Ground-roll characterization: Cold Lake 3-D seismic example

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ABSTRACT

A procedure to characterize regional variation of ground-roll for 3-D seismic data is outlined. Characterization is done in both the azimuth-offset domain and the (f,k) domain. Examples show that ground-roll present on the Cold Lake 3-D data set has very little azimuthal variance, and has a dip of 400 m/s f-k space.

INTRODUCTION

Ground-roll is a form of coherent linear noise which propagates at the surface of the earth, at low velocity and low frequency (Olhovich, 1964). Its presence on seismograms is due to the channeling of Rayleigh waves within the low-velocity surface layers; will often obscure seismic reflection information (Saatcilar and Canitez, 1988).

Azimuthal variance of ground-roll can be used to describe boundaries between different noise regions. Al-Husseini et al.,(1981) described an empirical approach to determine noise region boundaries by recording a dense, areal grid of noise analyses. They pointed out that, such a scheme would be too cumbersome and expensive to be practical (Al-Husseini et al., 1981). With increased availability of 3-D seismic, we are now presented with such areal grids.

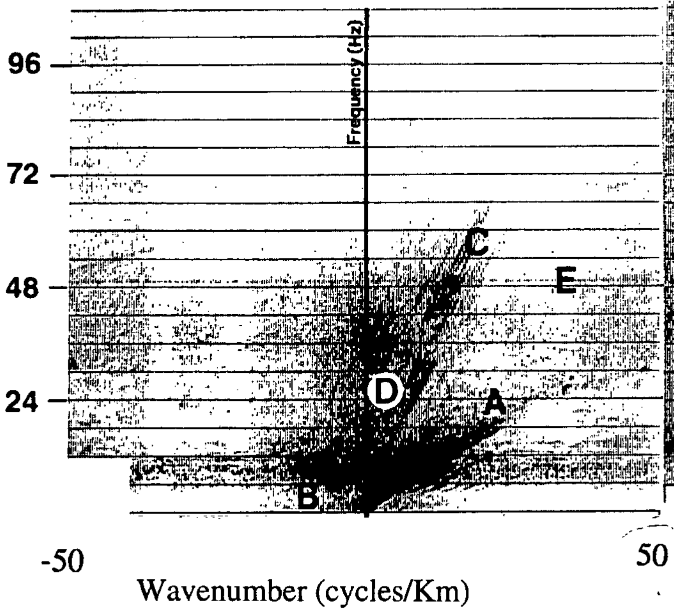
Separation of surface areas into ground-roll noise regions depends on the character of the ground-roll. Understanding this character in a data volume, means understanding the ground-roll frequency and wavenumber bandwidth and, therefore, dip in f-k space.

For a non-dispersive surface wave:

$$V = \frac{\Delta f}{\Delta k}, \qquad (1)$$

Where V = the dip of the ground-roll in f-k space which is equal to the surface propagation phase-velocity, and Δf and Δk are the frequency range, and wavenumber range (Al-Husseini et al., 1981).

Figure 1 is an example of using ground-roll dip in f-k space ; the ground-roll (event A) has a much lower velocity and lower overall frequency than the primary reflections (event C), resulting in a much lower dip. A filter designed on this dip separation effectively rejects the ground-roll (Figure 1b).



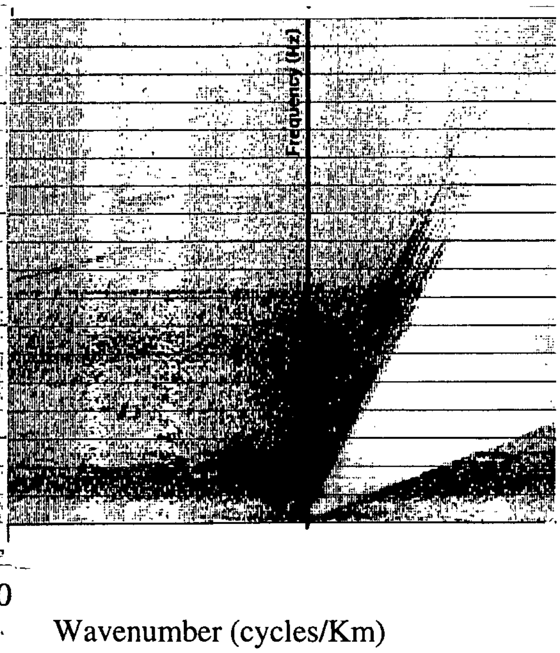


Fig. 1a. f,k spectrum of a shot record.

Fig. 1b. Ground-roll rejected.

Ground-roll (event A) has lower velocity and lower frequency than primary reflections (event C).

In 2-D seismic, characterizing ground-roll usually means analyzing shot records which show representative in-line variance (Yilmaz, 1988). 3-D seismic presents an additional consideration. The extra dimension allows the recording of ground-roll energy with possible azimuthal variance. How, then, can the variance of 3-D ground-roll be visualized?

This paper describes a method used to characterize the regional azimuthal variance of ground-roll for the vertical component of the Cold Lake 3-D seismic data set. The method will be described, and the results of the azimuthal characterization will be discussed.

METHODS

The method used begins with visualization. It was decided that 2-D Fourier transforms of slices through the 3-D volume, were the most practical visualization format, based on the available software. A group of CDPs located close to the center of the survey were selected, an azimuth was assigned to each trace of this CDP range, dead traces were added to each common-azimuth gather, and the data was analyzed.

Selection of CDP range

It was known from an analysis of shot and receiver depths of the Cold Lake data set, that the surface layer had little variation in thickness (shots and receivers were placed below the unconsolidated surficial till). This meant that azimuthal variations in ground-roll character would be the result of variations in ground-roll velocity, and much less from dispersion pattern changes due to surface layer thickness changes (Al-

Husseini, et al., 1981). A central group of CDPs was then selected (Figure 2.)

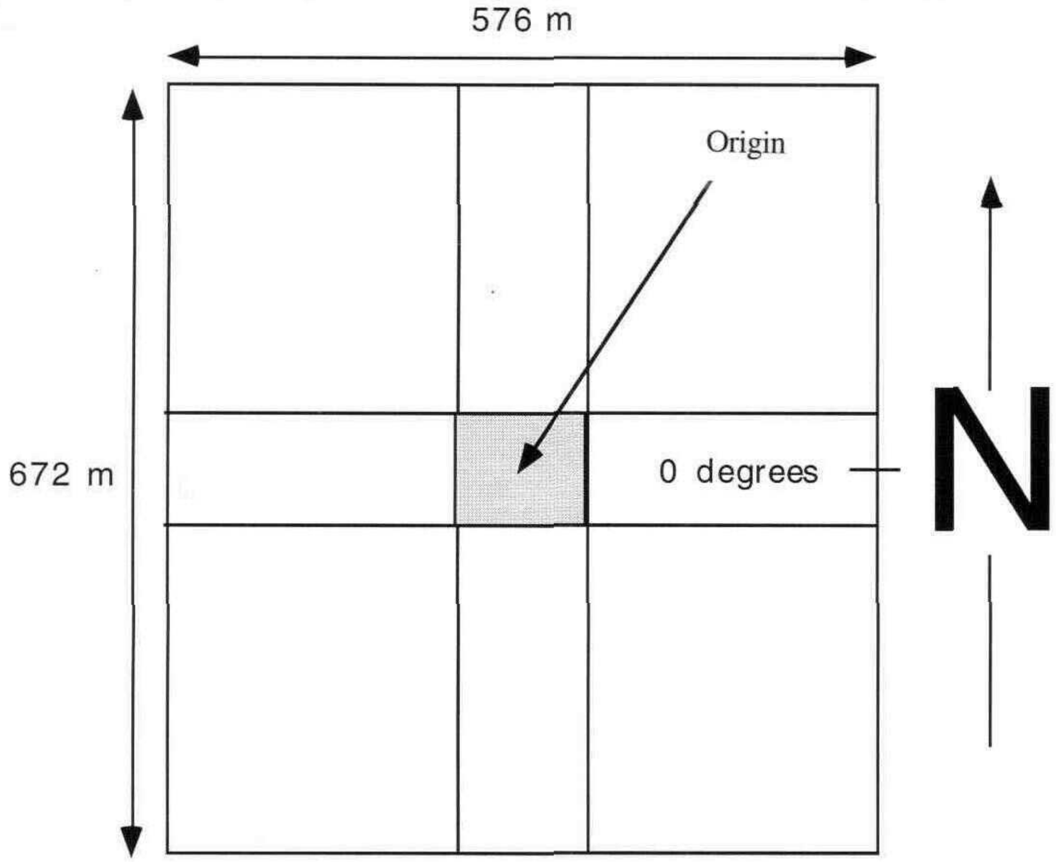


Fig.2. Plan view of Cold Lake 3-D. Gray area indicates central CDP range used in analysis. Zero degrees is East from the origin.

Of course, if the surface layer was structurally complex, subsets of CDPs, representative of local thickness changes, would be employed in the analysis.

Assignment of azimuth

Each trace within the CDP gather was assigned an azimuth based on its shot and receiver coordinates using:

$$\theta = \text{ATAN}\left(\frac{\text{receiver Y - source Y}}{\text{receiver X - source X}}\right) \qquad (2)$$

Where θ is the trace azimuth, X and Y are the coordinates of receivers and sources. The ATAN function in FORTRAN was used so that, for instance, traces at a true 225 degree azimuth would be assigned 45 degrees by the program. The result is that azimuthal rotation of 180 degrees gives 360 degree coverage.

The traces were then sub-grouped into azimuth bins between 0 and 180 degrees. Each bin was 5 degrees wide.

Trace padding

The gathers were then ordered by increasing absolute value of offset, and padded with dead traces to give an average trace interval of 2.3 meters (2.3 meters was found to be the average-smallest trace interval). Dead trace padding was done to preserve both relative ground-roll move-out on trace displays, and frequency-wavenumber dip in f-k space. The panels in Figure 3 are examples of different azimuth gathers. They are presented with NMO correction for better differentiation between ground-roll and reflection events.

DATA ANALYSIS

The discontinuous azimuth angle increase of the gathers (i.e. 0, 25, 65, 85, 120, 155 degrees) is the result of selecting azimuth gathers with a good balance of near and far offsets. For example, 45 degrees had very few near offset traces and was left out of the analysis. The ground-roll energy on each gather appears as a set of coherent-linear events which dip across the section (Figure 3).

Estimates of the ground-roll velocity were first made using only the NMO corrected azimuth gathers (velocities are annotated on each gather in Figure 3). *Keep in mind* that these velocities are useful only for comparison with each other. These velocities were found to lie between 430 and 440 meters/second.

A 2-D Fourier transform was performed for each of the gathers, and the resulting f-k spectra displays are given in Figure 4. Because of NMO correction, the reflection primaries can easily be identified as the coherent events at $k = 0$. The ground-roll energy can be identified by superimposing the average moveout velocity derived from the azimuth-trace gathers. Aliasing evident on the f-k spectra displays is due to trace padding. If the analysis based on the central group of CDPs reveals a ground-roll character change for some azimuth, then a larger portion of the survey can be grouped into that azimuth, and further analyzed.

The final step is to derive a conclusive characterization of the ground-roll, using f-k transforms. This is done by selecting and 2-D fourier transforming a representative subset of azimuthal gathers, with no NMO applied. This will be presented in the next section.

INTERPRETATION

The Cold Lake 3-D data was acquired in January 1990 for Imperial Oil as part of a reservoir monitoring program at Cold Lake, Alberta. The 3-D survey covered an area of 672 m x 576 m. The field layout consisted of 5 NE-SW shot lines of 43 shots each, giving 215 shots, and 7 NW-SE receiver lines of 37 receivers each, giving 296 receivers. Shots and receivers were placed below the unconsolidated surficial till (Isaac, 1994).

Inspection of the six gathers of Figure 4 shows that the character of the ground-roll seems constant for the range of azimuths presented. As can be seen on each f-k spectrum, the ground-roll is easily distinguishable from the primary reflection energy, and has a constant comparative velocity of about 432 meters/second. The ground-roll can be seen to be constant over the entire 3-D.

The zero degree azimuth gather was selected for a final characterization of the ground-roll. Figure 5 shows the zero degree azimuth-gather, and its 2-D Fourier transform, both with no NMO correction. The estimated surface velocity of the ground-roll is 400 meters/second. The dip in the f-k plane is 400 m/s as expected. The ground-roll region, represented by this 3-D volume can now be considered as having a regional surface velocity of 400 m/s

CONCLUSIONS

A procedure to characterize the regional variance of ground-roll on 3-D seismic data was outlined using seismic trace gathers in the azimuth-offset domain and the f-k domain. Examples show that the ground-roll present on the Cold Lake 3-D data set had very little azimuthal variance. It was concluded that the ground roll in the region represented by the 3-D survey had a surface velocity of 400 meters/second.

ACKNOWLEDGMENTS

The author would like to thank Mark Lane of the CREWES project for his help with trace header math.

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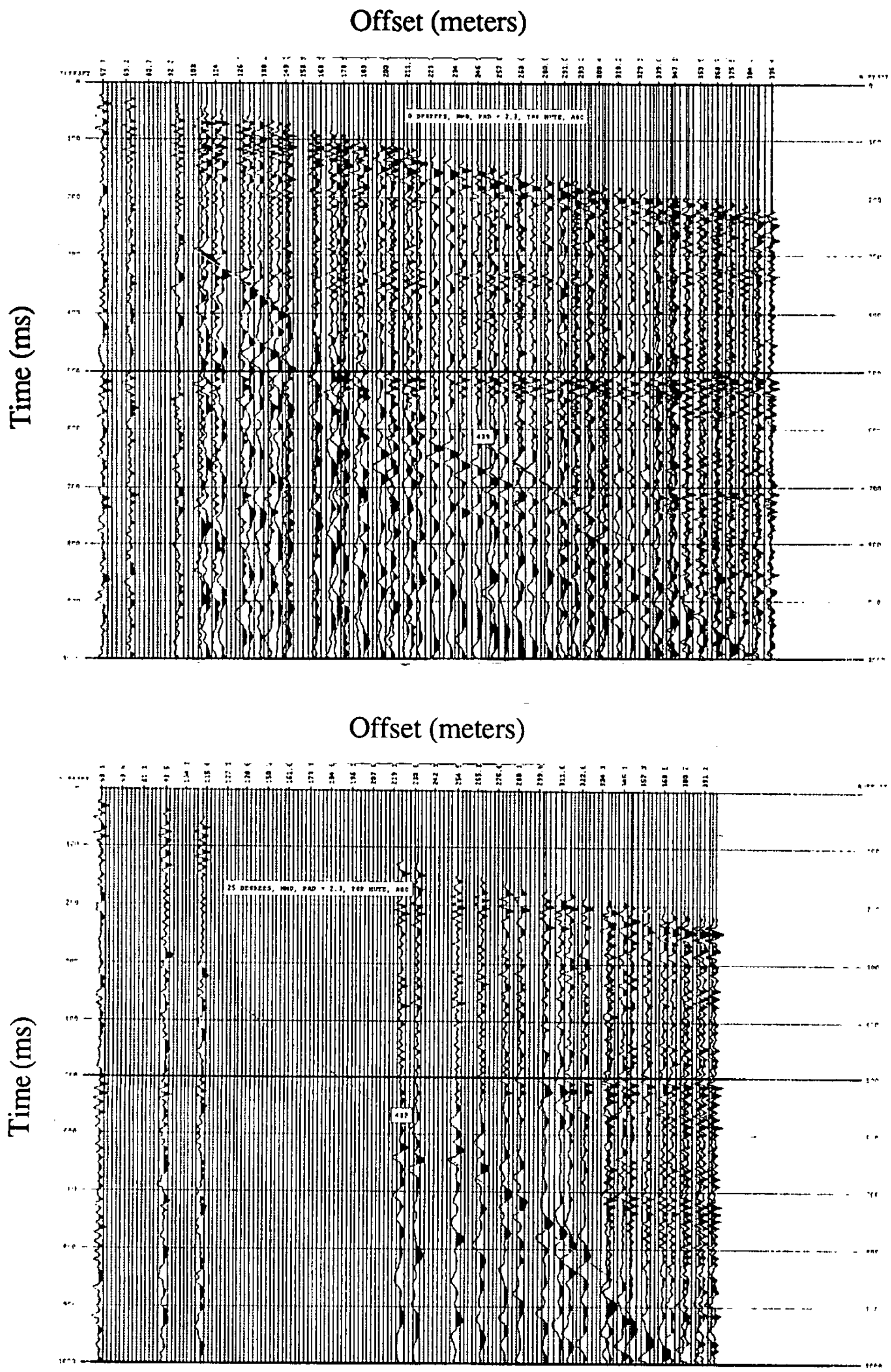
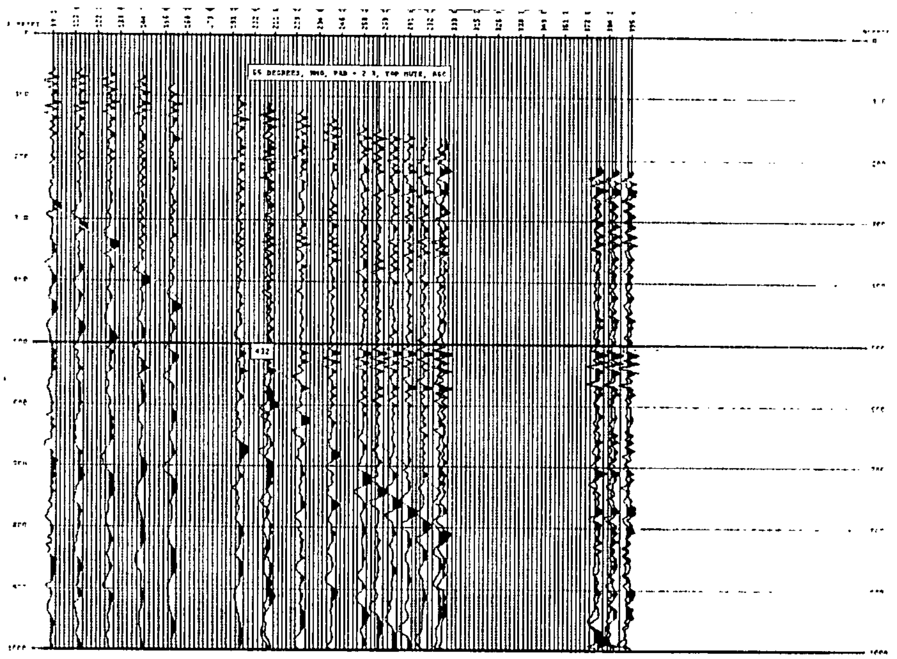


Fig. 3(continued on next two pages). Azimuth-gathers for angles 0, 25, 65, 85, 120, 155. All are sorted by increasing offset. Live traces padded with dead traces to give a trace spacing of 2.3 meters (preserves ground-roll moveout). NMO correction applied for easy event differentiation. Reflection primaries are horizontal events, ground-roll dips across each panel. Comparative ground-roll velocities annotated on each panel.

Offset (meters)



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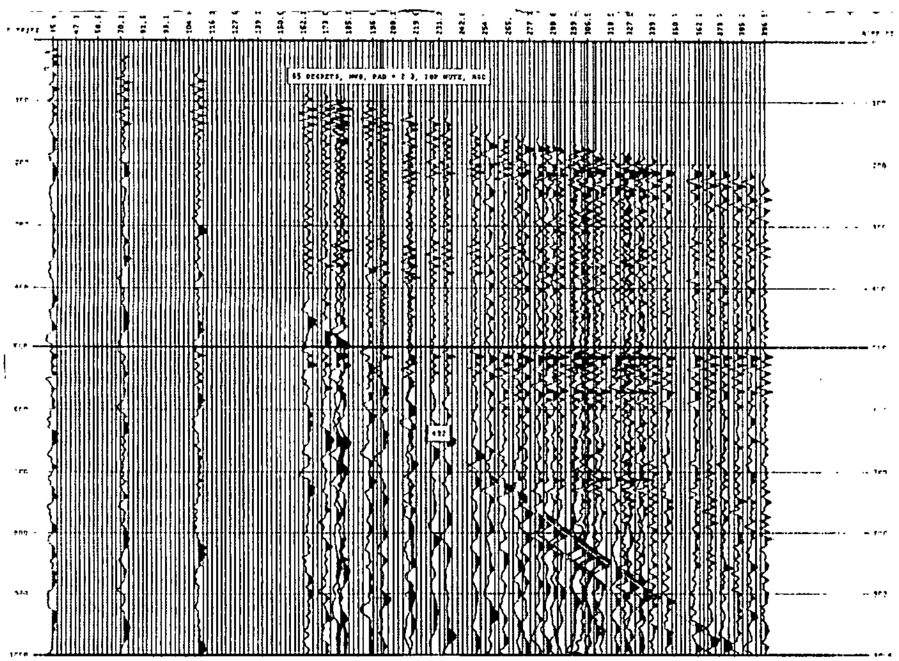
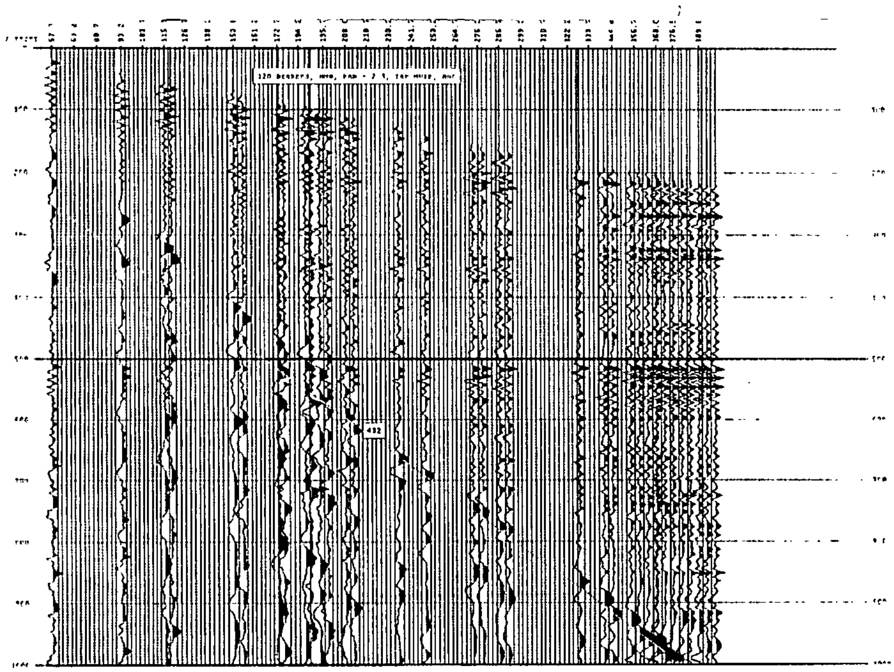


Fig. 3 continued.

Offset (meters)

Time (ms)



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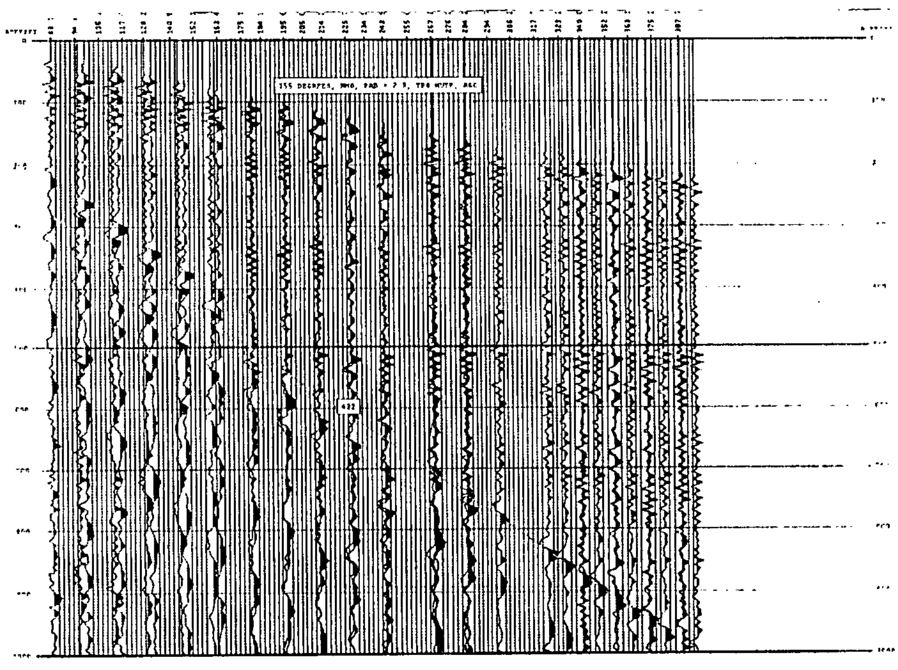

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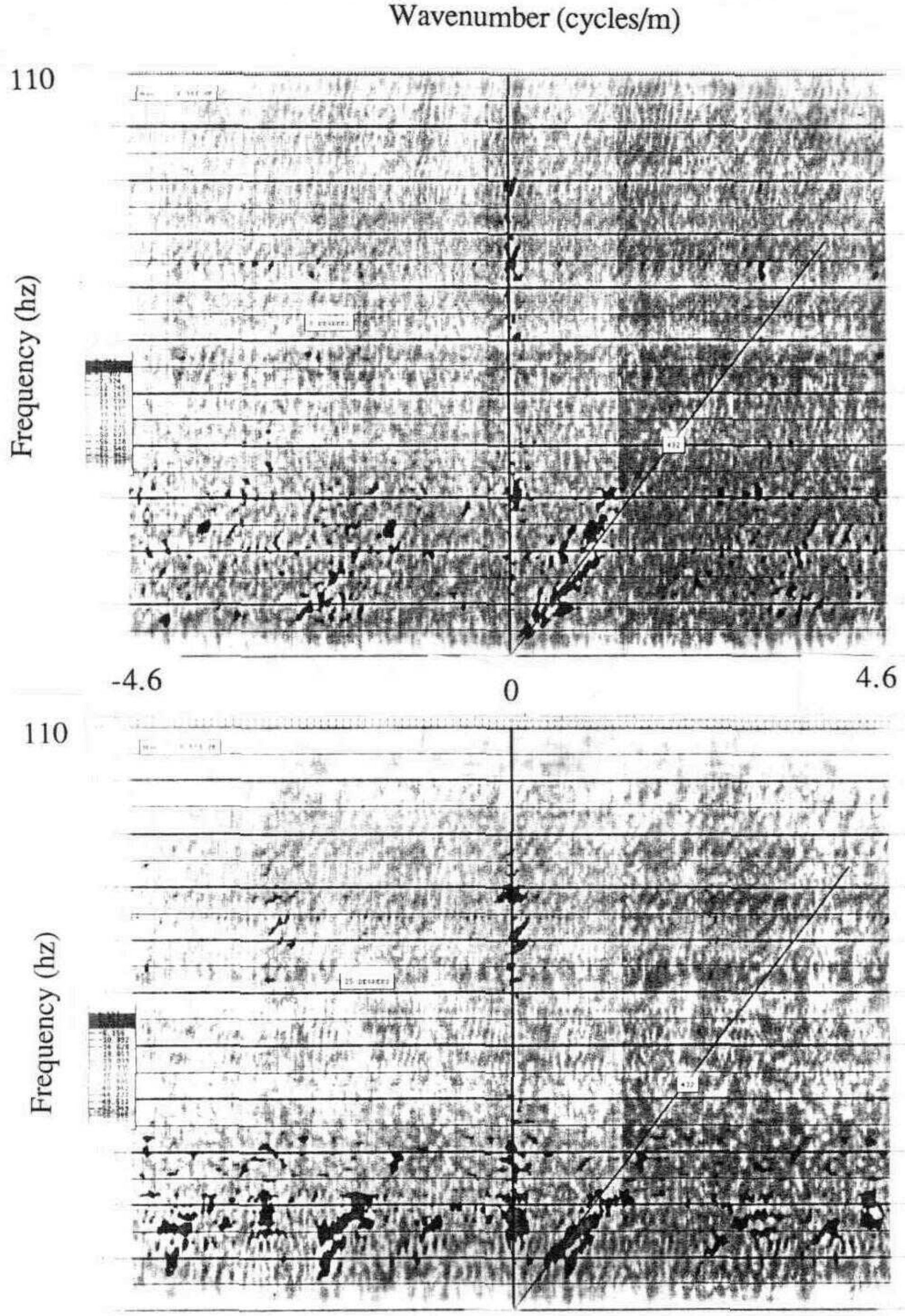
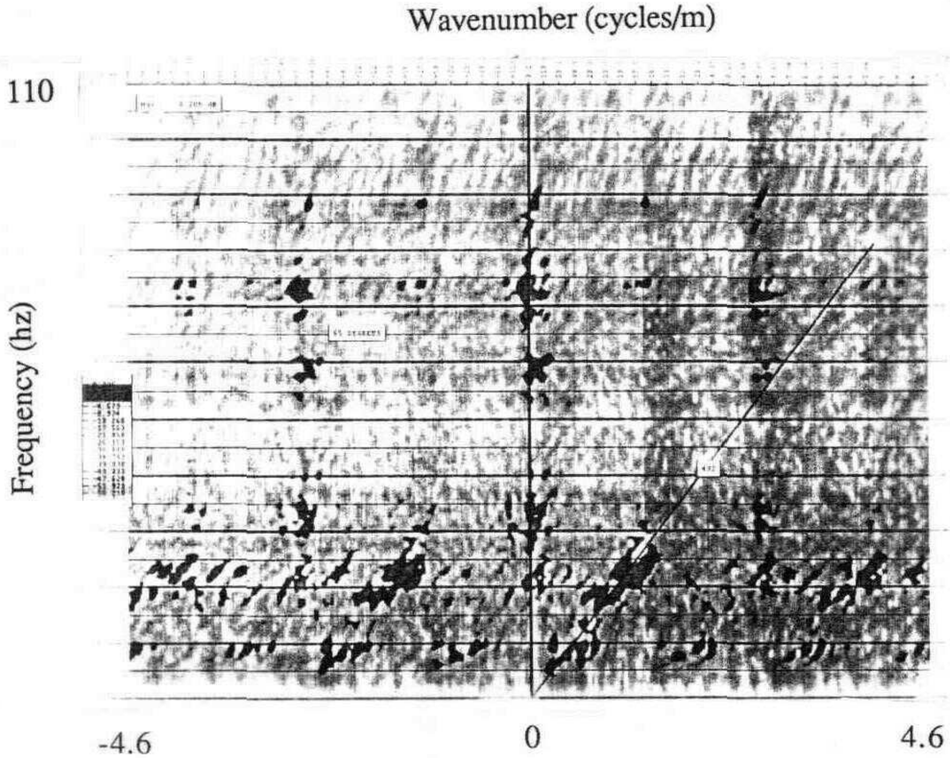
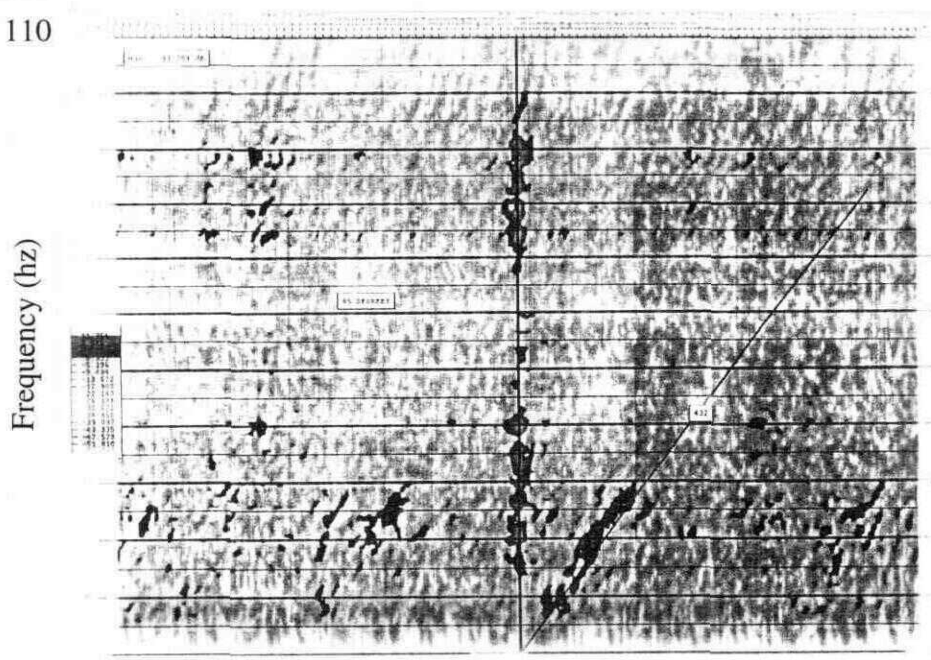


Fig. 4(continued on next two pages). 2-D fourier transform displays of azimuth-gathers for angles 0, 25, 65, 85, 120, 155. NMO correction applied for easy event differentiation. Reflection primaries are coherent events at k=0. Ground-roll is dipping energy. Comparative velocities are annotated for each panel. Note how the velocity is constant for all azimuths with a possible local increase at zero degrees-traced to offsets 200m-240m on common-azimuth gather. Aliasing is due to trace padding.





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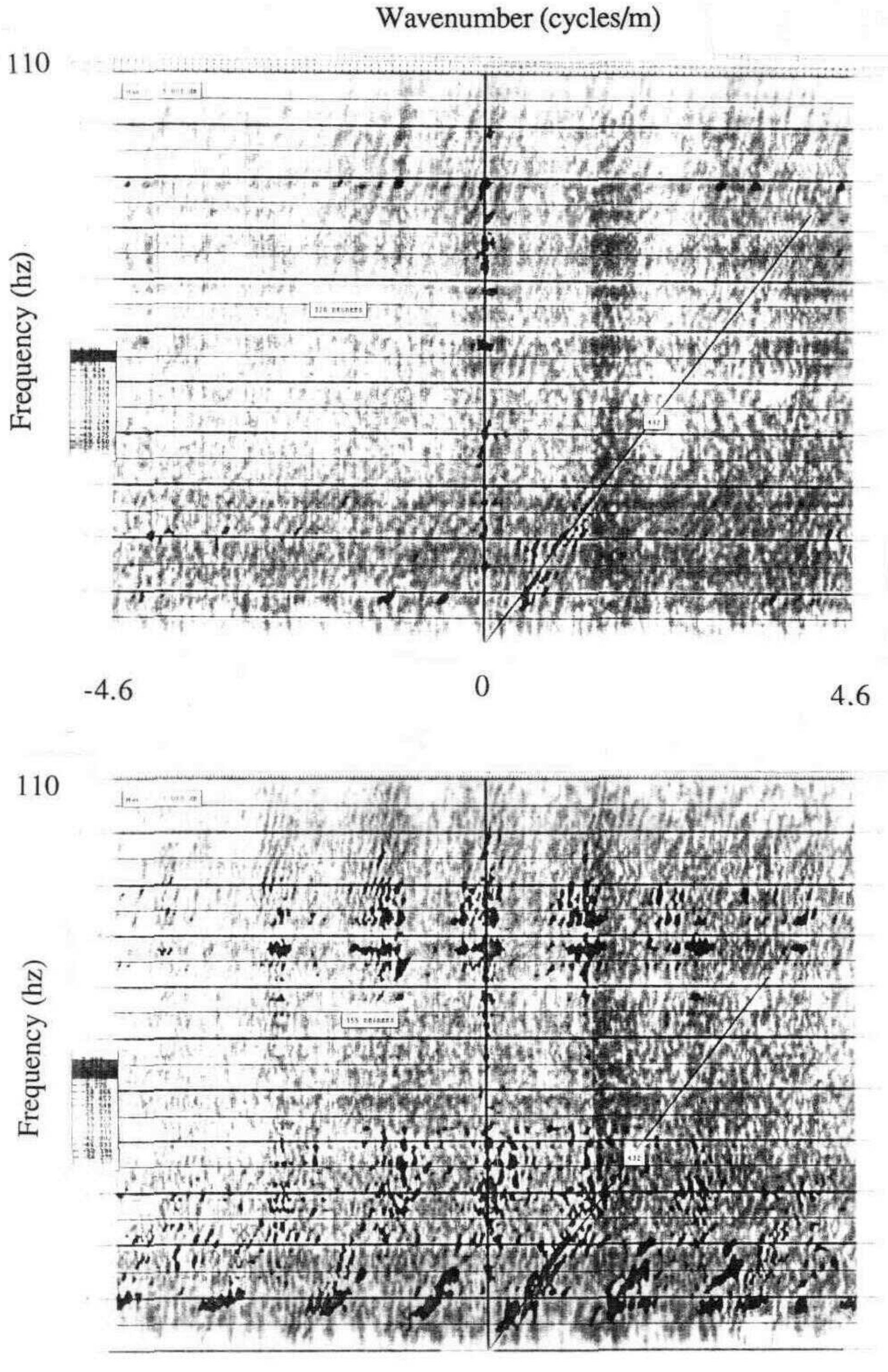

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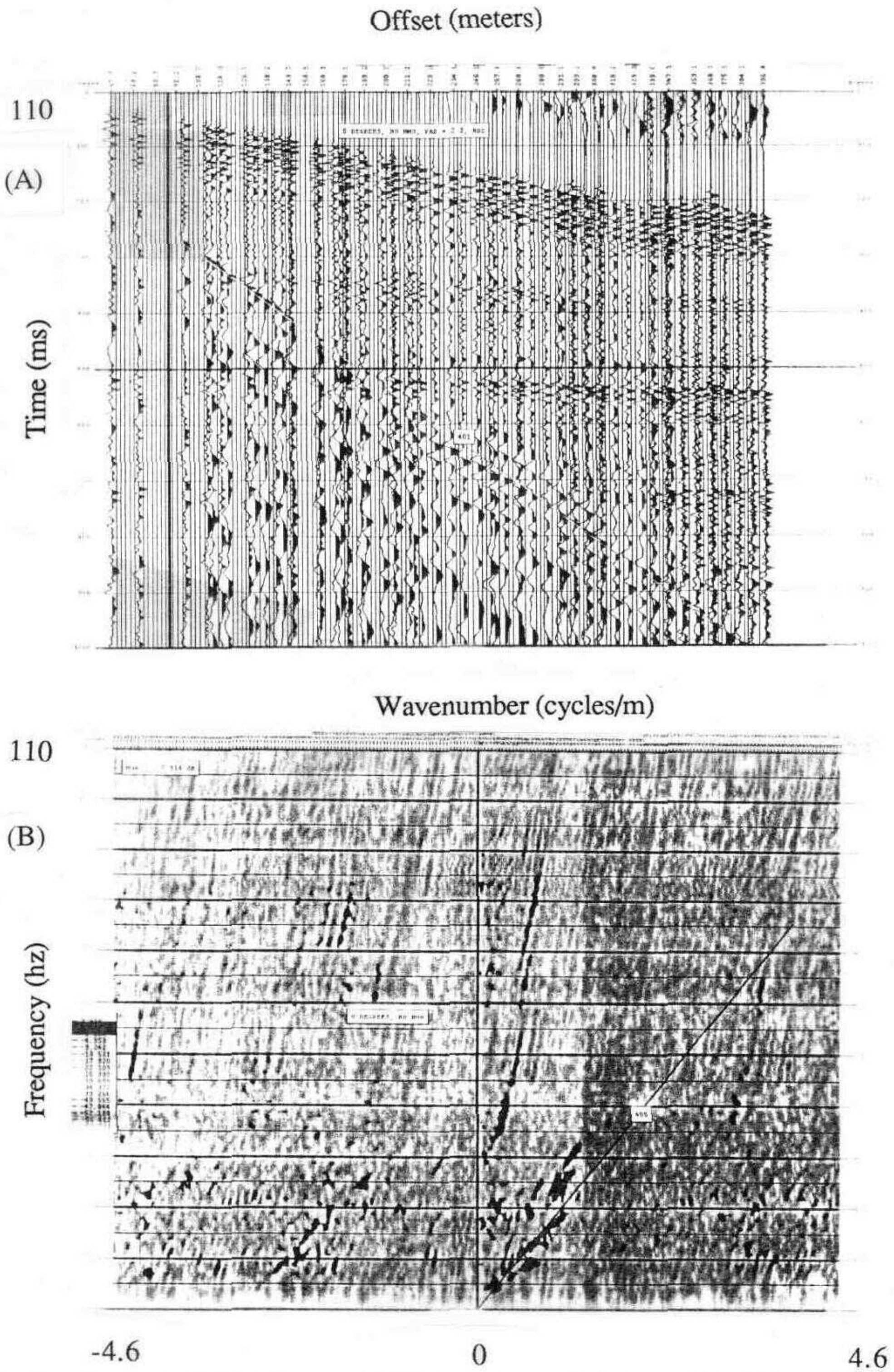

Fig.5. Azimuth gather and f-k spectrum used in final ground-roll characterization. Panel (a) is the zero degree azimuth gather ordered by increasing offset. No NMO correction has been applied The surface phase velocity of the ground roll 400 meters/second. Panel (b) is the 2-D Fourier transform of panel (a). The dip of the ground-roll is 400 meters/second as expected.