Geophone Arrays in Today's World of 2D and 3D

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CSEG Geophysics 2002

Overview

Since early in the history of reflection seismic programs, we have tended to use multiple geophone sensors to record each trace of information. Typically we record traces sparsely (between 10 and 60 meter group intervals are typical). This has been due largely to recording channel limitations and the need to record a broad range of offsets. In the youth of seismic, we recognized that an organized spatial distribution of analogue recording elements would form a wavenumber domain filter when summed together. This lead to a popular practice of designing arrays to attenuate coherent noise patterns (those with wavelengths generally shorter than our array length). As broader bandwidth became a requirement for sharper imaging of subtle stratigraphic plays, arrays fell into dis-favor. Many geophysicists perceived that conventional arrays were so long as to attenuate some of the high frequencies of the far-offset, shallow reflections. This led to a period of insanity where many geophysicists believed it wise to group or "pot" the geophones to eliminate that nasty array effect.

Unfortunately, many of today's geophysicists persist in this belief. In this paper, we will review briefly the need for distributed geophone groups and discuss how they should be applied in both 2D and 3D environments.

Electrical considerations

In days long past where weak analogue signals had to be passed down long, thin pairs of wires (sometimes over many kilometers), we experienced great signal loss. Therefore, we needed to combine the power of several geophone elements at the transmitting end of the cable in order to ensure we received a measurable and significant signal at the receiver end. This electrical advantage of using multiple geophones required some impedance matching concerns (relating to series-parallel configurations, number of elements, etc.). This particular reason for using multiple geophones did not require any particular spatial arrangement and is therefore not a concern for this paper. Nor is it much of a concern for distributed recording systems in use today where analogue paths are often shortened to a few meters.

Statistical considerations

We desire data that reflects subsurface geologic changes near our target zones. Amplitude and character changes can result from trace to trace simply due to surface coupling effects. If single geophones are used to record each trace, then these trace to trace variations are maximized. By using several geophones to record each trace and ensuring that the sensors are distributed over a reasonable area (probably at least 2 meters or so between individual sensors), we average some of these variation and provide more stable trace-to-trace signatures. There are those who worry about the effect of "intra-group" statics and the high frequency attenuation that may result. However, these effects are generally recoverable through deconvolution. If the effects are very dramatic, then it can be argued that we should be recording traces at a smaller group interval in order to properly evaluate such a complex near surface!

Again, we point out statistical averaging as a relatively minor effect of using multiple geophones to record each trace. However, this advantage requires some type of spatial distribution of the individual sensors. There is nothing in this consideration that dictates any organization to the distribution of the elements, and therefore this does not truly fall under the category of an array effect.

Superposition

One of our most powerful tools to enhance desired signal and suppress undesired noise is stacking. We frequently use CDP stacking to mix several traces that were recorded at different times, from different shots and receivers, and representing different offsets. Before stacking, we do our best to compensate for normal moveout and statics effects in our data. Thereby, we ensure that the desired signal will be (as much as possible) the same on each of the contributing traces. The result of such a mix is to constructively enhance those elements that are repeatable from trace to trace, and to attenuate (by destructive interference) those elements that are not consistent in source, offset, receiver or time domains. Few of us would argue that such a "mix" is not generally beneficial to our data.

We have a wonderful opportunity to utilize the power of superposition as we create each recorded trace. If we use multiple sensors summed together to form our recorded trace, we may form a trace of better signal to noise ratio than any individual sensor. However, if all the sensors are "potted", we will record identical noise on each trace and the superpostion principle will fail. Therefore, it is important to position the individual geophones in different local noise environments. For many of our applications, this requires that the sensors be at least one to two meters apart. This observation has been confirmed in the past when we use to run "saturation" tests as part of extensive parameter tests.

On many occasions, I have been party to tests evaluating single phones, potted phones, and phones distributed over various distances. In all of the tests I have evaluated, I have never seen a situation where the data was not improved substantially by distributing the geophones. Although, superposition considerations require a distribution of geophones, nothing here indicates an orderly distribution is required. Again, I do not classify superposition as an array phenomenon.

Arrays

It has long been recognized that an orderly, uniform distribution of source or receiver elements can form a wavenumber filter. There are several ways of perceiving arrays. For reflection seismic, I prefer to think of them as a passive wavenumber filter for wavenumber elements received along the line of geophones making up our seismic line (i.e. along the surface). Therefore, we must consider the "apparent wavelength" of all of the signal and noise elements of our recorded data. In antenna theory, we think more of "beam steering" where we make transmitted fields stronger in preferred directions (or receiver arrays that are more sensitive to fields incoming from certain directions). In seismic, we are usually beam-steering to show favor to elements of the wavefield propogating vertically (or at least normal to our line of seismic), and to attenuate elements propogating along our line.

In a laboratory, we can create hi-fidelity arrays that have attractive responses. In a 1973 publication by Newman and Mahoney called "Patterns with a Pinch of Salt" the authors demonstrated that such ideal arrays are not practical in the field. 10 to 20 percent errors in implementation (element spacing or element weighting/coupling) will substantially deteriorate the filter characteristics of the array. This paper has led some geophysicists to claim that field crews must be forced to plant geophones at exact spacings (unfortunately, a somewhat unrealistic expectation). Others have concluded that "arrays don't work anyway" and therefore advocate grouping of geophones (obviously this group of people did not actually read the paper). As I interpret it, the paper indicates that we must anticipate a limited filter effect for arrays implemented in typical seismic operations. However, the paper also illustrates that for 10 to 20 percent implementation errors, array filters will have a more stable reject band with 20 to 24 dB of attenuation. This is still a worthwile objective.

The key to array design is to ensure that the effective length of the array is short enough to pass all of our desired signal. In the next section, we will see this is related directly to our choice of group interval. Therefore, at least for 2D programs, our group interval becomes a practical selection for our array length. For those who believe that such an array is too long, then my reply would be "if an array spread over one group interval is attenuating signal wavelengths you desire to record, then your group interval is obviously too large!".

Spatial Anti-Alias Filters

Modelled shot records will be used to demonstrate the effects of sampling wavefields sparsely. Aliasing in the F-K domain will be reviewed. A geophone array is an effective wavenumber filter that can be used to attenuate those elements of the wavefield which will tend to alias destructively when sampled at our discrete group intervals.

Few of us would consider recording time domain data using instruments with no high cut anti-alias filter. And yet, in the space domain (where we are typically undersampled), many are still advocating "potted" geophone groups. This is tantamount to recording 2 ms time domain data with no instrument high cut filters applied. Our signal is already difficult enough to extract during processing. We must not compound the task by allowing aliased noise to blend with our data in such a way that it is no longer separable in any of our transform domains.

Arrays in 3-D

Since arrays provide a filter that tends to suppress undesired elements that propogate along our array (as opposed to across it), there arises a concern over the azimuth dependence of array responses. First we should recognize that two orthogonal linear arrays will spatially convolve to form a circular response that is not dependent on azimuth. Therefore, we do not generally require circular or star-shaped arrays. Therfore, for orthogonal or nearly orthogonal 3D grids, we need only to assure that the effective array response in the receiver direction is matched by the effective source array response on the orthogonal direction.

Secondly, we should recognize that for most of the Western Canadian Sedimentary Basin, signal wavelengths are seldom shorter than about 80 meters. Therefore, a 20 meter array is considered not to be a significant filter. Therefore, if expensive dynamite sources loaded in even more expensive drilled holes dictates that point sources be implemented; this does not dictate that point (or "potted") receivers must also be used. Indeed, if six or so receivers are distributed over 20 meters, there will not be a strong array effect, but we will gain from the other four considerations outlined above.

Another concern of arrays in 3D is that we cannot afford to distribute our sensors over the long group intervals used in most 3D's. Therefore, we risk losing the spatial anti-alias filter that we just claimed was very important. For this reason, mid-point scatter methods become an important part of spatial sampling. For example, a triple stagger method can distribute midpoints into a 9-dot pattern (dots separated by 10 m) in a 30 meter bin. Therefore, 20 meter surface arrays (with 10 meter subsurface expressions) may be sufficient to provide the continuous sampling necessary for filtering of elements in our wavefield with the potential to alias.

Summary

Like most of life, our attidudes towards geophysical theories tend to oscillate between extremes. We are at a point when most geophysicists have been dazzled by digital recording technology and are being told that arrays are an unnecessary evil. We should recognize that we are usually well sampled (and often over-sampled) in the time domain. This is where our digital technology has taken us. However, we still have too few recording channels to record wavefields of the complexity that we wish to image. Some simple examples show that we should be recording (and also generating) seismic wavefields at intervals of no more than about 10 meters. Until we can do that (technically, economically, culturally and environmentally), we must recognize that our discrete sampling of the wavefield as it returns to the surface is woefully undersampled. Therefore, we have a need to provide better sampling where ever possible prior to forming descrete recorded traces. A geophone array is as necessary today as an analogue anti-alias filter was for older multiplexed recording systems.

The Many Faces of Geophone Arrays

- 2D and 3D Applications -

Norm Cooper
and Yajaira Herrera

MUSTAGH RESOURCES LTD.

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A typical hand cut receiver line in a

Central Alberta 3D program

A definite need for "marsh" phones and planting poles

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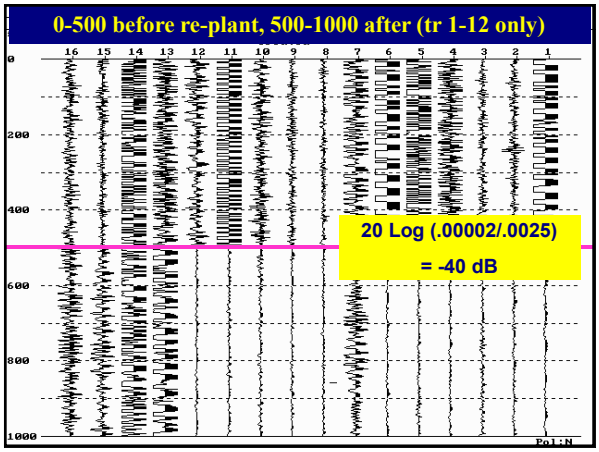

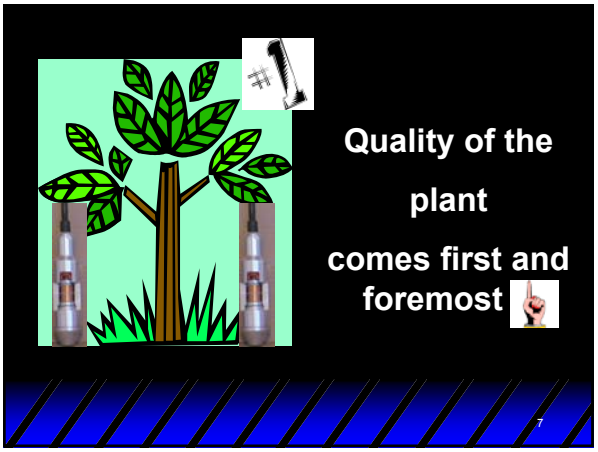

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Considerations for Multiple Geophones for each Trace

- Electrical - transmission losses
- Statistical - average coupling
- Superpostion - "in-group stack"
- Array - spatial filter
- Spatial anti-alias filter - Stack array
- Geophone response test - sensitivity

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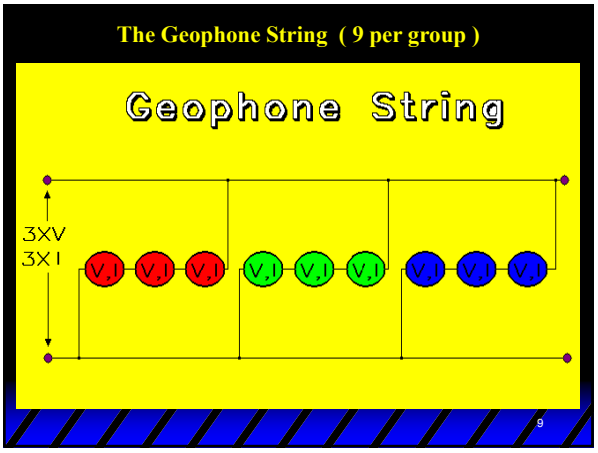

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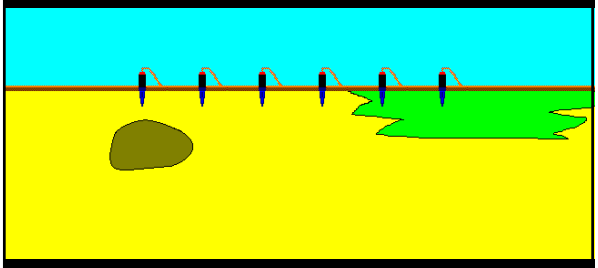
Statistical Advantage of Multiple Geophones



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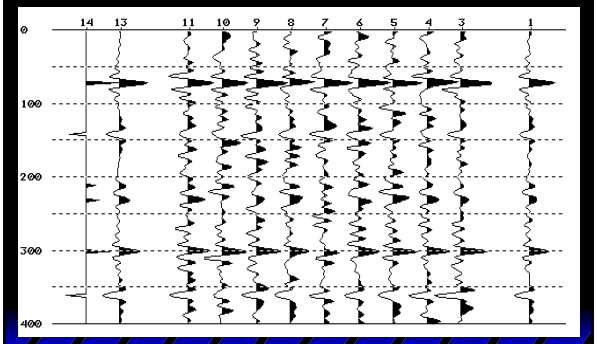
Principle of Superposition



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Organized Geophones - An Array -

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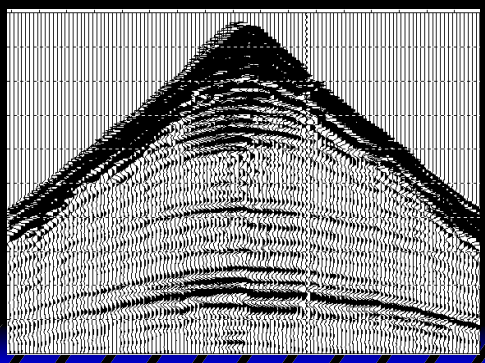
A Seismic Shot Record from Saskatchewan



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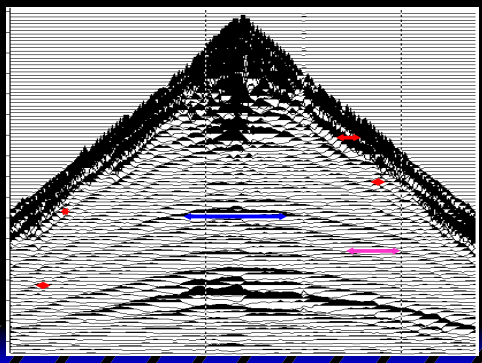
The Same Record as a set of Spatial Waveforms



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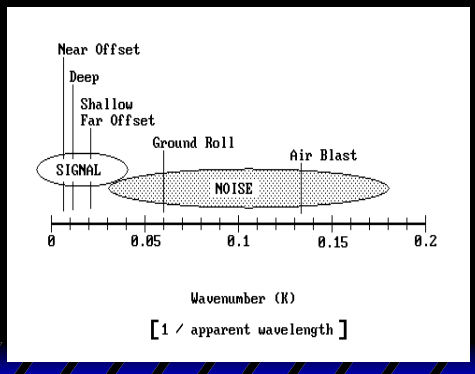

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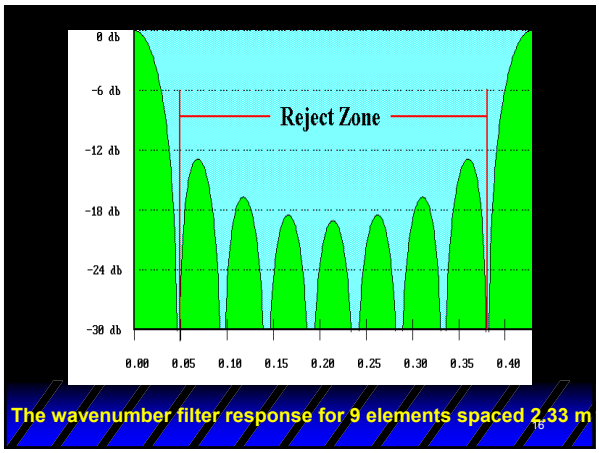

The wavenumber filter response for 9 elements spaced 2.33 m

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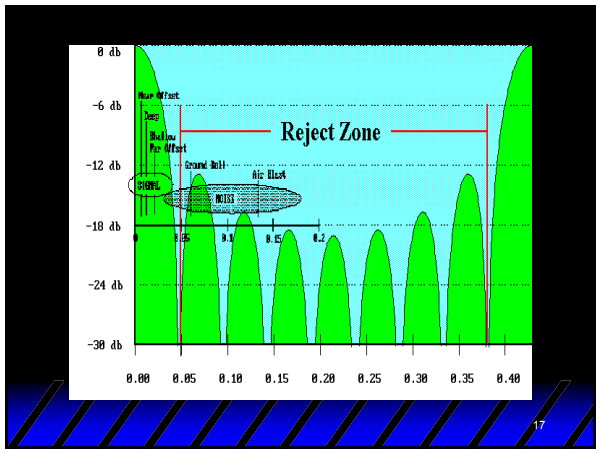

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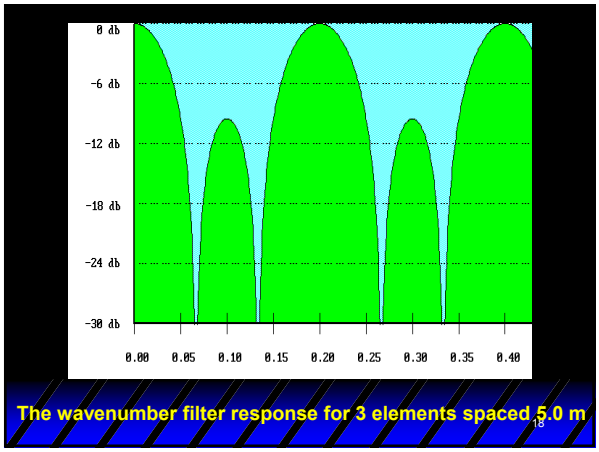

The wavenumber filter response for 3 elements spaced 5.0 m

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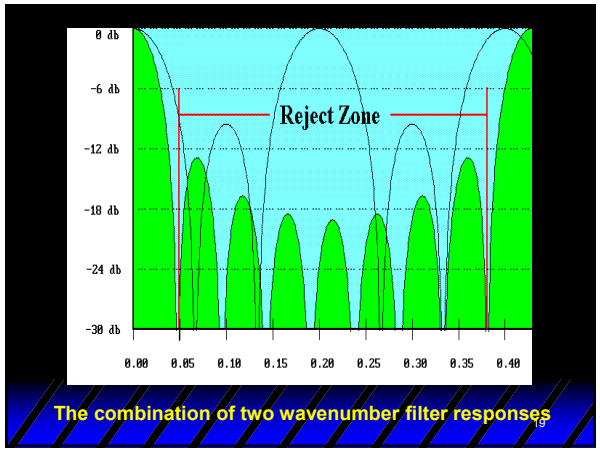

The combination of two wavenumber filter responses

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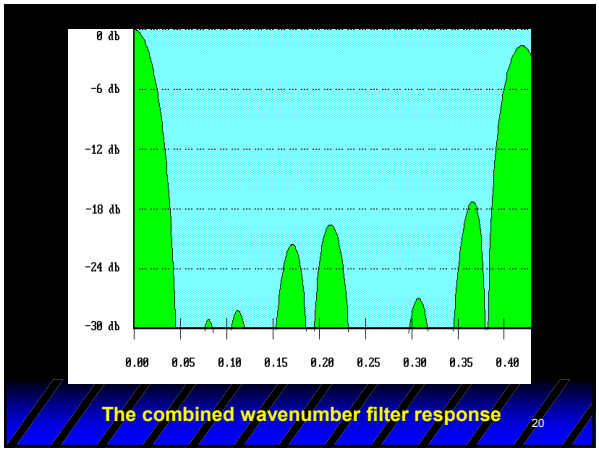

The combined wavenumber filter response

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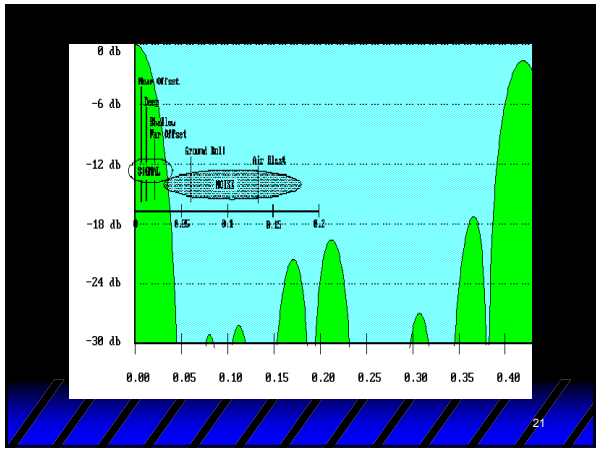

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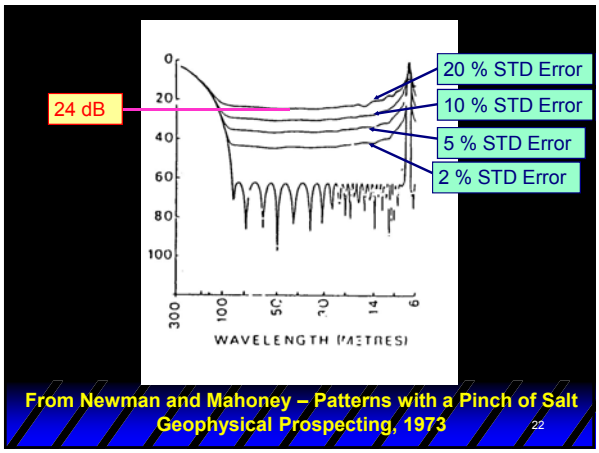

From Newman and Mahoney – Patterns with a Pinch of Salt Geophysical Prospecting, 1973

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An Array as a Special Filter . . .

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. . . a Spatial Filter . . .

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. . . a Spatial Anti-Alias Filter . . .

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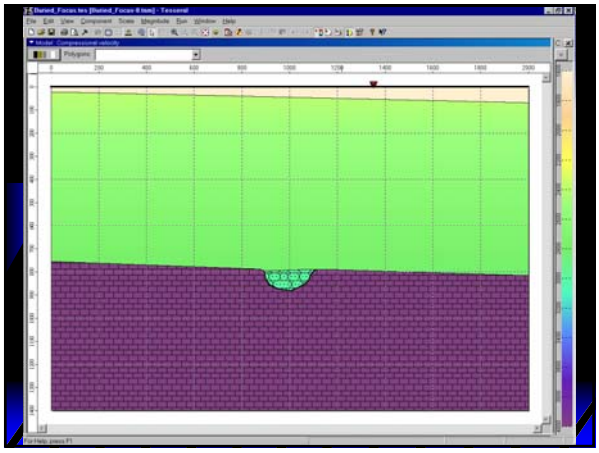

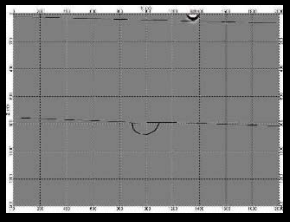

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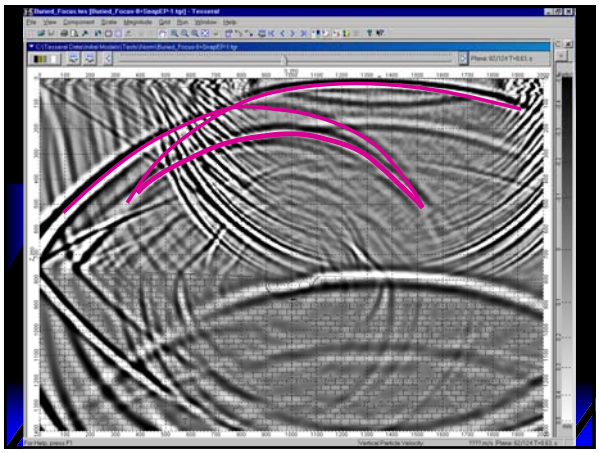
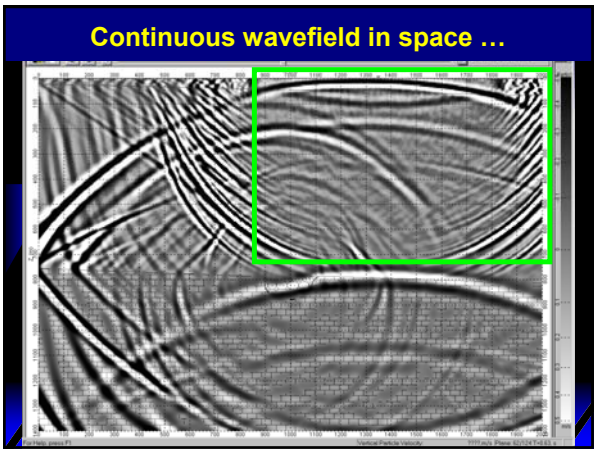
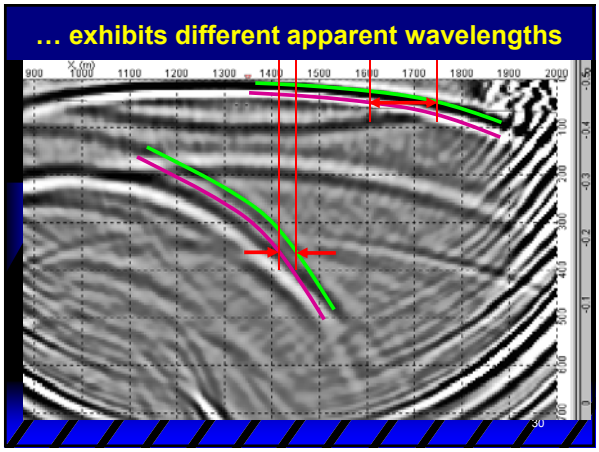



Continuous wavefield in space …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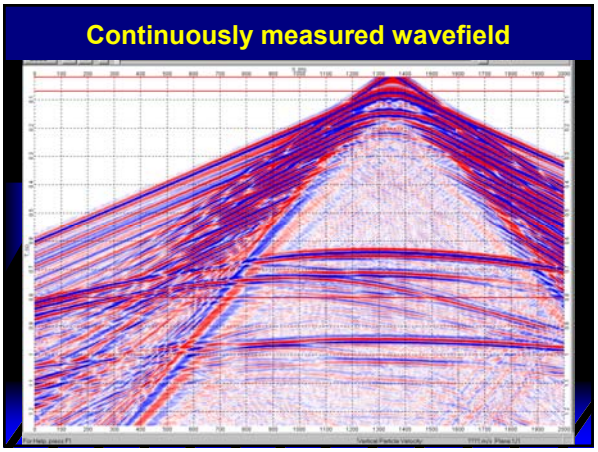
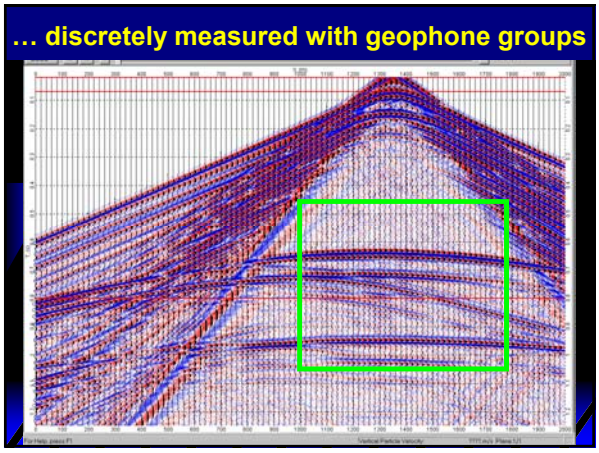
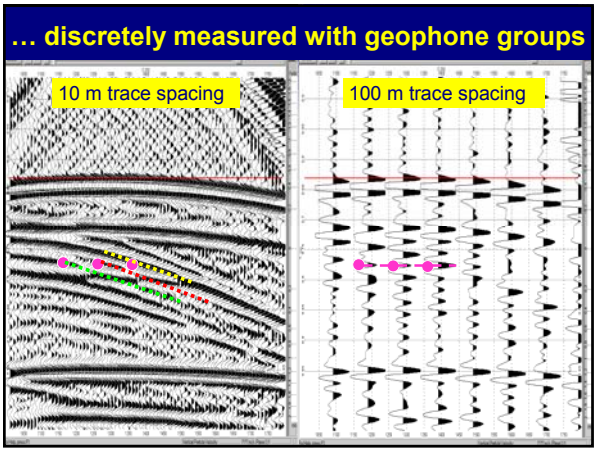
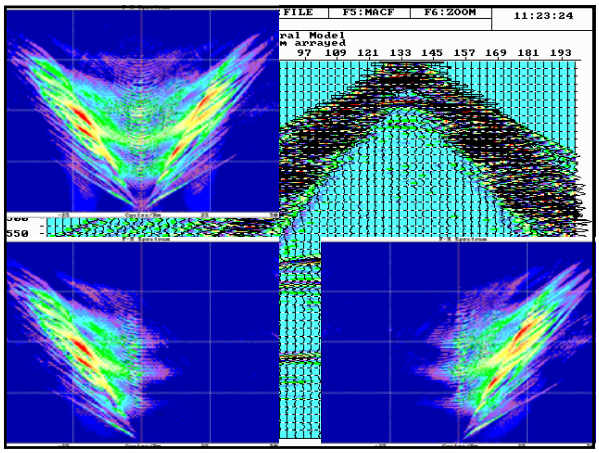

Continuously measured wavefield


… discretely measured with geophone groups


… discretely measured with geophone groups
10 m trace spacing
100 m trace spacing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F6:ZOOM
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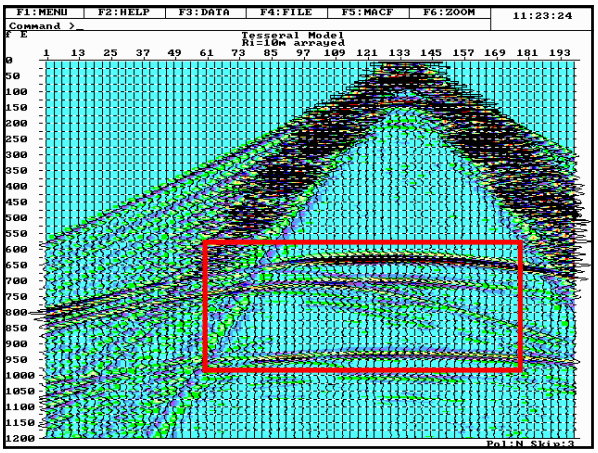
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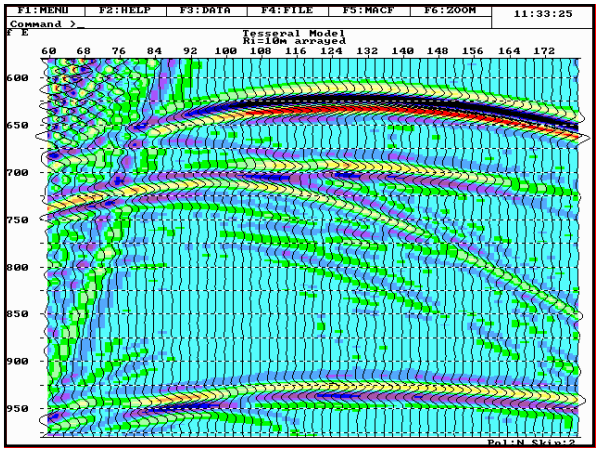
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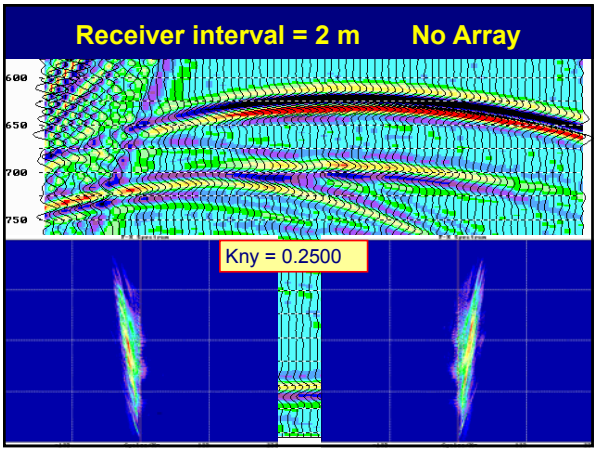
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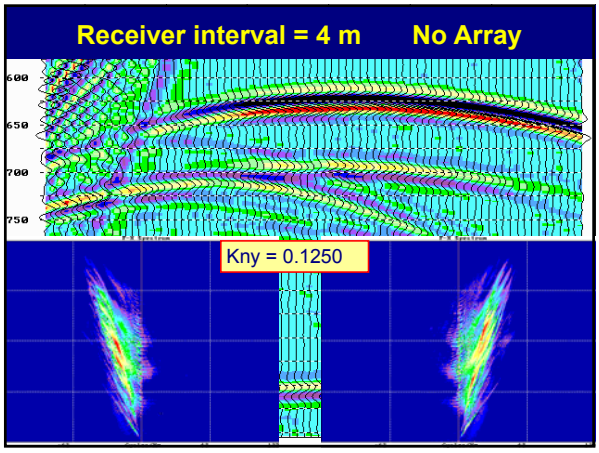
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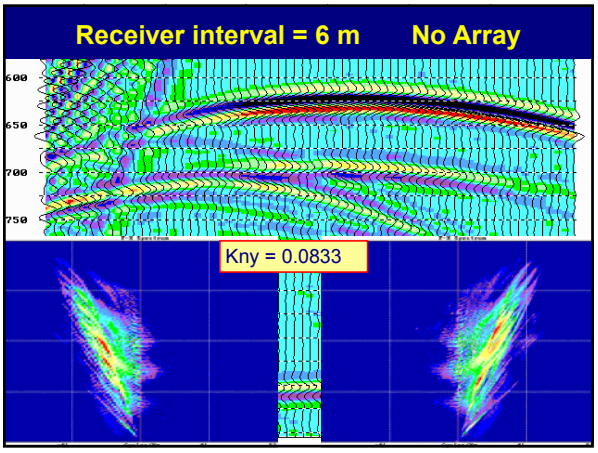
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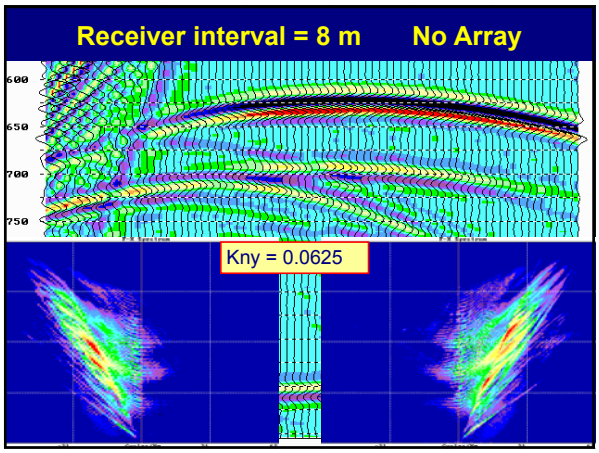
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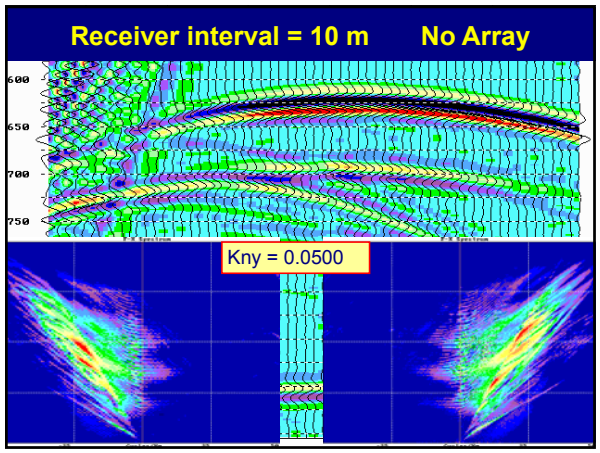
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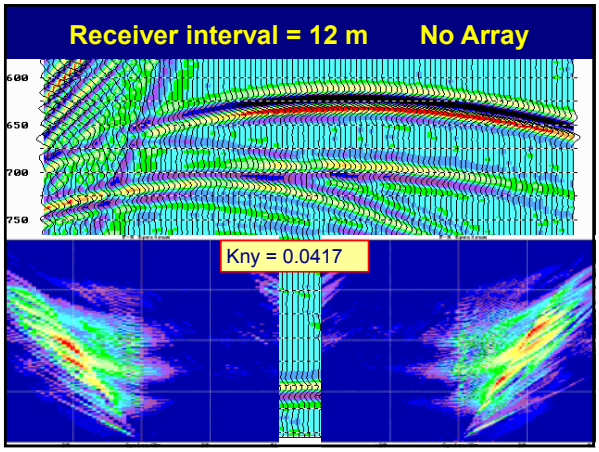
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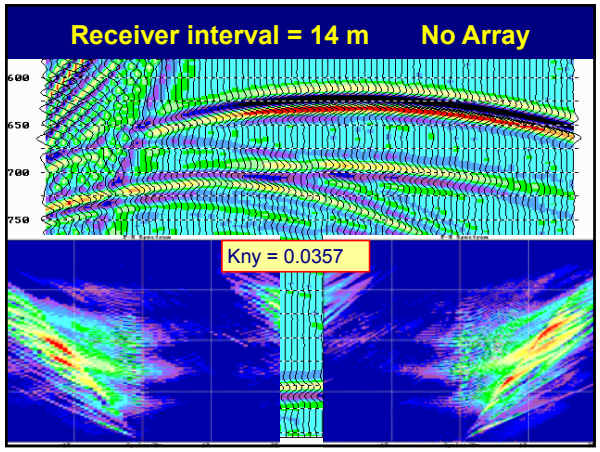
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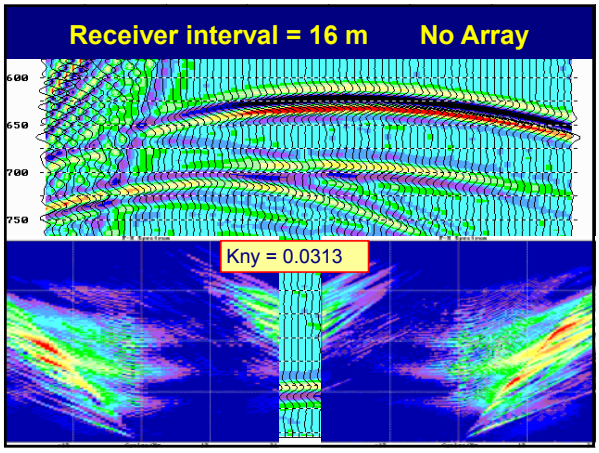
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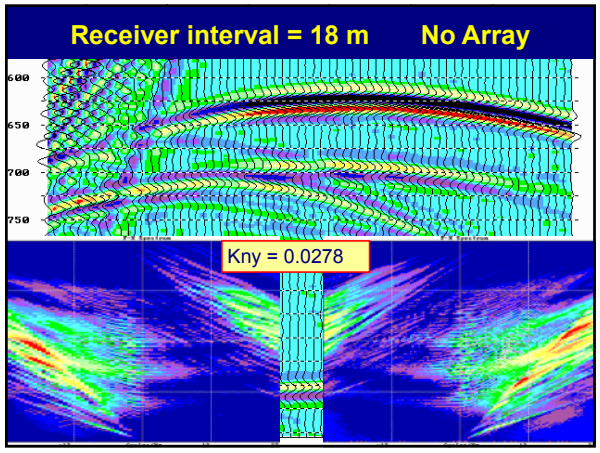
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750
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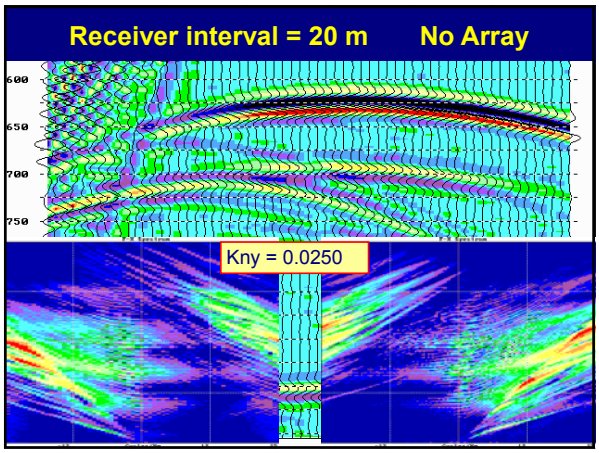
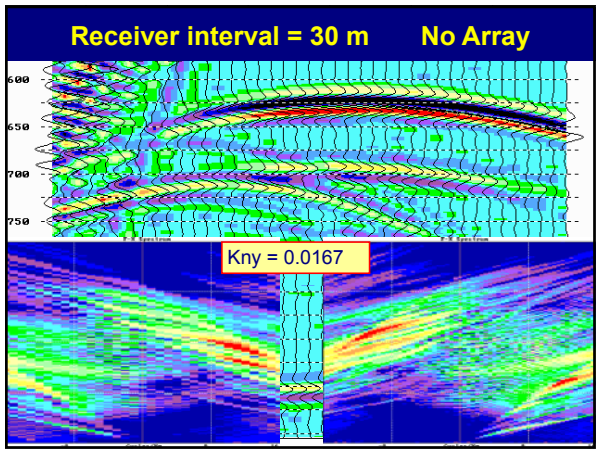
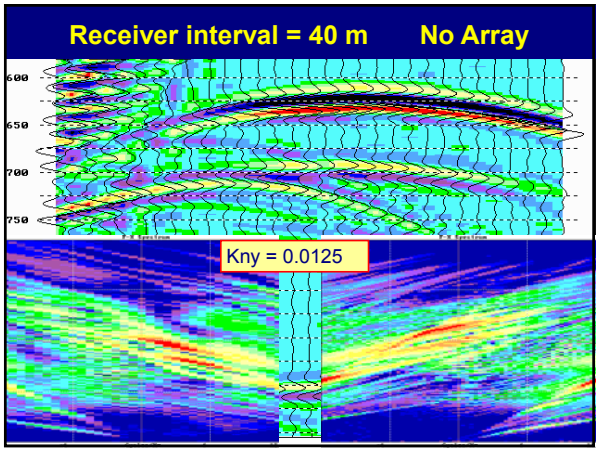
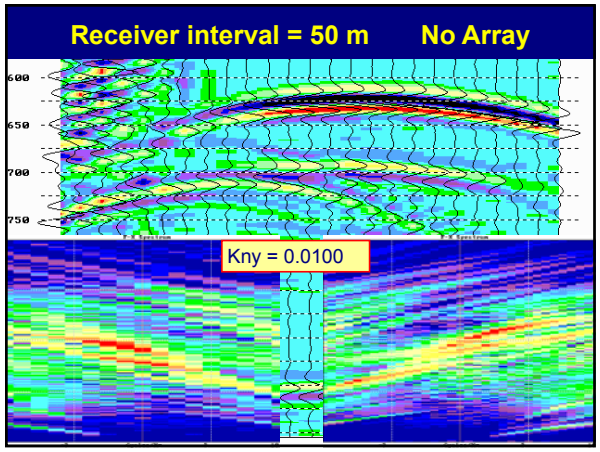
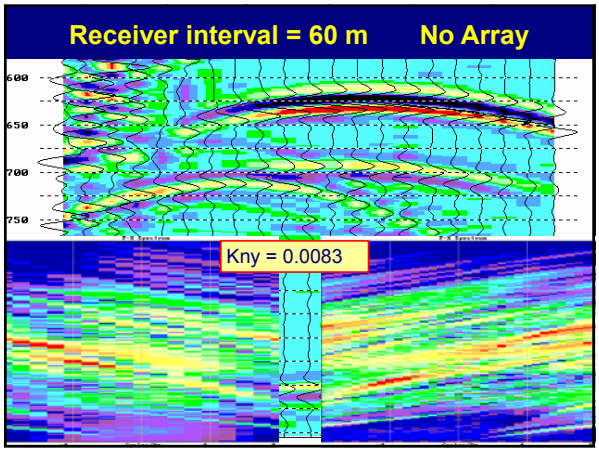
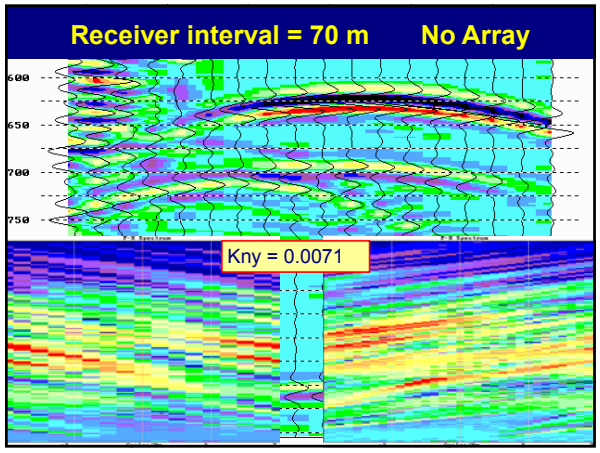

Receiver interval = 20 m
No Array
600
650
700
750
Kny = 0.0250

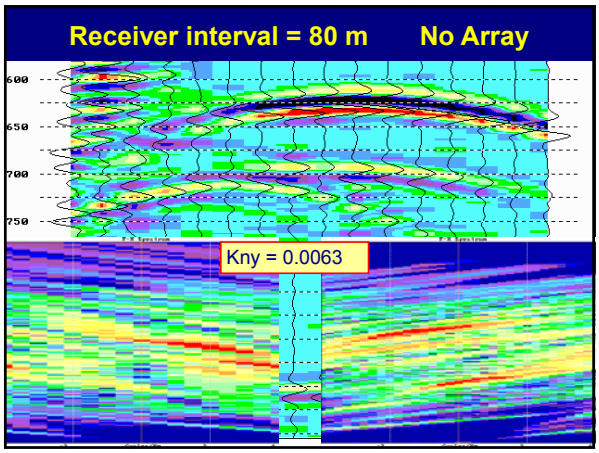

Receiver interval = 30 m
No Array
600
650
700
750
Kny = 0.0167

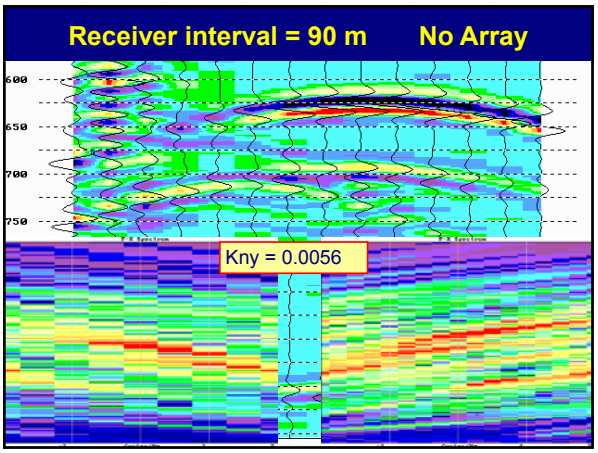

Receiver interval = 40 m
No Array
600
650
700
750
Kny = 0.0125

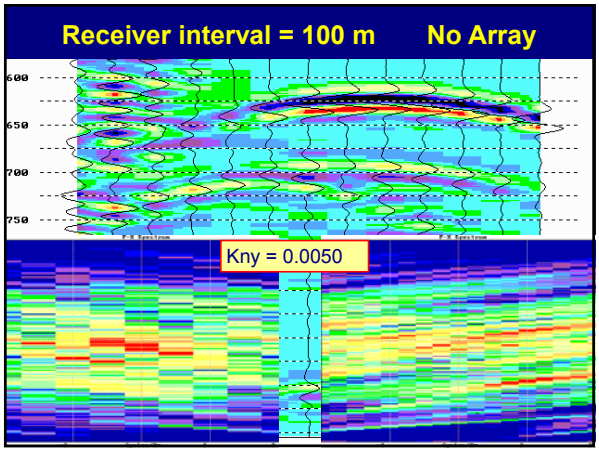

Receiver interval = 50 m
No Array
600
650
700
750
Kny = 0.0100

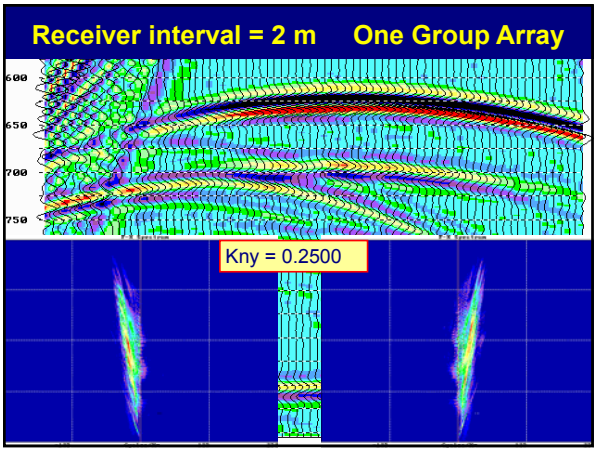

Receiver interval = 60 m
No Array
600
650
700
750
Kny = 0.0083

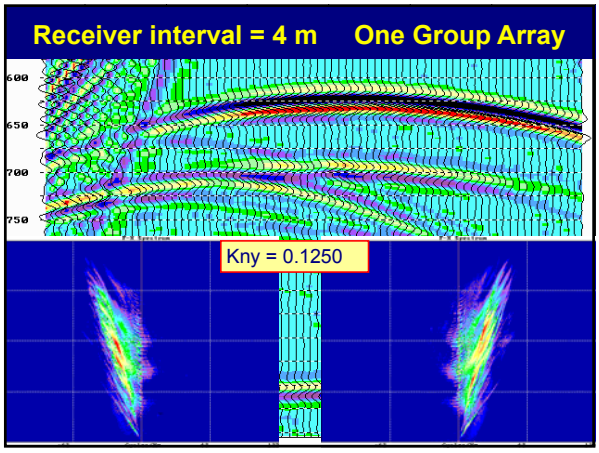

Receiver interval = 70 m
No Array
600
650
700
750
Kny = 0.0071

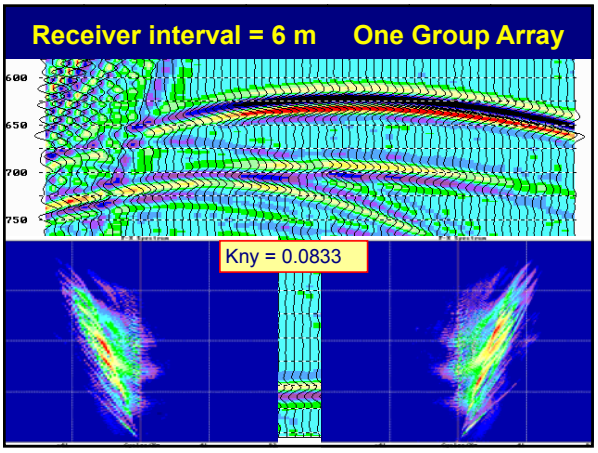

Receiver interval = 80 m No Array
600
650
700
750
Kny = 0.0063

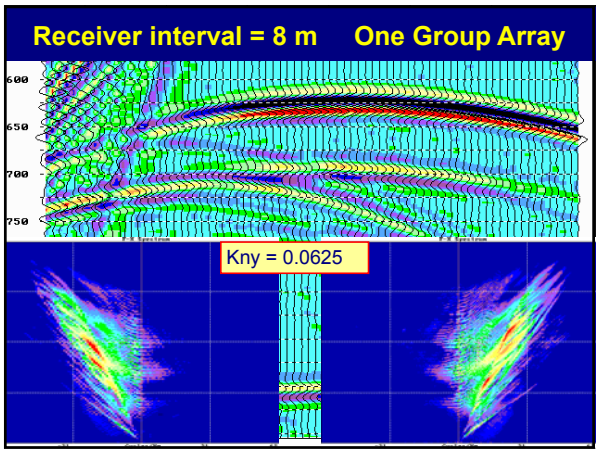

Receiver interval = 90 m No Array
600
650
700
750
Kny = 0.0056

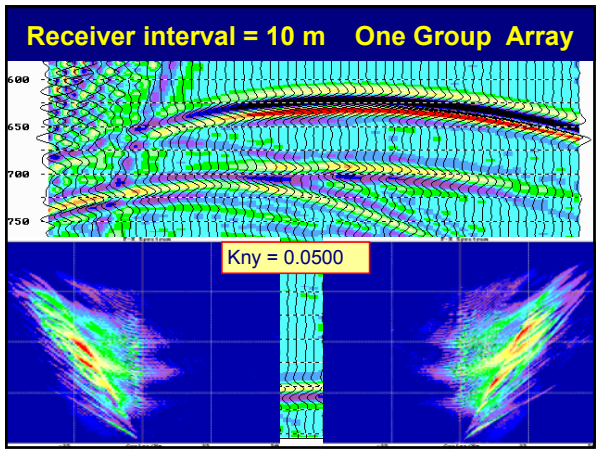

Receiver interval = 100 m No Array
600
650
700
750
Kny = 0.0050

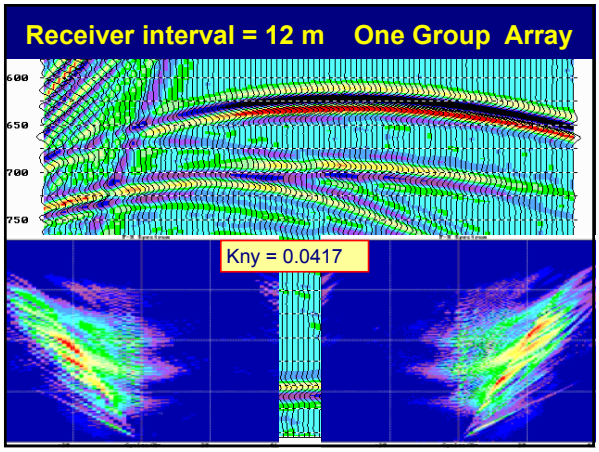

Receiver interval = 2 m One Group Array
600
650
700
750
Kny = 0.2500

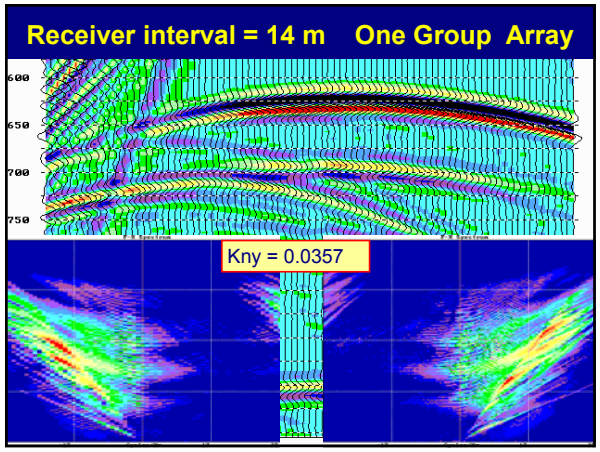

Receiver interval = 4 m One Group Array
600
650
700
750
Kny = 0.1250

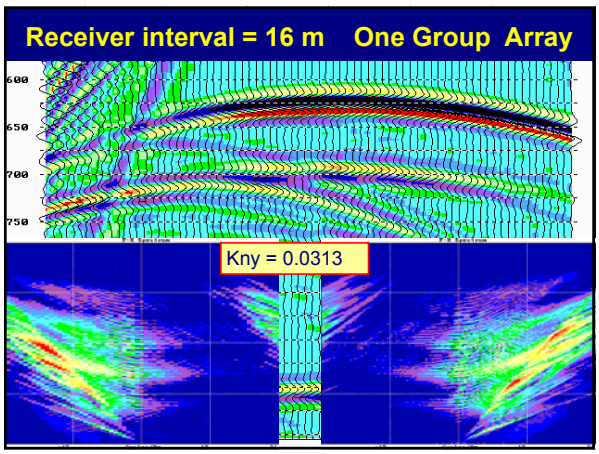

Receiver interval = 6 m One Group Array
600
650
700
750
Kny = 0.0833

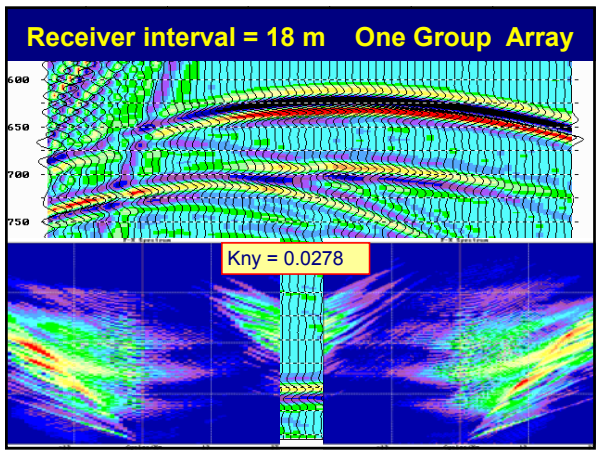

Receiver interval = 8 m One Group Array
600
650
700
750
Kny = 0.0625

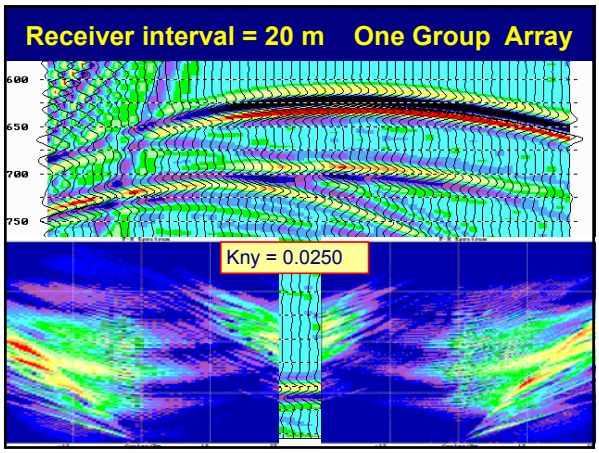

Receiver interval = 10 m One Group Array
600
650
700
750
Kny = 0.0500

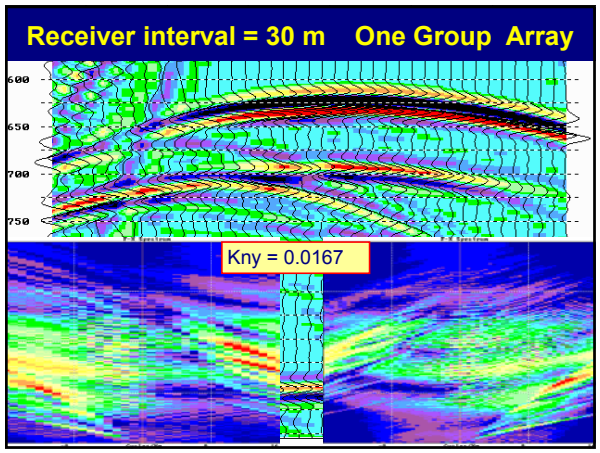

Receiver interval = 12 m One Group Array
600
650
700
750
Kny = 0.0417

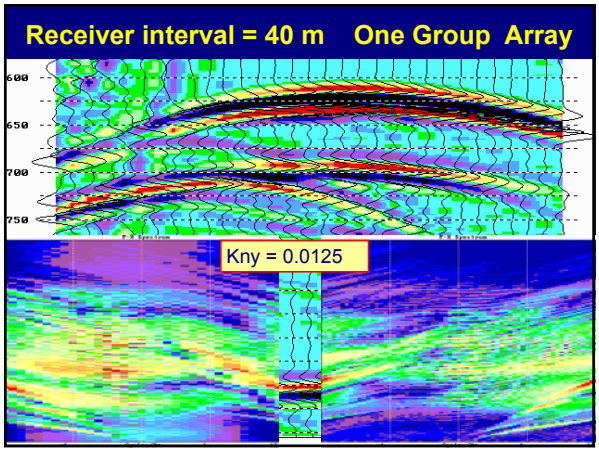

Receiver interval = 14 m One Group Array
600
650
700
750
Kny = 0.0357

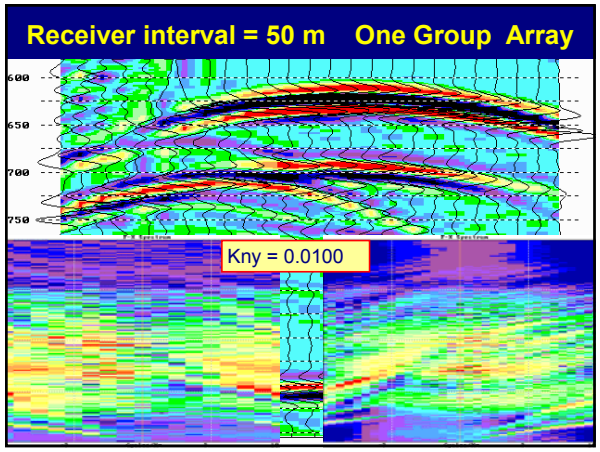

Receiver interval = 16 m One Group Array
600
650
700
750
Kny = 0.0313

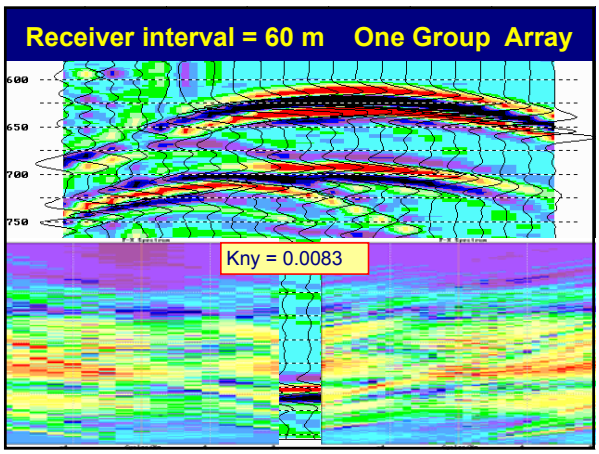

Receiver interval = 18 m One Group Array
600
650
700
750
Kny = 0.0278


Receiver interval = 20 m One Group Array
600
650
700
750
Kny = 0.0250


Receiver interval = 30 m One Group Array
600
650
700
750
Kny = 0.0167


Receiver interval = 40 m One Group Array
600
650
700
750
Kny = 0.0125


Receiver interval = 50 m One Group Array
600
650
700
750
Kny = 0.0100


Receiver interval = 60 m One Group Array
600
650
700
750
Kny = 0.0083

Let's review . . .
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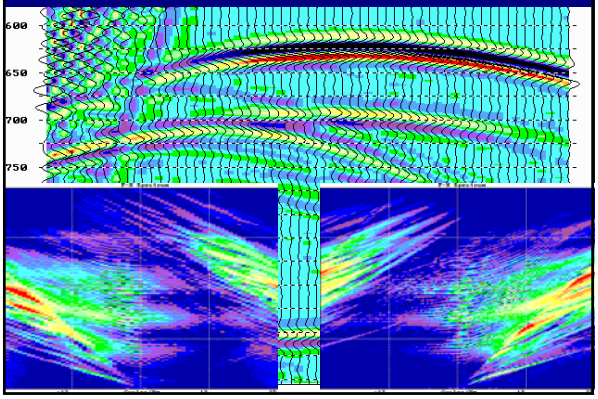
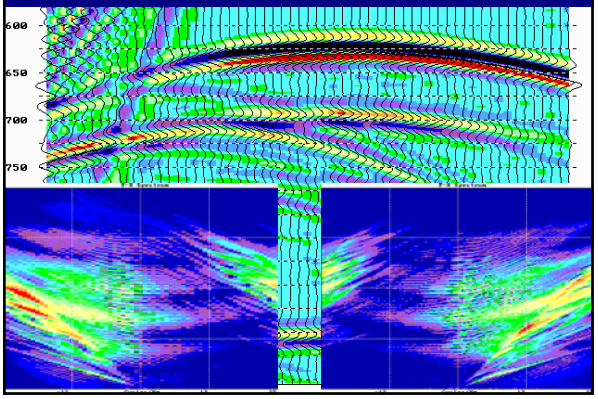
Receiver interval = 20 m No Array



Receiver interval = 20 m One Group Array



. . . the Anti-Alias Filter

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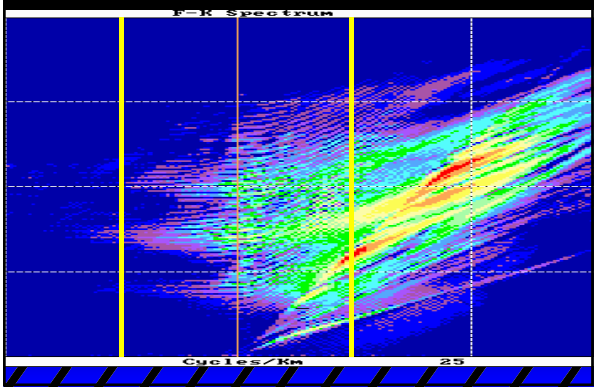
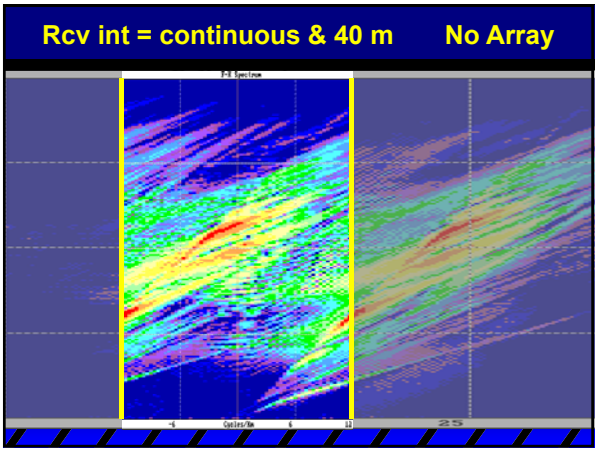
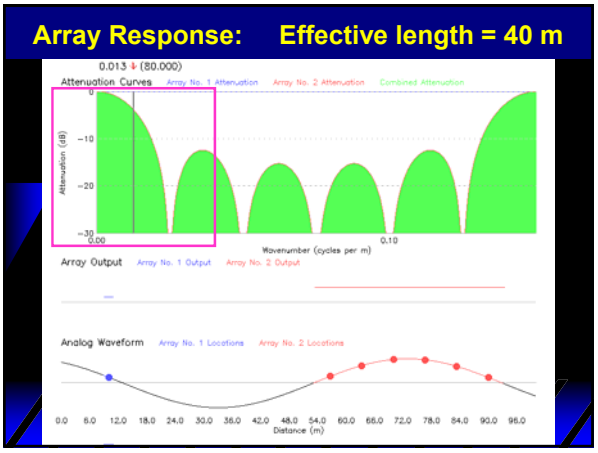
Continuous Receivers — 40 m No Array



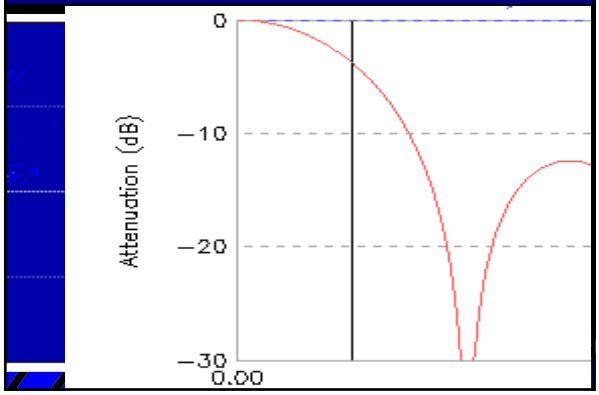
Rcv int = continuous & 40 m No Array



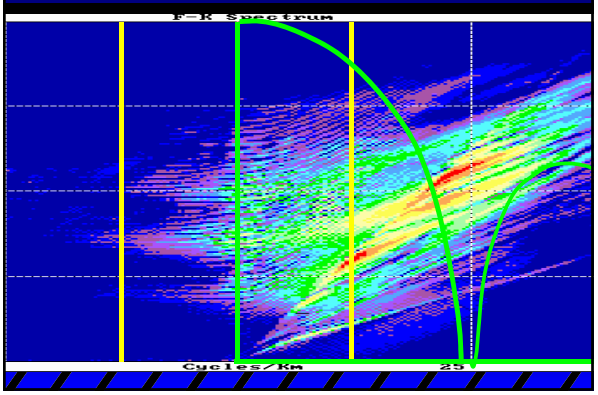
Array Response: Effective length = 40 m



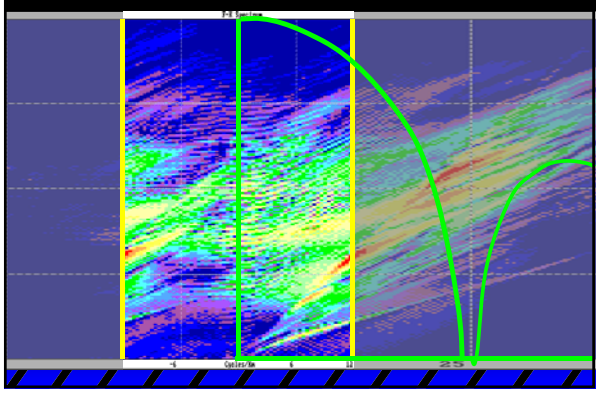
Continuous Receivers … …and Array



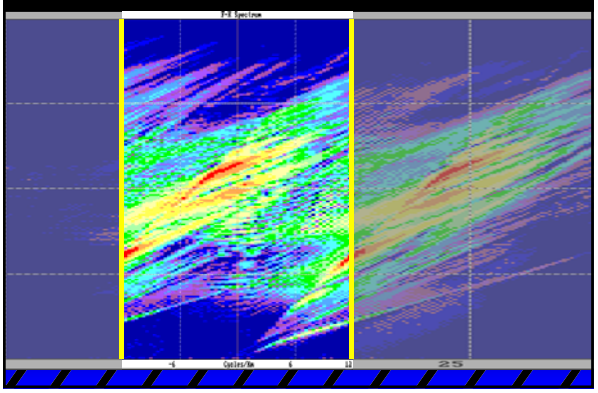
Continuous Receivers — 40 m 40 m Array



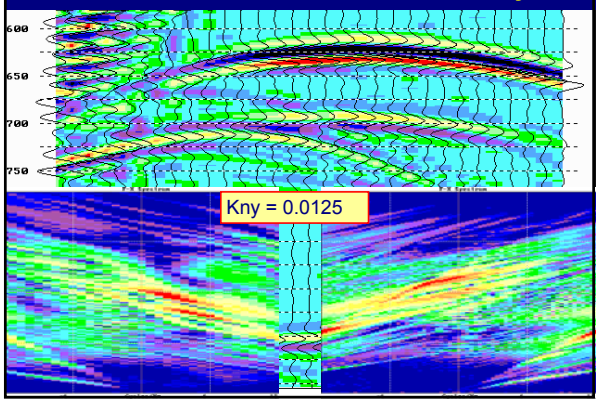
Rcv int = continuous & 40 m 40 m Array



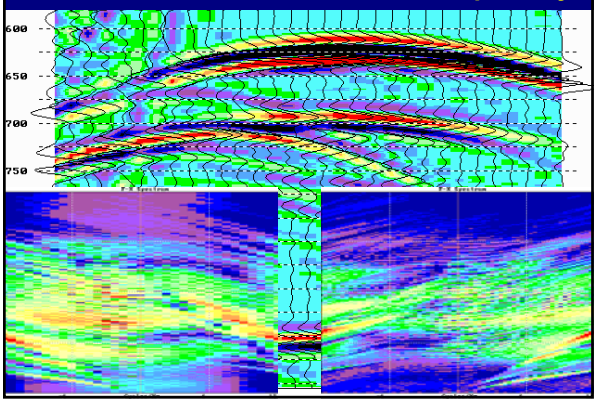
Rcv int = continuous & 40 m No Array



Receiver interval = 40 m No Array



Receiver interval = 40 m One Group Array



What does aliased data look like ?

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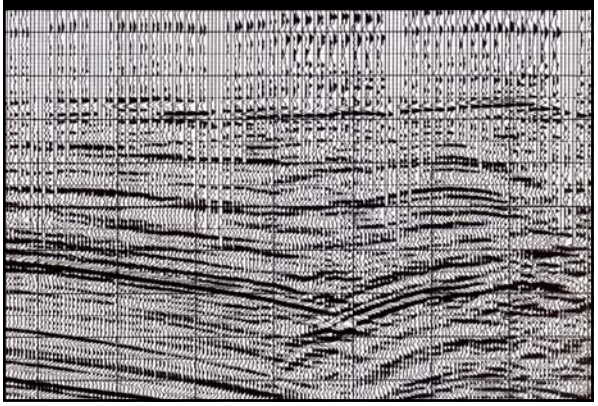
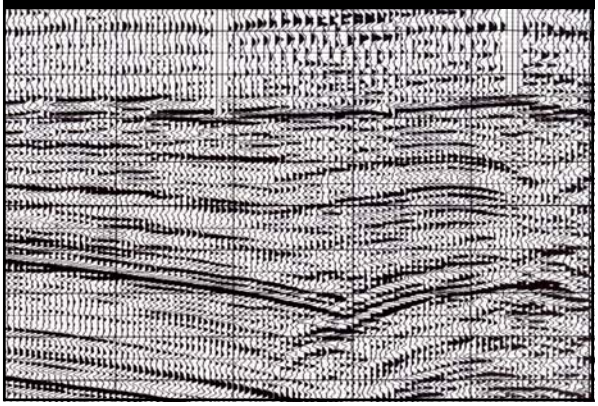
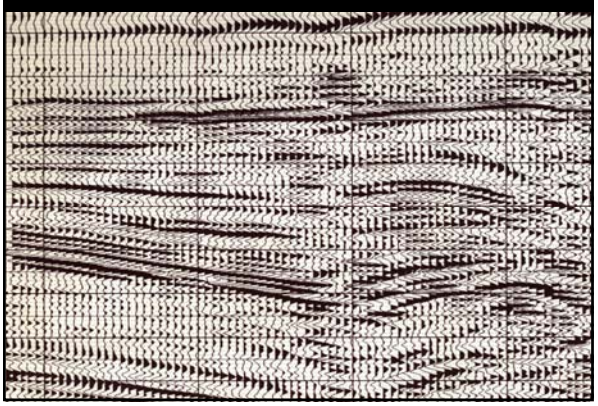
20 m Bins



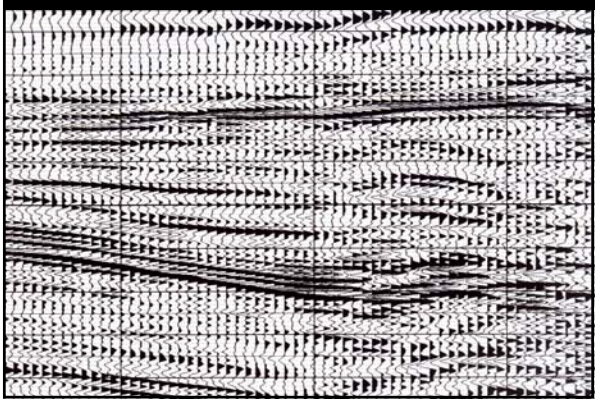
30 m Bins



40 m Bins



50 m Bins



Geophone Arrays as Spatial Anti-Alias Filters in 3-D Programs

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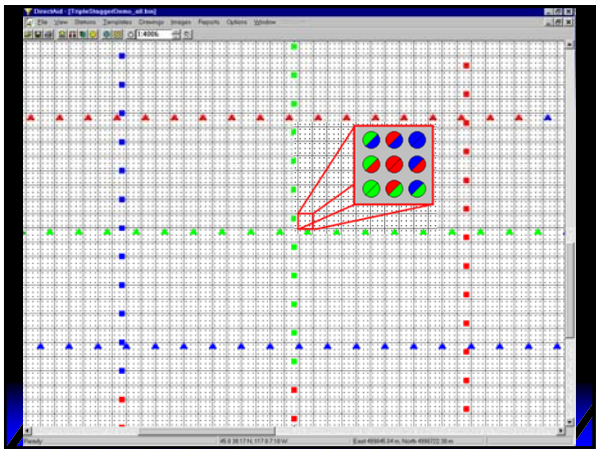
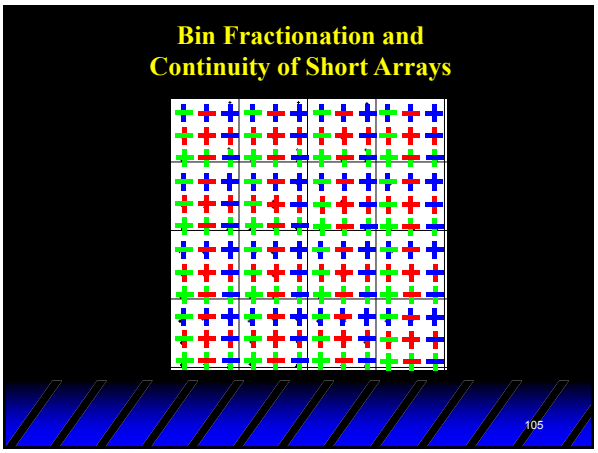
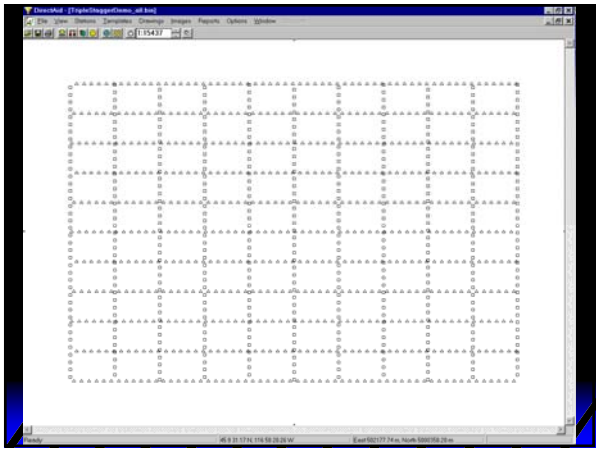
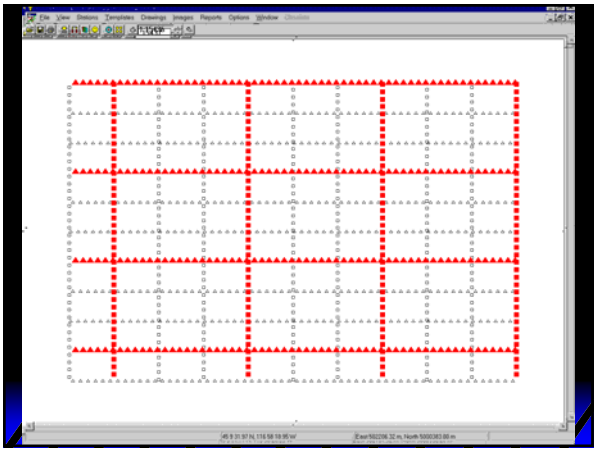
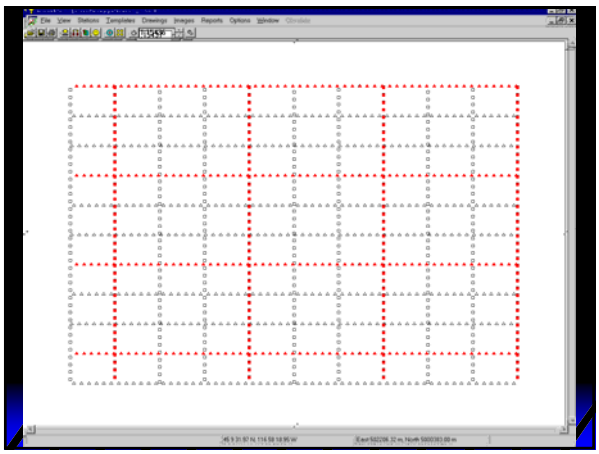
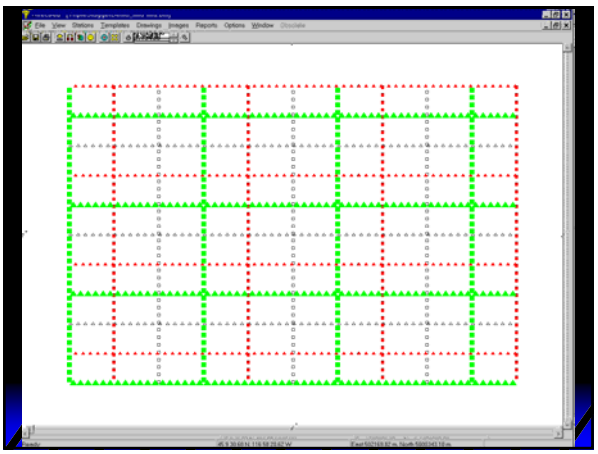


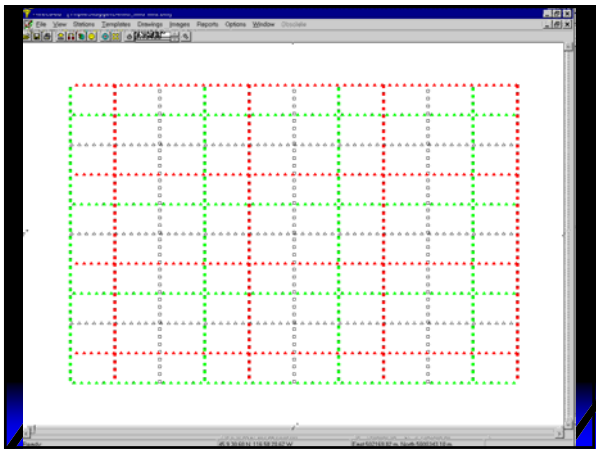

Bin Fractionation and
Continuity of Short Arrays
105

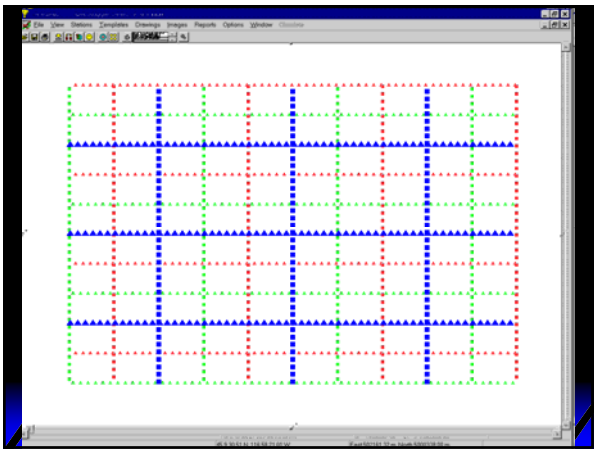


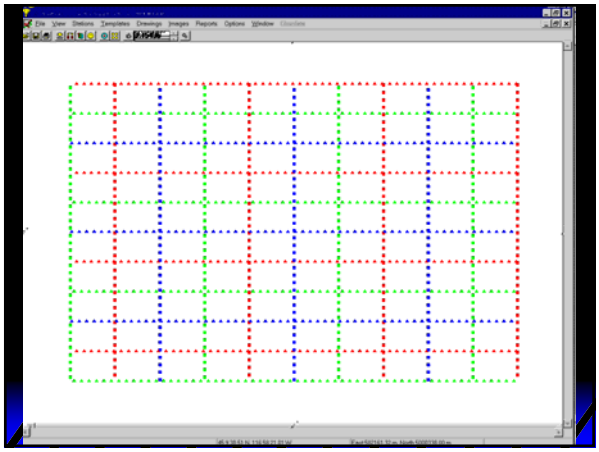


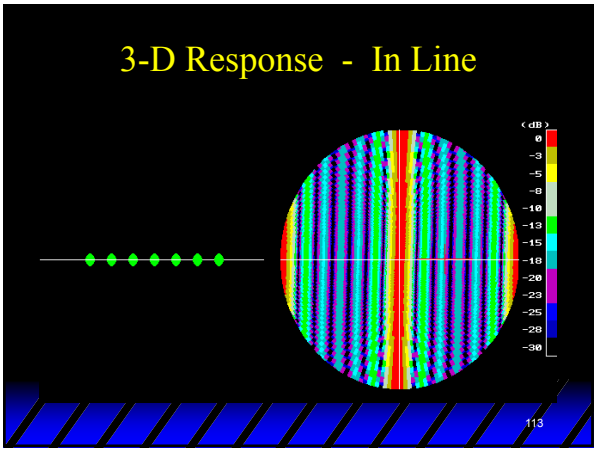


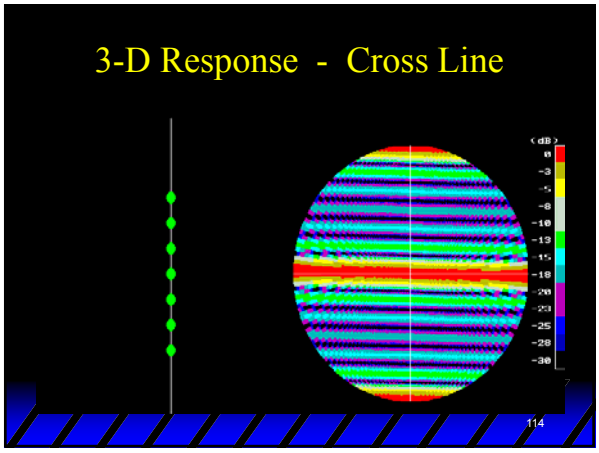


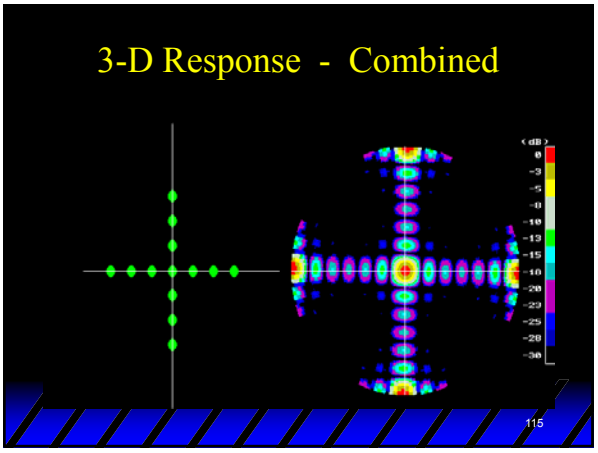




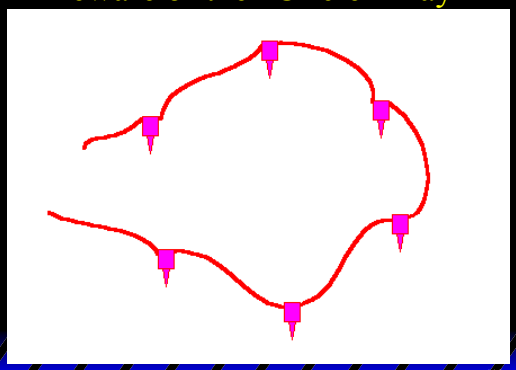



3-D Response - In Line
dB
0
-3
-5
-8
-10
-13
-15
-18
-20
-23
-25
-28
-30
113


3-D Response - Cross Line
dB
114


3-D Response - Combined
dB
115

Beware of the "Circle Array"



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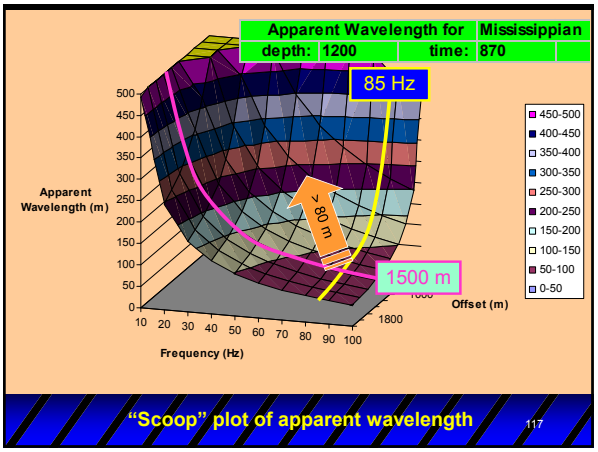

"Scoop" plot of apparent wavelength

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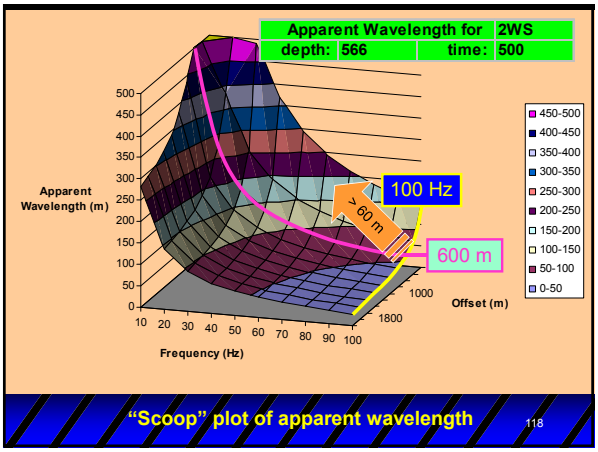

"Scoop" plot of apparent wavelength

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Recommendations – 2D

Distribute geophones uniformly over the group interval for an effective anti-alias filter

This will not attenuate desired signal
- UNLESS the group interval is TOO BIG !!

"Intra-Array Statics" may cause some signal attenuation, but this can be recovered by post stack whitening.

- Data lost to aliasing cannot be recovered

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Recommendations – 3D

Distribute geophones uniformly over 1/3 of the group interval

Choose a design that ensures generous mid-point scatter

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If you desire more information or would like a copy of this tutorial, please contact Norm Cooper or Yajaira Herrera

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