Design of Land 3-D Surveys*

By

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Optimum Geometry

In designing a 3-D survey, the geometry (arrangement of shots and receivers on the surface) must measure signal correctly and must also attenuate noise. Thus finding an optimum geometry should include the following steps:

1. Determine the maximum frequency required to resolve the target formation thickness -- from synthetics derived from well logs. This is Fmax.

2. Estimate average inelastic attenuation Q (the quality factor) over the interval from surface to target -- preferably using the log spectral ratio of downgoing wavelets from zero offset VSPs.

3. From spreading losses, transmission and reflection losses and the estimated Q value, graphs may be constructed (an example is shown in Figure 1), showing available frequency vs. time or depth.

   The available frequency at the target may be less than Fmax (point 1 above). If so, we must accept this new lower Fmax - because the earth itself will preclude higher frequencies at the target.

4. We now establish the desired S/N at the target. For example, the smallest change we wish to detect might be a 5 percent change in porosity, which will show up on a seismic trace as an 8 percent change in acoustic impedance (from petrophysical crossplots of acoustic impedance vs. porosity).

   If the seismic noise level is higher than this value, we will not be able to detect the change.

5. Estimate the expected S/N of raw shot data. This can be done either on some typical test shots or by dividing the S/N of a stack (or migrated stack) by the square root of the fold used to make this existing stack.

   Since:
   Fold = (S/N of final migrated stack / S/N of raw data)^2 ... then S/N raw = S/N migrated / Fold$^{0.5}$.

   Using an existing stack (possibly also migrated) has the advantage that the S/N improvement due to processing is taken into account.

6. From the desired S/N (point 4 above) and the estimated S/N of the raw data (point 5), we determine the required fold of the survey under design.

7. Next, the required bin size is calculated.

   The relationship between dip (θmax), velocity (Vrms), maximum unaliased frequency (Fmax) and bin size (Δx) is given by:
   $\Delta x = Vrms / (4 . Fmax . \sin(\theta max)$

   Thus, the optimum bin size to use for a dip of 90 degrees is given by Vrms / (4 . Fmax) -- or one quarter of the wavelength of the maximum frequency.

   In practice, this is often relaxed (a larger bin size is used), since it is really not practical (not to mention very expensive) to measure every dip with the maximum frequency.

   In Figure 2, an example of a crossplot of (Bin size, Vrms) vs. frequency (Fmax) is shown. The dip angle (θmax) is fixed at 30 degrees. This is based on the above equation and on Figure 1 (Fmax vs. time) above and shows how the frequency varies with velocity for a constant bin size (horizontal line). The increase in velocity can be related to an increase in time or depth, and the figure may be interpreted as showing the available Fmax on a dip of 30 degrees at increasing depths -- for different choices of bin size.

   Maximum frequency (Fmax) is critical. If Fmax is too high, then the consequent bin size will be too small -- and money will be wasted trying to record frequencies that are not available. Conversely, if Fmax is too low, the bin size will be too large and high frequencies coming from dipping events will be aliased and will not contribute to the final migrated image.

   Most surveys today are shot with too large a bin size and are thus under sampled!

8. Determine the minimum and maximum offsets (Xmin and Xmax). These are normally calculated from muting functions used in processing -- or automatic stretch mutes derived from velocities. The minimum offset corresponds to the shallowest target of interest -- and the maximum offset to the deepest target of interest.

   These two values (Xmin and Xmax) will be used to determine approximate shot and receiver line spacings (equal to Xmin multiplied by the square root of 2, for single fold at the shallowest target and equal line spacings) and the total dimensions of the recording patch.

9. Migration Aperture:
   Each shot creates a wavefield, which travels into the sub-surface and is reflected upwards to be recorded at the surface.

   Figure 3 shows an example of a model built for a complex sub-surface area. Such models can be ray-traced to create synthetic 3-D data volumes. Thus, the degree of illumination on any chosen target can be determined.

   In less complex areas, the migration aperture (amount to add to the survey to properly record all dipping structures of interest at the edges) is normally calculated from a 3-D "sheet" model of the target. This shows us how much to add on each side of the proposed survey and gives the total surface area of shots and receivers.

10. Now various candidate geometries can be developed. The shot and receiver intervals (SI and RI) are simply double the required bin size. Since fold, Xmin and Xmax are fixed, the only flexibility is to change the shot and receiver line intervals (SLI and RLI). However, we must have $Xmin^2 = SLI^2 + RLI^2$ (assuming orthogonal shot and receiver lines).

    We can make small changes in the line intervals (SLI and RLI), depending on whether shots or receivers are more expensive. For example, a ratio of 4/5 can give improved noise attenuation compared to 4/4.

    However, it is not wise to stray too far from shot and receiver symmetry. As the lack of symmetry increases, the shape of the migration response wavelet will change -- leading to undesired differences in resolution along two orthogonal directions.

11. The candidate geometries can each be tested for their response to various types of noise -- linear shot noise, back-scattered noise, multiples, and so forth. They can also be tested for their robustness when small moves of shot lines and receiver lines are made to get around obstacles.

    The "winning" geometry will be the one that does the best job of noise attenuation.

12. Acquisition logistics and costs may now be estimated for the "winning" geometry. Depending on the result (e.g., over or under budget), small changes may be made.

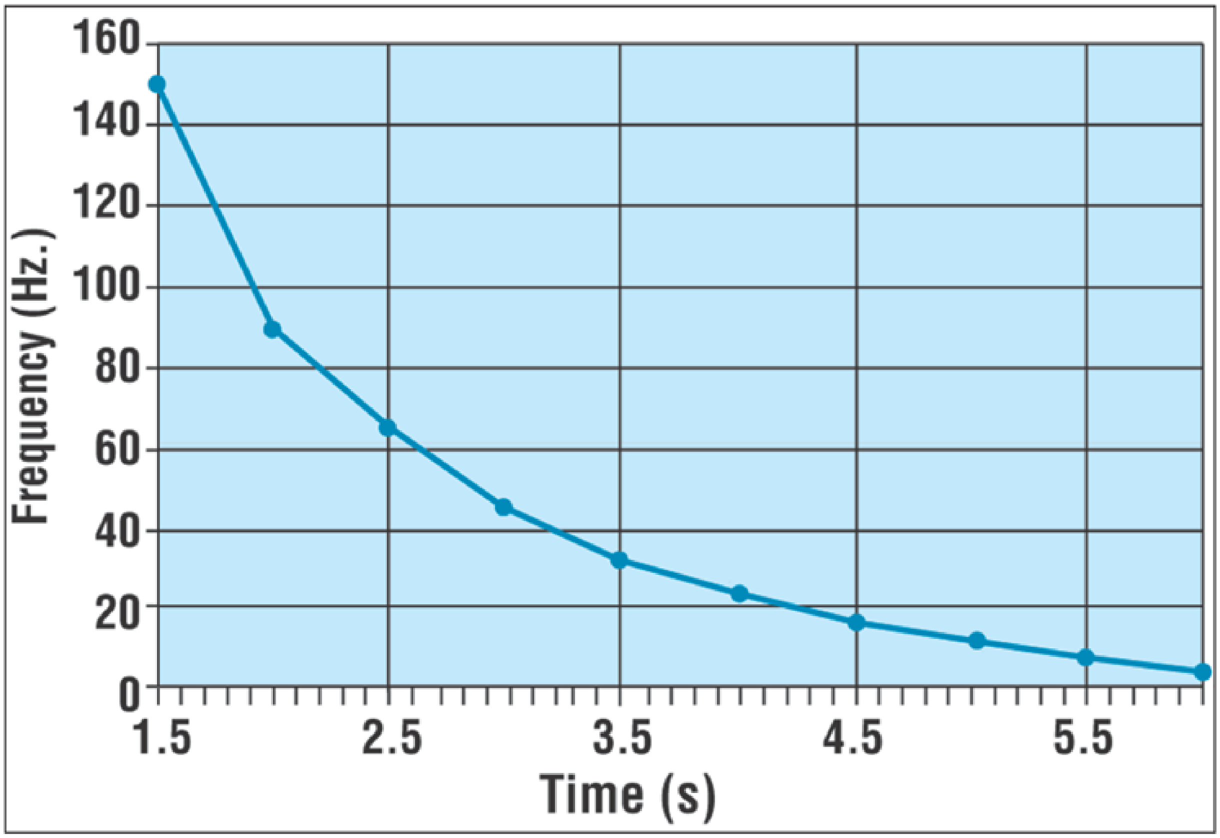
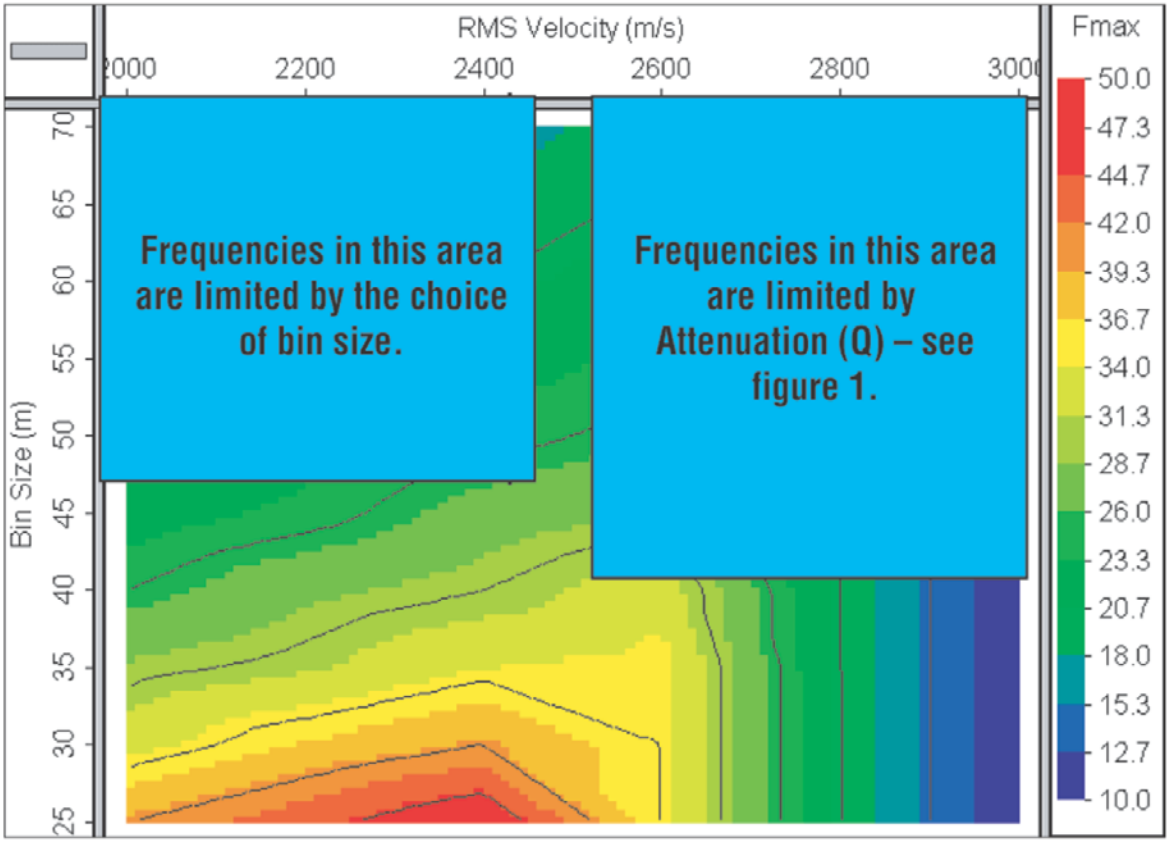


Figure 1 -- Maximum frequency vs. time, assuming Q=200.



Frequencies in this area are limited by the choice of bin size.

Frequencies in this area are limited by Attenuation (Q) – see figure 1.

Figure 2 -- Fmax vs. (Bin Size and Vrms) for θmax = 30°.

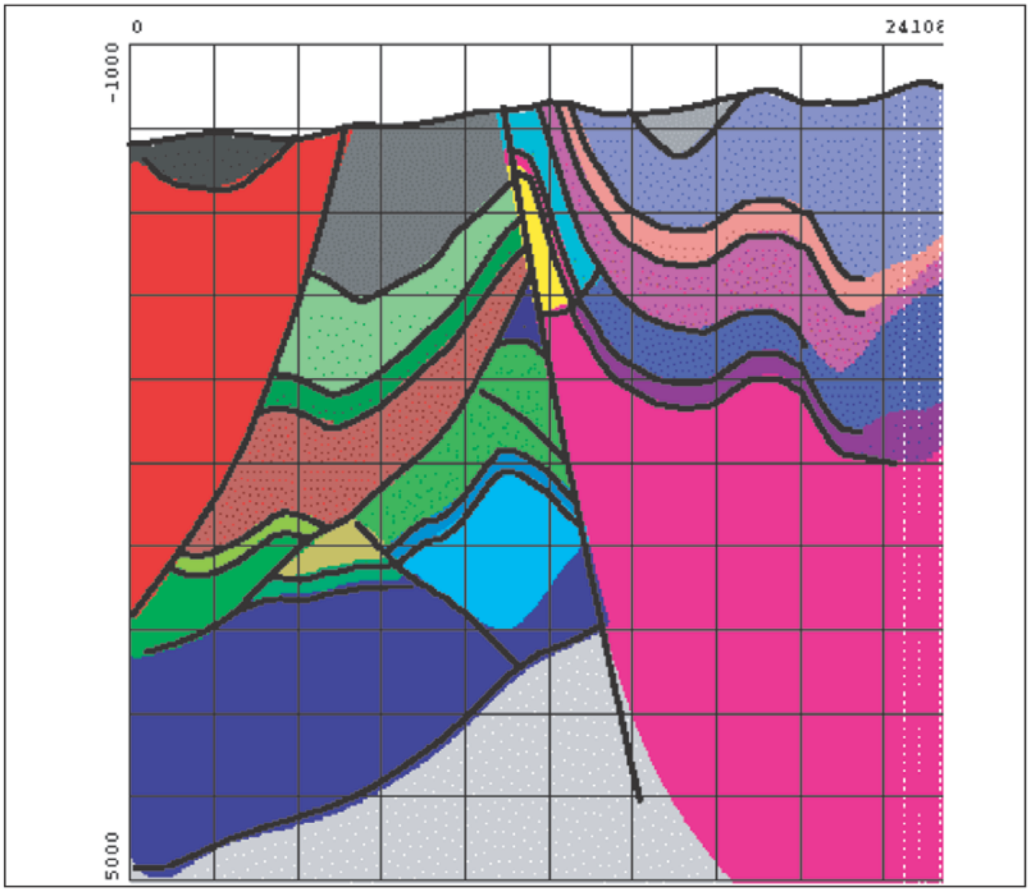


Figure 3 -- A model built for a complex sub-surface area. Models can be ray-traced to create synthetic 3-D volumes.

Possible Casualties and Concluding Statement

If large changes are needed, the usual first casualty is Fmax. Thus, dropping our expectations for high frequencies will lead to larger bins, which will lead to a cheaper survey. Another possible casualty is the desired S/N -- or, in other words, using lower fold.

Budget? Be prepared to spend some money! There is nothing as expensive as a 3-D survey that cannot be interpreted!