Land 3-D seismic survey designed to meet new objectives

When the need for higher channel count and better imaging bumps up against a requirement for greater environmental stewardship, planning land seismic surveys can be a balancing act.

Jon Cocker, DownUnder GeoSolutions

Land 3-D seismic surveys require hundreds of tons of state-of-the-art electrical equipment, large crews, and many vehicles to be distributed over tens to hundreds of acres of farmland, mountains, factories, and suburbs for several months. Being too conservative in the survey design can lead to a significant increase in the disturbance and the HSE exposure as well as reducing the economic rate of return. The goal is to design a "fit-for-purpose" survey that ensures the data adequately image the subsurface and are suitable for reservoir property prediction while minimizing environmental impact and cost.

Basic concepts

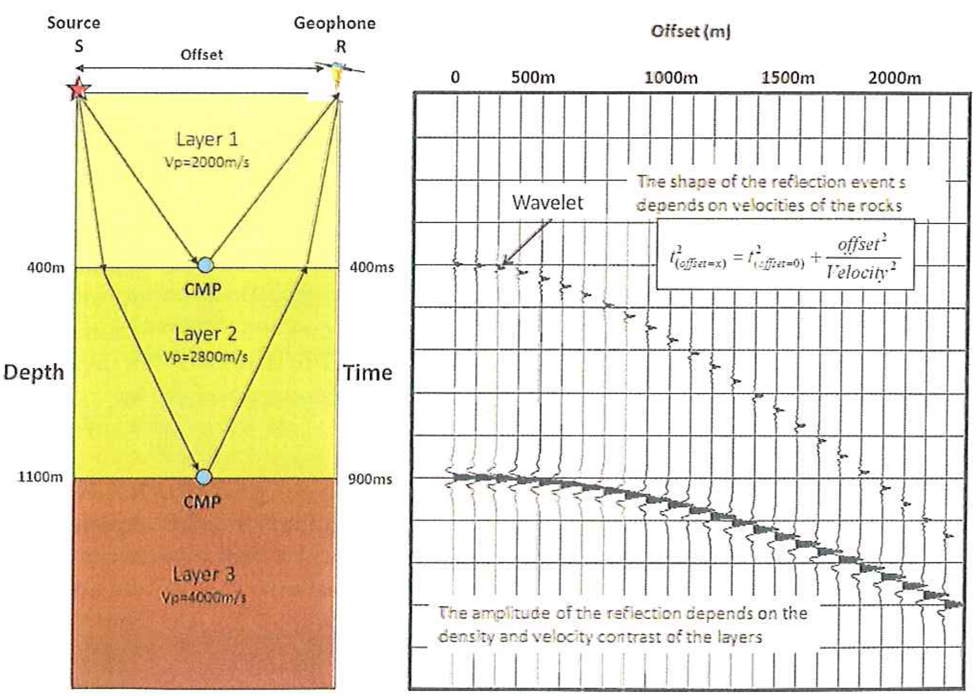
Seismic surveys are like sonar on steroids. They are based on recording the time it takes for sound waves generated by controlled energy sources, such as Vibroseis trucks or buried explosives, to travel through the subsurface and reflect off geological boundaries within the earth back to the surface.

The seismic energy generated at each source location (shot-point or SP) is recorded simultaneously by a patch of several hundred to several thousand recording instruments (receivers or geophones). Take, for example, the concept of seismic energy from one SP being recorded by one receiver. The energy generated at S travels through the earth, reflecting from each geological boundary at the mid-point (CMP), and recorded at R. The amplitude of the seismic energy is recorded every 1 or 2 ms for up to 10 seconds, and the datastream from each receiver location is called a trace. The traces from all the receivers are then grouped to form a "shot gather."

A typical survey consists of thousands of shot-points and thousands of receiver locations. Many source-receiver combinations have the same mid-point, and the data can be re-sorted to create a "CMP gather."

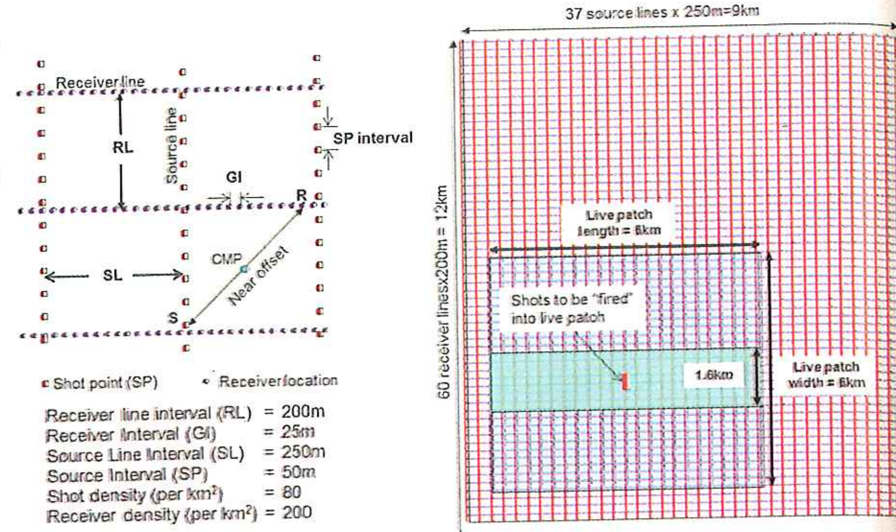
For many years, 3-D seismic land surveys consisted of a "live patch" of six to eight receiver lines due to restricted equipment capabilities; such a patch requires 1,920 channels. For a shot fired in the center of this narrow patch, the offsets recorded would be 2,625 ft (800 m) in the cross-line direction and 9,843 ft (3,000 m) in the in-line direction, resulting in poor azimuthal coverage for the larger offsets.

The 19,686-ft by 19,686-ft (6,000-m by 6,000-m) live patch is the ideal as it provides full azimuthal coverage at all offsets, but it requires 7,200 channels, stretching the limits of many contractors.



A three-layer model shows the modeled seismic response. (Images courtesy of DownUnder GeoSolutions)

A 3-D seismic source and receiver line layout can have two different live receiver patches. This survey would consist of 21,600 receiver locations and 8,880 source locations that need to be surveyed and pegged and would require approximately 600 miles (1,000 km) of track and 890 acres of land to be cleared.



a) Land 3D receiver and source layout

b) Full survey grid with two different live patch sizes (in blue - 30 receiver lines x 240 channels and in green - 8 receiver lines x 240 channels)

Main steps in survey design

There are four steps in designing a successful survey. The first step is to clearly identify the objectives, restrictions, budget, and timing. Many questions need to be answered at this stage.

Are the data used for basic structural interpretation, amplitude/inversion studies, or reservoir monitoring (4-D)? What resolution is required? When are the data required? What is the budget, and is there any flexibility? Are there any environmental restrictions? Clarity on these questions allows the survey designer to focus on the pertinent issues, i.e., will seismic be able to predict fluid and lithology for the target depth and expected fluid properties? Does the geological boundary have sufficient reflectivity? What offsets are required?

The second step is to identify the issues in existing data or acquire test data. Previous seismic surveys in the area are an invaluable resource to improve understanding of data quality, frequency content, noise issues, etc., to aid in the design process. Seismic source and receiver tests are recommended if no data have been acquired previously or if significant improvements are required from the existing data.

Step three is to design the survey. Information such as previous seismic survey data and reports, velocity profiles, well logs, target depth(s), maximum dip, and expected fluid properties are needed to optimize the 10 main survey design parameters:

1. Source type (explosives, weight drop, or Vibroseis) – Explosives generate the highest data quality and can be used in even the roughest terrain, but they require long lead times and can be expensive. Vibroseis is significantly cheaper in most situations but offers lower data quality per source point; it also requires a lot of land to be cleared and can be used only on relatively flat ground.
2. Receiver type – There are many options, but the decision generally is whether to use single geophones or geophone arrays (multiple geophones joined together to boost the signal). Large analog arrays are used when there is significant random or coherent noise. Arrays also can be created digitally using single geophones by summing the data during the processing stage. This can be preferable over analog arrays but requires a smaller receiver interval and hence the ability to record data from more receivers simultaneously.
3. Maximum offset (source-to-receiver distance) – The velocities and density of the target/subsurface are used to model the amplitude of the reflection event versus offset to determine which offsets are required for imaging and lithology/fluid prediction. The maximum offset required generally is around 1½ to two times the target depth.
4. Maximum bin size – Bin size is chosen to ensure the wavefield is sampled sufficiently to avoid data aliasing. It is dependent on the frequency content of the data, maximum dip, target depth, and velocity.
5. Source interval – This should be no more than double the maximum in-line bin size.
6. Receiver interval – This should be no more than double the maximum cross-line bin size. It also needs to be small enough to sufficiently sample the noise.
7. Source line interval – The source line interval mainly affects the distribution of the smallest offsets recorded in each bin. The minimum offset should be less than the target depth.
8. Receiver line interval – As for the source line inter-

val, the receiver line interval minimum offset should be less than the target depth.

9. Live patch dimensions – This terminology refers to the length and width of the patch of receivers that each shot is recorded into. This controls the maximum offset recorded, offset distribution, azimuthal sampling, and cross-line fold. The number of receiver lines in the patch and receiver line interval need to be optimized together to ensure the patch width is at least half the patch length. The patch size is limited by the number of receiver channels available.
10. Migration aperture – An extra fringe of data needs to be acquired around the target to capture all the required information.

Several survey designs that meet these technical requirements should be created to enable the cost of drilling, contractor capabilities, terrain, environmental, and logistical restrictions to be incorporated into the tender process.

The final step is to fine-tune the design to match the geography, infrastructure, and environmental restrictions. Once the basic survey parameters are finalized, the design needs to be fine-tuned to ensure that the planned locations match what is realistic and sensible. There are many reasons why a source or receiver point cannot or should not occupy a preplanned location; for example, they are too close to a well or facility. Changes also can be made to reduce impact, i.e., a source line could be moved to make use of an existing track or avoid rare flora. High-quality aerial photos and maps/shape files of roads, rivers, wells, power lines, etc., are invaluable at this stage.

Allocating sufficient time and budget and using a suitably experienced geophysicist to make these decisions and design a fit-for-purpose survey are critical. Adjusting the design to maintain the technical requirements while accounting for all of the constraints requires an understanding of how each component will affect data processing and interpretation. There needs to be flexibility in the budget to allow the survey design to deviate from previous designs that did not meet the objectives. E&P