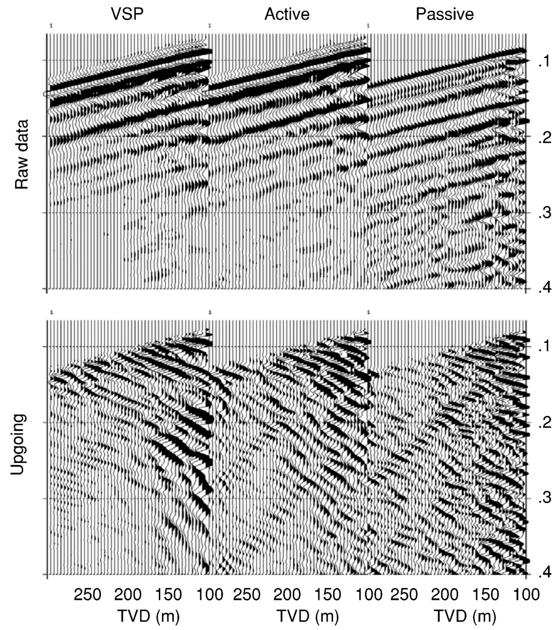

Figure 14. Fixed-offset survey comparing the cased hole wireline VSP with the fiber-optic sensor data acquired with the ASC and PSM. Each set of three plots contains axial and two orthogonal radial orientations. Data from the ASC best matches the VSP tool, whereas the PSM data exhibits both resonances in the direct P-wave signal and tube-wave-related noise. Fiber-optic accelerometer data are integrated for direct comparison with the VSP geophone data.

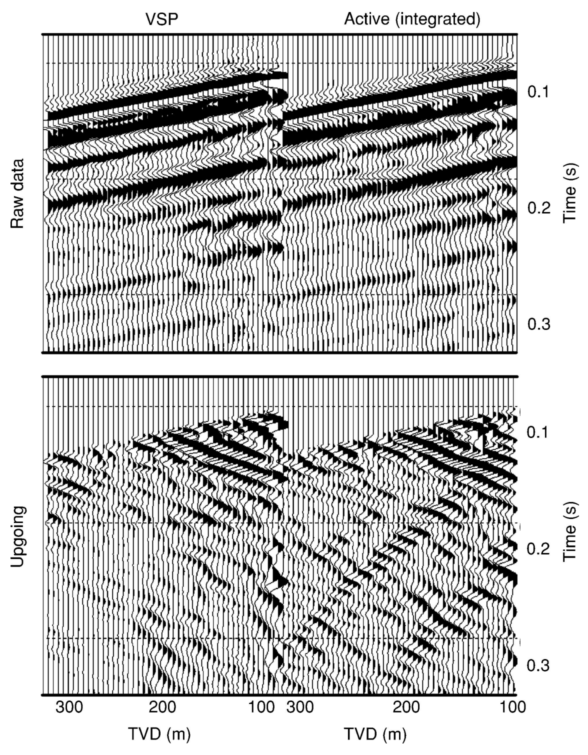

Figure 15. Wireline VSP and integrated ASC fiber-optic accelerometer data with active seismic mandrel for source location 5, 198 m from the wellhead. For both systems, axial components are plotted as a function of time and TVD.

the response of the fiber-optic sensors is at least comparable to the standard VSP sensors.

Although the primary objective of the field test was to evaluate different deployment techniques for a tubing-conveyed sensor, some seismic information was obtained in the shallow test well using the ASC device. Figure 17 shows a comparison with well-log-derived synthetics. Major upcoming energy clearly originates from reflectors around 180-m TVD. Regional surface seismic data is focused on deeper targets; therefore, no additional efforts were made to correlate this event.

Design improvements

Following the field test, the deployment methods were reviewed. The PSM was considered suitable for installation in a production well; however, the ASC design was considered to be insufficiently rugged. An improved design was achieved by integrating techniques used in standard completion equipment (Figure 18).

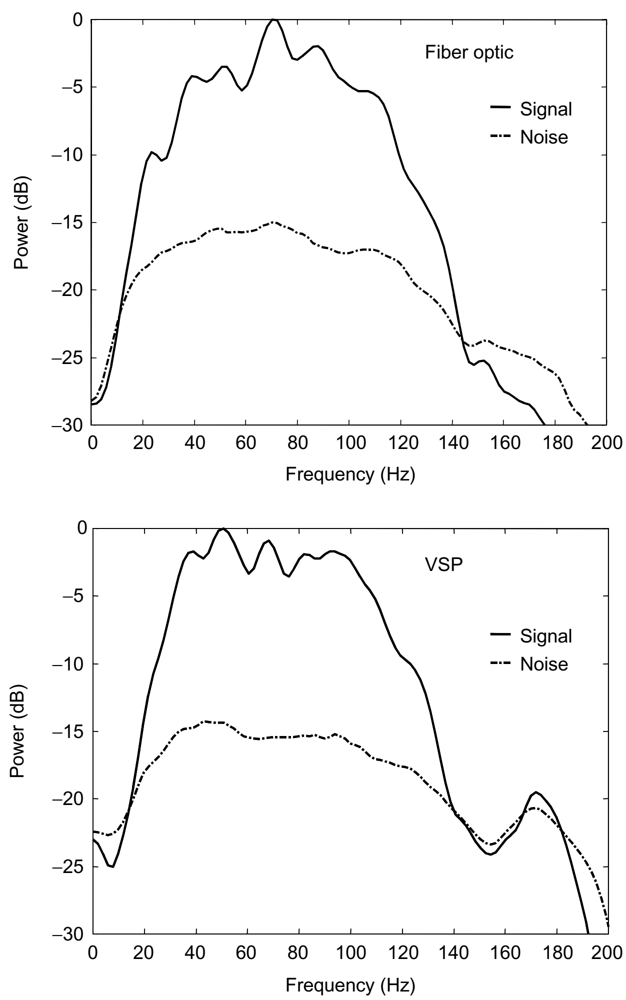

Figure 16. S/N analysis using the multiple coherency function method (White, 1973).

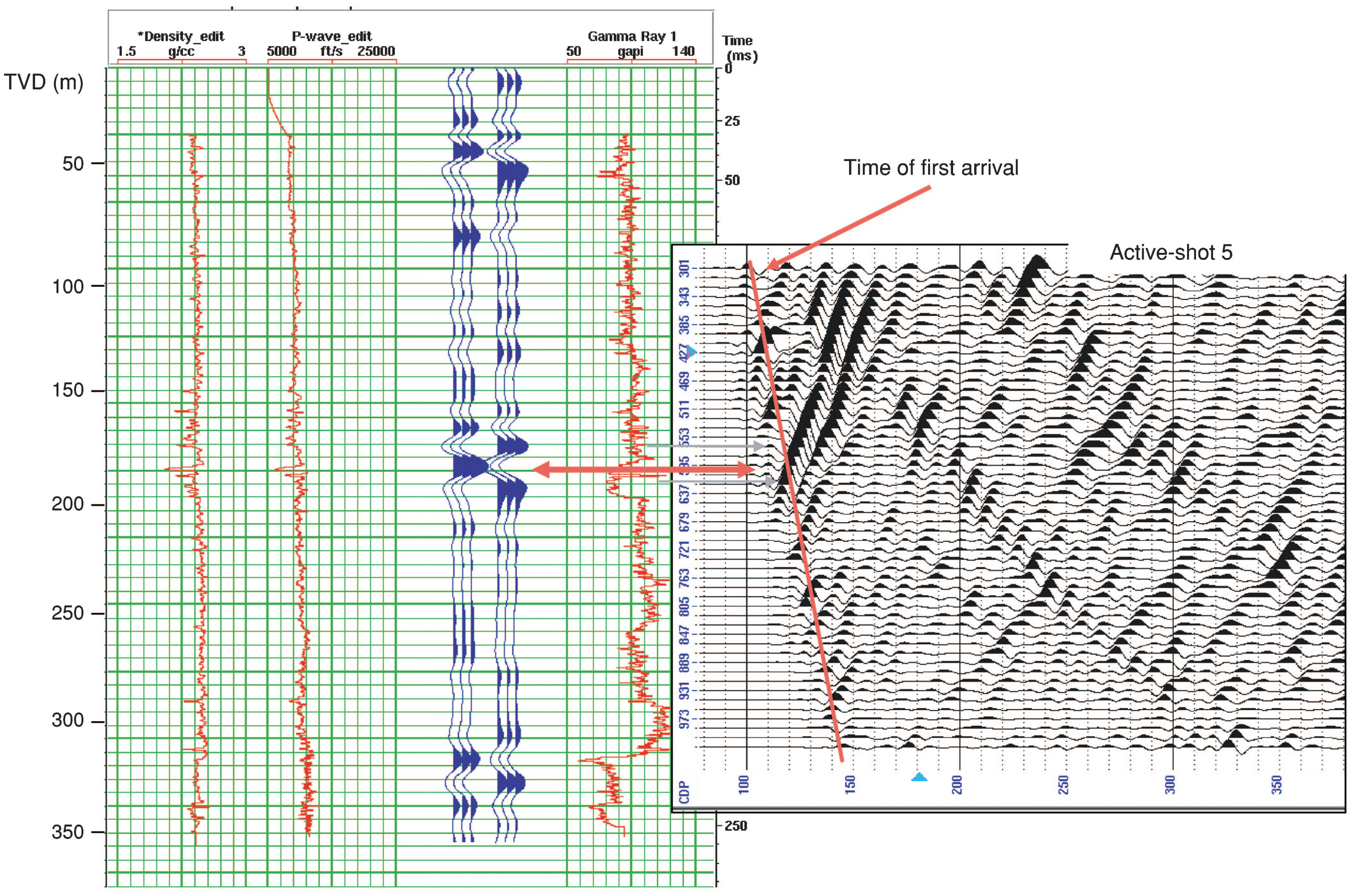

Figure 17. Comparison of ASC with well-log-derived synthetics. Major upcoming energy clearly originates from reflectors around 180 m TVD.

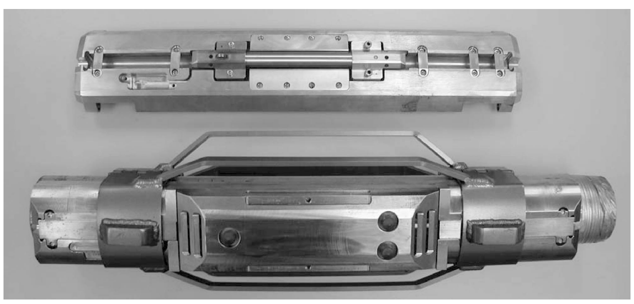

Figure 18. Prototype active seismic clamp (top) and subsequent production-well design (bottom).

CONCLUSIONS

Multicomponent seismic data were successfully acquired with tubing-deployed fiber-optic sensors. Two distinctly different deployment methods were used: a passive and an active coupling approach. In general, the passive seismic mandrel (PSM) exhibited similar behavior to conventional thru-tubing wireline data. The active seismic clamp (ASC) more closely resembled empty cased-hole wireline data. While both methods resulted in good quality directional data, the ASC generally exhibited higher S/N than the PSM. Data from the PSM data also exhibited both resonances in the direct P-wave signal and tube-wave-related noise, both of which interfere with acquisition of the reflected P-wave energy.

The production-tubing deployment of fiber-optic seismic sensors was shown to be feasible, and useful data were acquired from two different deployment methods. Active coupling exhibited data characteristics superior to the passive coupled device. Based on these findings, a rugged active seismic clamp was designed and built for production-well installation.

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