3-D Seismic Design on Land  
– a juggling act with image, economics and the environment

Presented to the Geological Society of Trinidad and Tobago  
by Norm Cooper, President of Mustagh Resources Ltd.  
April 21, 2005

While many courses have been taught on the theory of seismic program design, Norm Cooper will review a “common sense” approach to the process.

Beginning with the problem of designing a 3D grid to capture desired elements of the acoustic wavefield, we will introduce the use of full wave equation modeling. Viewing animated wavefields for a few simple examples will allow us to visualize the significance of wavefield elements and apparent dips.

Once spatial sampling is evaluated (either by calculations or by modeling), then it is an easy matter to design a survey that will do an excellent job of imaging our objectives. Only three things stand between us and a great seismic survey: economics, a concern for our environment and a myriad of types of noise!

We must compromise our design by contemplating how sparse can we decimate our ideal grid and still be able to achieve a certain objective (too often expressed as a target “fold”). This will lead us towards a sparser, but affordable grid. However, the value of the program is not retained if it does not lead to successful imaging of our targets. Perhaps the greatest (and most often underestimated) factor is the magnitude and type of noise we may encounter in our prospect. Study of surface conditions and previous seismic data should lead us towards a more optimal solution.

Therefore, we begin our juggling act by weighing seismic imaging against affordability, hopefully with a good understanding of the local noise characteristics. However, we must ensure that our surveys minimize environmental impact and that they are achievable with available equipment and within appropriate time frames. These harsh realities add more elements to our juggling act.

While each constraint serves to restrict our choice of design, many options remain open. 3-D design remains an under-constrained problem, were there are more possible design solutions than there are constraints to direct the solution. The “best” design will depend on the importance given to each constraint.

One thing we know … whatever design we start with on paper, it will be modified by reality when we implement it in the field. Our choices should favor the designs which are most robust in the presence of perturbation. There will be lots of room for imagination and examples of some unconventional solutions will be reviewed.
3-D Seismic Design on Land - a juggling act

Norm Cooper and Yajaira Herrera

Norm Cooper

- Graduated from UBC in 1977
- BSc with a major in Geophysics
- Amoco Canada 1977 to 1981
- Voyager Petroleums Ltd. 1981 to 1983
- Mustagh Resources Ltd. Founded in 1983

Yajaira Herrera

- Graduated from University of Zulia, Venezuela in 1994
- BSc in Industrial Engineering
- PDVSA 1992-1994
- Lubvenca 1994-1995
- MSc in Mechanical Engineering from U of C in 1999
- Mustagh 1998 to present

Mustagh Resources Ltd.

Since 1983 we have specialized in all types of Geophysical Consulting:

- Design and Management of 2D and 3D seismic programs.
- Quality Assurance and Parameter Optimization on program start ups.
Mustagh Resources Ltd.

We provide training programs in:

- Application of Seismic Methods,
- Land Seismic Acquisition,
- Array Theory, Instrumentation
- 3D design, Vibroseis Theory,
- and Basic Processing

Mustagh Resources Ltd.

We have worked extensively throughout onshore Canadian basins.

We design and implement 100 - 200 programs each year.
We visit about 20 seismic crews per year.

Mustagh Resources Ltd.

We have worked in over 26 countries across 6 continents:

- Canada, USA, Mexico, Nicaragua
- Argentina, Venezuela, Trinidad
- England, North Ireland, Poland, France, Germany
- Algeria, Tunisia, Libya, Egypt, Sudan, Chad, Mozambique
- Russia, Iran, Oman, Yemen, Qatar, Pakistan, Malaysia, Borneo, Japan, New Zealand

3-D Seismic Design on Land
- a juggling act

Objectives of Seismic

From the surface of the earth, create images of subsurface geologic features to assist in finding and producing Oil and/or Gas reservoirs

Image quality should be accurate in shape, character and location of stratigraphic and structural features

Cost of obtaining seismic images should be small compared to drilling costs

Our Model of the Exploration Cycle
3-D imaging

The Need for 3D Seismic

Overview of 3-D Theory

An example of an Orthogonal 3D grid...

Source Interval

Receiver Interval

Source Line Spacing

Receiver Line Spacing
An example of an Orthogonal 3D grid...

3D Survey with the Bin Grid Superimposed

A Single Source-Receiver Pair and the associated Mid-Point

This represents a Near Offset

Two Source-Receiver Pairs can share the same Mid-Point

We have added a Mid Offset

Three Source-Receiver Pairs sharing a common Mid-Point

Now we have added a Far Offset

20 Source-Receiver Pairs sharing a common Mid-Point

Note the Offset and Azimuth Distribution
Continuous wavefield in space ... exhibits different apparent wavelengths
Continuously measured wavefield

... discretely measured with geophone groups

... discretely measured with geophone groups

10 m trace spacing

100 m trace spacing

20 m Bins

30 m Bins

40 m Bins
Before Normal Move Out

After Normal Move Out

After Mute – 10 % stretch

After Mute – 15 % stretch
After Mute – 20 % stretch

Gjis Vermeer’s “Crossed Line” view . . .

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Gjis Vermeer’s “Crossed Line” view . . .

Crossed Line - offset limited
Effect of changing Mute - 1560 m

Our patch should be large enough to encompass all useable offsets

Our patch will be large enough to encompass all useable offsets.

Then the useful subsurface coverage...

Then the useful subsurface coverage will be $\pi R^2 / 4$.

Calculation of 3-D Fold

- The rectangular fold will be:
  
  $$\text{Surface Patch Area} = 4 \times \text{Source Line Spacing} \times \text{Receiver Line Spacing}$$

- And the offset limited (circular) fold will be:
  
  $$\frac{\pi R^2}{4 \times \text{SL} \times \text{RL}}$$

Assuming a patch encompassing all useable offsets.

2-D Design versus 3-D Design

- Source interval drives the cost of 2-D:
  
  $$\text{Source Interval} = \frac{\text{Offset}_{\text{max}}}{\text{Desired Fold}}$$

- Grid density drives the cost of 3-D:
  
  $$\text{SL} \times \text{RL} = \frac{\pi \text{Offset}_{\text{max}}^2}{4 \times \text{Desired Fold}}$$

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The Field and Some Tools

- 1:50,000 Topographic Map
- 12.5 m/pixel Satellite Imagery
- LiDAR-Based DEM
- LiDAR-Based Slope Map

Hilly Terrain - hills are small but quite steep
Many sharp hills and gullies

Steep Terrain - Hills may be up to 30° or more

East-west Flowlines will be crossed by most north-south lines

Road cut showing uniform dry clays in near surface

Firm clays vertically laminated near eastern Teak forest

“Mulchers” in Canada
"Mini-Vib" in Canada
<table>
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<tr>
<th></th>
<th>MiniVib</th>
<th>Litton?</th>
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<tbody>
<tr>
<td>Max. Theoretical Force</td>
<td>11,970 lb</td>
<td>A x P_H</td>
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<tr>
<td>Piston Area</td>
<td>3.99 in²</td>
<td>???</td>
</tr>
<tr>
<td>Reaction Mass Weight</td>
<td>990 lb</td>
<td>7,800 lb</td>
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<tr>
<td>Reaction Mass Stroke</td>
<td>2.75 in</td>
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<td>Servo Valve Flow</td>
<td>60 gpm</td>
<td>200 gpm</td>
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<tr>
<td>Baseplate Surface Area</td>
<td>1810 in²</td>
<td>4608 in²</td>
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<tr>
<td>Baseplate Assembly Weight</td>
<td>855 lb</td>
<td>3,800 lb</td>
</tr>
<tr>
<td>Hold Down Weight</td>
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<td>60,000 lb</td>
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I/O “X-Vib” in Canada

This is NOT a marine vibrator !!

Buggy Vibrators in Oman

“SeisPulse” in Nicaragua
AWD-1180
Compressed Nitrogen working in Chad

http://www.wojder.com/torgeo/awd1180.gif

“AWG - DigiPulse” in Chad

Polaris and Apache developed the “Explorer” in Canada

MacKenzie Delta

During a 3-Day Blizzard