P-SV stacking charts and binning periodicity

David W.S. Eaton and Donald C. Lawton

ABSTRACT

The use of multicomponent sources and geophones has stimulated an interest in the analysis of mode-converted reflections in the recent literature. Several schemes have been proposed for trace binning according to common-conversion-point (CCP), rather than common-midpoint (CMP), co-ordinates. We demonstrate that application of the asymptotic approximation to CCP sorting leads to a periodic fluctuation in stacking fold and offset range from one location to the next. In the worst-case scenario, certain combinations of acquisition parameters and P- and S-wave velocities lead to empty CCP bins, and consequently dead or missing stacked traces. To facilitate a better intuitive understanding of the relationships between survey parameters and CCP binning, we modify the conventional surface stacking chart by projecting onto it the CCP-bin boundaries. We also propose the use of additional binning parameters in order to improve the distribution of traces into CCP bins.

INTRODUCTION

A surface stacking chart (Sheriff and Geldart, 1982; Yilmaz, 1987) is a convenient graphical representation, in source-receiver space, of the trace geometry for a seismic survey. This display format facilitates examination of the relationships between different orderings of seismic traces, as well as efficient quality control and analysis of large, prestack data volumes (eg. Morgan, 1970; Milkereit, 1989). A common construction for surface stacking charts utilizes a horizontal axis to denote the receiver position (r) and a vertical axis to denote the source position (s) (Figure 1). Each seismic trace is then represented by a point with co-ordinates (r,s). A second set of orthogonal axes marking source-receiver offset (h) and midpoint position (m) is obtained by a clockwise rotation of the r-s axes through 45°. Collections of traces corresponding to common-receiver, common-source, common-offset and common-midpoint (CMP) gathers are aligned along vertical, horizontal 45° and 135° azimuths (θ), respectively (Figure 1). If the source spacing (Δs) is an integer multiple of the group interval (Δr), traces are exactly aligned in these directions (neglecting skids, detours, etc.). The subsurface multiplicity (fold) along lines of constant CMP is then given by the well known expression

$$f_{\text{P-P}} = \frac{n\Delta r}{2\Delta s} \quad , \tag{1}$$

where the number of recording channels (n) is even.

Here we consider waves that have undergone a single mode conversion from P to S upon reflection. Raypaths corresponding to events of this type are asymmetric. In order to stack the data, common-conversion-point (CCP), rather than CMP, sorting techniques are essential (Behle and Dohr, 1985; Chung and Corrigan, 1985;

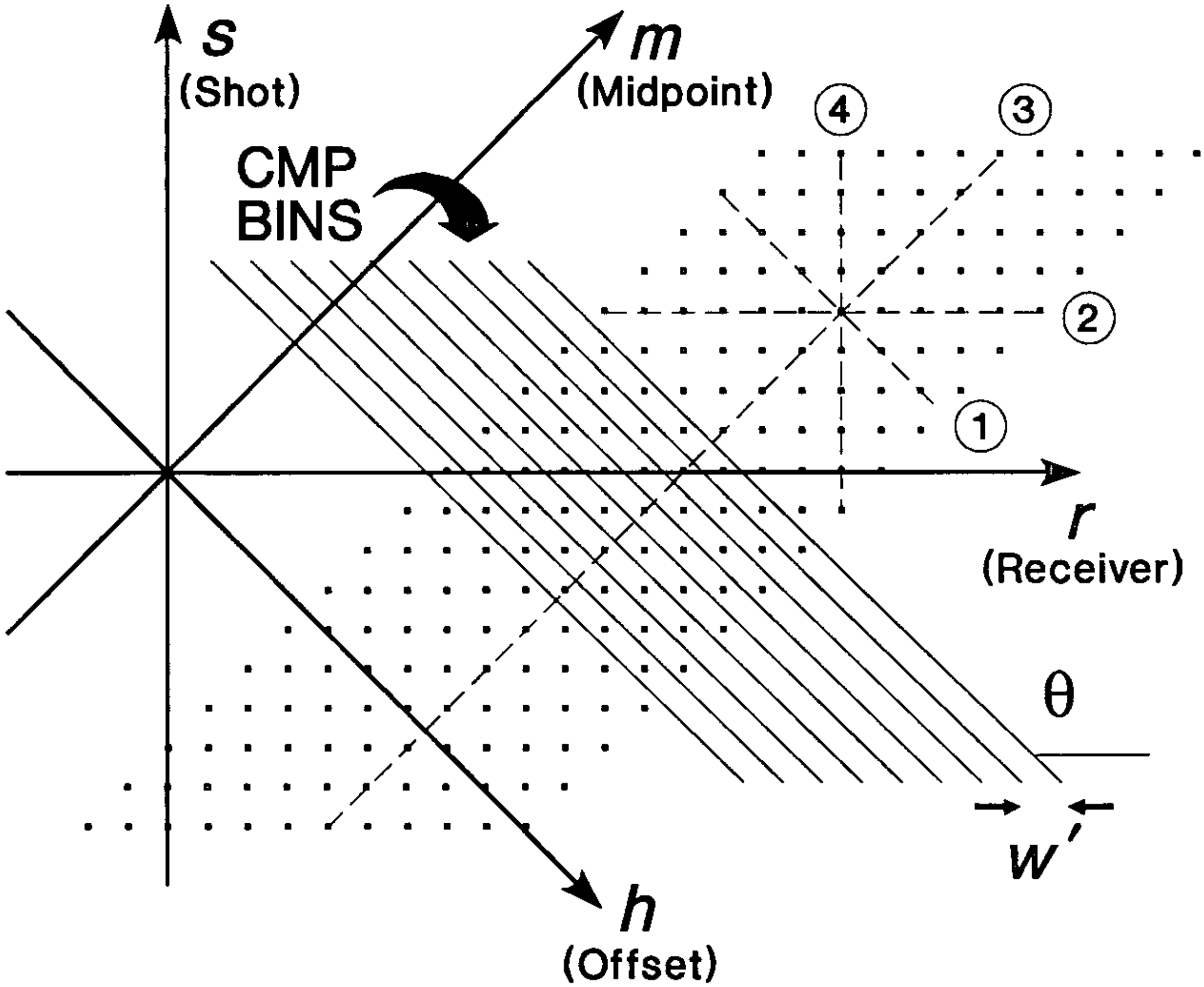


Fig. 1. Hypothetical stacking chart for 12-trace spread with $\Delta s = \Delta r$, showing projected CMP bins. Trace gathers are aligned as follows: 1) common midpoint, 2) common source, 3) common offset and 4) common receiver. Modified from Yilmaz (1987).

Tessmer and Behle, 1988). In previously published examples (eg. Tessmer et al., 1990; Frasier and Winterstein, 1990), converted-wave data have been sorted into CCP gathers that are spatially separated by $\Delta r/2$ in the subsurface. However, the interval between P-S conversion points is, in general, greater than $\Delta r/2$. As a result of this spatial resampling, the fold (as well as the offset range) is not constant, but oscillates around the mean value given by equation (1). This phenomenon is more than a mathematical curiosity; we have observed instances where periodic change in event amplitude and character after stack can be correlated with binning periodicity. In areas where detailed stratigraphic interpretation is required, this behaviour could be mistakenly attributed to poor data quality, residual statics, etc. Thus, it is desirable to gain an understanding of the intrinsic fold and offset patterns that are imposed by certain choices of acquisition and sorting parameters.

CCP AZIMUTH AND BIN DIMENSION

If the source-receiver offset is small relative to the depth of the conversion point, the position of the P-S conversion point (x_c) is given by (Fromm et al., 1985)

$$x_c \approx s + \frac{r - s}{1 + \beta/\alpha} , \tag{2}$$

where β and α are the average S- and P-wave velocities. We refer to equation (2) as the asymptotic approximation, because this estimate of the conversion-point position is the asymptote to the single-layer conversion-point trajectory (Tessmer and Behle, 1988). Rearranging (2) leads to the linear equation

$$s = -(\alpha/\beta)r + (1+\alpha/\beta)x_c \ . \tag{3}$$

Thus lines of constant CCP position have slopes equal to $-\alpha/\beta$ in (r,s) space, as noted by Frasier and Winterstein (1990). However, traces are aligned exactly along lines given by equation (3) only if α is an integer multiple of β. For the more general case, lines of equal CCP position will not necessarily pass through the trace locations on a stacking chart. Thus it becomes necessary to sort traces into bins of finite width, similar in principle to processing 3-D or crooked-line 2-D conventional (P-P) data.

This gathering procedure can be depicted graphically by projecting lines representing the *boundaries* of a bin onto the surface stacking chart, and collecting traces that fall between the two lines. For generality, we assign a bin width w and a bin interval Δx_b as additional parameters (for reasons that are discussed below). In common practice, these parameters are not explicitly considered, and have the values $w=\Delta x_b=\Delta r/2$. Thus, for a bin centred at (subsurface) position x_b, then from equation (3) the position of the boundaries are given by

$$s = -(\alpha/\beta)r + (1 + \alpha/\beta)(x_b \pm w/2) \ . \tag{4}$$

It is convenient to characterize the lines given by equation (4) according to a dimension w' (Figure 1) given by the difference in r-intercepts for the two boundary lines, thus representing a bin width in the r-direction. From equation (4) this gives, after some simplification,

$$w' = (1 + \beta/\alpha)w \ . \tag{5}$$

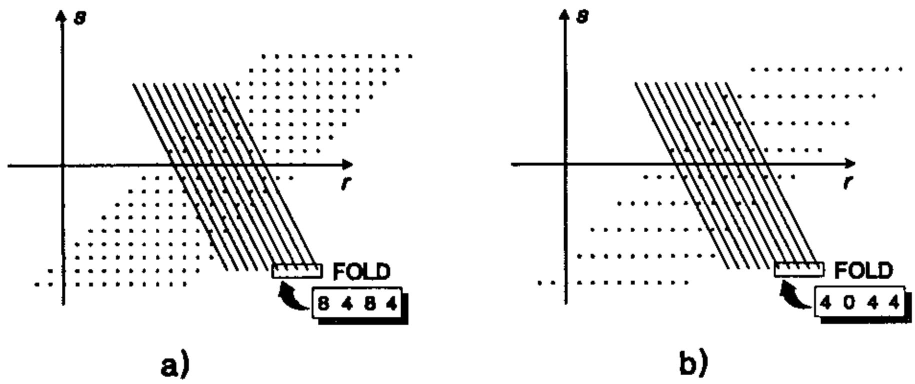


Fig. 2. a) Stacking chart showing projected CCP bins, with α/β = 2.0 and $w=\Delta x_b=\Delta r/2$.
b) Same as a), but with $\Delta s = 2\Delta r$.

For conventional CMP sorting, we set $\beta=\alpha$ in (4) and use $w=\Delta x_b=\Delta r/2$, giving $\theta=135°$ and $w' = \Delta r$, as illustrated in Figure 1. Figure 2a shows a P-SV surface stacking chart for a 12-trace spread with a shot at every station, using α/β = 2.0 and $w=\Delta x_b=\Delta r/2$. In this case $\theta=117°$ and $w'=(3/4)\Delta r$. Note that the fold oscillates between 4 and 8 about the mean value of 6 (from equation (1)). This periodicity in fold becomes more problematic if $\Delta s = 2\Delta r$, in which case every 4th bin contains no traces (for α/β =2.0). A stacking chart illustrating this situation is shown in Figure 2b.

The wavelength of the periodic binning for Figures 3a and 3b is 2 bins and 4 bins, respectively. In general, provided that Δs is an integer multiple of Δx_b, then if some trace with offset h is located within the CCP bin centred at x_b for the $k$threcord, then a trace having the same offset will be located in the bin centred at $x_b+\Delta s$ for the $(k+1)$th record. The sequence of traces collected into each of these two bins after considering all of the possible records will therefore be identical. Hence for CCP binning, the fold is spatially periodic with wavelength in bins, λ_b, given by

$$\lambda_b = \Delta s/\Delta x_b \quad . \tag{6}$$

EXAMPLES

Some examples of periodic oscillations in fold and offset range for CCP gathering are illustrated in Figures 3 to 6, based on the acquisition geometry summarized in Table 1. A similar spread geometry was used to collect a three component data set in central Alberta, Canada, that was acquired using a 240-channel recording system, giving 80 channels for each directional component. The majority of the records were recorded using an end-on spread, with offsets ranging from 180 m to 2550 m.

In Figures 3-5, the trace sorting was carried out in a conventional manner (ie. $w=\Delta x_b=\Delta r/2$). Figure 2a shows the variation in stacking fold for CCP sorting using an end-on spread (configuration A in Table 1), with $\alpha/\beta = 2.0$. As mentioned previously, when $\Delta s/\Delta r = 2$, sorting by this method results in an empty bin at every 4th location. The maximum fold in this case is 14. The corresponding oscillation in source-receiver offset (h) for the near- and far-offset traces in each bin is shown in Figure 3b. Reducing the velocity ratio (α/β) by 0.05 results in similar patterns in fold and offset range (Figure 4), but the fold now oscillates between 8 and 12 because the empty bins are no longer perfectly aligned for each record. Thus, by changing the velocity ratio slightly, the empty-bin problem is eliminated. However, the overall oscillatory nature of the CCP binning remains. The fold and offsets obtained using a split-spread (configuration B in Table 1) and $\alpha/\beta=1.95$ are shown in Figure 5. In this case, the pattern is symmetrical, with fold varying from 8 to 14.

DISCUSSION

There are a number of methods that can be used to obtain a better distribution of traces into CCP bins. First of all, at the survey design stage it is useful to study anticipated binning patterns, either numerically or by means of the PSV stacking chart described above. Fortunately, because the binning is periodic, it is necessary only to calculate the fold and offsets over a single binning wavelength (equation (6)). As a general rule, $\Delta s/\Delta r$ should be chosen so that it is not an integer multiple of the anticipated α/β ratio, since this leads to empty CCP bins when conventional trace sorting is employed. For example, for areas where α/β is typically about 2.0, a source interval that is an even multiple of the group interval should be avoided.

If α is an integer multiple of β, then it is sometimes possible to choose a "natural" bin interval Δx_b such that the fold is constant. For example, if $\Delta s = \Delta r$ as in Figure 2a, a choice of

$$w = \Delta x_b = \frac{\Delta r}{2(1+\beta/\alpha)} \quad , \tag{7}$$

leads to bins having a multiplicity given by

$$f_{P\text{-}SV} = \frac{n}{(1+\alpha/\beta)} \quad . \tag{8}$$

However, this is an inconvenient stacking interval and results in poor stacking fold. Furthermore, comparison between stacked P-P and P-SV data becomes more difficult because of the different trace spacing.

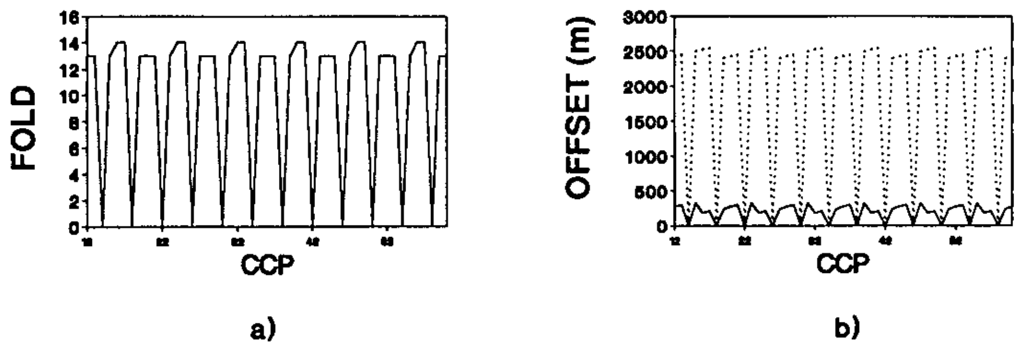


Fig. 3. a) Periodic fold pattern for CCP binning using spread configuration A (Table 1) and $\alpha/\beta = 2.0$. Tick marks show every 10th bin.

b) Near- and far-trace offsets for CCP bins corresponding to 3a. Far offset is dotted line.

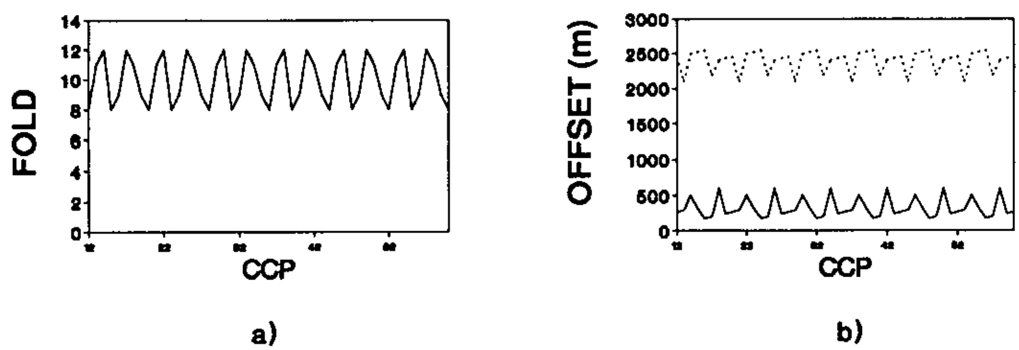
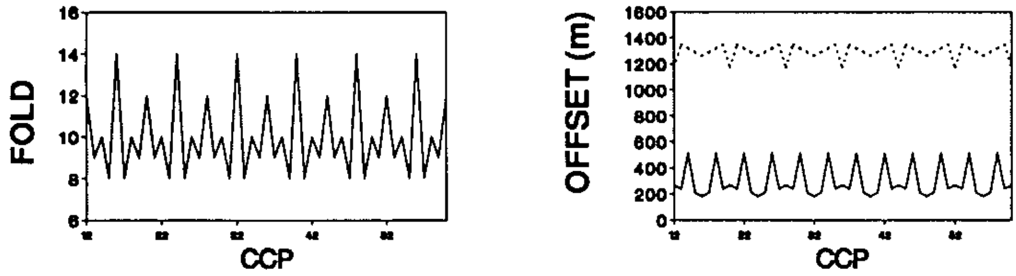


Fig. 4. a) Periodic fold pattern for CCP binning (configuration A), with $\alpha/\beta = 1.95$. Tick marks show every 10th bin.

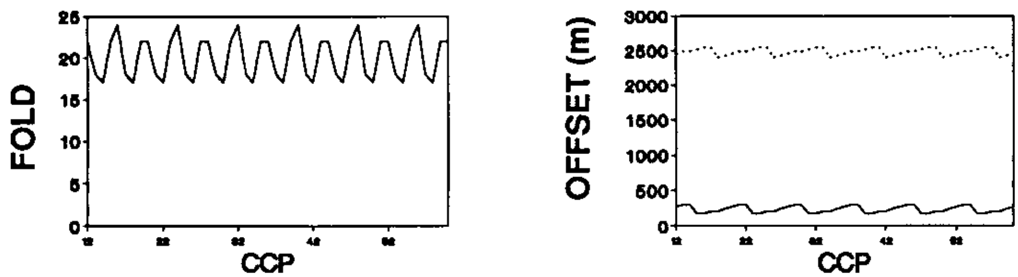
b) Near- and far-trace offsets for CCP bins corresponding to 4a.



a) b)

Fig. 5. a) Periodic fold pattern for CCP binning (configuration B), with $\alpha/\beta = 1.95$. Tick marks show every 10th bin.

b) Near- and far-trace offsets for CCP bins corresponding to 5a.



a) b)

Fig. 6. a) Periodic fold pattern for CCP binning (configuration A), with $\alpha/\beta=1.95$ and $w=\Delta r$.

b) Near- and far-trace offsets for CCP bins corresponding to 6a.

TABLE 1

Spread configurations

	A	B
Spread type	end on	split
Number of channels	80	80
Near offset (m)	180	180
Far offset (m)	2550	1350
Group interval (Δr) (m)	30	30
Source interval (Δs) (m)	120	120

A more general approach that appears to give satisfactory results is to set $w = \Delta r$ (ie. twice the normal bin width) while keeping the bin interval fixed at its normal value, $\Delta x_b = \Delta r/2$. This choice of w results in overlapping bins, and each trace that does not fall exactly onto a line given by equation (3) is collected into the two adjoining bins, rather than only the closest bin. Although this procedure results in trace duplication and a mild trace-mixing effect, the resulting loss in spatial resolution is small relative to the P-SV Fresnel radius (Eaton et al., 1990) and is compensated for by an improvement in stacked data quality. The fold and offset patterns that result for α/β=1.95 and spread configuration A are shown in Figure 6. Note that although little improvement in the relative variation in fold has been achieved, the variation in offset range has been reduced considerably. For example, for data gathered using $w=\Delta r/2$ (Figure 3) the near-offset trace in each gather varies from 180 m to 600 m, whereas in Figure 6 the variation is from 180 m to 300 m.

For simplicity, the preceding analysis is restricted to CCP gathering using the asymptotic formula (equation (2)). Alternatively, an exact single-layer formulation (Tessmer and Behle, 1988) or else ray-tracing, can be used to obtain more accurate conversion-point estimates. By incorporating offset and/or depth dependence, these techniques lead to bins that have curved surfaces in (r,s,z) space, thus considerably complicating the graphical analysis described here.

Finally, it should be noted that many of the considerations discussed here apply also to trace binning for S-P converted-mode data. The appropriate formulae can be obtained from the expressions presented here by interchanging α and β.

CONCLUSIONS

Trace gathering by common-conversion-point for P-SV surveys can be analyzed graphically by plotting projected boundaries of the CCP bins onto the surface stacking chart. Conventional binning parameters ($w=\Delta x_b=\Delta r/2$) for CCP trace sorting lead to patterns in offset and fold that repeat themselves periodically. To avoid empty bins, the source interval should be chosen so as not to be an integer multiple of the group interval multiplied by the anticipated average velocity ratio (α/β) to the depth level of the target horizon. When α is an integer multiple of β, it is sometimes possible to select a "natural" bin interval that produces a constant fold, analagous to CMP sorting. However, the resulting fold coverage is poor, and the trace spacing differs from P-P data. By using a bin width (w) equal to Δr rather than $\Delta r/2$, a better distribution of traces into CCP bins can be obtained, while retaining a normal stacked trace spacing ($\Delta r/2$). The penalty in terms of loss in spatial resolution is small relative to the P-SV Fresnel radius.

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