3-D symmetric sampling in theory and practice

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In brief, 3-D symmetric sampling criteria are:

1) shot station interval = receiver station interval.
2) shot line interval = receiver line interval.
3) maximum in-line offset = maximum cross-line offset.
4) center-spread acquisition for shots and receivers.
5) shot arrays required as much as receiver arrays.

Application of these criteria to orthogonal geometry leads to (a) square shape of cross-spreads, (b) common-receiver gathers that look like common-shot gathers, and (c) seismic character in the cross-line direction the same as in the in-line direction.

Figure 1 compares a wide geometry and a narrow geometry. The shot- and receiver-line patterns are the same; the only difference is the maximum cross-line offset (the distance between a receiver spread and the farthest shot shooting into that spread). The generating swaths indicate a possible layout in the field. Note that a cross-spread is not normally acquired in one go; each time a generating swath is acquired, small portions of different cross-spreads are collected.

Editor's note: This article is a summary of a more comprehensive treatment of this subject by the same author which appeared in the September-October issue of GEOPHYSICS.

In 3-D symmetric sampling, the maximum cross-line offset is equal to the maximum in-line offset. This maximizes the useful extent of the cross-spreads at all levels. Figure 2 illustrates this with time slices through a (nearly) square cross-spread.

Figure 3 shows the need for shot arrays as well as receiver arrays. Linear arrays are sufficient for alias protection in the cross-spread. Each array takes care of one (in-line or cross-line) component of the noise. If scattering is a problem, areal arrays may be considered.

The main criteria considered when designing 3-D surveys are spatial continuity, resolution, the shallowest horizon to be mapped, the deepest horizon to be mapped, and noise suppression. The remainder of this article will discuss how symmetric sampling is beneficial in these areas.

An important aim of 3-D survey design should be to maximize spatial continuity and to minimize the number of edges. Though a brick-wall geometry reduces the largest minimum offset, it breaks up continuity in the cross-line direction (Figure 4).

The concept of spatial continuity was tested in Nigeria. Until then the brick-wall geometry was used with parameters as indicated in the top left of Figure 5. Part of the production survey was reshot with the geometry shown on the right of Figure 5. Note the large difference in spatial continuity between the subsets of the two geometries (Figure 5, bottom left). A comparison at objective level

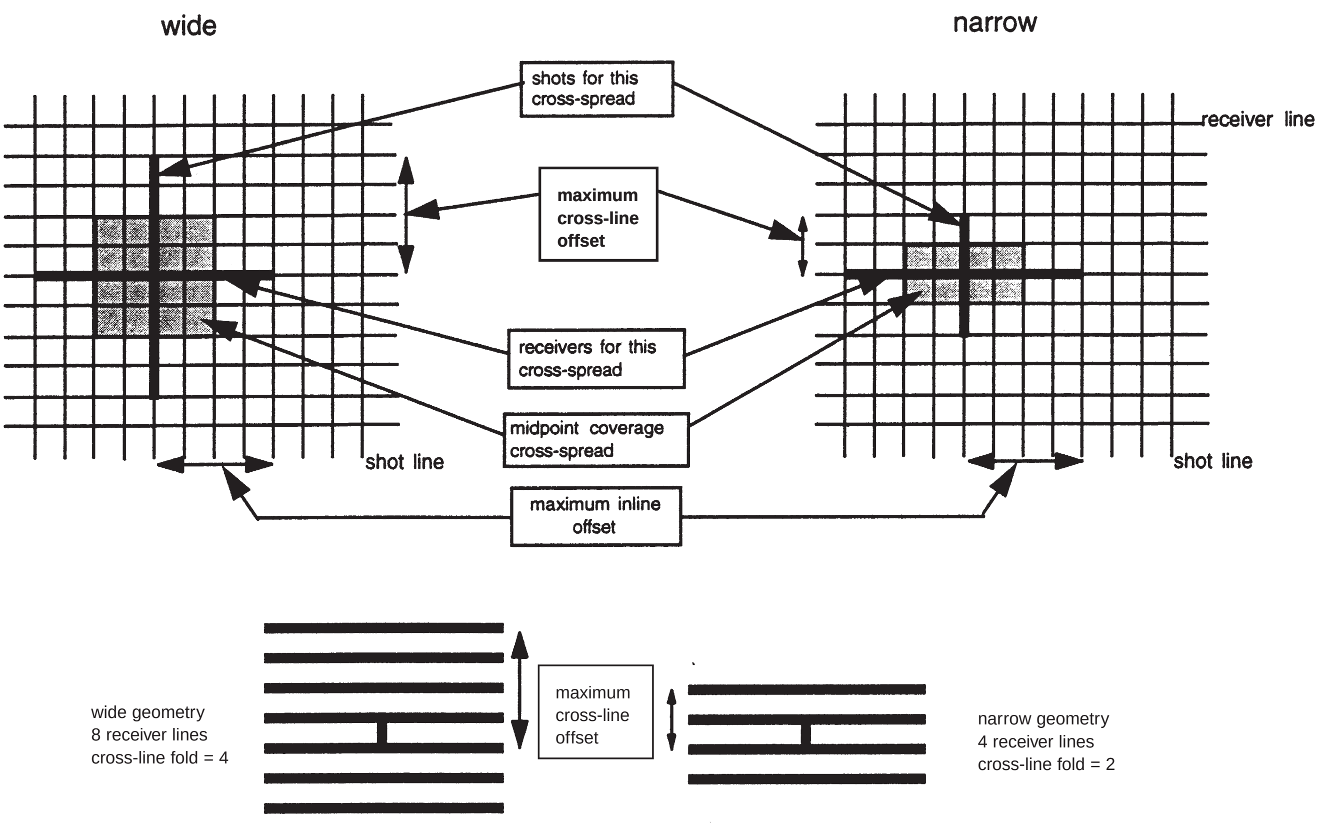

Figure 1. Narrow vs. wide geometries. Acquisition lines with cross-spreads (top) and corresponding generating swaths (bottom).

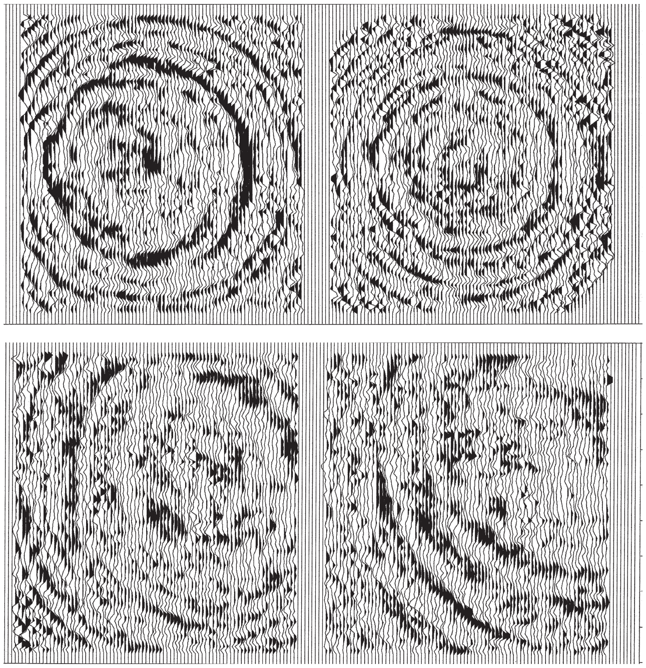

Figure 2. Time slices through cross-spread illustrate that square cross-spreads maximize spatial continuity: (a) 1700 ms, (b) 2100 ms, (c) 2500 ms, and (d) 2900 ms.

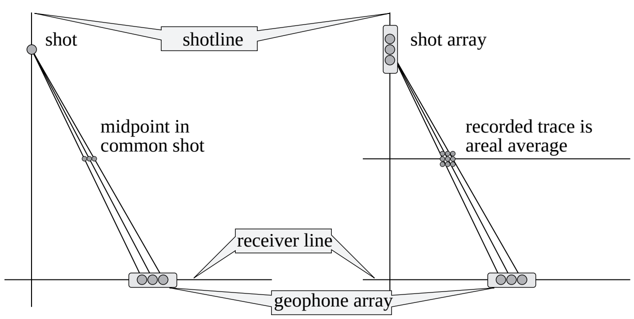

Figure 3. The need for arrays.

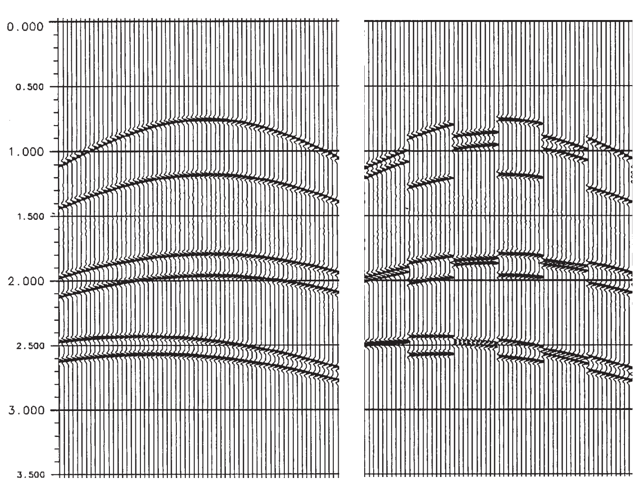

Figure 4. Continuous shot lines (left) vs. bricked shot lines (right), showing that the latter produce edges and reduce spatial continuity. Vertical axis is in seconds.

(Figure 6) demonstrates the better spatial quality of the cross-spread geometry.

Survey design. The design criteria listed above effectively reduce the choices that must be made during survey design because no distinction is made—in principle—between shot and receiver parameters.

As a starting point for design it is recommended that the shot line interval *S* be equal to the receiver line interval *R*, as this will produce the most regular coverage at shallow levels. Small deviations would not hurt too much.

A lot could be said about the choice of station intervals. The safest choice is to ensure that the desired signal is sampled without aliasing and to use arrays to take care of the ground roll with its smaller apparent velocities. But even this requirement tends to lead to station intervals, which are much smaller than generally believed to be affordable. Therefore, in actual practice, station intervals are selected larger, perhaps such as to prevent aliasing at the objective level (where the minimum apparent velocity is usually larger than at shallow levels).

The mute function (Figure 7, left) is of paramount importance for the determination of line interval and maximum offset, because it determines the range of offsets that can potentially contribute to each time level. The larger the line interval, the deeper the level where full single-fold coverage is reached.

As an example, assume four-fold coverage at level t_{sh} is deemed to be adequate. Only midpoints lying in a circle with radius $x_{sh}/2$ may contribute data to this level (see Figure 7, right). If line interval is $S = x_{sh}/2\sqrt{2}$, then at least four circles overlap in every point, i.e., at least four-fold coverage is reached at t_{sh}. The same reasoning may be applied to the fold requirement at other levels, leading to various line intervals of which the smallest would be the safest and the most expensive.

Often, the shallowest level determines the smallest required line interval. Then, with $M = (X_{max}/S)*(X_{max}/R)$ (*M* is full-fold multiplicity, X_{max} is maximum in-line and cross-line offset determined from mute function at objective or at deepest level), *M* is usually large enough for adequate noise suppression. If not, various actions may solve the problem. These include increasing fold (by making *S* smaller), using areal geophone arrays, or reducing the separation between shots and receivers.

It may also turn out that the fold *M* following from the choices of X_{max} and *S* may be deemed too large; then maximum offset may have to be reduced, or line interval enlarged.

The longer an offset, the deeper the time level where a trace with that offset starts to contribute. At shallow levels only very small offsets can contribute. A negative property of the orthogonal geometry is that between the acquisition lines no very small offsets can occur. At any point (or bin) there is a minimum offset, and the largest minimum offset (LMOS) determines the level where complete single-fold coverage is reached (Figure 8). Similarly, full-fold coverage is only reached for a time for which mute offset = $X_{max}\sqrt{2}$.

The smallest offsets occur around the intersections between the shot lines and the receiver lines. In combination with the mute function this means that fold is not constant at any time level above the level where full fold starts.

In Figure 9 the mute function is used to establish that at the shallowest level of interest (1000 m) the maximum offset equals 2000 m. For a required fold of 4 at that level

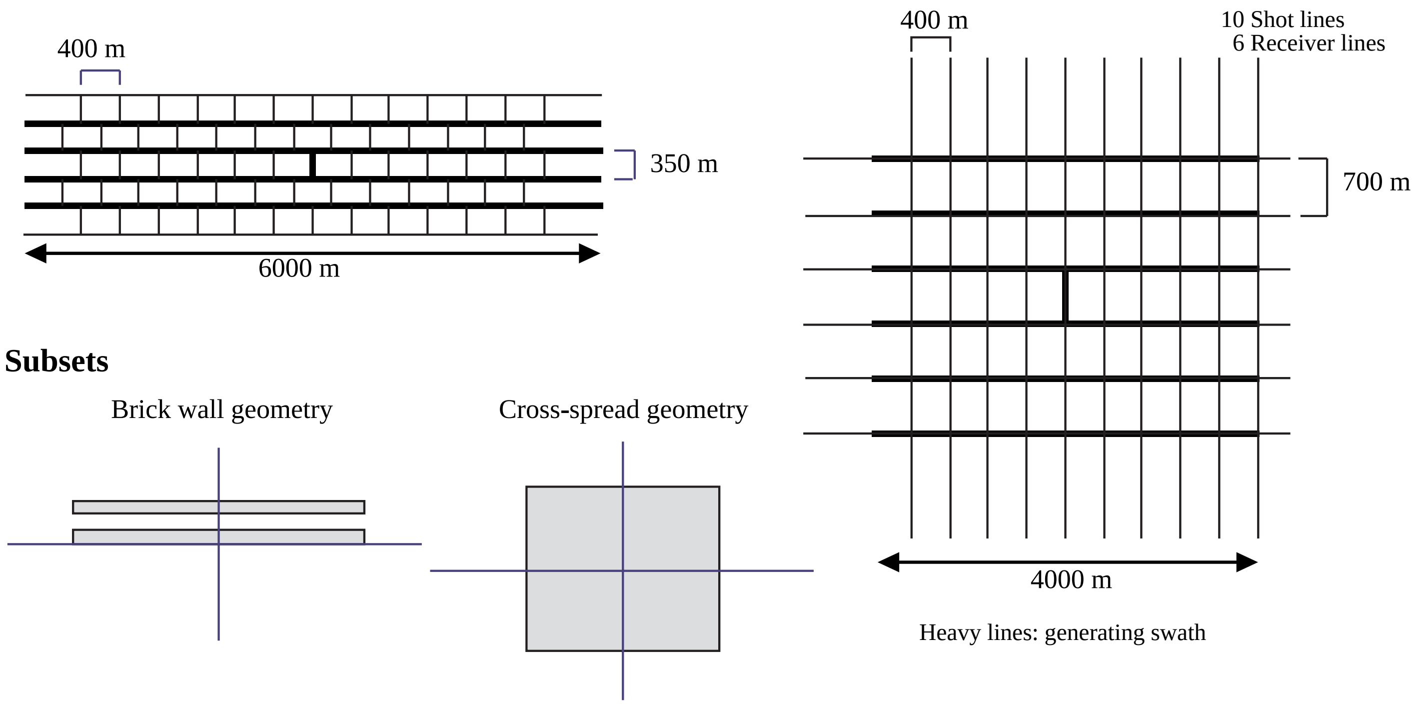

Figure 5. Conventional brick geometry (left) vs. cross-spread geometry (right).

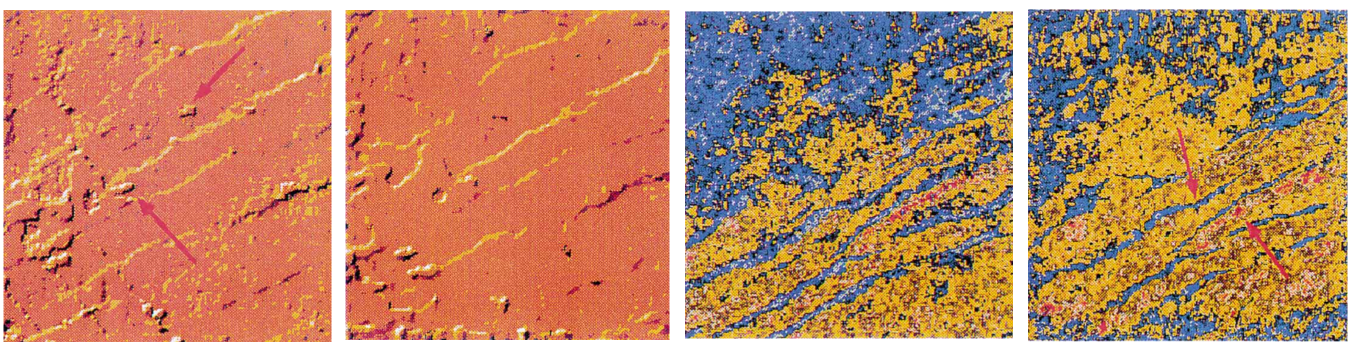

Figure 6. Illumination (left two blocks) and amplitude (right two blocks) produced by brick wall and cross-spread geometries. The cross-spread generates a cleaner image and more sharply defined faults. The brick-wall results are on the left of each pair of displays.

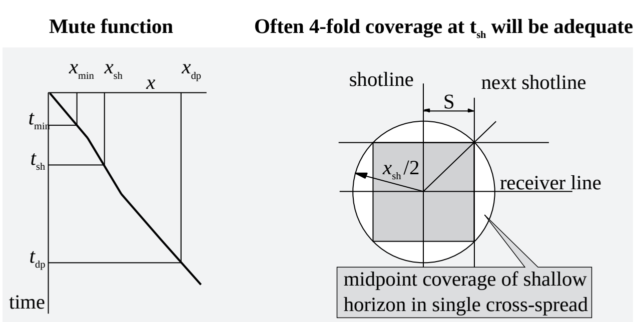

Figure 7. Determination of line interval and maximum offset.

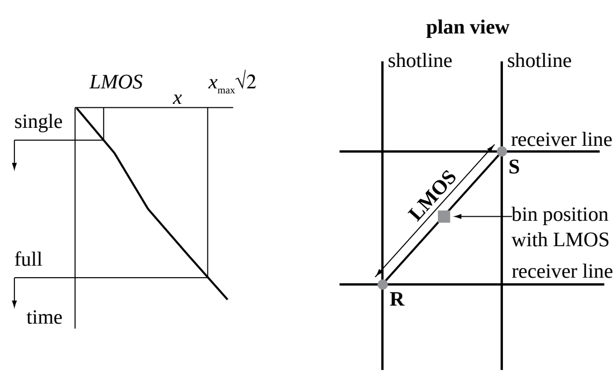

Figure 8. Impact of mute function (LMOS = largest minimum offset).

a line interval of 700 m is adequate. Alternatively, one can decide that there should be at least single-fold coverage at level t_{min} = 450 ms. The corresponding mute offset is the required LMOS, which then leads to a required S.

Finally, the mute function is used to read the optimal maximum offset valid for the deepest level of interest.

Fine tuning. After a decision has been made about the nominal geometry parameters, it is often necessary to move shot locations (or receiver locations) to accommodate obstacles. The conventional solution is the "midpoint-centering solution" (Figure 10, right). In this approach the shots are moved parallel to the receiver line across a distance equal to an integer number of receiver station intervals. In this way all midpoints will remain centered in the bins. As a consequence, discontinuities are created in the common-receiver gathers. In Figure 11 this is illustrated with a reflection, but coherent noise is similarly affected. Each discontinuity may lead to edge effects in later processing. A better alternative is to use a smooth acquisition line skirting the obstacle (Figure 10, left). This maintains continuity and reduces the amount of edge effects.

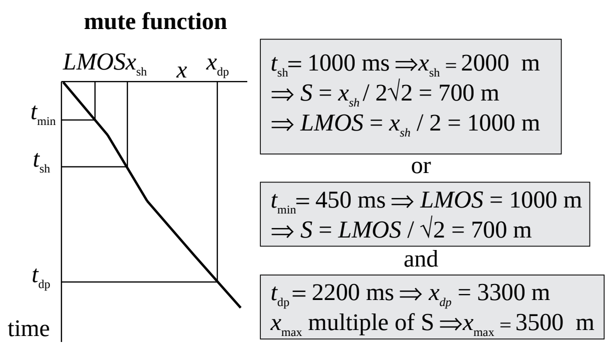

Figure 9. Example of determination of line interval

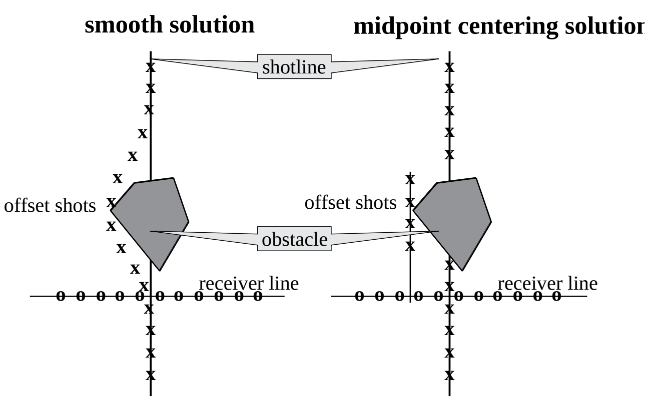

Figure 10. Avoiding data gaps due to obstructions.

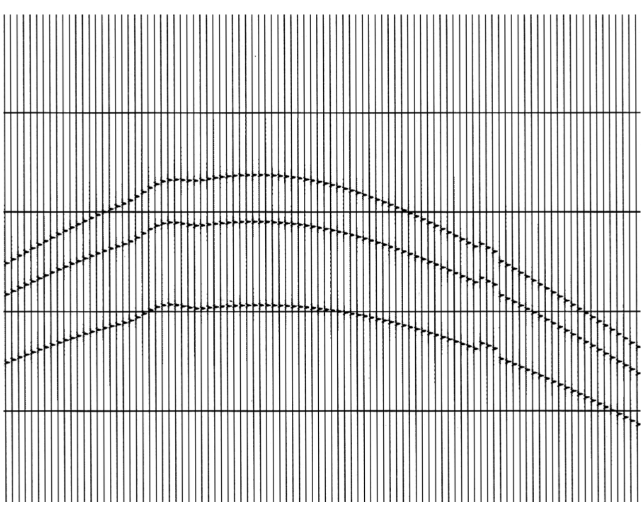

Figure 11. A smooth solution (left) avoids spatial discontinuities in signal and noise, thus minimizing edge effects. The midpoint centering solution (right) produces discontinuities.

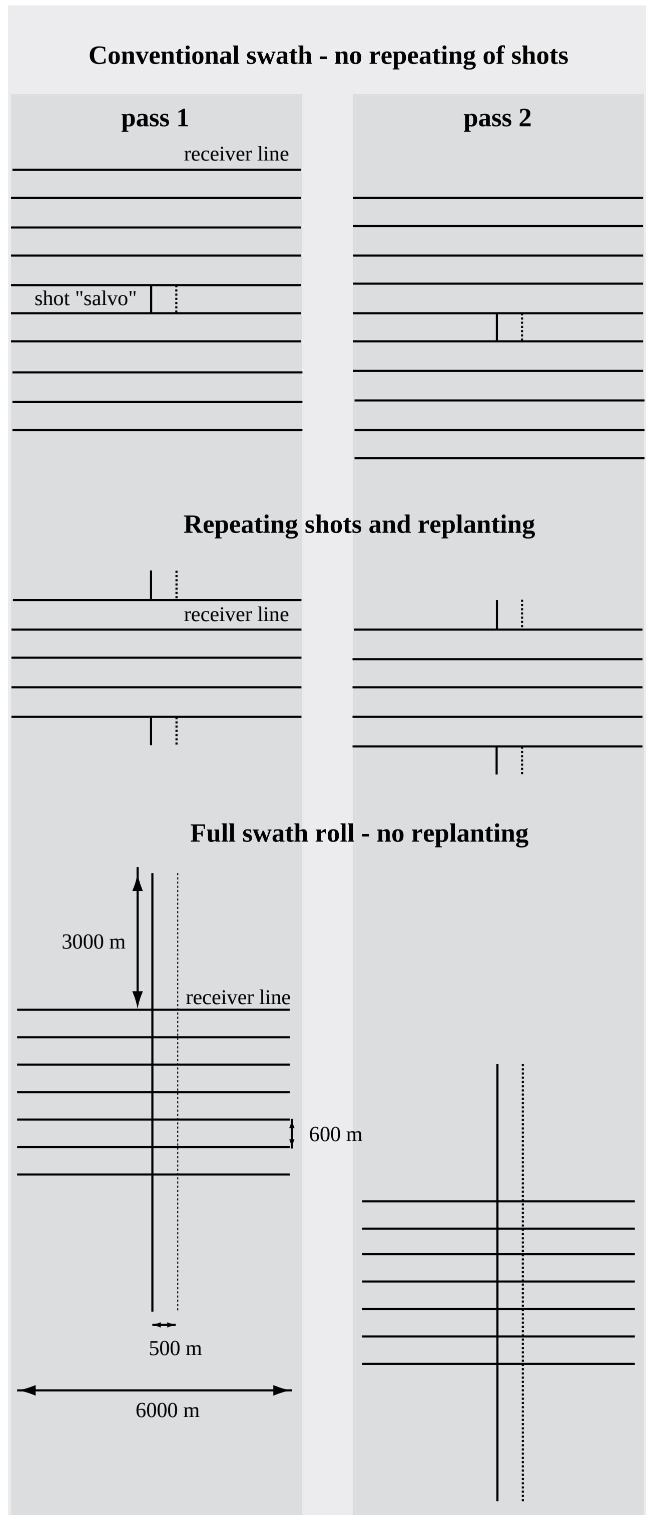

Figure 12. Same nominal geometry can be realized with different swath arrangements.

The use of a wide geometry may lead to some logistical problems. The conventional swath approach (Figure 12, top) requires many channels and much replanting of geophones. Fortunately, the same geometry may also be acquired in many alternative ways. The main degree of freedom is to compromise between replanting of geophones and reshooting of shot positions. Figure 12 (center) shows a solution requiring half as many channels. A solution with no replanting of geophones—the full-swath roll (Figure 12, bottom)—gives great flexibility as to the number of receiver lines to be used, but it requires repeating of shots.

Suggestions for further reading. 3-D symmetric sampling is an offshoot from the theory of 2-D symmetric sampling discussed in *Seismic Wavefield Sampling* (SEG, 1990) and in "Symmetric sampling" (*TLE*, 1991).

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