Acquisition design for 3-D converted waves

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ABSTRACT

Converted-wave *(P-SV)* fold and offset distribution were evaluated for a 3C-3D seismic survey planned for a program in the United States. Several design options were tested, including those for a conventional 3D seismic program encompassing the same area over which multicomponent data are to be collected. Optimum parameters for the converted-wave 3D acquisition were found to be a straight-line swath shooting method with a source line separation of 1540 ft (~470 m), a receiver line separation of 1760 ft (~537 m), and shot and receiver intervals of 220 ft (~67 m). A brick shot pattern was found to improve the offset distribution for *P-P* coverage but had little effect on *P-SV* offset distribution. Because of maximum offset requirements, it is recommended that all 3-component receivers be live for all shots encompassing the multicomponent survey area and for shots extending approximately 1700-1800 ft (~550 m) beyond the boundary of this area. This acquisition design requires 378 3-component geophones (1134 channels) and a total of 800 shots.

INTRODUCTION

A multicomponent 3D seismic survey has been planned in an area where it is desired to obtain *P-P* and *P-SV* coverage in order to properly illuminate a prospective interval containing reservoir sands. It has been found that mapping the distribution of these sands using conventional *P-P* data alone is difficult because of the low *P*-wave reflectivity at the base of the sands. Figure 1 shows a P-wave sonic log, a density log and a 1-D synthetic seismogram from the area showing the prospective sand interval (labelled "A") at a depth of approximately 4200 ft (1311 m). The sand interval is overlain by a high-velocity carbonate unit and is underlain by a shale which has a lower velocity but higher density than the sands. Consequently, the P-wave acoustic impedance contrast at the sand/shale boundary is quite low, as shown by the impedance and reflectivity logs in Figure 1. The synthetic seismogram shows that the seismic "A" event is dominated by a tuned reflection from the thin overlying carbonate horizon.

A template 3C-2D seismic line was acquired previously across the survey area and showed that the reservoir sands could in fact be mapped using a coupled *P-P* and *P-SV* interpretation, primarily because the *S*-wave reflectivity is greater than the *P*-wave reflectivity at the base of the sands. Also the *P-SV* traveltime within the sand interval is greater than the *P-P* traveltime because of the lower *S*-wave velocity. Figure 2 shows raw *P*-wave, *S*-wave and density logs from the same well used to generate the synthetic seismogram shown in Figure 1. The *S*-wave log has many intervals over which no reliable *S*-wave transit time data were obtained. This log was edited using an automatic process by which the null *S*-wave transit times were replaced by values determined from the average *Vp/Vs* ratio from robust log values immediately above and below the missing interval. Edited logs, and the extracted *Vp/Vs* log, are shown in

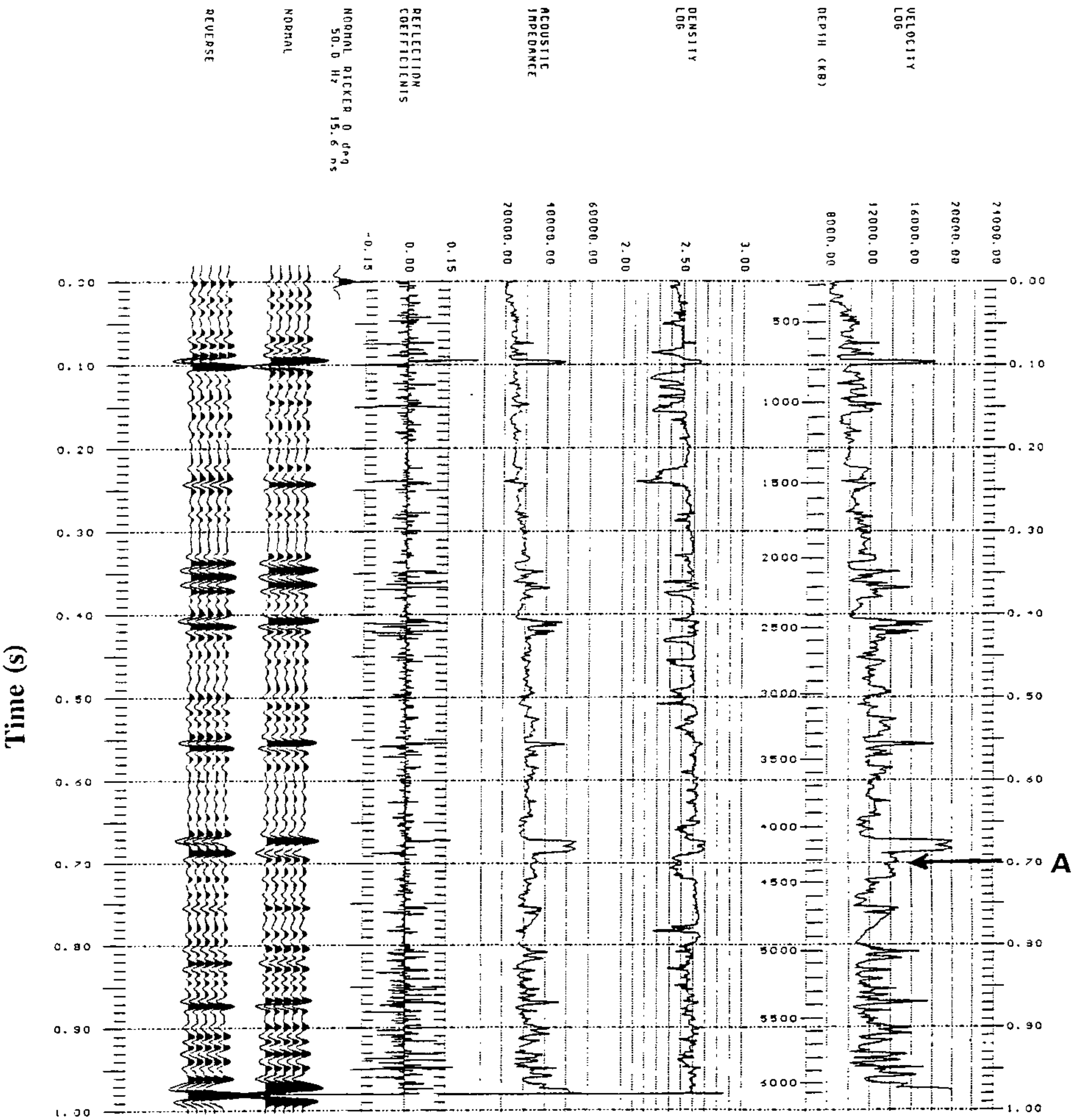

FIG 1. *P*-wave log, density log and 1-D synthetic seismogram from program area. Label "A" indicates prospective sand interval.

Figure 3. The average value of *Vp/Vs* decreases from about 2.2 in the upper part of the well to about 1.8 near the bottom of the well. An average *Vp/Vs* = 2 is a reasonable average for the full depth section.

Figures 4 and 5 show, respectively, the *P-P* and *P-SV* synthetic elastic offset gathers and stacks generated using a raytracing method developed within the CREWES Project (Lawton and Howell, 1992). Logs shown in Figure 2 were used as input into the synthetic seismogram routines. Portions of processed *P-P* and *P-SV* processed field data at the well location are also shown in Figures 4 and 5, and good ties were obtained between the synthetic stacks and the field data. Both *P-P* and *P-SV* synthetic stacks and processed field data are displayed such that a peak in both data sets corresponds to a positive impedance boundary. In Figure 4, the "A" event, corresponding to the *P-P* reflection from the reservoir sands, is dominated by the peak from the overlying limestone horizon, whereas in the *P-SV* data (Figure 5), the sands are identifiable by the extended trough that follows the limestone peak.

3C-3D DESIGN

Criteria for establishing parameters for design of the converted-wave 3D program were based on results obtained from the 3C-2D line recorded previously, as well as design considerations discussed by Lawton (1993). Figure 6 shows a typical common-offset stack of the radial component from the 2D survey, with inside and outside mute patterns indicated. The effective offset range for *P-SV* data at the target level (event "A") is from approximately 1500 - 6700 ft (457 - 2047 m). An additional target for the converted-wave survey was event "B", at a time of approximately 1.7 s. The optimum offset range for converted waves from this target was found to be approximately 2000 - 8500 ft (610 - 2591m).

For the 3C-3D design procedure, all fold and offset maps were computed assuming an asymptotic *P-SV* conversion point and a constant *Vp/Vs* = 2. Depth-variant fold maps are still in the development stage within the CREWES Project, although differences between the asymptotic and true conversion points at the depths of events "A" and "B" will be small.

Design of the 3C-3D program was undertaken with the above criteria in mind. Also, to be consistent with previous surveys in the area, both shot and receiver intervals of 220' (67 m) were used. Because the north-south and east-west dimensions of the multicomponent survey area are both less than twice the maximum useable source-receiver offset for event "B", it was required that all of the 3-component receivers be live for shots close to the centre of the multicomponent survey area. Hence, it was recommended that the entire patch of 3-component receivers be live for all shots. This objective was achieved with 9 receiver lines (each of 42 receivers) with a receiver line separation of 1760 ft, as illustrated in Figure 7. Note that the easternmost receiver line lies slightly outside of the designated multicomponent survey area; this line of receivers is required to maintain reasonable *P-SV* coverage within the eastern portion of the multicomponent survey area. This design requires 378 live 3-component receivers, or 1134 recording channels.

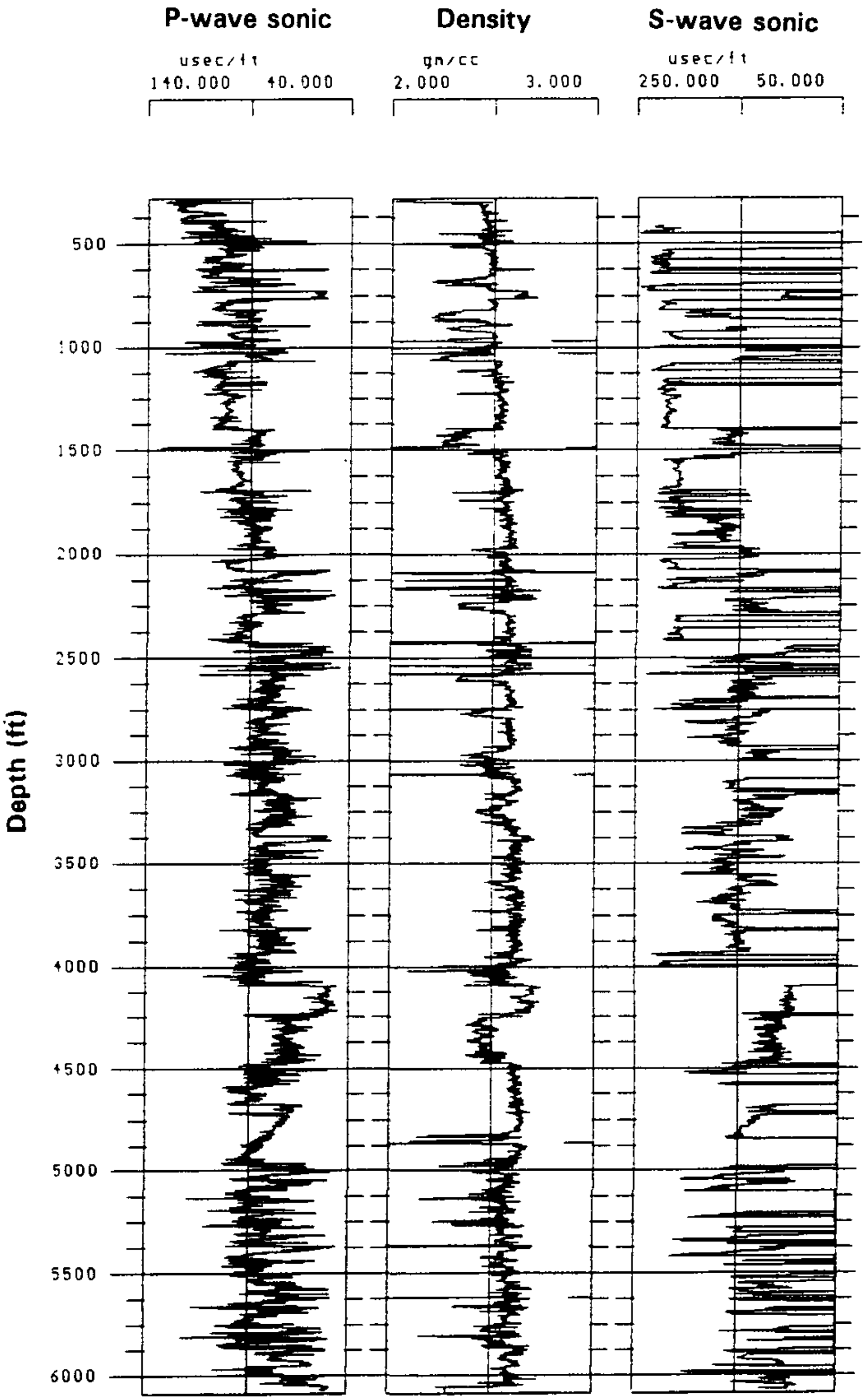

FIG 2. Raw *P*-wave, *S*-wave and density logs from program area.

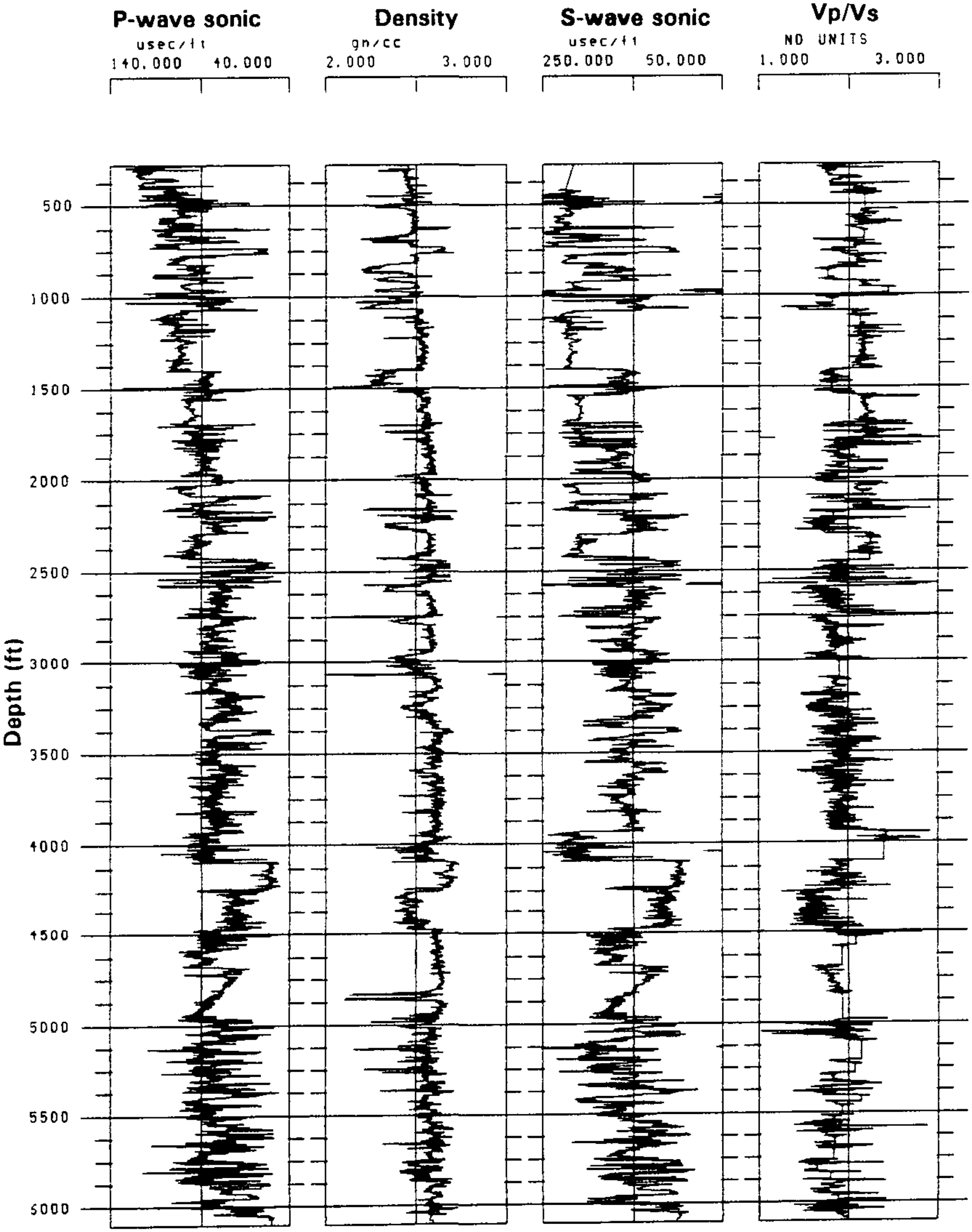

FIG 3. Edited *P*-wave, *S*-wave and density logs from program area. Raw logs are shown in Figure 2.

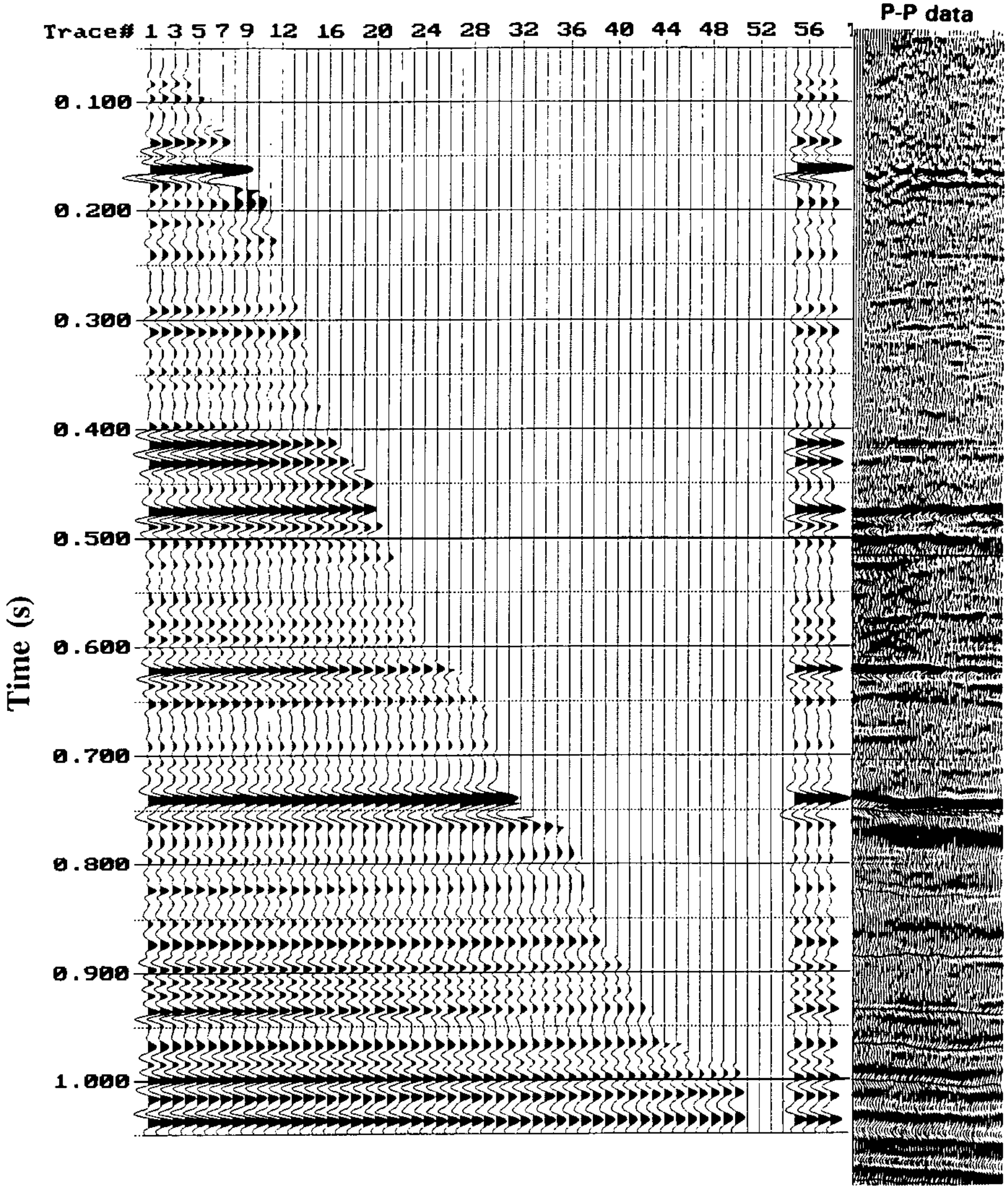

FIG 4. Synthetic *P-P* offset gather and stack based on the well data shown in Figure 3 with stack correlated with processed vertical component (*P-P*) seismic data at the well location. Trace interval is 164 ft (50 m).

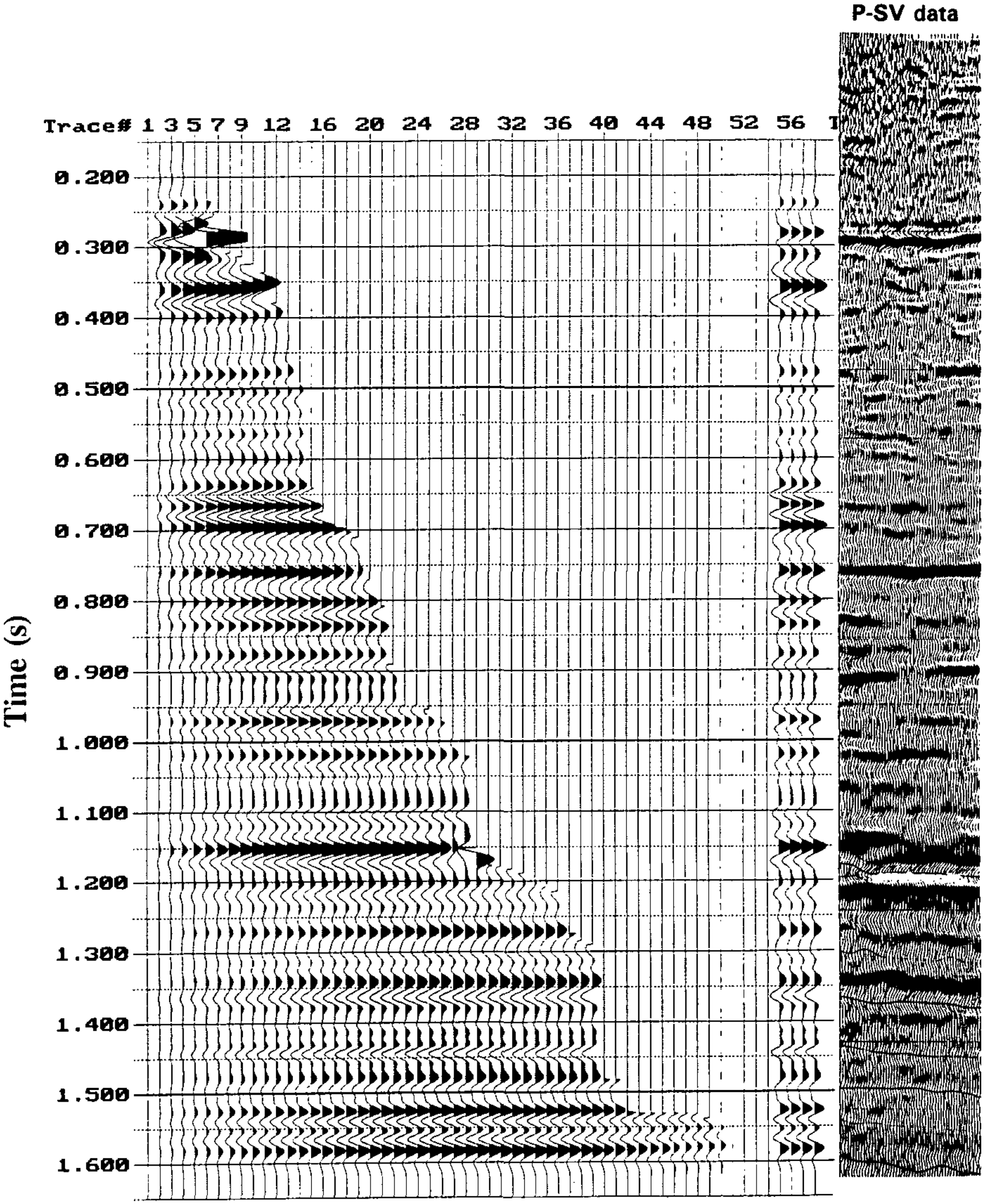

FIG 5. Synthetic *P-SV* offset gather and stack based on the well data shown in Figure 3 with stack correlated with processed vertical component (*P-SV*) seismic data at the well location. Trace interval is 164 ft (50 m).

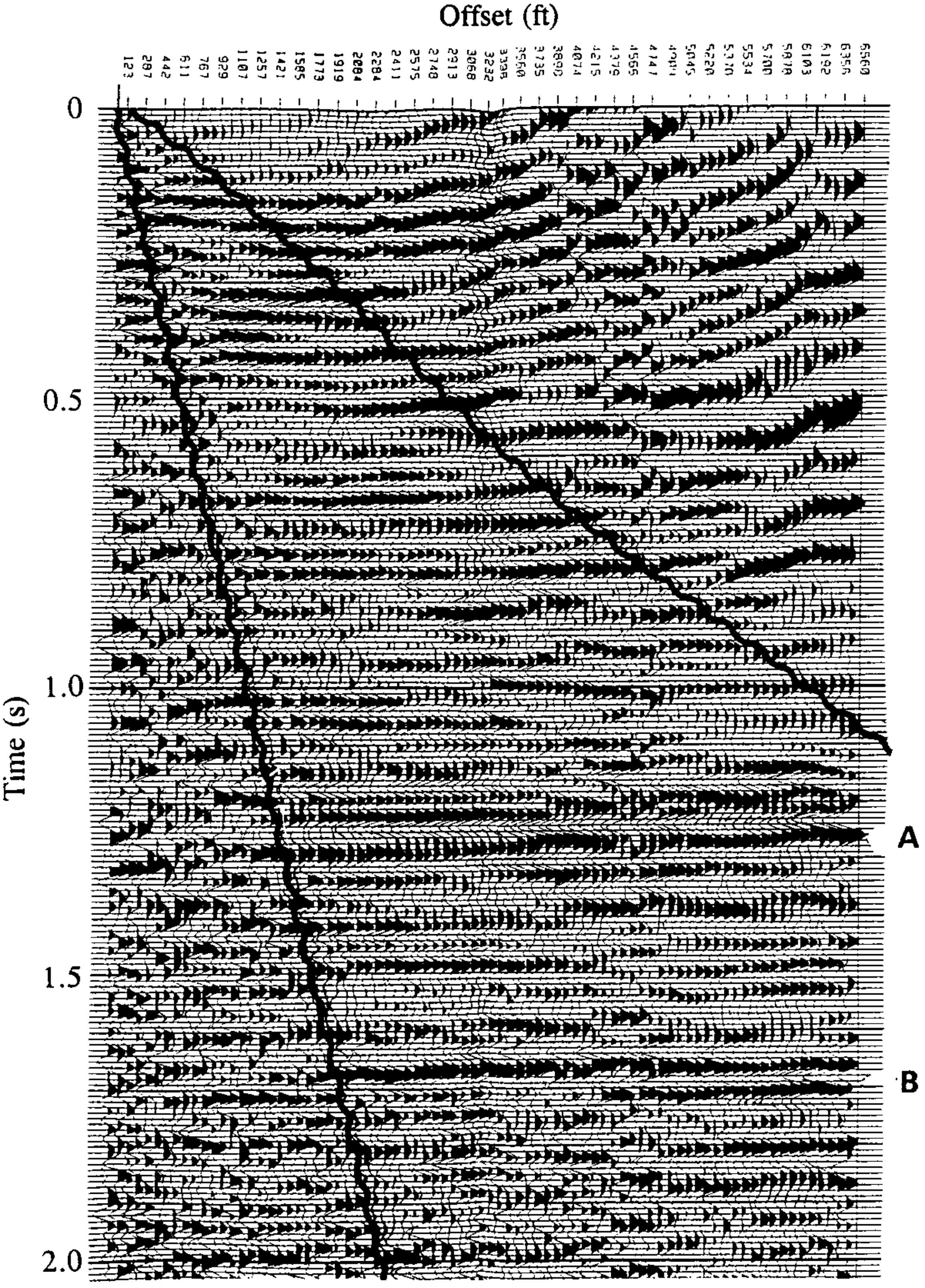

FIG 6. Radial component common offset stack from 3C-2D template seismic line. Marked lines show typical inside and outside mute patterns. Events "A" and "B" are target horizons for the 3C-3D survey.

The following design options relate to source line geometry. All source patterns used a staggered layout; i.e. source lines intersected receiver lines mid-way between receiver locations.

Design #1

Parameters for Design Option 1 are listed in Table 1. The layout of this design is shown in Figure 7, with the multicomponent survey area highlighted within the rectangle. Shots extend beyond this area in order to maintain fold close to the boundaries of the multicomponent survey area.

TABLE 1: Parameters for Design Option 1.

Source parameters:	
Line orientation:	East-West
Source interval:	220 ft
Source line interval:	1320 ft (straight line pattern)
Number of source lines:	11
Number of source-points/line:	80
Total number of source points:	880
Receiver parameters:	
Line orientation:	North-South
Receiver interval:	220 ft
Receiver line interval	1760 ft (straight line pattern)
Number of receiver lines:	9
Number of receivers/line:	42
Total number of receivers:	378
Number of recording channels:	1134
Patch parameters:	
All receivers live	

In Figure 8, *P-SV* fold for event "A" (offsets 1500 - 6700 ft) is shown, for bins with dimensions of 110' x 110' (34 m x 34 m). This figure shows that every 4th row of bins is empty, a feature which results from the fact that the shot line interval is an even multiple of the receiver separation (6 in this case). Empty bins can be avoided if *Vp/Vs* differs slightly from 2, although the fold will remain highly oscillatory. Using twice the bin size (220' x 220') results in non-empty bins (Figure 9) but fold is still irregular in the north-south direction. Using the optimum bin size of 146.7' x 146.7' (Lawton, 1993) results in the smoothest fold distribution (Figure 10), but at the expense of convenient coupled *P-P* and *P-SV* interpretation.

The preferred change to reduce irregular fold distribution for a standard bin size of 110' x 110' is to increase the shot line interval to an odd multiple of the receiver separation. This change was made in Design option 2.

Design #2.

Table 2 shows the acquisition parameters for design option 2. Figures 11 through 14 show the layout, fold, near offset distribution and far offset distribution, respectively, for *P-SV* data at event "A" for this design option, with a bin size of 110' x 110'. Figure 15 shows the quality of the offset distribution, given by a kurtosis parameter.

TABLE 2: Parameters for Design Option 2.

Source parameters:

Line orientation:	East-West
Source interval:	220 ft
Source line interval:	1540 ft (straight line pattern)
Number of source lines:	10
Number of source-points/line:	80
Total number of source points:	800

Receiver parameters:

Line orientation:	North-South
Receiver interval:	220 ft
Receiver line interval:	1760 ft (straight line pattern)
Number of receiver lines:	9
Number of receivers/line:	42
Total number of receivers:	378
Number of recording channels:	1134

Patch parameters:

All receivers live

This parameter examines the average distance between each offset, and provides a measure of the variance of the average separation, weighted by the fold. Values close to unity indicate a uniformly spaced offset distribution (leptokurtic) whereas values less then zero indicate a skewed offset distribution (platykurtic). The fold and offset patterns are reasonable and the fold could be smoothed without significant loss in lateral resolution. Within the inner 80% of the multicomponent survey area, an average multiplicity of about 16-fold is obtained. Using 220' x 220' bins (Figure 16) also results in regular, high fold. For comparison, Figures 17 through 20 show the fold, near offset, far offset distribution, and offset distribution kurtosis respectively, for event "A", using the optimum bin size of 146.7'x146.7'.

One alternative option proposed was to use a brick pattern for the shot lines in order to optimise the near offset distribution for the vertical component (*P-P*) data. This option was tested as Design option 3. However, in this pattern, the shot brick pattern was not symmetric, in order to maintain the shot stagger.

Design #3

Table 3 shows the acquisition parameters for design option 3. Figures 21 through 25 show the layout, fold, near offset distribution, far offset distribution, and offset distribution kurtosis respectively, for *P-SV* data for event "A" for this design option, with a bin size of 110' x 110'. The fold and offset patterns are similar to those obtained with Design option 2.

TABLE 3: Parameters for Design Option 3

Source parameters:

Line orientation:	East-West
Source interval:	220 ft
Source line interval:	660 ft & 880 ft alternating (brick pattern)
Number of source lines:	10
Number of source-points/line:	80
Total number of source points:	800

Receiver parameters:

Line orientation:	North-South
Receiver interval:	220 ft
Receiver line interval:	1760 ft (straight line pattern)
Number of receiver lines:	9
Number of receivers/line:	42
Total number of receivers:	378
Number of recording channels:	1134

Patch parameters:

All receivers live

DISCUSSION AND CONCLUSIONS

From the discussion above and the displays shown, it is concluded that either design option 2 or 3 is the preferred option for *P-SV* imaging of the sand interval corresponding to event "A". Design option 2 was also evaluated for event "B", allowing offsets from 2000 - 8500 ft. Figures 26 through 28 show the fold, near and far offset distributions for this event using this design. Fold is adequate over the desired offset range, but the near and far offset distributions tend to cluster towards the receiver lines. However, reasonable offset distributions are obtained over the inner 60% of the multicomponent survey area. Improvement in offset distribution would require more shots outside of the survey area.

Acquisition design for converted-wave 3D surveys is somewhat of a compromise between the number of recording channels available and the desired fold and offset range required to adequately illuminate the target interval. When planning surveys, forward modelling and examination of prestack data is very useful for evaluating the effective offset range within each bin. While the optimum bin size will produce the smoothest fold distribution, using a conventional bin size to gather the data will probably be satisfactory provided that the situation of having empty bins can be avoided. This requires that the shot line separation should be an odd integer multiple of the receiver spacing if the average *Vp/Vs* ratio is 2. The fold distribution in this case will still have a high frequency variation, but this should be able to be smoothed without excessive smear using post-stack trace mixing or some other form of smoothing operator, such as dip moveout.

REFERENCES

Lawton, D.C., 1993, Optimum bin size for converted-wave 3-D asymptotic mapping: CREWES Project, Annual Research Report, Volume 5, 28.1-28.16.

Lawton, D.C., and Howell, T.C., 1992, *P-P* and *P-SV* synthetic stacks: Expanded Abstract, 62nd SEG Annual International Meeting, October 25-29, New Orleans, USA, 1344-1347.

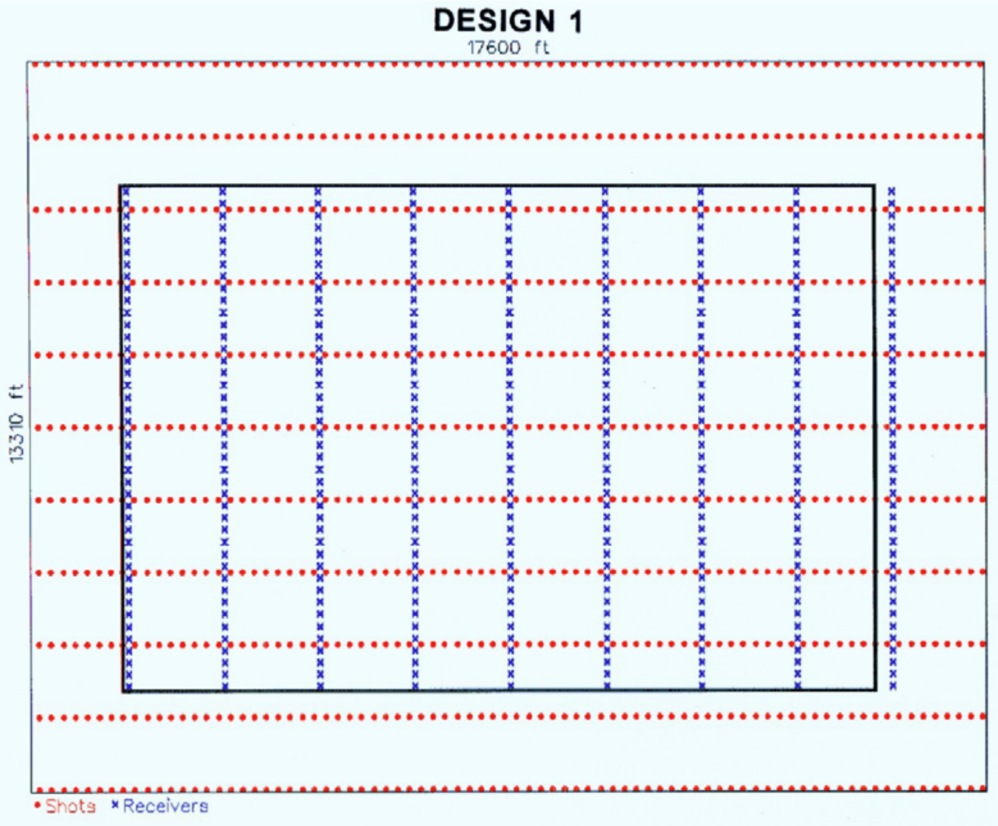

FIG. 7. DESIGN 1: 1760' receiver lines, 1320' shot lines (straight), 220' intervals

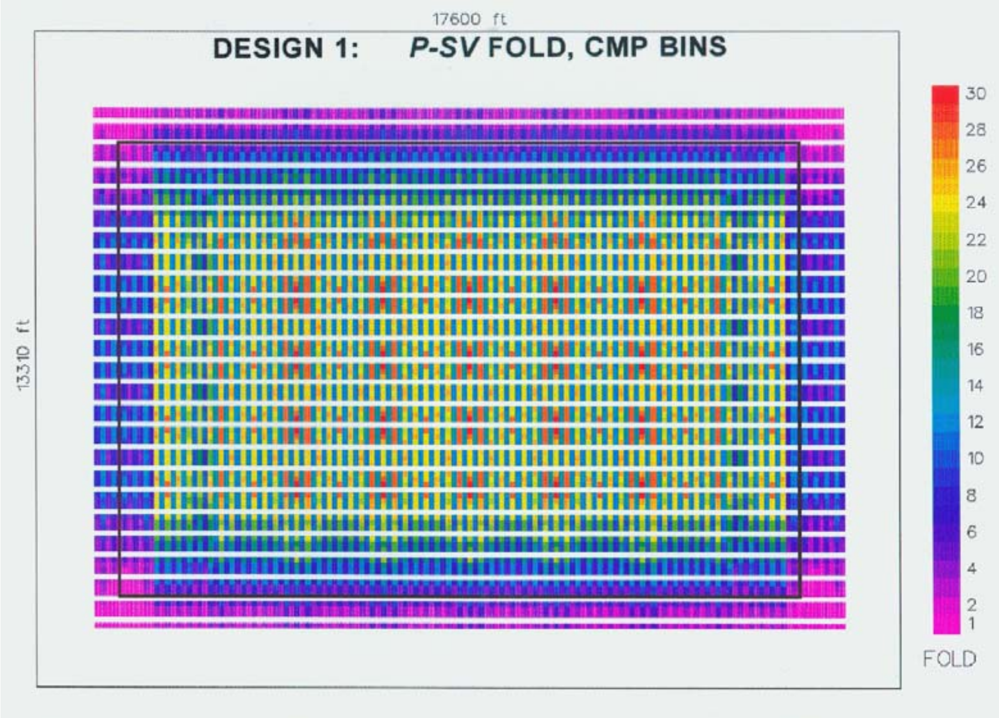

FIG. 8. DESIGN 1: P–S fold, 110' x 110' bins, offsets 1500'–6700' [event "A"]

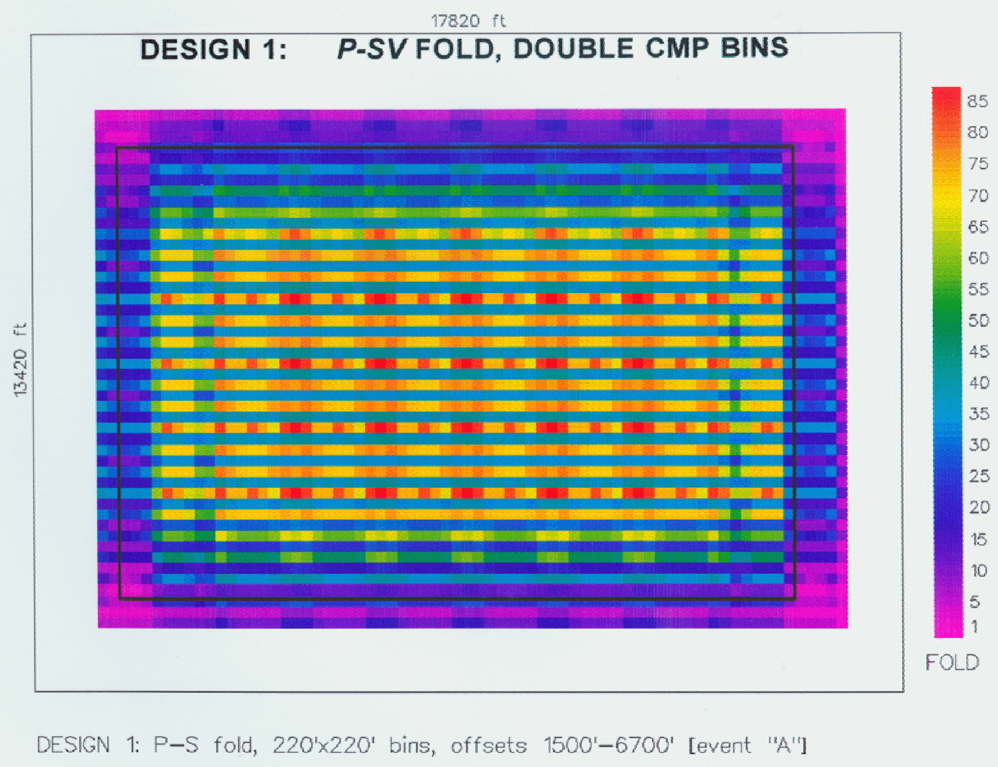

FIG. 9. DESIGN 1: P–S fold, 220'x220' bins, offsets 1500'–6700' [event "A"]

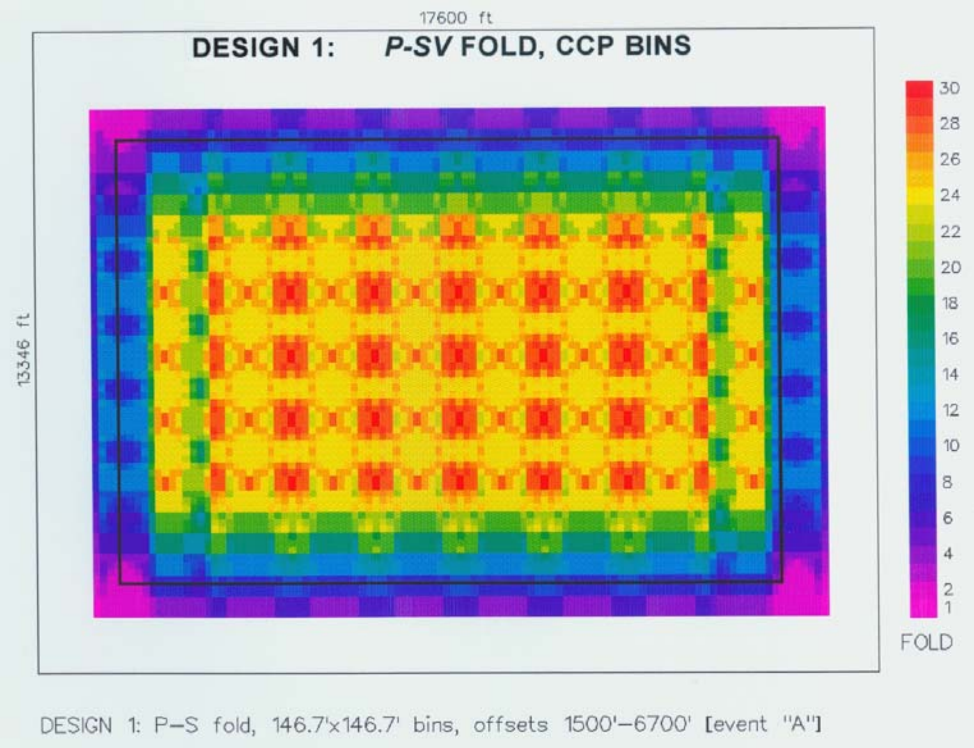

FIG. 10. DESIGN 1: P–S fold, 146.7'x146.7' bins, offsets 1500'–6700' [event "A"]

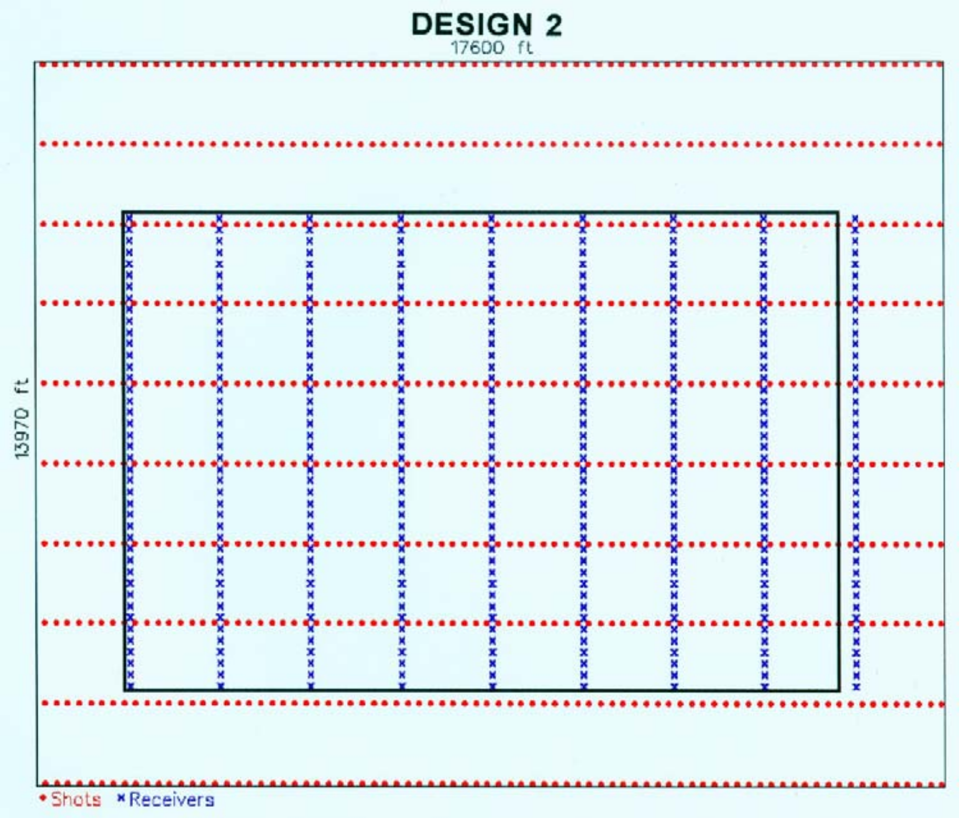

FIG. 11. DESIGN 2: 1760' receiver lines, 1540' shot lines (straight), 220' intervals

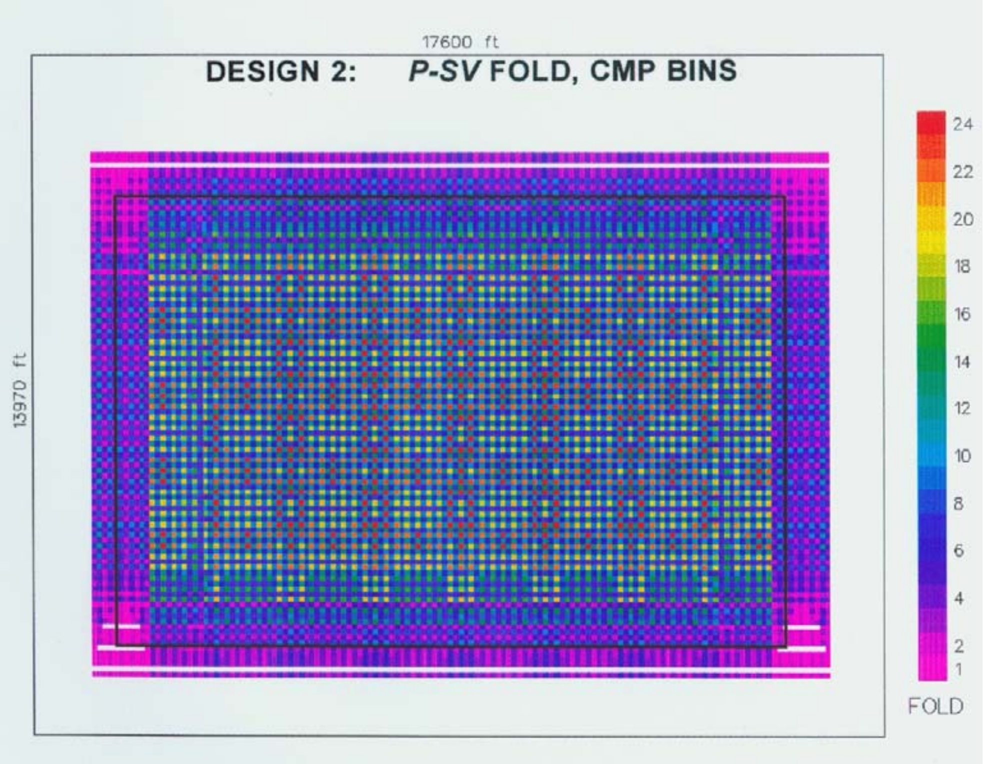

FIG. 12. DESIGN 2: P–S fold, 110'x110' bins, offsets 1500'–6700' [event "A"]


17600 ft
P-SV NEAR OFFSET DISTRIBUTION, CMP BINS
DESIGN 2
13970 ft
5697
1532
NEAR
OFFSET
(ft)
DESIGN 2: Near offsets, 110'x110' bins, offsets 1500'–6700' [event "A"]

FIG. 13.

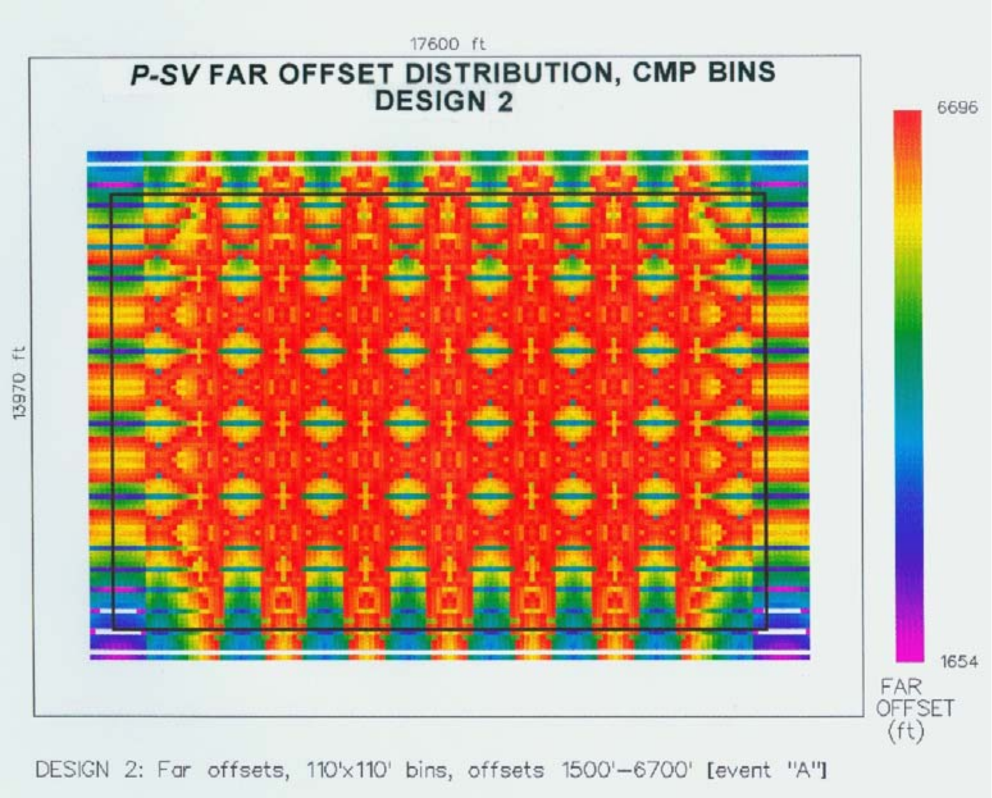
17600 ft
P-SV FAR OFFSET DISTRIBUTION, CMP BINS
DESIGN 2
13970 ft
6696
1654
FAR
OFFSET
(ft)
DESIGN 2: Far offsets, 110'x110' bins, offsets 1500'–6700' [event "A"]

FIG. 14.

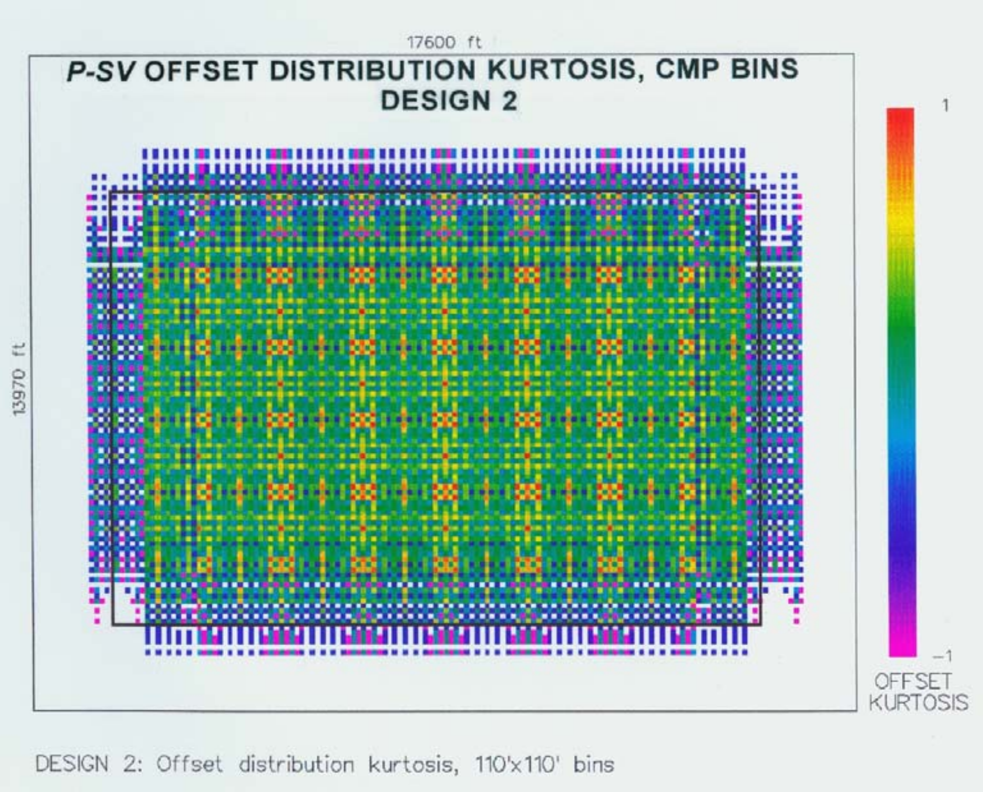

FIG. 15. DESIGN 2: Offset distribution kurtosis, 110'x110' bins

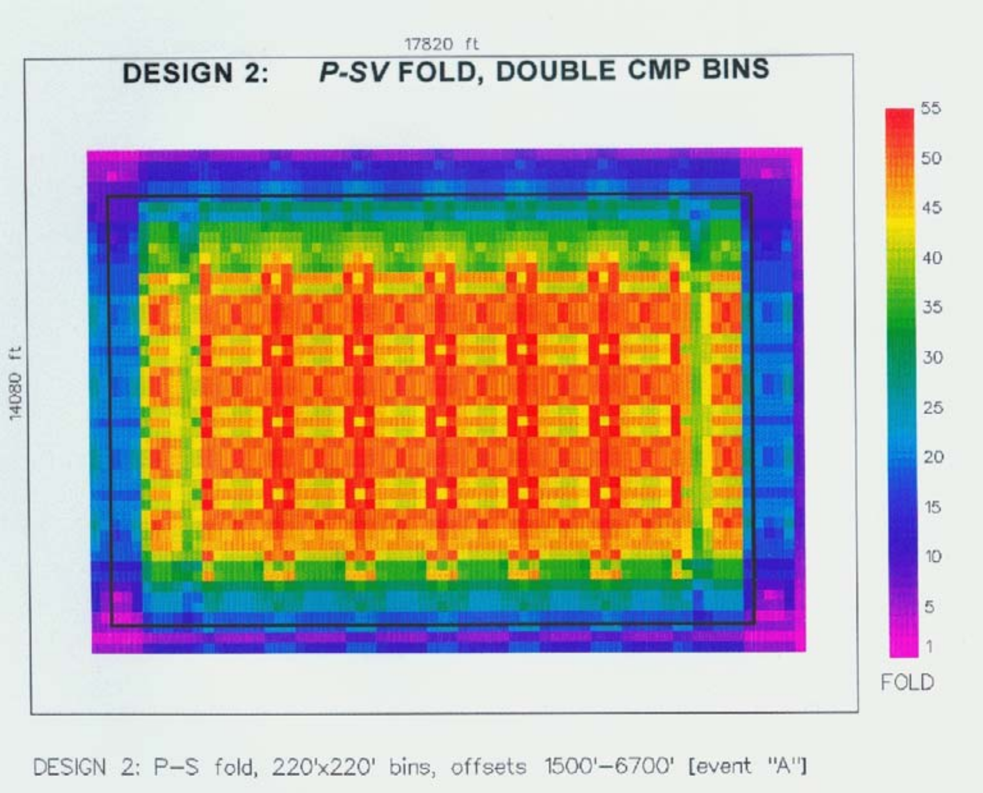

FIG. 16. DESIGN 2: P−S fold, 220'x220' bins, offsets 1500'−6700' [event "A"]

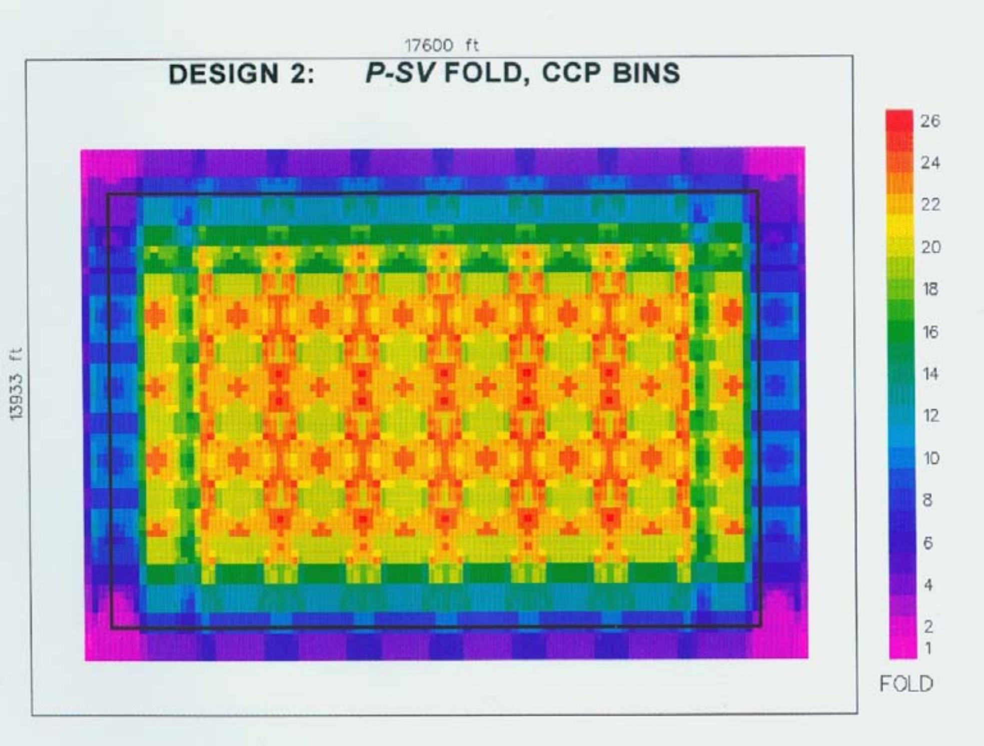

FIG. 17. DESIGN 2: P–S fold, 146.7'x146.7' bins, offsets 1500'–6700' [event "A"]

FIG. 18. DESIGN 2: Near offsets, 146.7'x146.7' bins, offsets 1500'–6700' [event "A"]

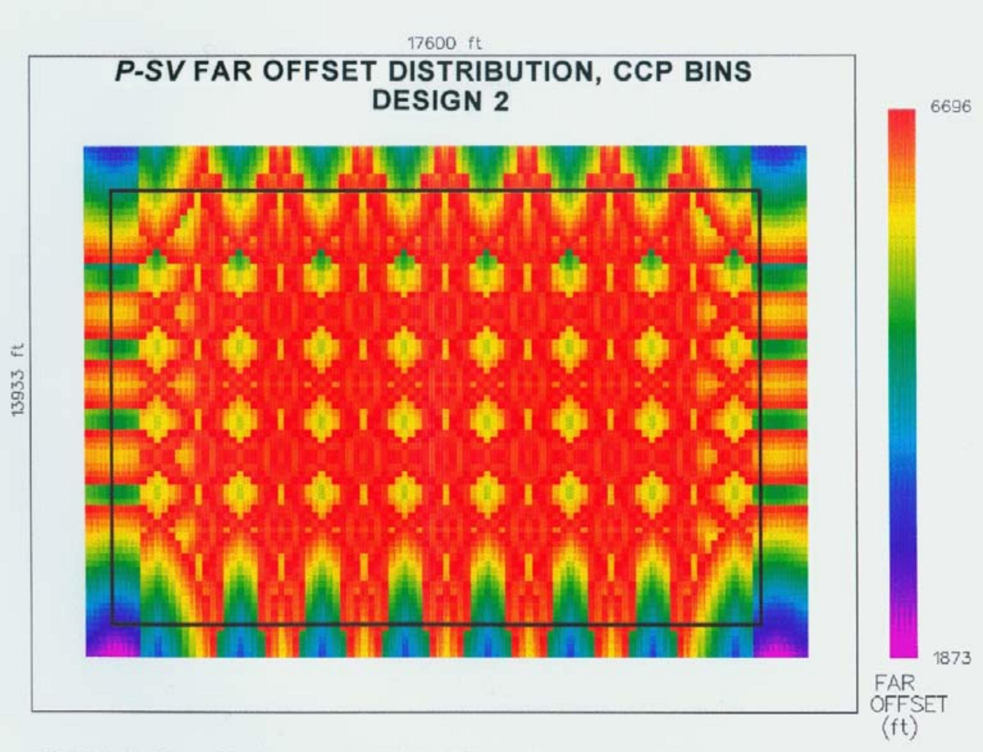

FIG. 19. DESIGN 2: Far offsets, 146.7'x146.7' bins, offsets 1500'–6700' [event "A"]

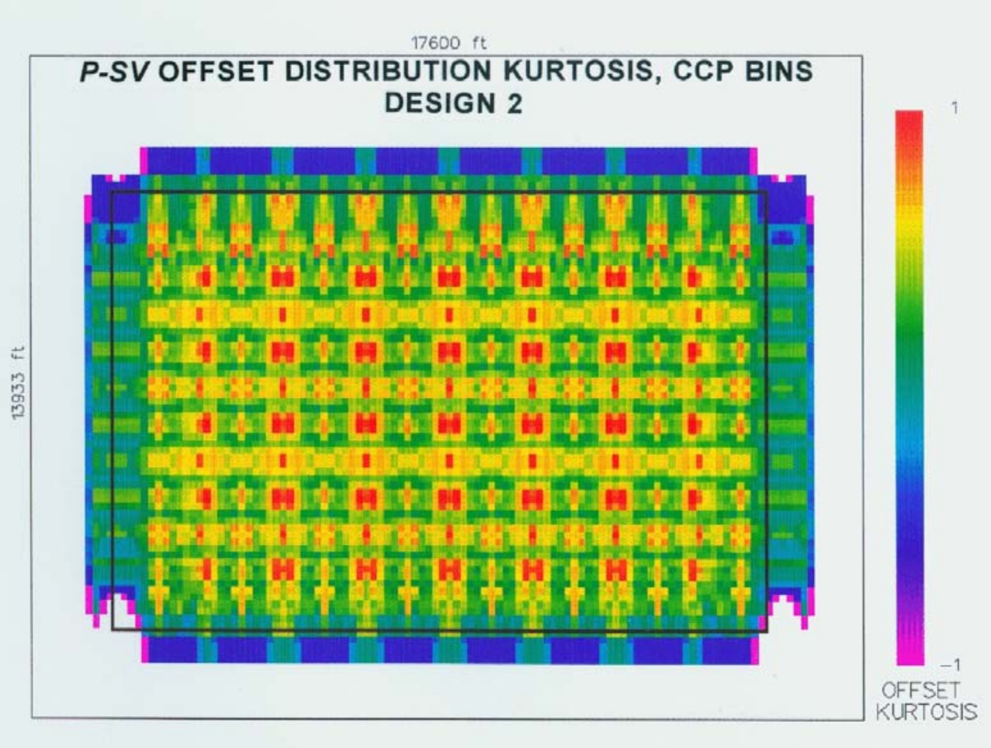

FIG. 20. DESIGN 2: Offset distribution kurtosis, 146.7'x146.7' bins

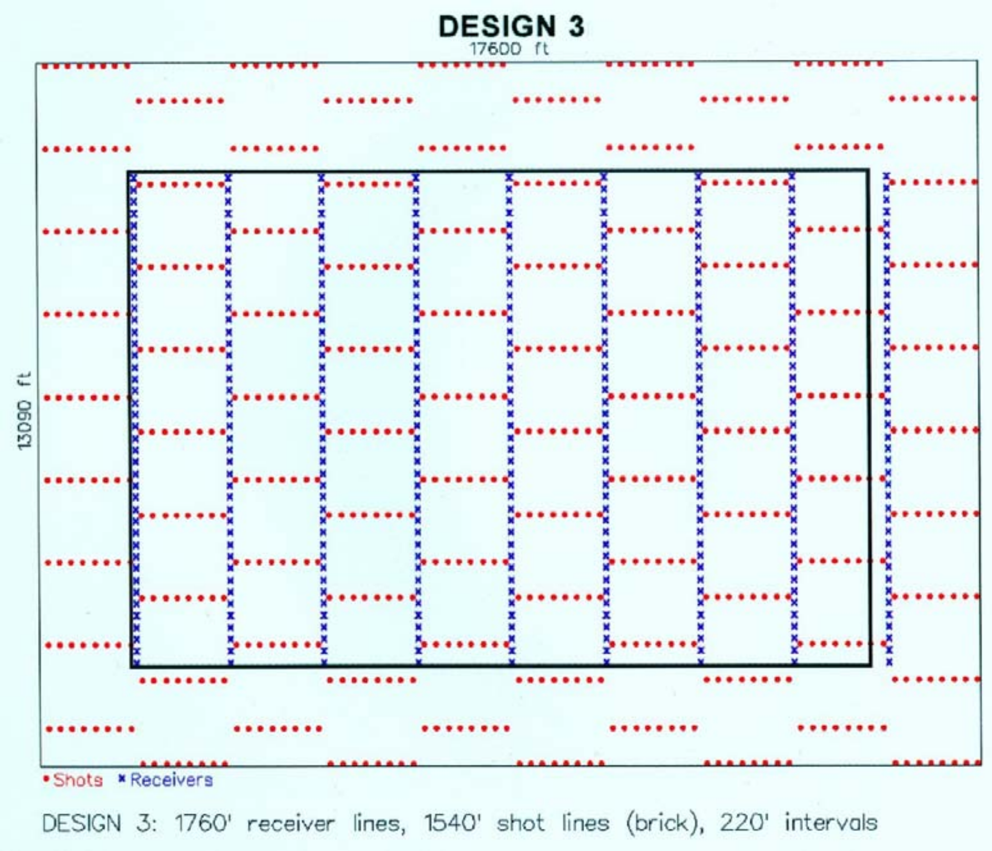
DESIGN 3
17600 ft
13090 ft
•Shots ×Receivers
DESIGN 3: 1760' receiver lines, 1540' shot lines (brick), 220' intervals

FIG. 21.

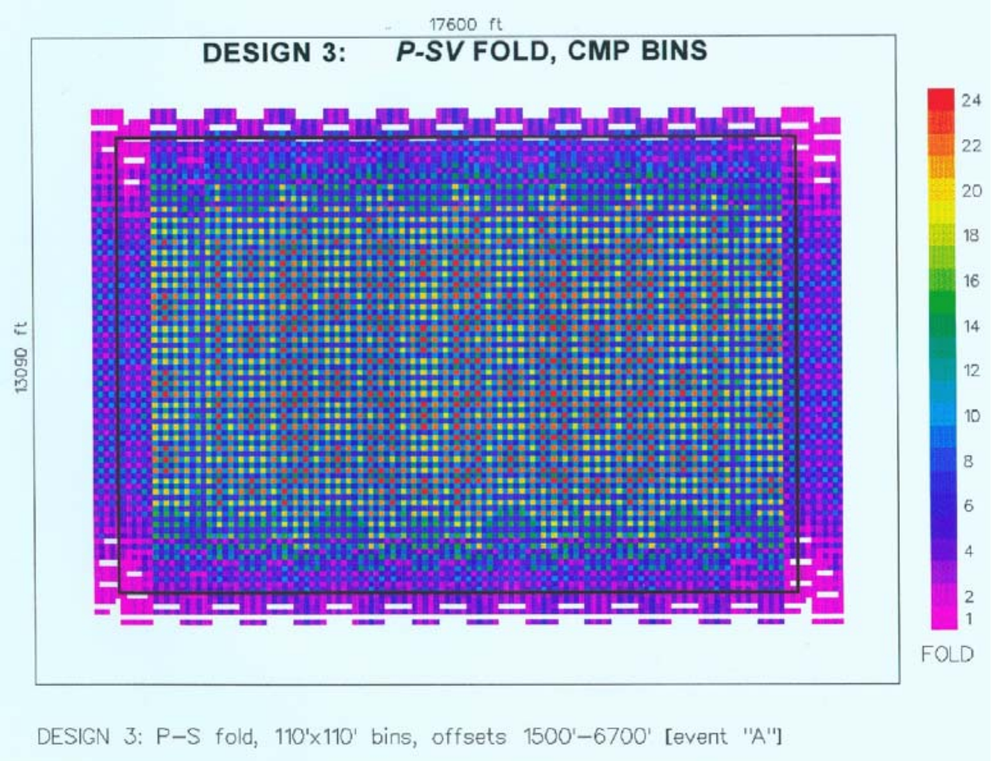
17600 ft
DESIGN 3: P-SV FOLD, CMP BINS
13090 ft
24
22
20
18
16
14
12
10
8
6
4
2
1
FOLD
DESIGN 3: P–S fold, 110'x110' bins, offsets 1500'–6700' [event "A"]

FIG. 22.

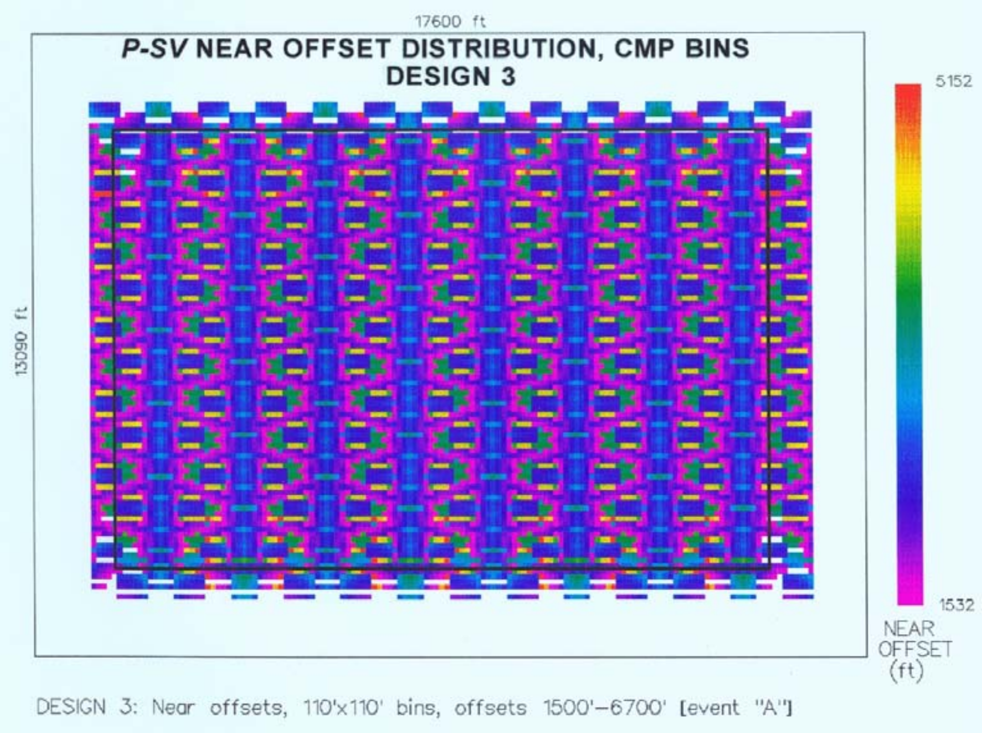

FIG. 23. DESIGN 3: Near offsets, 110'x110' bins, offsets 1500'–6700' [event "A"]

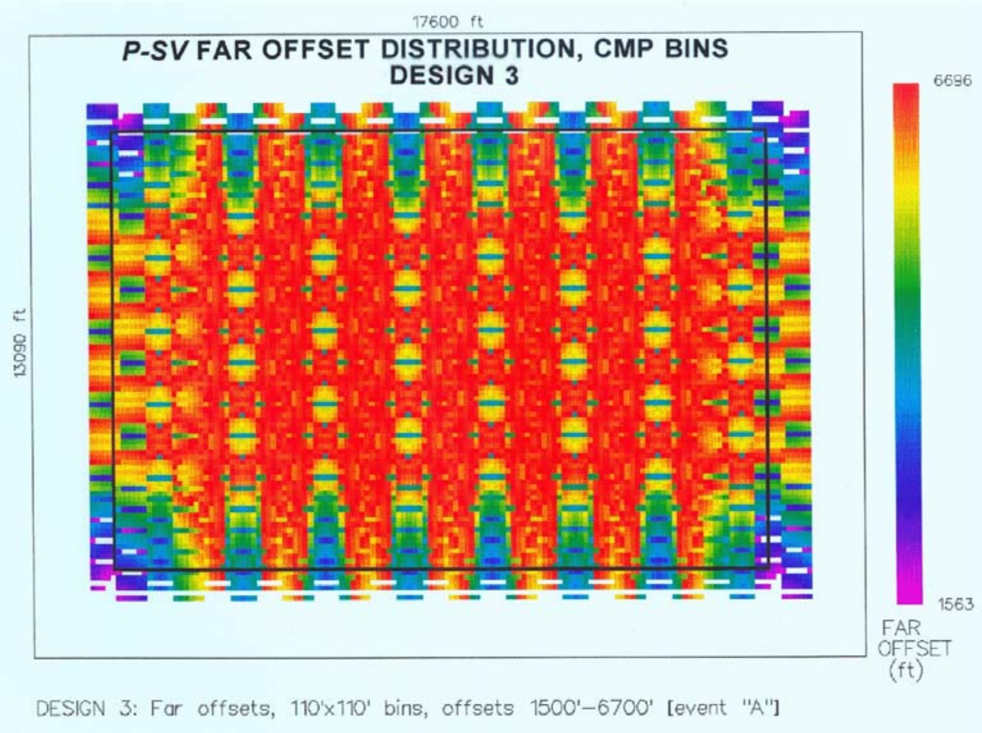

FIG. 24. DESIGN 3: Far offsets, 110'x110' bins, offsets 1500'–6700' [event "A"]

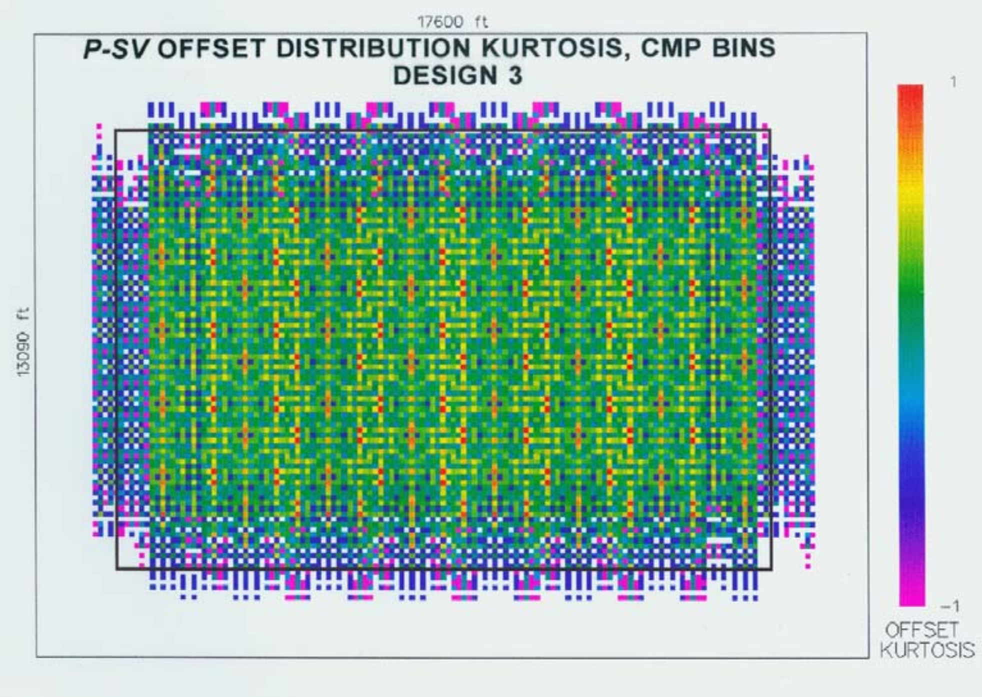

FIG. 25. Design 3: Offset distribution kurtosis, 110’ × 110’ bins

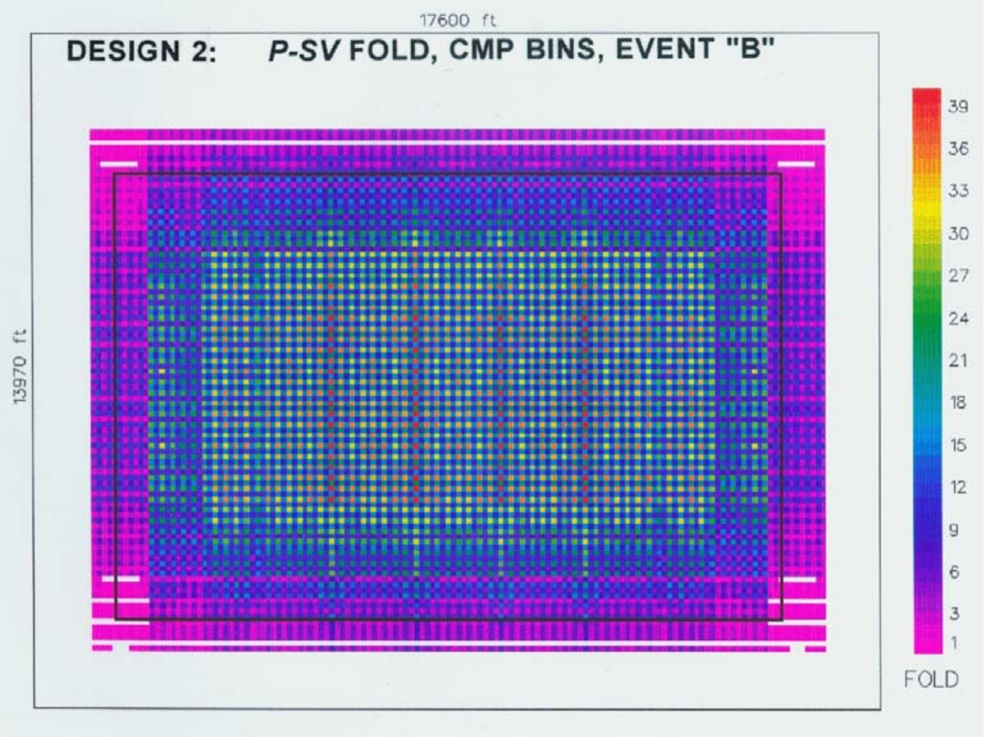

FIG. 26. DESIGN 2: P–S fold, 110'x110' bins, offsets 2000'–8500' [event "B"]

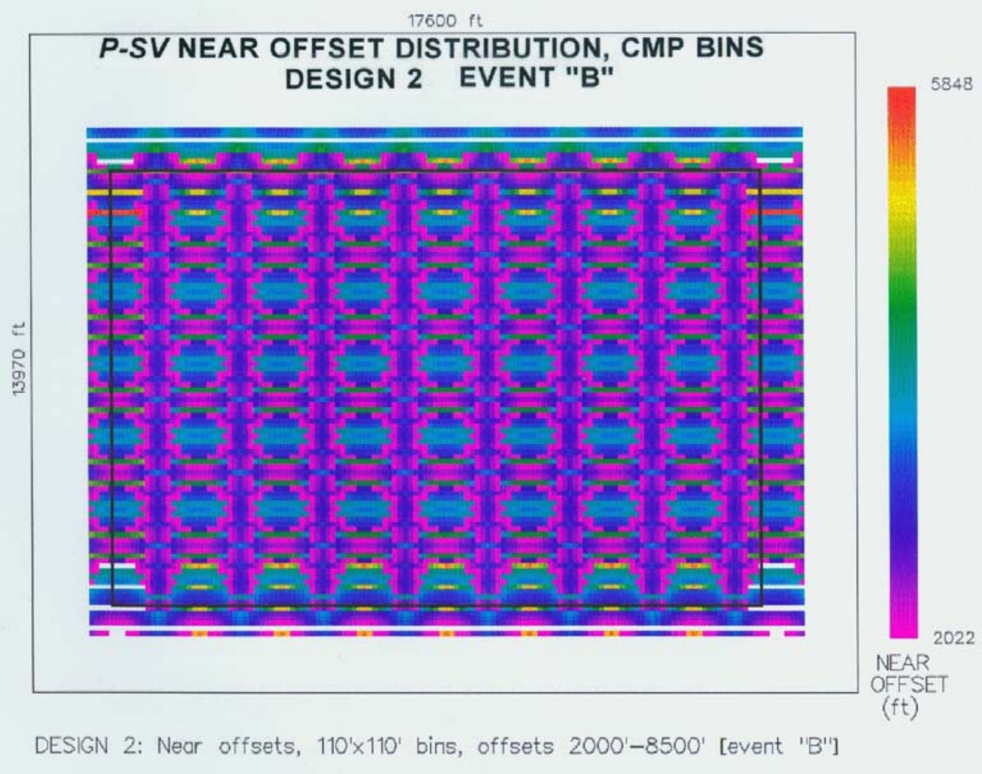

FIG. 27. DESIGN 2: Near offsets, 110'x110' bins, offsets 2000'–8500' [event "B"]

FIG. 28. DESIGN 2: Far offsets, 110'x110' bins, offsets 2000'–8500' [event "B"]