GC Estimating Seafloor Strength with C4 Data*

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General Statement

Marine 4C seismic technology was developed to assist hydrocarbon exploration and development – but 4C data have important marine engineering applications that have not been exploited. The data discussed here illustrate how 4C data can be used to define geomechanical properties of a seafloor where engineers need to install production facilities.

Emphasis is placed here on determining bulk moduli and shear moduli of seafloor sediment. Bulk modulus, K, for a homogeneous medium is given by the equation:

$$K = [(V_P)^2 - (4/3)(V_S)^2]$$

Shear modulus, μ, for the same homogeneous material is defined by:

$$\mu = (V_S)^2.$$

In these expressions, V_P and V_S are, respectively, P-wave and S-wave velocities in seafloor sediment, and is the bulk density of a sediment sample.

Examples

Figure 1 presents shallow data windows of compressional (P-P) and converted-shear (P-SV) profiles across an area of 4C/3D data acquisition. Data analysis will be confined to the layer extending from the seafloor (labeled WB) to horizon H4 shown on the profiles. Procedures used by the seismic data processor caused the water bottom interface WB to not be imaged on the P-SV profile.

The profile crosses a gas-invaded zone centered on crossline coordinate 200. P-P horizons H1 through H4 are interpreted to be depth-equivalent surface to P-SV horizons H1 through H4. For simplicity, the bulk density term in the two equations above is assumed to have a constant value of 1.8 gm/cm^3 across the data analysis space.

Figure 2 displays seismic-derived V_P velocities and calculated bulk moduli across the shallowest seafloor layer (WB to H4), and seismic-derived V_S velocities and shear moduli values calculated for the layer are shown on Figure 3.

Each elastic constant is shown as a 3-D surface and also in plan view. The position of the example profile (Figure 1) is marked across each 3-D surface and illustrates the relationship between the gas-invaded zone seen on the P-P image and a normal fault that extends across much of the image area in the vicinity of crossline coordinate 200. These figures show there is a one-to-one relationship between V_P and bulk modulus, and between V_S and shear modulus, for these high-porosity, near-seafloor, unconsolidated sediments.

Referring to equation 2, it is no surprise that V_S and μ have a one-to-one correlation. The one-to-one relationship between V_P and K is caused by the fact V_P is much larger than V_S within this shallowest seafloor layer. In areas having hard seafloor sediment and for deeper layers where the V_P/V_S ratio has values appropriate for consolidated rocks, the V_S term of equation 1 will be significant, and there will not be such a close correlation between K and V_P. The multicomponent seismic data application illustrated by this example can be done more rigorously by implementing a data-point by data-point inversion to create thin V_P and V_S layers that provide greater detail about zones of mechanical weakness.

Conclusion

The intent of this example is only to document that even simple velocity analyses of 4C data allow weak and strong areas to be recognized across a seafloor. Of the two elastic moduli that are considered, shear modulus is particularly important for understanding where seafloor slumping is likely to occur. Without 4C data, it is difficult to estimate shear moduli across large seafloor areas and to identify areas where seafloor slumping may be expected.

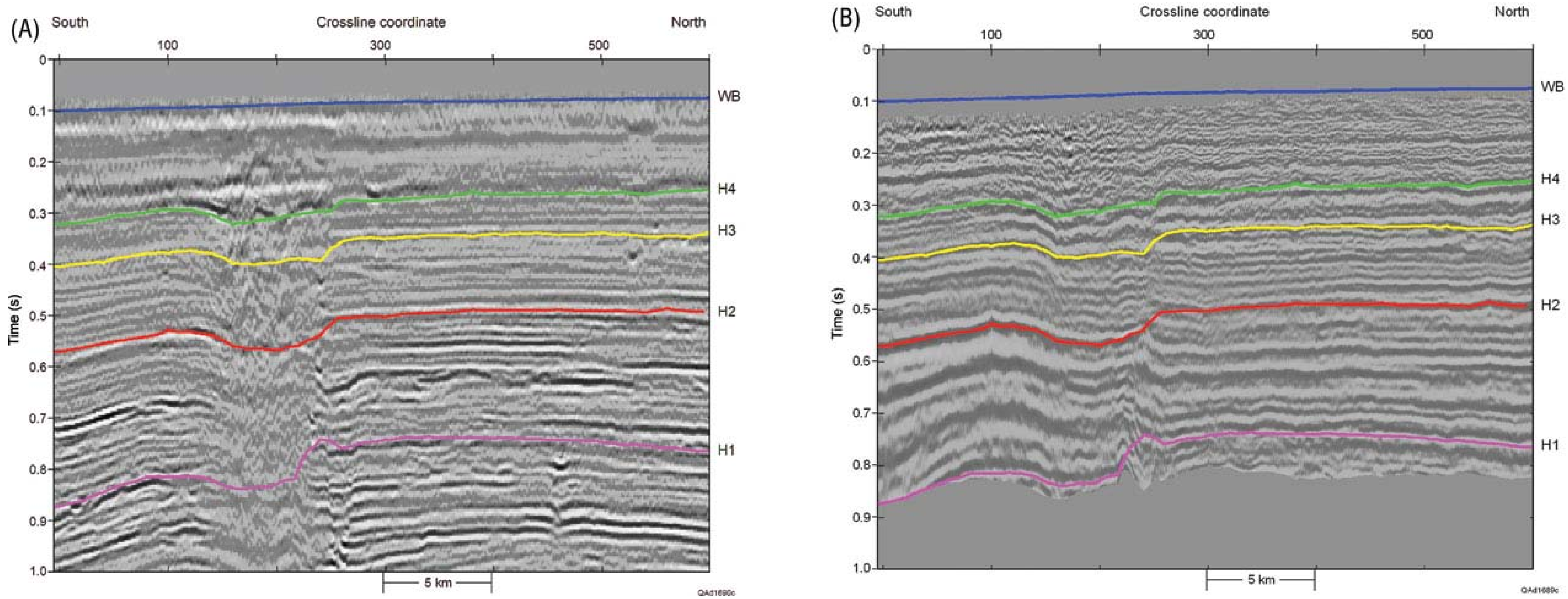

Figure 1. (a) P-P profile and (b) P-SV profile traversing a 4C/3-D data-acquisition area in the Gulf of Mexico. Geomechanical properties will be evaluated across the layer bounded by the seafloor (horizon WB) and interpreted horizon H4. The P-SV data are time warped to P-P image-time coordinates.

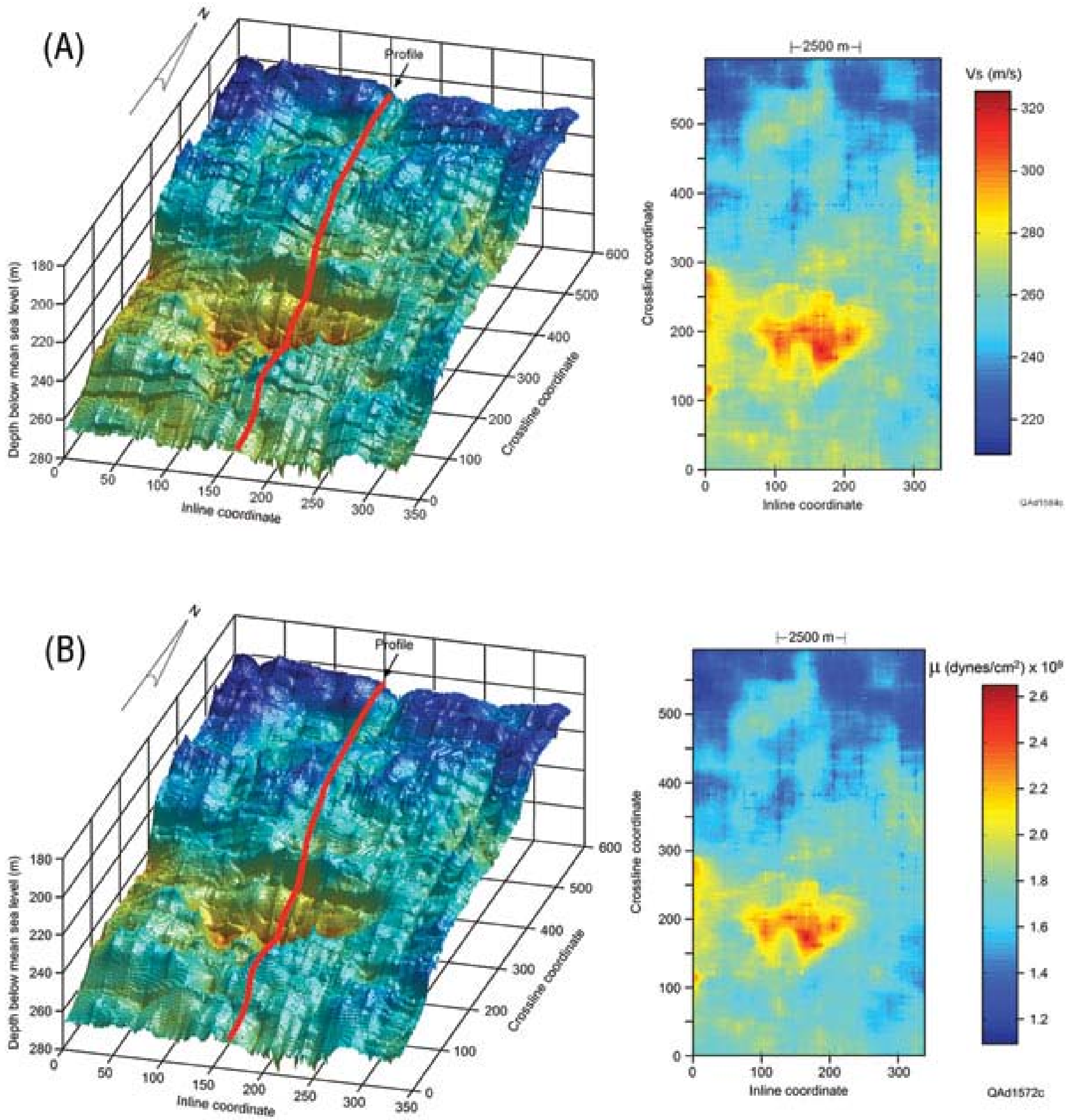

Figure 2. (a) Seismic V_P interval velocity across seafloor layer WB to H4. (b) Seismic derived bulk modulus for the layer. Note the one-to-one relationship between V_P and bulk modulus.

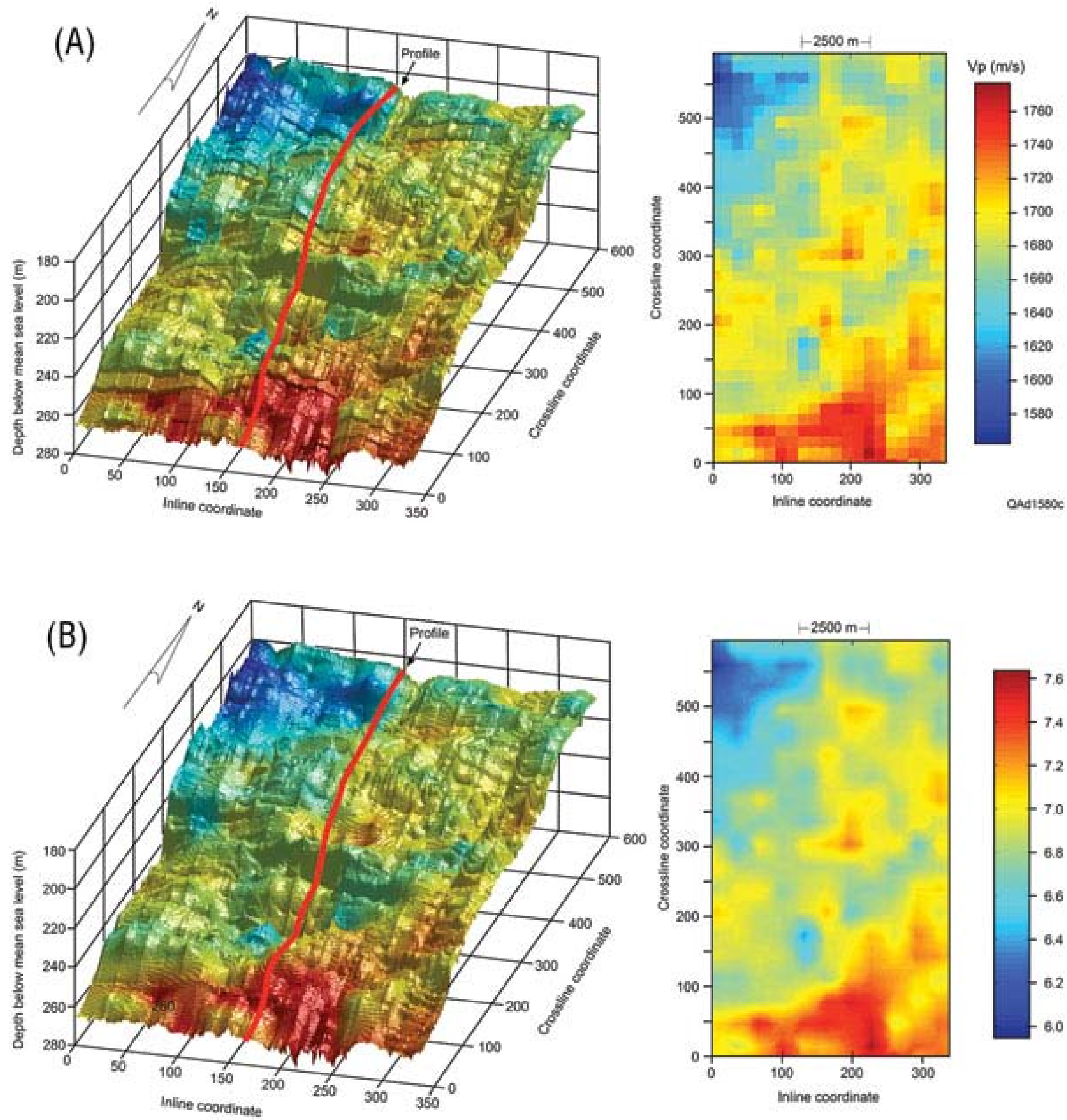

Figure 3. (a) Seismic V_S interval velocity across seafloor layer WB to H4. (b) Seismic derived shear modulus for the layer. Note the one-to-one relationship between V_S and shear modulus.