EFFECTS OF BINNING PARAMETERS ON LATERAL AND VERTICAL RESOLUTION OF P-S CONVERTED WAVES

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ABSTRACT

Tolerances allowed in the ratio of the P-wave velocity, Vp, to the S-wave velocity, Vs (Vp/VS) ratio and trace dispersion within a common conversion point gather(CCP) dictate the final quality of stacked P-S converted wave sections. These parameters can affect the positioning of reflection events, the signal-to noise ratio, and the lateral and vertical resolution of subsurface images obtained from P-S converted wave data.

Using synthetic and field P-S converted wave data, we evaluate the effects of varying the Vp/Vs ratio and the dispersion within a CCP on the final quality of the stacked sections. The results show that well focused images, in comparison to corresponding P-wave images, may be obtained by the CCP gathering method. The correct positioning of the events, the S/N ratio, and the resolution of the data can be preserved by careful selection of the Vp/Vs ratio and the tolerance in trace dispersion around a central point within a CCP.

INTRODUCTION

P-S converted waves can be used to obtain S-wave information of the subsurface and estimate anisotropy parameters in fractured reservoir studies (Garotta 1987; Kramer and Davis, 1992, Ata et al. 1994). The subsurface point where a P-wave converts to an S-wave is referred to as a conversion point. Figure 1 is an illustration of the conversion point location with respect to a midpoint location for a non-converted wave. Figure 1 shows that for multiplicity stacking, a common-depth-point (CDP) is at midpoint between source and receiver, while, a common conversion-point (CCP) location is asymmetric and skewed toward the receiver. Moreover, the CCP location varies as a function of horizontal offset, depth, and the average Vp/Vs ratio of the medium (Nedlin, 1986).

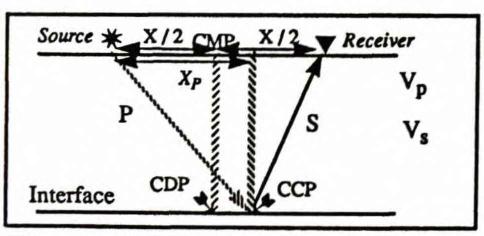

Figure # 1. Geometry of a conversion point

In a homogeneous and isotropic media or where lateral and vertical velocities vary smoothly, an asymptotic approximation of a CCP gather for multiplicity stacking has proven to yield good results (Chung and Corrigan, 1985, Tessmer et al. 1988, Fromm, 19xx, Frazier and Winterstein 1986). The gathering is normally done on a target oriented basis, assuming a constant Vp/VS ratio. On the other hand, in presence of lateral and vertical velocity variations, the problem becomes more complex. The same races that may contribute to a CCP for one horizon, will have a different CCP location for another horizon. As a result, the stacked data may be focused and properly positioned, only, in the vicinity of those CCP's that are confined to the correct Vp/Vs ratio. To overcome this problem, CCP gathers with the appropriate Vp/Vs ratio, down to each horizon of interest, will need to be sorted and stacked individually. Consequently, the correct Vp/VS ratio is a crucial factor to properly focus and position reflection events when stacking CCP gathers of P-S converted waves (Frasier and Winterstein, 1988).

Another parameter that affects the final quality of a stacked P-S section is lateral dispersion inherent within the traces that constitute a single CCP (e.g within a CCP, traces can be dispersed over distance equal to or grater than a CCP spacing). Figure 2 illustrates a possible dispersion patterns within a group of traces that constitutes a CCP gather. Such trace dispersion is more severe in presence of dipping structures and may diminish the lateral resolution of the stacked data. Limiting the traces that may contribute to a CCP gather, around a central point, may alleviate the resolution problem. However, this can introduce a drop in fold (lower signal-to-noise ratio, S/N), and irregular offsets for normal moveout velocity (Vnmo) analysis. As a result, the traces within a CCP must be manipulated to maintain a good S/N ratio, good lateral resolution and sufficient offsets for Vnmo analysis.

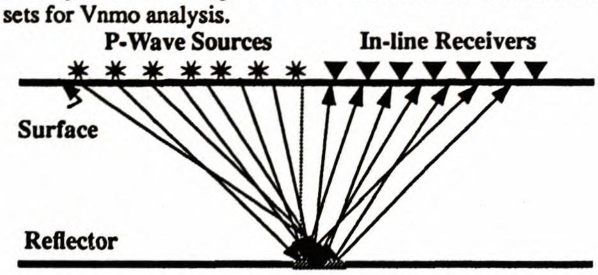

Figure 2. Traces within a CCP gather may be dispersed over a line segment (shaded line) rather than a point (solid circle). Based on field data study, traces within a CCP may spread over a distance grater than the CCP spacing. The dotted line indicates the midpoint location for a non-converted wave.

Tolerances allowed in Vp/VS ratio and trace dispersion within a common conversion point gather(CCP) dictate the final lateral and vertical resolution of the converted wave stacked sections. Using synthetic and field P-S converted wave data, we evaluate the effects of varying the Vp/Vs ratio and the dispersion within a CCP on the final quality of the stacked sections. The results show that well focused images, in comparison to corresponding P-wave images, may be obtained by the CCP gathering. The correct positioning of the events, the S/N ratio, and the resolution of the data can be preserved by careful selection of the Vp/Vs ratio and the tolerance in trace dispersion around a central point within a CCP.

THE BINNING ALGORITHM

Several algorithms have been developed to perform the gathering of converted P-S waves for multiplicity stacking. Such algorithms have been designed to minimize lateral smearing effects and appropriately position the structural events in their correct spatial subsurface locations (Fromm et al. 1985; Tessmer and Behle, 1988, Chung and Corrigan, 1985). In this study, CCP gathers are stacked following the asymptotic approximation of the conversion point as derived by Chung and Corrigan (1985):

$$X_P = \frac{X}{(1 + T_0^S V_S^2 / T_0^P V_P^2)} \quad (1)$$

where, X is the source-to-receiver offset, X_P is the distance from the source to the conversion point projected at the surface, T_0^S, T_0^P, V_S and V_P are respectively, the two way traveltimes and the average velocities to the target horizon of the S and P waves.

The traveltimes can be estimated from brute stacks of the P-P and P-S data, using the relation:

$$T^S = T_c^{(P-S)} - T^P \quad (2)$$

Since T_0^S/T_0^P is equivalent to Vp/Vs, traveltimes or velocities may be used alternately to approximate the CCP gathers, as it can be seen from equation (1).

The validity of this method was evaluated over synthetic data generated from models of fine sand lenses and reef structure (Chung and Corrigan, 1985). The results showed well resolved images of both geological features when data were stacked using CCP gathers. By contrast, images obtained with CMP gathering showed unfocused and smeared events, especially where dipping structures were encountered. Successful applications of similar approaches for CCP gathering have been shown for field data examples (Frasier and Winterstein, 1988; Tessmer et al. 1990).

SYNTHETIC EXAMPLE

The synthetic data were generated with a model derived from geological and physical parameters of the area of study. Using a paraxial ray tracing code in anisotropic media (Gibson et al., 1991), 50 synthetic shotgathers were generated. The source and receiver parameters were set to simulate the geometry used to record the field data which are shown in the following section. As the paraxial ray tracing allows the separation of events, both P-S and P-P events were generated and processed separately. The P-P data were used together with the P-S data to estimate the V_P/V_S ratio to the target horizon.

A near-offset (17 - 600 m) P-S stack section from the synthetic data was used to compare stacked sections obtained, using the full range of offsets (3.6 km), by CMP and CCP gathering methods. The near offset stack section of the P-S synthetic data is shown in Figure 3a. This section simulates a P-P zero offset stack and it is used as a reference to correlate positioning and smearing effects of reflection events obtained by various gathering methods. Figure 3b is the synthetic stack section obtained from CMP gathers, while 3c and 3d are obtained from CCP gathers with Vp/VS of 2.1 (actual) and 3.0 (overestimated), respectively. For CCP gathers, the Vp/Vs was derived from the traveltimes of the P-P and P-S data (equation 2). Comparison of Figure 3a with 3b, 3c and 3d shows signicant differences between the data stacked with the CMP gathers (3b) and the other sections. The fault identified by the arrow is very difficult to resolve in Figure 3b. Even with the simple structure of this model, lateral and vertical smearing effects are significant, and they suggest that stacking P-S converted waves by the CMP method must be avoided. By contrast, the refelection events are in good agreement when comparing Figure 3a and 3c. The agreement pertains to the position of the fault and the similarity of reflection events. However, stacking the data with an overestimated Vp/VS ratio (Figure 3d) introduces mis-positioning (point indicated by the arrow has moved to the right) and smearing effects of events (horizon at about 3.0 s). These results are to be expected, since CCP stacking of P-S waves with an overestimated Vp/VS ratio is equivalent to horizontal averaging of various CDP points in stacking non-converted wave data.

FIELD DATA EXAMPLE

The field data were stacked following the same processing sequence as for the synthetic example. We gathered the data first by CMP, and then by CCP method. The data sorted for CCP stacking were gathered using a V_P/V_S ratio of 2.5 (actual) and 3.0 (overestimated) for the field data. The average V_P/V_S ratio of 2.5 was estimated from the brute stacks of the P-P and P-S data down to the horizon of interest (~3.6 s).

The P-S reflection events are compared to their counterparts on a P-P stacked section. Figure 4 shows: (a) the P-P stack, (b) the stack section obtained with CMP gathers, and (c) and (d) are the CCP stacks obtained with a VP/VS ratios of 2.5 (actual) and 3.0 (overestimated). For this comparison, two events are marked by the dashed lines on the P-P section (Figure 4a). Then, the dashed lines are superimposed over the corresponding horizons to coincide exactly around the center of the section, in 4b. Both markers show that the structure shown by the P-P image has been modified on the P-S stacked with CMP gathers. The differences appear to be largest where indicated by the arrow and at the right-hand side of the section. Similarly, the dashed lines from the P-P section are superimposed on the CMP stacked sections. Both horizons exhibit a good agreement on both the P-P section and P-S section (4c) stacked with CCP gathers (Vp/Vs=2.5). The CCP stack (4d), obtained with the overestimate Vp/Vs ratio (3.0), shows similar, but less pronounced, effects then the section obtained with the CMP stack section (4b). The differnce between the actual VP/VS ratios of the synthetic and the field data (2.1 and 2.5, respectively) is due to the lack of S-wave information above the target horizon (~3000 m).

The P-wave data possess higher resolution and better S/N ratio than all P-S stacks (4c and 4d). The S/N ratio for the P-S converted-wave CMP stack (4b) is higher than that of the CCP stacks. This due to the fact that all traces were allowed to contribute to a P-S converted-wave CMP gather, while traces for a CCP gather were allowed to vary a distance of a half CCP spacing around a central CCP (Figure 2).

Figure 5 shows three CCP stack sections (different line than that shown in Figure 4). All three sections were gathered using a V_P/V_S ratio equal 2.5 given a central distance between CCP locations of 12 m. The central point is defined to be equal to the CCP spacing calculated from equation(1). The three stack sections were generated by allowing traces that varied from 2 to 4 m around the central point to fall within a common bin. A tolerance of 2, 3, and 4m are shown Figure 5a-5c, respectively. Using the small fault indicated by the arrow in figure 5a as a reference point, one can notice a deterioration in the vertical resolution of this feature in Figure 5c. These effects are slightly less in Figure 5b. However the direction of signal-to-noise ratio is inversely proportional to the vertical resolution direction (i.e. resolution diminishes as the S/N ratio improves). Consequently, a tolerance of 3 meters appears to constitute a reasonable compromise between the S/N ratio and the vertical resolution of the data. Although the resolution effects are subtle, resolving small faults as shown in Figure 5a may shed important information on fracture studies using P-S converted waves.

CONCLUSIONS

The trace sorting using asymptotic approximation was used to perform the CCP binning of both synthetic and field data. The results show how artificial effects like mis-positioning of events and lateral smearing after stacking the data could be identified and minimized. We also show the effects of varying the V_p/V_S ratio and the relative offset within the gather to minimize those artificial effects.

The V_p/V_S ratio and the relative offset within the gather are important factors in the final vertical and lateral resolution displayed by the data. The structural simplicity of the study area and that of the model suggests that CMP stacking of P-S data must be avoided. Images obtained with CCP gathering are more reliable than thôse obtained with CMP gathers, even when CCP gathers are binned using an erroneous Vp/Vs ratio. The correct Vp/Vs ratio and control of the dispersion effects within a CCP improve the accurate positioning of subsurface events and allow for better data resolution (both vertical and lateral). These parameters affect the fold of the stacked data and they must be carefully selected to maintain good S/N ratio in the final stack sections.

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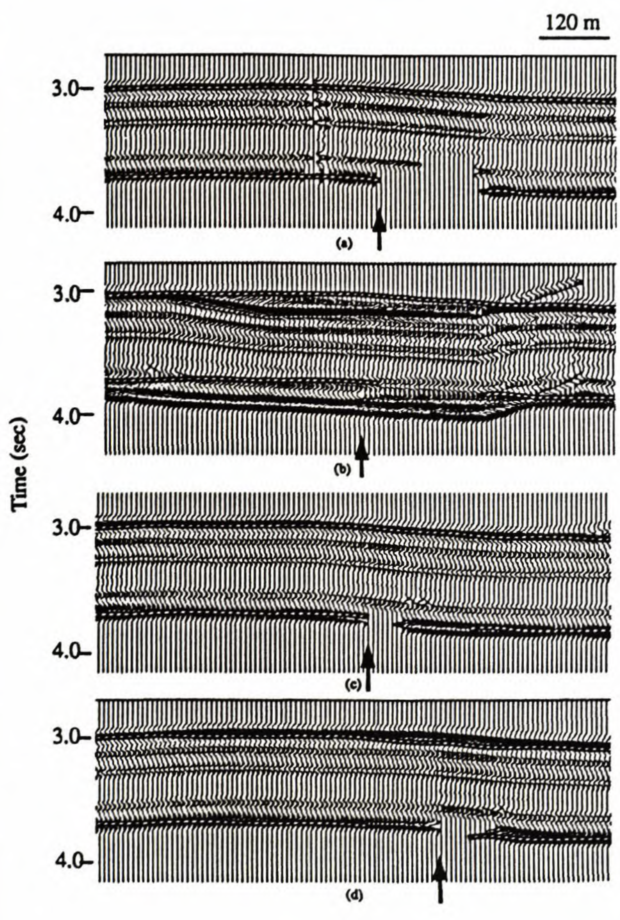

Figure # 3. The synthetic data: a) near offset section , b) P-S converted wave gathered by CMP, c) gathered by CCP wi h a Vp / Vs ratio of 2.1 and c) gathered by CCP with a Vp / Vs of 3.0.

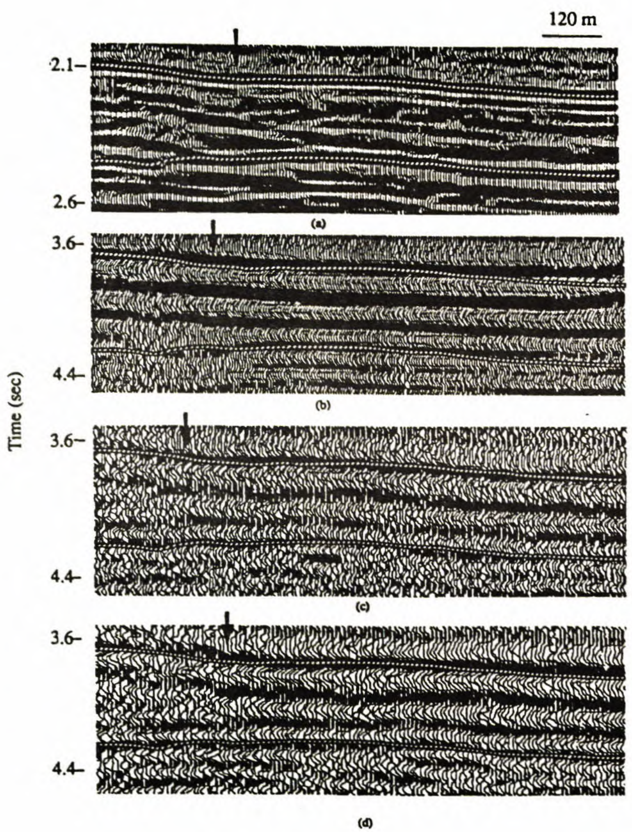

Figure # 4. The field data: a) P-P wave section, b) P-S converted wave gathered by CMP, c) gathered by CCP with a Vp / Vs ratio of 2.5 and c) gathered by CCP with a Vp / Vs of 3.0.

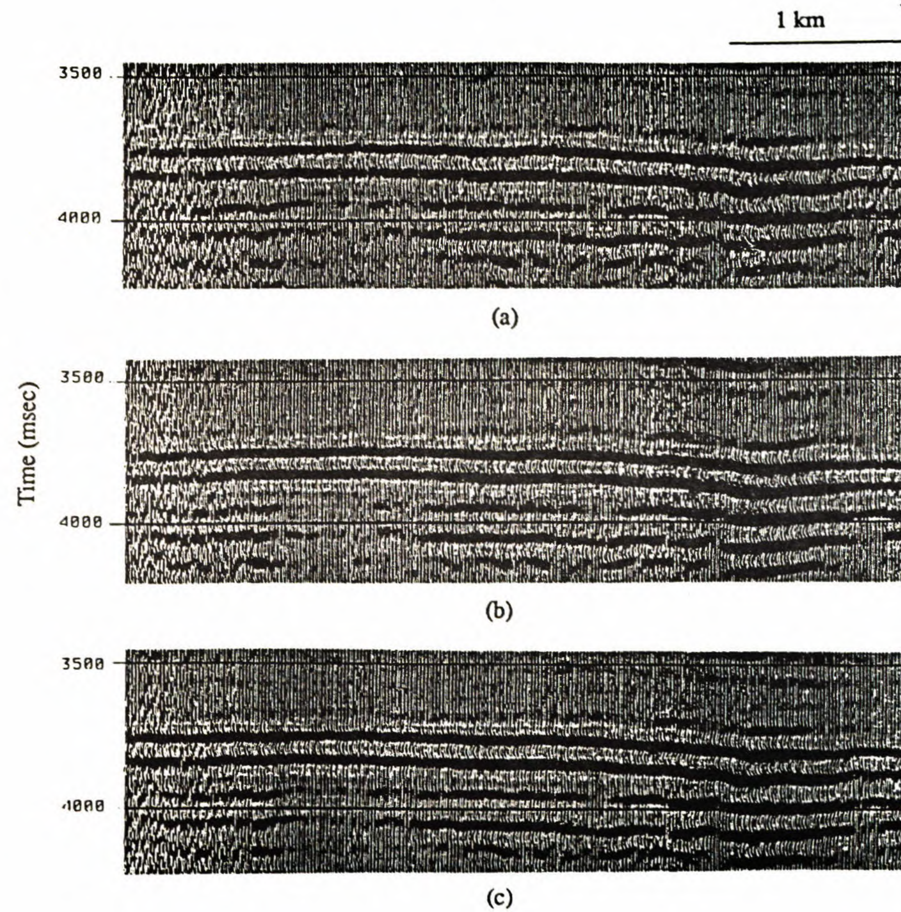

Figure # 5. Field data gathered by CCP with a Vp / Vs ratio of 2.5 : a) with tolerance of 2 meters, b) 3 meters and c) 4 meters.