Closing the Gap Between the Hydrate Stability Zone and Production Reservoirs

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As part of a program to image features within the hydrate stability zone, a deep-water seismic profiling technique has been developed that provides very high resolution in the shallow sub-bottom as well as relatively deep penetration. It is called the surface-source-deep-receiver (SS/DR) technique because it uses a conventional source of seismic energy towed beneath the source, as illustrated in the cartoon. The receiver depth of tow is great enough that the outgoing wave front approximates a vertically traveling plane wave.

One advantage of SS/DR geometry is that the wave which travels directly from source to receiver constitutes a far-field signature of the energy source. This direct wave can be used to "collapse" the waveforms of sub-bottom reflections, i.e. to compress their energy into shorter time spans. Two methods of doing so are called deterministic deconvolution and phase conjugation. Both methods remove the phase, i.e. the "kink", from the source signature reflected waveforms. The two differ in that the deterministic deconvolution output power spectrum is broader than that of the input while the phase conjugation input and output power spectra are identical. Results of the applying the two methods to an actual source signature are shown in the illustration. Both are seen to compress the signature's energy but deterministic deconvolution seems to do the better job. This is not always the case, however, because deconvolution can be very sensitive to noise. In practice, phase conjugation often provides better results overall.

During recent years, the SS/DR technique has been used to image regions of known hydrate occurrence in the northern Gulf of Mexico. Conventional pneumatic sources were used and the hydrophone was towed approximately 400m below the surface. In water depths ranging from 80m to 150m, it has been possible to resolve shallow layers about a decimeter thick and much deeper layers less than a meter thick. A phase-conjugated profile is shown here. It was acquired in 700m of water using a 15 in³ watergun. The enhancements show details within the boxed areas. The deeper one shows a layer about a meter thick whose upper boundary is a positive reflection and whose lower boundary is a negative reflection. This would be consistent with a sandy layer within a clay sequence.

A disadvantage of the SS/DR technique is that the depth of usable seismic penetration is dictated not only by the strength of the source but also by the arrival of other reflections generated at the boundaries of the water layer. Two such reflections are identified on the accompanying phase-conjugated profile which recorded in 600m of water using an 80 in³ watergun. They are a reflection from the sea surface called the "surface ghost" and a reflection from both the sea surface and the sea floor called a "water-bottom multiple." Both are seen to strongly overprint primary reflections of comparable travel times. The geometry of ghost and multiple reflections are illustrated in the adjacent cartoon.

An effort is currently underway to develop processing techniques by which ghost and multiple reflections can be suppressed. Results of applying the deghosting technique have been presented this morning in an oral presentation by Erika Geresi. The deghosting technique is still being developed and preliminary results are shown at the left. Indications are that the process reduced the amplitude of the ghost reflection by about 70%. Greater reductions are expected to result from fine-tuning the software.

When perfected, these types of processing will extend the usable penetration on SS/DR profiles, perhaps far enough that they will overlap with the shallower portions of industry-standard seismic profiles. This will close the gap that currently exists between ultra-high-resolution and deep exploration seismic information. The result will be images that are continuous from the hydrate stability zone down to the deep production reservoirs that supply the gas to form shallow hydrates in the Gulf of Mexico.