GEOPHYSICS, VOL. 57, NO. 11 (NOVEMBER 1992); P. 1502–1507, 6 FIGS.

Normal moveout stretch mute on shallow-reflection data

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ABSTRACT

This paper demonstrates the potential consequences of overlooking the significance of allowable stretch ratio when performing normal moveout corrections on shallow-reflection data. Two shallow reflection data sets with drastically different near-surface geologic settings conclusively show the significance of subtle changes in allowable stretch mute. An improper stretch mute can reduce the dominant frequency and bandwidth of a stacked reflection by as much as 50 Hz. The sensitivity of shallow reflections to offset may require allowable stretch selection accuracy to be within ±1 percent. It may be necessary to reduce the fold of an individual stacked shallow reflection by as much as 60 percent to avoid excessive degradation of wavelet properties and consequent loss of resolution. A proper normal moveout stretch mute can reduce distortion of reflection wavelet spectra caused by nonvertical incidence recording to less than 10 percent. Stretched reflection wavelets improperly muted can be misinterpreted on CDP stacked sections as stacked refractions or subtle stratigraphic features.

INTRODUCTION

Selection of an improper normal moveout (NMO) stretch mute on shallow reflection data can drastically degrade the spectral and amplitude characteristics of CDP stacked sections. On the average, maximum allowable frequency change or stretch for processing reflection data for petroleum targets generally ranges between 50 and 100 percent (Yilmaz, 1987). By contrast, optimal maximum allowable frequency change or stretch for engineering, ground water, and environmental targets can be as low as 15 percent (Miller et al., 1990). Ignoring allowable stretch ratio when processing shallow-reflection data can significantly reduce the dominant frequency bandwidth and apparent coherency by allowing overstretched reflection wavelets to be included in CDP stacked traces.

Dynamic adjustment of reflection wavelets for nonvertically incident raypaths is necessary prior to CDP stacking. The amount of sample dependent dynamic-adjustment or NMO correction necessary depends on source-to-receiver offset and reflection-wavelet arrival time. The NMO correction adjusts recorded reflection wavelets to simulate vertically incident raypaths. This dynamic adjustment of reflection times is accomplished through increasing or stretching the time separation between individual samples according to arrival time and selected NMO velocity. The stretching process distorts the reflection wavelet (Buchholtz, 1972; Dunkin and Levin, 1973). The effects of excessive stretch on reflection wavelets must be removed prior to the stacking process to avoid degradation of wavelet properties and misleading interpretations.

The detrimental effects of the stretching process are most prominent on shallow reflections at larger offsets (Yilmaz, 1987). Damage to spectral and amplitude properties of a stacked wavelet can be minimized with a proper prestack mute. The selection of allowable stretch ratio, which is directly related to the mute zone, has traditionally been based on qualitative comparisons of signal-to-noise ratio versus wavelet distortion. The stretch mute zone for data sets with several reflection events is generally conservative so as to retain as many of the long offset traces as possible. The inclusion of long offset traces improves both signal-to-noise on shallow events and the effectiveness of multiple reflection suppression routines. Shallow reflection data are chronically plagued with poorly recorded reflection events due to both limited recording channels and narrow optimum offset windows (Steeples and Miller, 1990; Hunter et al., 1984). Subtle changes in allowable stretch ratio can have drastic effects on the overall quality of reflections from shallow interfaces (Miller et al., 1990).

The significance of allowable stretch is evident from the examination of two reflection data sets targeting interfaces shallower than 50 m. One example data set from Henderson,

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Manuscript received by the Editor July 31, 1991; revised manuscript received February 13, 1992.
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Nevada, possesses three shallow reflections from a depth of less than 20 m, with NMO velocities around 500 m/s. Reflections can be interpreted on a second example data set from Independence, Kansas, at a depth of between 30 and 125 m possessing NMO velocities between 1500 and 2200 m/s. These data sets, from different geologic settings, demonstrate the sensitivity of shallow data quality and accuracy to sample stretch.

DATA PROCESSING

The processing sequence for all CDP stacked data was similar to conventional petroleum exploration processing flows with the main distinctions related to scale and emphasis on event identification after each processing step.

Stacking velocities were determined through qualitative analysis of constant velocity stacks. For nondipping reflections the NMO correction, Δt, is given by,

$$\Delta t = \{x^2/v^2 + t_0^2\}^{1/2} - t_0, \tag{1}$$

where x = source-to-receiver offset, v = stacking velocity, and t_0 = zero-offset reflection time. The mute zone is determined by the percentage of allowable stretch. The stretching relationship for constant stacking velocity is

$$\Delta f/f = \Delta t/t_0, \tag{2}$$

where f is dominant frequency, and Δf is change in frequency (Yilmaz, 1987). For variable stacking velocities, the stretch is proportional to

$$\left(\frac{dt_x}{dt_0}\right)^{-1} - 1, \tag{3}$$

where t_x and t_0 are related by the NMO equation (1).

PITTMAN LATERAL

The Pittman transect in Henderson, Nevada, is a site where polluted waters from an unknown source are moving laterally toward the intake facilities for the Las Vegas water supply. The water table at this site is roughly 5 m deep and is overlain by alluvial material, predominantly poorly sorted sands and clays. Drill data suggest these sands and clays terminate against a semiconsolidated clay bedrock at a depth of 12-30 m.

A 260-m-long CDP line was acquired to determine the location of topographic lows in the bedrock surface. The data were collected using a silenced .30-06 hunting rifle as the energy source and single 100-Hz geophones as receivers. An end-on source/receiver configuration with a source-to-closest-receiver distance of 3.7 m and a 0.6 m shot and receiver station interval were used to collect the data. A 24-channel 12 bit, fixed gain seismograph sampling every 0.25 ms recorded the 125 ms of data on half-inch magnetic tape in a modified SEG-Y format.

Reflection events can be identified on the filtered and scaled shot gathers (Figure 1A). The direct and refracted arrivals were removed from each trace prior to velocity analysis (Figure 1B). The stacking velocity ranges from 500 to 650 m/s for reflections identified between 8 and 22 m deep. The dominant reflection frequency of the filtered field files is more than 175 Hz. The apparent dominant frequency and amplitude of the 42 ms reflection drastically changes as it becomes asymptotic to the refraction. Variations in wavelet properties and arrival geometry of the reflection at approximately 42 ms are observed at source-to-receiver offsets greater than about 10 m. Reflection arrivals recorded at offsets approaching the critical angle can possess inconsistent amplitude and phase characteristics that are a direct result of energy partitioning (Pullan and Hunter, 1985). If not properly removed, reflection arrivals with angle of incidence approaching or beyond critical will distort the dominant frequency and amplitude characteristics of a CDP stacked reflection.

Improper NMO stretch muting can also degrade the spectral and amplitude characteristics of a CDP stacked reflection (Figure 2). The 25 percent stretch limit (Figure 2a) artificially enriched the low-frequency components of shallow stacked reflection wavelets (Figure 3). The inclusion of far offset traces possessing the 42 ms wide-angle reflection (not sufficiently removed with a 25 percent stretch mute) reduced the effectiveness of subsequent CDP processing routines to enhance reflections on the stacked section.

Reduction in the signal-to-noise ratio and slight degradation of the dominant frequency of stacked shallow-reflection wavelets resulted from a 15 percent NMO stretch mute limit (Figure 2c). This severe stretch mute produced less than a 10 percent reduction in the dominant frequencies of both the 42 and 65 ms events between CDP stacked and unstacked reflection wavelets (Figure 3). The severe stretch mute decreased the fold and, in some places, the signal-to-noise ratio of the 42 ms reflection on stacked traces. Extreme

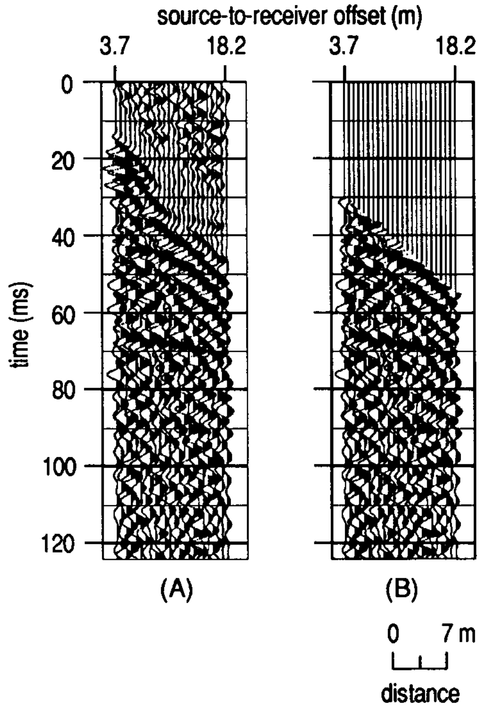

FIG. 1. Shot gathers from Henderson, Nevada, filtered and AGC scaled. The reflections at 42 ms and 65 ms are easily interpretable. Shot gather (B) after application of first-arrival mute.

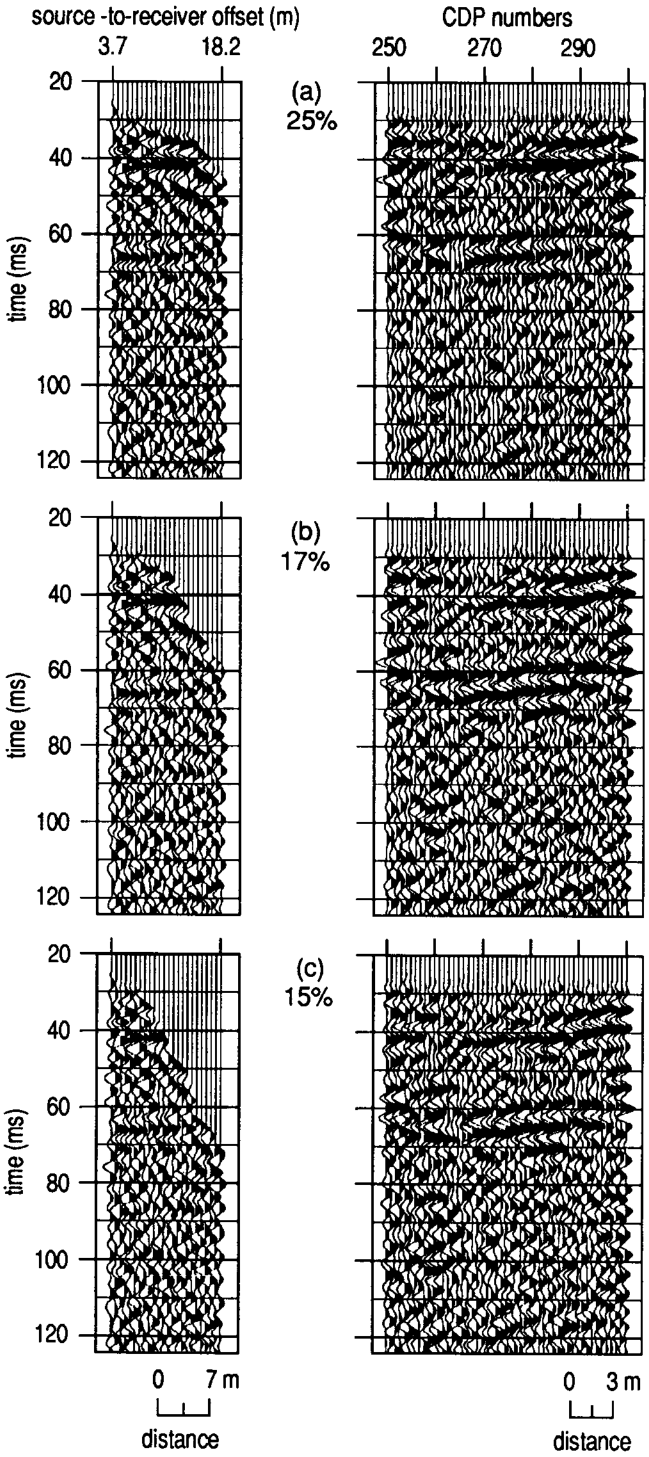

FIG. 2. Comparison of a) 25, b) 17, and c) 15 percent stretch limits on data from Henderson, Nevada. The moved-out field files (same shot gather as Figure 1) and associated CDP stacked sections demonstrate the sensitivity of data quality to stretch limits.

limitations on sample stretch maintained spectral integrity at the expense of reflection coherency and the signal-to-noise ratio of stacked data.

Selection of a reasonable percentage stretch limit on these data is a compromise between signal-to-noise, coherency of stacked event, and dominant frequency (Figure 2b). Variations in signal-to-noise ratio, coherency, amplitude, and frequency are most prevalent on the 60 ms reflection event. A 17 percent stretch mute maximizes the amplitude and coherency of the 60 ms reflection on stacked data. The dominant frequency on the 17 percent stretch mute stack is a compromise between equivalent stacks with 15 and 25 percent stretch mutes. Comparison of NMO-corrected shot gathers suggests a 17 percent stretch mute, which represents the optimum trade-off between coherency and frequency on stacked data from this site.

INDEPENDENCE, KANSAS

A half kilometer seismic profile was acquired near Independence, Kansas, to determine the feasibility of high-resolution seismic-reflection techniques to delineate potential shallow stratigraphic and structural petroleum reserves. The strata of interest are Pennsylvanian-aged interbedded limestones, shales, and sandstones. The near-surface material consists of a weathered shale overlying a shale-limestone sequence starting at a depth of about 3 m.

The acquisition parameters were selected to optimize reflections from 15 to 100 m deep. The data were acquired using a downhole .50-caliber seismic gun, 3-40 Hz geophones in a 1-m array, 2.5 m station spacings, and an end-on source/receiver configuration. The source-to-closest-receiver offsets ranged from 10 to 20 m, dependent on in-field reflection analysis. A 24-channel 15-bit, floating point seismograph was used to record 512 ms records with a sampling interval of 0.2 ms.

Several reflection events can be identified directly from filtered and scaled shot gathers (Figure 4a, b). The relatively broad-band nature of refracted arrivals allows surgical removal without significant alteration of trailing reflection

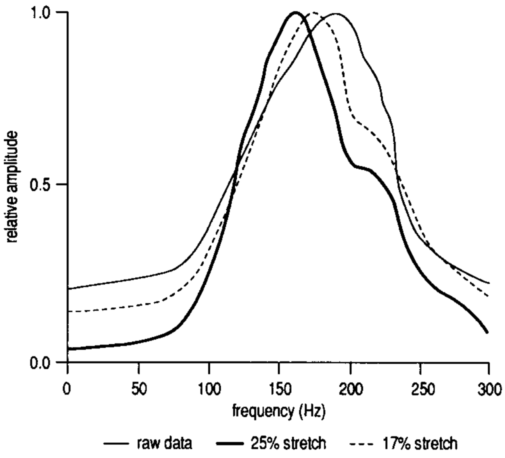

FIG. 3. Normalized spectra of shot gather (Figure 1A) and the same shot gather with 25 percent (Figure 2a) and 17 percent (Figure 2b) stretch mute.

events (Figure 4A, B). An abrupt change in the spectral characteristics of the 33 ms reflection event occurs between traces with source-to-receiver offsets of 30 and 35 m on file A and 22.5 and 27.5 m on file B. These changes in spectral characteristics are consistent with previously modeled and observed phenomena associated with energy partitioning at or near critical reflection angles (Pullan and Hunter, 1985). Due to long source-to-receiver offset effects and interference from the refracted arrivals, attenuation of the 33 ms reflection beyond about 35 m is critical to meaningful interpretation of the data in a CDP stacked format.

Insufficient NMO stretch mute produces pronounced spectral degradation of the 30-ms reflection (Figure 5). Comparison of uncorrected field files (Figure 4A, B) with the NMO-corrected field files (Figure 5) suggests that allowable stretch greater than 50 percent reduces the bandwidth and dominant frequency of the 30-ms reflection on far-offset traces by more than 50 Hz (Figure 6). The apparent dominant reflection frequency is slightly less than 100 Hz when far-offset wavelets of the 30-ms reflection are included in stacked sections. The frequency characteristics of the overstretched, 30-ms reflection wavelet on far traces are directly transferred to the stacked sections. Close offset traces experience significantly less distortion. Far-offset reflections, specifically near critical-angle, are most sensitive to stretch and most clearly display the detrimental effects of incorrect allowable percentage stretch on stacked data.

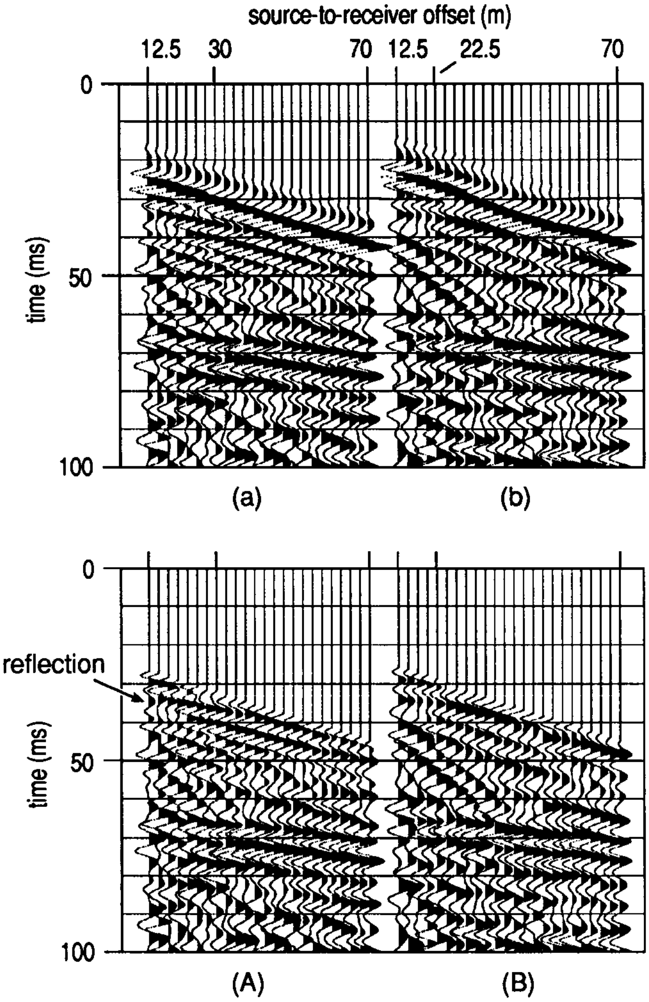

FIG. 4. Shot gathers (a, b) separated by 30 m with digital filter and AGC scale. Shot gathers (A, B) after application of first-arrival mute. The reflection events at 35 and 65 ms are easily interpretable on these field files.

A severe stretch mute removes the 30-ms reflection on far-offset traces allowing the spectral properties of near-offset traces to dominate the stacked wavelet (Figure 5). A drop of less than 15 percent in dominant frequency is observed in the stacked reflection wavelet when the allowable stretch mute is less than 20 percent (Figure 6). Reflections deeper than the 30-ms event have insignificant distortion regardless of selected allowable stretch mute. Stacking only the four or five shallow-reflection wavelets from traces with near-vertical incident raypaths (Figure 5d) produced a 50 percent higher stacked-reflection dominant frequency. The wavelet characteristics of the 30-ms reflection on stacked sections with allowable stretch greater than 50 percent are consistent with stacked refractions. Selective removal of high signal-to-noise ratio reflection information increased the resolution of the CDP stacked section.

A high-frequency event, arriving at approximately 35 ms on near-offset traces, represents a potential interpretation pitfall on stacked data. Assuming hyperbolic moveout, the 35 ms event is clearly of lower velocity than the reflection arriving 5 ms earlier on NMO-corrected field files. For the 35 ms event to be a reflection, a velocity inversion needs to be present in the interval between the 30-ms reflection and the 35-ms event. The interval velocity for the 30- to 35-ms window compared to the interval above 30 ms would decrease by over 80 percent. The 35-ms event appears to be linear and subparallel to the refraction arrival (first arrival), and is probably related to refracted energy. The 35-ms event appears coherent between CDPs 240 and 260 when the data are CDP stacked using a 50 percent or greater allowable stretch. The 35-ms refraction and 30-ms reflection merge at approximately CDP 357 on 50 percent or greater allowable stretch on the CDP stacked section, forming an apparent stratigraphic pinch out. The 35-ms refraction arrival does not appear as a coherent event on CDP stacked sections with an appropriate percentage of allowable stretch.

CONCLUSIONS

Subtle changes in the percentage of allowable NMO stretch can drastically alter the wavelet properties as well as interpretations of CDP stacks. The percentage of allowable stretch for the two data samples presented here seems to be optimized around 17 to 19 percent. Changes of only a few percent can alter the properties of stacked reflections. The percentages of allowable stretch are significantly different for shallow reflection data than default values routinely used during seismic data processing for petroleum exploration.

Improper NMO stretch mute can degrade the spectral and amplitude characteristics of reflection wavelets. Far-offset information, especially near critical-angle reflection information, is most sensitive to stretch and most clearly displays the detrimental effects of incorrect allowable percentage stretch on stacked data. Overstretched wavelets will artifi-

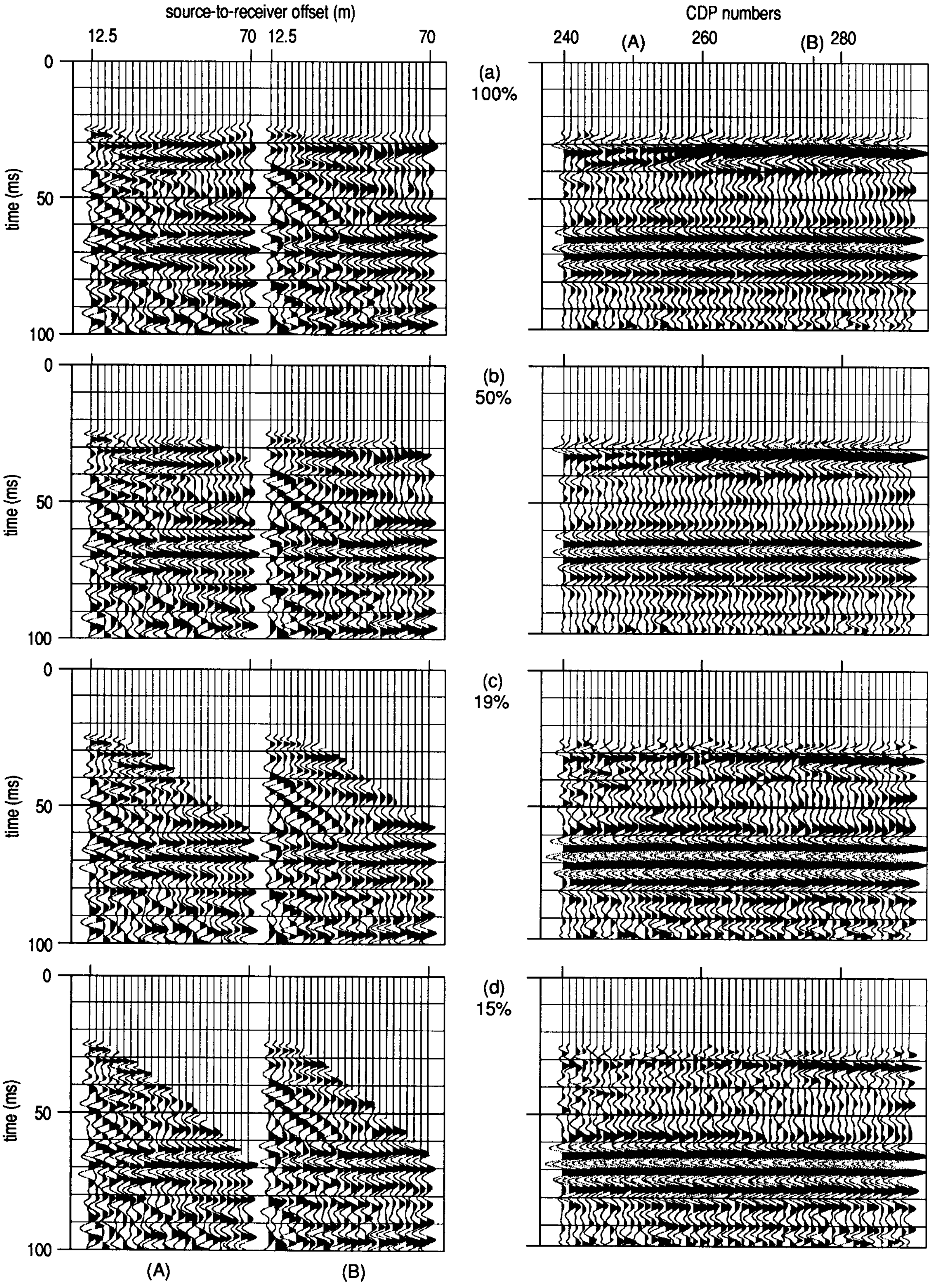

FIG. 5. Comparison for a) 100, b) 50, c) 19, and d) 15 percent stretch limits. The moved-out field files and associated CDP stacked sections demonstrate the sensitivity of data quality and accuracy to stretch limits. Locations of field files (A, B) are shown on CDP stacked sections.

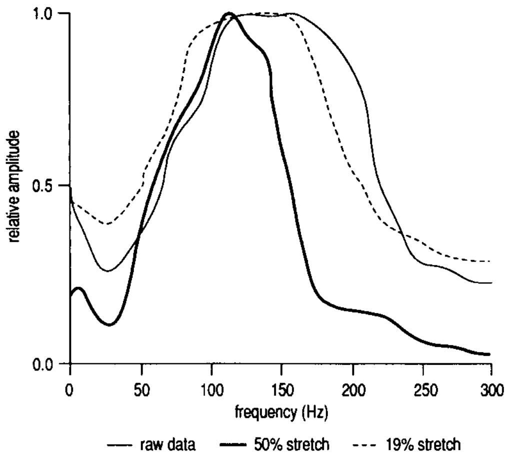

FIG. 6. Normalized spectra of field file (Figure 4a) and the same field file with 50 percent (Figure 5Ab) and 19 percent (Figure 5Ac) stretch mute.

cially enrich the spectra of stacked reflections toward lower frequencies. A stretch mute designed to selectively remove high signal-to-noise reflection information can improve the resolution of CDP stacked data. A correct NMO stretch mute will also stabilize the spectral properties of shallow reflections, allowing effective use of wavelet and multiple suppression routines. The optimum stretch for reflections shallower than about 50 m is generally less than 20 percent and represents a trade-off between signal-to-noise ratio, coherency of stacked event, and dominant frequency.

ACKNOWLEDGMENTS

Thanks goes to Esther Price for her work in manuscript preparation, Brett Bennett for computer assistance, and Pat Acker for the quality graphics. The helpful comments and suggestions from Don Steeples, Rex Buchanan, and Ross Black were greatly appreciated. Associate editor (D. Thompson) and reviewers' (anonymous, Robert Withers, and Arthur Barnes) comments and suggestions helped the overall clarity and quality of this paper. Seismic data displayed in this paper was acquired with support from DOE Grant #DE-FG07-90BC14434 and EPA Contract 68-03-3245.

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