Near-surface velocity gradients and their effect on shallow reflection data

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Summary

Near-surface velocity gradients can be large enough to inhibit normal moveout corrections on a single pass of a complete shallow velocity function during routine shallow seismic reflection processing flows. Stretch artifacts that are the result of inversion and compression within the highest rate of velocity change portion of the shot gather can stack coherently on CMP sections. The constant velocity nature of a single shallow, low velocity reflection wavelet when corrected with a time varying velocity function can result in dramatic distortion of the waveform. Structural variations in the top of the high velocity surface can be sufficiently undersampled spatially even with 2 ft receiver intervals to result in moveout curves on shot gathers with sufficient non-symmetry to inhibit accurate correction to vertical incidence.

Introduction

Contrasts and comparisons between conventional seismic reflection, predominantly used for petroleum exploration, and shallow seismic reflection, which focuses on environmental, engineering, mining, and groundwater problems, consistently suggests reciprocity of methodologies and techniques is not automatic and is more than just a simple relationship of scale (Steeples and Miller, 1990; Miller, 1992; Steeples et al., 1995). This lack of linearity is not surprising when considering the diversity and unique propagation characteristics of source generated noise in the early time portion of a seismogram. Shallow seismic reflection studies have routinely been plagued by overwhelming near-source noise arriving within the optimum time and offset window for most shallow reflecting events. One of the more troublesome and potentially detrimental near-surface problems relates to the occasional extreme contrast in the interval velocity between the vadose zone and the bedrock surface or the piezometric surface (Birkelo et al., 1987; Miller and Xia, 1997). Degradation in frequency content of reflection wavelets when going from shot gathers to CMP stacked sections has been related to insufficiently compensated static, incomplete correction for non-vertical incidence, reflection wavelet changes with source offset, and source/receiver variability (Pullan et al., 1991).

Adjusting reflection wavelets on seismic data for non-vertically incident raypaths is necessary prior to CMP stacking (Mayne, 1962). Since average velocity normally increases with depth, the normal moveout curves (NMO) of a series of reflection events on shot gathers will possess decreasing curvature at a given offset with increasing depth (Yilmaz, 1987). Correcting or flattening these curves to allow enhancement stacking of all reflection wavelets regardless of offset and depth requires a dynamic adjustment be made to each sample. This dynamic adjustment is accomplished through stretching the time separation between individual samples in a fashion consistent with the velocity, depth, and source-receiver offset of a particular wavelet. This stretching process produces artifacts (Buchholtz, 1972; Dunkin and Levin, 1973) and if not accompanied by a very aggressive mute on shallow reflection data occasionally will decrease resolution potential, alter amplitude characteristics, and/or reduce the signal-to-noise ratio (Miller, 1992). The adjustment for NM0 on shallow reflection data is generally complicated by the high frequency nature of the data, low-signal-to-noise, and minimal traces with identifiable reflections at near-source offsets and/or within the optimum reflection window.

The extreme increase in average velocity across the water table surface can be directly attributed to saturation (Elliot and Wiley, 1975). Changes in compressional wave velocities of 30% to 40% have been measured as a result of increases in clay content of 30% (Marion et al., 1992). An increase in compressional wave velocity of almost 500% has been observed on shallow reflection data recorded in a dry unconsolidated sand with a measured piezometric surface of about 9 ft (Birkelo et al., 1987). In settings like this where the average velocity rapidly changes within a very short travel time a 250 Hz reflection wavelet will interfere with any reflection arrival from interfaces less than 20 ft beneath it. Estimations of vertical bed resolution based on l/4 wavelength criteria using a single velocity would be in error in this setting. In the physical setting previously described (Birkelo et al., 1987), if the extreme change in velocity is considered (velocity gradient), 250 Hz data should provide about a 5 ft theoretical vertical resolution (l/4 wavelength), while estimating the resolution potential using only the velocity of the shallow 250 Hz reflection a resolution potential of 1.3 ft would be calculated.

Stacking velocities have traditionally been determined for 2-D reflection surveys using constant velocity stacks, curve fitting to shot gathers, or semblance routines (Yilmaz, 1987). The use of these techniques to determine appropriate stacking velocities for a series of shallow reflecting layers in an area with an extreme vertical velocity gradient will not allow easy discrimination of artifacts in or sufficient insight into the accuracy of resulting stacked sections. The error in the NM0 correction process becomes more obvious as the velocity gradient increases. The error or distortion is the result of defining a time varying velocity function for a reflection wavelet of finite length and constant velocity. Any portion of the wavelet extending above or below a specific time where the stacking velocity of that wavelet is defined will be distorted relative to the vertical rate of change of the time-varying velocity function. The process of generating an accurate stacked waveform in settings with abrupt changes in the near-surface velocity is complicated when relatively small static anomalies (on the order of a couple msec) having lateral extent consistent with or smaller than the length of the spread are present.

Dramatic changes in near-surface velocity are not a concern in all unconsolidated settings where depth to the piezometric surface is at least 10 ft deep (Figure 1). A shot gather from the Mississippi River Valley in Minnesota shows a prominent low velocity reflection with several high frequency, significantly higher velocity reflections at longer offsets and greater times (Figure 1A). Water table at this site is around 20 ft. Contrasted with that is the field file from the Monterey Bay area of California which possesses a water table of about 80 ft and a near-surface geology dominated by dune sand deposits (Figure 1B). The reflection events on this shot gather have very unique curvatures consistent with a well behaved velocity function. The shot gather from near Henderson, Nevada, possesses a couple of very low velocity reflections (Figure 1C). This very difficult reflection area has a water table about 10 ft deep and a sandy near-surface. Very high signal-to-noise ratio shot gathers were recorded in the Atlantic Coastal Plain in eastern North Carolina (Figure 1 D). The water table there is at about 15 ft with the near-surface predominantly alluvial sediments. The extremely high quality reflection events define a very well behaved gradually increasing velocity function. Clearly, of the four shot gathers displayed here, all with similar lithologies and saturation char-

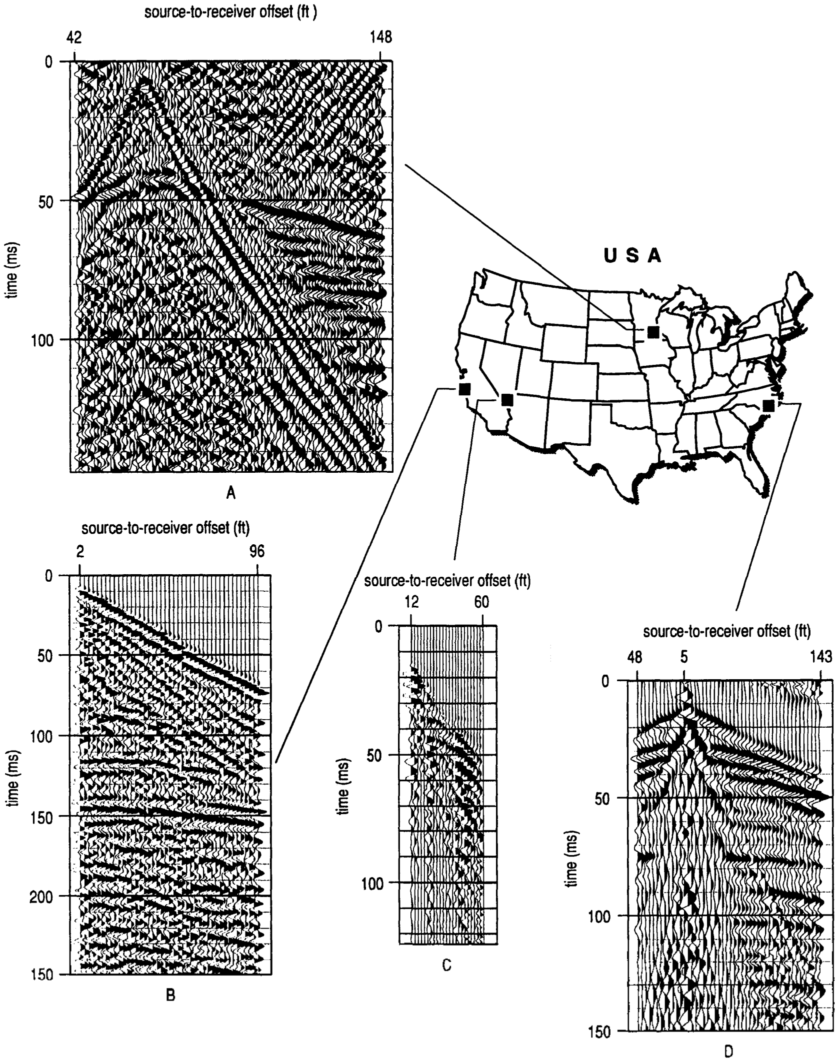

Figure 1. Shot gather from four different unconsolidated near-surface settings. Reflection events and their unique characteristics are interpretable on all records.

acteristics, only the one from Minnesota possesses a dramatic vertical velocity gradient.

Applying the NM0 correction as dictated by a velocity function defining an extremely large velocity gradient will result in degradation of the spectral properties of the reflection wavelet, incorrect apparent zero offset reflection time, and in some cases high frequency artifacts (Figure 2B). Compounding the problems for shallow reflection data sets is the need for a very low allowed percent stretch ratio (Miller, 1992). When a reasonable stretch mute (17%) for shallow reflection data is accompanied by a complete velocity function, all reflection arrivals are muted below the defined high velocity contrast (Figure 2B). If the stretch mute is relaxed to around 100%, the entire suite of shallow reflections are present and moved out, but obvious distortion is evident within the portion of the section possessing the extremely high velocity gradient (Figure 3A). A potentially significant problem with data corrected with this large a stretch mute are the artifacts generated by the inversion and compression of the longer offset wavelets. These artifacts are more evident on shot gathers

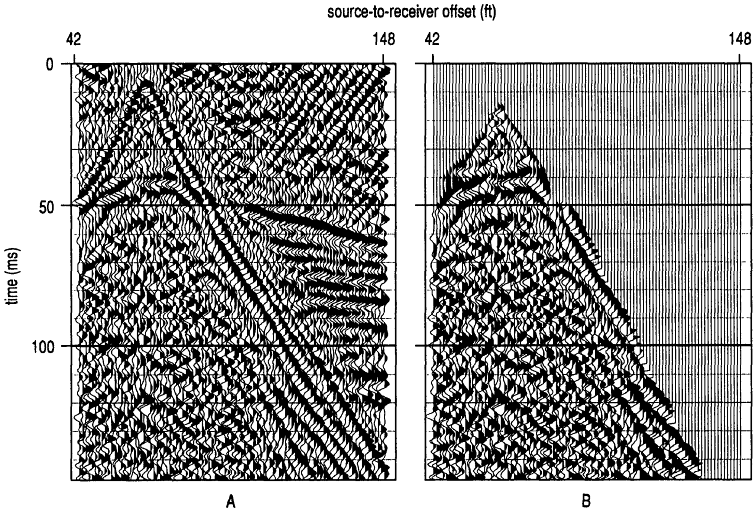

Figure 2. Filtered and scaled shot gather (A) moved out (B) with the complete velocity function and appropriate for the reflections between 40 msec and 120 msec with a 17% stretch mute.

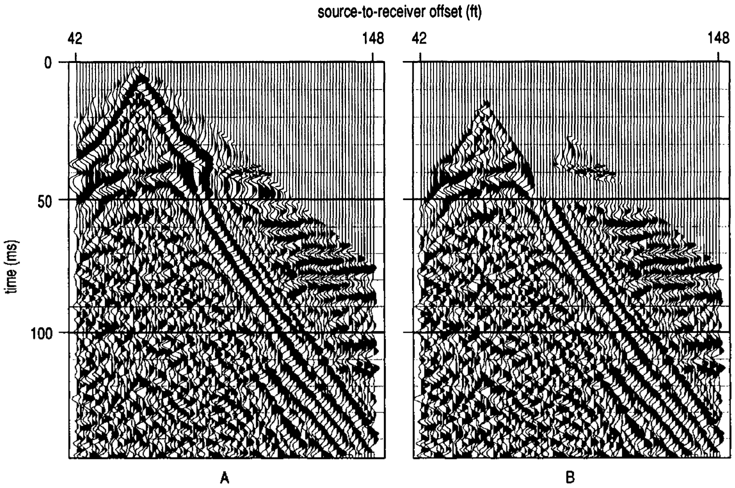

Figure 3. Shot gather with complete velocity function and a 17% stretch mute applied (A) and the same gather and velocity function after the first arrivals are muted (B).

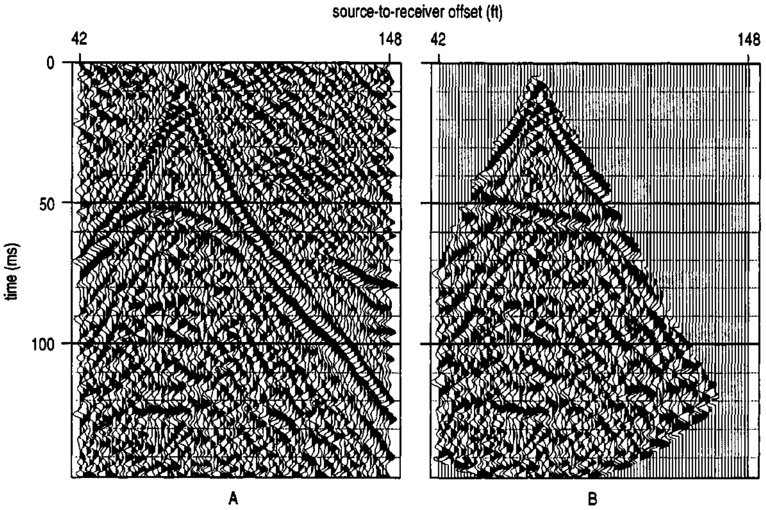

Figure 4. Filtered and scaled shot gather (A) moved out (B) with a single velocity appropriate for the 50 msec reflection with a 17% stretch mute.

that have been first arrival muted (Figure 3B). Structural features or static anomalies on the shallow low velocity reflection curve dramatically alter the effectiveness and completeness of the moveout correction (Figure 4). Using an appropriate velocity function for this curve demonstrates the potential degradation of stacked reflection wavelets in areas with moderate structural features.

Conclusions

Extremely similar unconsolidated near-surface lithologies with alternating sands and clays and relatively shallow water tables can be represented by dramatically different velocity functions. In some settings, due to the extreme velocity contrast at the piezometric surface, the velocity gradient may not allow corrections for non-vertical incidence to be performed on reflections above and below this surface within the same processing pass. Artifacts that could easily go undetected under "normal" processing flows and procedures could result in inaccurate, misleading, and potentially devastating interpretations.

Acknowledgments

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