Introduction

In 1997 a 3D survey was acquired in the Golfo San Jorge Basin in the center of the Argentinean Patagonia. This 3D showed areas of very poor quality data. After thorough analysis it was possible to correlate the poor data areas with intrusive bodies that occur at shallow levels and appear as overlapping lenses of irregular shape. These lenses generate diffraction points that interact with the reflections in a chaotic manner. The zones of interest lay at a significant depth below these intrusives.

The poor data areas cover an important extent of the basin and it would be valuable to the company if data could be improved with revised acquisition parameters. Therefore, a new 3D was approved in the same location as the 1997 survey. It was noted that where the data was of good quality, the original acquisition parameters sufficed. Nevertheless, more effort was required in the poor data areas.

Different techniques were used to accomplish these objectives including reprocessing, wave equation modelling, data simulation, increasing trace density and statistical diversity, midpoint scatter, receiver arrays and source arrays. The results will be presented here.

Background

The Golfo San Jorge Basin is an E-W oriented, intracratonic basin. D-129 Formation is the most important source rock of the basin. Overlying it, the sandstones of Mina del Carmen and Comodoro Rivadavia formations contain the reservoirs that host the hydrocarbon accumulations of the basin. In the 3D seismic study area, the D-129 formation lies between 1.700 m and 2.200 m (below sea level). The Comodoro Rivadavia “K” level lies between 600 to 900 meters below sea level and the “M7” level lies between 900 to 1.200 meters below sea level (Figure 1) (Ramos, 2015; Sylwan, 2001).

Figure 2a shows a sample of the data quality from the 1997 survey. The no-record area of the in-line stack correlates with the mottled zone evident in the time slice of the coherency cube (Figure 2b). Well information shows the presence of basaltic sills at depths about 500 m. These basalts generate a mode of noise that creates uncertainty in the continuity and geometry of the reflectors.

Chaotically scattered source-generated noise is created locally by the strong diffractions and scattered waves that interact chaotically due to the random spatial locations of the variable near surface basaltic sills. The noise present dominates any weak reflection energy that may be passing through this part of the wavefield when recorded at the surface (Cooper et al., 2017).
Reprocessing

The first strategy to improve the data quality was to reprocess the data. More modern algorithms and processing flows were used. The results showed an improvement in the quality of the information, but the level of confidence was low (Cooper et al., 2017).

Wave Equation Modeling

Wave equation modelling software was used to study the seismic response in both the good and bad data areas. A geologic initial depth model of the line in Figure 2 was used as input. Lenses of very fast material representing the basaltic sills were added at depths near 500 m. Synthetic shot points were generated from various positions across the surface as seen in Figure 3.

Figure 3a shows one snapshot of the wave field generated by a source point located in the good data area. The wave front has propagated through all layers to the base layer and is now reflecting upward toward the receivers at the surface. Concave waves are downward propagating and convex are upward propagating. The basement reflection was highlighted with a dashed yellow line. Clearly the reflection is travelling to the surface through a relatively quiet part of the wave field. The signal to noise ratio is very good and that reflector will be clear on the resulting recorded data.

Figure 3b shows a snapshot of the wave field generated by a source point located in the bad data area. Due to energy loss through the shallow basaltic sills, the basement reflection (highlighted by the dashed yellow line) is somewhat weaker. Also, the edges of the erratic sills have acted as Huygens scattering points and have generated high amplitude reverberating noise in the shallow section. As the weak deep reflection tries to make its way to the surface, the signal to noise ratio is drastically reduced due to the strong near-surface scattered wave field. The modelling suggests that the chaotically scattered source generated noise is much worse in magnitude compared with deeper reflection signals. It was concluded that a greater acquisition effort is needed in the poor data areas.

Data Simulation

Data simulation software was used to simulate stacked data volumes for a variety of 3D models, using super gathers from the good and bad data areas. Figure 4a shows a reference super gather in the top left and is comparing that to the offset distribution predicted for one bin from a 3D computer model. The super gather shows one sample of the signal and noise conditions from an existing 3D program. The computer model shows the offset distribution for a set of parameters considered for the next 3D program. Figure 4b shows only the selected traces from the reference super gather that correspond to the offsets described for that bin by the model. Then, a stack subset of traces was performed to create one stacked trace for that bin.
Then the process is repeated for each bin in the model. Each stacked trace will be unique since each bin presents a different sub-set of offsets from the reference super gather. Finally, a full synthetic 3D data volume is generated. Any trace-to-trace variation in the simulated volume will be entirely due to the bin-to-bin offset variations of the 3D model combined with the changing nature of the reflection signal and noise with offset in the super gather. Data simulation is used to compare the seismic response for models of higher trace density compared to the original parameters. Figure 5 shows the parameters for the original survey plus the two models evaluated.

Figure 6 shows the same inline from data volumes for the three models using the poor-quality super gather. In this case, the dense model suppresses the strong noise better than the other 2 models due to improved spatial sampling. Increasing trace density by decreasing source and receiver line spacings is an effective method because it adds more traces to each bin and maximizes statistical diversity amongst those traces. In the presence of strong chaotically scattered source-generated noise, it is important to have high trace density but particularly important that statistical diversity is maximized amongst those traces.

The “Sparse” design was selected for the 2018 acquisition due to budgetary constraints. Figure 7a shows the stacked data from the 1997 survey, Figure 7b shows the stacked data from the reprocessing which yielded a low confidence level, and Figure 7c shows the better data obtained with the 2018 parameters.

Sub-Sampling in 3D seismic

The parameters used in the 2018 acquisition are shown in Figure 5 under the sparse column. Note that for the M7 reflector the fold is 47.53 using offsets to 1,670 m and the trace density is 82,525 traces/km².

If a mid-point focused design is used, then each bin will contain an average of about 48 mid-points, all coincident at the center of each bin. Assuming the survey uses point receivers and point sources, then the trace density would be 82,525 traces/km² (Fold normalized by bin size). Figure 8a shows the midpoint distribution for such a design. The heavy black grid in one of the bins shows a sub-division of a natural bin into 8x8 m sub-bins, but only the center of these is populated.
In a triple-stagger design, the offset of the nearest source or receiver at line intersections is varied from 1/6 to 3/6 to 5/6 of an interval in a repeating pattern. This results in a forced midpoint scatter in natural bins as shown in Figure 8b. The natural sub-surface bin is still 24x24 m and contains midpoints from about 48 pairs of point source and point receiver. However, the fold is distributed into nine different midpoints within each natural bin. Therefore, it can be considered sub-bins of 8x8 m where each will contain about 5.3 traces. However, the trace density is still 82,525 traces/km2. With proper recognition of the sub-bin definition, this can result in more generous anti-alias filtering which permits migration of steeper dips and higher frequencies.

![Figure 8 Mid-point Scatter a) mid-point focused design b) Triple scatter design c) Triple scatter with arrays.](image)

Additional subsampling can be obtained replacing the single point receivers with a 6-element array, it could be possible to record the summed output of each geophone array as a single trace, so the recorded trace density is still 82,525 traces/km2. But the actual trace density in the field is 459,150 traces/km2. Likewise, replacing the single point source with a 3-element array and interacting with the geophone array, then the actual trace density in the field is now up to 1,485,450 traces/km2, as seen in Figure 8c.

The main difference between the high-density point receiver and point source strategy versus the array strategy is that all individual components will be processed independently in the former and sets of 18 components will be averaged in the field in the latter. The use of short arrays is not likely to damage the recoverable bandwidth of data, but the averaging suppresses some noise and provides some protection against aliased short wavelengths of chaotically scattered source-generated noise. This will prove a helpful tool in the attempts to recover useful data in the survey.

**Conclusions**

This case history shows how past experience and wave equation modelling helped identify the critical noise modes. Data simulation was used to demonstrate the potential data quality improvements that may be expected using increased trace density. This also proved to be a very useful tool to help managers visualize the potential gains versus budgetary concerns.

In areas with strong scattered noise, increased trace density with improved statistical diversity is critical to improving data. Additional benefits are provided by spatial sub-sampling through the application of intentional mid-point scatter. Sub-sampling can be further enhanced with the use of short source and receiver arrays.

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**References**

