Optimum bin size for converted-wave 3-D asymptotic mapping

Don C. Lawton

ABSTRACT

A program has been developed to generate fold maps for converted waves recorded in multicomponent 3-D seismic surveys. The asymptotic conversion point is assumed for computing subsurface multiplicity. When a conventional common-midpoint bin size of half the receiver interval ($\Delta r/2$) is used, the fold distribution is highly variable and empty rows of bins parallel to the shot lines may result for the case when $Vp/Vs = 2$ and the shot line spacing is an even integer multiple of Δr. Overlapping adjacent bins removes the empty bin problem but does not necessarily result in a smooth fold distribution. The optimum bin size for 3-D converted wave data is $\Delta r/(1 + Vs/Vp)$. Asymptotic binning using this bin dimension was found to produce a smooth fold distribution which is relatively insensitive to Vp/Vs.

INTRODUCTION

The acquisition design and data processing flow for multicomponent, 3-D reflection seismic programs, particularly those which focus on converted waves (*P-SV*), are still in early development. In this paper, we examine binning strategies for 3-D converted-wave data and discuss possible implications for survey design. An asymptotic binning scheme is devised which minimises undesirable short-wavelength variations in subsurface multiplicity (fold) without the need to mix traces between adjacent bins. Relatively constant fold across the survey area is critical for robust post-stack amplitude mapping as well as for pre-stack amplitude versus offset (AVO analysis, particularly for evaluating azimuthal dependence.

Converted-wave raypaths are not symmetric and the conversion point alway lies on the receiver side of the midpoint. When stacking this type of data, common-conversion-point (CCP) rather than common-mid-point (CMP) techniques are required, such as asymptotic (Behle and Dohr, 1985; Fromm et al., 1985), single depth (Tessmer and Behle, 1988; Tessmer et al., 1990), depth-variant CCP mapping (Eaton et al, 1990; Stewart, 1991), and converted-wave DMO (Harrison, 1992). For simplicity, the present analysis will consider only the asymptotic approach in order to provide an initial insight into the problem and to provide a basis from which a more sophisticated approach can be developed, such as that proposed by Larson et al. (this volume).

CCP SORTING

The asymptotic CCP, x_c, is given by the following relationship (Fromm et al., 1985):

$$x_c = s + \frac{r - s}{1 + \frac{V_s}{V_p}} \qquad (1)$$

where *Vs* and *Vp* are the average *S*- and *P*-wave velocities, *s* is the source position and *r* is the receiver position. This position of the CCP is the asymptote to the single layer CP trajectory in the limit of a small offset-to-depth ratio (Tessmer and Behle, 1988).

In previous studies involving 2-D converted-wave data (e.g. Frasier and Winterstein, 1990; Nazar and Lawton, 1993), CCP gathers have been sorted at a spatial interval equal to half the receiver interval; i.e. equivalent to the CMP interval used for gathering conventional *P-P* data. Eaton and Lawton (1992) analysed *P-SV* stacking charts and showed that when the CMP gathering interval is used, the fold is not constant, but oscillates about a mean value equal to the CMP fold for equivalent *P-P* gathers. The spatial perturbation in fold can, in fact, be severe. Eaton and Lawton (1992) found that empty gathers occur ar regular intervals if the source interval is an integer multiple of the receiver interval multiplied by the velocity ratio (*Vp/Vs*). For example, if the source interval is twice the receiver interval and *Vp/Vs* = 2, then every 4th stacked trace will be empty.

In 3-D surveys, we might anticipate a similar periodicity in fold in the receiver line direction if the shot line spacing is an integer multiple of the receiver spacing, and perhaps also if the receiver line spacing is an integer multiple of the source spacing. These possibilities were examined by developing a program to produce asymptotic CCP fold maps for 3-D surveys with various source and receiver geometries. Fold maps from single and crossed 3-C receiver lines within a 3-D patch were examined, as well as fold maps for full 3-Dx3-C surveys. In all of the examples displayed in this paper, a common shot and geophone separation of 50 m was used, and a maximum source-receiver offset of 800 m was permitted for each shot. A constant ratio *Vp/Vs* = 2.0 was assumed for all examples except those in Figure 9.

Single receiver line

Figure 1 shows *P-P* and *P-SV* fold maps for a single 3-C receiver line (25 geophones) laid orthogonally to the shot line direction. The shot line spacing was 4 receiver intervals (200 m). The fold maps in Figure 1 were both created using CMP binning (i.e. 25 m x 25 m bins). For *P-P* data (Figure 1a), the fold pattern follows the expected behaviour, with a constant subsurface multiplicity of 8 within the central part of the survey area. The fold pattern parallels the shot line direction. In comparison, the fold distribution in the CCP map is very irregular, with every 4th bin in the receiver line direction being empty. The fold in the shot line direction also oscillates significantly and the subsurface coverage is more proximal to the receiver line than it is in the *P-P* map.

Eaton and Lawton (1992) showed that the empty bin problem could be reduced by making the shot interval an odd integer multiple of the receiver interval. Figure 2a shows the CCP fold map for the same geometry as that used for Figure 1 except that the shot line interval has been increased to 5 receiver intervals. The empty bins over the central part of the survey area have been eliminated, but the fold is still highly oscillatory in both the shot line and receiver line directions.

The simplest solution to the empty bin and irregular fold patterns shown in Figures 1b and 2a might be to overlap adjacent bins in both shot and receiver directions. This effectively is a mild form of trace mixing between adjacent bins.

Figure 2b shows the fold map for the same acquisition geometry used to generate Figure 1b, except that adjacent bins have been overlapped by 25% when computing the stacking fold. Testing showed that the relationship between fold and mixing ratio is definitely non-linear and it was very difficult to obtain an even fold distribution in the mixed output. Note that after mixing, the empty bins in Figure 1a now have the highest fold. Clearly, subsurface binning using the CMP binning dimension is inappropriate for converted-wave data and a new binning strategy is required.

Optimum CCP binning

A preferred approach to P-SV binning a based on the fundamental separation of conversion points in the subsurface. This is easily calculated by considering the raypaths to two adjacent receivers (r_1 and r_2) from a common shot (s). From equation (1), the separation of conversion points, Δx_c is given by:

$$\Delta x_c = \frac{(r_1 - s) - (r_2 - s)}{\left(1 + \frac{V_s}{V_p}\right)}$$

$$= \frac{\Delta r}{\left(1 + \frac{V_s}{V_p}\right)} \qquad (2)$$

If shots are coincident with receiver locations and placed at an integer multiple of the receiver interval, then the preferred optimum CCP bin dimension is given by equation (2). Note that the regular CMP binning dimension of $\Delta r/2$ is obtained by the degenerate case of $Vp/Vs = 1$. For the case when $Vp/Vs = 2$, the CCP bin dimension would be $2\Delta r/3$.

Figure 3b shows the fold map for the single receiver line geometry when the preferred CCP bin dimension (33.3 m for $Vp/Vs = 2$ and $\Delta r = 50$ m). Clearly the fold pattern is more regular when the CCP bin dimension is used compared to the CMP bin dimension (Figure 3a). The higher fold row along the bottom of the coverage map is caused by

In the CREWES Project, we have encouraged the acquisition of a single line of 3-C receivers during a conventional 3-D survey. One consideration is whether it the preferential direction of the 3-C line should be perpendicular or parallel to the shot lines. If the latter geometry is chosen, then the line should be placed along a shot line in order that 2-D *P-SV* section can be obtained from along this line. Figure 4 shows fold maps generated for the case of a single receiver line along the middle shot line of the survey area. As predicted, the fold pattern is more regular when the optimum CCP bin interval is used (Figure 4b) than when the CMP bin interval is used (Figure 4a). The processed data in this acquisition scenario could be envisioned as parallel 2-Dx3-C lines recorded with different source-receiver azimuths.

Crossed receiver lines

The fold distribution for crossed receiver lines through the centre of the survey is shown in Figure 5. Again, binning based on the CMP bin dimension results in an irregular fold distribution (Figure 5a) whereas that based on the CCP bin dimension is more uniform (Figure 5b). This type of survey design would provide a low-fold swath parallel to the receiver line and nested, higher-fold lines parallel to the shot lines.

Shot and receiver grid

The ultimate goal in multicomponent seismic acquisition is to obtain full 3-D coverage with 3-C geophones. At present, the CREWES Project is directing its interests toward 3-Dx3-C surveys using a conventional P-wave source (explosives or vertical vibrator) rather than full 9-C recording. The following displays are fold maps for isotropic 3-D *P-SV* data, assuming that for each trace within each bin, the horizontal components have been rotated into the appropriate source-receiver plane (Lane and Lawton, this volume).

Figure 6 shows *P-P* and *P-SV* fold maps for a grid of 5 receiver lines and 7 shot lines, with the separation of both shot and receiver line being 4 group intervals (200 m). Both maps were produced using the CMP bin dimension (25 m) and Vp/Vs = 2. It is clear that the observations about fold irregularity and empty bins noted from Figure 1b (single receiver line) are also evident in the full 3-D survey. The empty bins are eliminated if the shot line interval is increased to 5 group intervals (Figure 7a) but the high frequency variation in fold persists. A much smoother fold pattern is produced if the optimum CCP bin dimension (33.4 m) is used (Figure 7b) rather than the CMP bin dimension. A slightly better fold distribution is produced for both bin sizes if the receiver line spacing is also reduced to 3; i.e. an odd integer multiple of the group interval (Figure 8).

All of the previous examples used the same ratio $Vp/Vs = 2$. The sensitivity of the optimum CCP bin size to variations in Vp/Vs was also tested. In Figure 9, fold maps are displayed for the same acquisition geometry as in Figure 8 but using Vp/Vs = 1.75 (Figure 9a) and $Vp/Vs = 2.50$ (Figure 9b). The bin dimensions in these examples were 31.8 x 31.8 m and 35.7 x 35.7 m respectively. Both of the fold maps in Figure 9 indicate that the optimum CCP bin dimension is robust in terms of maintaining an even fold distribution.

DISCUSSION

The examples in this paper have demonstrated that, for asymptotic binning of 3-D *P-SV* data, a smoother subsurface fold distribution can be obtained by using the optimum CCP bin size rather than the standard CMP bin size. This approach is robust and is preferable to other smoothing processes, such as overlapping adjacent bins, but it does require *a priori* information about Vp/Vs. The optimum CCP bin size is larger than the CMP bin size. Conventional *P-P* fold maps can also be produced using this algorithm simply by using $Vp/Vs = 1$.

The concept is currently being further developed for depth-variant mapping of 3-D *P-SV* data and will be also be extended to provide maps of azimuth and offset for these types of data.

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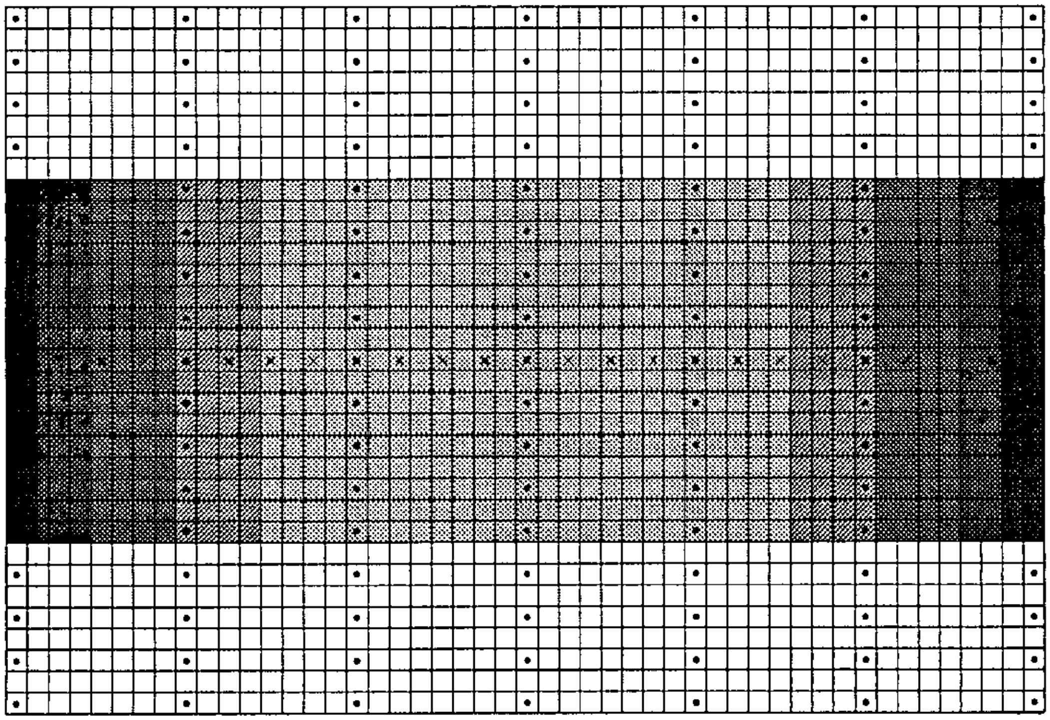
(a)



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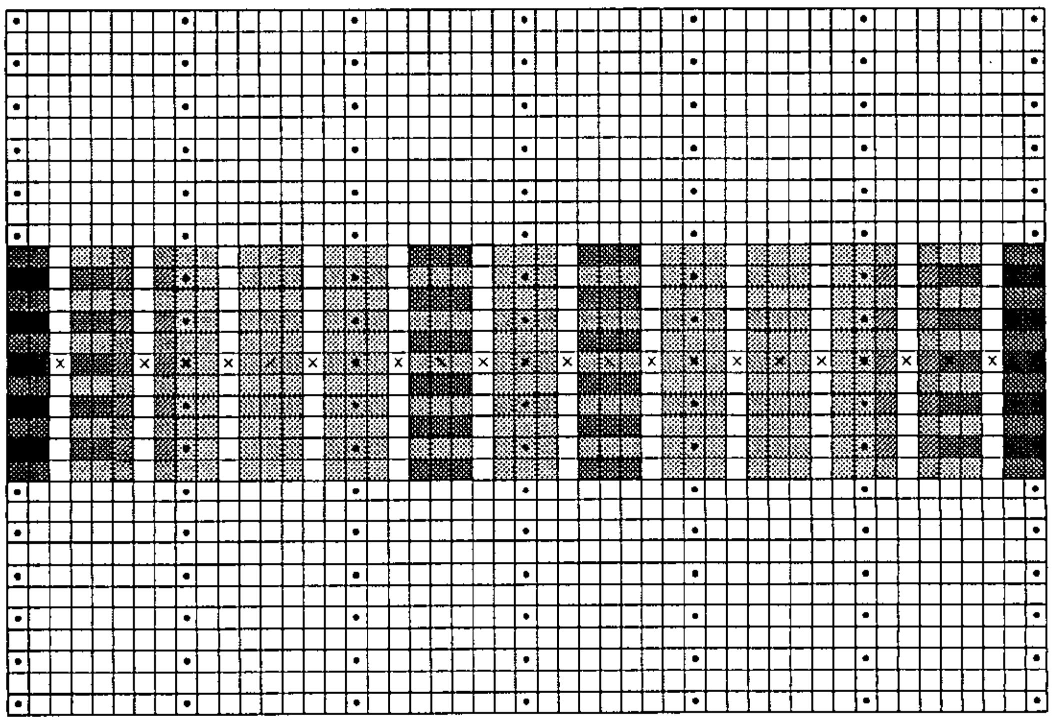


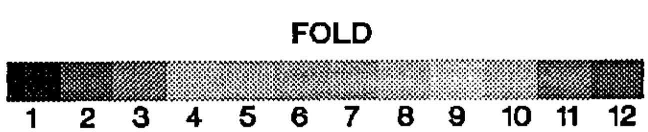


FIG. 1 (a) CMP fold map for a single receiver line (*P-P* data) using a bin size equal to half the receiver and shot interval (CMP bin size). Dots are shotpoints and crosses are 3-component geophone locations; receiver line is orthogonal to the shot lines; (b) CCP fold map (*P-SV* data) using asymptotic binning for the same acquisition geometry as in (a) and a CMP bin size.

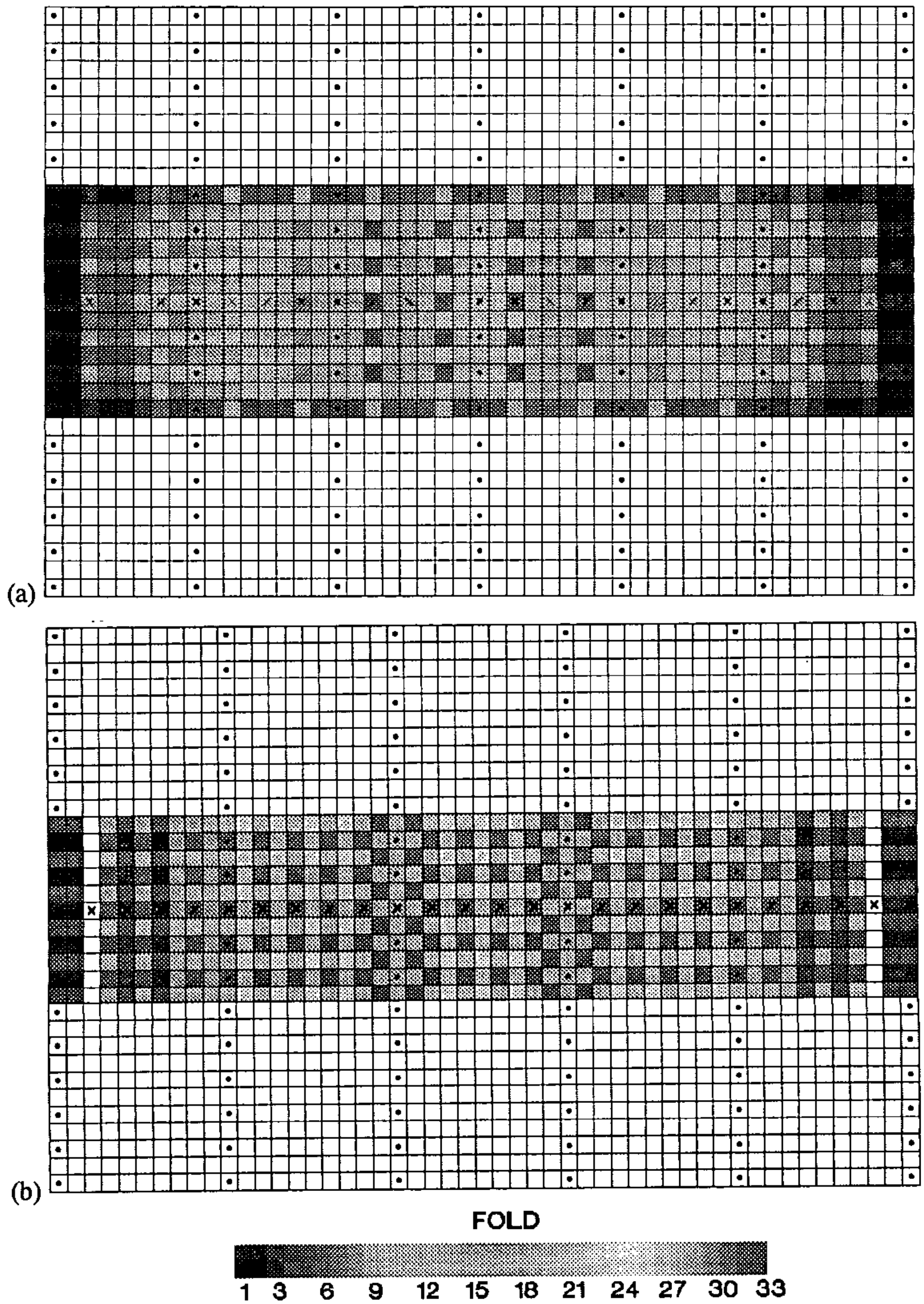


FIG. 2 (a) CCP fold map with a 25% overlap between adjacent bins, using the same acquisition geometry as Figure 1; (b) CCP fold map with the shot line interval increased to 5 receiver intervals.

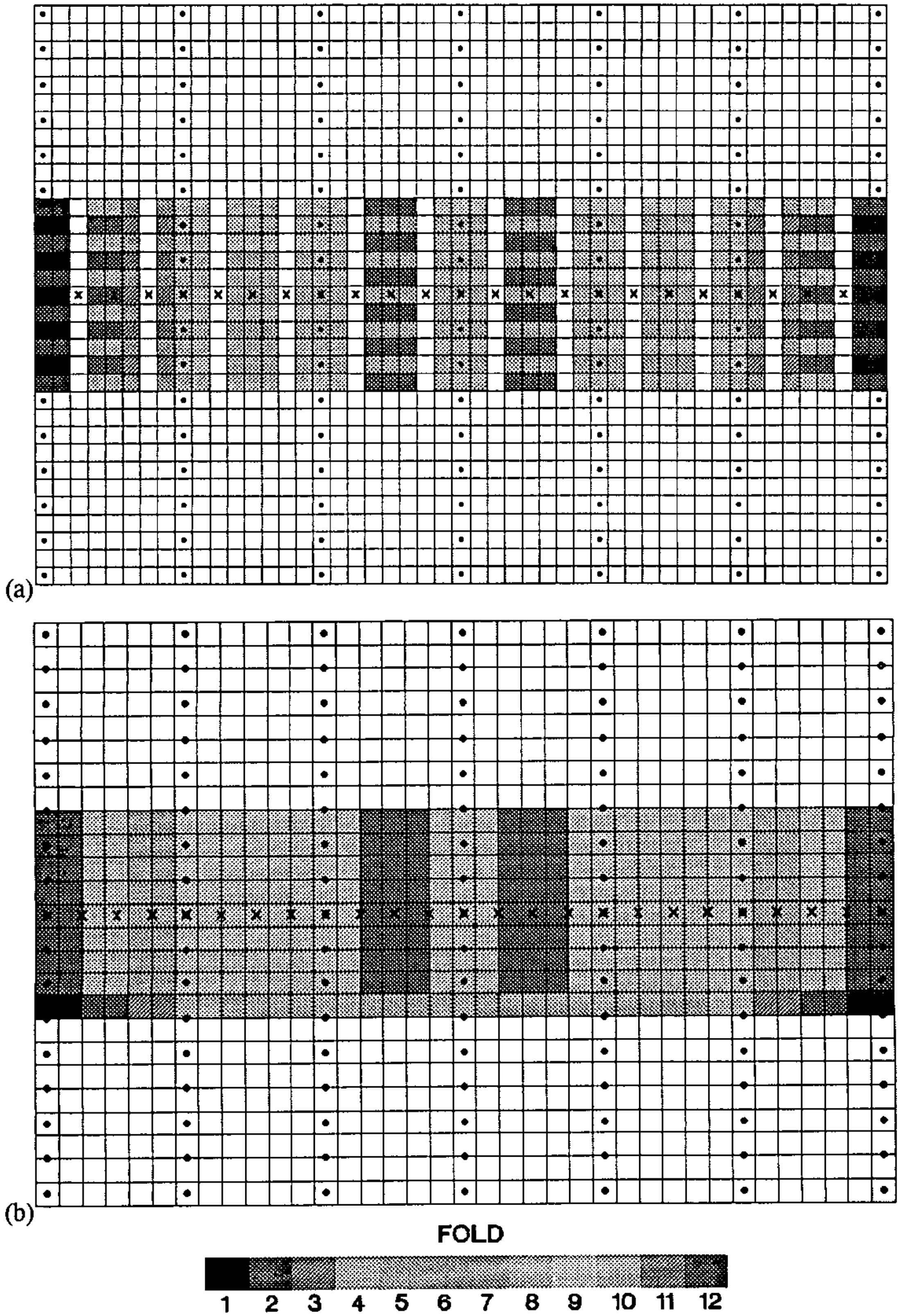


FIG. 3 (a) CCP fold map for a single receiver line using a CMP bin size; (b) CCP fold map for the same data as in (a) but using the optimum CCP bin size.

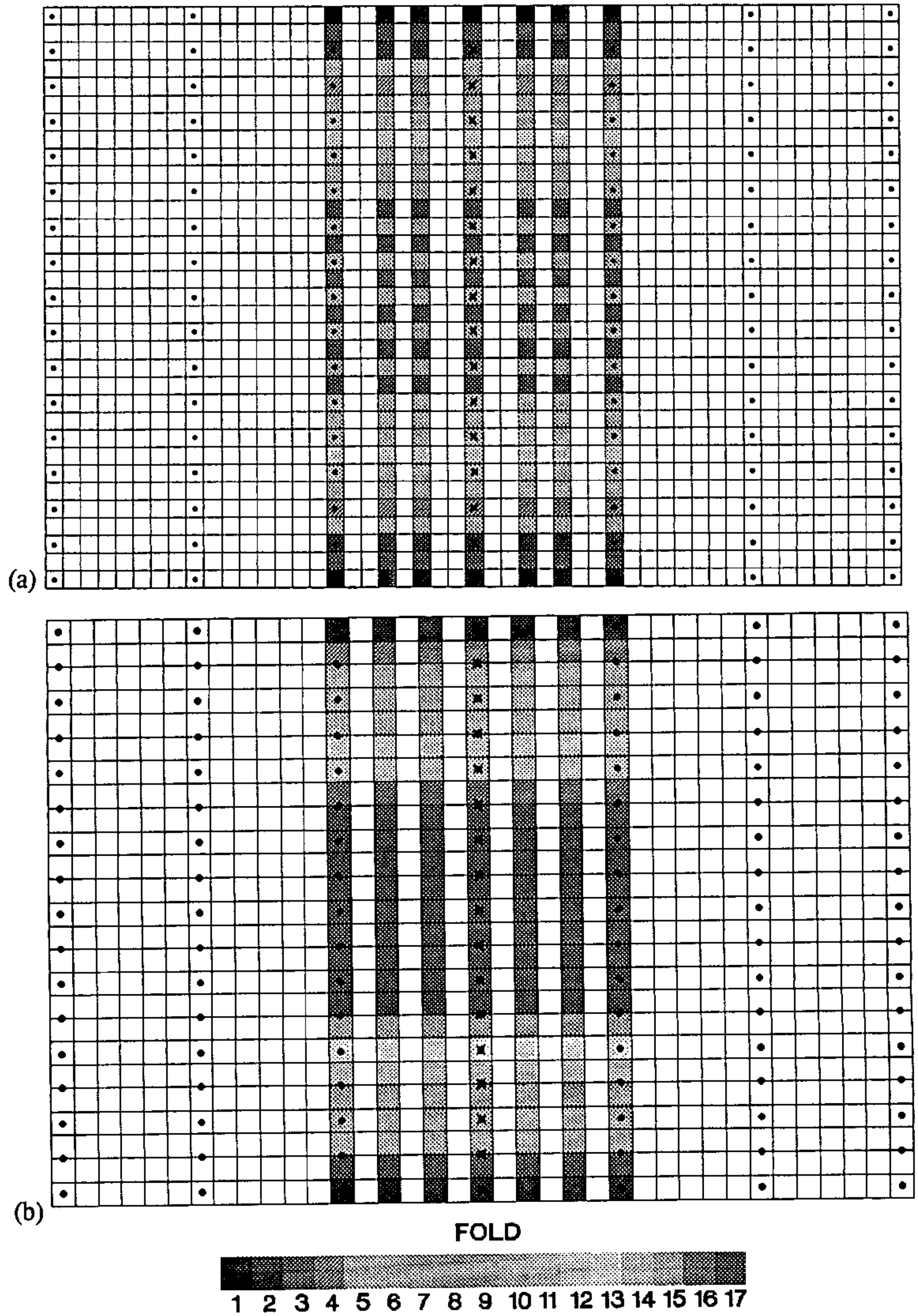


FIG. 4 (a) CCP fold map for a single receiver line using a CMP bin size; receiver line coincides with the central shot line; (b) CCP fold map for the same data as in (a) but using the optimum CCP bin size.

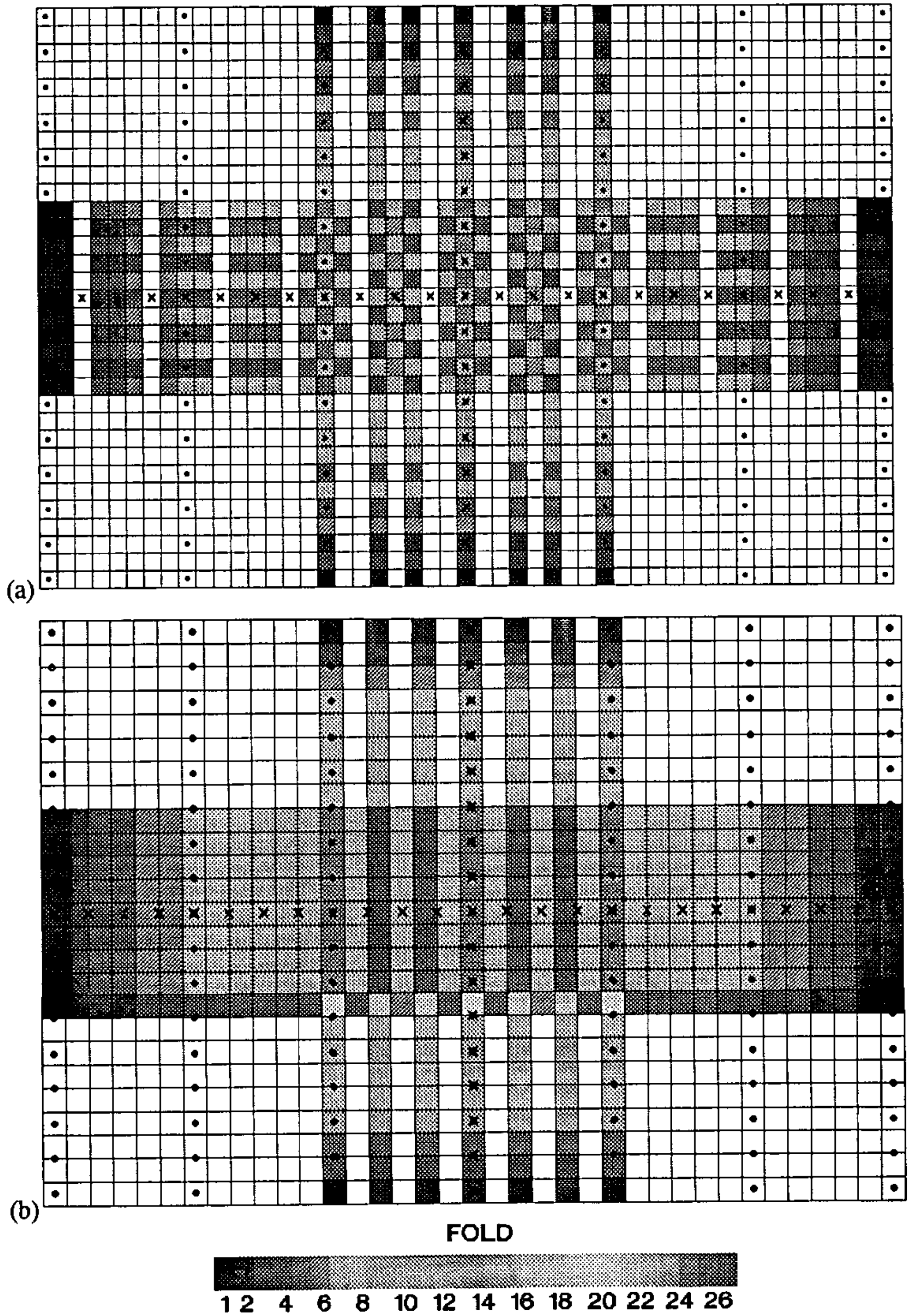


FIG. 5 (a) CCP fold map for crossed receiver lines using a CMP bin size; (b) CCP fold map for the same data as in (a) but using the optimum CCP bin size.

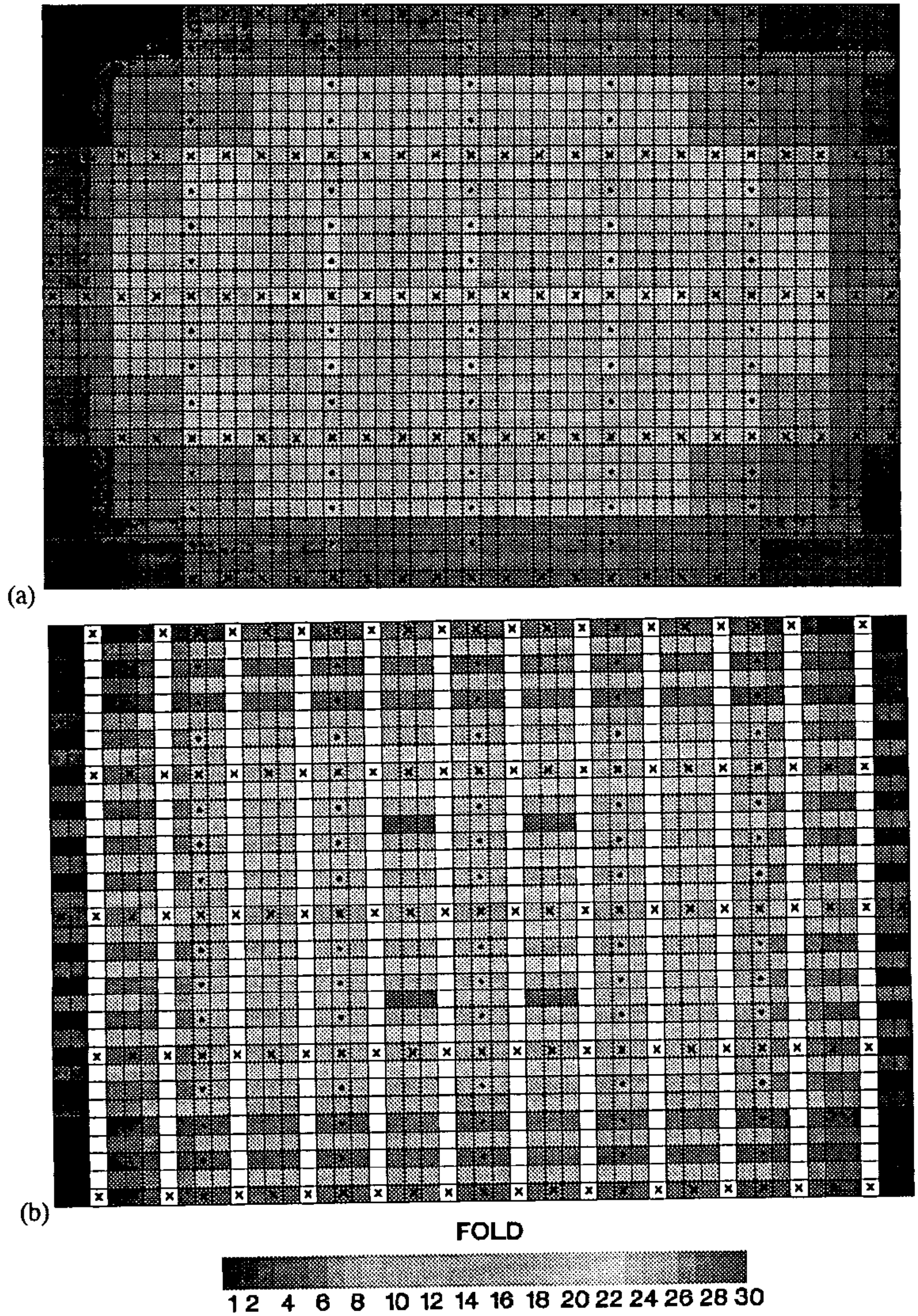
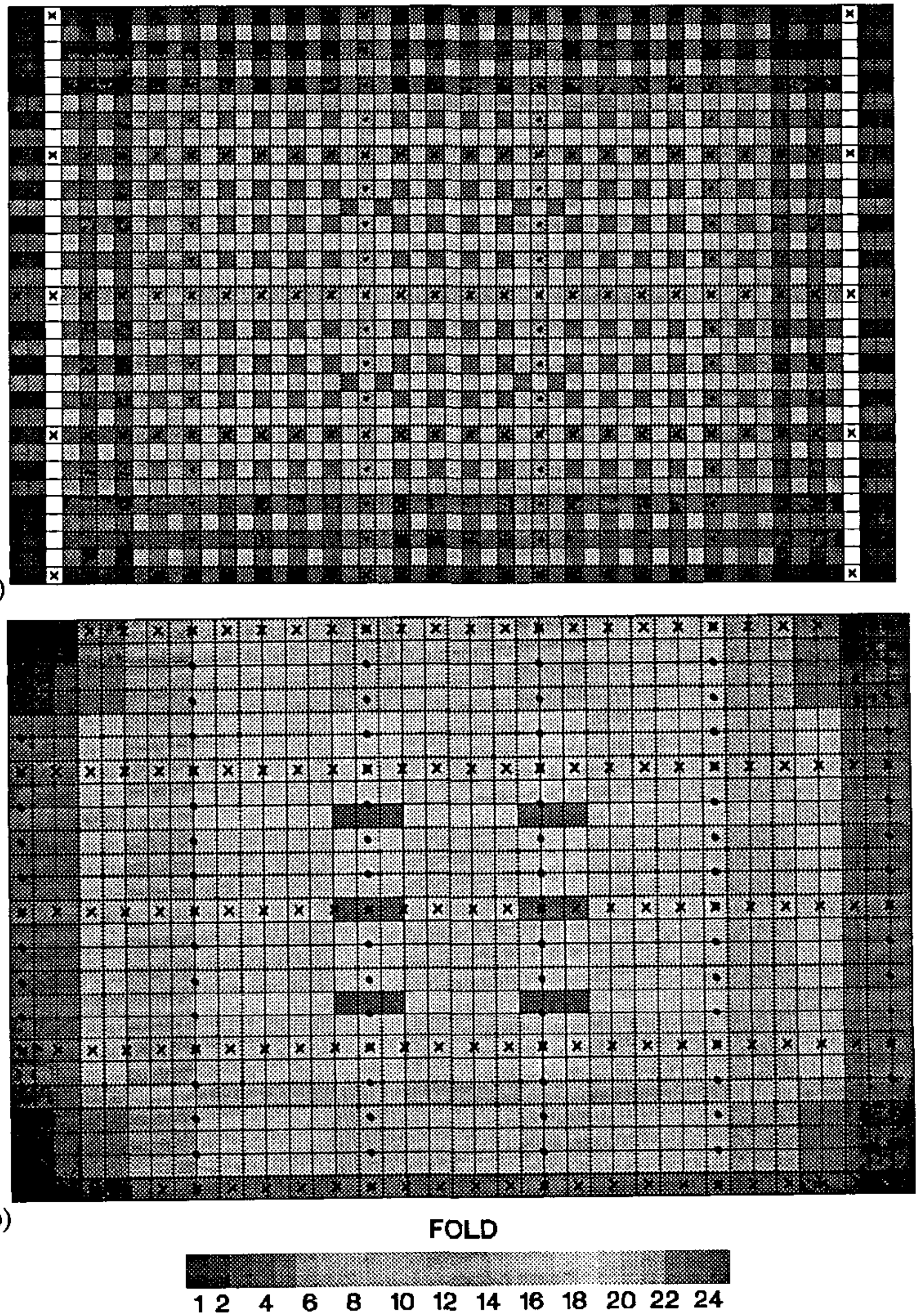


FIG. 6 (a) CMP fold map for a grid of shots and receivers (*P-P* data); shot and receiver line spacings are both 4 group intervals; (b) CCP fold map for *P-SV* data for the same acquisition geometry as in (a) and a CMP bin size.



(a)

(b)

FIG. 7 (a) CCP fold map equivent to that in Figure 6b except that the shot line interval has been increased to 5 group intervals; (b) CCP fold map for the same data as in (a) but using the optimum CCP bin size.

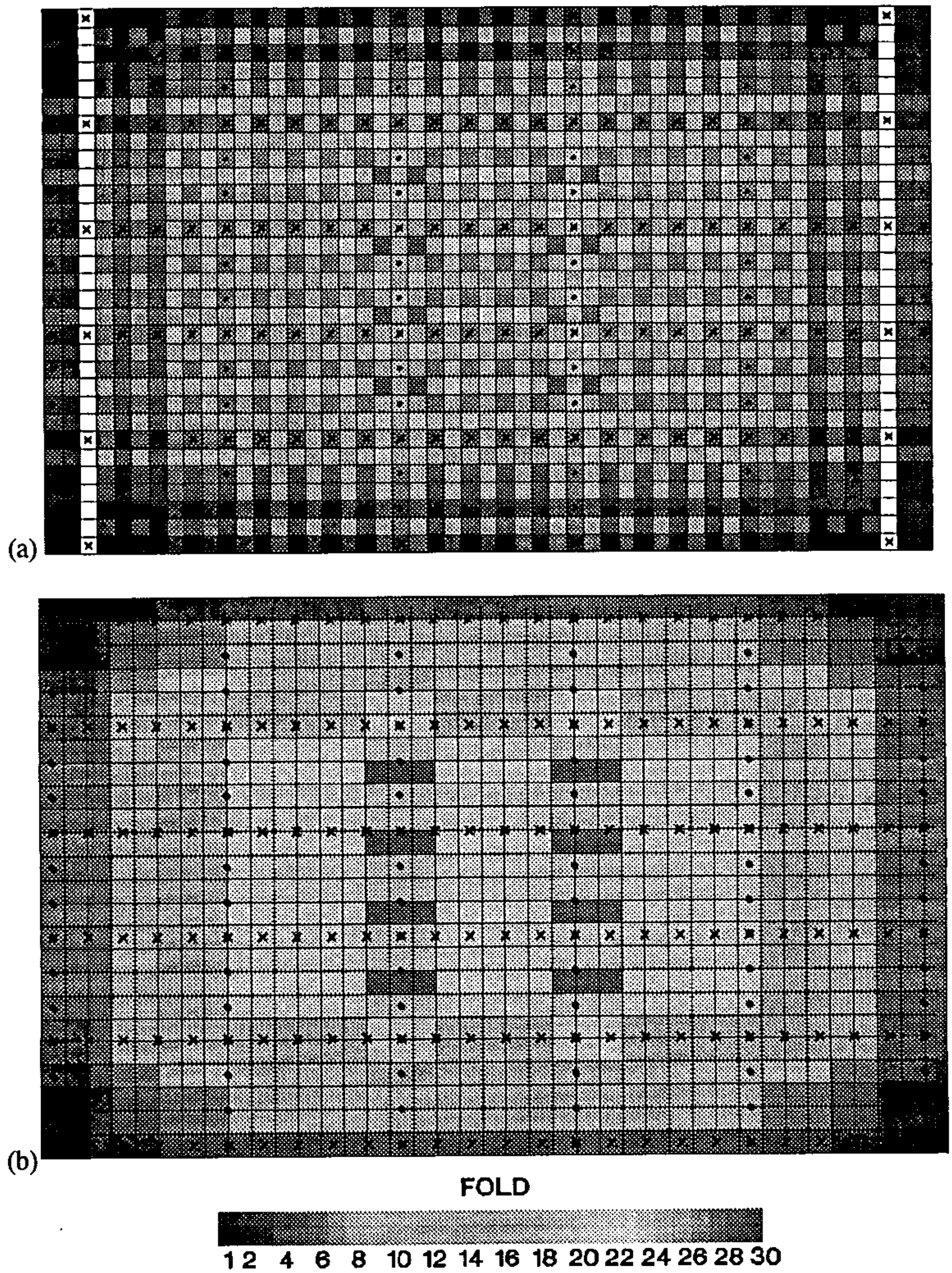
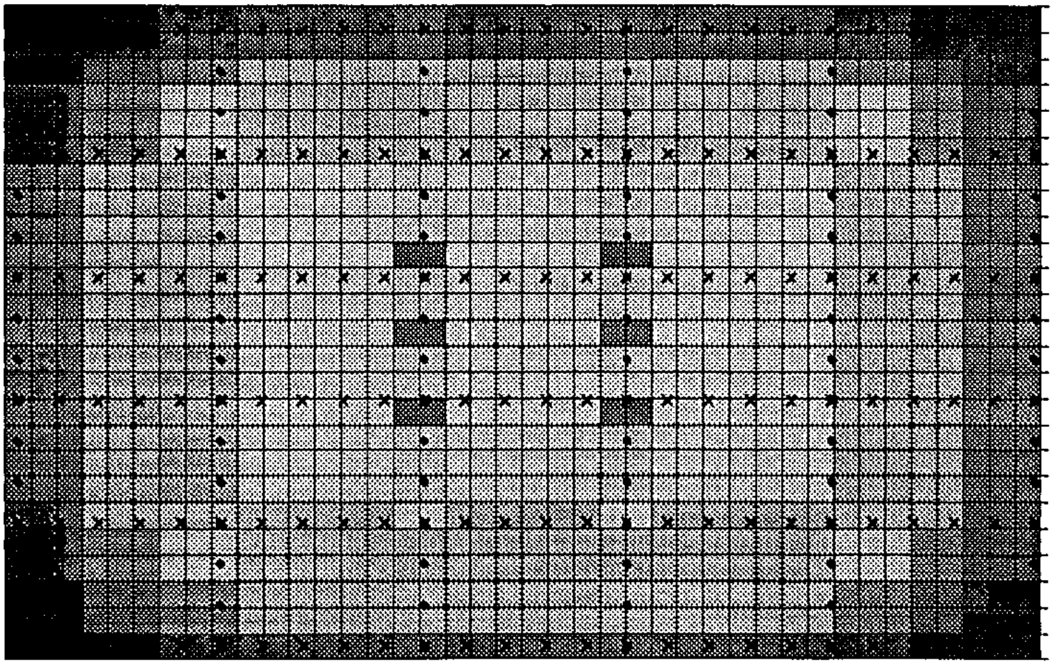
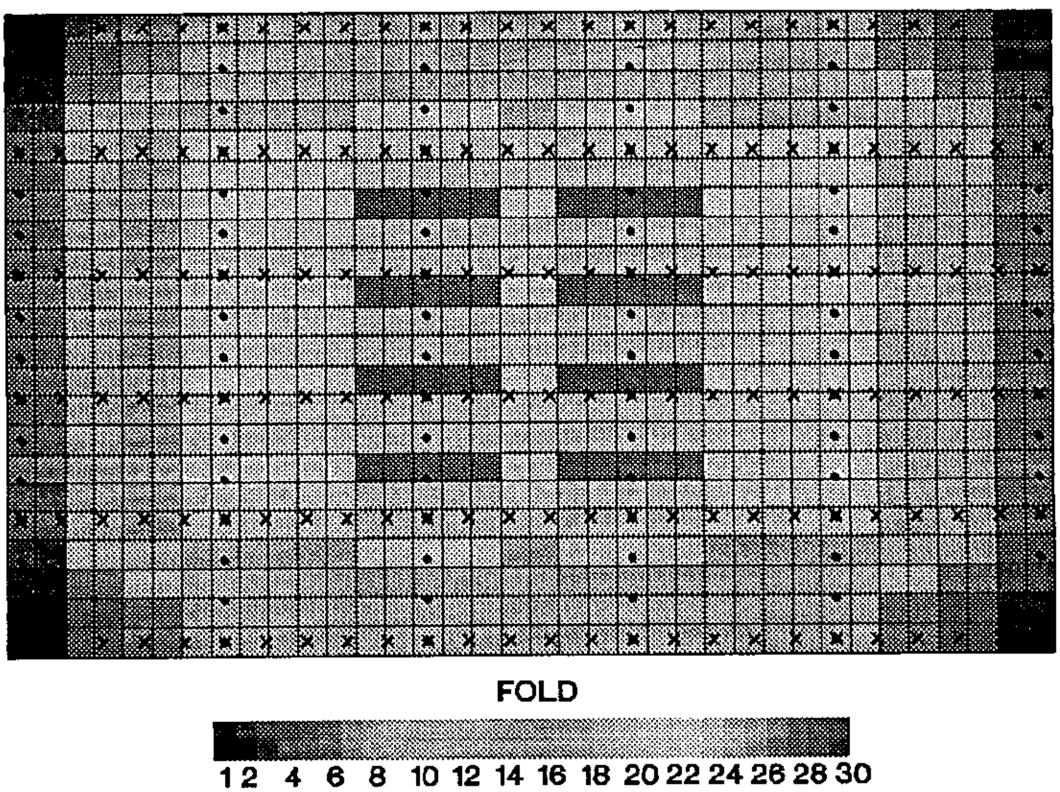


FIG. 8 (a) CCP fold map equivent to that in Figure 7a except that the receiver line interval has been decreased to 3 group intervals; (b) CCP fold map for the same data as in (a) but using the optimum CCP bin size.



(a)



(b)

FIG. 9 CCP fold maps equivalent to that in Figure 8b except for different values of *Vp/Vs*; (a) *Vp/Vs* = 1.75; (b) *Vp/Vs* = 2.5.