Processing and preliminary interpretation of multicomponent seismic data from Lousana, Alberta

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ABSTRACT

Two orthogonal three-component seismic lines were shot by Unocal in January, 1987, over the Nisku Lousana Field in central Alberta. The purpose of the survey was to calibrate a Nisku patch reef thought to be separated from the Nisku shelf to the east by an anhydrite basin. A study is underway within the CREWES Project to improve the quality of the existing processed products by reprocessing the data using ITA and CREWES software, and to use these products to evaluate the incremental benefit of multicomponent versus conventional recording for this type of exploration target. Preliminary interpretation of vertical and radial component products show time interval and amplitude variations in the zone of interest. Further processing, modeling, and interpretation will be undertaken to assess the quality of primary events at or near the Nisku level and to determine if, and with what degree of certainty, lithological predictions can be made. A secondary objective of the project is to use the radial and transverse data from both lines to understand any local anisotropy that might affect the quality of the predictions. This interim report describes work to date and future plans.

INTRODUCTION

Conventional seismic data are routinely employed to map stratigraphic changes and porosity, though not always successfully. Recording multicomponent data can provide additional independent measures of rock properties in the subsurface. Due to the difference in travel path, wavelength, and reflectivity, converted-wave seismic sections may exhibit geologically significant changes in amplitude or character which are not apparent on conventional data. Multicomponent seismic data can enhance our ability to make predictions about mineralogy, porosity, and reservoir fluid type.

Lithological identification is a task which was generally considered beyond the scope of seismic data until recently. Multicomponent seismic data are suitable for this type of work because of the well-documented association between the *Vp/Vs* ratio and lithology (e.g.. Pickett, 1963; Nations, 1974; Tatham, 1982; Eastwood and Castagna, 1983; Rafavich et al., 1984, Miller and Stewart; 1990). A number of studies, some of which are described below, have indicated that multicomponent seismic technology has practical applications in carbonate settings.

Rafavich et al. (1984) did a detailed laboratory study of velocity relationships with petrographic character in carbonates. They concluded that the primary influences on *Vp* and *Vs* are porosity and density, with lithology also exerting an influence.

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Neither pore shape nor pore fluid were significant factors. The *Vp/Vs* ratio successfully differentiated limestones and dolomites, but anhydrites were more difficult to identify. Anhydrite *Vp/Vs* values ranged from about 1.72 to 1.85. Porosity-velocity trends were well described by the Wyllie time-average equation, provided the correct matrix velocities were used. The results of the laboratory analysis were used to interpret porosity and lithology variations in seismic data from a carbonate sequence. The interpretation agreed with well log data.

Wilkens et al. (1984) concluded that carbonate content was the primary influence on the *Vp/Vs* ratio in siliceous limestones, with total porosity and pore geometry acting as lesser factors.

Robertson (1987) interpreted porosity from seismic data by correlating an increase in porosity with an increase in *Vp/Vs*. He based his interpretation on the model of Kuster and Toksöz, which incorporates pore aspect ratio as a factor in velocity response. According to this model, *Vp/Vs* will rise as porosity increases in a brine-saturated limestone with flat pores, but will decrease slightly if the pores tend to have a higher aspect ratio (are rounder). If the limestone is gas saturated, *Vp/Vs* will drop sharply as porosity increases if pores are flat, and drop slightly if pores are rounder.

Goldberg and Gant (1988) studied full-waveform sonic log data in a limestone/shale sequence and found the *Vp/Vs* ratio effective at identifying limestone/shale boundaries, but ineffective at identifying fracturing in the limestone. They concluded that shear-wave amplitude attenuation is more useful for detecting fractures. Shear-wave amplitude was also attenuated in the shale zones, and thus could also be used for lithology identification in this case.

Georgi et al. (1989) did not observe a reduction in *Vp/Vs* due to gas in their full-waveform sonic log study of Alberta carbonates. They concluded that this may have been because the pores in the formations studied were primarily round in shape. Both compressional and shear transit times were useful for computing porosity from the Raymer-Hunt-Gardner transform (1980), which was modified to accommodate shear-wave transit times.

Well log data from the Pekisko limestone of Alberta was analyzed by Miller and Stewart (1990). They observed a decrease in both *Vp* and *Vs* as porosity increased, but did not observe a correlation between *Vp/Vs* and porosity.

Multicomponent data have been used successfully to differentiate tight limestone from reservoir dolomite in the Scipio Trend in Michigan. Pardus and others (1991) mapped the variation in the *Vp/Vs* ratio across the interval of interest on *P*- and *S*-wave seismic data and related it to the ratio of limestone to dolomite. Limestone tends to a *Vp/Vs* value of 1.9, dolomite of 1.8. Petrophysical studies suggest that anhydrite also has a higher *Vp/Vs* ratio than dolomite and thus might be used in a similar manner to track dolomite/anhydrite variations (Miller, 1992).

Wang et al. (1991) analyzed over 80 cores from over ten carbonate reservoirs in Alberta for seismic velocities, porosity, permeability, electrical properties, capillary pressure, and petrographic image analysis. Results showed that seismic velocities are related to core porosity, although there was scatter in the data. Saturating the cores with oil or water increased *Vp*, but had a nominal effect on *Vs*. Pore geometry, pressure, and fluid distribution and properties influenced the magnitude of the increase in *Vp*. The data did not fit well to either the time-average equation or the Gassman equation, suggesting that it may be advisable to establish velocity-porosity relationships for specific reservoirs.

In 1987, Unocal acquired two three-component lines across the Lousana Field. Unocal donated these data to the CREWES Project, and they are currently being reprocessed using ITA's software and converted-wave code developed by CREWES. Modeling and interpretive studies are also underway. The goals of this project are to:

- improve the quality of existing products by reprocessing the data,
- determine if multicomponent data analysis can discriminate among the porous dolomites and tight limestones found in the reef and shelf environments, and the anhydrite in the basin,
- identify character, amplitude, or time interval variations which may be associated with productive zones, and attempt to calibrate these variations to changes in geology through forward modeling,
- use radial and transverse data from both lines to understand any local velocity anisotropy that might affect the quality of lithological predictions,
- determine if converted waves can better image horizons which are contaminated with multiple interference on conventional data, and,
- evaluate the incremental benefit of multicomponent versus conventional recording for this type of exploration target.

GEOLOGIC BACKGROUND

The Lousana Field is in central Alberta (Township 36, Range 21, West of the 4th Meridian) and is located west of the Fenn West Big Valley Oil Field (Figure 1).

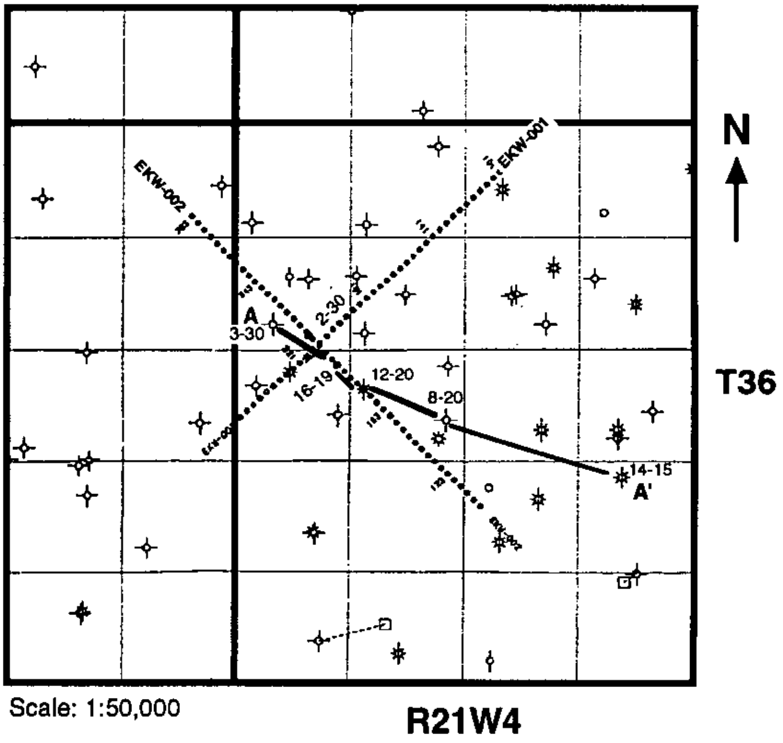

FIG.1. Shotpoint map of the Lousana survey showing seismic lines EKW-001 and EKW-002, cross-section A-A', and well control.

The Lousana Nisku reef is separated from the Nisku carbonate shelf to the east by an anhydrite basin, which forms the seal for the reef. The Nisku is 50 - 60 m. thick and is overlain by the Calmar Formation, a shale which is generally only about 3 m. thick, and underlain by the Ireton Formation, a limy shale. Geological cross-section A-A', shown in Figure 2, roughly parallels line EKW-002, and is built from well logs from each of the shelf, basin, and reef environments.

The Nisku at Lousana is a dolomite oil reservoir with up to about 25 m. of porosity in producing wells. The two oil wells in the field, 16-19-36-21W4 and 2-30-36-21W4, have about 25 m. of porosity and 10 m. of pay. The 16-19 well went on production in 1960 and has produced about 78,000 m^3 of oil to date. The 2-30 well has produced over 58,000 m^3 of oil since it went on production in 1962. The porosity is primarily vuggy, ranging to intergranular, and averages about 10% in the two producing wells. Dry holes in the field are either tight or wet carbonate, or massive anhydrite at the Nisku level. There is also gas production from the Viking and other Lower Cretaceous formations in this area.

SEISMIC DATA ACQUISITION

The field acquisition parameters are summarized in Table 1. The survey was carried out using a dynamite source and two 240-trace Sercel SN-348 recording systems; one to record the vertical and one horizontal components, and the other to record the second horizontal component. A string of six three-component geophones was used at each receiver station, measuring motion in the vertical and two orthogonal horizontal directions; H1 (north-south) and H2 (east-west). A single shot hole was used for line EKW-001, while a 4-hole pattern was used for line EKW-002. Data were typically collected from 110 receivers for each sourcepoint using a split-spread layout.

Vertical-, H1-, and H2-component gathers are shown in Figures 3, 4, and 5 respectively for one sourcepoint from each of the two lines. A time-variant gain function followed by individual trace-balance scaling has been applied to these field records. For both lines the geophones were oriented at 45 degrees to the line direction, giving comparable amounts of shear energy on H1 and H2. The horizontal-component records are seen to have good signal strength, with events that roughly correspond to those on the vertical component.

Table 1. Field acquisition and recording parameters for the Lousana survey.

Energy source	dynamite
Source pattern, EKW-001	single hole, 2 kg at 18 m
Source pattern, EKW-002	4 holes, 0.5 kg charges at 5 m
Amplifier type	2 - Sercel SN348
Number of channels	2 x 240
Sample rate	2 ms
Recording filter	Out-125 Hz
Notch filter	Out
Geophones per group	6 spread over 33 m
Type of geophones used	OYO 3-C, 10 Hz
Number of groups recorded	110
Group interval	33 m
Normal source interval	66 m
Nominal CMP fold	27

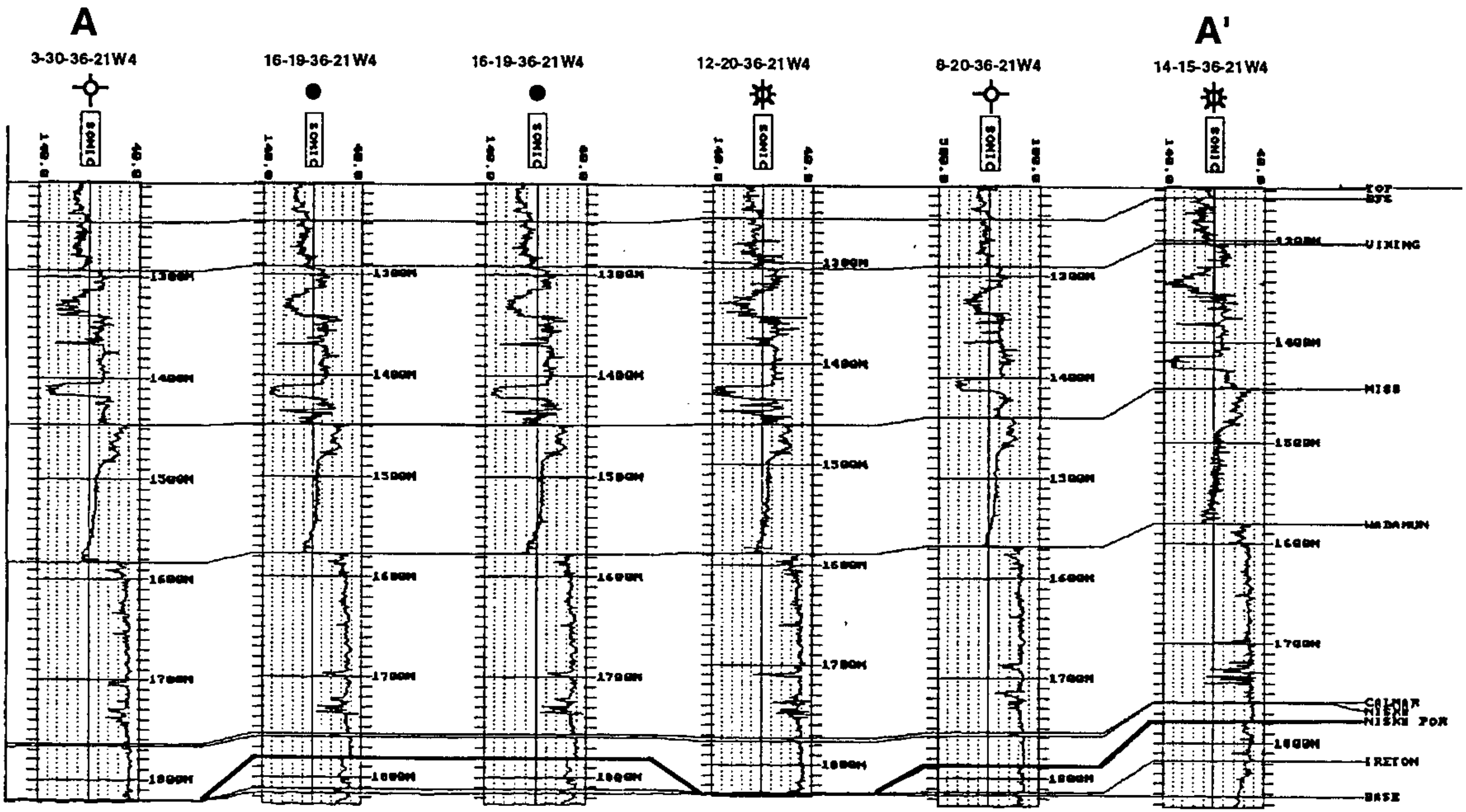

FIG. 2. Cross-section A-A', based on sonic logs from wells from the carbonate shelf (14-15, 8-20), anhydrite basin (12-20, 3-30), and porous reef (16-19) environments. 14-15 and 12-20 are suspended gas wells, with gas occuring in the Viking Formation. The 16-19 producing well is repeated as there is no sonic log for the nearby 2-30-36-21W4 oil well. The horizon named "NISKU POR" is the top of the porous dolomite in the Nisku Formation.

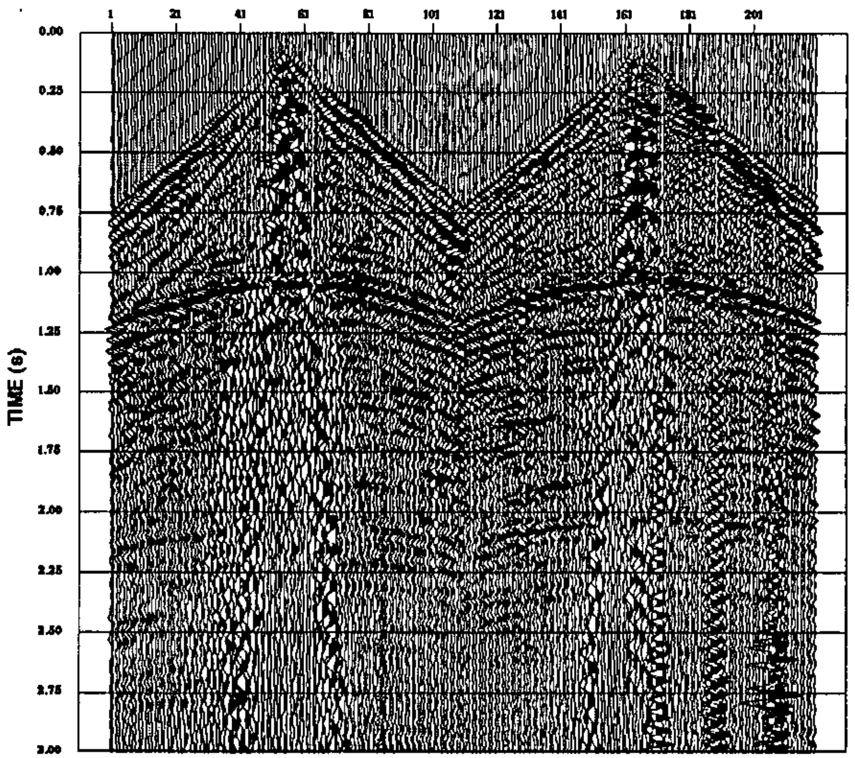

FIG.3.Vertical-component records:(a) EKW-001, SP 181.5; (b) EKW-002, SP185.5.

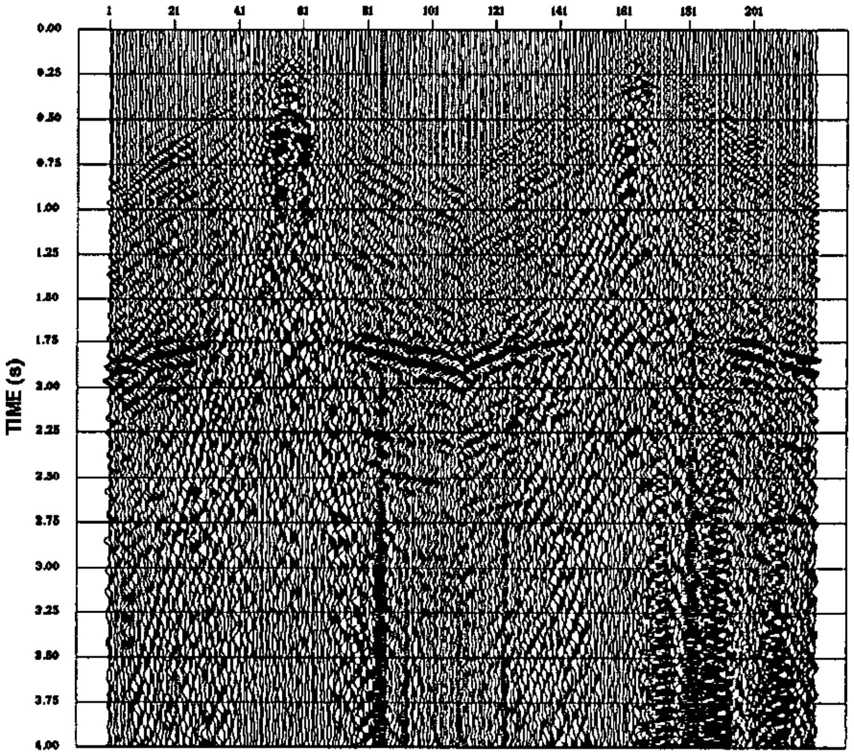

FIG.4. H1-component records: (a) EKW-001, SP 181.5; (b) EKW-002, SP 185.5.

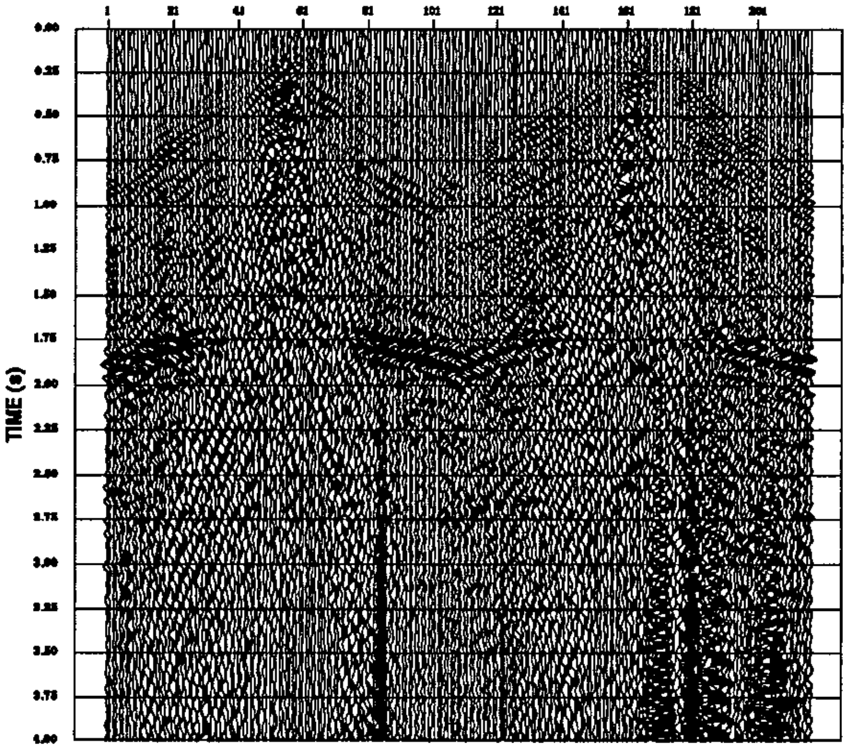

FIG. 5. H2-component records: (a) EKW-001, SP 181.5; (b) EKW-002, SP 185.5.

SEISMIC DATA PROCESSING

The vertical channel data were processed using the flow outlined in Figure 6. The records were picked for best-guess arrival times, from which layer replacement statics were computed. Geometric spreading compensation using a t-squared gain, and two-component surface-consistent deconvolution were applied . Poststack processing included zero-phase deconvolution, f-x prediction filtering (Canales, 1984), and phase-shift migration (Gazdag, 1978). The final migrated P-wave stack sections are shown in Figures 7 and 8, and are qualitatively seen to have good overall signal strength.

The horizontal (P-SV) components were processed using the sequence shown in Figure 9. At present, only the radial-component data have been processed to stack sections. We do, however, intend to continue working on the transverse-component data.

The initial step in the processing flow was to apply a 45° geophone rotation, in order to bring the horizontal components for each line into the radial and transverse directions. An energy maximization analysis was done on the horizontal data for each line to confirm the angle of rotation. In both cases the angle that maximized the energy on the output radial component was found to be within two degrees of the expected value, with considerable record-to-record variance. This geophone rotation was followed by geometric spreading gain compensation and two-component surface-consistent deconvolution.

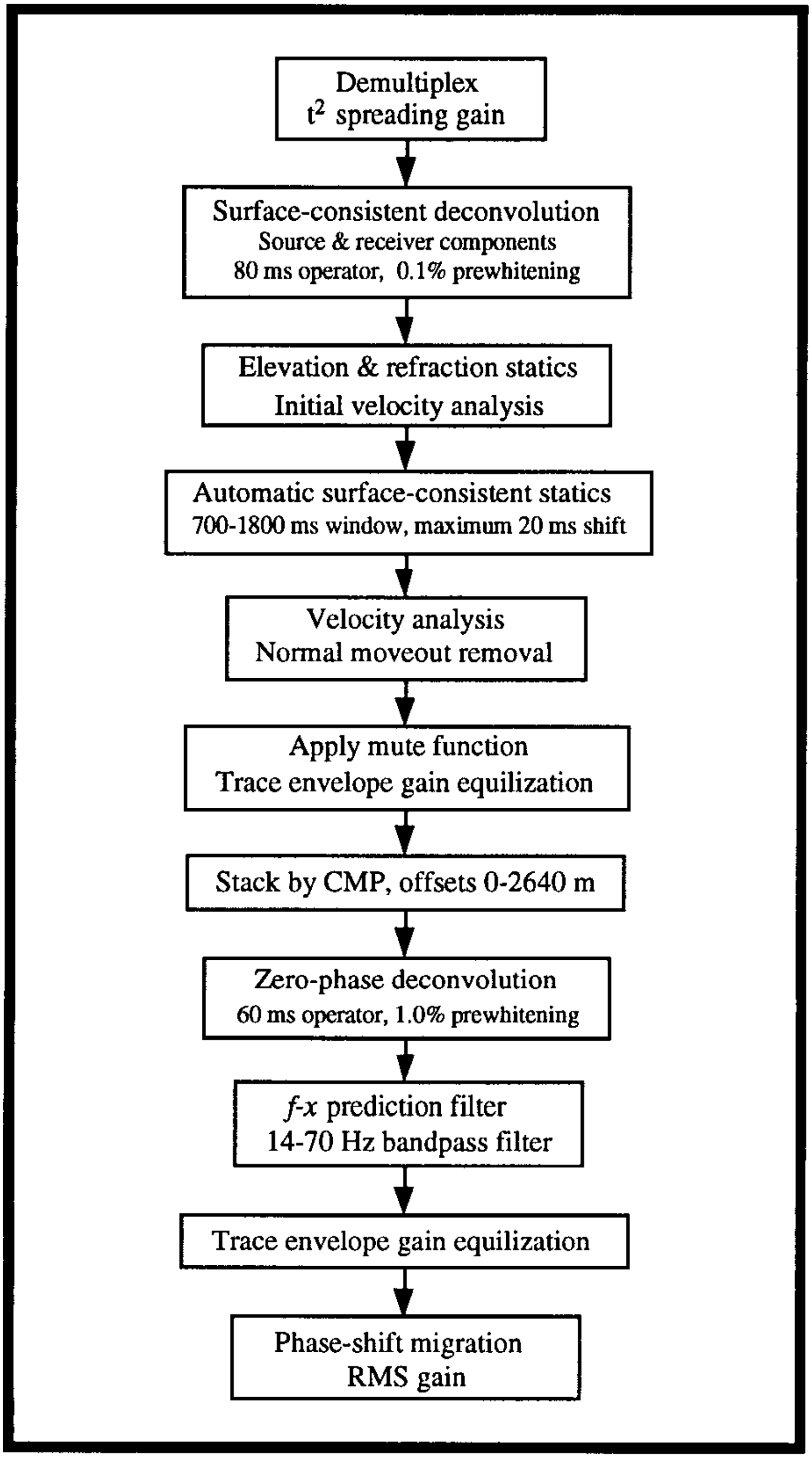

FIG. 6. Processing flowchart for the vertical-component data.

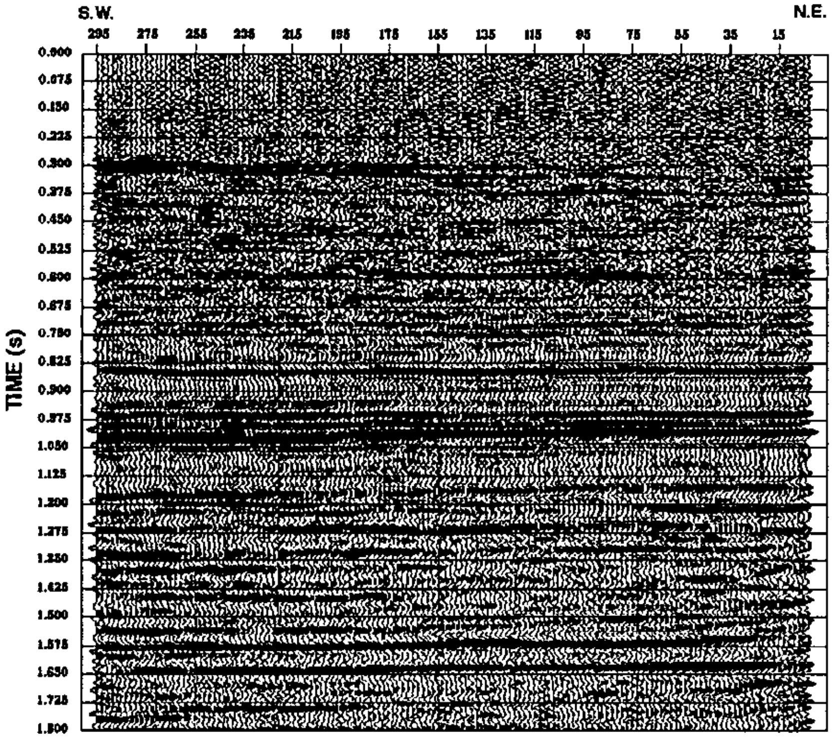

FIG. 7. Migrated vertical-component stack section for line EKW-001.

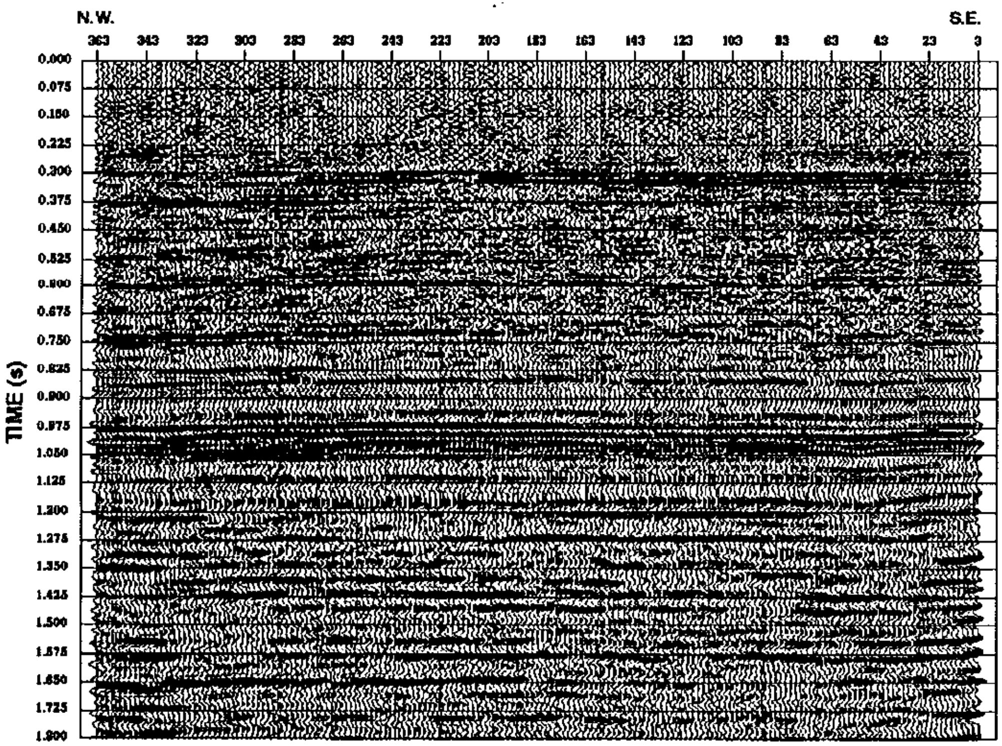

FIG. 8. Migrated vertical-component stack section for line EKW-002.

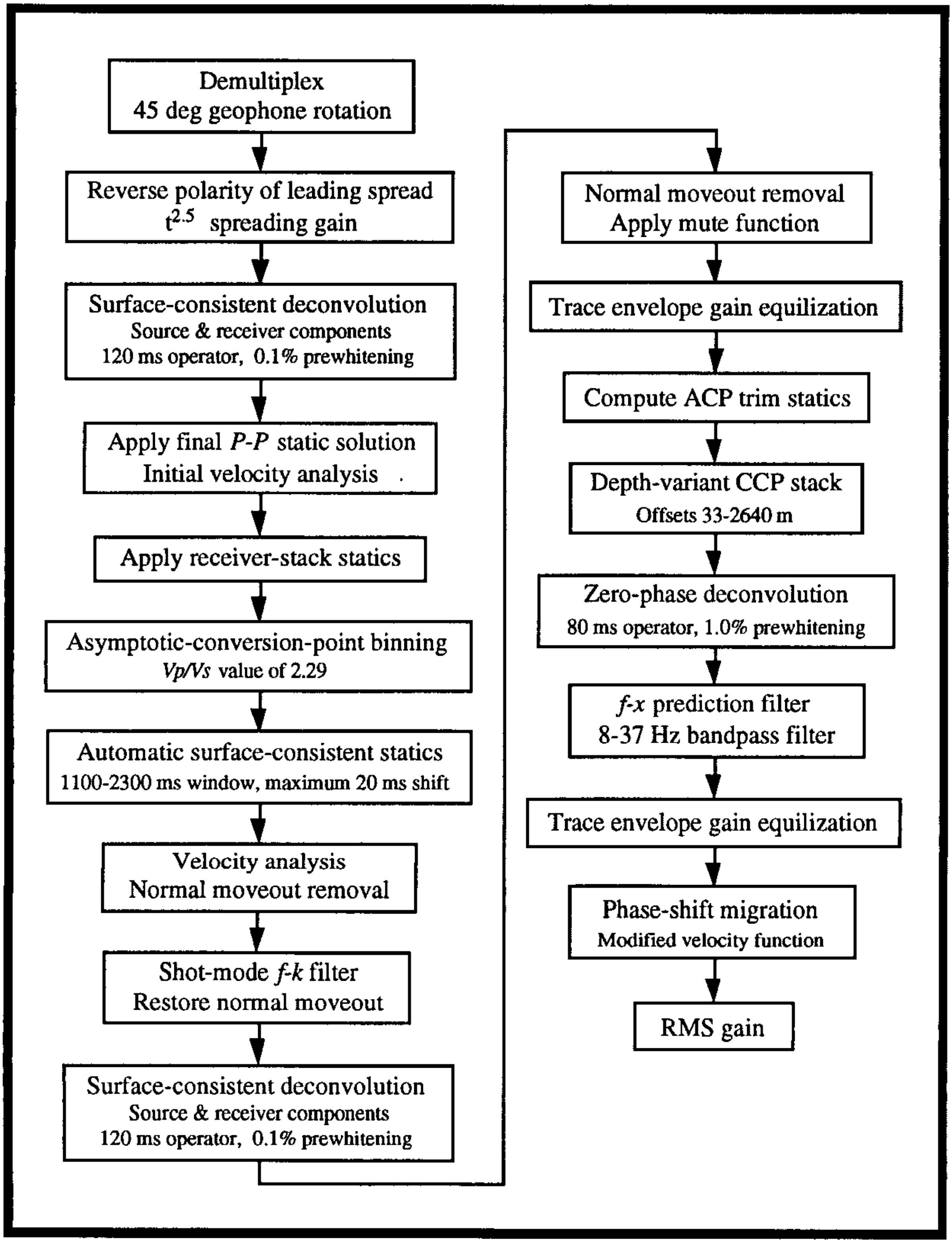

FIG. 9. Processing flowchart for the radial-component data.

Residual receiver statics were picked by hand from common-receiver stack sections, and were found to be in the range of ±50 ms. A pass of automatic surface-consistent residual statics was made later in the processing sequence to remove any remaining static values. Once the statics problems were resolved, velocity analysis was done on the data using conventional hyperbolic NMO curve-fitting.

After residual statics and stacking velocities were obtained, the *P-SV* data were stacked using an approximate *Vp/Vs* value to give initial *S*-wave sections. Events were then correlated between the stack section for line EKW-001 and a series of *P-SV* synthetic records (Howell et al., 1991), produced from a *P*-wave sonic log from well 16-19-36-21W4 and constant *Vp/Vs* values ranging from 1.8 to 2.2. Interval *Vp/Vs* values were taken to be that of the synthetic record that gave the closest time fit to the stack section across the interval.

Prior to stacking, a shot-mode *f-k* filter was applied to the data after NMO correction in order to reduce the low-velocity linear noise found within the data. After *f-k* filtering, NMO was restored to the data, and a second application of surface-consistent deconvolution was made. This was done in the hope of better-whitening the data after removal of the linear noise. The data were then NMO-corrected and stacked using the depth-variant-binning method (Eaton et al., 1990).

Poststack processing included zero-phase deconvolution, *f-x* prediction filtering, and phase-shift migration using modified migration velocities (Harrison and Stewart, 1993). The resulting migrated stack sections are shown in Figures 10 and 11.

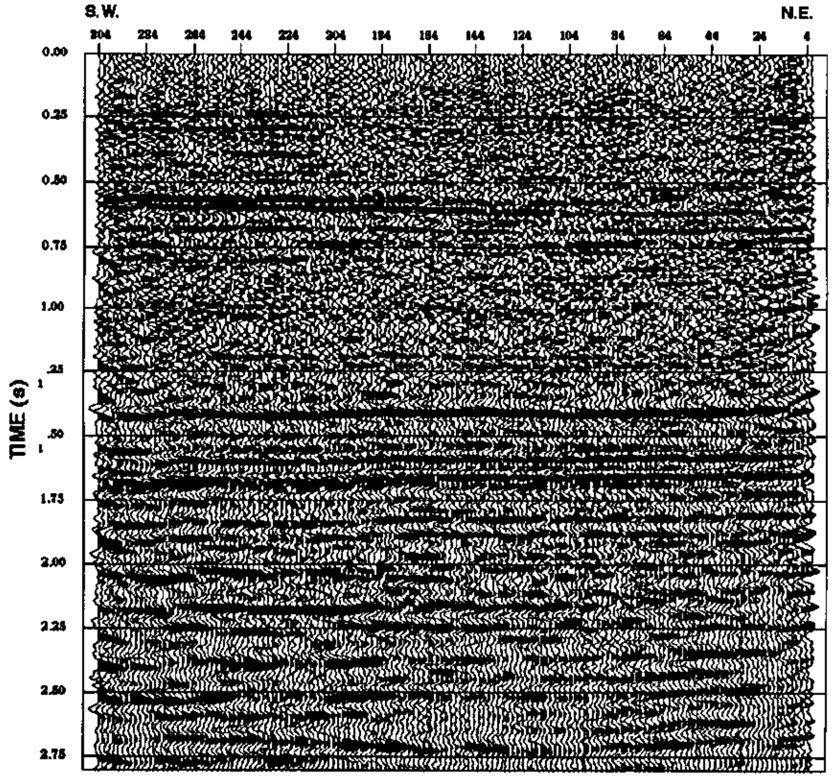

FIG. 10. Migrated radial-component stack section for line EKW-001.

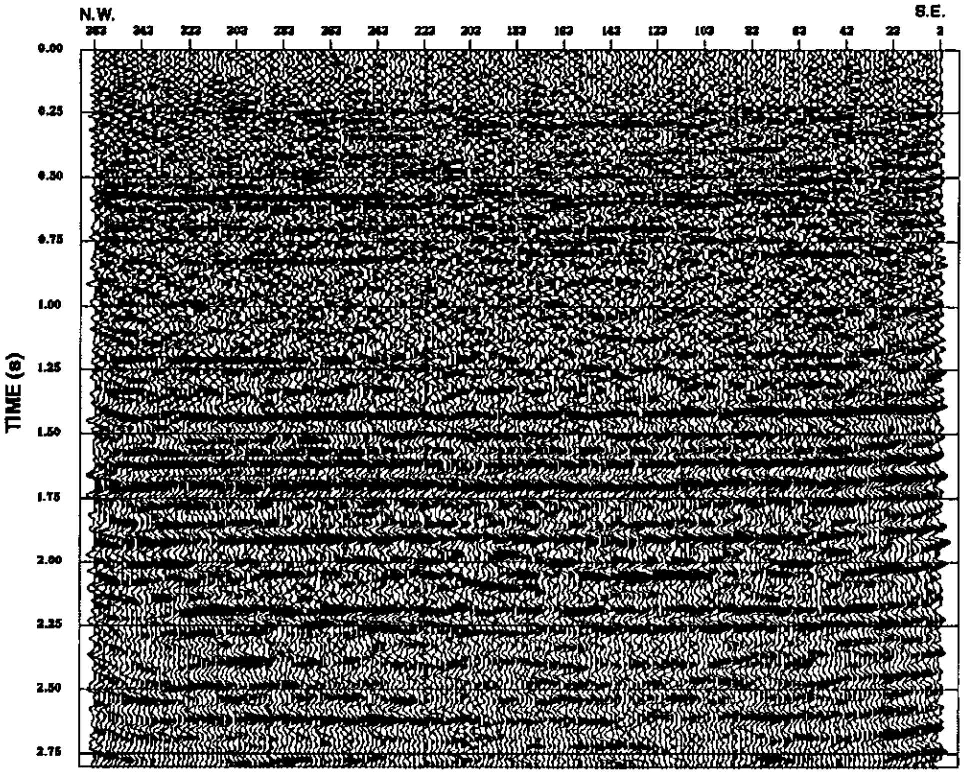

FIG. 11. Migrated radial-component stack section for line EKW-002.

PRELIMINARY INTERPRETATION

Horizons were interpreted on the vertical (*P-P*) component in the conventional manner of matching a synthetic created from a sonic log to the seismic data. The data shown use the polarity convention that a peak represents a positive increase in acoustic impedance. The zero-offset *P*-wave synthetic, from 16-19-36-21W4, matched the seismic very well through most of the section. However, the Wabamun, a strong acoustic impedance contrast on the log, cannot readily be identified on the vertical component. This is thought to be due to contamination from short path interbed multiples, probably originating in the coal beds of the Manville Formation. This multiple energy also appears to interfere with the primary reflections from deeper in the section. A mistie occurs at the Nisku, where the peak on the seismic line occurs 10 ms. after the peak associated with the Nisku on the synthetic. For the initial correlation, the peak at about 1170 ms. was tentatively identified as the Nisku event.

A character change at the Nisku level is evident on both *P*-wave sections at the oil well locations. Both lines show the development of a small peak just above the Nisku event which merges with the Nisku event as we move off the buildup. Line EKW-002 also shows a velocity pulldown at the Nisku level in the vicinity of the oil wells. On EKW-001 there is no pulldown, but there is a decrease in frequency in the trough immediately beneath the Nisku event at the oil wells. It is encouraging that there are seismic anomalies associated with the producing well locations. Forward modeling is indicated in order to determine the geological origins of these features. On both *P-P* sections, the Nisku event becomes shallower on the eastern end of the lines, and the isochron between the Mississippian and the Nisku begins to thin at about shotpoint 121 on line EKW-002 and shotpoint 155 on line EKW-001. Well control is limited, but indicates that these are reasonable locations for the edge of the Nisku shelf. This suggests that we can detect the shelf edge seismically. The apparent structure persists into shallower horizons, which may be draped over the shelf.

There are no full-waveform sonic logs or 3-C VSPs available from this area to serve as control for the *P-SV*, or radial component, interpretation. Therefore, offset *P-P* and *P-SV* synthetics were created from the 16-19 well, initially using a constant *Vp/Vs* ratio of 2.0. The offset synthetic modeling program is described in Howell et al. (1991). Ricker wavelets were used, with a central frequency of 30 Hz for the *P-P* synthetic and 15 Hz for the *P-SV* synthetic. The offsets used are from 0 to 1800 m., with a group interval of 66m. Time-shifted hyperbolic NMO (Slotboom et al., 1990) and mutes were applied before stack.

Our polarity convention is that a peak on the *P-SV* section represents an increase in acoustic impedance, as do peaks on the *P-P* data. Because both synthetics were created from the same depth model, the correlation between the synthetics was straightforward. The *P-SV* synthetic was then used to identify the events on the radial section. The data quality was reasonably good, and many of the major events could be correlated easily and unambiguously (Figure 12).

The Nisku shelf edge also appears to be detectable on both *P-SV* sections; again, the Nisku event becomes shallower, and isochrons between the Nisku and shallower events thin. On the radial component of line EKW-002, there are character changes between the oil wells and the dry holes. The trough just above the Nisku brightens and has a higher frequency at the oil wells than it does at the dry holes. There is pulldown at the Nisku event near the producing wells on the radial component of EKW-001, as well as some character changes. However, more detailed modeling and interpretation are required to determine if these features are associated with reservoir rock properties.

The Wabamun, a strong impedance contrast on logs, is generally weak on conventional seismic in this area. The problem is attributed to short path interbed multiple interference. Because converted waves have a different travel path and different reflectivity from compressional waves, we expect that they may be more successful at imaging this event. There is an event on the radial component of line EKW-001 which may correlate with the Wabamun, but the lack of *S*-wave control in the area makes it difficult to draw any conclusions at this point.

PROPOSED WORK

The data requires further processing to possibly remove some of the multiple contamination and resolve misties between the synthetics and the seismic. An accurate match is needed to apply the results of the log-based models to the field data and to confidently interpret interval travel time variations. The data will be reviewed prestack and tests performed for the removal of multiples by either the parabolic radon transform method (Hampson, 1986) or offset varying predictive deconvolution.

Preliminary interpretation reveals time interval and amplitude variations associated with the productive zones on both components. We plan to modify available

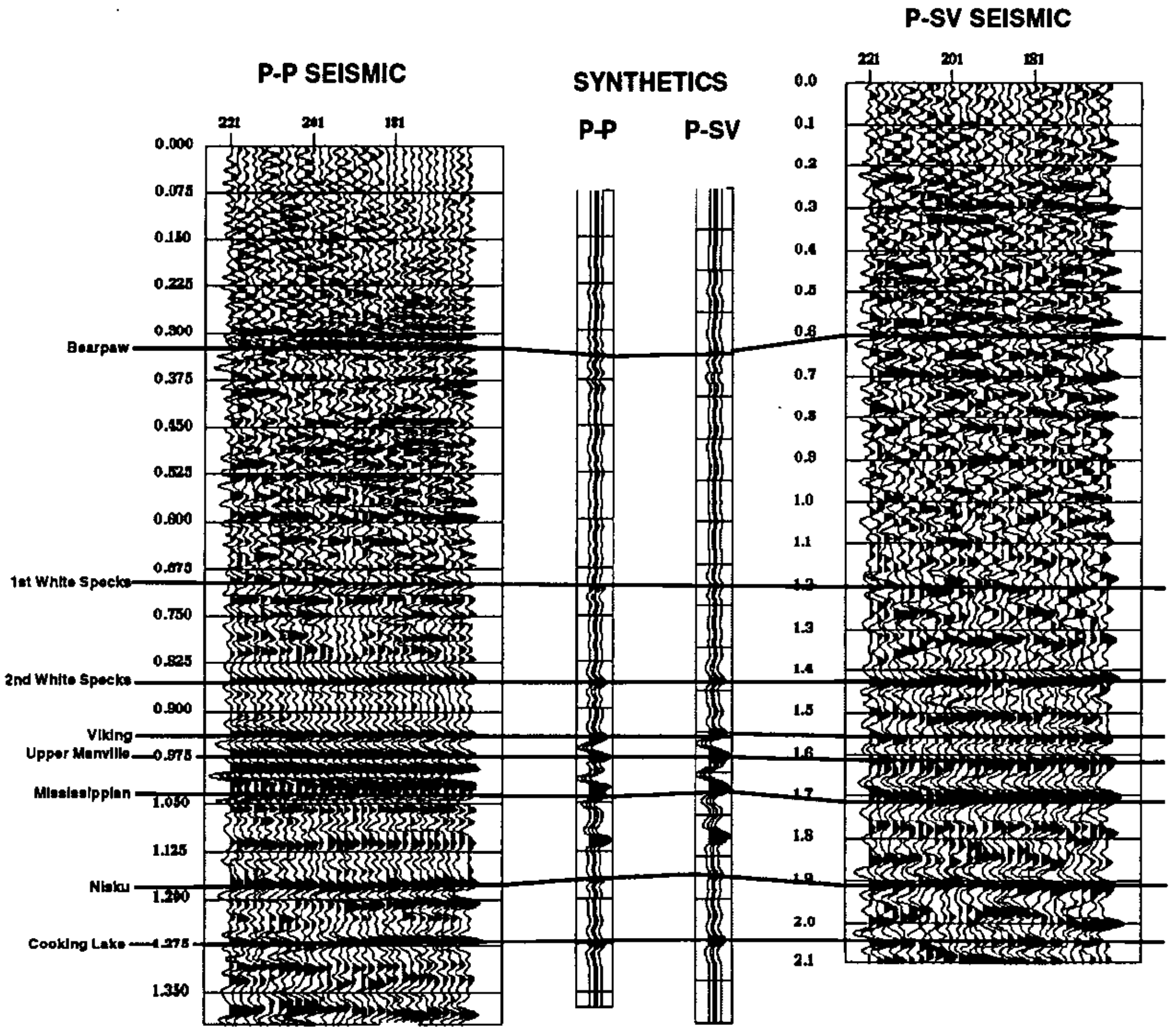

FIG. 12. Horizon correlation of the vertical *(P-P)* and radial *(P-SV)* components from line EKW-002. The offset synthetic stacks are generated from the 16-19-36-21W4 sonic log using a constant *Vp/Vs* ratio of 2.0. Varying the *Vp/Vs* ratio would cause the events to line up. Only the central portion of the line is shown for each component; the well is on the line at shotpoint 191. The *P-P* data are plotted at 1.5 times the scale of the *P-SV* data to facilitate visual correlation.

well data to create synthetics representing a variety of possible porosities, lithologies, and pore saturants in shelf, basin, and reef settings. The *P-P*, *P-SV*, and *Vp/Vs* response to a range of geological settings will be used to calibrate the field data.

There appear to be isochron changes associated with the shelf and reef environments. The data have been loaded onto the workstation, where they will be interpreted for horizon time structures and isochrons. Once the events have been confidently correlated between vertical and radial components, a *Vp/Vs* ratio section can be created to aid in lithologic characterization. For converted-wave data, the *Vp/Vs* ratio is equivalent to (2Is/Ip) -1, where Is and Ip are the *P-SV* and *P-P* interval transit times respectively (Garotta, 1987). If the event correlations between the components are accurate, the dimensionless ratio will be free of effects due to depth or thickness variations, as these will affect both components equally. Variations may be caused by factors such as changes in lithology, porosity, pore fluid, and other formation characteristics (Tatham and McCormack, 1991). Performing this analysis on the entire section allows us to examine horizons other than the Nisku for hydrocarbon potential. For example, gas production occurs in the Viking Formation in this field. Gas in sandstones has been associated with AVO effects and a marked decrease in the *Vp/Vs* ratio (e.g. Gregory, 1987; Ostrander, 1984; Ensley, 1984 and 1985; Tatham and McCormack, 1991). Other planned interpretive analyses include velocity inversion, AVO modeling, and seismic attribute analysis.

The radial and transverse components from the two lines will be analyzed for vertical shear-wave splitting effects using the cross-correlation technique of Harrison (1992). Having two orthogonal lines in the survey should allow an assessment of the consistency of the method, and, perhaps, a comparison to the results of a four-component Alford rotation analysis (Alford, 1986) using data from each line at the tie-point .

Converted waves can sometimes successfully image horizons which are obscured by multiple contamination on conventional data. Different ray paths, velocities, and reflectivities contribute to the difference in multiple activity. The relationship between multiples on *P-P* data and *P-SV* data is not well understood, and is a potential area of interest which could be pursued with this data set.

SUMMARY

Two orthogonal three-component seismic lines were shot by Unocal in January, 1987, over the Nisku Lousana Field in central Alberta. The purpose of the survey was to calibrate a Nisku patch reef thought to be separated from the Nisku shelf to the east by an anhydrite basin. Unocal donated these data to the CREWES Project, and work is underway to improve the quality of the existing products by reprocessing the data with ITA and CREWES software, and to evaluate the incremental benefit of multicomponent versus conventional recording for this type of exploration target.

The vertical and radial components on both lines have been processed to migrated stacked sections. Major events were correlated across the vertical and radial components using *P-P* and *P-SV* offset synthetic stacks. Preliminary interpretation of vertical and radial component products shows time interval and character variations associated with oil well locations at or near the Nisku level. The carbonate shelf edge appears to be seismically detectable by a changing time structure and thinning isochrons. Forward modeling is proposed to calibrate the observed seismic features.

Planned analyses include lithologic characterization using a *Vp/Vs* ratio section, velocity inversion, AVO modeling, and attribute analysis. In addition, radial and transverse data from both lines will be analyzed for any local anisotropy that might affect the quality of the predictions. Further processing, modeling, and interpretation will be undertaken to assess the quality of primary events in the zone of interest, and to determine if, and with what degree of certainty, lithological predictions can be made.

ACKNOWLEDGMENTS

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