GCSeismic Model for Monitoring CO_2 Sequestration*

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General Statement

Sequestration of CO_2 in sealed brine is an important issue in industrialized countries that are concerned about the impact of excessive atmospheric CO_2 on the environment. A general consensus is that long-term seismic monitoring of injected CO_2 will be essential for successful CO_2 sequestration programs. In this column we consider the P-wave reflectivity associated with tracking a CO_2 plume in one reservoir considered for CO_2 sequestration.

Model

The physical properties of injected CO_2 that affect seismic imaging are its density and acoustic propagation velocity at the pressure and temperature of its host medium. Because CO_2 has a shear modulus of zero whether it is a gas or a liquid, shear-wave velocity in CO_2 is zero. The only velocity that has to be known for seismic modeling purposes is VP, the propagation velocity of the P-wave mode in CO_2. The density and P-wave velocity of CO_2 over a range of pressure and temperature conditions are defined by the curves displayed in Figures 1 and 2, respectively.

An Earth model that defines reflecting interfaces at the top and base of the sandstone reservoir and at the fluid interface between CO_2 and brine internal to that reservoir is shown as Figure 3. From available log data at this site, the Earth layers have the following petrophysical properties:

Sealing carbonaceous shale:
$\Delta t_p = 65\ \mu s/ft$, $\rho = 2.633\ gm/cm^3$.

Reservoir sandstone:
$\Delta t_p = 80\ \mu s/ft$, $\rho = 2.357\ gm/cm^3$, $\Phi = 22$ percent.

Granite basement:
$\Delta t_p = 55\ \mu s/ft$, $\rho = 2.70\ gm/cm^3$.

The sandstone reservoir is at a depth of 6,000 feet; it is important to define the depth of the injection interval in order to determine the temperature and hydrostatic pressure that act on the sequestered CO_2. This temperature and pressure, in turn, specify the density and VP values that should be used to describe the seismic properties of the in situ CO_2 (Figures 1 and 2). A factor of 0.433 psi/ft was used to convert target depth to hydrostatic pressure. In utilizing the curves in Figures 1 and 2, the in situ temperature was assumed to be 130 degrees Fahrenheit. These assumptions lead to VP and ρ values of 1,285 ft/s and 47.0 lb/ft^3, respectively, for the sequestered CO_2.

Calculations
Two reflectivity curves are calculated for the top and base of the reservoir: One curve describes the reflectivity of a brine-filled reservoir unit. The second curve describes the reflectivity of a reservoir that has a CO_2 saturation of 100 percent. These reflectivity curves are shown as Figures 4a and 4c. The reflectivity at the brine-CO_2 contact is defined by the single curve in Figure 4b.

Examination of Figure 4 shows that P-P reflectivity increases by about 20 percent at the top of the reservoir when brine is replaced by CO_2. This brightening of the P-P reflection can be detected only if good-quality seismic data are acquired and if seismic data processing is carefully done. For this particular geologic layering, the P-P reflection from the interface at the base of the reservoir does not vary when brine is replaced by CO_2 (Figure 4c).

Results
An encouraging result is that there should be a measurable P-P reflection at any brine/CO_2 contact boundary that is created within the reservoir unit. Figure 4b shows that P-P reflectivity at the brine/CO_2 boundary is 3 percent to 6 percent. Comparing this fluid-contact reflectivity with the P-P reflectivity at the top and base of the reservoir indicates that a P-P reflection from a brine/CO_2 $interfac_2$ will be one-third to one-tenth the magnitude of the reflection amplitudes from the upper and lower interfaces of the sequestration interval. Again, this smaller fluid-contact reflection response can be detected only if good-quality seismic data are acquired and great care is

used in processing the data.

An additional requirement is that the distance from the fluid interface to both the top and the base of the sequestration interval should be more than half the dominant wavelength of the illuminating wavefield. In amplitude-versus-offset (AVO) parlance, the top of the reservoir is a Class 4 AVO interface (Figure 4a), and the fluid-contact boundary is a Class 3 AVO interface (Figure 4b). These differing AVO behaviors allow a valuable data-processing strategy to be implemented. Two P-P seismic images need to be made: Image 1 would use only small-offset data (incidence angle range between 0 and 20 degrees), and Image 2 would utilize only large-offset data (incidence angles between 20 and 50 degrees).

In Image 1, the reflection from the top of the reservoir will be five to six times greater than the fluid-contact reflection. In Image 2, the reflection from the top of the reservoir will reduce and will be only two to three times brighter than the fluid-contact boundary. The reflectivity behaviors in these two images should allow a fluid-contact boundary to be identified.

Conclusion

For simplicity, this modeling assumes that the pore space in the sandstone reservoir is filled with either 100 percent brine or 100 percent CO_2. In reality, the pore space will be occupied by various percentage ratios of brine and CO_2. Our only purpose here is to emphasize that a detailed seismic modeling should be done to determine the viability and strategies of seismic monitoring of injected CO_2 before any CO_2 sequestration project is initiated. Some CO_2 plumes may require that careful and precise procedures be implemented for monitoring plume growth, as in this case. Appropriate modeling can show if a CO_2 plume in another geologic setting will be easier to image.

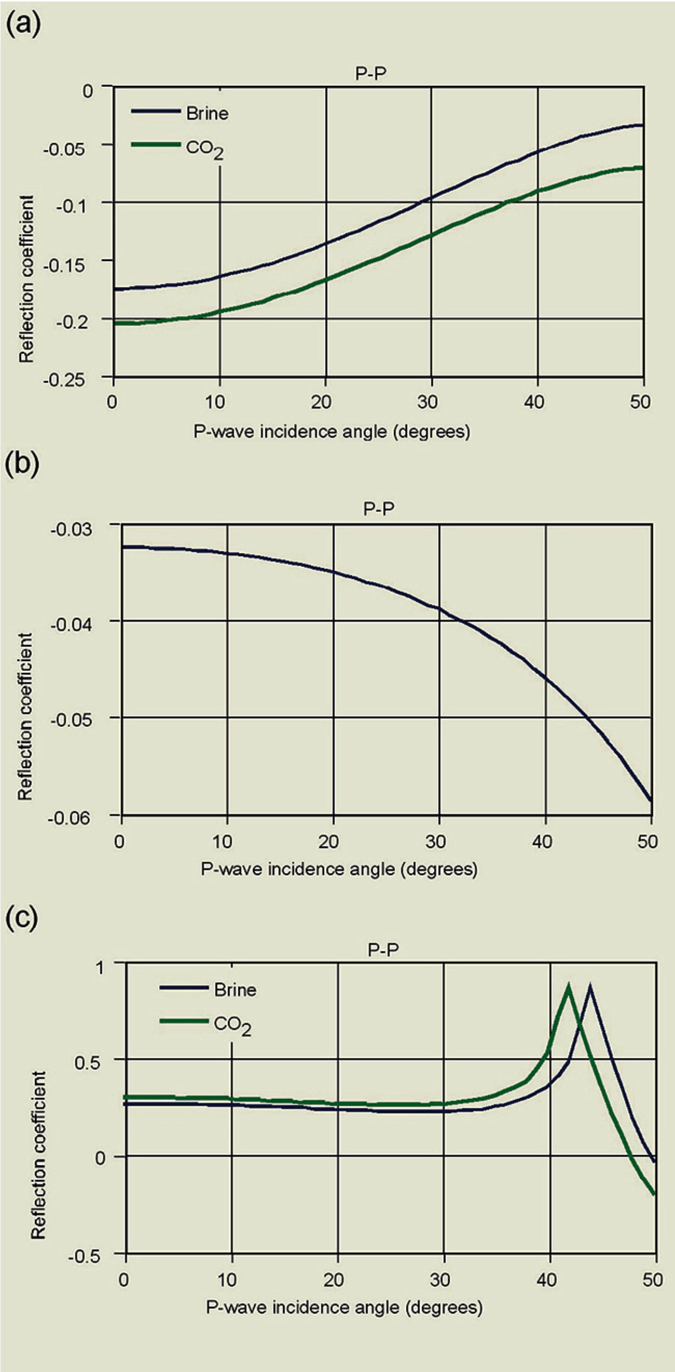

Figure 1. Density of CO_2 for a range of pressures and temperatures. Numbered triangle 1 defines the value of CO_2 density used to model seismic responses at a CO_2 sequestration depth of 6,000 feet. As a reference, the density of water (1 gm/cm^3) is 62.43 lbs/ft^3.

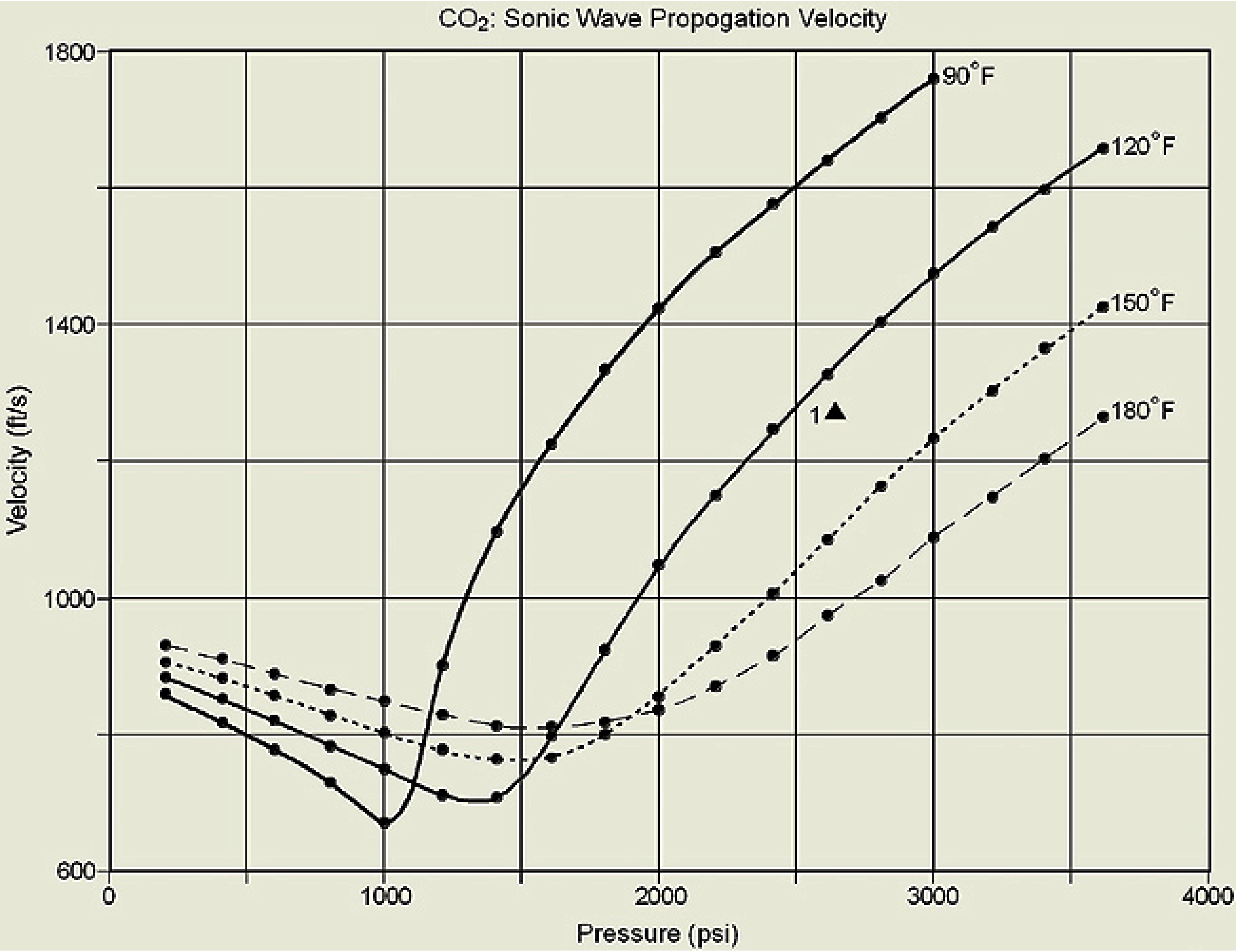

Figure 2. P-wave propagation velocity in CO_2 for a range of pressures and temperatures. Numbered triangle 1 defines the velocity value used to model seismic reflectivity at a CO_2 sequestration depth of 6,000 feet. As references, the velocity in water is approximately 4,800 feet/second, and the velocity in air is 1,100 feet/second.

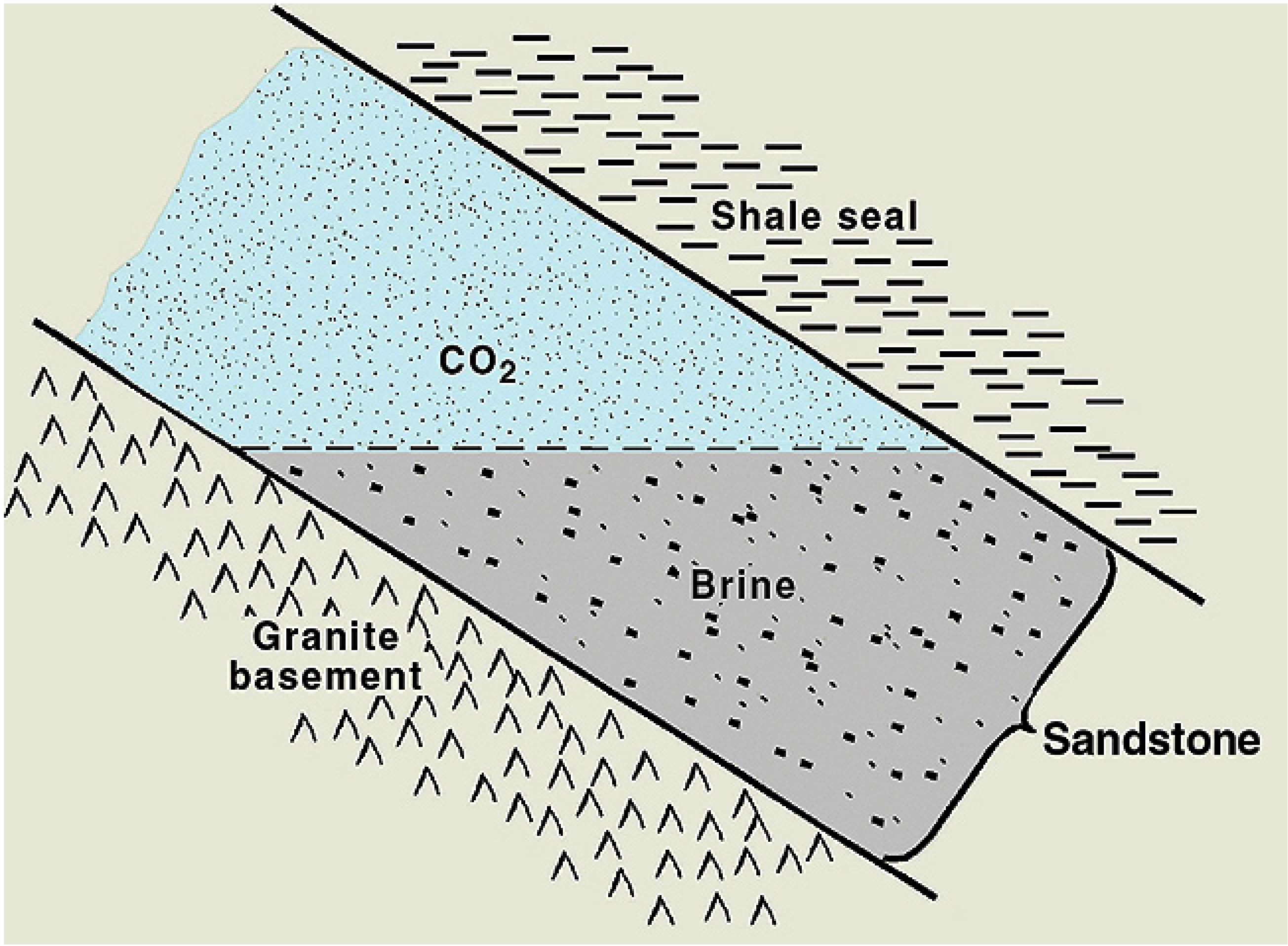

Figure 3. Earth model of the CO_2 sequestration target.

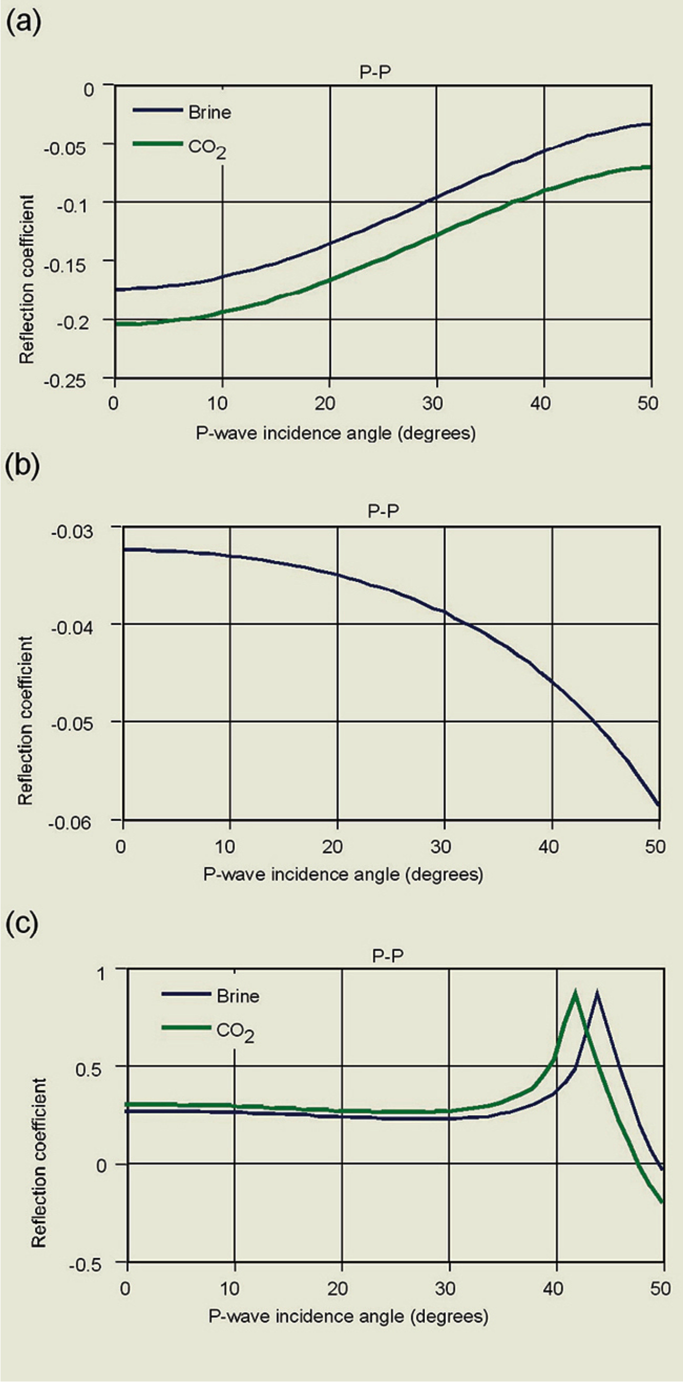

Figure 4. (a) P-wave reflectivity at top of reservoir; (b) P-wave reflectivity at brine/CO_2 interface; (c) P-wave reflectivity at base of reservoir.