Acquisition and processing of the Pikes Peak 3C-2D seismic survey

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ABSTRACT

During March 2000, the Consortium for Research in Elastic Wave Exploration Seismology (CREWES) at the University of Calgary, with financial assistance from the Alberta Oil Sands Technology and Research Authority (AOSTRA) and Husky Energy Inc., acquired a high-resolution multicomponent seismic survey at the Pikes Peak heavy oil field located east of Lloydminster, Alberta/Saskatchewan. The 3.8 km 3C-2D survey consisted of recording vibroseis sources into conventional vertical component geophone arrays, single microphones and single 3C geophones.

Source gathers of both vertical and radial components show good reflection data with a high signal-to-noise (S/N) ratio. The microphone source gathers are dominated by the strong air wave generated by the vibroseis source. Structural and migrated P-P and P-S stacks of both the conventional vertical geophone arrays and single 3C geophones also possess a high S/N ratio. A cursory examination of these sections show that they adequately image the target area. The analyses of the data from the different portions of the survey remains as future work.

INTRODUCTION

On March 1 - 2, 2000, CREWES at the University of Calgary with financial assistance from AOSTRA and Husky Energy Inc. recorded a high-resolution 3C-2D seismic survey at the Husky-owned Pikes Peak heavy oil field. The Pikes Peak field is located approximately 40 km east of the town of Lloydminster, Alberta/Saskatchewan (see Figure 1). The Pikes Peak oil field produces heavy oil from the sands of the Waseca Formation of the Lower Cretaceous Mannville Group. The Pikes Peak field itself is located on an east-west structural high within an incised valley fill, estuarine channel complex (Sheppard et al., 1998). The Waseca Formation lies at depth of about 500 m and has an average thickness of 15 m. The porosity of the Waseca sands ranges from 32 to 36% and has permeabilities in the

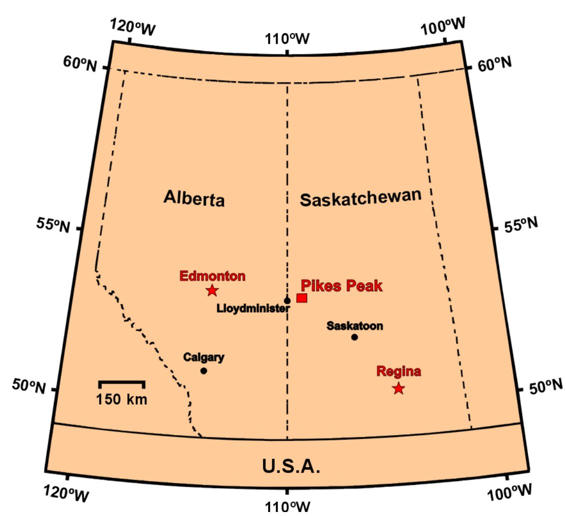

Figure 1. Map showing the location of the Pikes Peak field with respect to major cities and towns in Alberta and Saskatchewan.

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range of 1 to 10 darcies. The reservoir contains 12º API oil and cumulative production to the end of 1999 was 5.7×10^6 m^3 (35.9 MMbbls).

The survey involved the acquisition of a 3.8 km 3C-2D reflection profile which consisted of a combination of conventional vertical geophone arrays, single microphones and single 3C geophones. The source interval employed was 20 m recorded on the station. However, the receiver interval used for the vertical geophone arrays and single microphones was 20 m whereas the single 3C geophones used a 10 m receiver interval.

The primary objectives of this seismic survey were: 1) acquire and process high-resolution vibroseis data over a steam-driven heavy oil field, 2) suppress surface waves via a dual-sensor approach, 3) perform AVO analysis on vibroseis data acquired over a steam-driven heavy oil field, 4) examine vibroseis correlation vs. deconvolution (Brittle et al., 2000) and 5) re-acquisition over a previous 1991 2D seismic line to observe 4D effects.

ACQUISITION

Veritas DGC Land acquired this data set using a ARAM24 24-bit seismograph. The preamp gain used for recording was 36 dB with low and high cut filters set at 3 Hz and 164 Hz respectively. The data were recorded in SEG-Y IBM format with a 16 s sweep length and a 4 s listen length (i.e. 20 s record length) at a 2 ms sample rate.

There were a total of 191 source points which consisted of 2 × 25,000 kg Hemi 44 vibrators spaced over 10 m. There were 4 sweeps per source point with no move-up between sweeps. A 16 s sweep consisting of two segments was used: 1) 0.375 s, 8 – 25 Hz linear and 2) 15.625 s, 25 – 150 Hz non-linear (0.2 dB/Hz). A 0.2 s taper length was used for both the start and end of the sweep. The uncorrelated and un-summed data was recorded for each of the 4 sweeps per source point. The weighted sum estimate for the ground force was also recorded for each vibrator and each sweep. A 20 m source interval was used with the two vibrators straddling the source station flag resulting in the source point being positioned on the station.

The conventional vertical geophone arrays consisted of 6 OYO 30-CT 10 Hz geophones spaced over 20 m. The group interval for the arrays was 20 m. The type of 3C single geophone used for the survey was the Litton LRS-1033 10 Hz. The receiver interval for the 3C geophones was 10 m. A split-spread configuration was chosen with maximum offsets of ± 1330 m and a maximum of 1064 live channels per source point. In order to reduce possible wind noise, all of the 3C geophones were planted in holes of about 0.3 m depth which were mechanically dug by a post-hole auger. The single microphones used in the survey were designed, manufactured and tested by CREWES at the University of Calgary. The main component of these microphones was a Panasonic WM-54BT electret condenser microphone element which has a frequency range of 20 Hz to 16 kHz. These microphones were deployed at the vertical geophone array centers also at 20 m spacing in the augured holes used for the 3C geophones. A schematic of the field layout is presented in Figure 2.

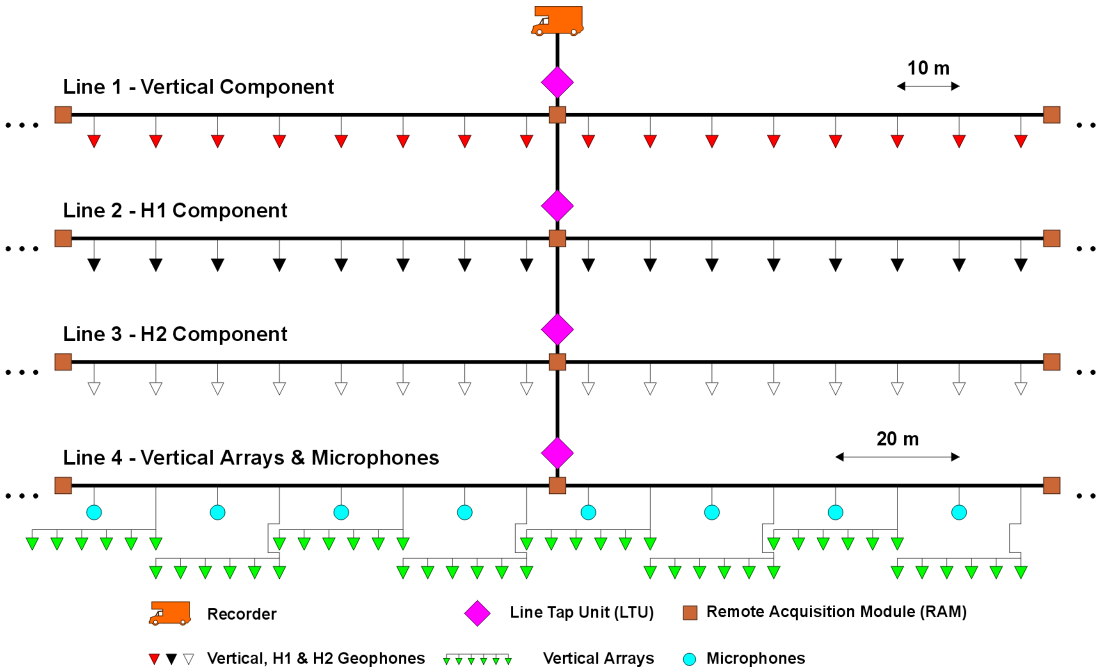


Figure 2. Field layout used for the Pikes Peak 3C-2D survey. Note that the vertical, H1 and H2 components of the 3C acquisition were recorded separately as three distinct receiver lines. The vertical arrays and microphones were assigned to a fourth receiver line.

PROCESSING

The 3C-2D data acquired at Pikes Peak was commercially processed by Matrix GeoServices Ltd. of Calgary, Alberta. The processing flow used to produce the P-P and P-S post-stack time migrations is presented in Tables 1 and 2.

Table 1. P-P post-stack time migration processing flow.

1.	Geometry Assignment
2.	Trace Kills and Reversals
3.	Amplitude Recovery
4.	Surface-Consistent Deconvolution
5.	Phase Compensation
6.	Time-Variant Spectral Whitening
7.	Refraction Statics
8.	Velocity Analysis
9.	Surface-Consistent Statics
10.	Velocity Analysis
11.	Normal Moveout Correction
12.	Front-End Muting
13.	Time-Variant Scaling
14.	CDP Trim Statics
15.	Bulk Shift
16.	CDP Stack
17.	Time-Variant Spectral Whitening
18.	Trace Equalization
19.	*f-x* Prediction Filtering
20.	Post-stack Wave Equation Re-datuming
21.	Phase Shift Migration

Table 2. P-S post-stack time migration processing flow.

1.	Geometry Assignment
2.	Asymptotic Binning
3.	Trace Kills and Reversals
4.	Rotate into Fast/Slow Coordinates
5.	Select Slow Component
6.	Reverse Polarity for Negative Offsets
7.	Amplitude Recovery
8.	Shot *f-k* Filter
9.	Surface-Consistent Deconvolution
10.	Phase Compensation
11.	Time-Variant Spectral Whitening
12.	Refraction Statics
13.	Velocity Analysis
14.	Residual Receiver Statics
15.	Velocity Analysis
16.	Surface-Consistent Statics
17.	Velocity Analysis
18.	Converted Wave NMO
19.	Front-End Muting
20.	Time-Variant Scaling
21.	CCP Trim Statics
22.	Bulk Shift
23.	Converted Wave DMO
24.	Time-Variant Spectral Whitening
25.	Trace Equalization
26.	*f-x* Prediction Filtering
27.	Kirchhoff Time Migration

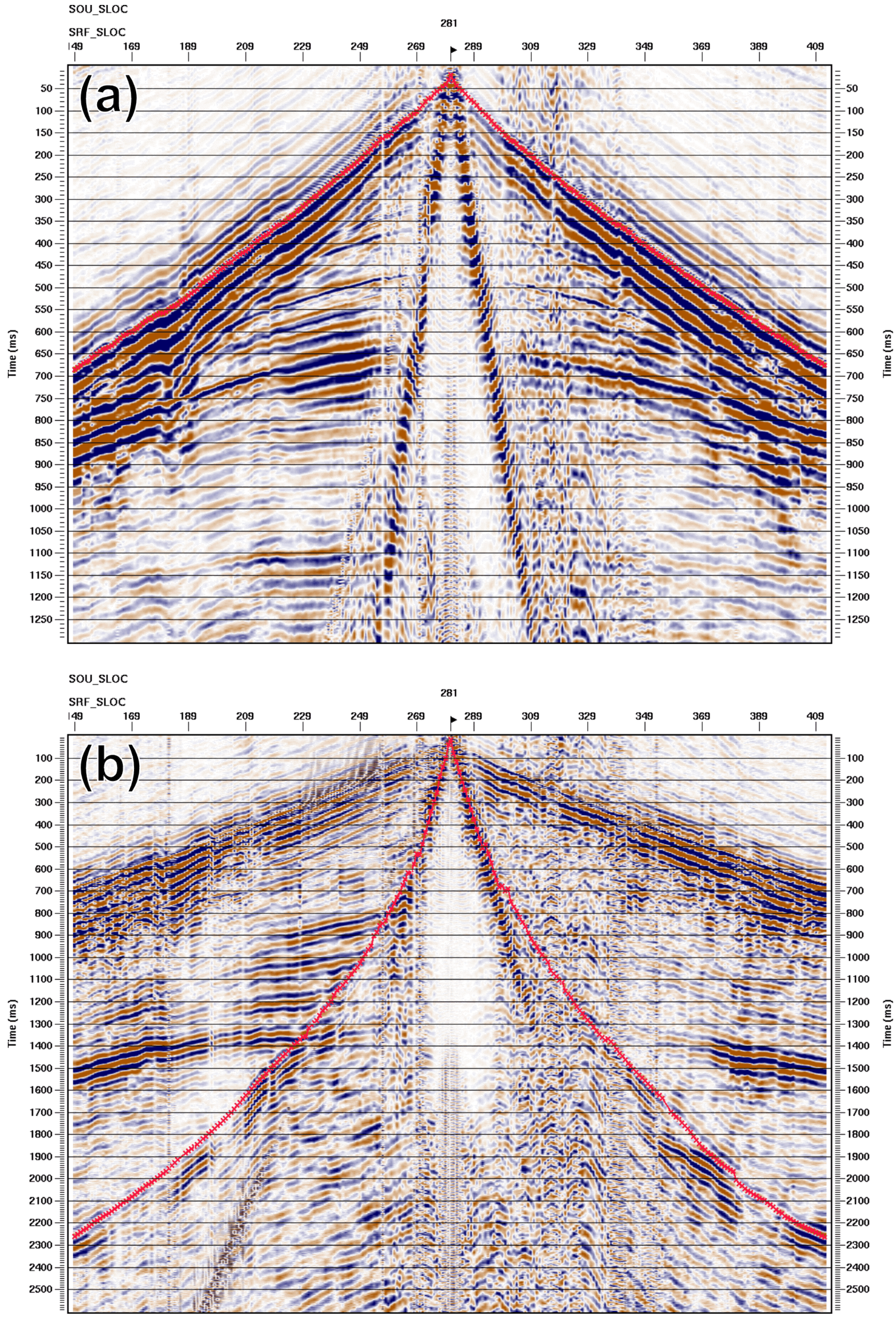
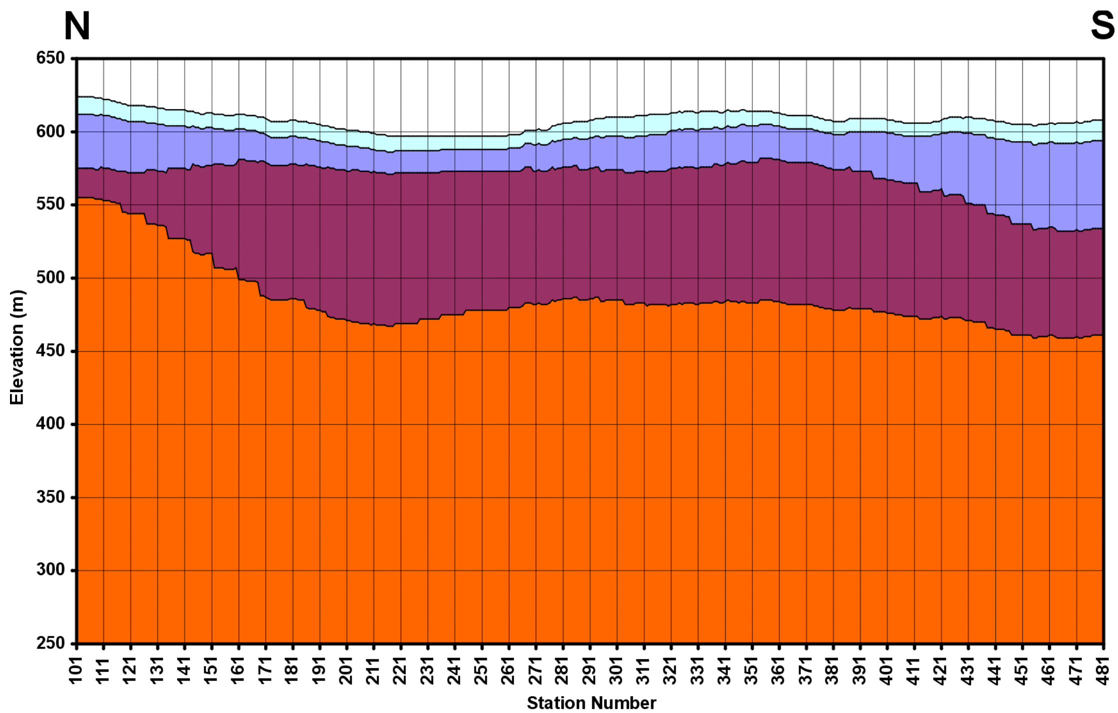
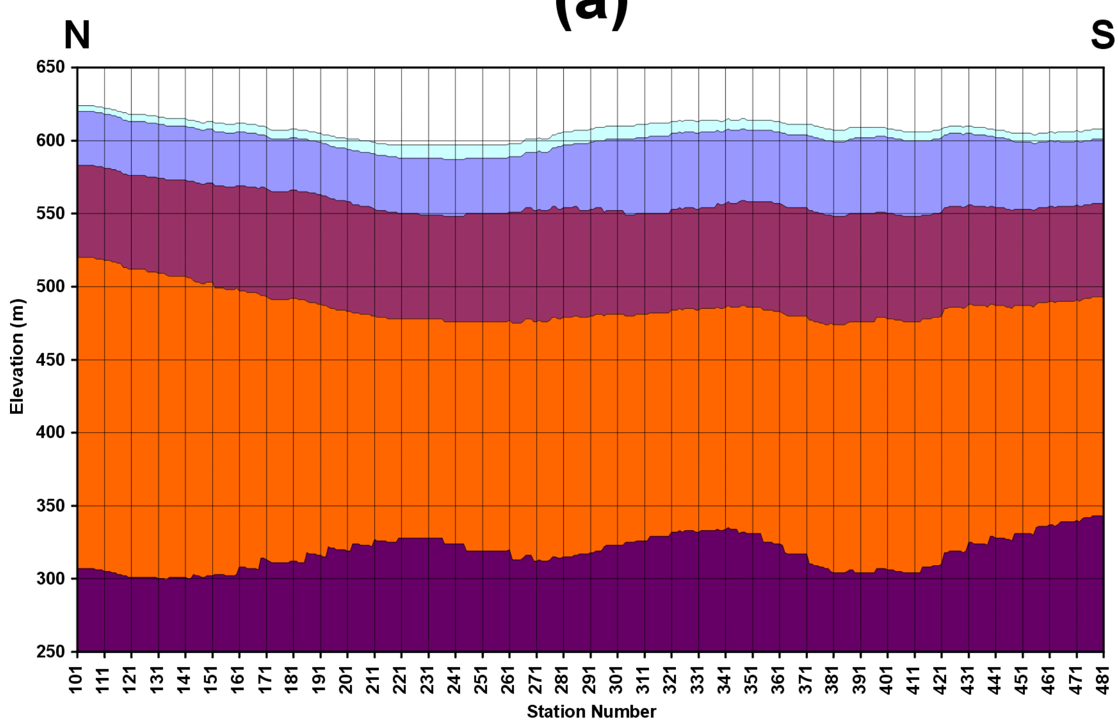


Figure 3. Selected source gathers for (a) vertical component data and (b) radial component data. Travel-time picks of the P and S refracted wave on (a) and (b) respectively is indicated in red. These travel times were used to compute the P-wave source statics and S-wave receiver statics of the P-S refraction statics solution.



(a)



(b)

Figure 4. The refraction statics solutions computed from the travel time picks of (a) refracted P-wave of the vertical component data and (b) refracted S-wave of the radial component data. Note that the P-wave solution utilized a three layer replacement model whereas the S-wave used a 4 layer model.

Figure 3 shows typical source gathers for both the vertical and radial component data acquired by this survey. Source gathers of the radial component data exhibited a strong shear head wave that could be confidently picked (see Figure 3). The travel time picks of the refracted shear wave were then used to directly compute the S-wave receiver statics. Combining these S-wave receiver statics with the P-wave source statics provided a P-S refraction statics solution. The refraction static solutions computed independently from the vertical and radial component data are shown in Figure 4.

Because the refracted shear wave was prevalent on the radial component data, it demonstrates that, in this case, the vibroseis source generates significant shear wave energy. This observation may be important in providing receiver statics solutions for future processing of multicomponent data utilizing a vertical vibroseis source.

RESULTS

As previously stated, one of the objectives of this survey was to investigate the suppression of surface waves via a dual-sensor approach (i.e. microphone + vertical geophone). Stewart (1998) first suggested that by combining pressure (microphone) and vertical velocity (vertical geophone) measurements in land seismic recordings, suppression of air blast and ground-coupled air waves might be achieved. This method has been successfully used in the marine environment for the suppression of one type of water-column multiple (Hoffe et al., 2000). Figure 5 shows common source gathers for the vertical geophone data decimated from the vertical component of the 3C geophones and the microphone data. Analysis of this data is provided by Dey et al. (2000) in this research volume.

Structural and migrated stacks of the conventional vertical geophone arrays (20 m receiver interval), vertical (P-P) and radial (P-S) components of the multicomponent data (10 m receiver interval) are shown in Figures 6, 7, and 8 respectively. All of these sections are of excellent quality showing clear and coherent reflection events.

The *f-x* phase spectra (Margrave, 1999) of windowed portions of the P-P and P-S structural stacks (single vertical and radial components) are presented in Figure 9. The P-P phase spectrum shows the presence of coherent phase up to 140 Hz. Similarly, the P-S phase spectrum shows coherent phase up to 40 Hz. The P-P and P-S sections correlate well and exhibit interpretable ties between many of the major reflectors including the producing Waseca Formation.

CONCLUSIONS

The Pikes Peak vibroseis seismic survey was successfully completed and acquired a high-resolution 3C-2D data set. The initial P-P and P-S sections of the conventional vertical arrays, single vertical and radial components of the survey all show a series of clear and coherent reflection events. Correlation between the P-P and P-S is good with interpretable ties between many of the major reflectors in the zone containing the producing Waseca sands. Further analyses of the data acquired by this survey remains as future work.

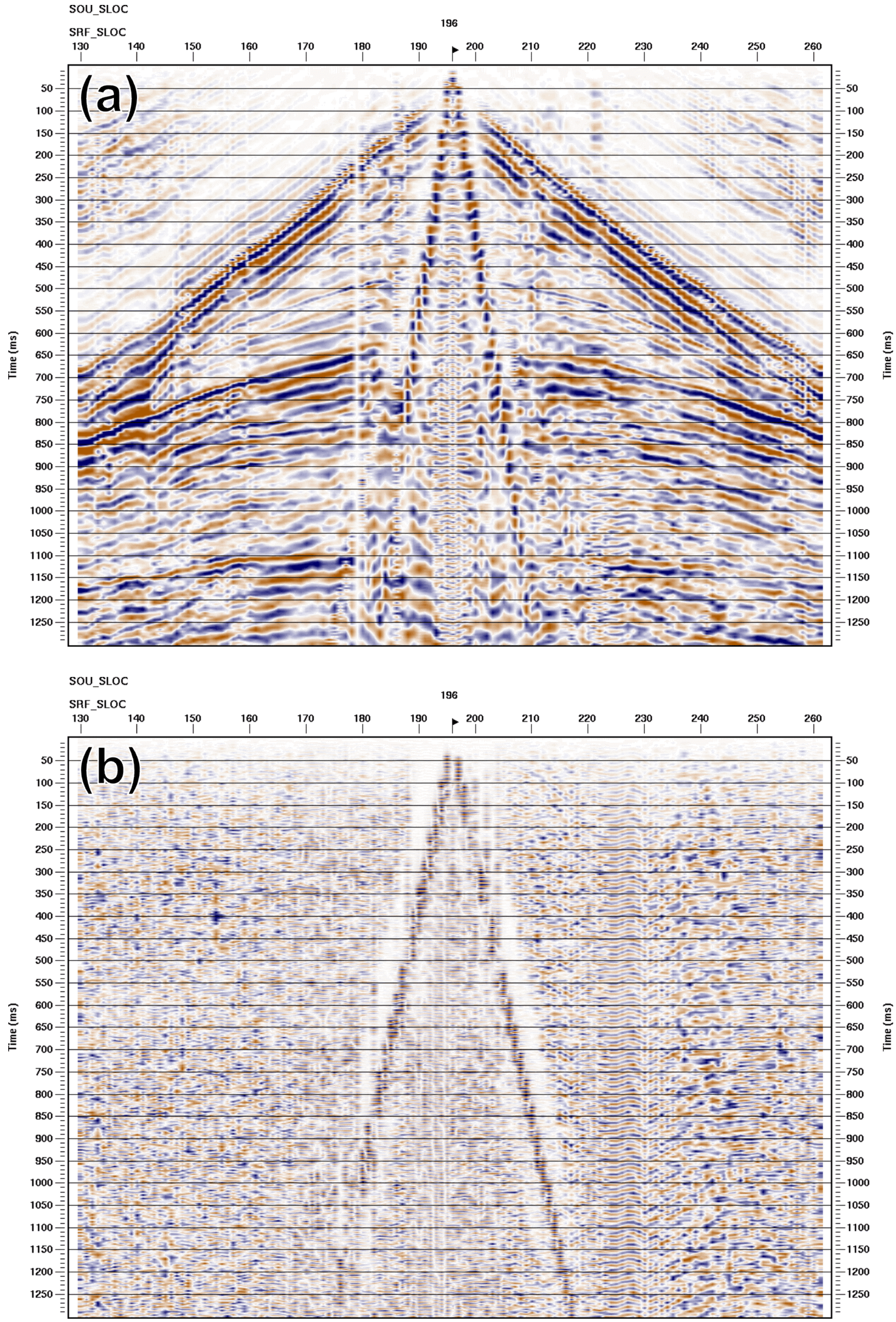


Figure 5. Common source gathers for (a) vertical geophone data decimated from the vertical component of the 3C geophones and (b) microphone data. Note that the air blast (~ 330 m/s) is the dominate energy on the source gather of the microphone data.

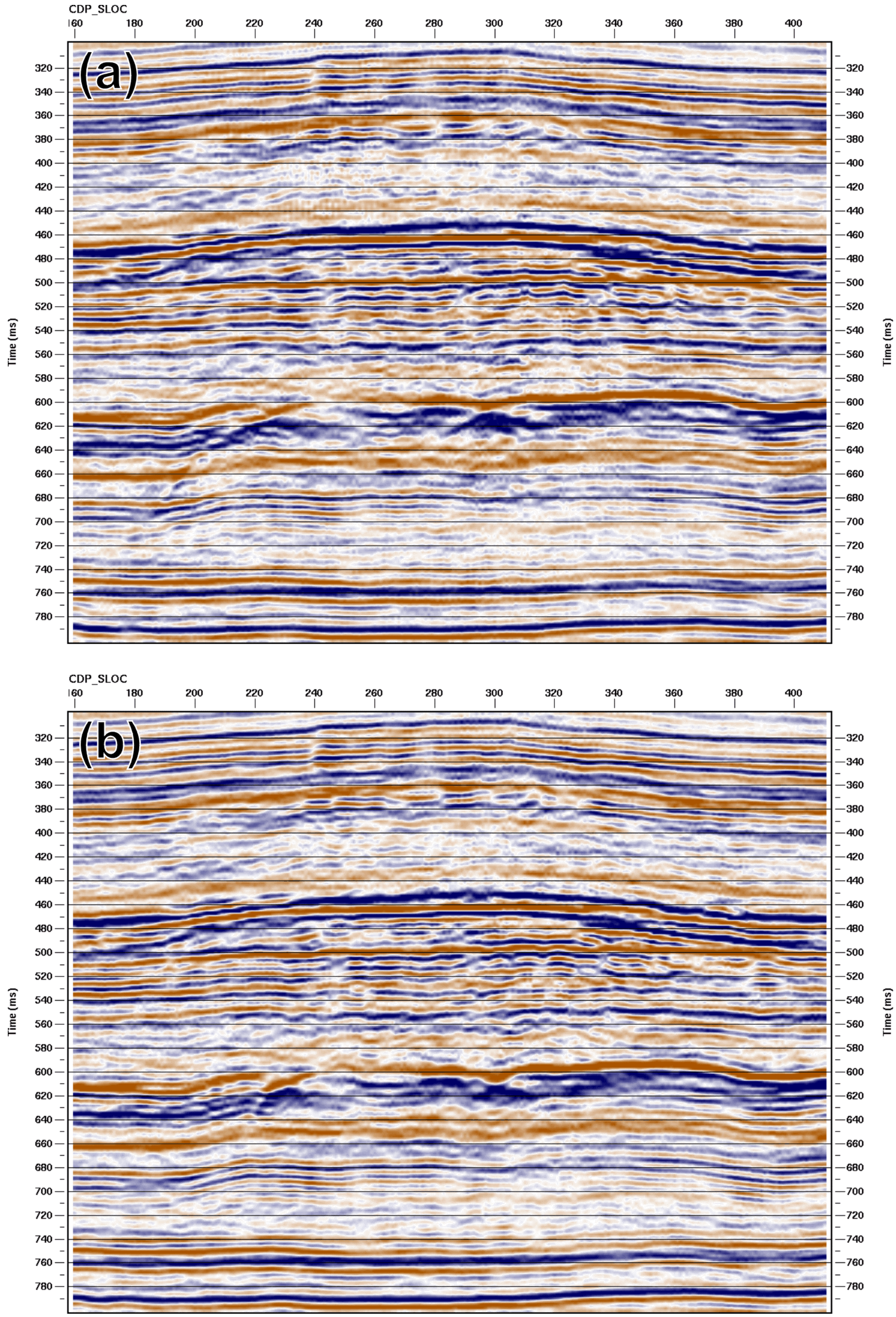


Figure 6. (a) Structure stack of the vertical geophone array P-P data and (b) its post-stack time migration. The data has been windowed between stations 160 – 410 and 300 – 800 ms to encompass the reflectors of the producing Waseca Formation. The top of the Waseca Formation is situated approximately at 450 ms.

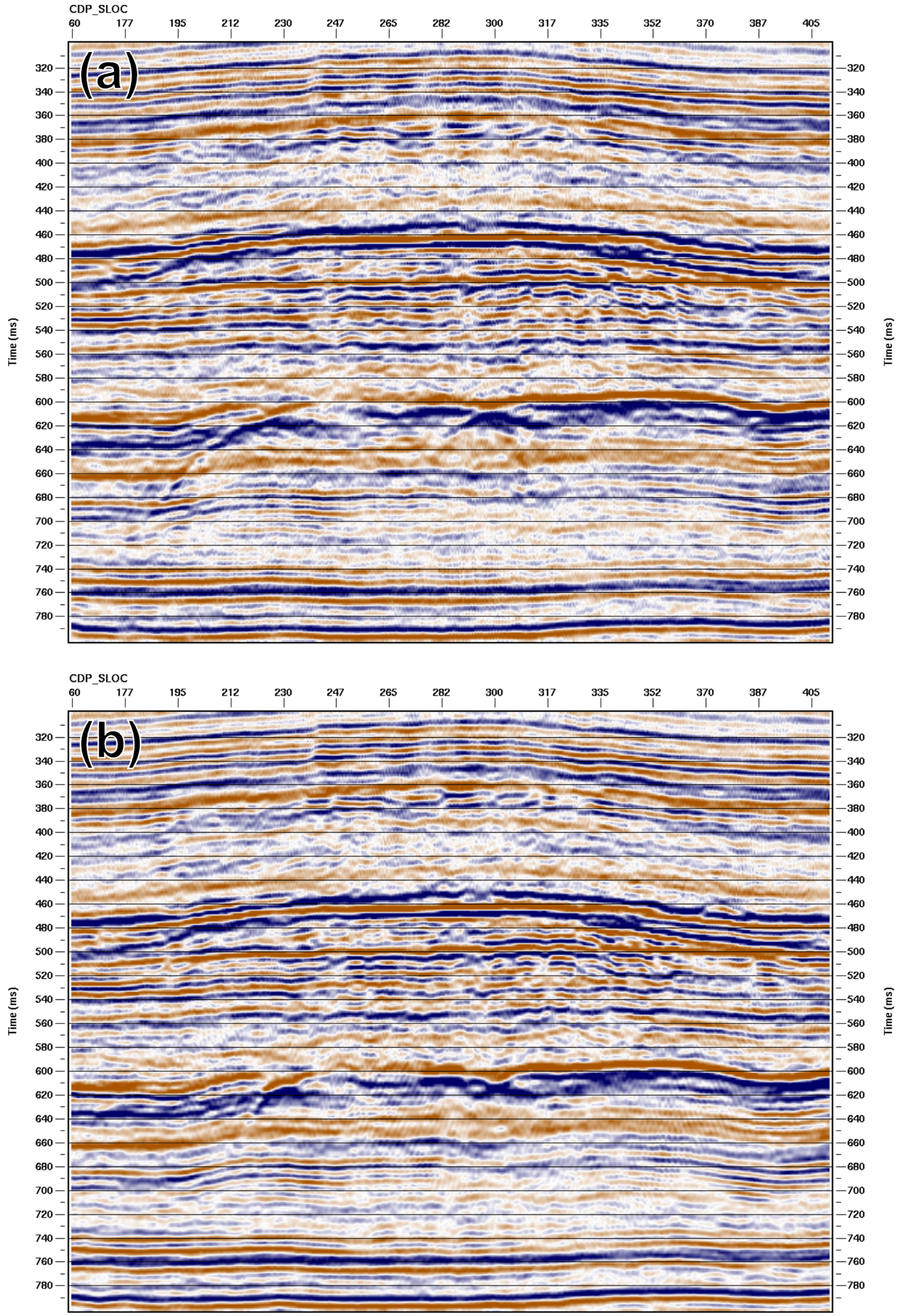


Figure 7. (a) Structure stack of the single vertical component P-P data and (b) its post-stack time migration. The data has been windowed between stations 160 – 410 and 300 – 800 ms to encompass the reflectors of the producing Waseca Formation.

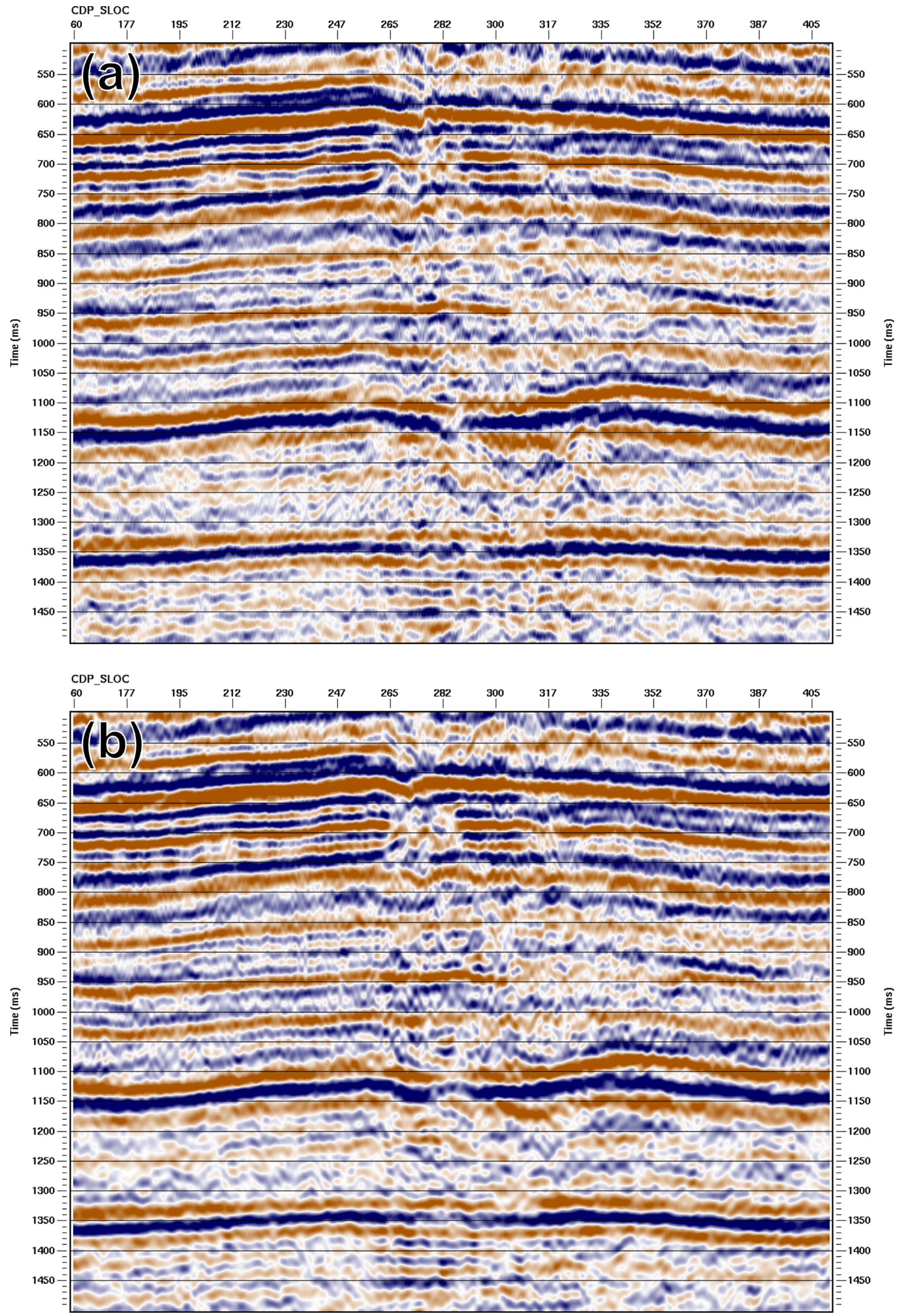


Figure 8. (a) DMO structure stack of the radial component P-S data and (b) its post-stack time migration. The data has been windowed between stations 160 – 410 and 500 – 1500 ms to encompass the reflectors of the producing Waseca Formation. The top of the Waseca Formation is situated approximately at 950 ms.

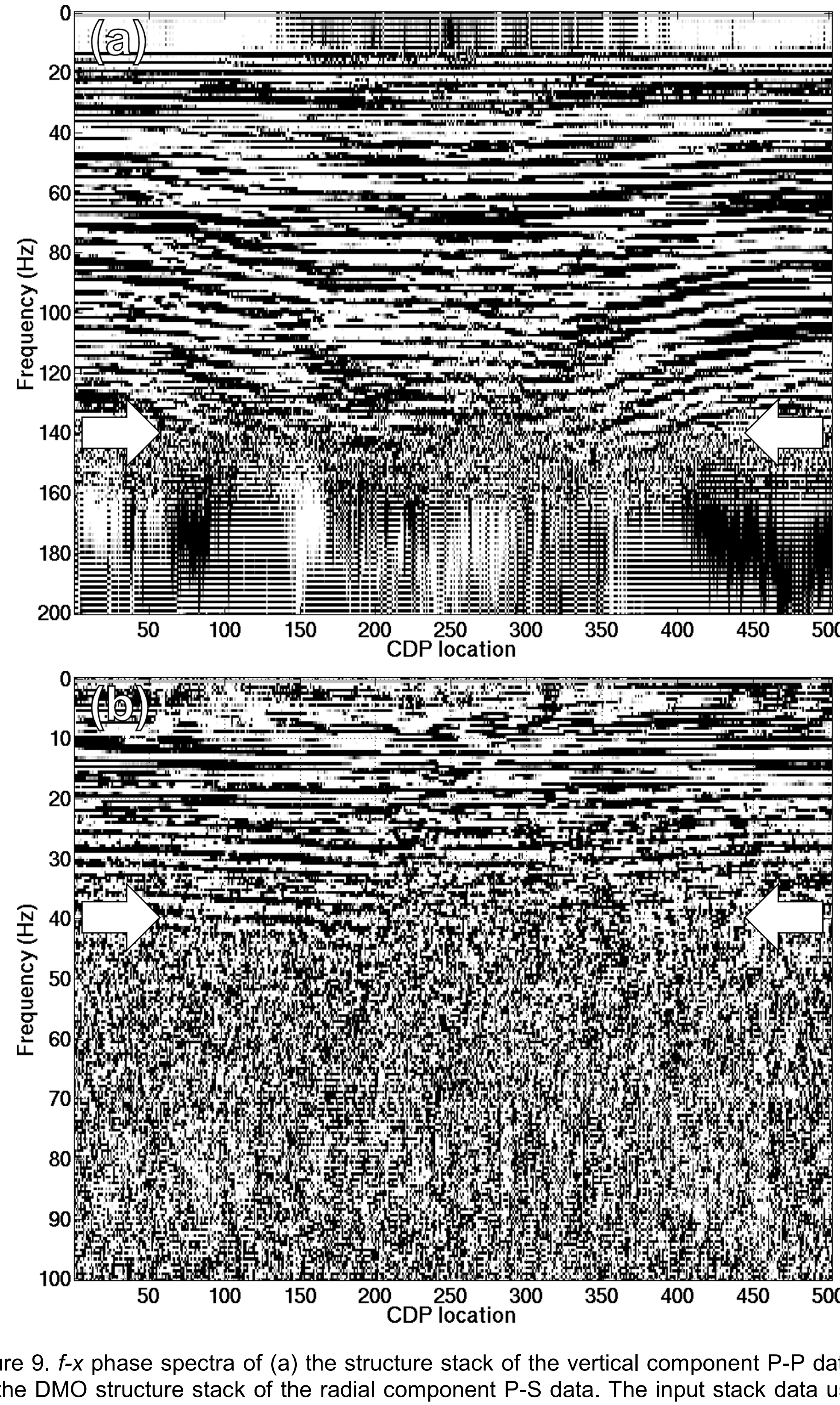


Figure 9. *f-x* phase spectra of (a) the structure stack of the vertical component P-P data and (b) the DMO structure stack of the radial component P-S data. The input stack data used to compute the phase spectra have been windowed as per Figures 7 and 8. The white arrows indicate the frequency limit of the maximum coherent phase which is ~140 Hz for (a) and ~40 Hz for (b).

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