GEOPHYSICS, VOL. XXVII, NO. 6, PART II (DECEMBER, 1962), PP. 927-938, 8 FIGS.

COMMON REFLECTION POINT HORIZONTAL DATA STACKING TECHNIQUES*

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Techniques are described whereby multiple coverage of the subsurface is obtained. Detector spreads and shotpoints are arranged so that the channels representing common depth points are recorded with appreciably different horizontal distances between the shotpoints and detector stations. The channels which have a common reflection point are combined, or stacked, after appropriate corrections for angularity and travel time to datum have been applied. Reflections which follow the assumed travel paths are greatly enhanced, and other events are reduced. Methods for attenuating multiple reflections with respect to primaries are discussed in considerable detail.

Typical field comparisons between conventional and stacked traverses are shown to illustrate the degree of improvement which can be obtained in the signal-to-noise ratio.

General considerations applicable to field usage, and the geographic range of field experience are summarized.

INTRODUCTION

Improvements in the signal-to-noise ratio of seismic signals has been a continuing project with geophysicists for many years. As certain problems have yielded to solution, new ones have been encountered. From Kilipsch (1936), Rieber (1936), Poulter (1950), Woods (1953), Reynolds (1954), Parr (1955) to Graebner (1960), various techniques have been described to utilize the noise attenuation properties of multi-element arrays.

Applications of these and related techniques, either singly, or in combination, have produced solutions to many difficult problems. As the multiplicity of shotpoints and detectors is increased to cope with still more difficult situations, however, we are eventually confronted with an inherent limitation. As the arrays become larger and larger, the subsurface area which is averaged increases correspondingly. In practice the summation or integration of reflection arrivals from a subsurface area theoretically as great as ten acres may result from pattern dimensions of less than 700 ft. This, of course, tends to obscure the very detail which is being sought. The multiple-coverage, common-reflection point technique was devised to provide a practical means of increasing multiplicity without this limitation.

DESCRIPTION OF THE METHOD

Multiple coverage of the same subsurface with different shot and detector positions has been suggested for several purposes. Green (1938) advocated multiple paths centered about a common depth point to eliminate the effect of dip on velocity determinations.

This writer (1956) proposed that the information associated with a given reflection point, but recorded with a multiplicity of shotpoint and geophone locations, be combined algebraically after applying appropriate time corrections. Thus, if the reflected signals received along the several paths are adjusted for coincidence, their resultant sum will be proportional to the number of signals. Perturbations following other than the postulated ray paths will not be coincident, and hence will be degraded relative to the reflections. For random incidence the average theoretical enhancement will be proportional to the square root of the number of signals. This is analogous to pattern performance. Since, however, the source and receiving points have been selected so that the reflection point is common to all paths, the limitations of conventional pattern techniques no longer apply. The horizontal spacing between source and receiver is restricted only by the following considerations:

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1. The greatest distance which will permit coincidence adjustments of the requisite accuracy. The probable error in the postulated stepout increases with distance and must be kept small with respect to the reflection period.
2. The greatest distance over which the reflected signals persist with adequate similarity.

Magnetic tape recording equipment, Loper and Pittman (1954), has become readily available, and has made the necessary summation processes convenient and economical.

Figure 1 illustrates one simple field procedure for obtaining multiple coverage of the subsurface. This 24-detector station arrangement has the unique property of recording data from a specific reflection point on the same channel throughout a sequence of 12 shots. The multiplicity, i.e. the number of available paths which have a common reflection point, is 12 or one-half the number of stations in the spread. Note that the progressive variation in horizontal distance between the shotpoint and detector for the end stations is 22 intervals. Thus, summation of the number one channels of the 12 shots is equivalent to a 12 element array with a total length of more than one-half mile if typical station intervals are used. This is, of course, many times longer than would be permissible with conventional techniques, and thus provides effective attenuation of events with extremely great apparent wavelengths. Each of the shots recorded in this manner will require a different moveout correction program, but summation can be made without channel transposition.

ALTERNATE ARRANGEMENTS

It is possible to develop the desired multiple coverage in a variety of ways. In the following examples, 24-detector station spreads will be used. If a standard split-spread configuration is preferred, the arrangement of Figure 2 can be used. In this example both the spread and shotpoint are advanced two intervals so that a symmetrical setup is maintained. The depth points corresponding to each shot have been indicated by the dots underneath the setup. It is seen that channels from a total of 12 shotpoints must be

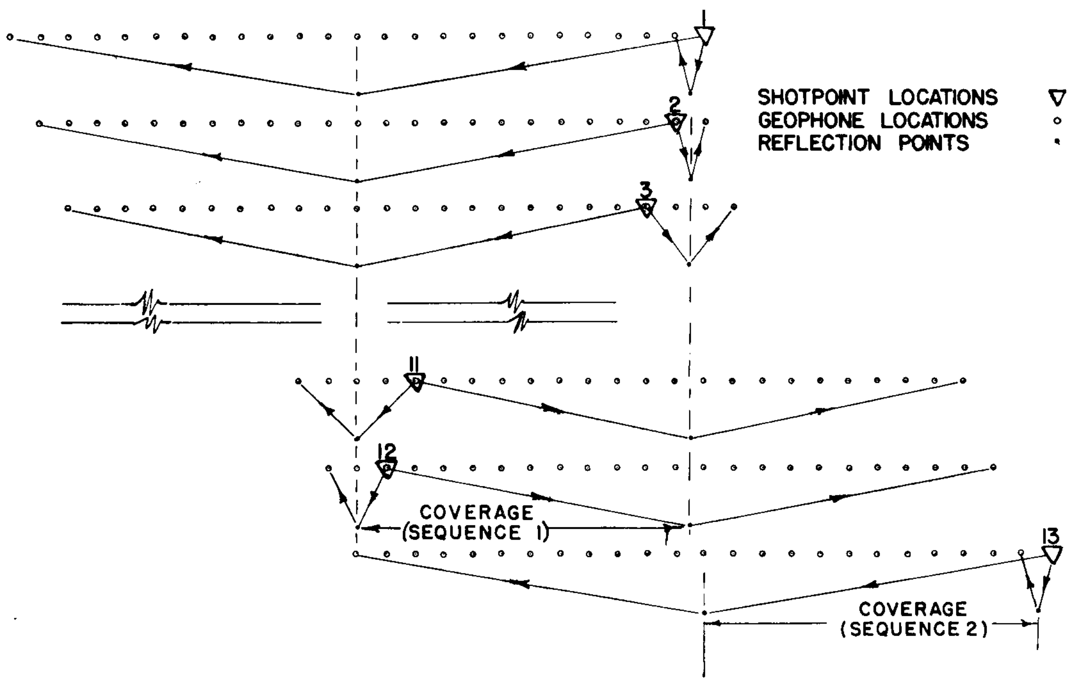

FIG. 1. Common-channel spread sequence giving 12-fold coverage of subsurface (multiplicity). Detector spread advances one station, shotpoint backs up one station for a total of twelve recordings. Common depth points are recorded on the same channel throughout each sequence of twelve recordings.

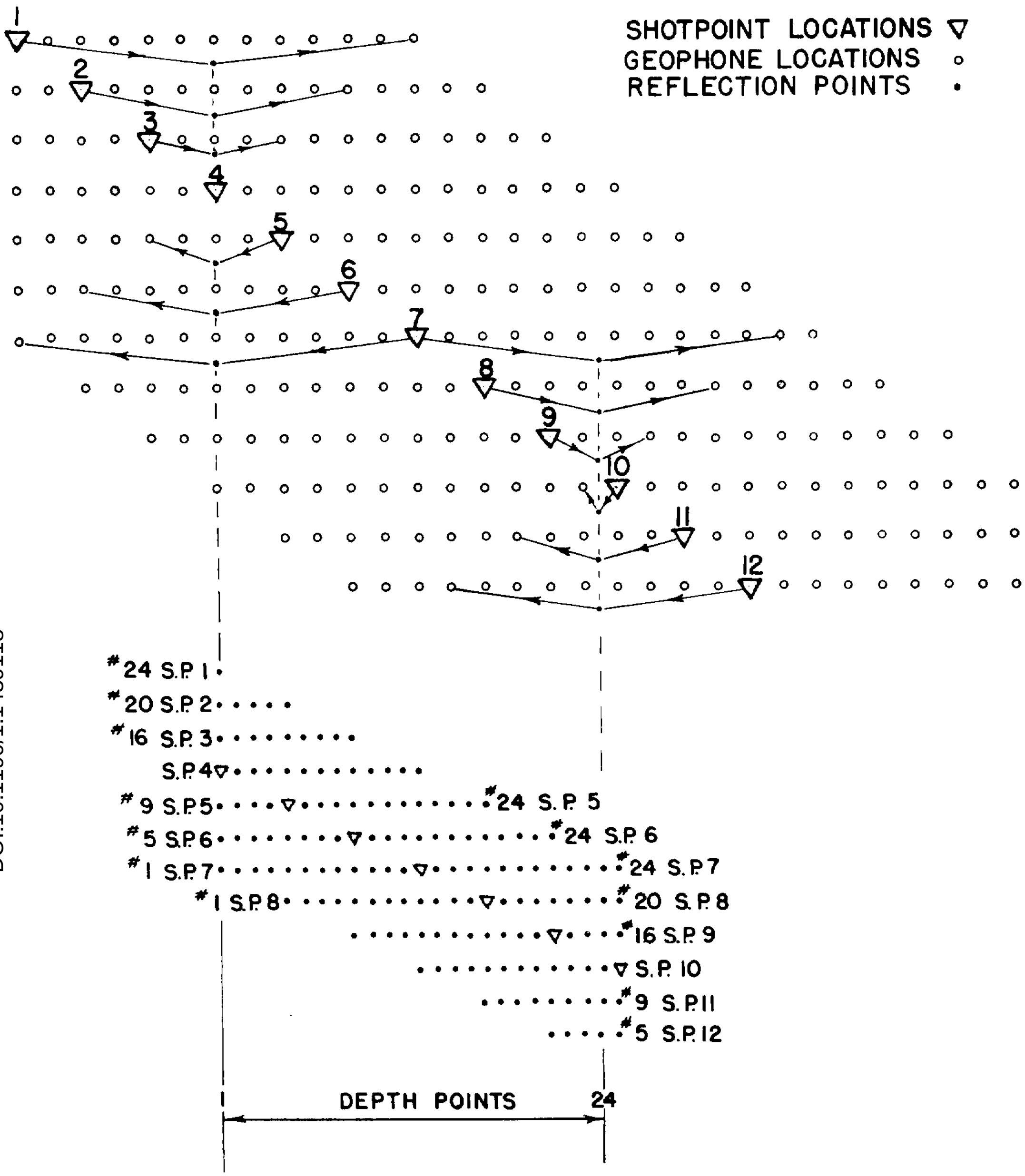

Fig. 2. Symmetrical straddle spread sequence giving six-fold multiplicity. Detector spread and shotpoint are advanced together by two stations for successive recordings.

used to obtain the full multiplicity of six.

Table 1 shows the channels recorded from each shotpoint which are used to compose the 24 depth points under Shotpoint 7.

In each of the previous examples only one shot is made into each instrument spread. Figure 13 illustrates a sequence which also yields six-fold multiplicity using three shots per spread, but allows the spread to be moved six stations ahead each time. Table 2 shows the corresponding channel composition schedule.

The preceding examples point the way to the

Table 1. Table illustrating the channel combination schedule for data recorded using the spread sequence of Figure 2. Depth points of the stacked resultant are composed of the channels included in each vertical column, as recorded from the indicated shotpoints. Depth points of the stacked resultant correspond to those recorded on channels one thru 12, respectively, of shotpoint 7. Stacked depth point 13 is under shotpoint 7, and stacked depth points 14 thru 24 correspond to those recorded on channels 13 thru 23 of shotpoint 7 respectively.

S. P. No.	Depth point No.																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	24																							
2	20	21	22	23	24																			
3	16	17	18	19	20	21	22	23	24															
4	—	13	14	15	16	17	18	19	20	21	22	23	24											
5	9	10	11	12	—	13	14	15	16	17	18	19	20	21	22	23	24							
6	5	6	7	8	9	10	11	12	—	13	14	15	16	17	18	19	20	21	22	23	24			
7	1	2	3	4	5	6	7	8	9	10	11	12	—	13	14	15	16	17	18	19	20	21	22	23
8					1	2	3	4	5	6	7	8	9	10	11	12	—	13	14	15	16	17	18	19
9									1	2	3	4	5	6	7	8	9	10	11	12	—	13	14	15
10													1	2	3	4	5	6	7	8	9	10	11	12
11																	1	2	3	4	5	6	7	8
12																					1	2	3	4

general expression for the multiplicity of any particular progression. Thus if:

M = path multiplicity (as previously defined),
N = number of detector stations in the spread,
n = number of stations by which the spread is advanced,
S = number of shot positions for each spread,

the following expression will define the multiplicity for any sequence:

$$M = NS/2n.$$

Figure 6 illustrates a third arrangement which develops six-fold multiplicity. This is similar to the sequence of Figure 2 since the shot location and spread are both advanced two stations, and only a single shot per spread is taken. However, the shot is located at the end of the spread, which changes the geometry of the common-reflection-point paths. Table 3 shows the channel composition schedule. This type of arrangement is particularly efficient in attenuating multiple reflections.

MULTIPLE REFLECTIONS

Powerful evidence confirming the existence of multiple reflections was presented by Ellsworth et al (1948). Later experience and theoretical studies on synthetic seismograms have indicated that occurrence of this insidious form of "noise" is dangerously common.

The common-reflection point technique can be an excellent tool in reducing multiple reflections even though their source in many cases cannot be precisely determined. Figure 5 illustrates a rather typical example, assuming for simplicity that the shot and the near-surface velocity contrast generating the multiples are at the same level. A hypothetical velocity function of $6{,}000+0.2Z$, where Z = depth below the shot, has been as-

Table 2. Table illustrating the channel combination schedule for data recorded using the spread sequence of Figure 3. Depth points represented by the stacked data are the same as those recorded from shotpoint 2 C.

S. P. No.		Depth point No.																							
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	A	17	18	19	20	21	22	23	24																
	B	15	16	17	18	19	20	21	22	23	24														
	C	13	14	15	16	17	18	19	20	21	22	23	24												
2	A	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24				
	B	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24		
	C	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
3	A									1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	B											1	2	3	4	5	6	7	8	9	10	11	12	13	14
	C													1	2	3	4	5	6	7	8	9	10	11	12
4	A																					1	2	3	4
	B																							1	2
	C																								

Table 3. Table illustrating the channel combination schedule for data recorded using the spread sequence of Figure 4. Depth points represented by the stacked data are the same as those recorded from shotpoint 6.

S. P. No.	Depth point No.																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	21	22	23	24																				
2	17	18	19	20	21	22	23	24																
3	13	14	15	16	17	18	19	20	21	22	23	24												
4	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24								
5	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20								
6	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
7					1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
8									1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
9													1	2	3	4	5	6	7	8	9	10	11	12
10																	1	2	3	4	5	6	7	8
11																					1	2	3	4

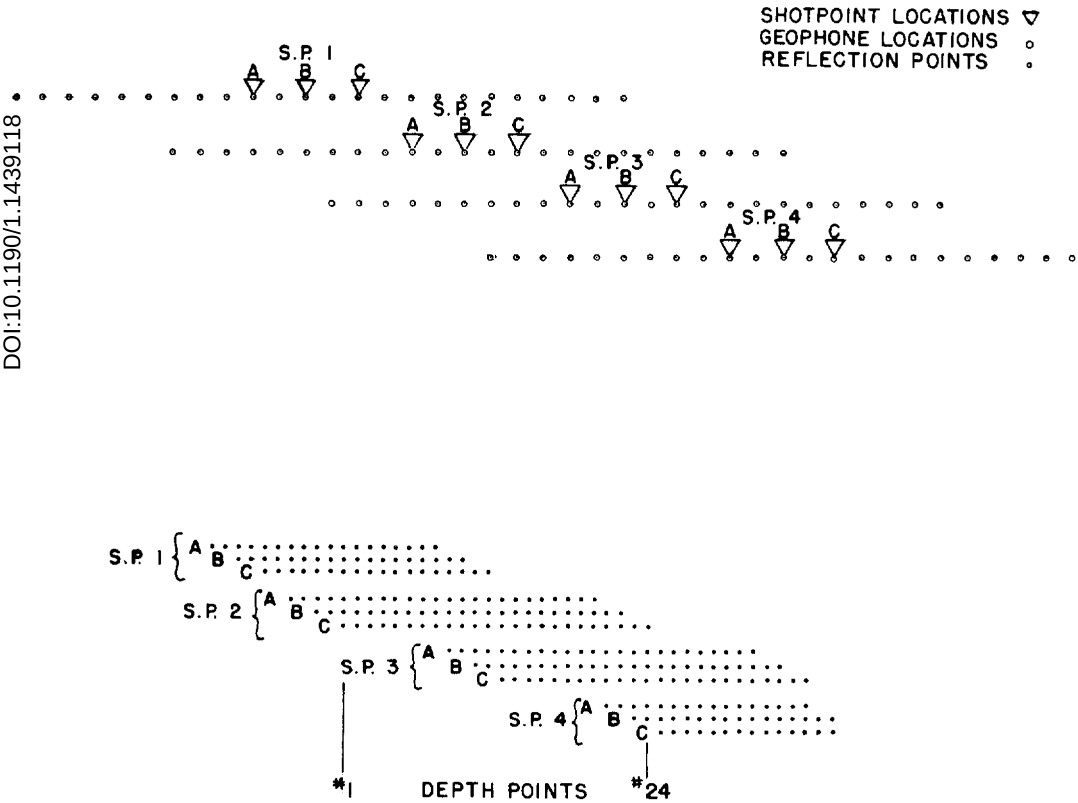

FIG. 3. Nonsymmetrical spread sequence which gives six-fold multiplicity using three shotpoint locations for each detector spread. The detector spread is advanced six stations forward after each sequence of three recordings. Shotpoints spaced two intervals apart.

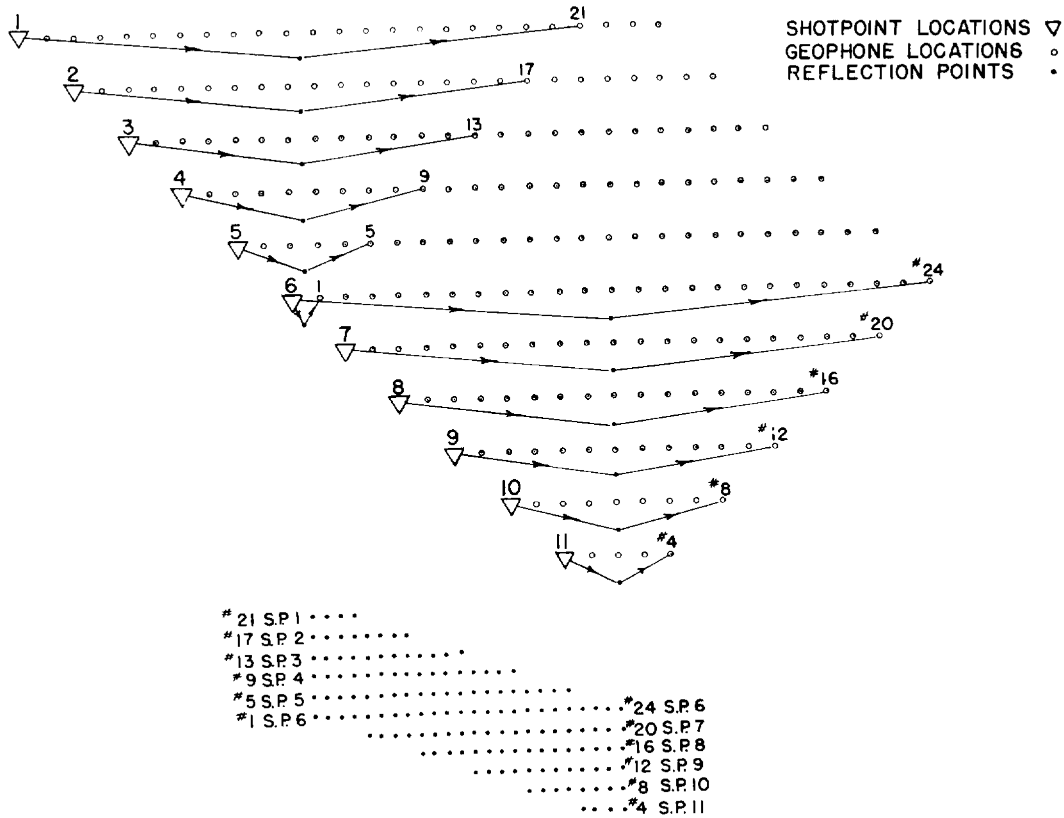

FIG. 4. Single-ended spread sequence giving six-fold multiplicity. Shotpoint and spread advanced together by two stations between successive recordings. Similar arrangements with the shotpoint at one end of the spread are preferred for use in attenuating multiple reflections.

sumed. An objective of major interest is postulated at a depth of 8,960 ft which corresponds to a vertical two-way time of 2.300 sec. The second-order reflection (simple multiple) from a shallow reflector at 3,898 ft would also have a total travel time of about 2.300 sec. The relative strength of the two reflections will, of course, depend on the reflection coefficients involved. Since the travel path of the multiple is confined to a lower velocity zone, it will exhibit the stepout shown by the upper curve of Figure 5, assuming straight-path geometry. The deep primary reflection will follow the stepout shown by the middle curve. The lower curve shows the difference in stepout between the two events. Hence if a number of channels with different shotpoint-to-detector distances are combined so that the primaries are in coincidence, the multiples will be out of phase as indicated by the lower curve. For example, suppose we combine five paths, and the multiple has a period of 0.035

Table 4. Table comparing the actual stepout differences obtained with the desired theoretical optimum values when the spread arrangement of Figure 4 is adapted to the example shown in Figure 5. The detector spacing is chosen to provide the desired overall difference in stepout between the nearest and the farthest common-reflection-point channels recorded. More attenuation can be obtained by using only five channels as shown, since there is so little difference in stepout between channels one and five. Station interval is 215 ft.

Station No.	Distance	Actual Stepout	Stepout for Optimum Attenuation
1	215		0
5	1070		
9	1925	.006	.007
13	2785	.011	.014
17	3640	.019	.021
21	4500	.028	.028

Actual attenuation of 5 channel summation > 4.5 to 1.

sec. Attenuation behavior will be the same as for a five-unit pattern array. Hence we must have a minimum of 0.035/5 or 0.007 sec difference in stepout between the successive paths, or a total of 0.028 sec between the extremes if adequate attentuation is to be obtained. The estimated distances required to establish the necessary differences are indicated in Figure 5 by the circled points numbered one through five on the lower curve. Note that the distance to the fifth or farthest channel in this example is 4,500 ft. Shorter distances will seriously reduce the attenuation and should not be considered. Longer distances will not seriously affect the attenuation, but become increasingly unwieldy. Obviously paths with a common reflection point must be used if excessive subsurface averaging is to be avoided. Of equal importance is the fact that the amount and direction of dip of either reflector is not significant if common-reflection point geometry is applicable.

One problem is apparent from Figure 5. Since the differential-stepout-versus-distance curve is not linear, the desired station intervals are nonuniform. Suppose that data are to be recorded using the spread arrangement of Figure 4. If the required 0.028 sec stepout is developed between a station 1 and a station 21 (Table 3), our station interval should be 4,500/21 or approximately 215 ft. Table 4 shows the comparison between the theoretical stepout desired, and the actual values obtained. These approximations yield better than a 4.5-to-1 theoretical improvement in the primary-to-multiple ratio, assuming sinusoidal waves. There is so little stepout difference between the nearest channels (1 thru 4) and their next corresponding common-reflection-point channels (5 thru 8) that better attenuation is

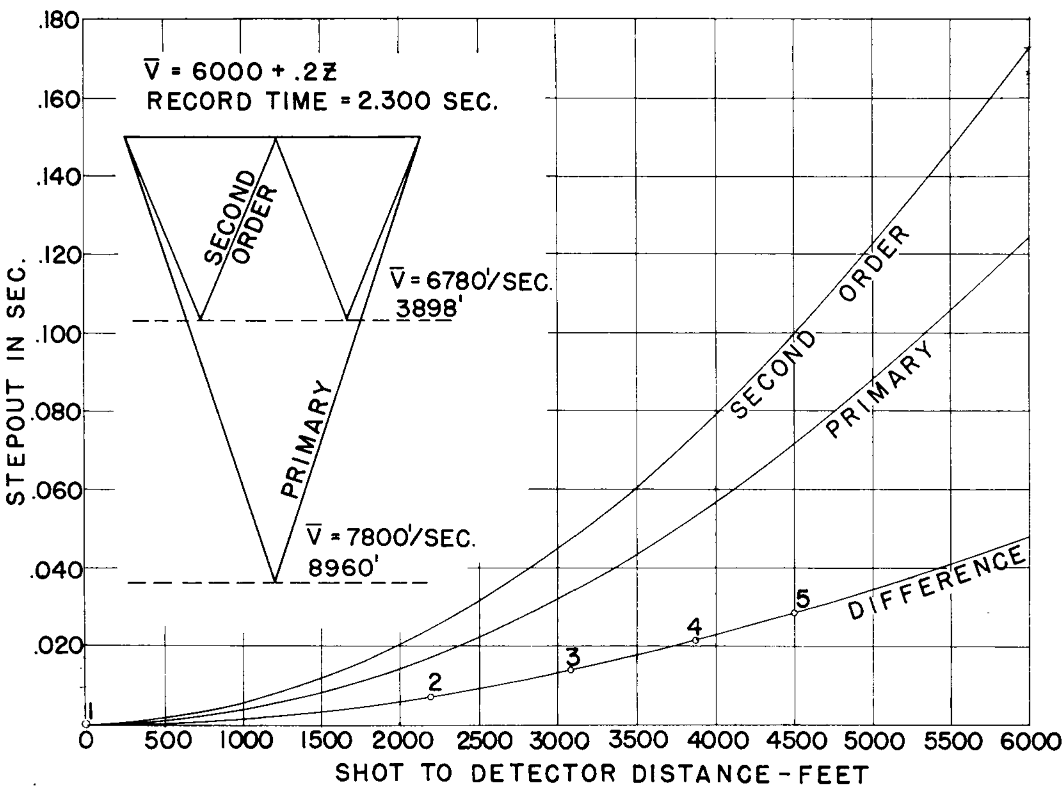

FIG. 5. Stepout as a function of shotpoint-to-detector distance for a primary reflection and a multiple with the same total travel time. Assumed velocity function is typical of the Gulf Coast of Texas. The lower curve represents the difference in stepout between the multiple and the primary at each distance. The circled points numbered 1 thru 5 on the lower curve show the distance at which channels should be recorded to obtain infinite theoretical attenuation of a sinusoidal multiple with a period of 0.035 sec. Corrections for the moveout of the primary would be applied, and the five channels combined to produce a single resultant.

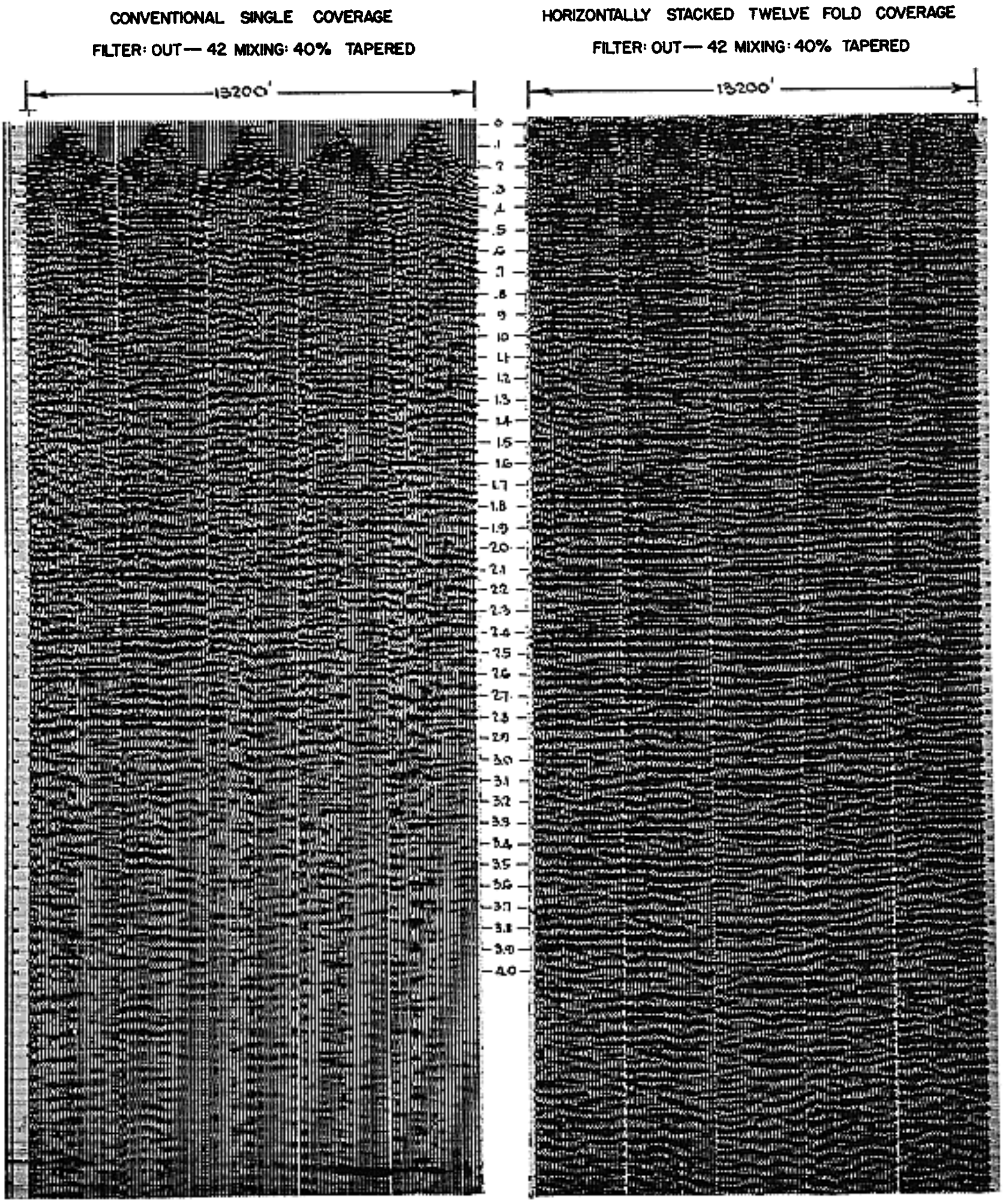

FIG. 6. Comparison of the same traverse recorded with conventional single coverage and stacked 12-fold multiplicity in the Powder River Basin of Wyoming. Shot and detector patterns, and playback settings were identical for both sections.

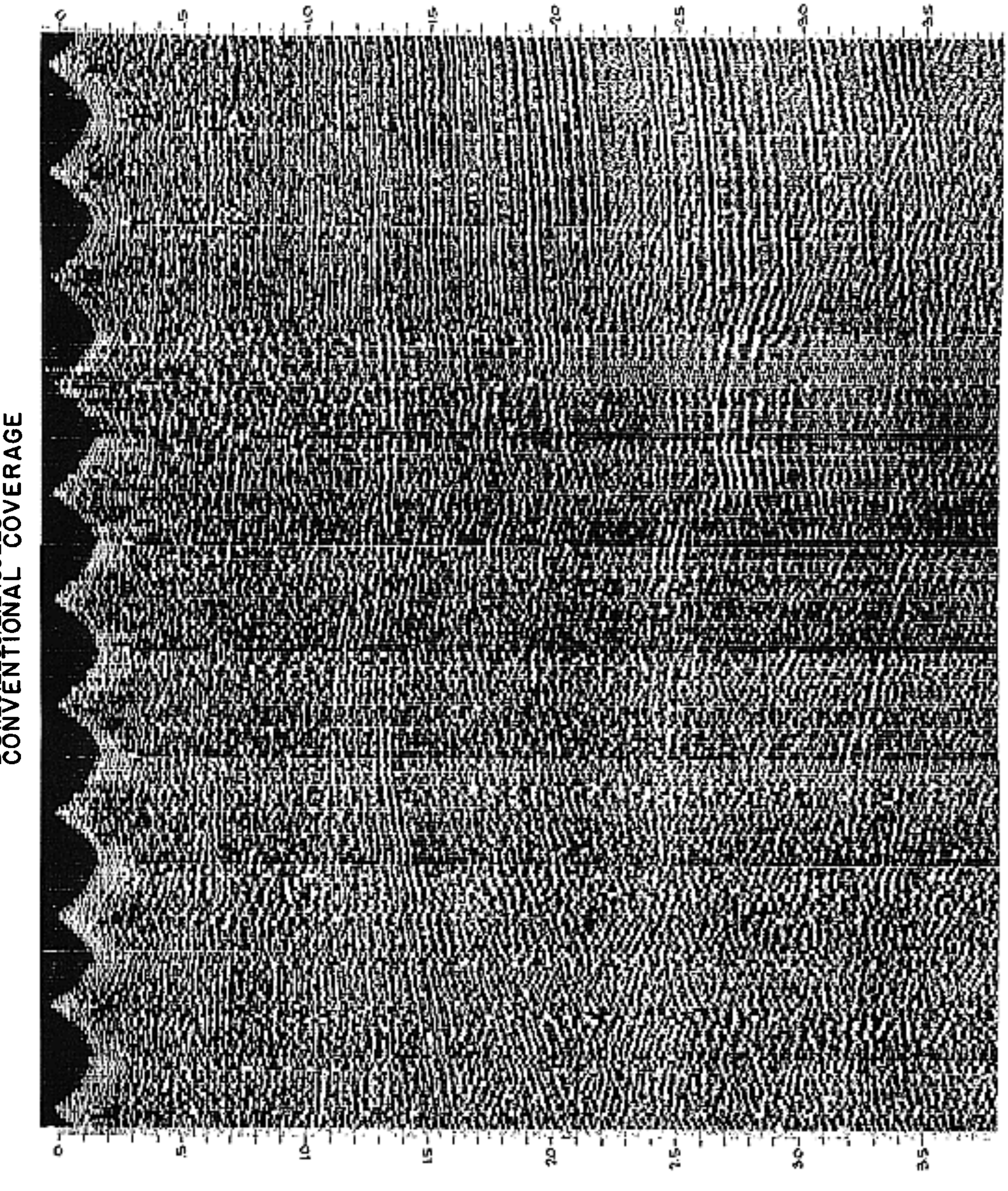

FIG. 7. Conventional single coverage traverse recorded in Southern Oklahoma indicating highly complicated geological conditions. Shot and detector patterns, and playback settings are identical with those used for Figure 8.

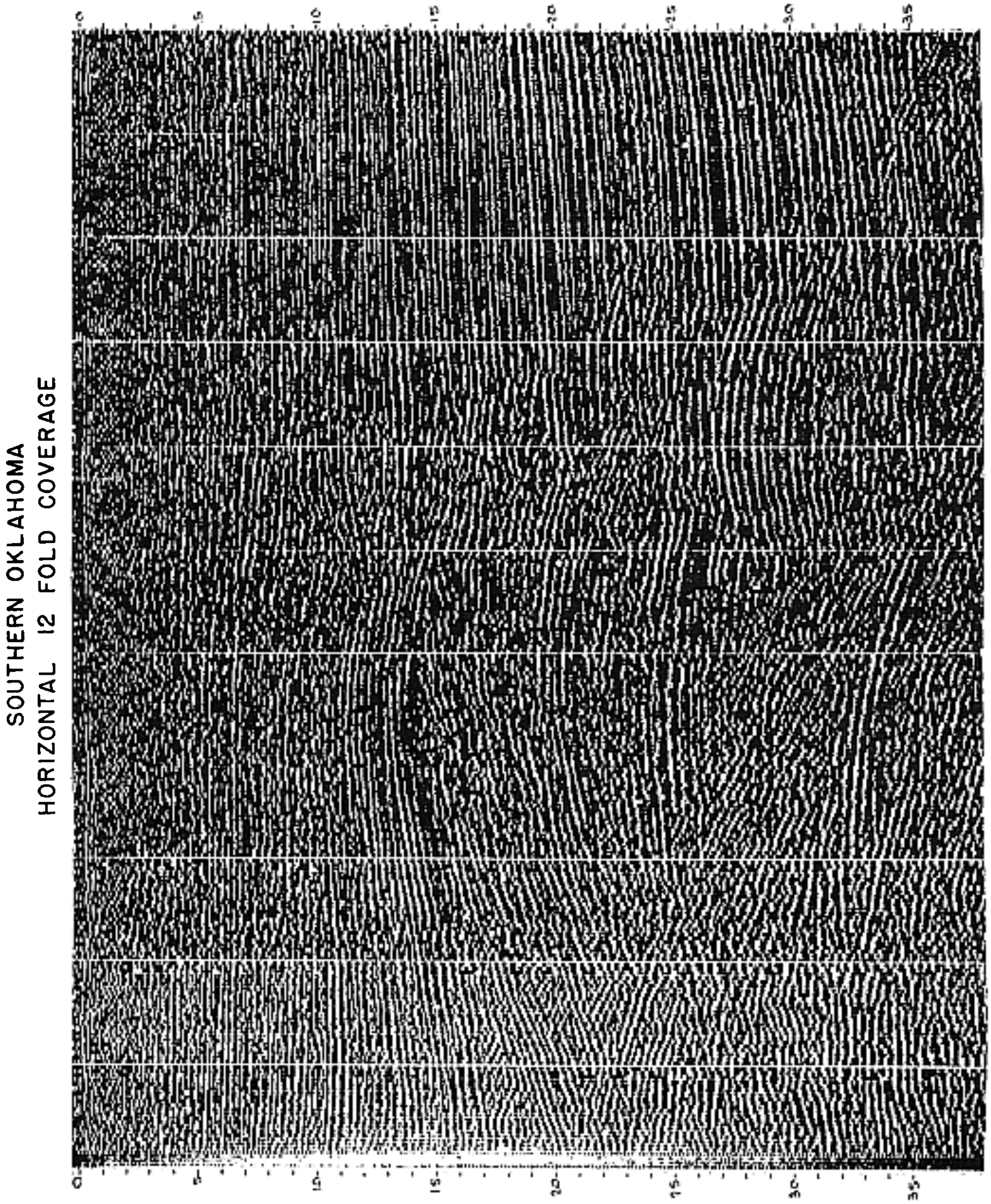

FIG. 8. Same traverse as Figure 7 using stacked 12-fold multiplicity. All field and playback parameters identical with those used in obtaining Figure 8.

obtained if channels 5 thru 8 are omitted. Use of all six channels reduces the corresponding ratio to 2.5 to 1.

The common-reflection-point technique is also advantageous when inverted-polarity mixing is used to attenuate multiple reflections. This form of skip mixing is effected by first adjusting the multiples to time coincidence. After adjustment the polarity of one channel is reversed, and it is then combined with any normal polarity channel having similar waveform and amplitude.

Attenuation of the multiple reflection will be limited only by the degree of waveform identity between the two signals, and the precision of the phase and amplitude adjustments.

Destructive interference will also attenuate the primary reflections unless they happen to be approximately one-half cycle out of phase on the channels which are combined. This means that the differential stepout between the multiple and the primary reflections must be one-half the period of the primary reflections, and the resultant primary reflection pulse will be broadened by one-half cycle. Thus, for a primary reflection period of 0.035 sec, Figure 5 indicates that channels separated by a spread distance of approximately 3,500 ft must be selected to avoid attenuation of the primary reflection. Although fortuitous dip relations might permit combination of channels closer together, this illustrates the order of subsurface averaging which will probably occur.

This excessive subsurface averaging will be avoided if common-reflection-point channels which possess the proper difference in stepout are used. The multiple reflection will be attenuated as before, but use of the common-reflection-point technique will eliminate subsurface averaging, and will also make the process independent of the dips involved.

DATA COMPARISONS

Figure 6 illustrates a conventional traverse in the Powder River Basin of Wyoming compared to the same traverse with 12-fold multiplicity.

Shot pattern, geophone arrangement and playback settings were identical.

Figures 7 and 8 show a similar comparison in Southern Oklahoma.

FIELD EXPERIENCE

Considerable field experience in a wide variety of terrain has been accumulated. While experience has varied somewhat from place to place, certain common considerations have become apparent.

1. Filter: Because of improved attenuation of "ground roll" and other extraneous low-frequency noise, wider-band filters can generally be used. They are preferable because reflection character and apparent damping are improved, and the required correction precision is somewhat reduced.
2. Spreads should be as long as practicable. Not only are they more efficient from a production standpoint, but data quality is enhanced. Detector stations should be at least 220 ft apart, and 440 ft is desirable if conditions permit. The longer spreads are much less vulnerable to multiple reflections, and complement the multiplicity obtainable with conventional pattern arrays.
3. The most effective shot and detector patterns permitted by economic considerations should be employed. The added multiplicity available with this technique should be used as a supplement to normal good practice and not in substitution thereof.
4. Preliminary traverses in an area should be recorded with greater multiplicity than may be necessary. Test processing can then be performed to select the most economical arrangement.
5. Corrections for moveout, weathering, and elevation must be accurately determined and precisely applied. Careful editing of corrections, and deletion of obviously poor data can be of great benefit.
6. Approximately the same daily production can be maintained using this method as would be attained with conventional operations.

CONCLUSION

The common-reflection-point, horizontal-data-stacking technique has added a new order of magnitude to the usable dimensions of multipath pattern array geometry. Signal-to-noise ratios have been enchanced well beyond the saturation point of conventional pattern methods. Field effectiveness has been demonstrated in Mississippi, South Louisiana, the deep Frio and Wilcox trends of the Texas Gulf Coast, the Delaware and Palo Duro Basins of Texas, the thrust areas of Southern Oklahoma, the Powder River Basin of

Wyoming and Montana, and Colombia, South America.

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