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

MUSTAGH RESOURCES LTD.

THE GEOLOGICAL SOCIETY OF TRINIDAD AND TOBAGO

NEAL & MASSY ENERGY RESOURCES LIMITED

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

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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

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Mustagh Resources Ltd.

Since 1983 we 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.

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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

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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.

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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

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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

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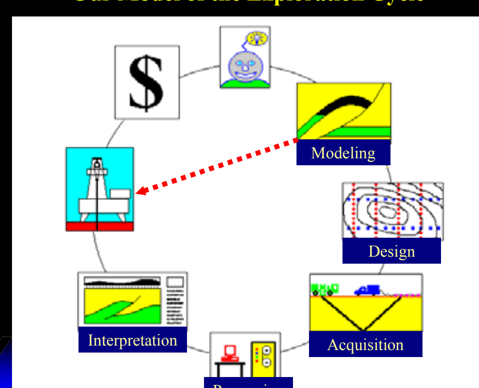
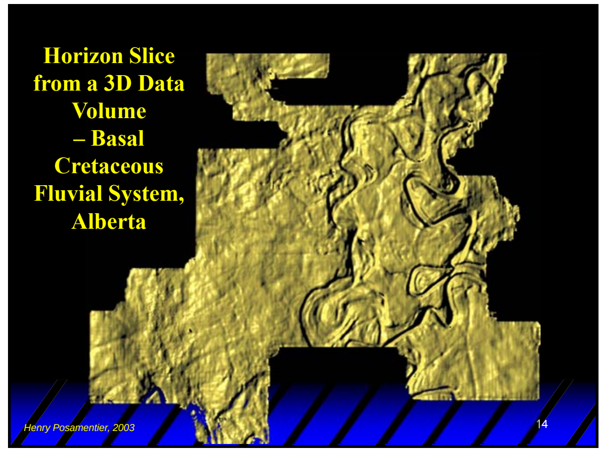
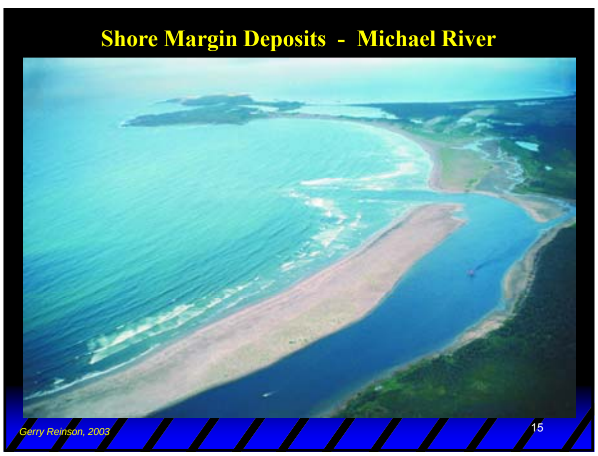
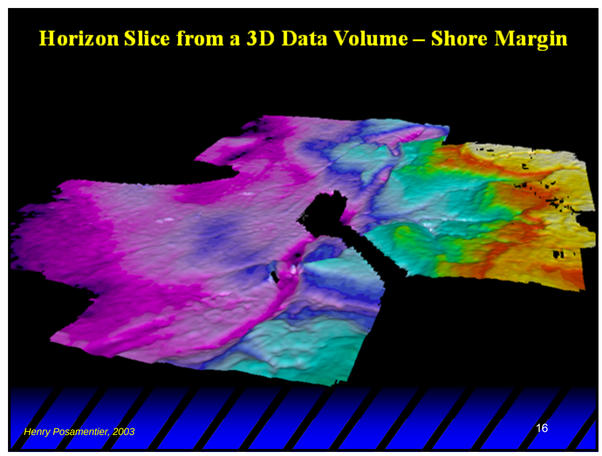
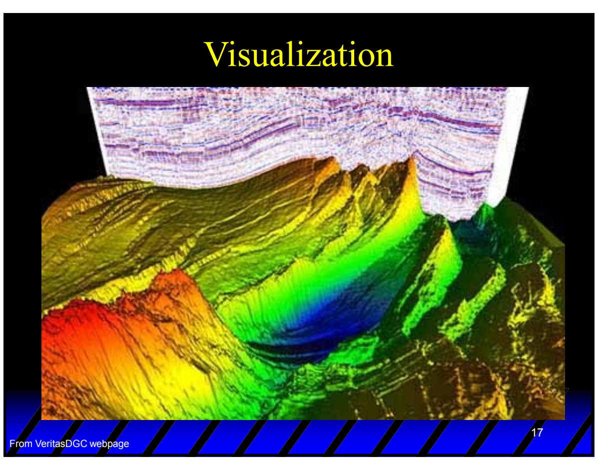
Our Model of the Exploration Cycle

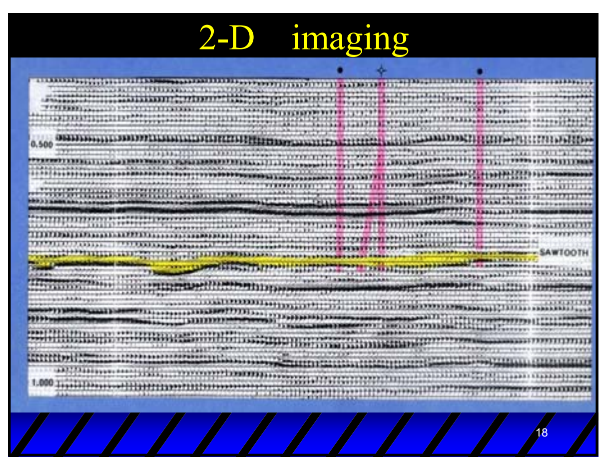


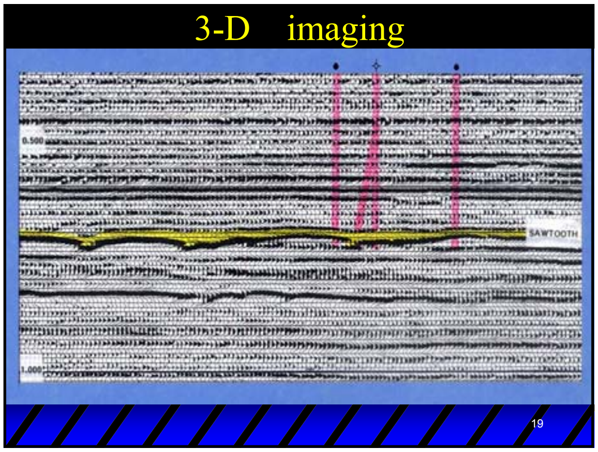

Horizon Slice
from a 3D Data
Volume
– Basal
Cretaceous
Fluvial System,
Alberta
Henry Posamentier, 2003
14


Shore Margin Deposits - Michael River
Gerry Reinson, 2003
15

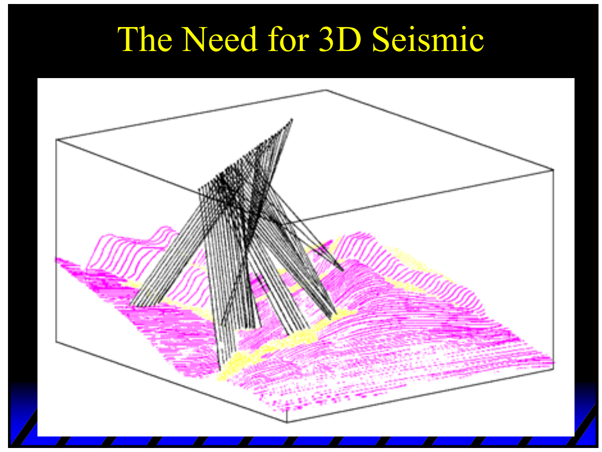

Horizon Slice from a 3D Data Volume – Shore Margin
Henry Posamentier, 2003
16


Visualization
From VeritasDGC webpage
17


2-D imaging
0.500
SAWTOOTH
1.000
18



3-D imaging
SAWTOOTH
19



The Need for 3D Seismic

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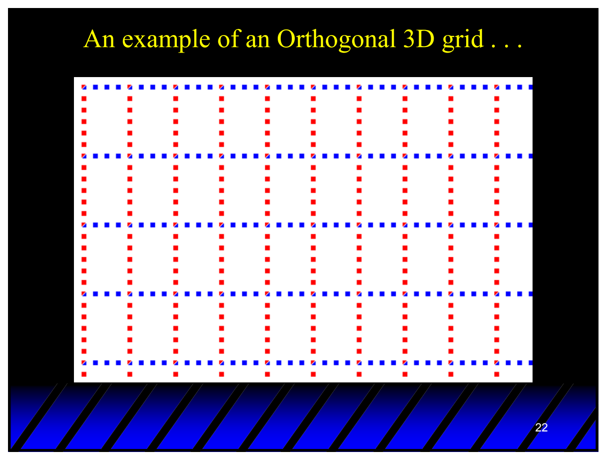
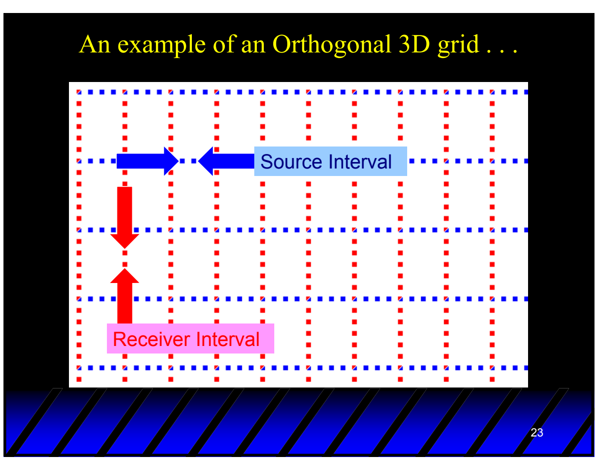
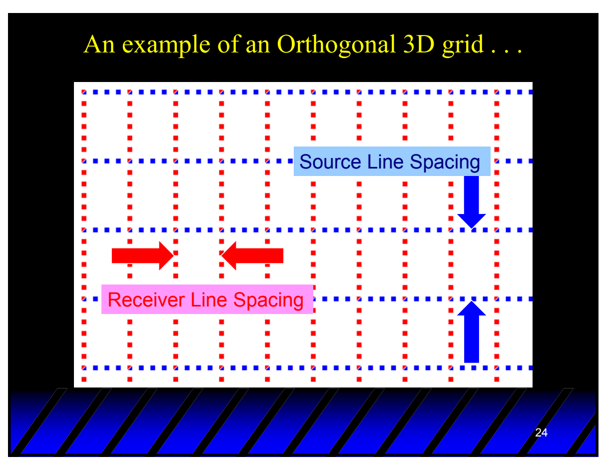
Overview of
3-D Theory
21



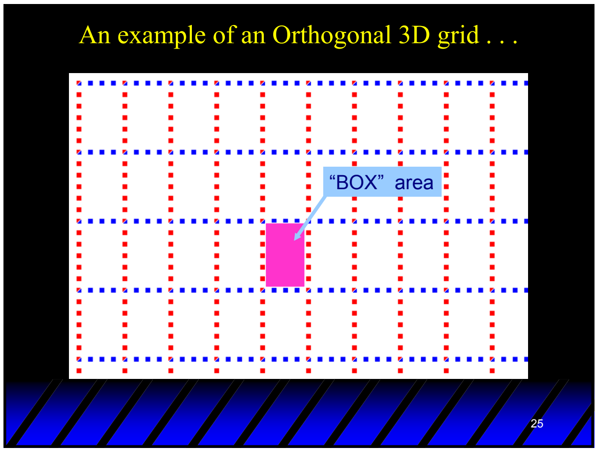
An example of an Orthogonal 3D grid . . .
22

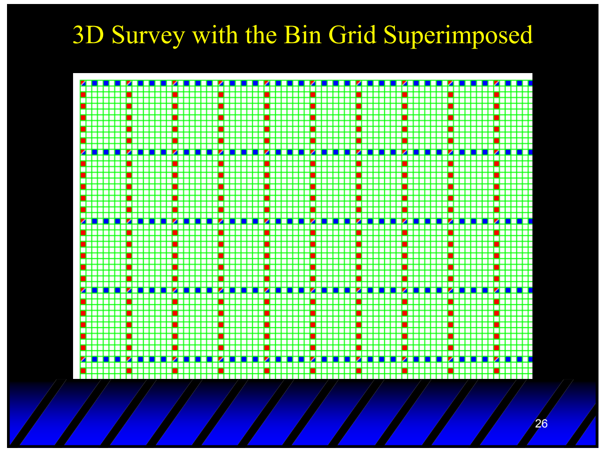


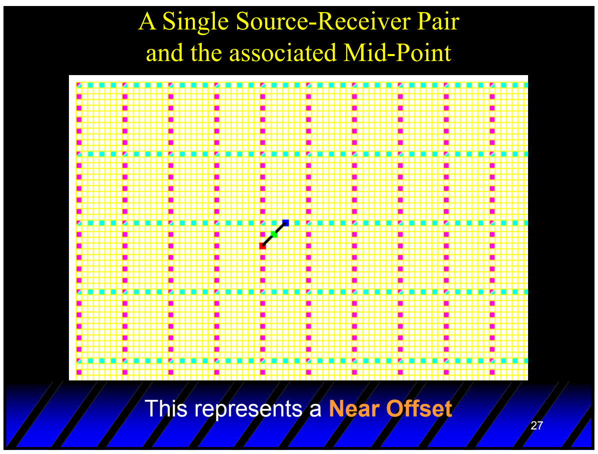
An example of an Orthogonal 3D grid . . .
Source Interval
Receiver Interval
23

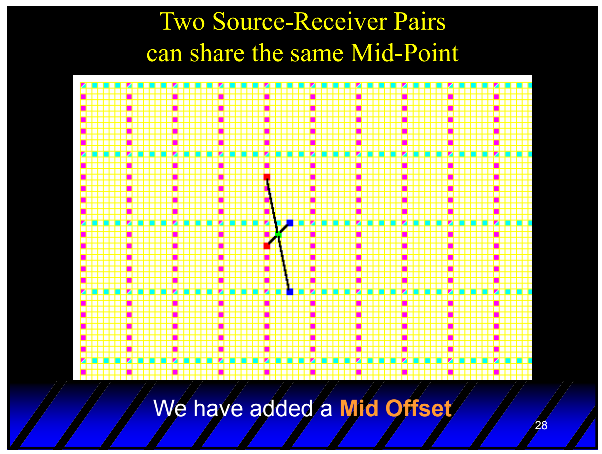


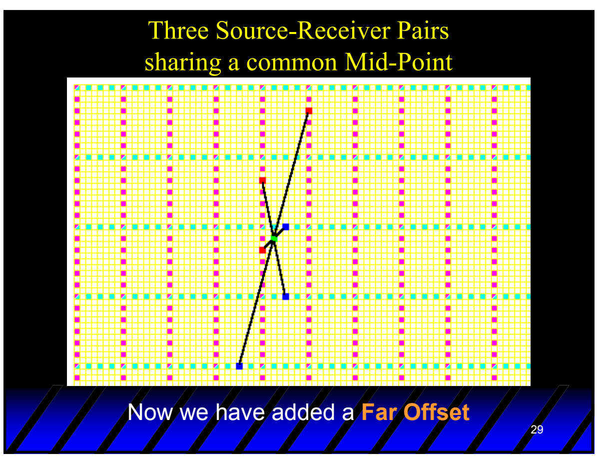
An example of an Orthogonal 3D grid . . .
Source Line Spacing
Receiver Line Spacing
24

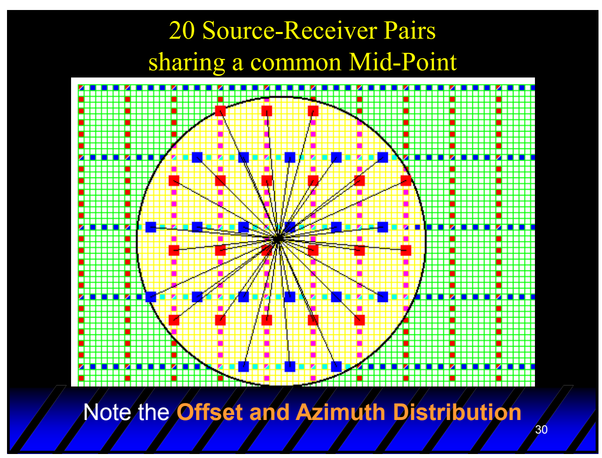

An example of an Orthogonal 3D grid . . .
"BOX" area
25


3D Survey with the Bin Grid Superimposed
26


A Single Source-Receiver Pair
and the associated Mid-Point
This represents a Near Offset
27


Two Source-Receiver Pairs
can share the same Mid-Point
We have added a Mid Offset
28


Three Source-Receiver Pairs
sharing a common Mid-Point
Now we have added a Far Offset
29


20 Source-Receiver Pairs
sharing a common Mid-Point
Note the Offset and Azimuth Distribution
30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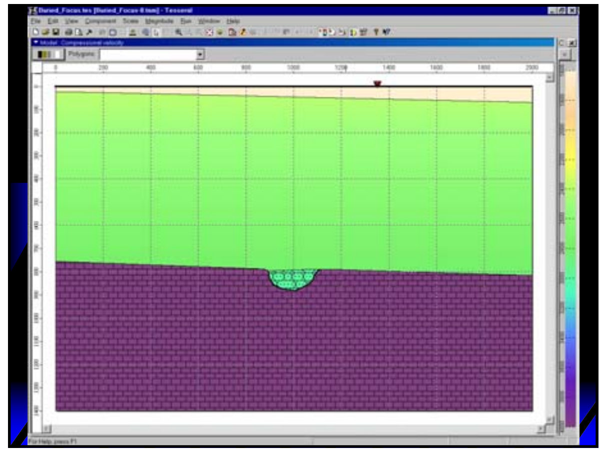
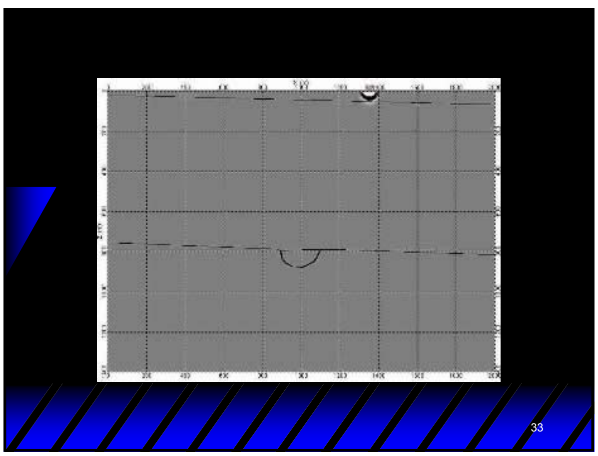
Bin Size Considerations
31

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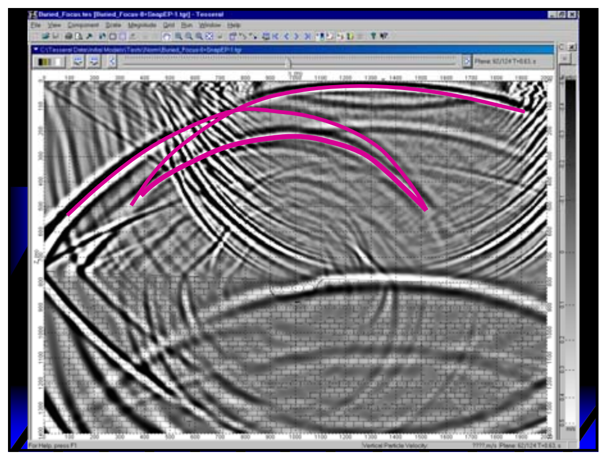
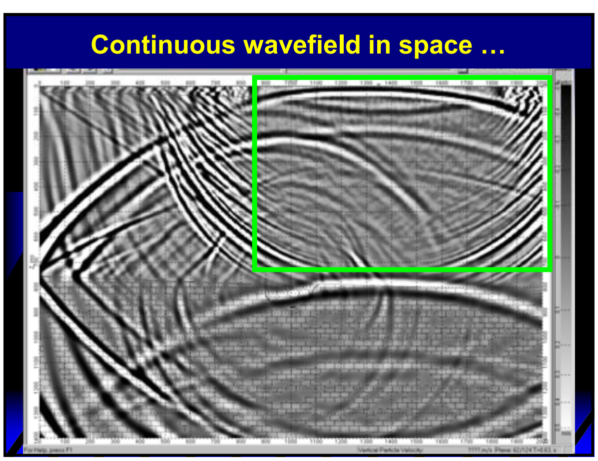
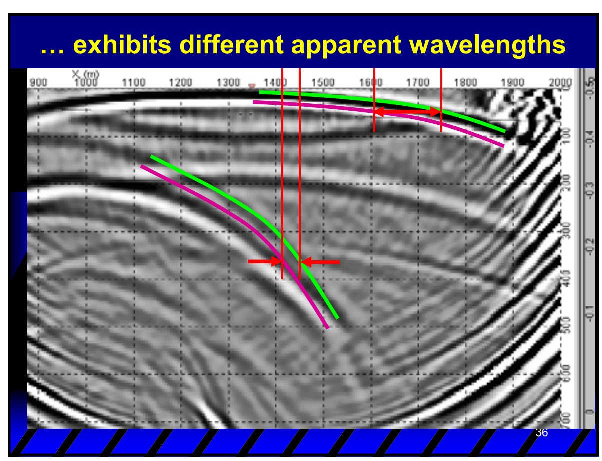
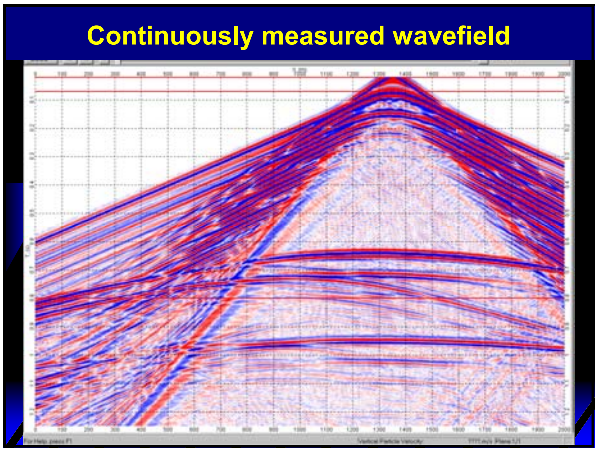
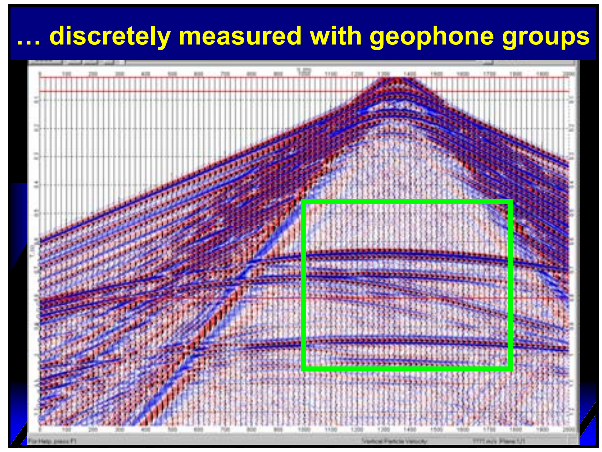
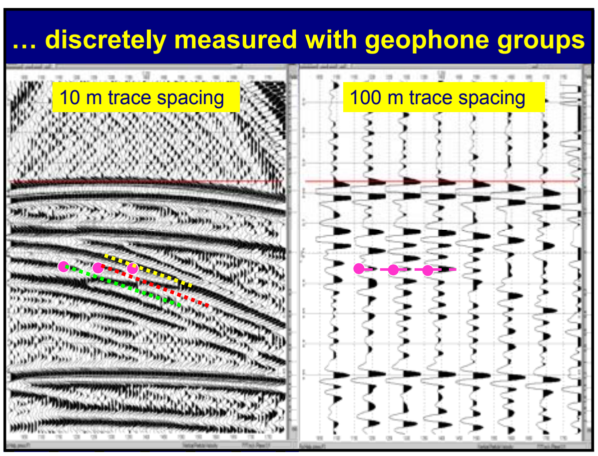


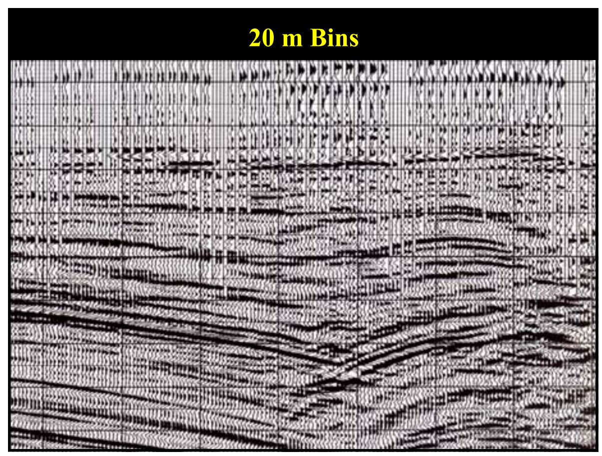

Continuous wavefield in space …

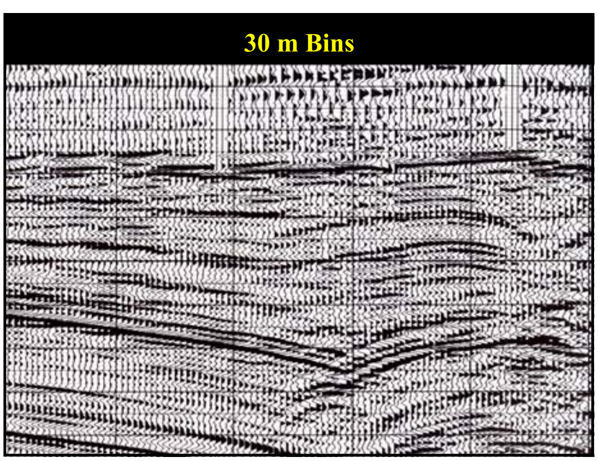

… exhibits different apparent wavelengths
36

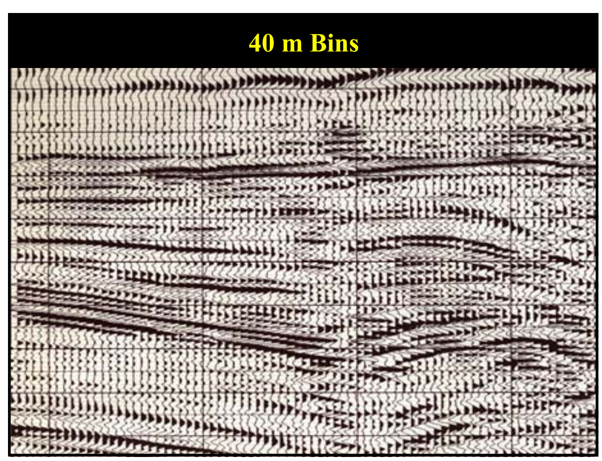

Continuously measured wavefield


… 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

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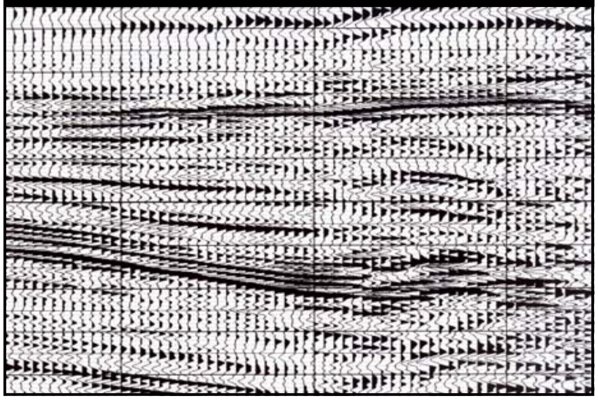
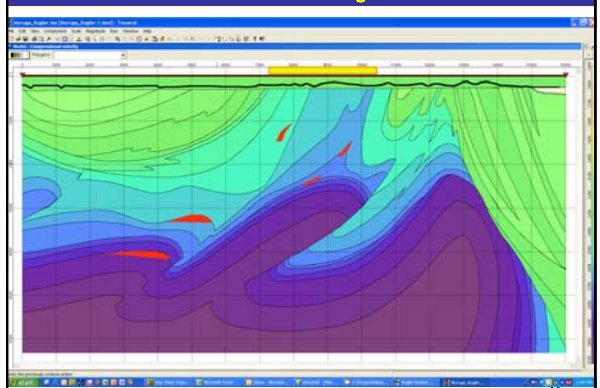
50 m Bins

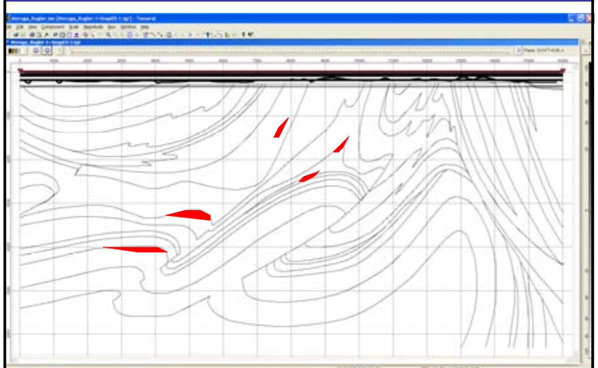


Tesseral Model – based on Kugler Cross-section



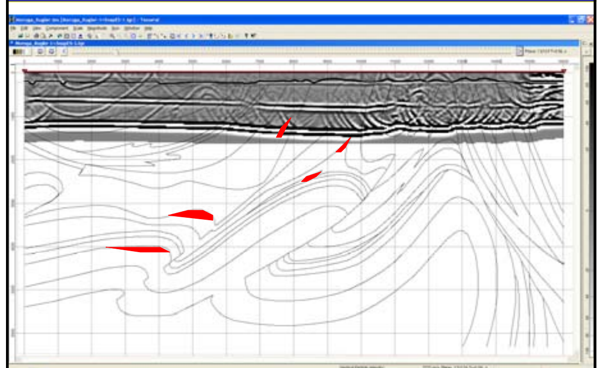
44

Tesseral Model – based on Kugler Cross-section



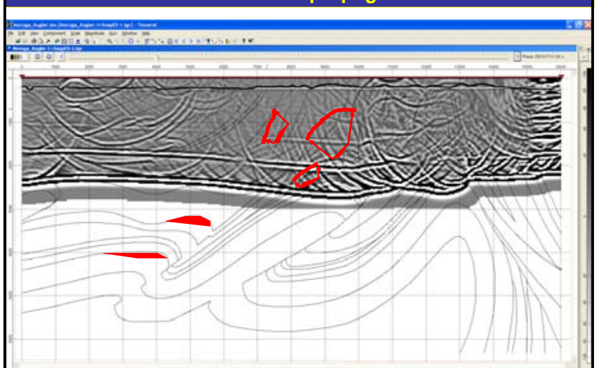
45

Tesseral Model – wavefield propogation – 0.560 secs



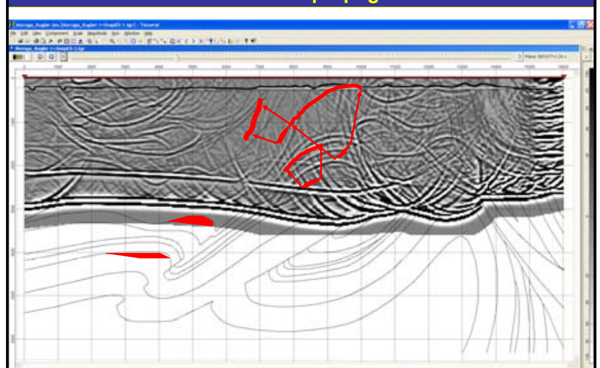
46

Tesseral Model – wavefield propogation – 1.040 secs



47

Tesseral Model – wavefield propogation – 1.240 secs



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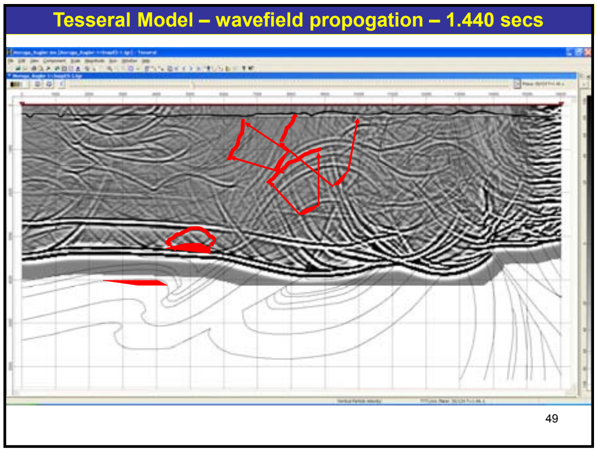
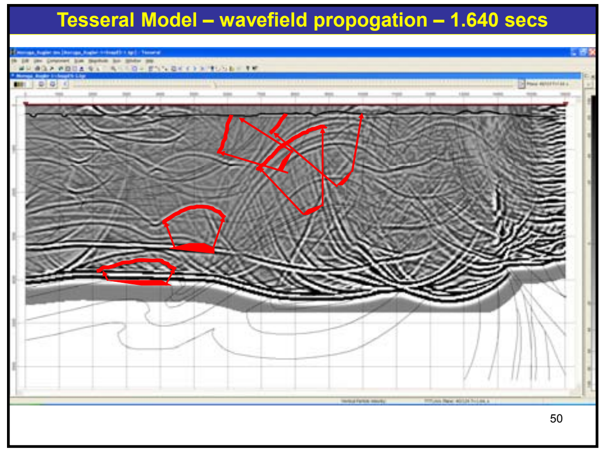
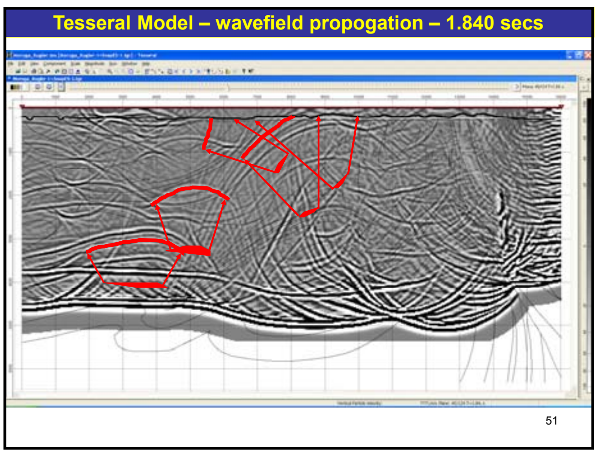
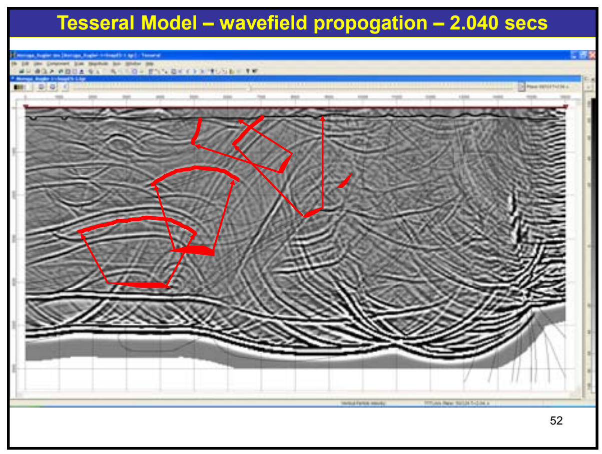
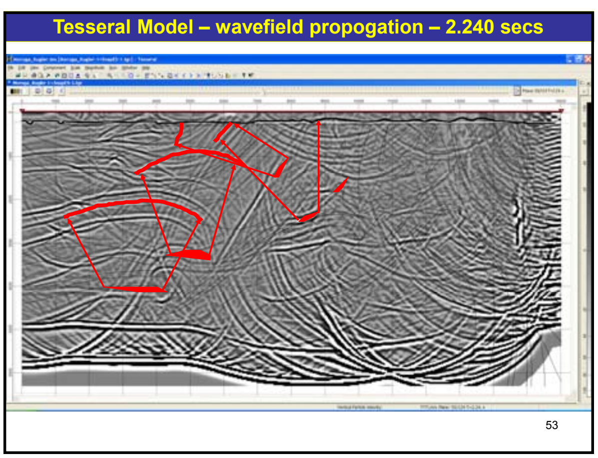

Tesseral Model – wavefield propogation – 1.440 secs
49


Tesseral Model – wavefield propogation – 1.640 secs
50


Tesseral Model – wavefield propogation – 1.840 secs
51


Tesseral Model – wavefield propogation – 2.040 secs
52


Tesseral Model – wavefield propogation – 2.240 secs
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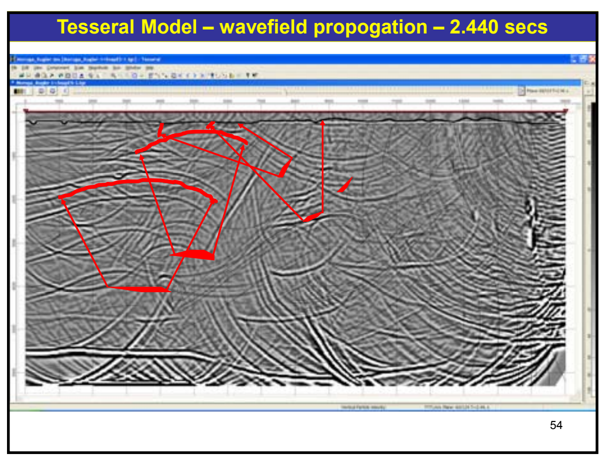
Tesseral Model – wavefield propogation – 2.440 secs
54

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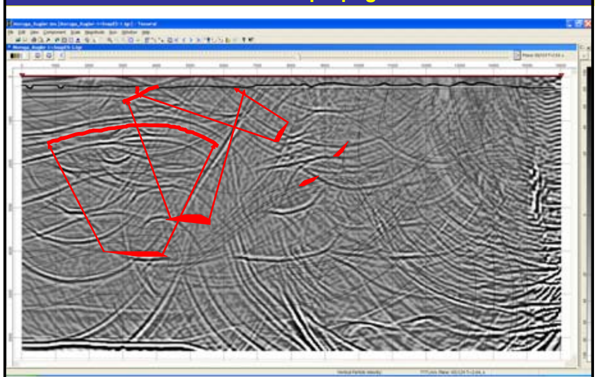
Tesseral Model – wavefield propogation – 2.640 secs



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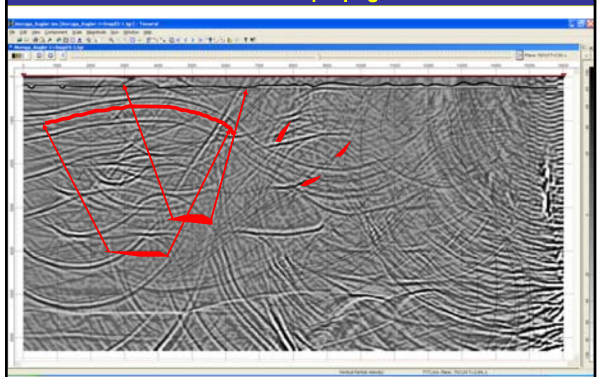
Tesseral Model – wavefield propogation – 2.840 secs



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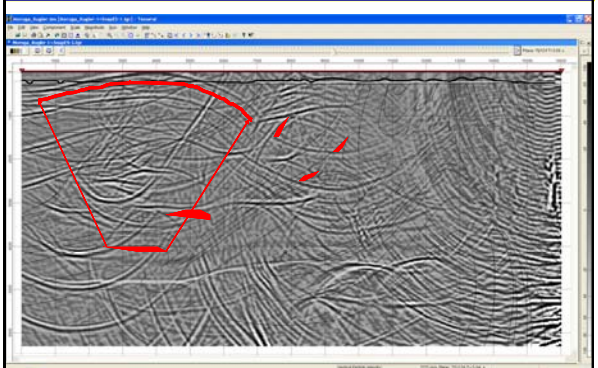
Tesseral Model – wavefield propogation – 3.040 secs



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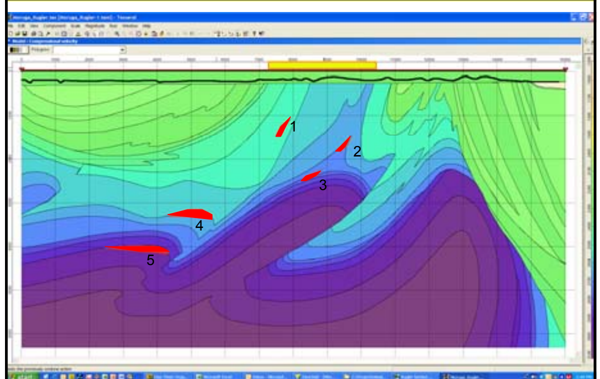
Tesseral Model – with five prospective zones



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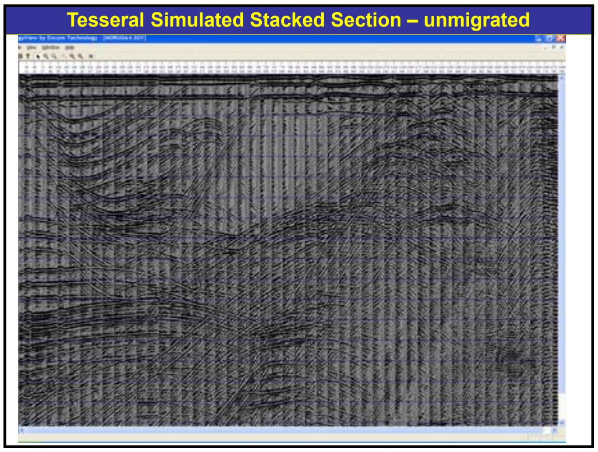
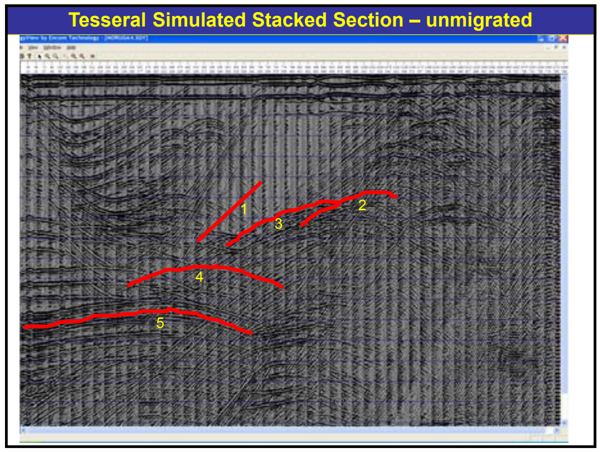
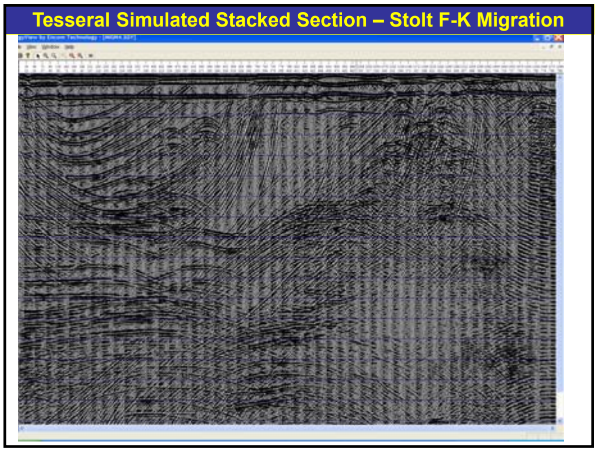
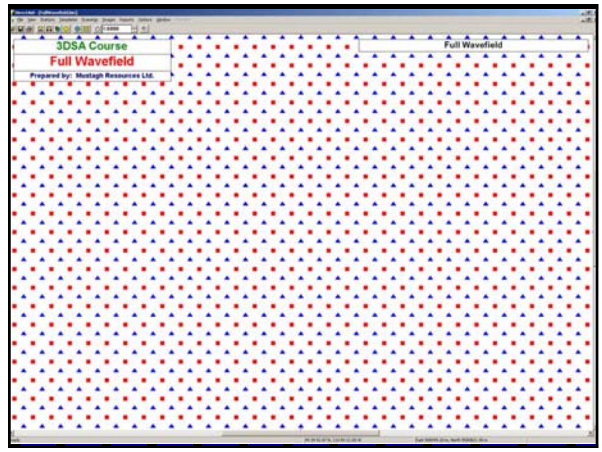
Tesseral Simulated Stacked Section – unmigrated

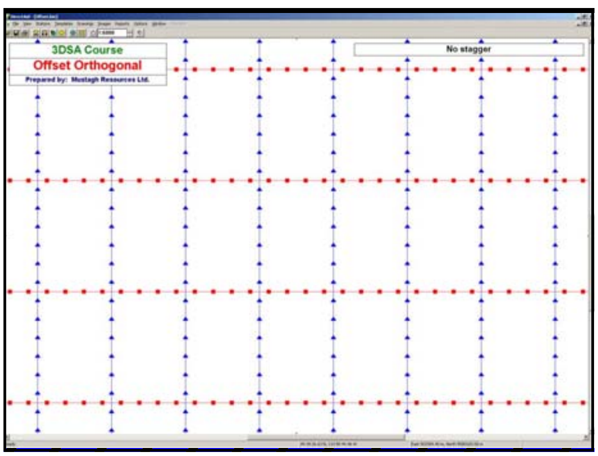


Tesseral Simulated Stacked Section – unmigrated




Tesseral Simulated Stacked Section – Stolt F-K Migration


3DSA Course
Full Wavefield
Prepared by: Mustagh Resources Ltd.
Full Wavefield


3DSA Course
Offset Orthogonal
Prepared by: Mustagh Resources Ltd.
No stagger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Modeling …
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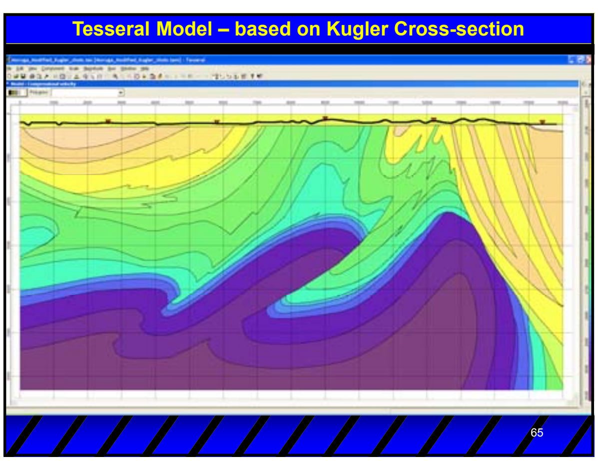
Tesseral Model – based on Kugler Cross-section
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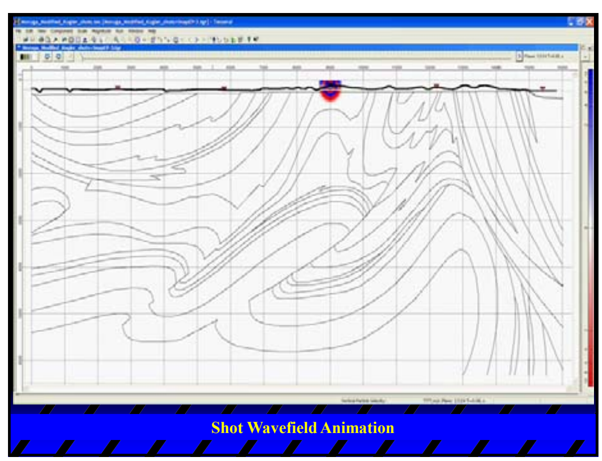
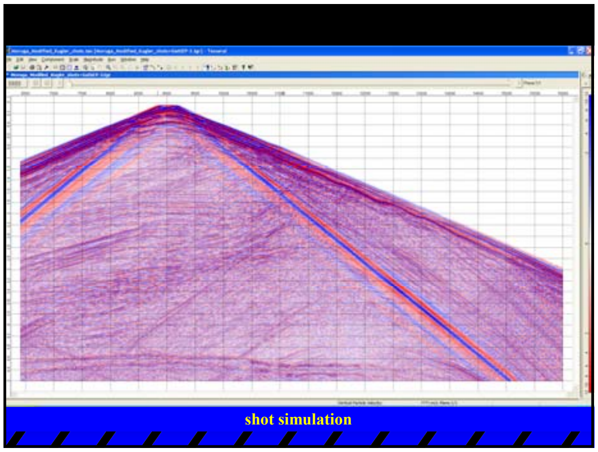
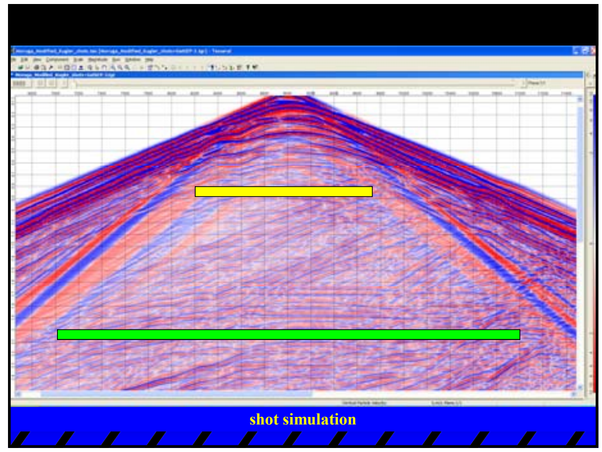
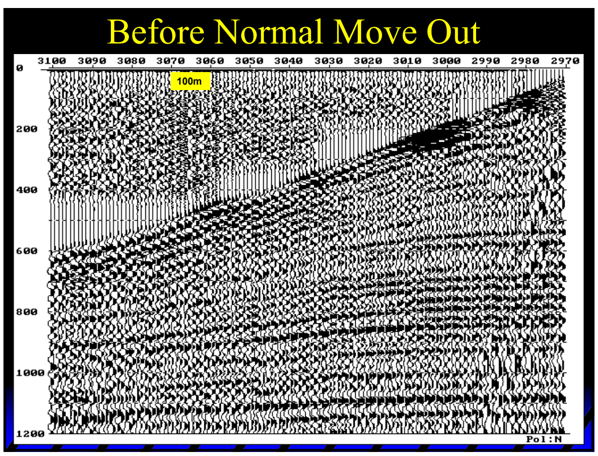
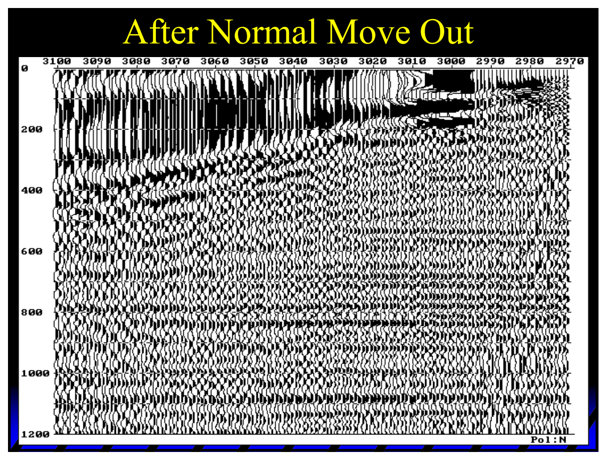
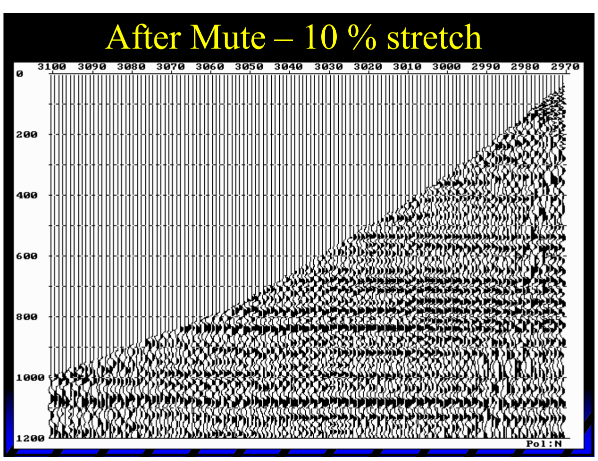

Shot Wavefield Animation

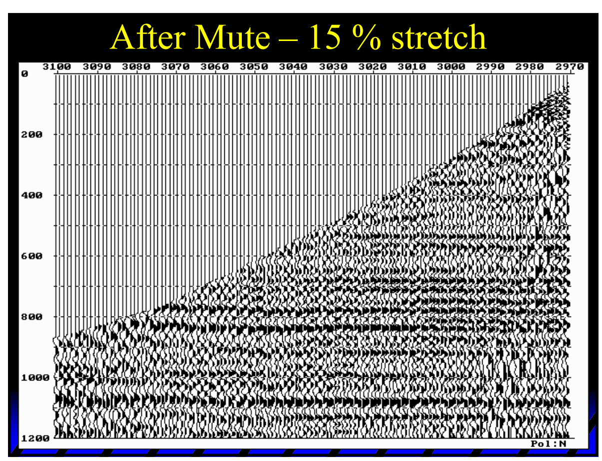

shot simulation

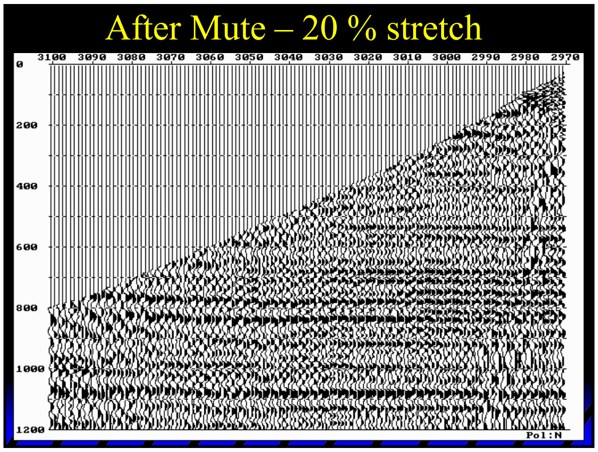

shot simulation

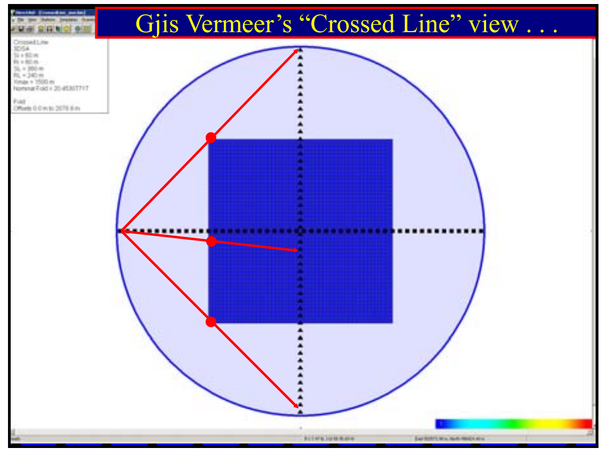

Before Normal Move Out
100m
Pol:N

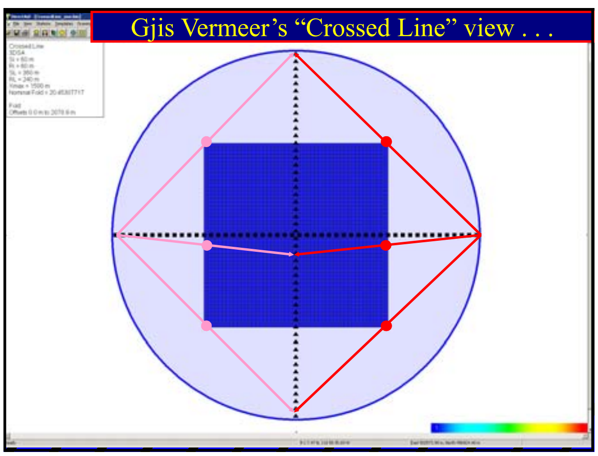

After Normal Move Out
Pol:N

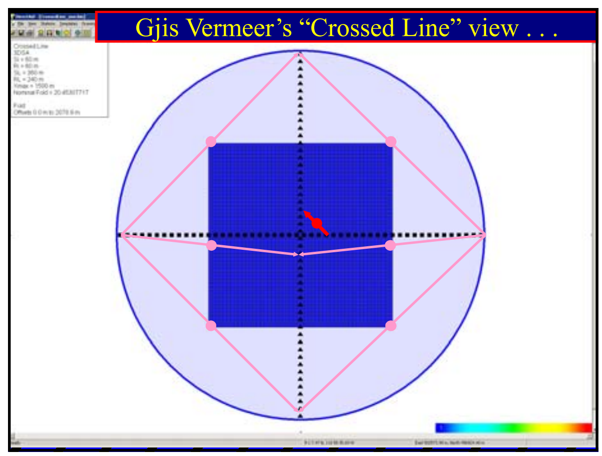

After Mute – 10 % stretch
Pol:N

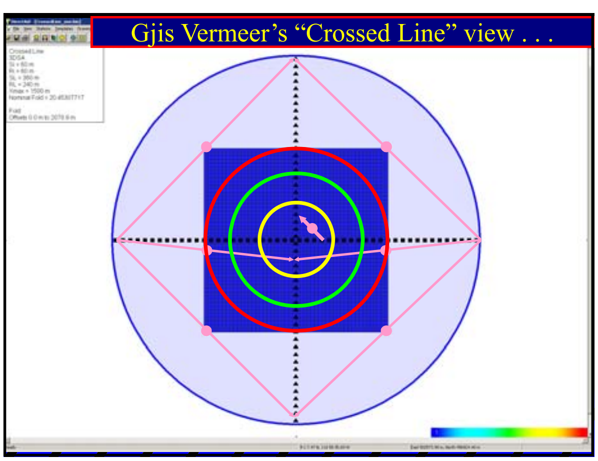

After Mute – 15 % stretch
Pol:N

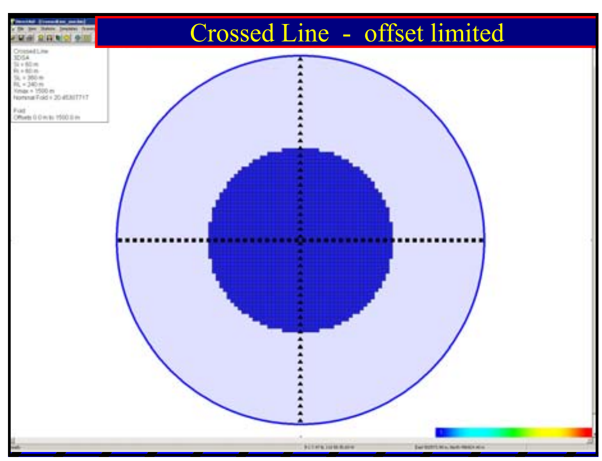

After Mute – 20 % stretch
3100 3090 3080 3070 3060 3050 3040 3030 3020 3010 3000 2990 2980 2970
0
200
400
600
800
1000
1200
Pol:N

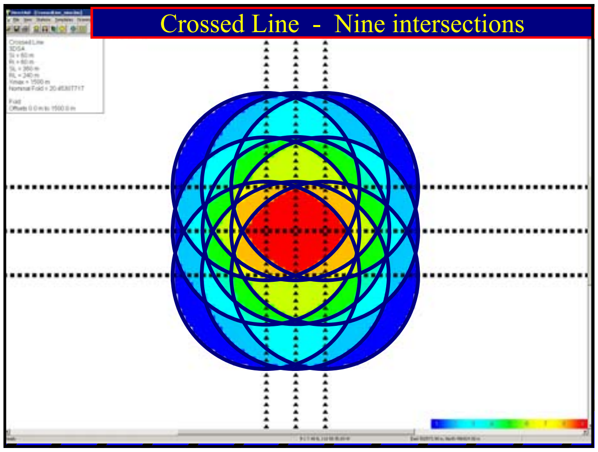
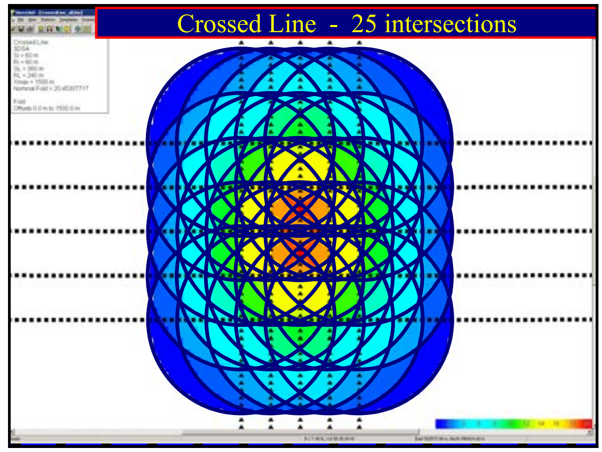
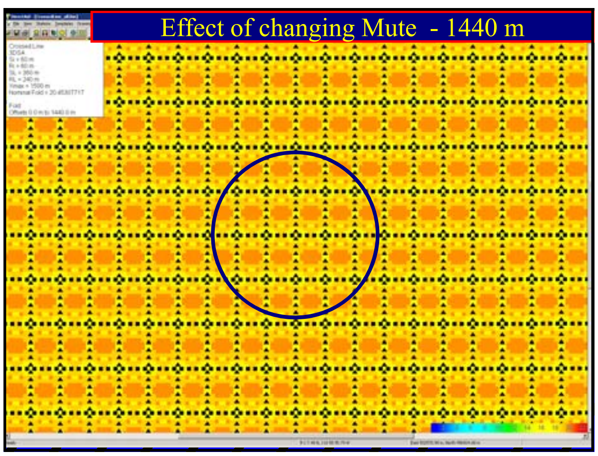
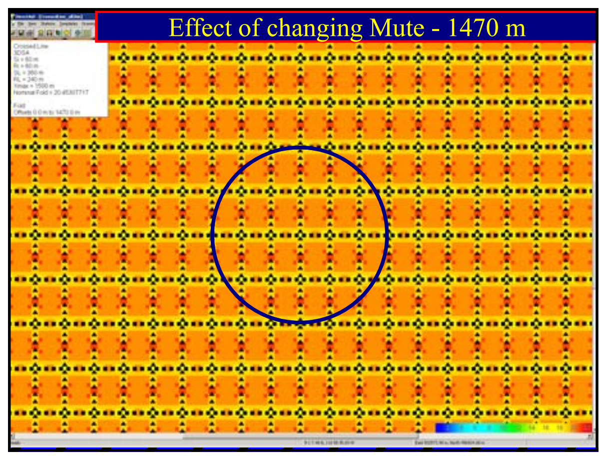
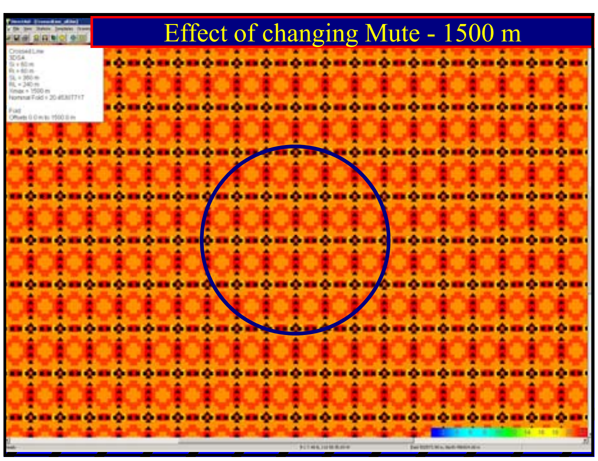
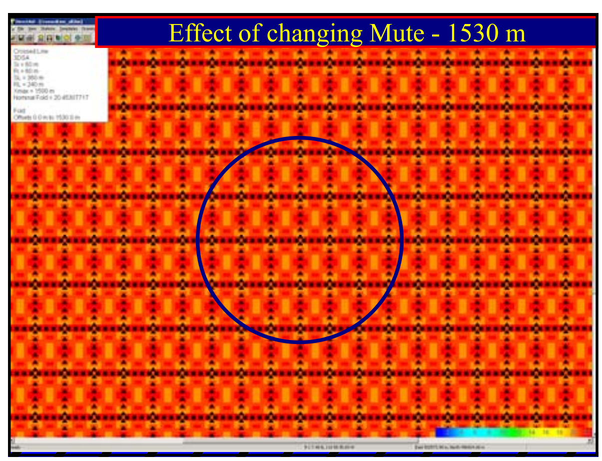

Gjis Vermeer's "Crossed Line" view . . .

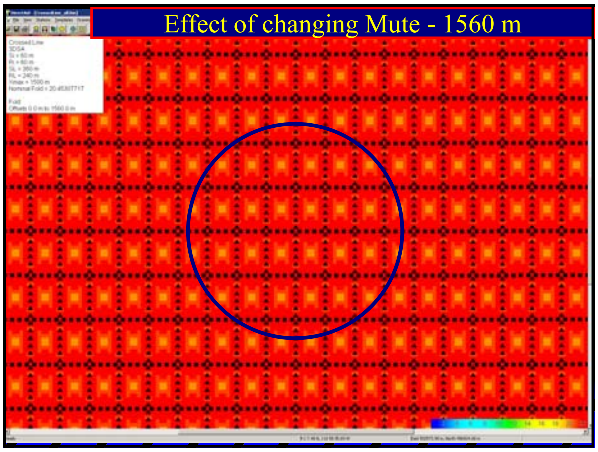

Gjis Vermeer's "Crossed Line" view . . .


Gjis Vermeer's "Crossed Line" view . . .

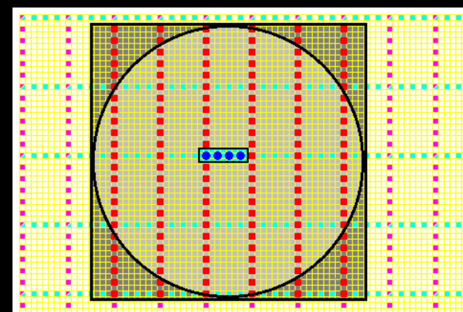

Gjis Vermeer's "Crossed Line" view . . .


Crossed Line - offset limited


Crossed Line - Nine intersections

Crossed Line - 25 intersections

Effect of changing Mute - 1440 m

Effect of changing Mute - 1470 m

Effect of changing Mute - 1500 m

Effect of changing Mute - 1530 m



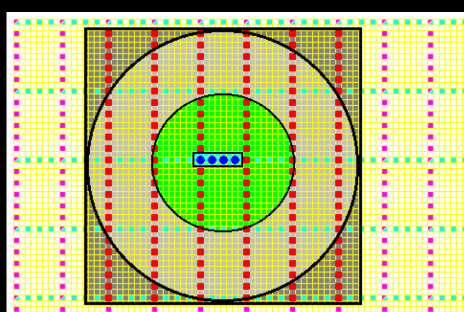
Our patch should be large enough to encompass all useable offsets



. . . longer offsets may not contribute to the fold at our zone of interest

86

Then the useful subsurface coverage . . .



. . . will be $\pi R^2 / 4$

87

Calculation of 3-D Fold

- The rectangular fold will be:

$$\frac{\text{Surface Patch Area}}{4 \times \text{Source Line Spacing} \times \text{Receiver Line Spacing}}$$

- And the offset limited (circular) fold will be :

$$\frac{\pi R^2}{4 \times SL \times RL}$$

Assuming a patch encompassing all useable offsets

88

2-D Design versus 3-D Design

- Source interval drives the cost of 2-D:

$$\text{Source Interval} = \frac{\text{Offset}_{max}}{\text{Desired Fold}}$$

- Grid density drives the cost of 3-D:

$$SL \times RL = \frac{\pi \, \text{Offset}_{max}^{2}}{4 \times \text{Desired Fold}}$$

89

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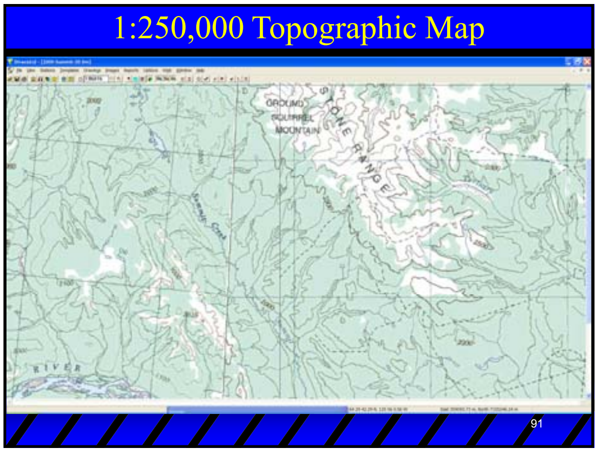
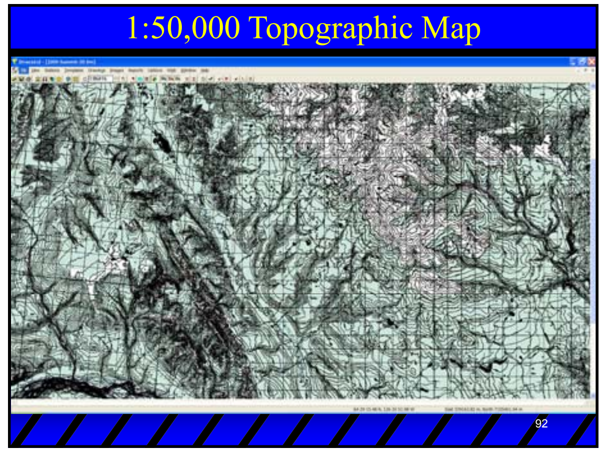
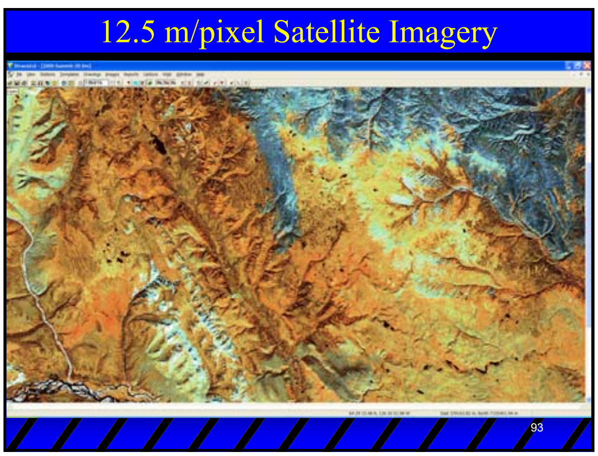
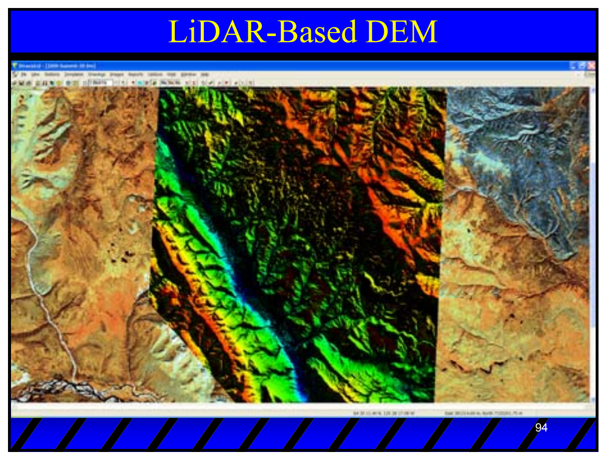
LiDAR

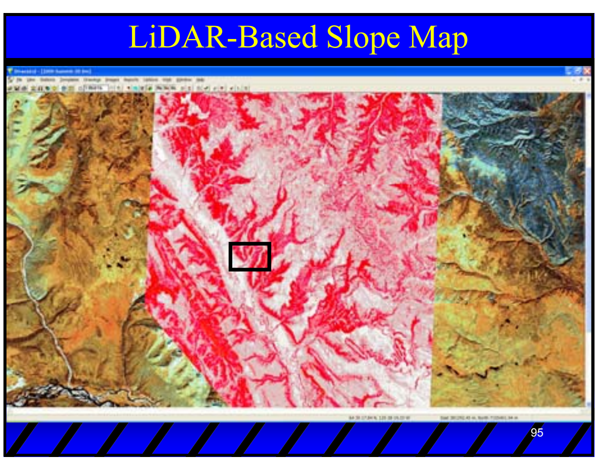
90

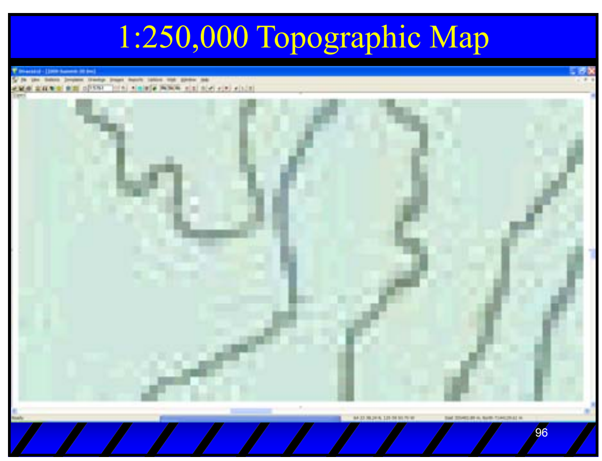

1:250,000 Topographic Map
91

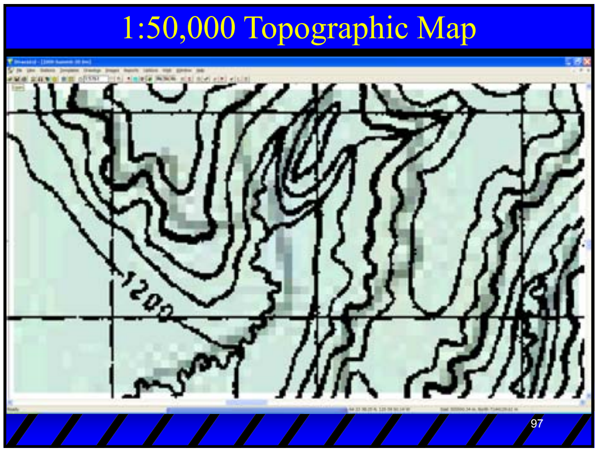

1:50,000 Topographic Map
92

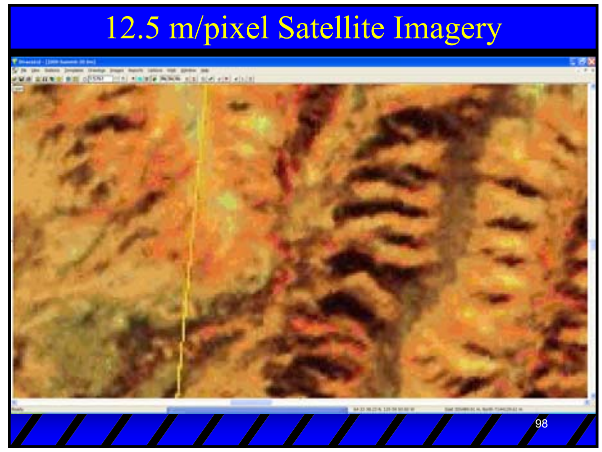

12.5 m/pixel Satellite Imagery
93

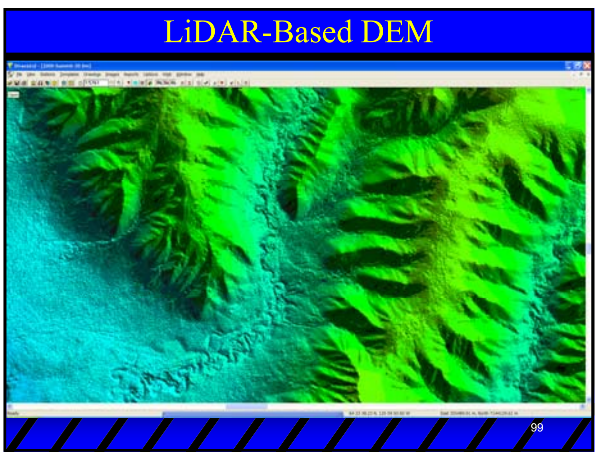

LiDAR-Based DEM
94


LiDAR-Based Slope Map
95


1:250,000 Topographic Map
96


1:50,000 Topographic Map
1200
97


12.5 m/pixel Satellite Imagery
98


LiDAR-Based DEM
99


LiDAR-Based Slope Map
100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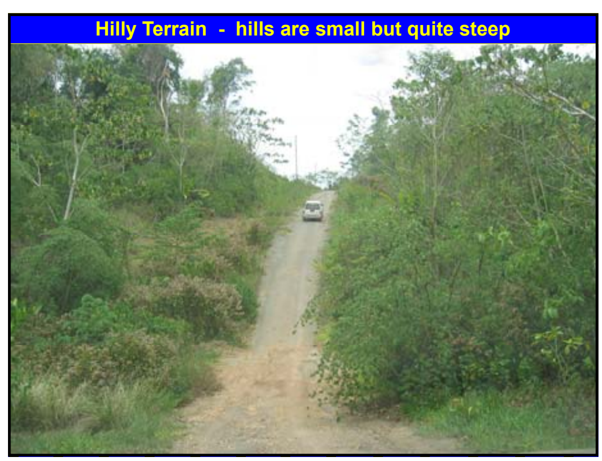
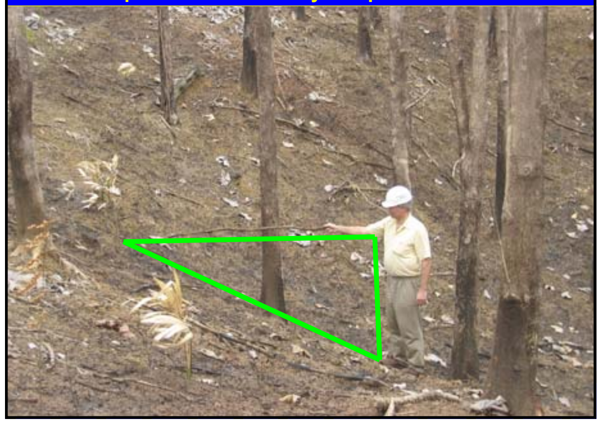
The Field and
Some Tools
101

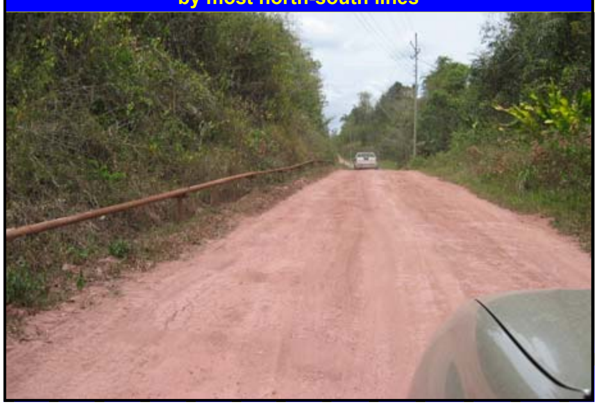

Hilly Terrain - hills are small but quite steep

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


2500 RPM


4810
110


"Mini-Vib" in Canada

	MiniVib	Litton?
Max. Theoretical Force	11,970 lb	A x P_H
Piston Area	3.99 in^2	???
Reaction Mass Weight	990 lb	7,800 lb
Reaction Mass Stroke	2.75 in	3.00 in
ServoValve Flow	60 gpm	200 gpm
Baseplate Surface Area	1810 in^2	4608 in^2
Baseplate Assembly Weight	855 lb	3,800 lb
Hold Down Weight	13,200 lb	60,000 lb

115

I/O “X-Vib” in Canada

Buggy Vibrators in Oman

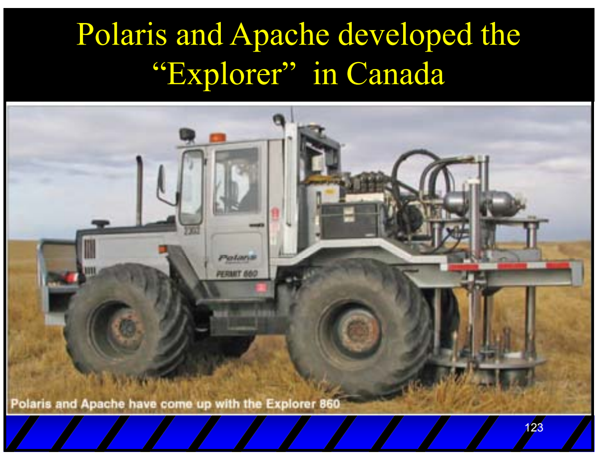
This is NOT a marine vibrator !!

“SeisPulse” in Nicaragua

120


AWD-1180
Compressed Nitrogen
working in Chad
AWD-1180
http://www.wojer.com/torgeo/awd1180.gif
121


"AWG - DigiPulse" in Chad
122


Polaris and Apache developed the
"Explorer" in Canada
Polaris and Apache have come up with the Explorer 860
123


MacKenzie Delta


Norm Cooper – old tree being devoured by drifted snow


During a 3-Day Blizzard