

A CASE HISTORY OF 3D DESIGN IN AN AREA OF CHAOTICALLY-SCATTERED SOURCE-GENERATED NOISE

Norman Cooper¹, Yajaira Herrera-Cooper¹, Luis Vernengo²

1: Mustagh Resources Ltd.

2: Pan American Energy LLC

INTRODUCTION

Design of 3D seismic programs must anticipate the surface sampling requirements necessary to properly record elements of the emerging wavefield that are relevant to desired target reflectors. However, parameters that are sufficient to measure desired reflection signals should not be our only consideration. In many areas, it is also important to consider the type and magnitude of noise. In particular, areas with a strong occurrence of chaotically-scattered, source-generated noise require special attention.

In this study we show a clear example of an area with local occurrences of this type of noise. We show how to recognize the noise and propose a model for the cause of the noise. A conventional design for this area leads to parameters that are sufficient to produce good data where the noise is not present. However, the data quality deteriorates to an unacceptable level in the noise-prone areas. We then show a method to help evaluate to what extent parameters must be changed in order to provide confidence that useful data will result.

The project area in southern Argentina is shown in Figure 1.



Figure 1. The study area is in the San Jorge basin in the province of Chubut in Southern Argentina.

In the Cretaceous San Jorge basin, the Pozo D-129 formation is considered the primary source rock and production comes from the inter-bedded fluvial and lacustrine sandstones of the Mina Del Carmen and Comodoro Rivadavia formations (see Figure 2).

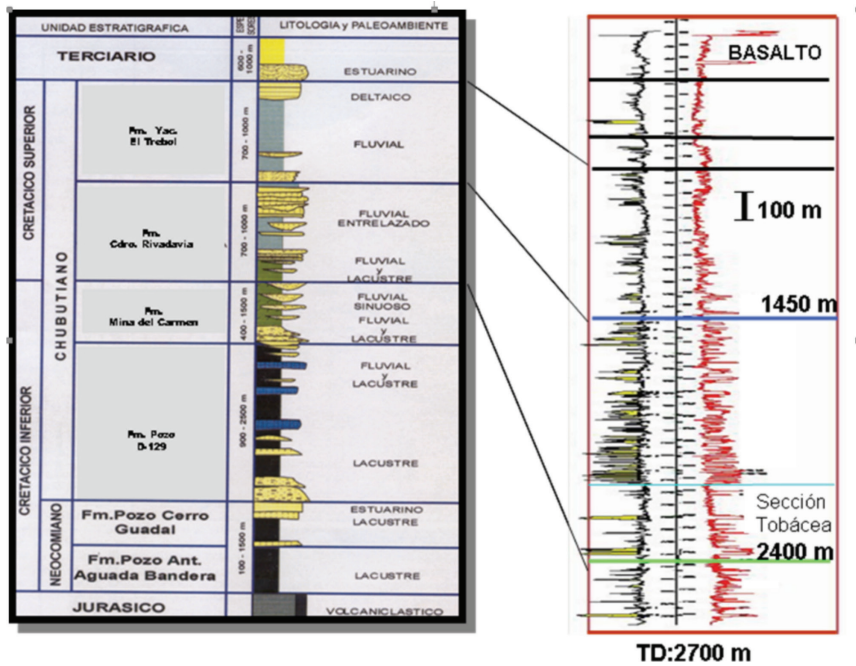


Figure 2. Stratigraphic column and type well.

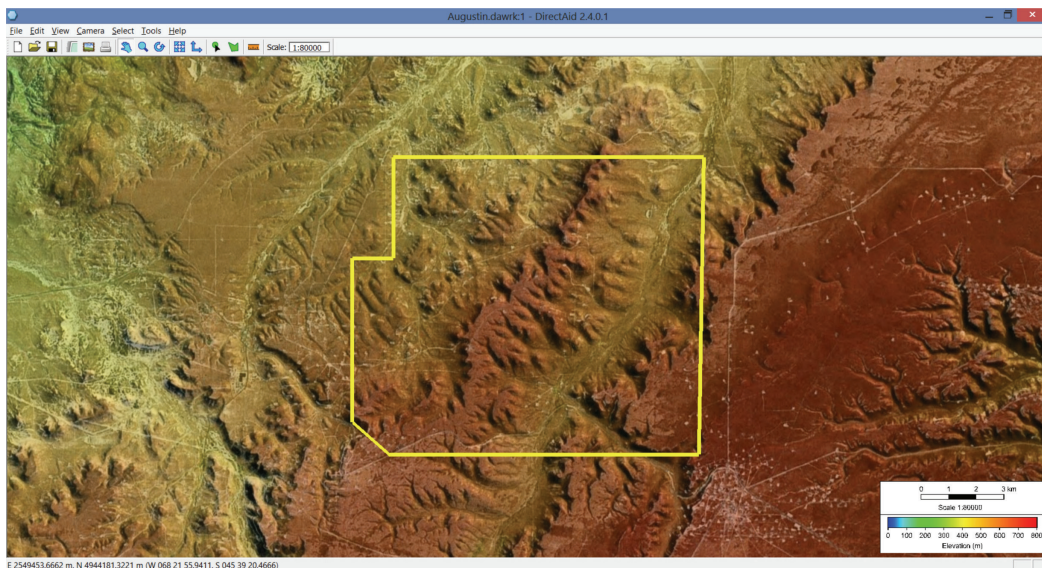


Figure 3. The Agustin 3D seismic program outline is in Yellow. Surface elevations vary from 500 to 700 m above sea level. It covers a fairly well developed producing field.

Figure 3 shows the 130.6 square kilometer outline of the Agustin 3D seismic study area. The D-129 formation lies between 1700 m (below sea level) in the northern part of the study area to 2200 in the southern part. The Comodoro Rivadavia “K” sand lies between 600 to 900 meters below sea level. It is interesting to note that significant geologic trends and faults mapped from wells and from the 3D data run east-west and do not conform to the surface structure trends (Figure 4).

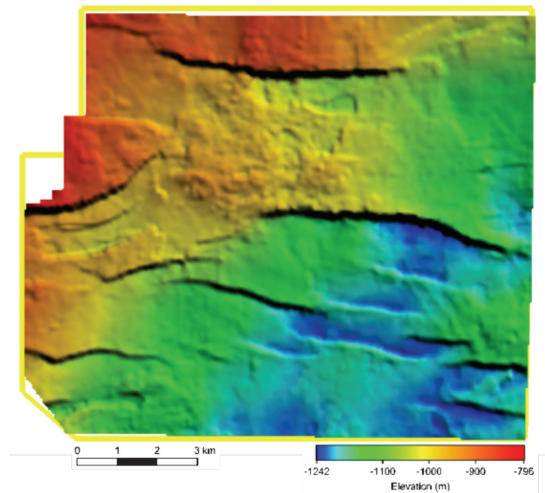


Figure 4. Depth to M7 as mapped from Agustin 3D.

REVIEW OF LEGACY PARAMETERS

The Agustin 3D was recorded in April and May of 1997 by Western Geophysical using I/O System Two recording equipment with Litton RHV 321 60,000 lb vibrators and Pelton Advance II control system. Source and receiver intervals were both 50 meters, receiver line spacing was 250 meters and source line spacing was 350 meters.

Sweep effort was 4 vibrators spaced 12.5 meters pad-to-pad using 4 sweeps of 8 seconds per VP. The sweep (Figure 5) was 8-90 Hz hi-dwell (0.2 dB/Hz) with 250 ms start and end tapers. We believe the sweep effort was sufficient for the objectives, although we question the choice to use a

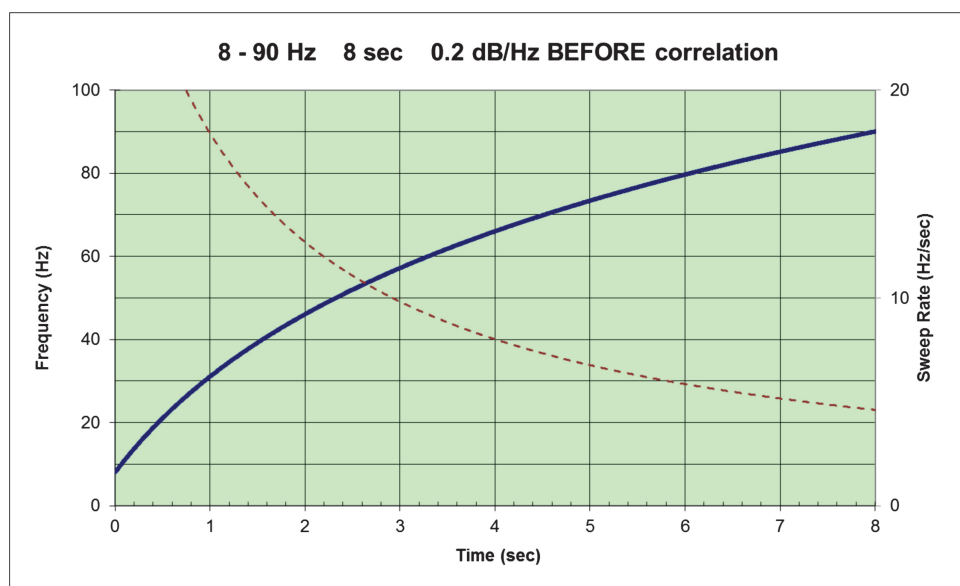


Figure 5. The production sweep used was a non-linear hi-dwell sweep where the first three seconds exceeded a sweep rate of 10 Hz/s and only the first two seconds were spent below 50 Hz.

hi-dwell sweep. We would recommend one or two sweeps of 16 seconds rather than 4 of 8 seconds and we would recommend a linear or mild low-dwell sweep with a lower frequency emphasis.

We reviewed several sonic logs within the project area and prepared the table of basic geologic inputs for 3D Design as shown in Figure 6.

GEOLOGICAL PARAMETERS

Target name	Basalt	El Trebol	Comodoro Rivadavia		Top MEC	D129	Basement
			K	M7			
Depth to target	300	665	1480	1680	1940	2500	3300
Time to target	313	644	1254	1385	1541	1860	2300
Average velocity	1917	2065	2360	2426	2518	2688	2870
RMS velocity	1956	2086	2409	2476	2569	2771	2989
Avg / RMS ratio	98	99	98	98	98	97	96
Multiple velocity	1900	1980	2050	2110	2150	2250	2300
Maximum frequency	89	70	47	44	40	34	27
Dominant period	19	24	35	38	42	49	62
Steep angle of emergence	25	15	30	35	30	25	25
Mild angle of emergence	20	10	25	30	25	20	20

Figure 6. Analysis of basic geologic input parameters for seven zones spanning the zones of interest.

Using our standard 3D design formulae, we reviewed several factors controlling the expected maximum useable offsets and minimum required offsets. We also calculated surface sampling requirements. The results shown in Figure 7 confirm that a source and receiver interval of 50 meters provide more than adequate sampling for all zones of production interest.

OFFSET LIMITATIONS

	Basalt	El Trebol	K	M7	Top MEC	D129	Basement
Direct wave interference	1093	3909	4404	4647	4892	5411	6299
Refractor interference	400	#NUM!	5699	5800	5903	6288	7200
NMO stretch	348	763	1715	1947	2248	2927	3904
Minimum for NMO	267	455	883	994	1144	1463	1975
Minimum for Multiples	375	620	1074	1210	1367	1696	2170
Estimated Xmax	310	680	1500	1670	1880	2400	3120

SURFACE SAMPLE LIMITATIONS

	Basalt	El Trebol	K	M7	Top MEC	D129	Basement
Aliasing of steep dips	34	76	67	64	84	125	168
Aliasing of mild dips	42	113	79	74	99	154	207
Aliasing of NMO	32	44	77	86	100	129	179
Aliasing of noise	38	38	38	38	38	38	38
Potential Vert. Res. (Δ /4)	5.4	7.4	12.6	13.8	15.7	19.8	26.6
Potential Horiz. Res. (Δ /2)	10.8	14.8	25.1	27.6	31.5	39.5	53.1

Figure 7. Calculations for offset limitations and surface sample intervals.

1997 Parameters							
Receiver interval	50	m	Survey Type	Orthogonal	Active patch lines	10	lines
Source interval	50	m	Box aspect ratio	1.4000	Active patch stations	98	stations
Receiver line spacing	250	m	RL sparsity	5.0	Active patch channels	980	channels
Source line spacing	350	m	SL sparsity	7.0	Recorded patch width	2,500	m
					Recorded patch length	4,900	m
					Patch diagonal radius	2,750	m
Natural bin size (receiver)	25.0		Processed bin size (receiver)	25.0	Nominal full patch fold	35.0	
Natural bin size (source)	25.0		Processed bin size (source)	25.0	Fold in processed bins	35.0	
Receiver line km's per km ²	4.00	km per km ²	Receiver point density	80.00	rcvs per km ²		
Source line km's per km ²	2.86	km per km ²	Source point density	57.14	srcs per km ²		
	Basalt	El Trebol	K	M7	Top MEC	D129	Basement
Effective fold in proc'd bins	0.86	4.15	18.59	21.39	24.72	32.67	35.00
Trace Density (per sq km)	1380	6641	29741	34223	39553	52265	56000

Figure 8. Basic design parameters resulting from normal geologic inputs for target fold of 22 at M7.

Our basic design process produces the same parameters as used for the 1997 Agustín 3D if our objective is to generate about 22 fold at the M7 target level (using offsets 0-1670 meters) as seen in Figure 8.

The calculated line spacing is based on a common equation for offset limited fold and is determined by the equation:

$$SL \times RL = \frac{\pi \times X_{max}^2}{4 \times \text{Desired Fold}} \quad \text{Equation 1}$$

To solve for the line spacings SL and RL, it is also necessary to specify an aspect ratio. In this case we ask for an aspect ratio of SL/RL = 1.4. This aspect ratio increases statistical diversity, reduces second-offset gap size in some parts of the model and allows for economic implementation.

Note in Figure 9, however, that the patch used in the 1997 survey (10 x 98) is somewhat narrow compared to our desired cross-line aperture. This may be justified given the limited amount of recording equipment available at that time.

Patch Analysis

Agustín 3D 50-50 250-350

1997 Western Geco

Reflector: M7 - offsets 0-1670 m

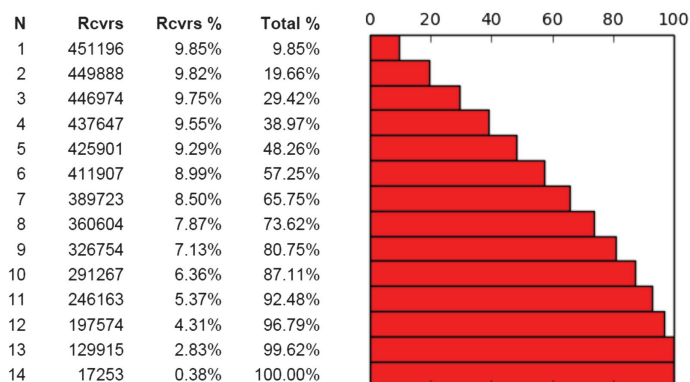


Figure 9. This Patch Analysis for the 1997 Western Geco survey suggests that a patch of 12 or 14 lines would have served better than the 10-line patch that was used (which recorded only 87% of the useful traces available at the M7 reflector level).

Unfortunately, the data produced by the 1997 Agustin 3D was extremely variable in quality. Cross-Line 300 shown in Figure 10 contains areas of no reflectors (below 800 ms) over a considerable part of the line. And yet in other areas reflection quality is good and ties known well control.

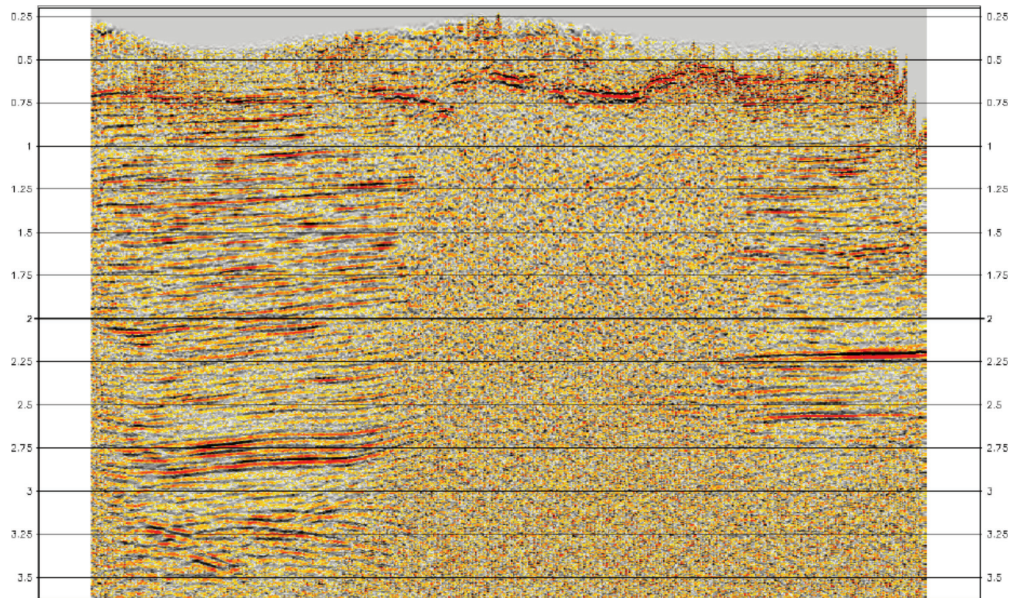


Figure 10. Cross-Line 300 from CGG re-processing before 5D interpolation (Note: this display is plotted with east on the left and west on the right).

Such areas of no-record quality are also observed sporadically throughout several adjacent 3D programs.

At one time, it was thought that a 5D interpolation algorithm might be able to generate the offsets and azimuths necessary to image reflectors amidst this noise.

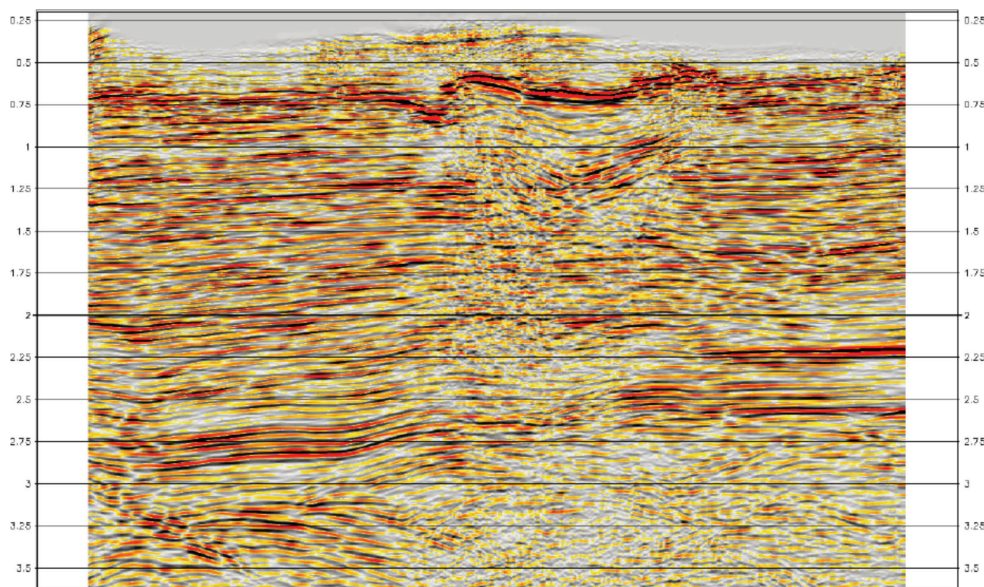


Figure 11. Cross-Line 300 from CGG re-processing after 5D interpolation.

However, in Figure 11 we see that while some reflectivity is produced, there is low confidence that much of the added reflectivity is geologically real.

Another proposed theory was that the near-surface statics from the dramatic surface topography may have caused data deterioration. However, it is clear in the above figures that a strong shallow reflector is easily imaged even without sophisticated additional processing. First break and tomographic statics solutions were quite robust despite the somewhat rugged surface features.

The poor data areas become very evident when looking at time slices through a coherency cube. Figure 12 is an example of such a display. Note the mottled appearance in two distinct areas. This correlates with the no-record areas on the in-line and cross-line displays. These areas are also consistent with well locations that show layers of basaltic sills at depths of about 500 meters.

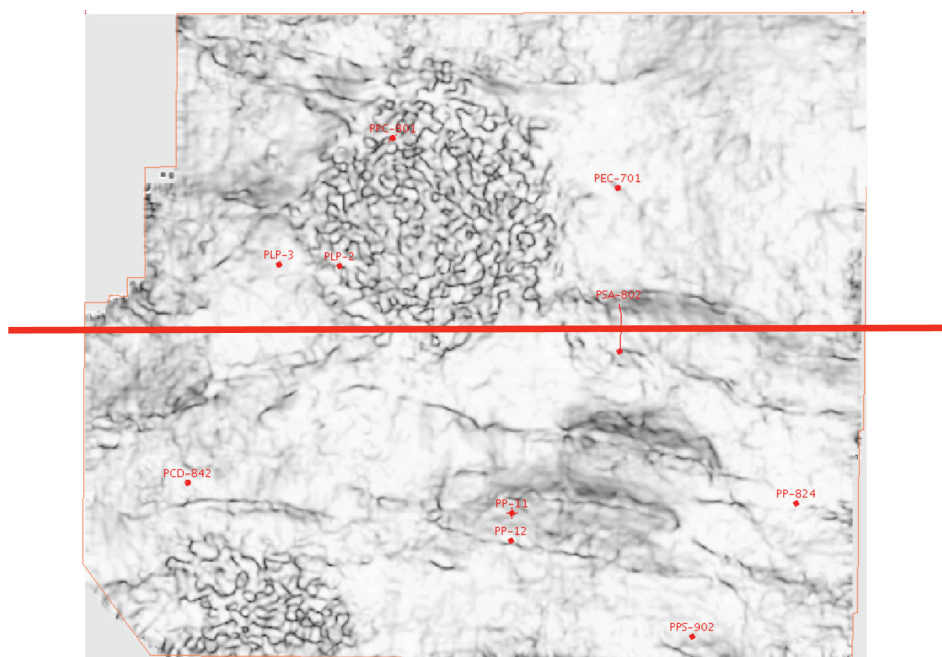


Figure 12. This is a time slice at 900 ms through a coherency display of the 1997 Agustin 3D. Cross-line 300 runs east-west through the PLP-2 and PLP-3 wells and is indicated by the red line.

EVALUATION OF NOISE PROBLEM

The poor data areas indicated in Figure 12 correlate with wells that show variable thicknesses of basaltic sills at depths from about 200 to 500 meters. The logs for one such well (PLP-2) are shown in Figure 13. Similarly, the good data areas tend to correlate with wells that do not have these basalts such as shown in Figure 14.

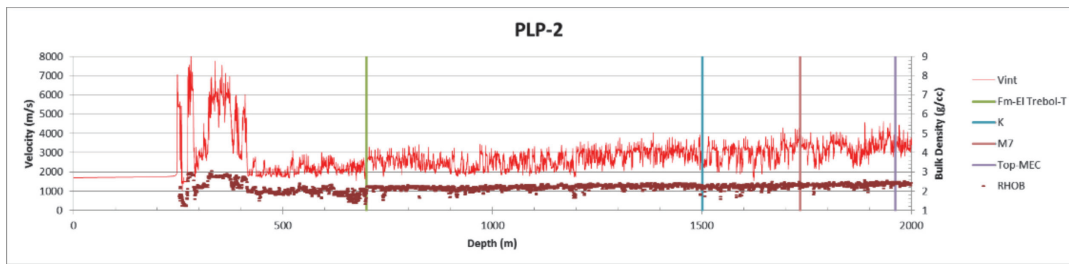


Figure 13. The interval velocity and bulk density curves for the PLP-2 well show several basaltic sills at depths between 200 and 450 meters below surface.

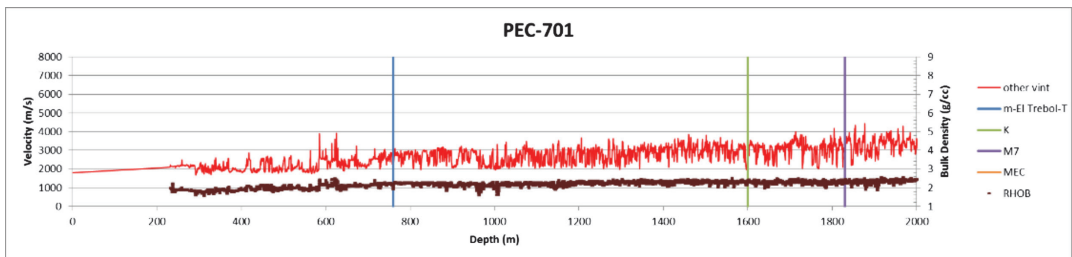


Figure 14. The interval velocity and bulk density curves for the PEC-701 well show no indication of basaltic sills in the same interval.

Wells in the poor data area consistently contain basaltic sills in the 200 to 500 meter interval, but the sills are generally of erratic thickness and depth and are not correlatable from well to well. In order to partially investigate the effect of such erratic sills on seismic records, we prepared the velocity model shown in Figure 15. We then input this model into “Tesseral” wave equation modelling software in order to simulate the 2D shot records for 25 different shot locations indicated by the inverted red triangles.

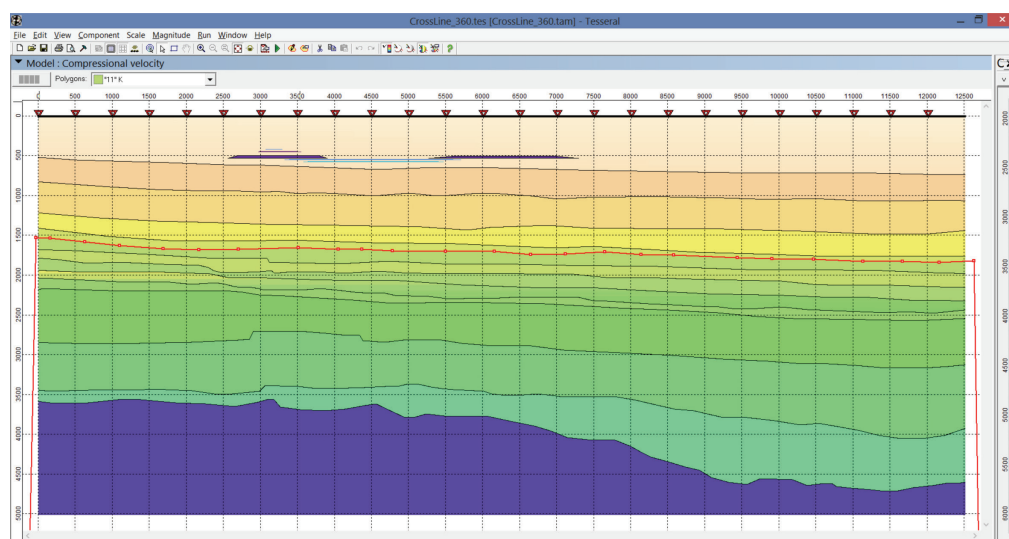


Figure 15. This X-Z velocity model was prepared based on an interpreted cross-line 360 from the 1997 Agustín 3D data. We used this for input to “Tesseral” wave equation modelling software.

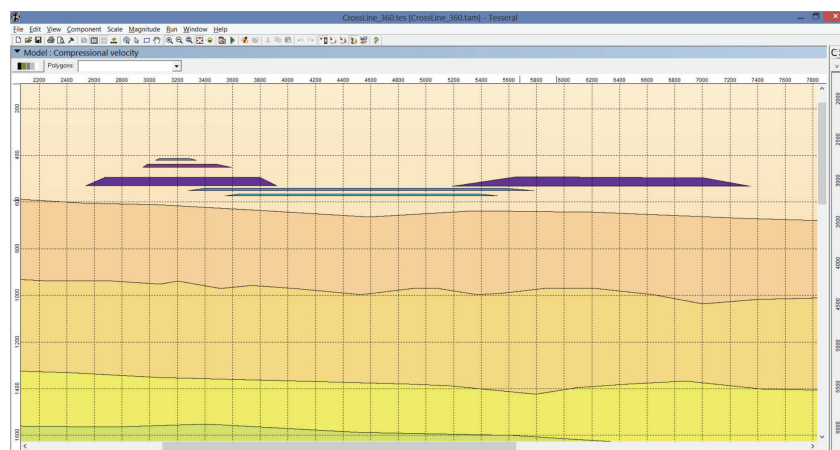


Figure 16. This detail of our model shows variable sized segments of high velocity intended to represent the erratic basalt sills known to exist in parts of the study area.

Notice in the detail of the shallow part of the left half of the model (Figure 16) that we inserted some very high velocity segments. These are intended to approximate the effect of erratic basaltic sills of variable thickness and position.

We created movies of the progression of the wavefield for each of the source locations indicated by the inverted red triangles in Figure 15. We show a snapshot of these wavefields in Figure 17 and Figure 18. These snapshots are shown for a time 1.780 seconds after the source initiation. Downward propagating wavefronts appear as concave arcs while upward propagating reflections appear as convex arcs.

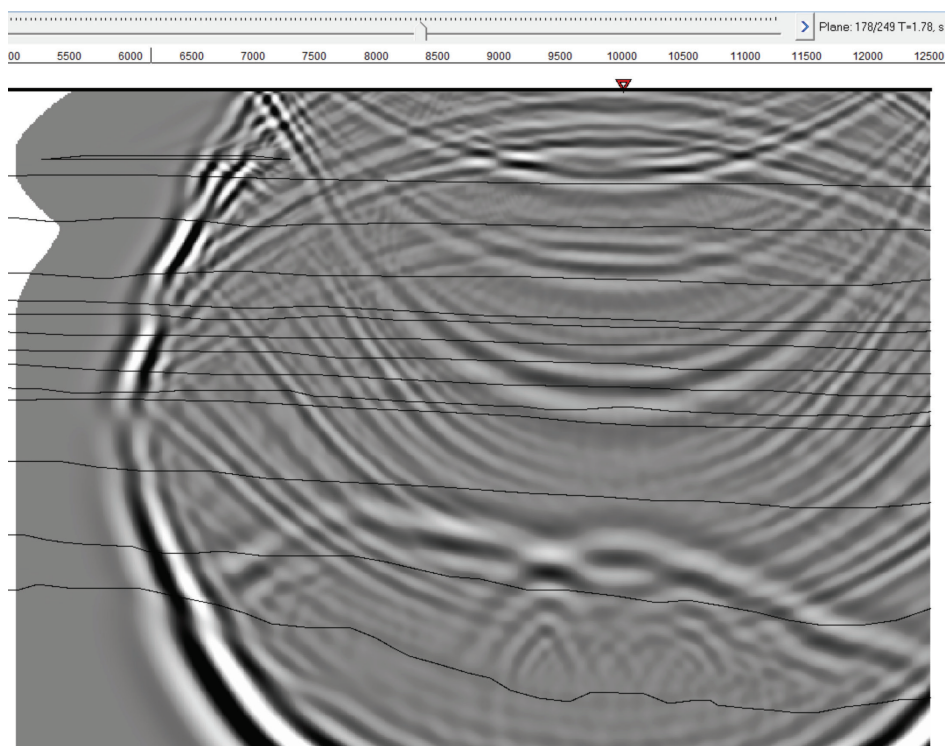


Figure 17. A snapshot of the generated wavefield at 1.780 seconds in a good data area.

Figure 17 depicts the wavefield for a source at location 10000 representing a good data area where there are no basaltic sills in the near-field vicinity of the source. Note that reflections are clearly being generated and they are returning to the surface without interference. Since our geophones are located at the surface, it is imperative that reflections return to the surface unimpeded in order to generate good quality seismic data.

However, the wavefield shown in Figure 18 shows reflections being generated at the deep targets, but as they rise towards the surface they are obliterated by much stronger chaotic events generated by diffractions from the erratic boundaries of the basaltic sills. Furthermore, we must recognize that the strength of the primary wavefield that transmits downwards through the layers of basalt is dramatically reduced due to the strong reflectivity of the basalt layers.

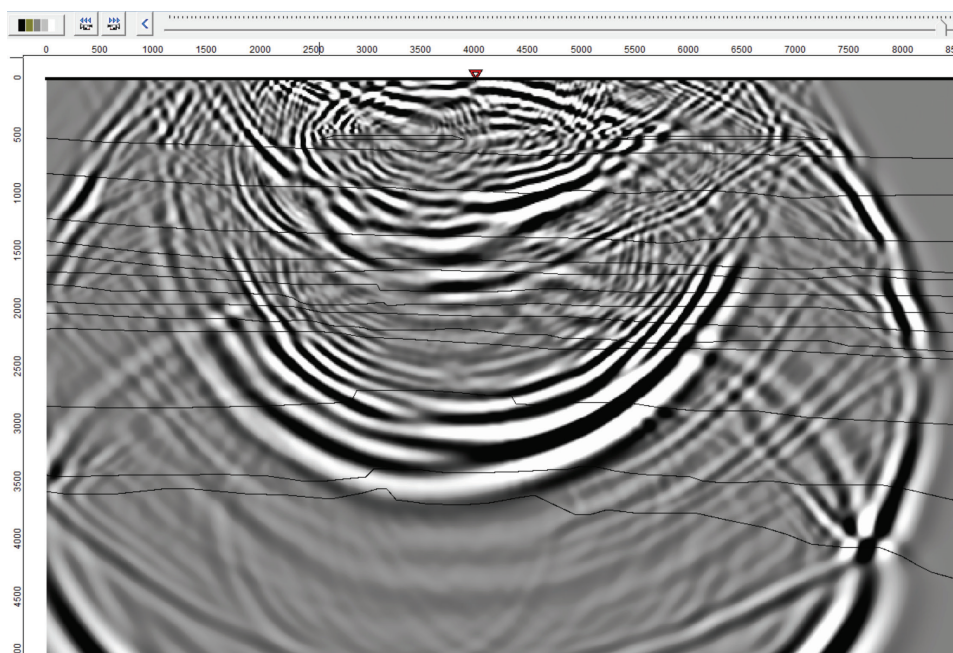


Figure 18. A snapshot of the generated wavefield at 1.780 seconds in a bad data area.

So in areas where these erratic sills exist, we expect very weak transmitted energy below the sills plus strong scattered energy from the edges and irregularities of the sills. Since the sills are erratic, then the scattered source-generated noise will be chaotic (random in space).

The very strong source-generated chaotically-scattered noise from these near-surface irregularities dominates any weak reflection energy that may be passing through this part of the wavefield on its way back to the surface. Basically, our weak reflection signal is lost in the presence of the chaotic noise.

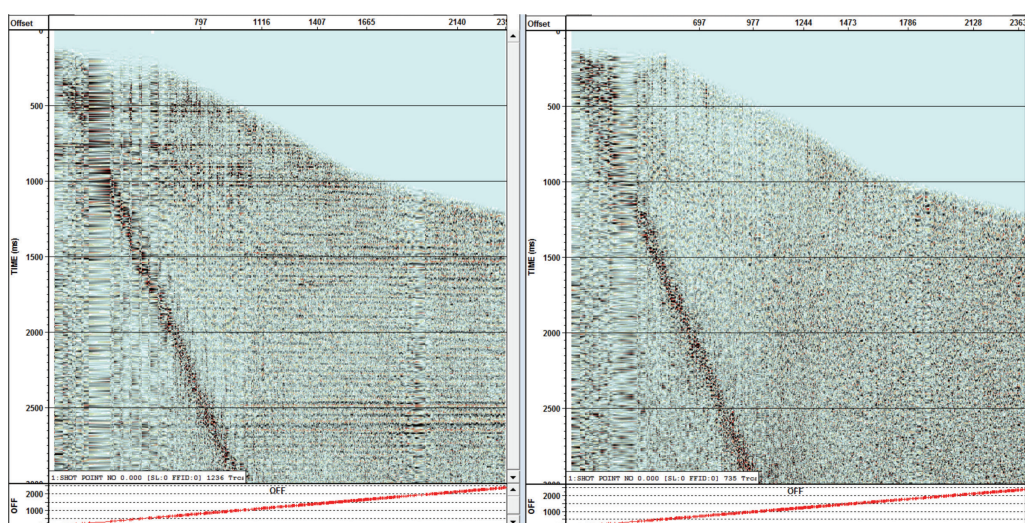


Figure 19. A CDP super-gather from a good data area (left) and a bad data area (right).

This phenomenon is clearly evident in Figure 19 which shows 5x5 bin super-gathers sorted by offset for two areas taken from the 1997 Agustin 3D data volume. The gather on the left comes from a good data area in the northeast of the study area. The gather on the right comes from a poor data area where erratic sills of basalt are known to exist. Note that the correlated air blast (a strong surface wave) is clearly evident on both records. However, deep reflections are not easily detectable in the poor gather. This is consistent with our expectations from modelling.

DESIGN OF ALTERNATE PARAMETERS

We normally think that poor signal to noise ratio can be overcome by high fold stacking or by increasing source and receiver density. However, the type of noise in this situation is not time-variant random noise. Each time a source is repeated at or near the same source location, we will generate exactly the same scattered noise. Signal to noise ratio will not improve if the noise is repeatable on each trace in a high-fold stack. Therefore, the most critical parameter to attenuate this noise is to ensure that all traces contributing to a stacked trace come from significantly different source and receiver locations.

In other words, fold by itself is not a sufficient defense against this type of noise. It is important that the fold consists of a broad variety of offsets and azimuths. This is usually evaluated by generating a polar plot for each bin of offset (radial distance of dot from center) versus azimuth (angle from center to dot represents source to receiver azimuth).

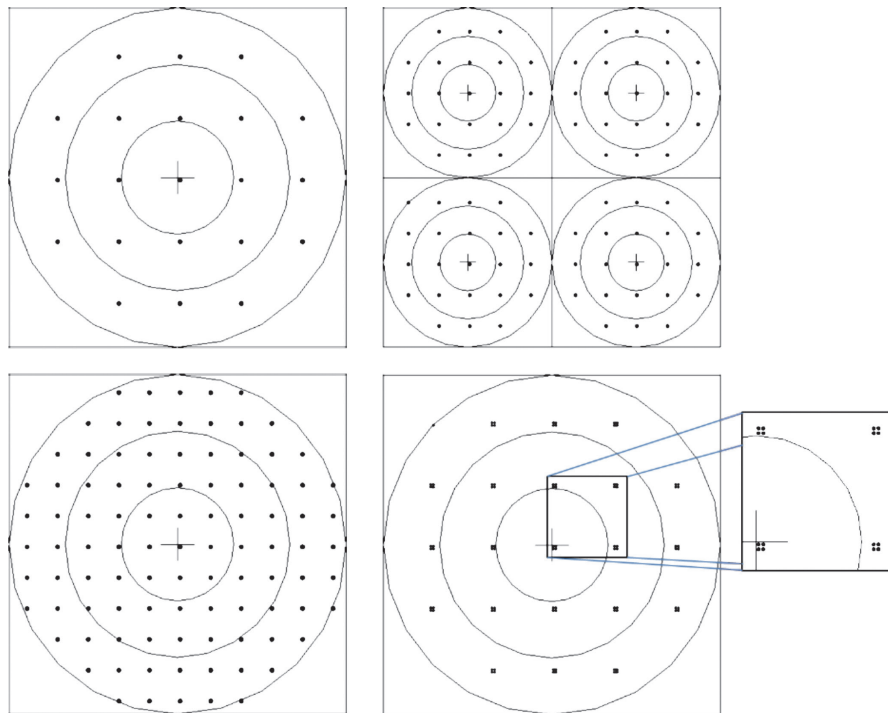


Figure 20. Bin area of 25 m by 25 m for four 3D models.
 Top left uses $S_i=R_i=50\text{m}$ and $SL=RL=300\text{m}$ with bin size of $25\times25\text{ m}$.
 Top right uses $S_i=R_i=25\text{m}$ and $SL=RL=300\text{m}$ with bin size of $12.5\times12.5\text{ m}$.
 Bottom right uses $S_i=R_i=25\text{m}$ and $SL=RL=300\text{m}$ with bin size of $25\times25\text{ m}$.
 Bottom left uses $S_i=R_i=50\text{m}$ and $SL=RL=150\text{m}$ with bin size of $25\times25\text{ m}$.

In Figure 20 we show such polar plots for four survey geometries. Each plot shows a bin area of 25 by 25 meters. The plot in the top left is one natural bin for a survey using a source and receiver interval (S_i and R_i) of 50 meters with source line and receiver line spacings (SL and RL) of 300 meters. Such a survey should deliver a nominal fold of 23.76 when limited to offsets from 0 to 1650 meters. The concentric circles represent offsets of 550, 1100 and 1650 meters. Each dot represents the offset and azimuth statistics for one trace whose mid-point falls within that bin. This particular bin contains 21 traces.

The top right shows four bins of 12.5×12.5 meters each. The geometry for this plot was $S_i = R_i = 25$ meters and $SL = RL = 300$ meters. This should generate a trace density that is four times greater than the diagram in the top left. If gathered in natural bins of 12.5×12.5 meters, these bins show a folds of 21 or 22 traces per bin. The offset and azimuth sampling of each bin is very similar to that shown in the top left.

However, if we gather this second survey in bins of 25×25 meters comparable to the first geometry, we get the plot in the lower right of Figure 20. Note that while the fold in this bin is now about 4 times that of the survey depicted in the top left, the offset and azimuth distribution is not diverse. In fact there are only 22 significantly different offsets and azimuths but each one (except one) is virtually repeated four times.

In the bottom left, we see the result of reducing line spacings rather than source and receiver intervals. Notice that the fold is increased to 97 and that each trace delivers a unique offset and azimuth. The statistical diversity of this model is much superior to the statistical diversity of the second model.

This demonstrates a well-known fact of 3D design. Although trace density can be increased by decreasing source and receiver intervals, this does not provide good statistical diversity. **The only way to increase fold with improved statistical diversity is to reduce line spacings.**

We should re-consider equation 1. In that equation it is normal to round the solutions for SL and RL so that: $SL = M \times Ri$ (some integer multiple of the receiver interval) and $RL = N \times Si$ (some integer multiple of the source interval). This ensures that the number of sources or receivers in each salvo will always remain constant. In the Western Geco 1997 design, N and M were chosen as 5 and 7 respectively. We call the resulting model an N x M sparsity, or in this case a 5 x 7 sparsity.

Equation 1 only presents the **largest** source and receiver line spacing that will accomplish our imaging objectives (fold) within the limits imposed by the maximum useable offset for our zone of interest.

$$Ri \times Si \leq SL \times RL \leq \frac{\pi \times X_{max}^2}{4 \times Desired\ Fold} \quad \text{Equation 2}$$

However, the choice of line spacings is more of a continuum as represented in $Ri \times Si \leq SL \times RL \leq \frac{\pi \times X_{max}^2}{4 \times Desired\ Fold}$ Equation 2 with $N = M = 1$ at the lower extreme and a larger sparsity at the upper extreme. Which values we choose between these limits should be based on our evaluation to the amount of chaotically-scattered, source-generated noise we expect in our project area.

Note that the lower extreme with $SL = RL = Si = Ri$ is the equivalent of “Stack Array” geometry in 2D in that every natural bin will contain all possible offsets and the offset and azimuth distribution in every bin will be the same as every other bin. There will be no bin-to-bin variation in offset or azimuth distribution and therefore there will be no trace-to-trace variation in signal to noise ratio and no geometrical imprinting.

DEMONSTRATION OF EXPECTED RESULTS

We recognize that the original parameters of the 1997 Agustin 3D survey were adequate for capturing reflection signals provided there is not a high level of source-generated chaotically-scattered noise. However, it is clear from the data acquired that in areas where basaltic sills are prevalent the 1997 parameters were inadequate.

The recognized solution would be to re-acquire the data with parameters using smaller source

and receiver line spacings. But how small will be necessary? And can we really expect a more useable data set? These are very important questions that relate to the true value of seismic (benefit as a ratio to cost).

After careful study of the required parameters for imaging both signal and noise, we proposed two alternate sets of parameters. The following table (Figure 21) compares some of the statistical parameters of our two proposed models versus the original parameters used for the Agustin 3D.

		Mustagh Recommended	Mustagh Alternate	Original Agustin
Receiver Interval	(m)	42	48	50
Source Interval	(m)	42	48	50
Receiver Line Spacing	(m)	126	192	250
Source Line Spacing	(m)	168	240	350
Receiver line sparsity		3.0	4.0	5.0
Source line sparsity		4.0	5.0	7.0
Box Aspect Ratio	SL / RL	1.333	1.250	1.400
Active Patch lines		28	18	10
Active Patch stations		104	100	98
Receiver point density	(per sq km)	188.96	108.51	80.00
Source point density	(per sq km)	141.72	86.81	57.14
Receiver line density	(km / sq km)	7.94	5.21	4.00
Source line density	(km / sq km)	5.95	4.17	2.86
Useable offset (EI Trebol)	(m)	680	680	680
Natural fold (EI Trebol)		17.16	7.88	4.15
Trace Density (EI Trebol)	(per sq km)	38,904	13,683	6,641
Useable offset (M7)	(m)	1,670	1,670	1,670
Natural fold (M7)		103.48	47.53	21.39
Trace Density (M7)	(per sq km)	234,641	82,525	34,223
Useable offset (D129)	(m)	2,400	2,400	2,400
Natural fold (D129)		173.31	81.47	32.67
Trace Density (D129)	(per sq km)	392,993	141,435	52,265
Estimated Cost Ratio versus Original		233%	137%	100%
Trace Density (EI Trebol) vs Original		586%	206%	100%
Trace Density (M7) vs Original		686%	241%	100%
Trace Density (D129) vs Original		752%	271%	100%

Figure 21. Summary of parameters for three design models considered in this study.

It is obvious that both of our proposed parameters will result in higher program costs. In order to propose this strategy to management, we must be confident that the increased effort will result in useable data. Using “DirectAid” software, we were able to generate theoretical models using each of these parameters. As with any typical 3D design software, we were able to plot a variety of statistics including fold, offset heterogeneity, azimuth heterogeneity, largest offset gaps, offset and azimuth distributions, cross-plots of statistics, et cetera. However, none of these tools tell us how the stacked data will appear. They only quantify various statistical properties. We need to know if the changes in these statistics will produce useable data or not.

In this study, we also had super-gathers available to us (Figure 19) from the original version recorded in 1997. These super-gathers show us the actual character of signal and noise at every possible offset that can be expected in both a good and a bad data area. We know that our models will generate a different subset of recorded offsets in each bin. We then use a “Data Simulation” tool to demonstrate how a stacked trace would appear for each bin.

In data simulation, we use a 3D model to determine what source-receiver offsets contribute to each bin. The right side of Figure 22 shows an example of the offset distribution of a typical 3D program with one bin hi-lighted. The distribution for that bin (near to far is left to right) is reversed (near to far is right to left) and expanded on the left side of the figure. Also on the left side of the figure is a representative CDP super-gather. From this gather, we select only the traces that correspond to the offsets that will occur in the selected bin. These are hi-lighted on the left side of Figure 22. The selected traces are then averaged together to produce a simulated stacked trace for the bin under consideration. We then move to the next bin, select traces that correspond to the offsets expected in that bin and use them to form a stacked trace for that bin location.

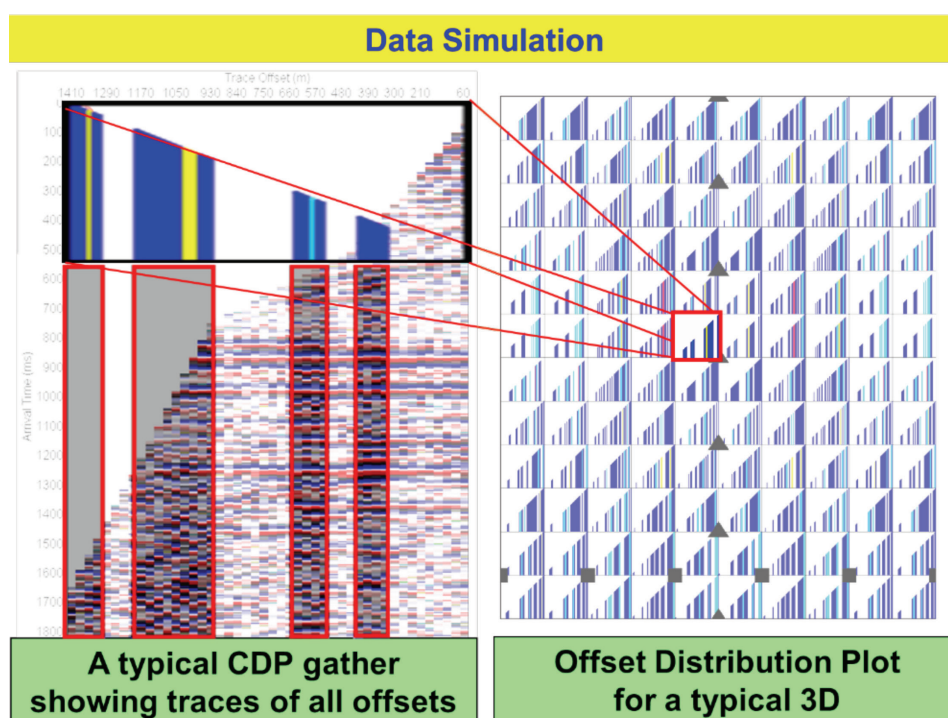


Figure 22. Demonstration of Data Simulation for one bin in a typical 3D.

We repeat this process for the entire 3D area where we wish to produce simulated data. Note that the same CDP reference gather is used to predict every stacked trace. Therefore, there will be no geologic difference from trace to trace in the simulated volume. The only differences from trace to trace will be how well the signal stacks constructively and how well the noise stacks destructively given that a different sub-set of all available offsets contribute to each bin.

In Figure 23 we show data simulations for the three models described in Figure 21. We refer to the sparsity of each model. 5x7 refers to the original 1997 Agustín parameters, 4x5 refers to the alternate model proposed by Mustagh Resources Ltd. and 3x4 refers to the model recommended by Mustagh.

Note that where data quality is good, there is no significant motivation to use the more dense line spacings. Given that the estimated cost of the 3x4 model is about 2.33 times the cost of the 5x7 model, we do not believe the additional cost is justified by the moderate improvement in

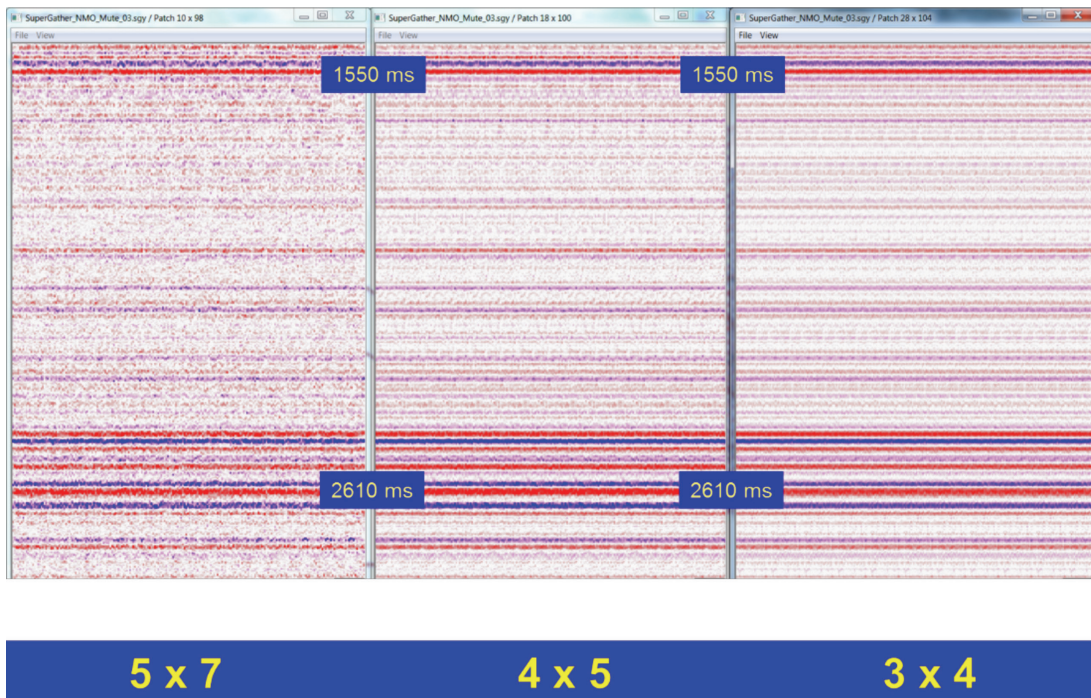


Figure 23. Data simulations for the three proposed models of different sparsity where data quality is good.

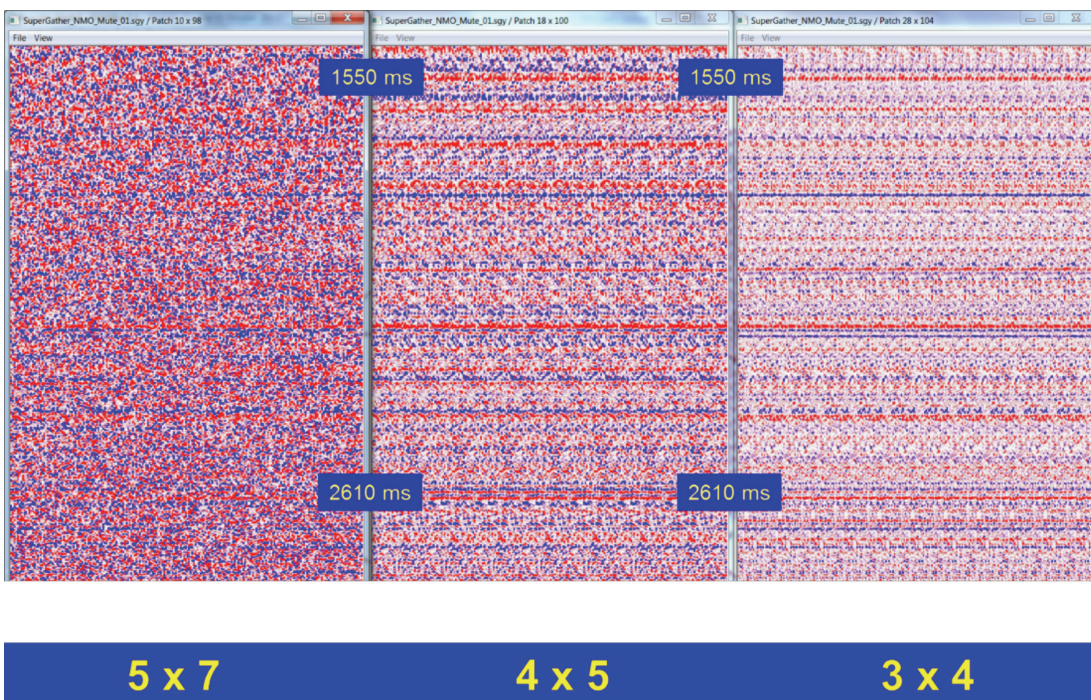


Figure 24. Data simulations for the three proposed models of different sparsity where data quality is bad.

reflector continuity. Certainly, the denser grid reduces trace-to-trace variations in signal to noise ratio, but this would not result in a substantially different interpretability of the data volume.

However, in Figure 24 we demonstrate the effectiveness of the more dense grids in areas where source-generated chaotically-scattered noise is known to dominate the raw records. In this case, the added offset diversity provided by the enhanced parameters clearly demonstrate a significant improvement in interpretability of the simulated data sets. This analysis gives us the confidence to recommend the 3x4 sparsity even though the cost increase is substantial.

CONCLUSIONS

In the Agustin project area, we are satisfied that the discrepancy between locally good data results and locally bad data results can be explained as due to source-generated chaotically-scattered noise events. We believe these noise modes are generated locally where variable basaltic sills are present within the near-field of the energy source. The high reflectivity of the sills reduces transmitted signal strength to deeper reflectors. Furthermore, the erratic boundaries of these inhomogeneities in the near-surface result in strong diffractions and scattered waves that interact chaotically due to the random spatial locations of the sills. These strong wavefield components dominate the weak reflections that are returning through the near-surface field to the recording spread.

Since this type of noise is not time-variant random, it requires an enhanced diversity of offsets and azimuths to provide unique and different measures of the noise within CDP gathers. The best way to improve stacked data quality in these conditions is to reduce line spacing in the 3D grid.

Reduction in line spacing will result in a significant increase in the cost of the program. Therefore, we need a tool that helps us decide how much we must modify the geometric parameters and what the potential benefit may be. There is no added value if we spend more money and do not gain significantly in the interpretability as indicated in Figure 23.

However, the worst possible value is to spend any amount of money and effort and get the no-record results represent at the left of Figure 24. The data simulation tool is a useful addition to help gauge the value of our final parameter selections.

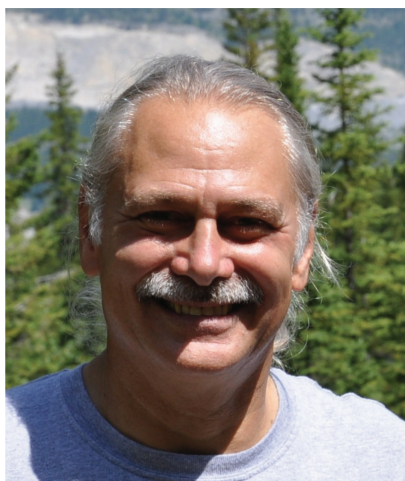
It is important to be aware that design of 3D seismic programs should focus not only on measuring desired reflection signals, but also should evaluate the potential for scattered noise modes and allow for sufficient measurement of the noise components of the wavefield.

In the Agustin project area, a program has been approved and will soon be recorded using the recommended denser parameters. We trust that the lessons learned in this analysis will result in improved exploration and development success that will more than justify the increased costs of the revised parameters.

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NORM COOPER - SPEAKER BIOGRAPHY

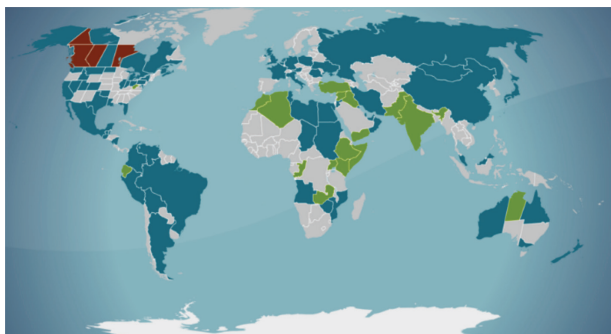


Norm Cooper received his BSc with a major in Geophysics from U.B.C. in 1977. After a short experience with the mining industry he joined Amoco Canada Petroleum Company. With Amoco, he was allowed a free hand in experimenting with unique field and processing methods. This practical experience, combined with Amoco's excellent training program, armed Norm with some solid geophysical tools. Prior to leaving Amoco, he became involved with their training center in Tulsa, Oklahoma, periodically teaching courses as part of their geophysical training program.

In 1981 Norm moved to Voyager Petroleums Ltd. There he became more directly involved with seismic field operations and program design in addition to his normal interpretation and exploration responsibilities. His field of experience was broadened to encompass all of Western Canada as well as minor exposure to the Beaufort, East Coast and Northern States.

By late 1983, Norm felt the urge for independence and founded Mustagh Resources Ltd. Since then he has been very active in geophysical consulting, survey design, and general exploration. He developed a series of courses focusing on fundamental seismic principles and acquisition and program design. Teaching now constitutes about 40% of Mustagh's business. Norm and his partner/wife Yajaira have presented a broad variety of courses to thousands of geophysicists and contractors around the world.

Mustagh's principle business is design and management of 2D, 3D and 4D seismic



programs and Norm and Yajaira have been responsible for more than 3000 projects in a great variety of basins. Norm has been active in quality assurance of field operations and of high-tech processing techniques. He has worked in areas as diverse as the Green Mountains of Libya to the Jungles of Borneo; from the Rocky Mountains of Canada to the basalt plains of Northern Ireland; and from the Arctic Islands to Tierra del Fuego. He has worked on seismic programs in over 50 countries spanning six continents.

Norm is a member of the CSEG, SEG, CAGC, APEGGA, CSPG, CWLS, and ASEG. He has served two terms as a director of the CAGC, has been a vice-president of the CSEG, was a director of Genesis Exploration and has served on numerous committees serving the geophysical community. He has received the CSEG Meritorious Service Award and several Best Paper awards.



Norm has published several papers and made presentations at many conventions.

Some of his abstracts and publications are available on our FTP site at <ftp://Publications.mustagh.com:Research@ftp.mustagh.com>

YAJAIRA HERRERA-COOPER

In 1994 Yajaira graduated from the University of Zulia in Maracaibo, Venezuela with an Industrial Engineering degree. She worked from 1993 to 1994 in the Venezuelan oil industry. In 1995 she moved to Canada where, by 1999, she added a Master's degree in Mechanical Engineering to her portfolio.

Yajaira started working for Mustagh Resources on a casual basis as early as 1997 when she translated Mustagh's reports into Spanish for our clients in Argentina. She started work full time with Mustagh in 1999 and also attended the University of Calgary in her spare time and completed another Masters degree in Geophysics by 2005.



In addition to managing her own clients and projects in a variety of countries, she also shares in the development and presentation of the courses with Norm. She was the lead geophysicist in the research and authoring of the book "Geophysical Guidelines for Seismic Operations in Colombia" prepared under contract to ANH (The governing authority for exploration and development in Colombia).

For 15 years Yajaira has been a strong contributing geophysicist to Mustagh. She has contributed her own professional style to much of our consulting work. She has been an instrumental part of

Mustagh's rapid growth in the international marketplace.

The synergy of Yajaira and Norm working together brings a unique strength to Mustagh's services.

Yajaira is a member of the CSEG, SEG and the ACGGP (Asociación Colombiana de Geólogos y Geofísicos del Petróleo). She has participated in several CSEG education committees.

LUIS ALBERTO VERNENGO

In 1988 Luis graduated from the Universidad de La Plata, Argentina, with a degree in Geophysics. He started the same year as a Young Professional in Bidas Company, Argentina.

In 1991 he moved to ASTRA CAPSA as a Sr. Interpreter, and in 1994 he held different positions as a consultant.

From 1995 to 2005 he worked as a Sr. Staff Interpreter for Bidas-Pan American Energy, when he moved to Tecpetrol Company in Tordillo Oilfield.

After a position of Chief Reservoir Geophysicist he was proposed as Head of Discipline Geophysicist in Pan American Energy, position he holds until this days.

He published in several Congress of Exploration and Production in Argentina, and also some papers in The Leading Edge (SEG).

His principal interests are Seismic Attributes, Interpretation, Visualization and new technologies in Seismic Recording and Processing.

Luis is member of SEG, EAGE and AAGyGP.

