Using 3C-3D seismic data to delineate a sandstone reservoir, Alberta, Canada
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Summary
This paper describes the interpretation of the 3C-3D seismic survey acquired in the Cavalier field, near Strathmore, Alberta (Township 23, Range 23 W4).

Structural interpretation shows a horst block in the south-central part of the area, evident from basal Cambrian through Viking time. A fault running in a north-south direction bounds the eastern part of the block at basal Cambrian time. The fault is clearly mappable on both P-P and P-S data. More detailed structural variations are noted on the P-S time structure map than from P-P data in the west-central part of the survey area.

Time slice analysis indicates that P-P amplitude anomalies occur not only along the Glauconitic channel trend (target of survey), but also where regional wells were drilled. P-S time slices and isochron maps indicate clearly the valley fairway trend, and Vp/Vs values very accurately predict the locations of producing wells.

Introduction
The Cavalier field is located in the southern Alberta, 45 km south-east from Calgary. The 3C-3D seismic survey was conducted by Boyd Exploration Consultants Ltd., a group of industrial participants, and the CREWES Project in 1995. The objective was to evaluate the effectiveness of integrated 3-D P-P and P-S surveys for improved hydrocarbon exploration. In the Cavalier Field, the main problem is to map cut-and-fill channel trends in Lower Cretaceous rocks, and to distinguish between sand-fill and shale-fill lithologies within the channel, e.g. to distinguish between porous sandstone and shale plugs. A stratigraphic column of the reservoir interval is shown in Figure 1.

Analysis and Interpretation
From well data in the Blackfoot area, the reservoir is interpreted to be in an incised valley system formed in an estuarine environment. The Glauconitic sandstones and shales fill valleys which were incised into the regional Lower Mannville stratigraphy. Conventionally, only P-P seismic data is used to delineate the channel, although difficulties have been encountered in discriminating the sand fill from the shale fill within the channel.

Seven key seismic horizons (Viking, Mannville, Lower Mannville, Top Channel, Mississippian, Wabamum and basal Cambrian) were selected, interpreted and mapped because of their seismic continuity and adequate seismic-to-well correlation. They are identified and picked on both P-P and P-S sections based on the synthetic seismograms generated from the available dipole sonic and density logs in the area as well as nearby VSP surveys. These seven key horizons form the framework for structural interpretation and isochron mapping. Seismic amplitude variations across the zone were evaluated, isochrons between these events were computed, and Vp/Vs across several intervals were calculated using the relationship Vp/Vs = 2 t_{ps} / t_{pp} -1 (where t_{ps} is the P-S isochron and t_{pp} is the P-P isochron).

Time-slices were also used to assist the interpretation. Time-slice display and interpretation was undertaken by first flattening the data volume on a horizon above the Glauconitic channel level which could be picked confidently on both P-P and P-S data sets. The purpose was to remove long-wavelength structure from the data caused by drape and mid-Cretaceous uplift of the horst block in the center of the survey area. The Mannville event was chosen to flatten the volume in this data set.
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Results

Figure 2 is the time slice at 1054 ms from the flattened $P$-$P$ volume. The time slice cuts the volume at about the level of the channel. The time slice in Figure 1 shows an amplitude anomaly along the trend of oil wells (01-08 through 16-08) in the southern part of the Glauconitic patch. However, the channel signature is non-unique, with bright amplitudes also occurring at the locations of regional wells (14-09, 11-08). Figure 3 is a time slice for the $P$-$S$ data (at 1560 ms) and shows a high-amplitude anomaly in the valley trend across the survey area.

Figure 4 displays a $V_p/V_s$ map for the top channel -Wabamum interval. Shale-plugged wells 04-16 and 12-16 lie within the zones of higher $V_p/V_s$, whereas the producing wells all lie in the zone of low $V_p/V_s$ values. The $P$-$S$ data interpretation, particularly isochron analysis, shows the channel trend clearly, and $V_p/V_s$ analysis show areas interpreted to be reservoir sands, which correlate spatially with the well control. The techniques of mapping $V_p/V_s$, using flattened time slices, and stratigraphic amplitude analysis have brought a new perspective to the geophysical interpretation.

Conclusions

The Blackfoot 3C-3D survey has shown that converted-wave ($P$-$S$) analysis has provided significant additional value to conventional, $P$-wave surveys for the exploration of valley-fill sandstone reservoirs. The integration of both $P$- and $S$- wave data increases our ability to view the valley fairway and delineate spatial distribution of sand and shale in the area.

Acknowledgments

The authors wish to acknowledge the support of Pan Canadian Petroleum Ltd., the University of Calgary, CREWES and its members, the twenty-two (22) Blackfoot sponsors, the members of the Technical Advisory Group (TAG), Geophysical Exploration and Development Corporation (GEDCO), Veritas Geophysical Ltd., Pulsonic Geophysical Ltd, and Sensor Geophysical Ltd.
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FIG 2. *P*-*P* time slice section at 1080 ms (flattened at Mannville).

FIG 3. *P*-*S* time slice section at 1590 ms (flattened at Mannville).
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FIG 4. Vp/Vs map, top channel event - Wabamum, showing that the oil wells lie within the smaller Vp/Vs values of light color, while the 12-16 and 4-16 dry holes lie within the larger Vp/Vs value zone of darker colors.