GC 3-D Design Philosophy – Part 2: Target Depth*

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Shallowest Target and Line Spacings

This article is the second of a four-article series – this topic considers Part 2 labeled on the Figure 1 flow chart of 3-D seismic design methodology.

The depth of the shallowest target that must be imaged across a prospect is a key control on the geometry of a 3-D acquisition grid, because that depth dictates the distance that source and receiver lines should be separated. If there is a shallow interface that has a known dip across a prospect, that interface should be imaged even if it is not related to a reservoir – because by making the image dip match the known dip, data processors are assured the static corrections, shallow velocity analyses and other data processing procedures that affect reflector dip and continuity have been correctly done. In other cases, a shallow reflector may need to be imaged so it can be used to make isopach maps. If this shallowest target is at a depth Z_1, then a 3-D grid should be structured so that for every stacking bin there are several (at least three or four, and ideally seven or eight) source-receiver pairs that:

- Are separated a distance no greater than Z_1.
- Cause reflection points to fall inside the bin.

Figure 2 is a section view showing raypaths that result when a source-to-receiver offset equals the shallow-target depth Z_1. If a source-to-receiver offset exceeds Z_1, there is a high probability that the illuminating wavefield will be critically refracted at or above Z_1 and will not provide a reflection image of the shallow target. Therefore, a 3-D design must ensure that at every stacking bin there are several source-receiver pairs that are separated a distance that does not exceed offset distance X_{min} shown on Figure 2, where $X_{min}=Z_1$, the depth of the shallowest target. An effective way to ensure this minimum source-to-receiver offset exists is to define the source-line and receiver-line spacings to be approximately the same as, or less than, the shallow-target depth Z_1. A good choice is to set the line spacing at one-half or less of the shallow target depth.

An example of one possible design is shown on Figure 3. This particular geometry illustrates a common design philosophy in which the receiver-line spacing is approximately the same as the shallow-target depth, but for reasons of economy (that is, to reduce the number of source stations per square mile), the source line spacing is slightly larger.

For this design, all source-receiver pairs inside shaded area ABCD satisfy the offset restriction that results in reliable imaging of stratigraphy at, and even slightly above, depth Z_1 within that shaded area. Similar overlapping, restricted-offset areas like ABCD extend completely across this particular 3-D grid. Thus, by answering the simple question "what is the shallowest target to preserve in the 3-D image?" a first approximation for source-line and receiver-line spacings that should be used in the 3-D field program can be made.

Deepest Target and Swath Size

The next parameter in the 3-D design is the depth of the primary, or deepest, target that is to be imaged. This depth is labeled Z_{tar} on Figure 2, and the raypath picture shows the source-to-receiver offset range that is particularly critical to imaging a target at this depth involves source-receiver pairs that are separated distances that range from zero to X_{max}, where X_{max} equals depth Z_{tar}.

Larger source-to-receiver offsets up to a distance of $2Z_{tar}$ also are important for both data processing and imaging reasons; thus offsets in the range Z_{tar} to $2Z_{tar}$ also should be created by the recording swath. When a seismic wavefield is generated at a particular source station, the 3-D recording swath is defined as that area spanned by the active receivers that record the seismic response generated at that station.

In concept, these active receiver stations should form a continuous areal coverage completely around the source point and extend at least a distance Z_{tar} (the depth to the primary target) in all directions away from each active source station. In practice, however, only approximations of this type of ideal recording swath sometimes can be created.

For example, if a square swath with side dimensions of $2Z_{tar}$ causes the number of receiver stations to exceed the channel capacity of the recording system, then a rectangular-shaped swath is commonly used, with the long dimension of the rectangle being $2Z_{tar}$ to create the required long offset distances, and the narrow dimension being as large as the channel capacity of the recording system will allow.

A typical, rectangular 3-D recording swath is illustrated on Figure 4. The active source stations are all of the source points on source lines S_1 through S_9 that are between receiver lines R_5 and R_6, and the recording swath spans all the receivers inside rectangular area ABCD centered about source point E.

To satisfy the raypath requirement shown on Figure 2, either the diagonal distance EC or one of the half-widths EF or EG must be approximately the same as the target depth Z_{tar}.

It is arbitrary as to which of these recording swath dimensions to set equal to Z_{tar}. The number of receiver lines included in swath dimension AD is determined by the receiver-line spacing (Figure 3).

Next Step

All of the first set of design parameters indicated on Figure 1 now have been calculated using geology to guide the design. The next step is to determine if these choices of source- and receiver-station spacings, source- and receiver-line spacings and recording swath size result in an acceptable stacking fold.

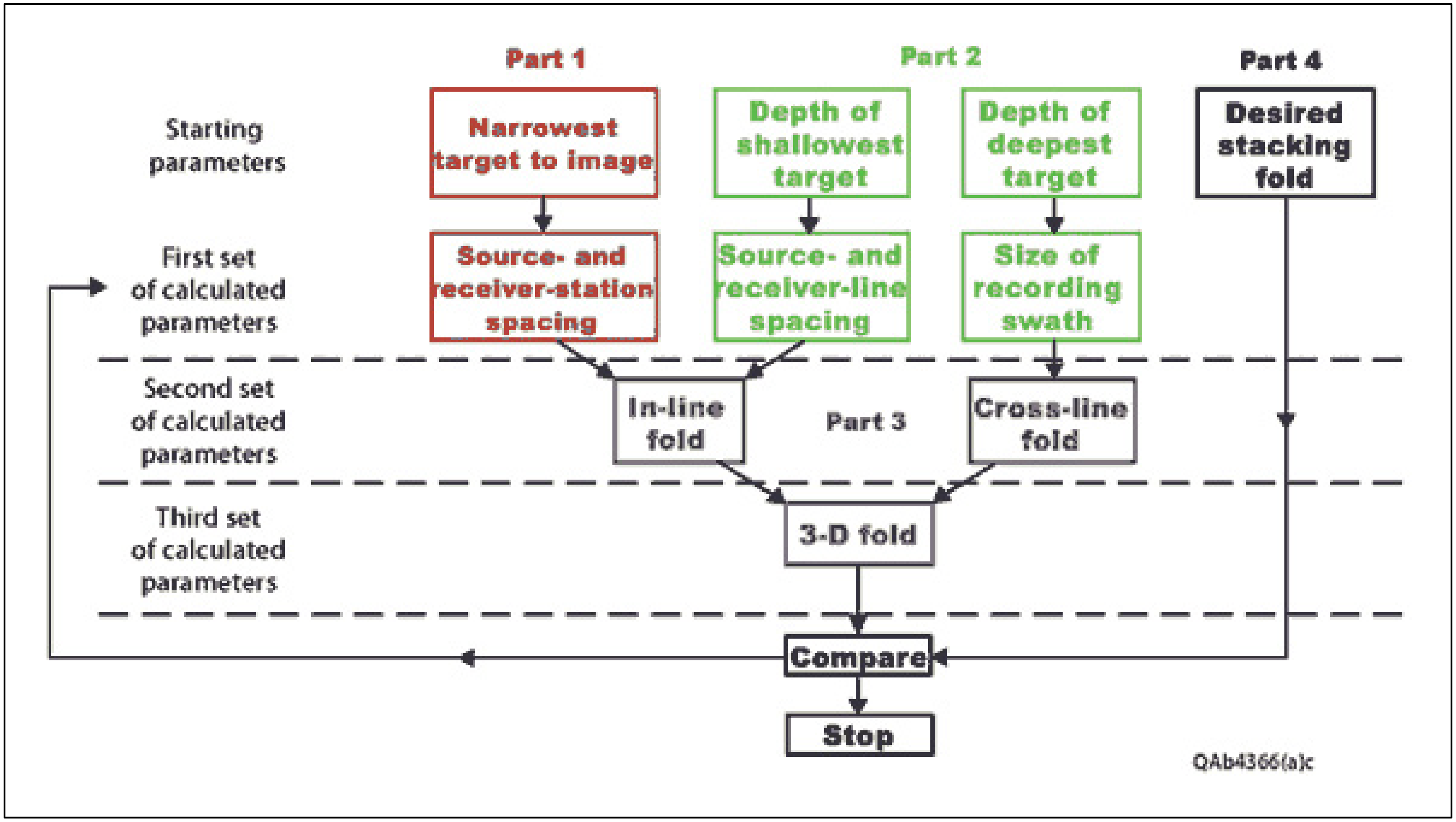

Figure 1. Planning steps that can be followed to design a 3-D seismic acquisition geometry. This article discusses the topics identified by the outlined area labeled Part 2.

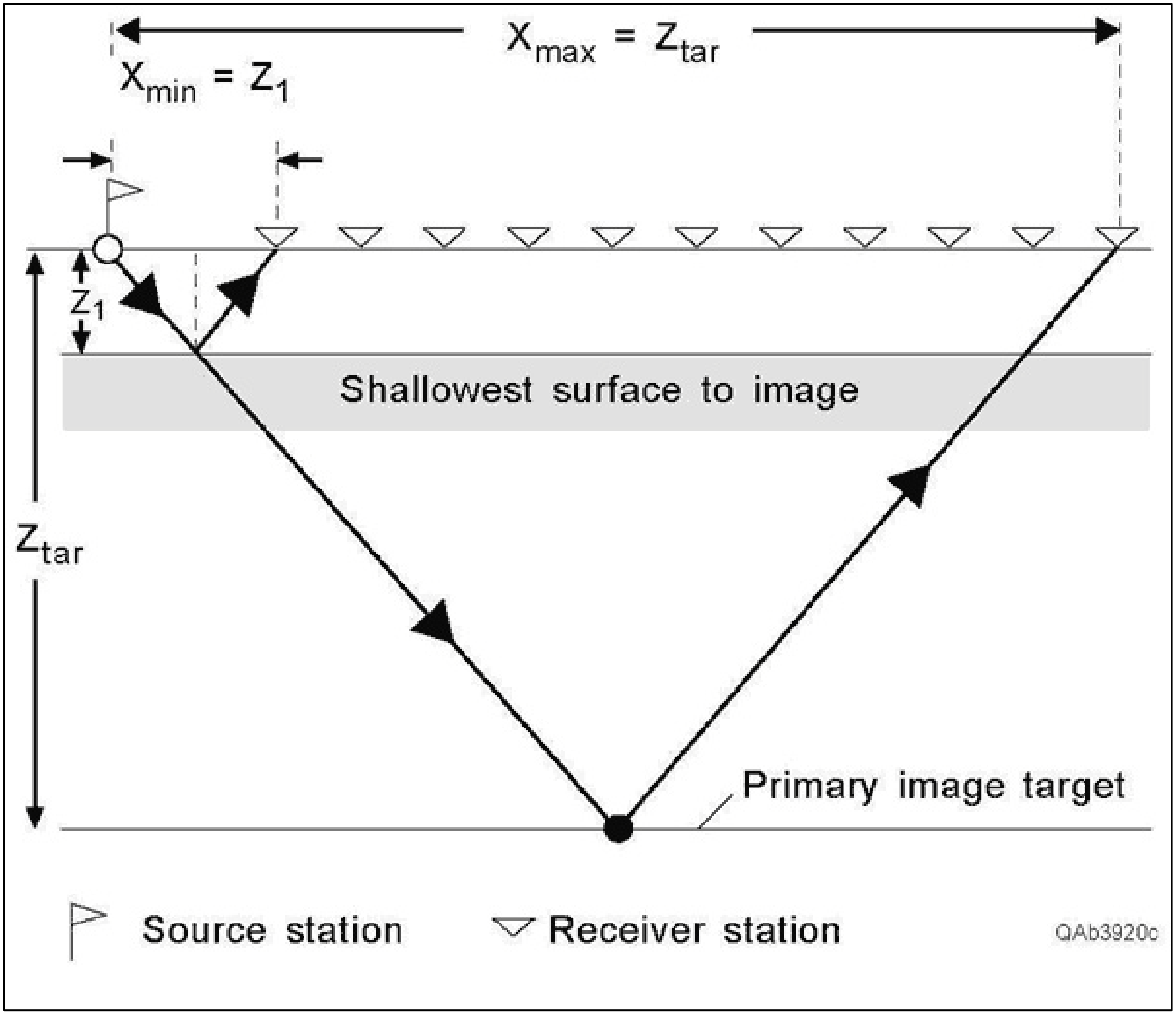

Figure 2. Section view of Earth layering that is to be imaged. A 3-D designer needs to know two critical depths: (1) depth Z_1 of the shallowest reflector that has to be Imaged, and (2) depth Z_{tar} of the primary target to be studied. If multiple targets exist at various depths, then Z_{tar} should be defined as the depth to the deepest target. The shallow target depth Z_1 controls the source-line and receiver-line spacings, which should be no larger than the offset distance X_{min} shown here. The deep target depth Z_{tar} defines the physical size of the recording swath, which should span an area having a width of about $2X_{max}$ in both the in-line and cross-line directions.

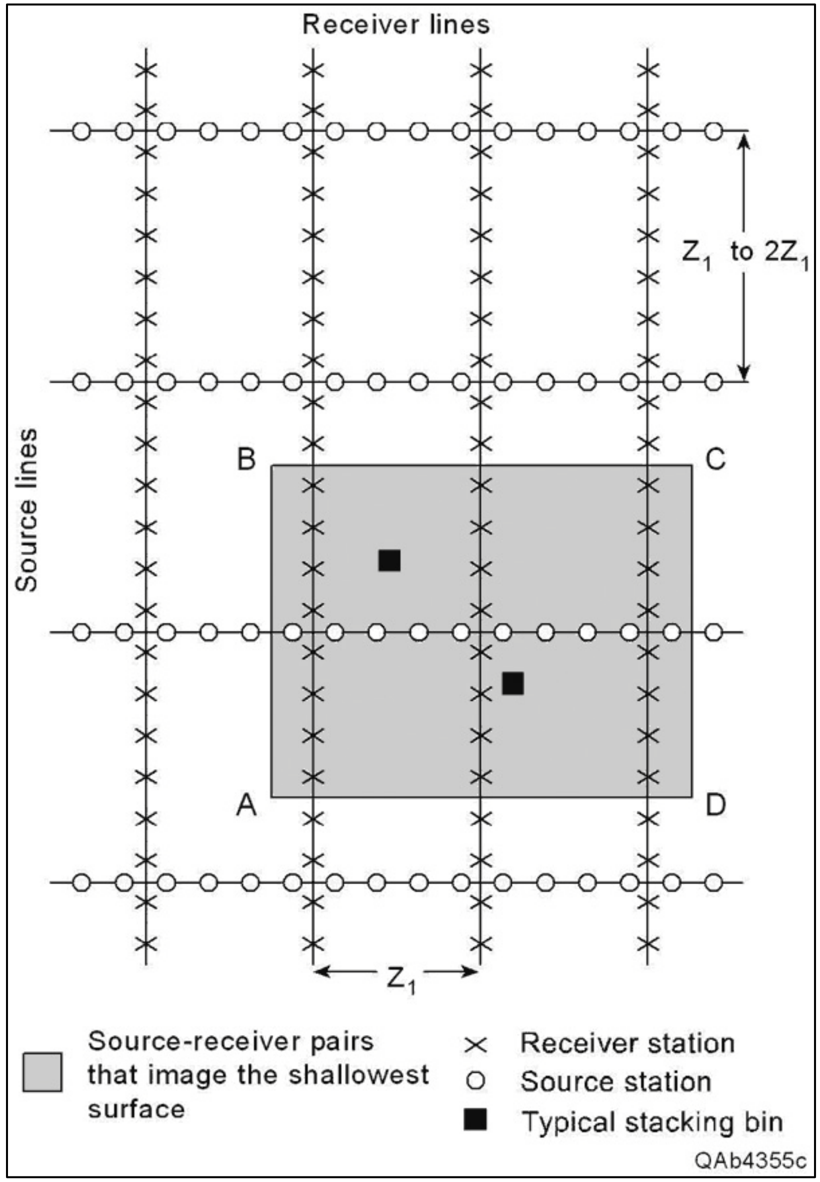

Figure 3. An example of source/receiver-line spacings designed to image a shallow target at a depth Z_1. In this example, the distance between the receiver lines is set to a value that equals shallow-target depth Z_1. In other instances a designer may elect to set the receiver-line spacing to be $0.5Z_1$ or less. All of the source-receiver pairs inside the shaded area ABCD have offset separations that are small enough to image stratigraphy at depth Z_1. Several (three to five) source-receiver pairs can be found that cause reflection points to be positioned inside each stacking bin, such as the two bins that are highlighted, which creates a continuous, low-fold image across the shallow target. For reasons of economy, the source-line spacing often is made larger than the receiver-line spacing, as is done here, to reduce the number of source stations per square mile.

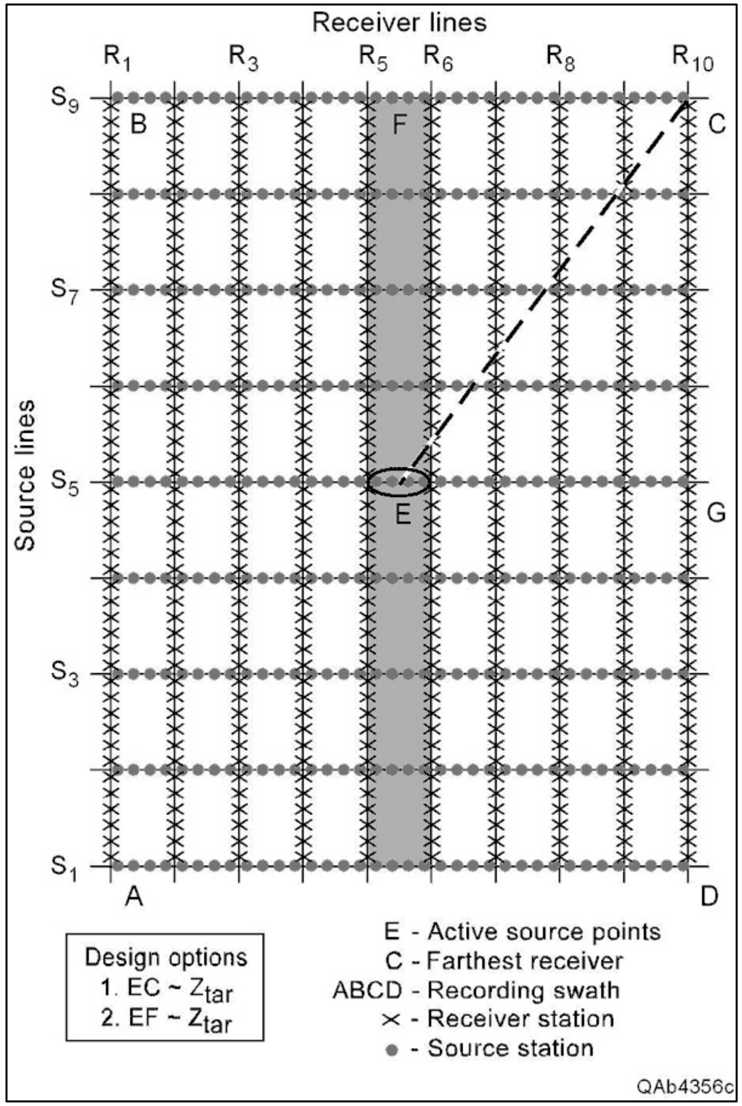

Figure 4. Recording swath designed to image a deep target at depth Z_{tar}. The swath is the area enclosed by rectangle ABCD, and the active source stations for the swath are all of the stations on source lines S_1 through S_9 that are between receiver lines R_5 and R_6 (the shaded strip). The fundamental requirement is that there must be several source-receiver offsets that are approximately twice the magnitude of target depth Z_{tar}. This offset condition exists when (1) the active source stations are on source lines S_1 and S_2 and the receiver stations between source lines S_8 and S_9 are active, or when (2) the active source stations are on source lines S_8 and S_9 and the receiver stations between source lines S_1 and S_2 are active. Some designers set diagonal distance EC equal to Z_{tar}; others set one of the widths EF or EG equal to Z_{tar}. Either option is satisfactory. At least one dimension of the recording swath must be approximately twice as long as depth Z_{tar} to the primary (or deepest) target. The number and length of receiver lines inside the swath are controlled by the source-line and receiver-line spacings and by the channel capacity of the recording system.