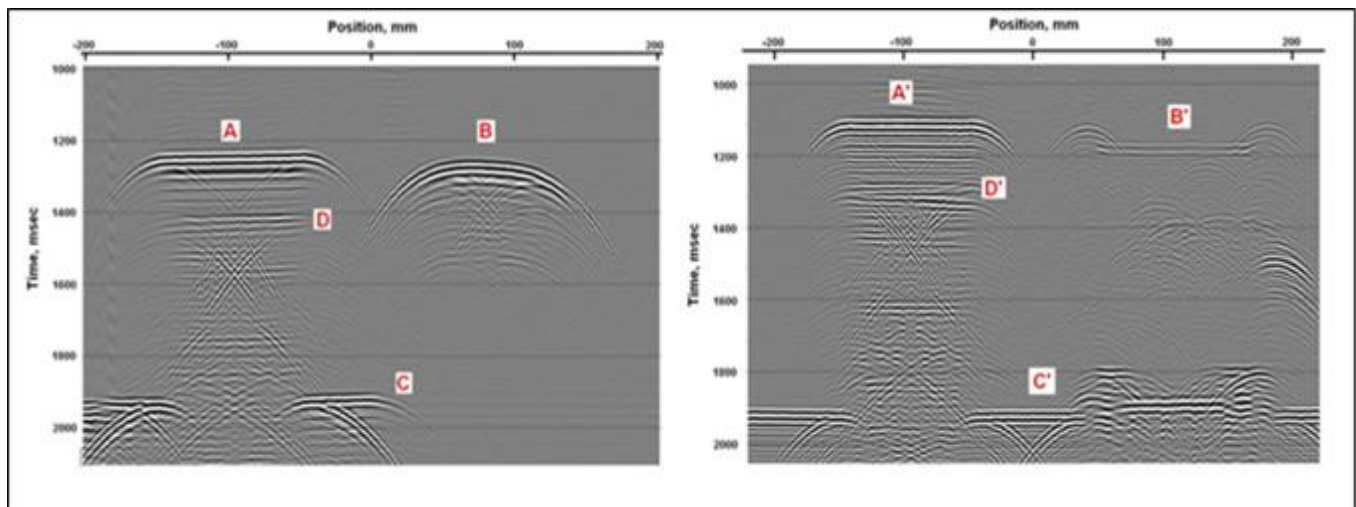


FIG. 3. Fixed-gain display of common offset gathers over aluminum and Crisco blocks immersed in water. Left: data for unaltered Crisco (depth to top of aluminum ~ 91 mm; depth to top of unaltered Crisco ~ 93 mm). Right: data for altered Crisco (depth to top of aluminum ~ 81 mm; depth to top of altered Crisco ~ 86 mm (both blocks here have been raised an extra 10 mm above the levels of the blocks on the left-hand side).

For the altered Crisco, the reflection amplitudes off the water-Crisco interface are significantly weaker. In contrast to the case for unaltered Crisco, there is now a strong reflection (seen to the right of Event C') from the bottom of the Crisco block. The interpretation is that acoustic attenuation and the associated Q through altered Crisco are much less than those for unaltered Crisco, where there is no observable reflection off the bottom of the Crisco block. Several traces from Figure 3 over the centres of the aluminum (events A and A') and Crisco (events B and B') blocks were aligned according to the reflection times, windowed, and summed to produce average reflection traces. On Figure 4, these average traces (plotted in red) are compared with Sondergeld's traces (plotted in black). The vertical

scales on Figure 4 give an accurate measure of the relative amplitudes for aluminum reflections and for the Q-induced reflections for Crisco.

From Figure 4, we find that the ratio of amplitudes of unaltered Crisco reflections (event B on Figure 3) to aluminum reflections (event A on Figure 3) is about 0.83. For altered Crisco, this ratio is about 0.047, almost 18 times less than the corresponding ratio for unaltered Crisco and aluminum. Since the velocity and density of Crisco did not change materially because of melting and re-solidification, we conclude that the dramatic decrease in reflection amplitude between unaltered and altered Crisco must be caused by a large increase in Q. We note that there is a distinct phase rotation in the reflected wavelets for both unaltered and altered Crisco when compared to the aluminum reflected wavelets.

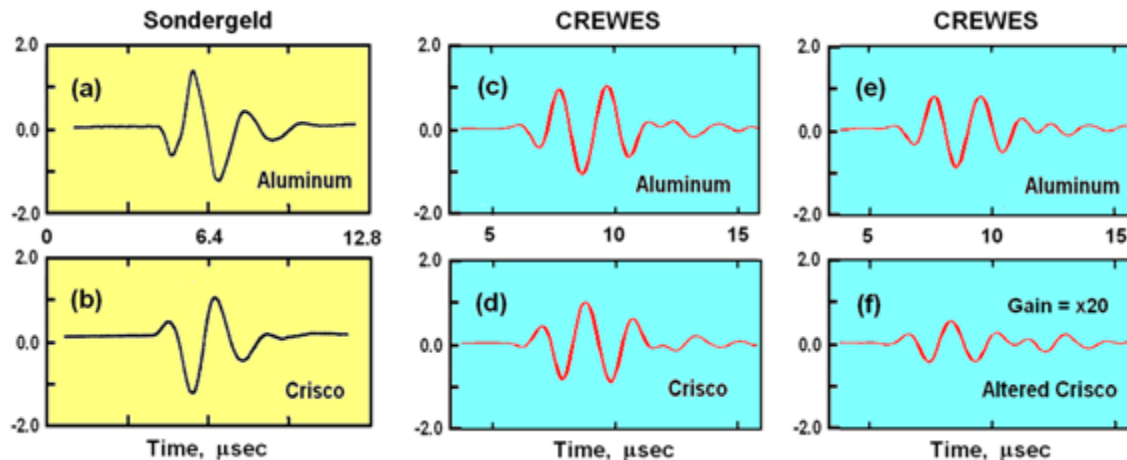


FIG. 4. Comparison of reflected wavelets off aluminum and Crisco immersed in water. CREWES results are shown in red. Sondergeld's results are shown in black.

Summary and Discussion

Our measurements have confirmed Sondergeld's original experimental data showing that strong reflections occur at a water-Crisco interface, even though the density and velocity contrasts are negligible. For unaltered Crisco, the reflection amplitudes are almost equal to those observed for a water-aluminum interface, even though the traditional acoustic impedance of Crisco is almost identical to that of water, while the impedance of aluminum is about 16 times that of water. For melted and re-solidified Crisco, the reflection amplitudes are about 18 times less than those for aluminum, suggesting that the Q of altered Crisco has increased from that of unaltered Crisco, even though the density and P-wave velocity remained essentially unchanged. Synthetic seismograms created using a reflectivity algorithm verified the experimental observation that a material with extremely low Q immersed in water can result in strong reflections, even if the acoustic impedances are virtually identical.

Acknowledgements

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References

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