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SEISMIC SPECTRAL SIGNATURES OF THE BADAK OIL AND GAS FIELD, ONSHORE KUTEI BASIN, KALIMANTAN, INDONESIA: AN EXAMPLE OF SEISMIC RESERVOIR IMAGING AND CHARACTERIZATION

Arif Wibowo*
Jeff Towart*
James Dirstein **
Maher Maklad***

ABSTRACT

While attenuation zones ("dim-spots") have been visually noted on seismic sections associated with some hydrocarbon accumulations for almost twenty years (Taner and Sheriff, 1977; Anstey, 1977; Dobrin, 1984), early attempts at measuring attenuation in the laboratory and from seismic data met limited success. Work during the mid eighties set the stage for further investigation and development of these ideas, including discussions of a frequency dependent attenuation model by Terry Jones (1986) and experimental work by Bourbie et al. (1986) demonstrating that gas attenuates more P wave energy than water in rock pores.

Factors affecting the spectral character of the seismic data generally fit into two categories (Dilay and Eastwood, 1995). The first is a lithological factor where the spectral character changes in response to time-thickness variations within a formation or a group of formations. The second is a petrophysical factor where spectral attributes can also be used to estimate the attenuation characteristics of a certain formation. It has been experimentally established that fluid-bearing porous rock formations attenuate seismic waves preferentially (i.e. higher frequencies within the seismic band are more severely attenuated than lower frequencies). Generally, gas attenuates seismic energy more than oil, and oil attenuates more than water.

Spectral analysis was used to measure the attenuation of seismic frequencies beneath the Badak oil and gas field, located in the Sanga-Sanga PSC in East Kalimantan, Indonesia. This study utilized recently developed techniques for spectral and attenuation analysis (Maher, 1988). The spectral analysis method employed in the study contains several proprietary algorithms to overcome some limitations of previous methods for measuring attenuation from stacked seismic data. Comparison with AVO attributes indicates that spectral analysis provides additional information necessary to characterize the deeper reservoirs.

EAST KALIMANTAN OIL AND GAS FIELDS

VICO Indonesia operates 4 major fields in East Kalimantan. Current estimated reserves of 14 TCF EUR are found in multiple stacked distributary channel sands at depths ranging from 1,000 to 14,000 feet. The fields are simple anticlinal structures that have been exploited over the past 20 years by progressively tighter infill drilling. Contributions by geophysicists during this period were largely limited to providing accurate structural control. Future field development plans require drilling wells targeted for specific single channel reservoirs. Consequently, geophysical data are now being used to characterize and map the hundreds of individual channel sands.

* VICO Indonesia
** TOTAL Depth Pty. Ltd.
*** Signal Estimation Technology Inc.

Detection of distributary channels becomes progressively more difficult with increasing depth of burial. The normal band-width at average reservoir depth in Badak and Nilam fields is only 5-50 Hz. This means that most reservoirs are below the minimum resolution limit and fall into the "thin bed" response zone (Wibowo et al., 1996).

Badak Field

Badak Oil and Gas Field is located in the onshore portion of the Kutei Basin; it underlies the northern portion of the Mahakam delta system of eastern Kalimantan (Duval et al., 1992; Figure 1). Exploration in this highly productive Mahakam Tertiary delta province began in the late 1800's with surface mapping that resulted in large discoveries (Sanga-Sanga and Samboja) during the early 1900's.

Badak Field was discovered in 1972. Hydrocarbons are trapped in a large anticlinal structure with stacked accumulations at depths from 3,500 to 12,000 feet, as shown by the seismic line in Figure 2. This study examines a zone of productive sands in the Upper Miocene at depths of around 6,000 feet below the surface.

Seismic Attributes

AVO (Amplitude Variation with Offset) techniques have been used extensively on 2D seismic data in Badak and Nilam fields in the northern Mahakam Delta region. AVO response is useful in delineating some producing reservoirs at shallow depths, but deeper producing reservoirs do not show a sufficiently robust AVO response (Wibowo, 1996).

Seismic characterization of these reservoirs requires (1) upgrading existing techniques for defining seismic attributes, and (2) identification of other seismic attributes that are meaningful to reservoir definition. Spectral analysis provides an additional method of reservoir characterization and direct hydrocarbon detection (Dirstein, et al, 1996).

SPECTRAL ANALYSIS

The factors affecting the spectral character of the seismic data generally fit into two categories (Dilay and Eastwood, 1995):

LITHOLOGICAL: The spectral character changes in response to time-thickness variations within a formation or a group of formations. These variations can usually be associated with changes in velocity within the formation, stratigraphic pinch-ins and pinch-outs, changes in sand/shale ratio, and lateral changes in the impedance of the reservoir.

PETROPHYSICAL: Spectral attributes can also be used to estimate the attenuation characteristics of a certain formation. Experiments have established that fluid-bearing porous rock formations attenuate seismic waves preferentially (i.e. higher frequencies within the seismic band are more severely attenuated than lower frequencies). Gas generally attenuates more than oil, and oil attenuates more than water. Klimentos (1995) discussed a well log example and Eastwood and Dilay (1994) documented a case history using attenuation as measured by the method used in this study. Their technique was designed to minimize lithological effects on seismic spectral analysis, thereby isolating the petrophysical effects on attenuation.

Post Stack Processing

2D line K7802 (Figure 2) was selected for study because (1) this line crosses several producing reservoirs in the anticlinal structure of Badak field, and (2) an intensive and detailed AVO analysis had been conducted on it. Stacked seismic data from K7802 were analyzed for evidence of attenuation beneath the oil and gas accumulations. The seismic data were not reprocessed pre-stack prior to spectral analysis, although preconditioning of the data before spectral analysis or evaluation of other seismic attributes is often beneficial.

Figure 3 shows the post-stack seismic energy spectra (SPECTRA) processing flow. The first step was application of a noise attenuation technique to reduce the levels of coherent and random noise in the data and thus improve the Signal-to-Noise-Ratio (SNR). This method (Maher et al., 1993) utilizes a localized principal component analysis technique. A portion of the raw stack data is shown before and after noise attenuation in Figures 4 and 5. Examination of the difference or residual stack (Figure 6) provides validation that this technique has eliminated noise and not signal. This shows that only coherent and random energy was removed from the data, without any adverse affects to horizon consistent data.

Inspection of the SNR of the data before and after noise attenuation provides further confirmation that the signal was retained. Figure 7 shows the Power and SNR spectra of several windows of the data before (upper panels) and after (lower panels) noise attenuation. The horizontal axes of the plots are in frequency and the vertical axes are in dB. Note that 0 dB on the SNR spectra shows where signal energy is equal to noise energy. Before noise attenuation, signal and noise energy are equal in some of the analyses windows at frequencies greater than 40 Hz. After the application of noise attenuation, the SNR is positive in all analysis windows up to 90 Hz. Most attribute analyses and extraction techniques or spectral shaping algorithms will benefit from using the higher SNR data following noise attenuation as input.

For spectral analysis, care is required when using data modified with spectral whitening and time variant processes. Spectral shaping, on the other hand, can often be used advantageously to look for spectral signatures from stacked hydrocarbon zones. No spectral shaping was applied to the input data for figures shown in this study. After noise attenuation, the next step was to estimate the signal spectrum for each trace from a horizon-consistent time window (250 msec) extending both above and below the zone of interest. These spectra were processed further to estimate attenuation spectra.

Estimated Wavelet and Residual Wavelet Spectra

Figure 8 shows the common offset gather of K7802 tied to well Badak #1640. This figure shows the B12 and C08 zones, producing reservoirs at around 5,500 feet depth that provided the AVO response. Also shown is the deeper E 11 gas reservoir at around 8,300 feet, which gave no AVO response on the common offset stack gather. Demonstrating seismic spectral attenuation for the E11 is of particular interest because this zone did not show AVO indications of a gas reservoir.

Figure 9 is the diagram of the time window above and below the E 11 reservoir. The estimated wavelet and residual wavelet spectra from the window above the E 11 reservoir are shown in Figure 10. An analysis window of 250 milliseconds was selected to help limit the non-stationarity effects of the wavelet spectra. The upper panel shows the seismic data with the analysis window highlighted in red. The Badak Oil and Gas Field occupies the anticlinal structure on the right (SE) side of the section. The middle panel shows the estimated wavelet spectra, which was determined from the estimated signal spectra to help minimize the effects of reflectivity. The 15th , 50th , and 85th percentile frequencies are highlighted in yellow on the estimated wavelet spectra panel to quantify the seismic spectral changes. The residual wavelet spectra shown in the lower panel of the figure are determined from the estimated wavelet spectra, and these highlight anomalous portions of the spectra. Note that the window of analysis is positioned below the shallower hydrocarbon accumulations of the Badak Field and shows a significant loss of higher frequency seismic energy. This study, however, focuses on a deeper reservoir with more subtle seismic characteristics.

Figure 11 shows the estimated spectra from the window below the zone of interest. Examination of the estimated wavelet spectra from this window shows a shift in dominant spectral energy towards lower frequencies beneath the hydrocarbon accumulation. The spectral signature is further enhanced in the residual wavelet spectra display. Comparison of the wavelet spectra from the windows above and below suggests a loss of higher seismic frequencies below the E 11 gas reservoir (anticlinal structure on the right end of the display).

Normalized Attenuation Spectra

The normalized attenuation spectra were then determined using the estimated wavelet spectra from the window above and the window below the zone of interest. The purpose of this stage of the analysis was to ensure that the attenuation observed below the reservoir was relative to the energy in the seismic data immediately above the zone of interest. The normalized attenuation display from a portion of line K7802 with the well ties annotated is shown in Figure 12. The normalized attenuation spectra show the attenuation plotted using a dB scale, with white representing minimum and black representing maximum attenuation. In the E 11 reservoir interval, the normalized attenuation spectra shows that there has been a loss of seismic frequencies (20-50 Hz.) from the analysis window beneath Badak oil and gas reservoirs compared to the analysis window above the reservoir. The normalized attenuation spectra shows the well ties with reservoir thickness posted. The E 11 reservoir thickness at well Badak #1640 is 55 feet (all gas), at Badak #0400 it is 100 feet of gas with 10 feet of oil column, and at Badak #0760 no gas but 6 feet of oil. The E 11 reservoir is not present in the Badak #0520 and #1190 wells. Since these wells were not used to calibrate the initial spectral analysis, these well results appear to validate the presence of a relationship between occurrence of hydrocarbons and attenuation of seismic frequencies.

SUMMARY AND CONCLUSIONS

The spectral analysis technique used in this study demonstrates a measurable loss of higher seismic frequencies below the hydrocarbon accumulations in Badak Field.

While AVO analysis has been quite useful in evaluation of the shallower Badak reservoirs, application to deeper reservoirs is problematic. Limiting factors might include insufficient offsets recorded and lower SNR. Consequently, AVO analyses alone are insufficient to characterize the deeper reservoirs.

In this example, the normalized spectral attributes appear to provide useful discriminating information for both shallow and deep reservoirs. Moreover, the spectral attenuation analysis (SPECTRA) uses a time window from stacked seismic data; it appears robust versus noise and can withstand AGC, NMO, decon and de-multiple processing.

Seismic data with high signal to noise ratios are an important precursor for effective attribute analysis and extraction. The presence of hydrocarbons in the Miocene sandstone reservoirs at Badak Field appears to result in measurable attenuation of higher seismic frequencies. Gas reservoirs both with (shallow) and without (deeper) AVO effects can cause measurable attenuation of higher seismic frequencies. Since the attenuation measurement was made from archived stacked seismic data and the analysis is independent of phase, this type of spectral analysis can provide a rapid means of extracting useful seismic attributes. The integration of these spectral attributes with other attributes in the geophysical interpretation workflow may make a significant contribution in the exploration, appraisal, and exploitation of new and existing hydrocarbon reserves.

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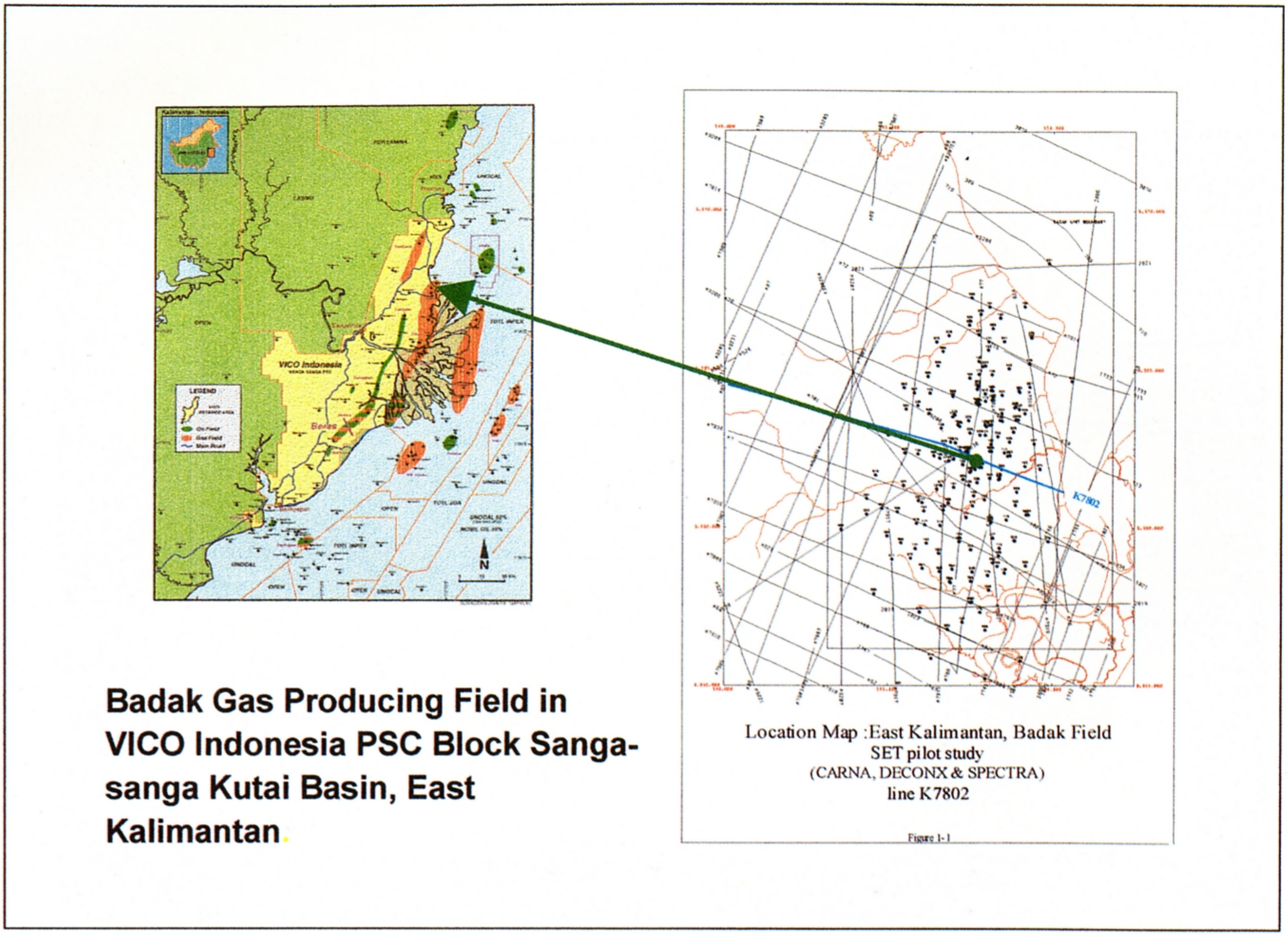

FIGURE 1 : Location Maps.

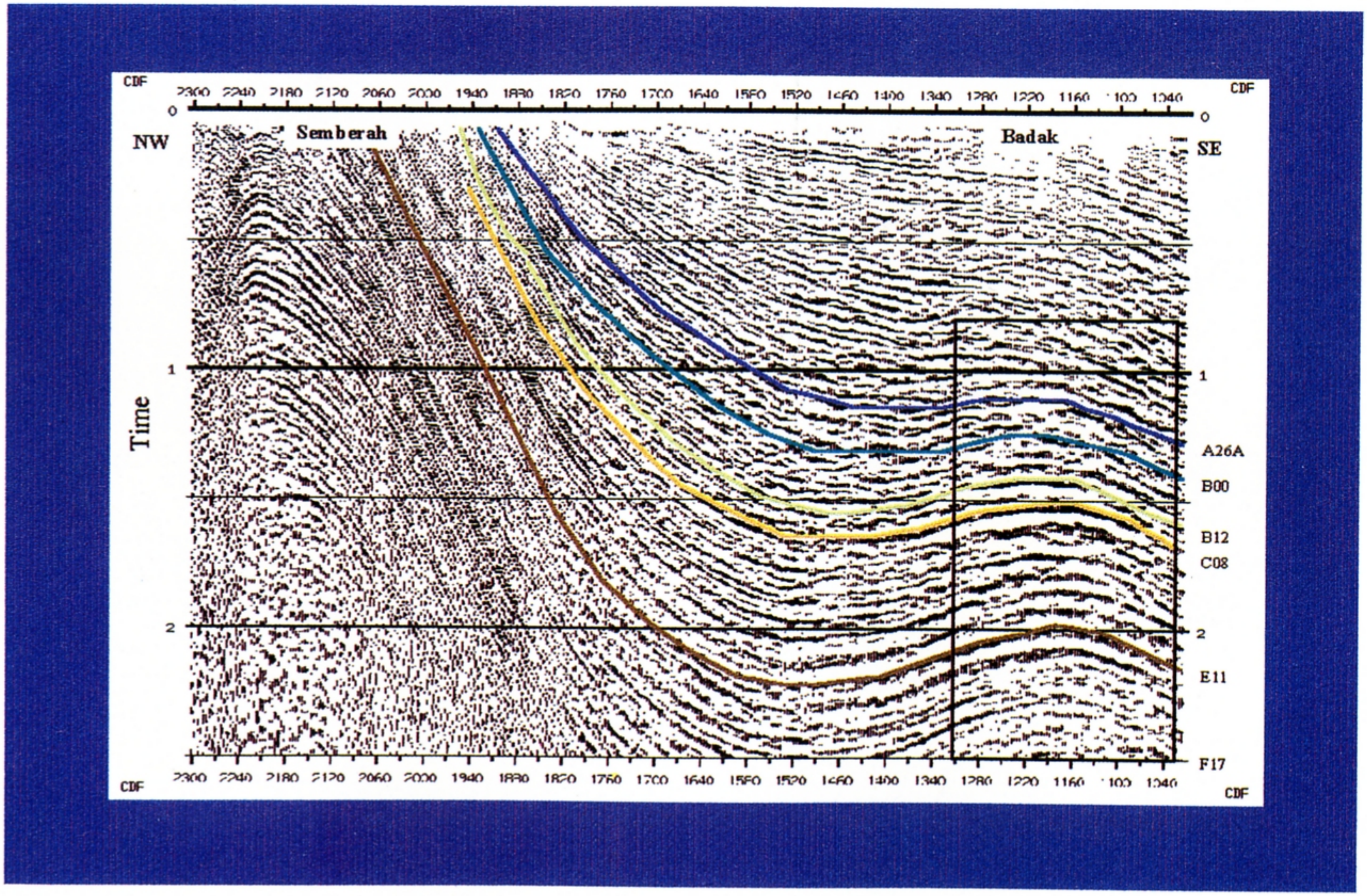

FIGURE 2 : East Kalimantan Seismic Line K7802 with Zones Containing Reservoirs.

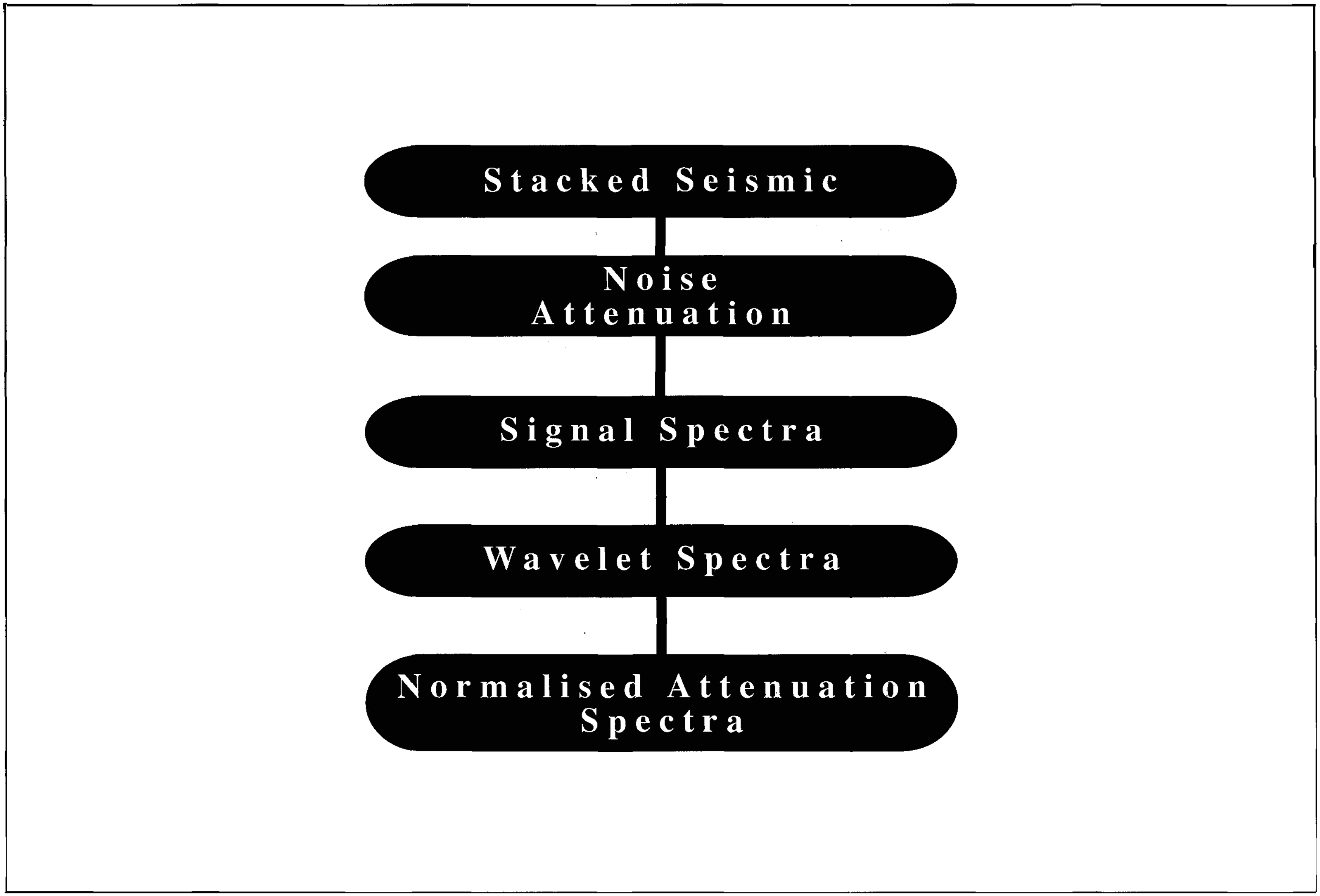

FIGURE 3 : Post-Stack SPECTRA Processing Flow.

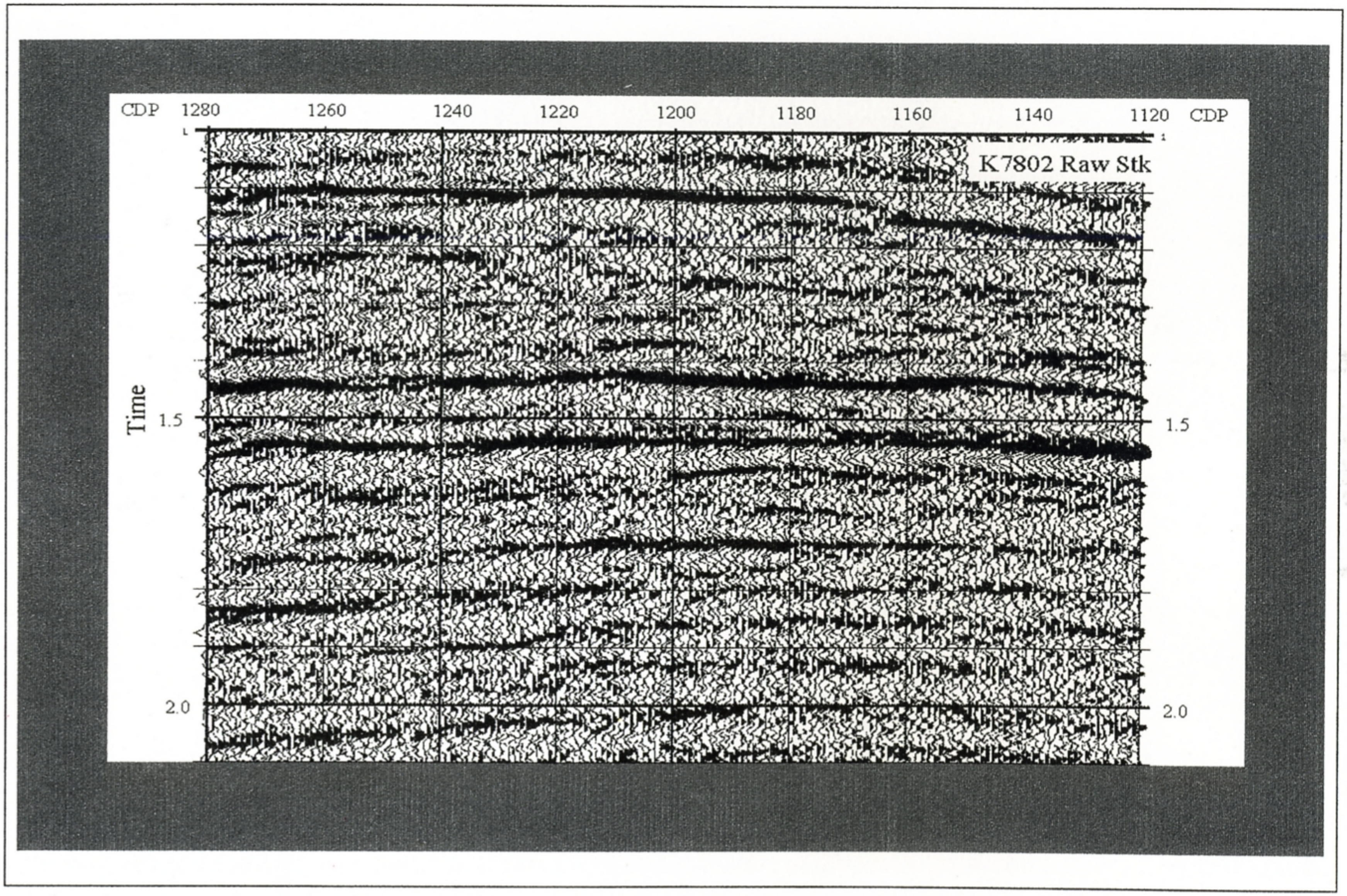

FIGURE 4 : Raw Stack before Noise Attenuation.

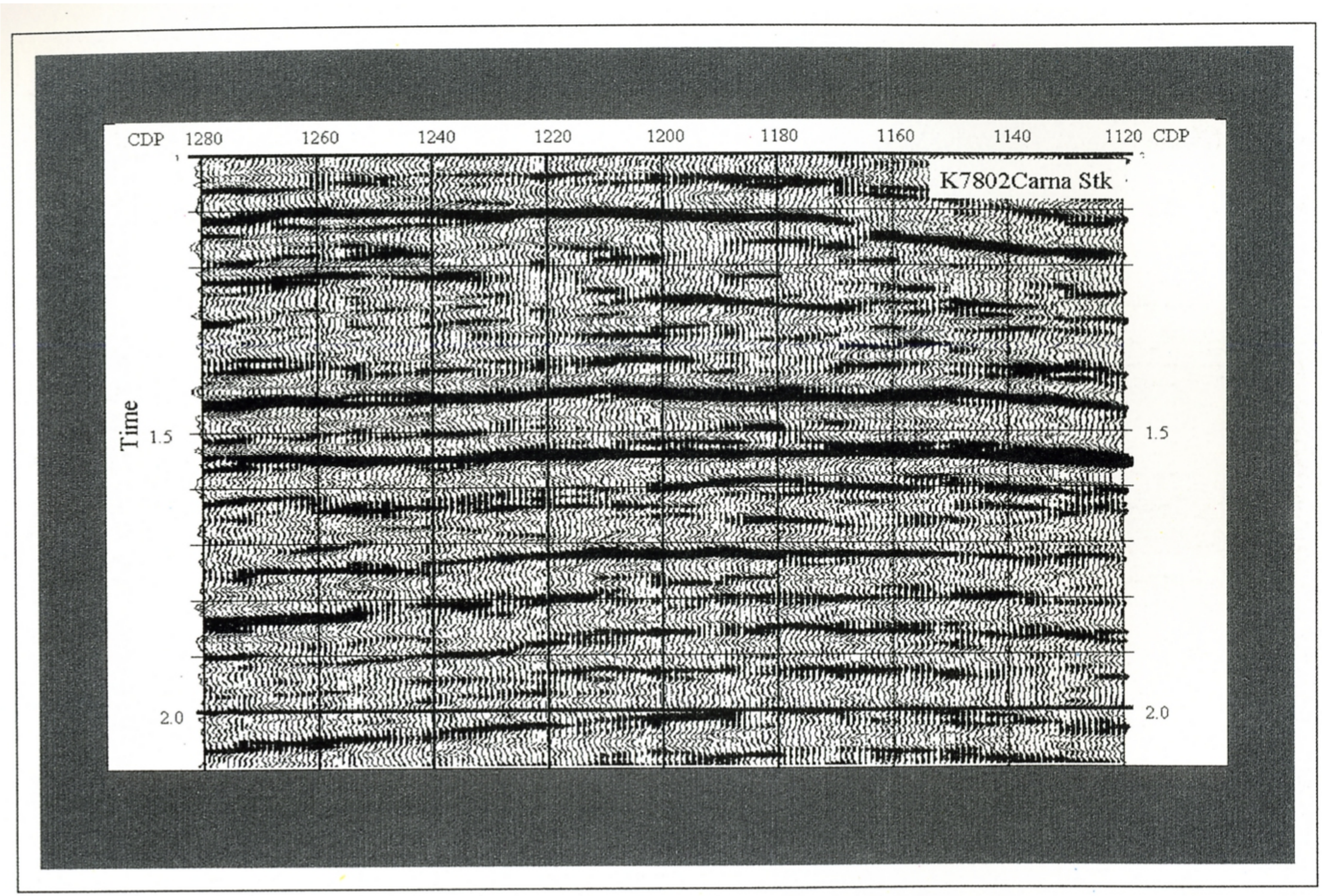

FIGURE 5 : Raw Stack after Noise Attenuation.

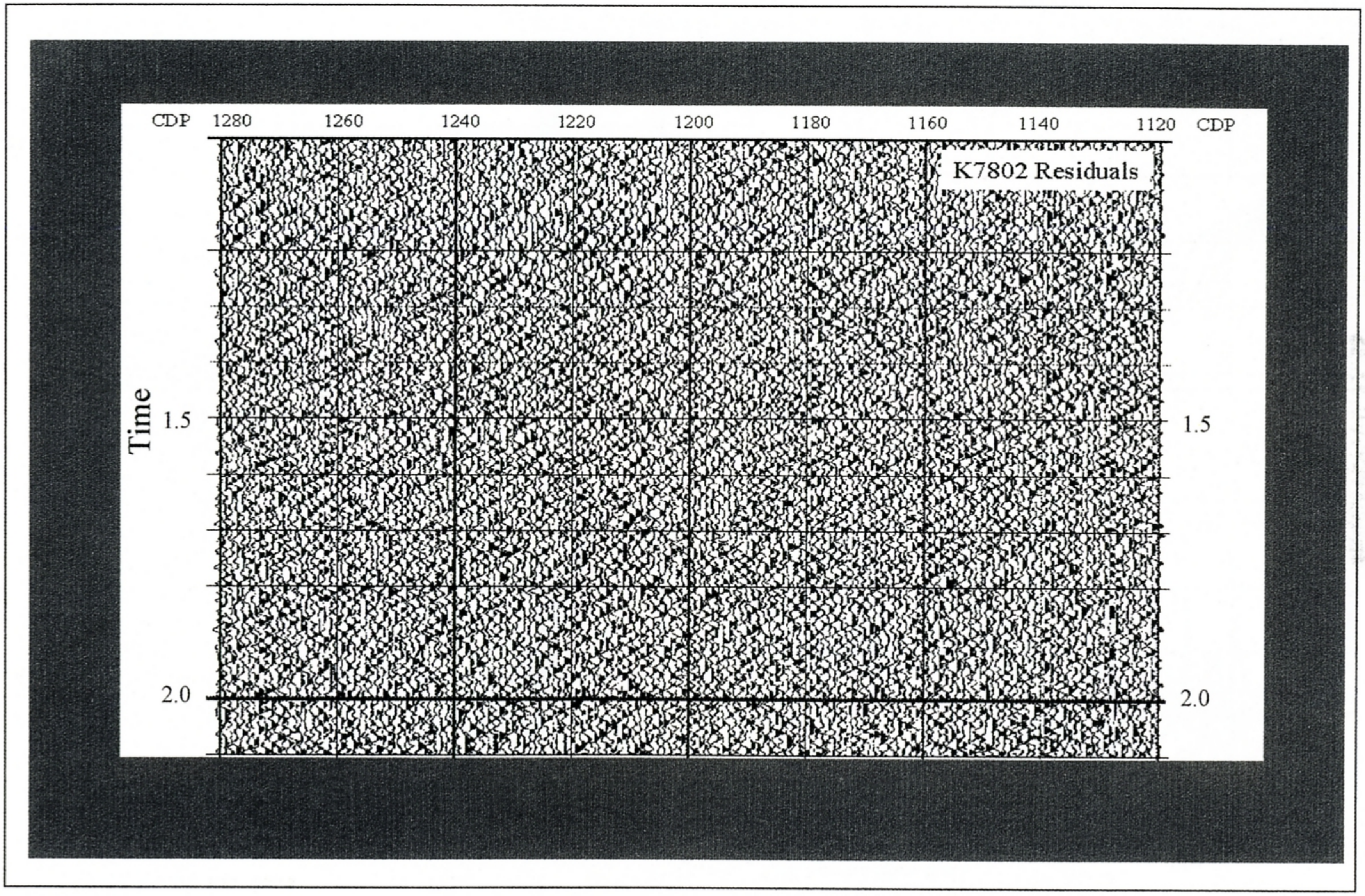

FIGURE 6 : Difference/Residual Stack (Random and Coherent Noise).

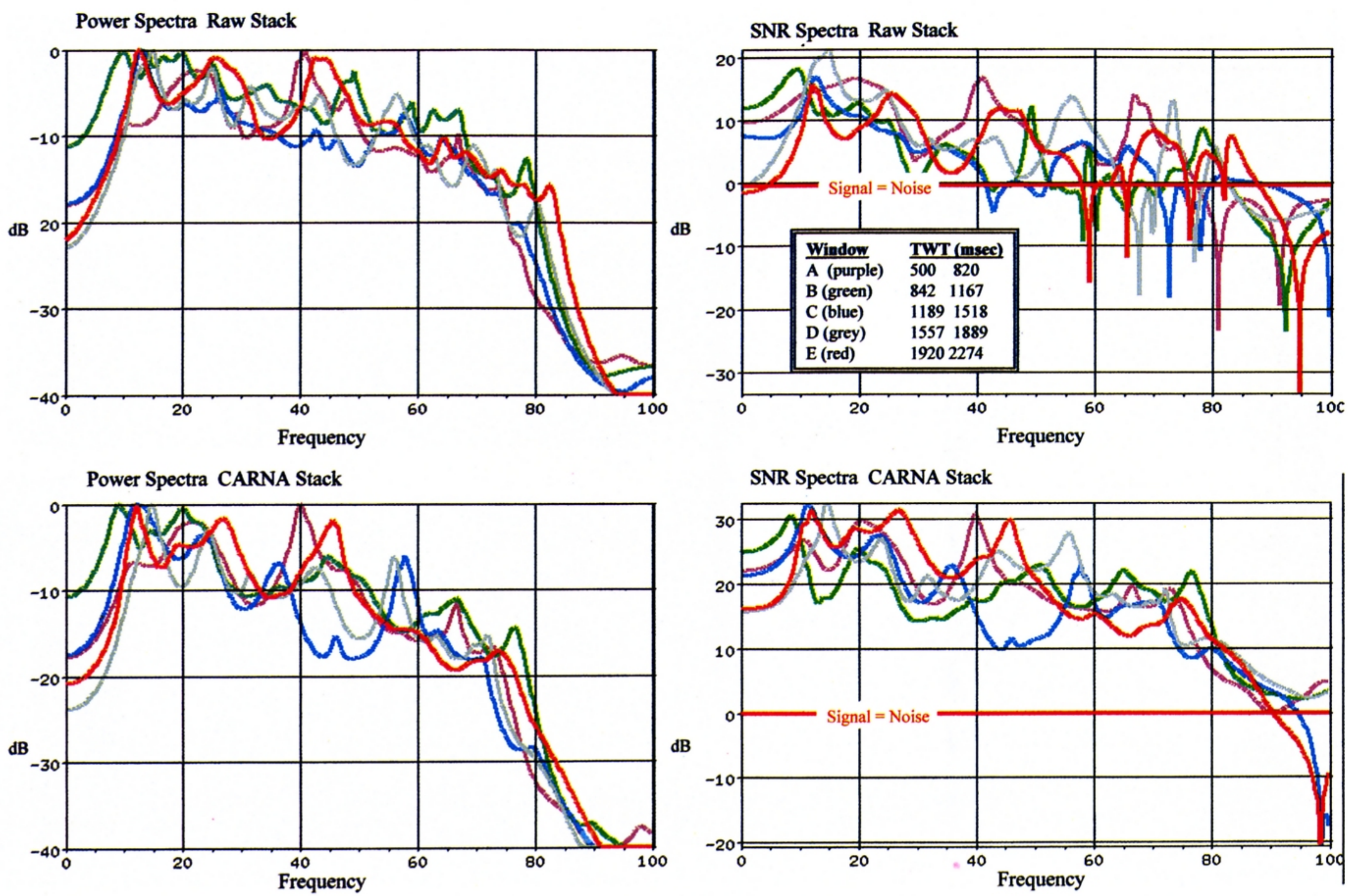

FIGURE 7 : Power and Signal to Noise Ratio (SNR) Spectra before and after Noise Attenuation.

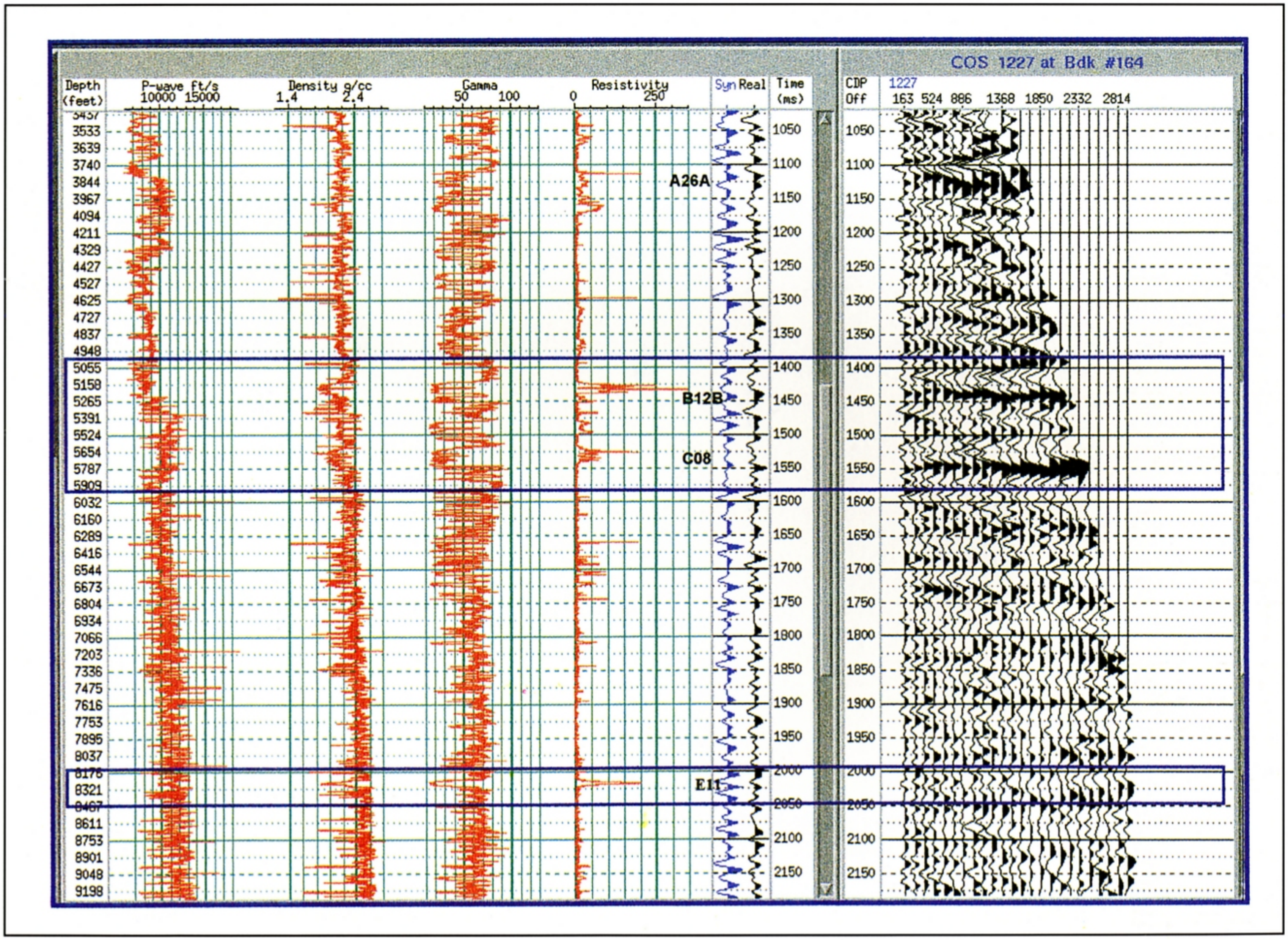

FIGURE 8 : Line K7802 Common Offset Stack Gather tied to Well Badak #164.

Window Position of Spectral Analysis for E11 Reservoirs

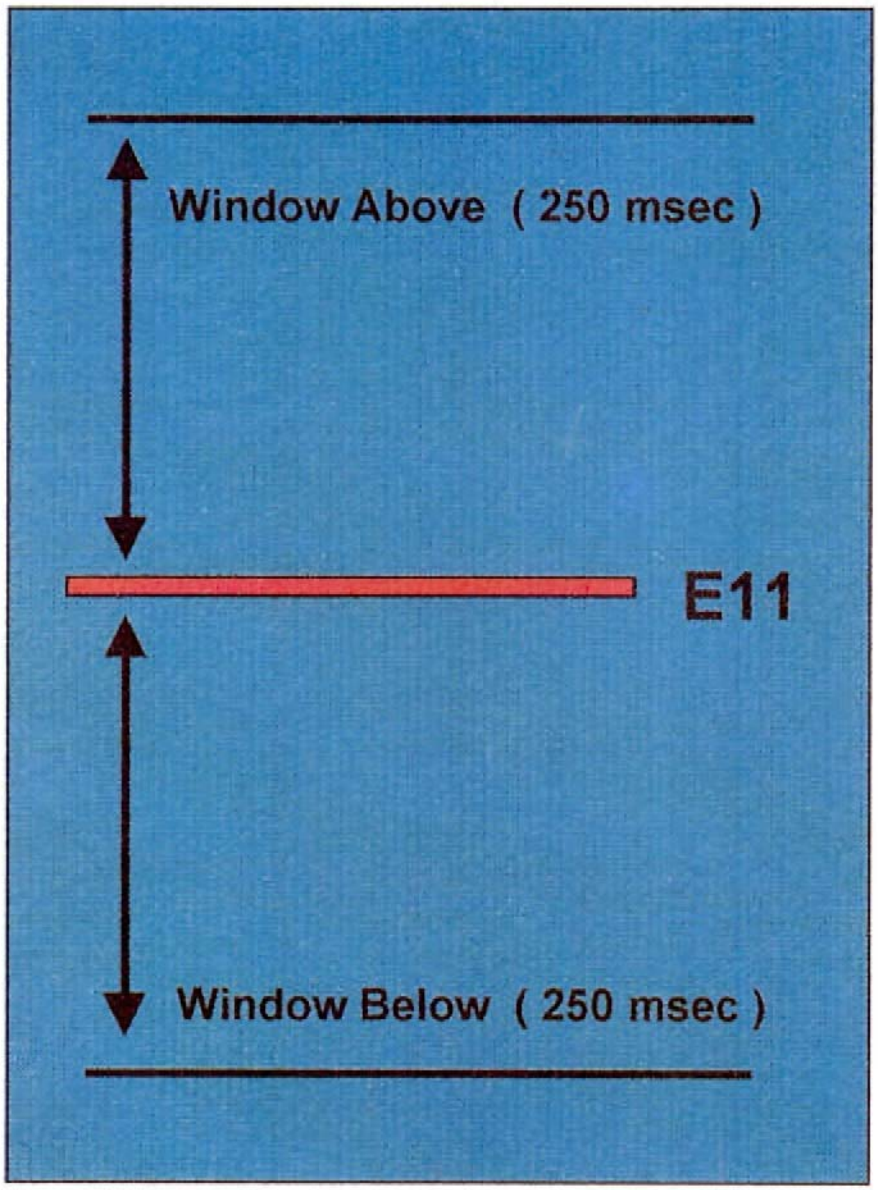

FIGURE 9 : Analysis Windows above and below E11 Reservoir.

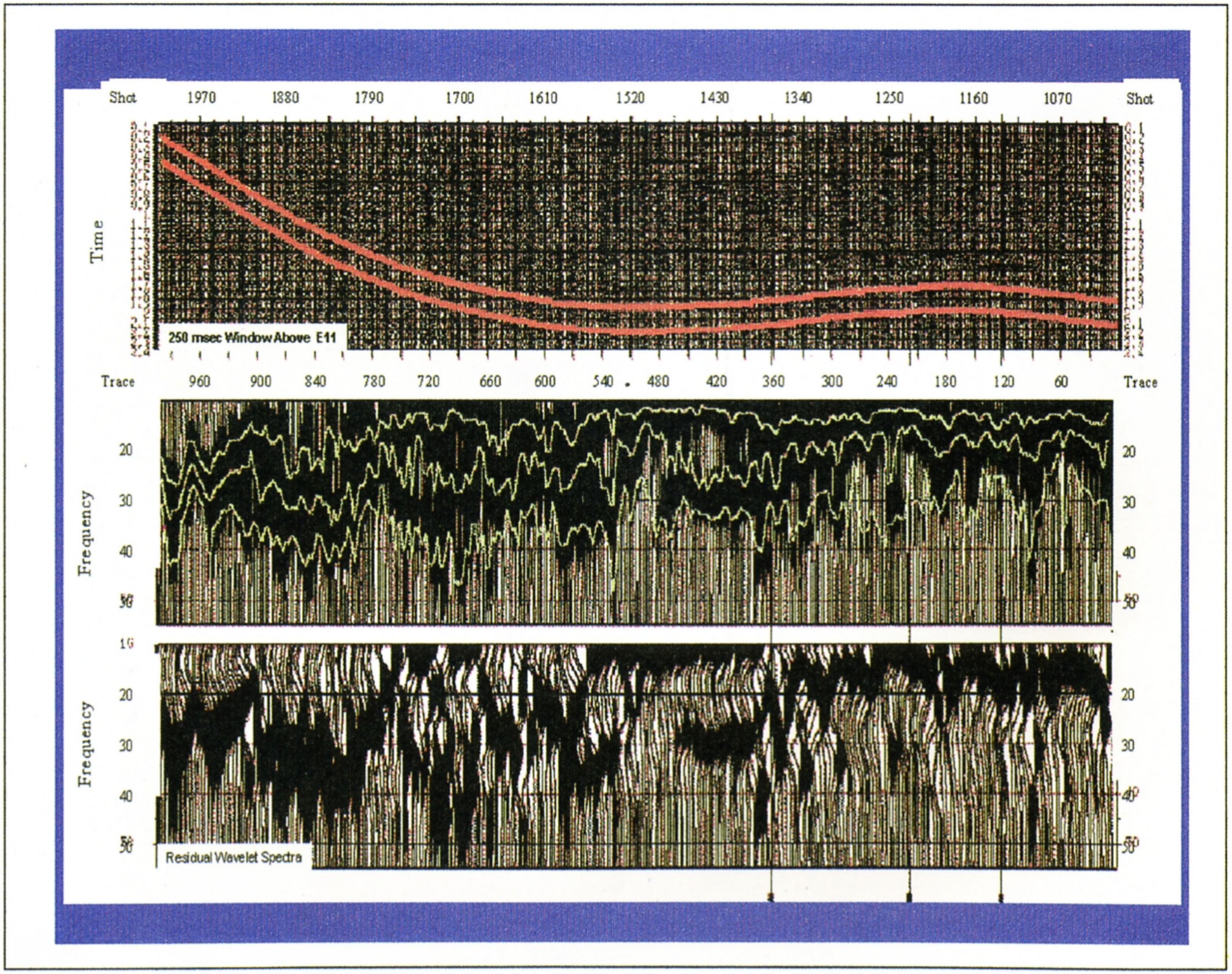

FIGURE 10 : Estimated Wavelet Spectra above the E11 Reservoir.

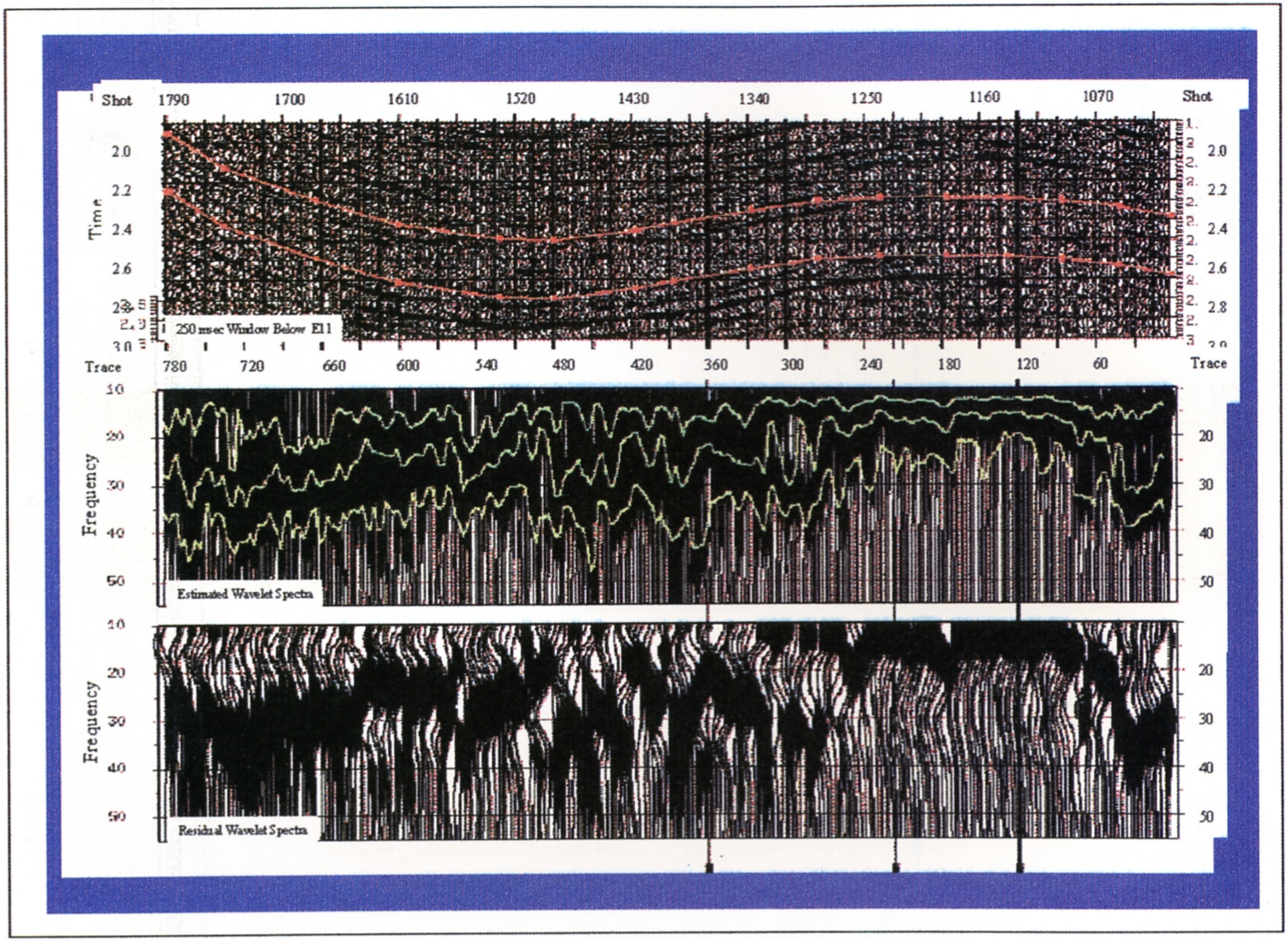

FIGURE 11 : Estimated Wavelet Spectra below the E11 Reservoir.

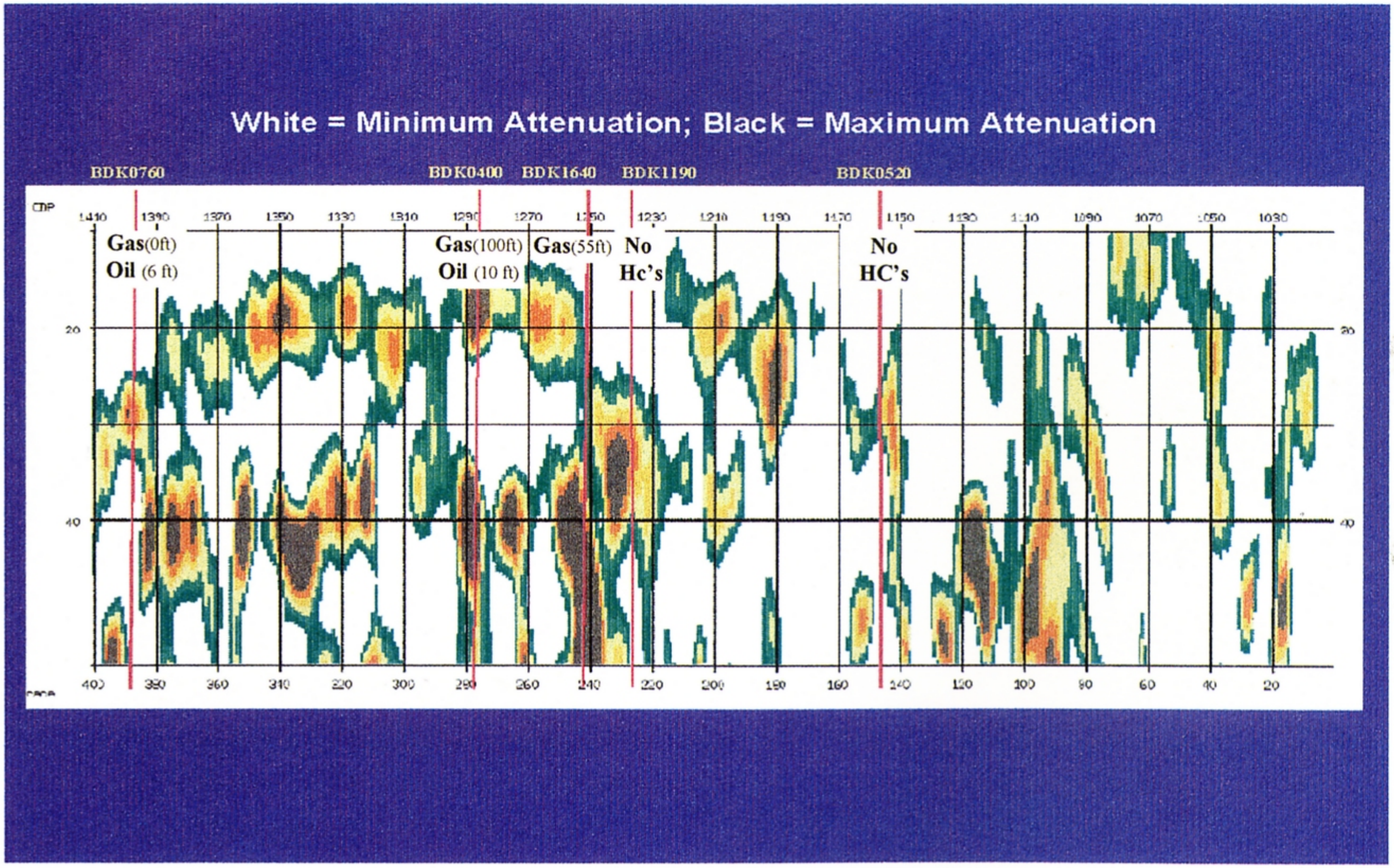

FIGURE 12 : Normalized Attenuation Spectra on Line K7802 for the E 11 Reservoirs. Well Ties are Annotated with Oil and Gas Column.