NEAR-SURFACE SEISMIC METHODS TO ENHANCE REFLECTION EVENTS IN HIGH DESERT REGION

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Abstract

Statics are a concern on most seismic surveys and the key to addressing the statics problem is accurate estimations of near-surface velocity variability. Near-surface variabilities in weathered or sub-weathered layers can cause trace-to-trace time irregularities that adversely affect the ultimate quality and therefore useability of a CMP stacked section. In some dry, unconsolidated geologies velocity analysis can present a significant problem due to considerable overburden thickness with lateral variability and relatively shallow target depths (500-700 m). In this study we explore different methods to enhance NMO corrections by focusing on defining a detailed velocity model for the “weathered” interval. These methods attempt to increase reflection coherency by selecting a velocity function that possess realistic NMO and interval values using unfiltered data. Data for this study was acquired in the high desert of northern Nevada. Vibroseis data were recorded across a 15-150 Hz sweep range using a 240 channel recording system. Attention to variability in the velocity model both laterally and in depth, results in a superior image of the subsurface.

Introduction

Near-surface reflection seismology is an increasingly important tool for both environmental and exploration applications. It is a deductive problem and most commonly approached with little to no well control or specific knowledge about the study area. The target for most near-surface exploration surveys is at or below bedrock and can only be imaged properly with an accurate velocity model in the weathered layer. In areas with a mature topography, the surface profile does not indicate velocity variations in the near surface (Figure 1). Old topography is infilled with sediments over time due to activities in the environment like erosion, rivers, and gravity-flow processes. Fluvial features can vary widely from area to area, with depths from tens to hundreds of meters (Cox, 1999). Seismic energy will disperse in these unconsolidated environments and create static (time shifts) problems that screen the target reflectors.

Figure 1: Generalized cross-section illustrating mature topography, containing weathered layer and four sub-weathered layer: vertical exaggeration is 50x (Thralls and Mossman, 1952).
Velocity analysis is one of the most important steps in near-surface reflection processing. As with most processing steps velocity correction assumes laterally homogenous layers with small velocity gradients with depth. In highly irregular weathered areas, the near-surface velocities change laterally and the reflecting layers are often discontinuous, creating a challenge in high-resolution velocity modeling. Adjustments for NMO on shallow reflection data are generally complicated by low S/N ratio, high static-shift-to-dominant-period ratio, and a minimal number of traces with identifiable reflections with the optimum window (Miller and Xia, 1998).

**Geologic Setting**

Data for this study were collected in a valley of the basin and range region of western U.S.. Unconsolidated fluvial deposits throughout the study area dominate the near-surface geology. The survey was designed as a 2-D common-midpoint reflection (CMP) study with a receiver spacing of 16 ft. and a source spacing of 32 ft.. The east/west CMP line totaled 2.6 miles and was acquired using a rolling fixed-spread with 240 live receivers per shot. The receivers were three Mark Products 10 Hz geophones and the source was an IVI Minivib II generating a 10 s long upsweep from 15-150 Hz. The Geometrics Strataview seismograph recorded for 12 s at a sampling rate of 1 ms.

**Methods**

A typical CMP\(^1\) processing sequence was followed to initially process the data set (Figure 2). Raw vibroseis data was first pre-whitened and cross-correlated with a synthetic sweep to produce a zero-phase wavelet in the shot records, which is not shown in Figure 2. Conventional bandpass filtering, f-k filtering, and automatic gain control (AGC) were then applied to the shot gathers in order suppress noise and enhance reflections. Long-wavelength static shifts due to the change in surface topography (elevation statics) were applied to the data using a sloping datum (Pugin and Pullan, 2000). Elevation changes along the line were small relative to the length of the line, with a 262 ft. change over 2.6 miles.

In the first processing pass a single velocity layer model was used for the normal moveout correction, with an allowable stretch ratio of 100%. The resulting CMP-stacked section had very little coherency in reflection events, most likely due to the oversimplified velocity model and pre-stack filtering (Figure 3\(^2\)). In Figure 3, there is a strong reflecting event at 500 ms around CDP number 2200 that correlates back to shot records. This event represents a target reflector to be enhanced by further velocity analysis.

The frequency band of unprocessed reflections in this data set is relatively low (50-100 Hz), so the data was reprocessed without any pre-stack filtering to bring out higher amplitude reflection events. Most reflections identified in the shot gathers were wide-angle and could not be correlated back to the optimum reflection window. The entire noise cone was also muted to eliminate the air wave and most of the ground roll because reflecting events in the shot gathers did not remain coherent in that zone.

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1 Common midpoint (CMP) and common depth point (CDP) have the same meaning and are interchangeable.

2 The CMP data was split into 4 sections across the total length of the line. The easternmost section is represented in Figure 3 and will be the only section presented in this paper.
Figure 2: CMP processing flow used for these data flow. Pre-stack is any process before CDP stacking.

Figure 3: The first CMP-stacked data using a single velocity layer model (5000 ft/s) and conventional processing.

The highly irregular weathered layers present in this study area create a problem with conventional approaches to velocity analysis (Yilmaz, 2001). NMO velocity and stretch problems are exacerbated by the inherent static problems, which in turn make reflections appear incoherent during velocity picking. Also, without filtering, guided waves and ground roll are more prominent in the record and can constructively stack to be misinterpreted as reflections. To avoid stretching and compression of
the wavelets, picked velocities must have smooth changes and minimal velocity gradients both laterally and in depth. The conventional use of common velocity panels was taken a step further to create common velocity stacks. This method ultimately increases the number of consecutive CDP’s to help the user manually pick reflecting events and optimize the velocity function. The optimum NMO stretch was also tested and found to be ~25%. From these stacked sections, strong events at different velocities are apparent (Figures 4 and 5).

Fourteen constant velocity stacks were created for this segment of the CMP section between 3500 ft/s and 8500 ft/s. Strong events were chosen from 5 common velocity stacks to produce a laterally varying velocity model. The velocity model was then modified iteratively to bring out near-surface and deeper reflectors.

**Figure 4:** Constant velocity stack at 4500 ft/s. Coherent reflecting events as shallow as 200 ms.

**Figure 5:** Constant velocity stack at 7500 ft/s. Coherent reflecting events as deep as 650 ms.
Techniques to Estimate Lateral Velocity Variability

During processing, some techniques were used to estimate the relative lateral variability across the survey line. The first indicator of significant velocity variations and sloping beds were the inconsistency in first arrival slopes across the line. In an isotropic medium with uniform elevation, the direct waves should mirror each other in a shot gather where the source is in the middle of the receiver line (Burger, 1992). Figure 6 is an example of the velocity variability across a receiver length (3840 ft.).

**Figure 6:** A shot gather showing the difference in first-arrival velocity near the source. The refractions on the right side of the source show a velocity of 4542 ft/s, and the refractions on the left show a velocity 3184 ft/s.

Once the shot gathers are sorted into their field geometries, a common-receiver gather can be used to estimate the severity of the static time shifts in the data as function of offset from the source. This is an effective estimate of velocity variability because the common-receiver gathers represent some source to receiver shots as well as their inverse. The reciprocity of a shot should be the same in a laterally homogenous, flat layer scenario. The receiver static shifts were as high as 30 ms at an 82 ft. offset (~5 stations), 40 ms at 145 ft. of offset (~9 stations), and 100 ms at 272 ft. of offset (~17 stations). A time shift of 100 ms is 10% of the total record length and can cause cycle skipping events as low frequency as 10 Hz. This produces significant problems when picking velocities and stacking.

**Discussion**

Conventional processing can be inefficient in areas with significant velocity variations and sloping layers. With very few reliable, coherent reflectors in the processed shot gathers, the difficult problem of velocity analysis becomes even more inconsistent. Pre-stack filtering can push to increase the resolution of the data at the expense of reflection coherency (Figure 3). Once the data were reprocessed without any filtering, strong low-frequency reflections came out. Muting the noise cone also increased the S/N ratio. The velocities in the model range from 3500 ft/s to 7500 ft/s.
Figure 7: CMP-stacked section using the normal-moveout corrections produced by a high-resolution velocity model of the subsurface.

A strong reflection event can still be seen at 500 ms around CMP number 2200, which relates back to the first stack (Figure 2). This event (Figure 2), however, appears to be a high-frequency event with multiples below it. The frequency band left in unfiltered data set improved coherency and amplitude in this event (Figure 7). The layers in the middle of the section appear to lap up on one another, which is consistent with fluvial deposits. There are near-surface static issues yet to be fully resolved that prohibit some of the lower velocity layers from stacking. Improvement in these events is expected with a more complicated near-surface velocity function, which will require an iterative analysis approach with statics.

Figure 8: CMP-stacked section using a velocity model which includes an added velocity of 4500 ft/s at 300 ms between CMP’s 2300 and 2400.
A wide range of reflection events exist in this area (Figure 8). The NMO correction used to create the CMP stack (Figure 8) includes only a single extra velocity from the one used previously (Figure 7). The added velocity, 4500 ft/s at 300 ms between CMP’s 2300 and 2400, brought out a reflecting layer above the other reflections, which seem to represent some kind of braided deposit geometry. The added velocity decreased the coherency, however, in the middle of the stack. Tradeoffs must be made between coherency and resolution, depending on the target of the study.

Conclusions

Static shifts in the data are a result of a laterally inhomogeneous subsurface. Certain processing techniques can highlight and adjust for variability within a spread. A smooth and detailed velocity function increases the coherency of the stacked reflections and therefore the accuracy of interpretation. Velocity analysis that uses a larger number and size of panels clearly helps to define the near-surface NMO function. The specific properties of the velocity model will depend on the target and degree of change in the near-surface.

Conventional pre-stack reflection processing in the near-surface usually includes filtering: either bandpass, f-k or both. This technique is valuable in reducing low-frequency noise like ground roll, or linear events such as refractions and guided waves; therefore, improving the signal to noise of the shot record when very few identifiable reflections are present. However, in sandy, weathered environments the seismic signal is attenuated quickly. For this reason, pre-stack bandpass filtering can be detrimental to accurate intermediate analysis. Lower frequency reflecting events, which can be essential on the final stacked section, help define the velocity function, and with excess filtering to optimize resolution may be filtered out of the shot records.

References


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