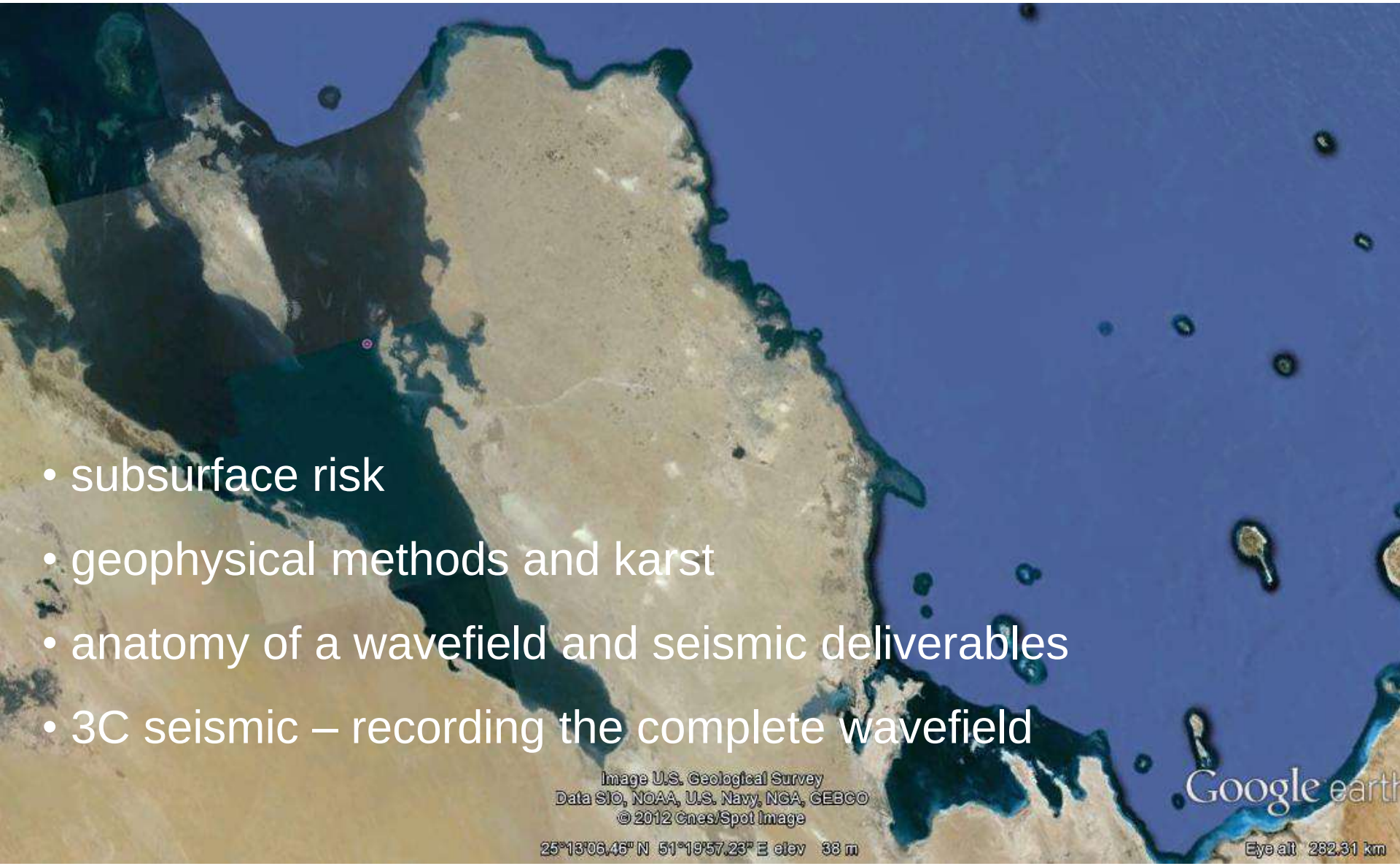
Seismic Imaging of Karst: Work In Progress

Dr Rod Eddies

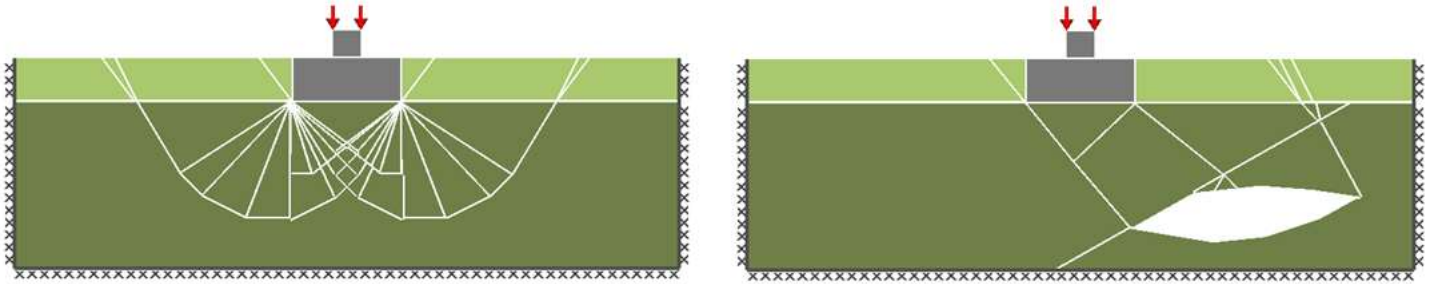
December 2013

Synopsis



- subsurface risk
- geophysical methods and karst
- anatomy of a wavefield and seismic deliverables
- 3C seismic – recording the complete wavefield

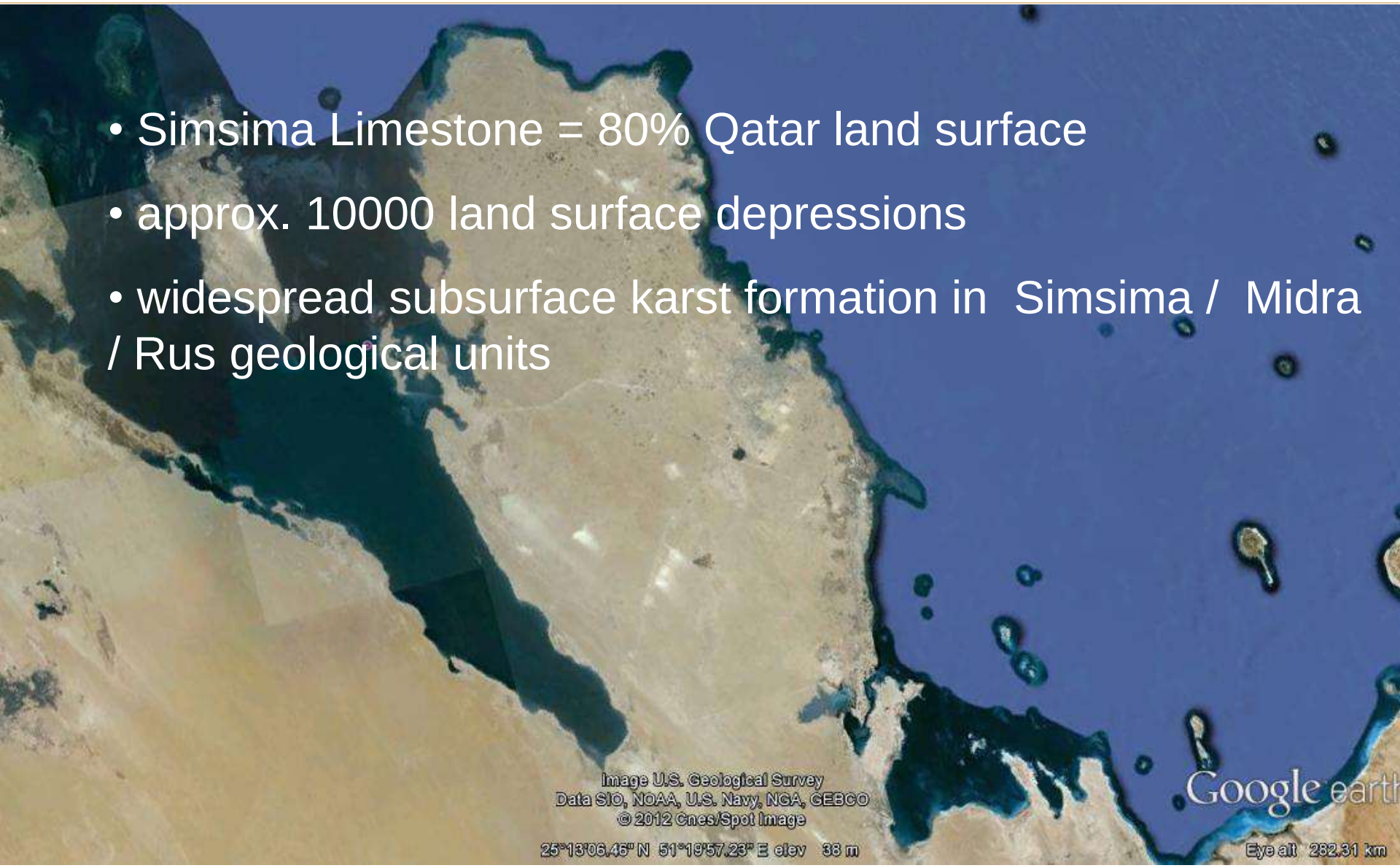
- Easy to model effects of arbitrary features, such as voids



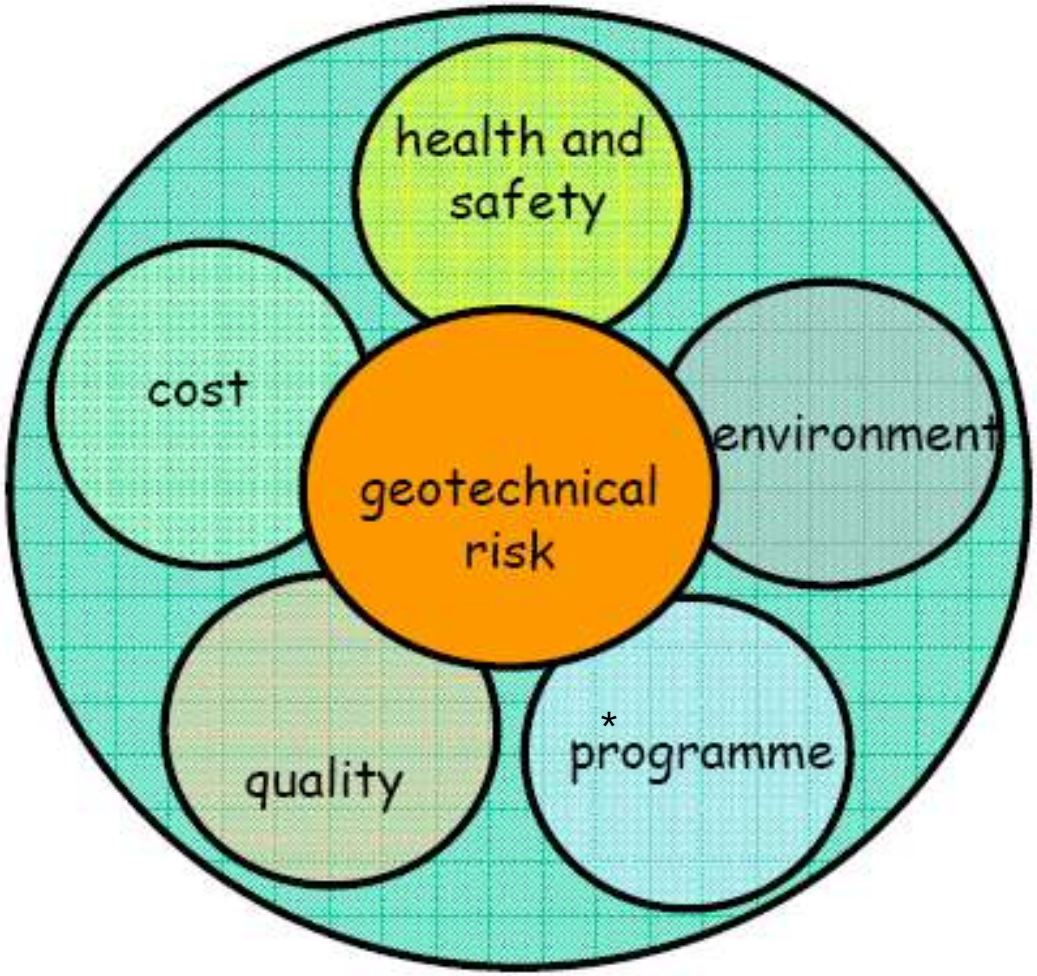
(assuming their location & extent are known!)

after Gilbert, 2013

Geological Overview

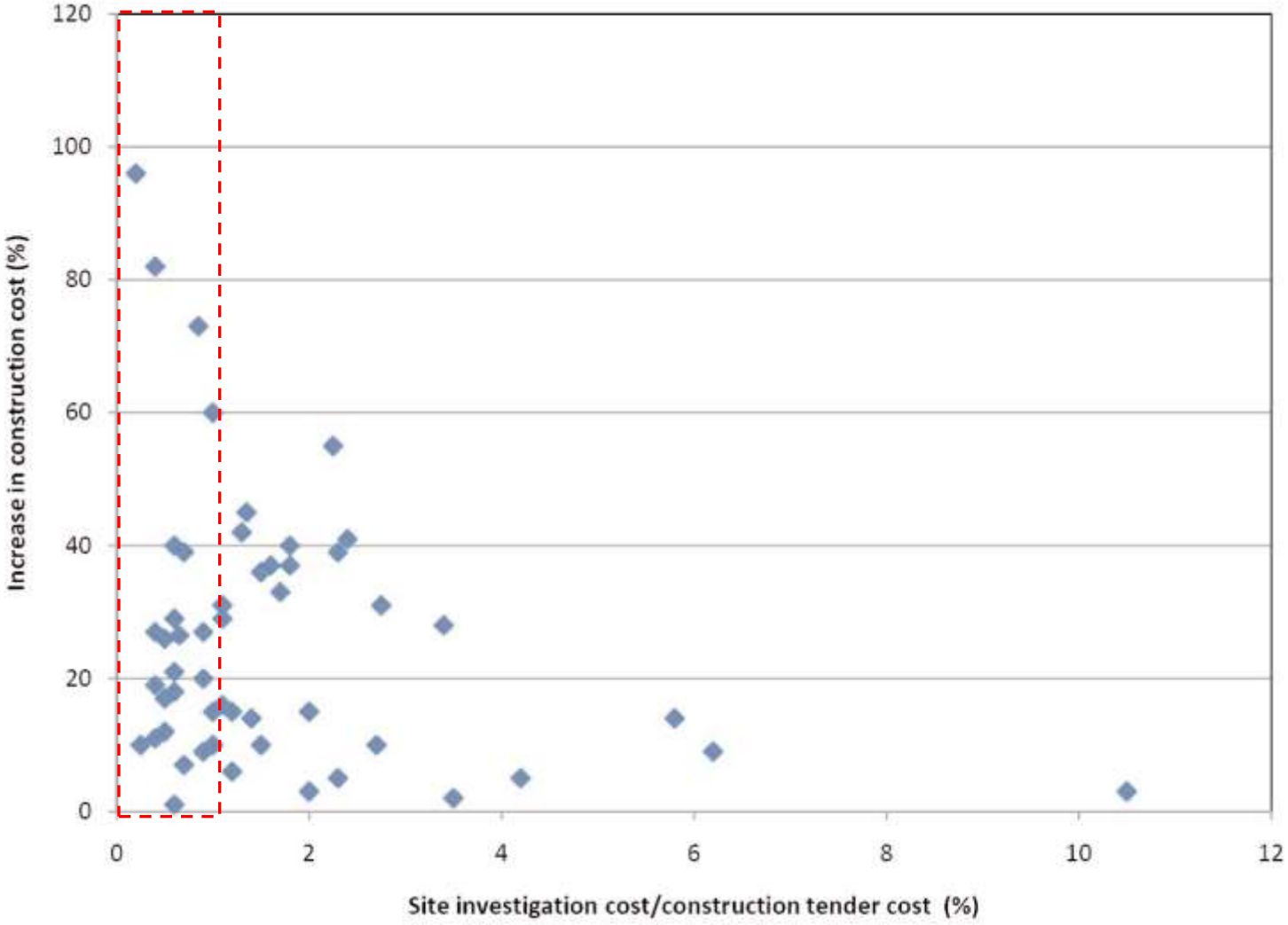


Why manage risk?



Source: Clayton 2001

Impact of Site Investigation On Overrun



Impact of Site Investigation on highway contract cost over-runs in the UK from TRL Project Report 60

Intrusive Investigations

- derive key ground data

  geological
  geotechnical
  hydrogeological

- are spatially representative?
- are optimally planned both in number, distribution and depth?

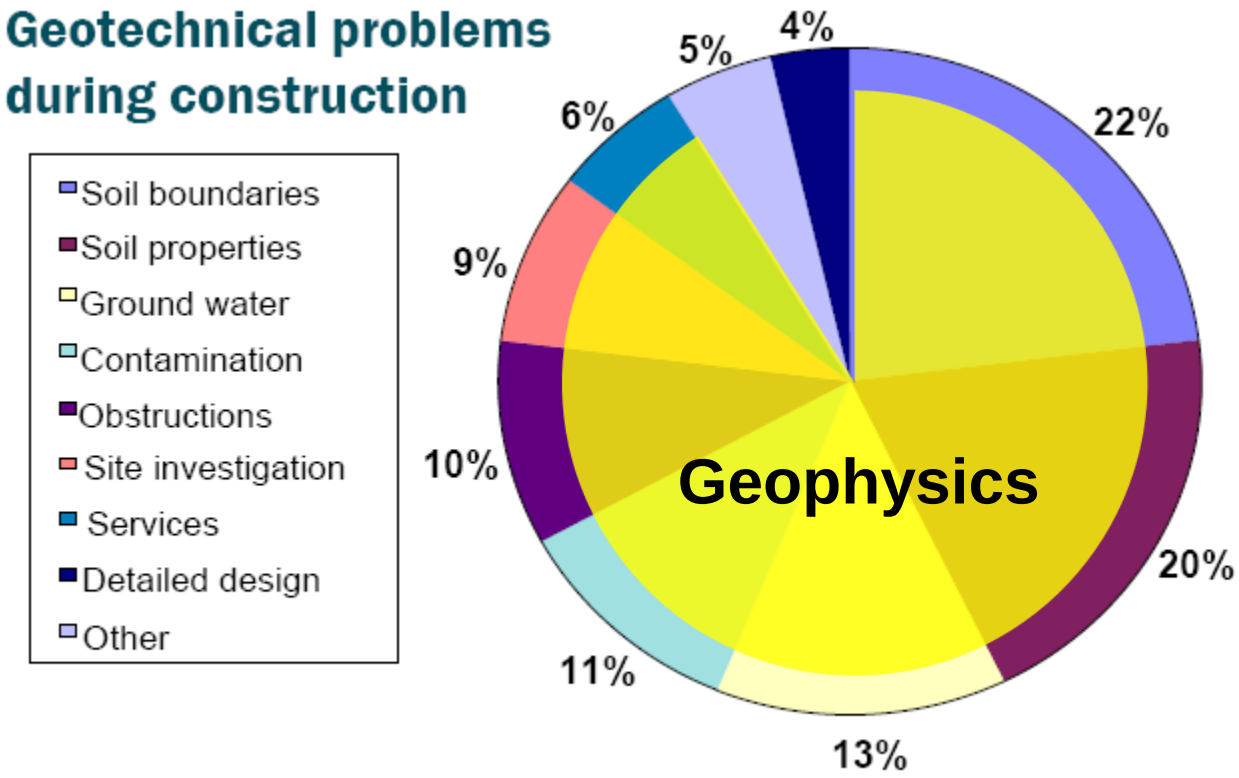
Geophysical Investigations

- derive key ground data

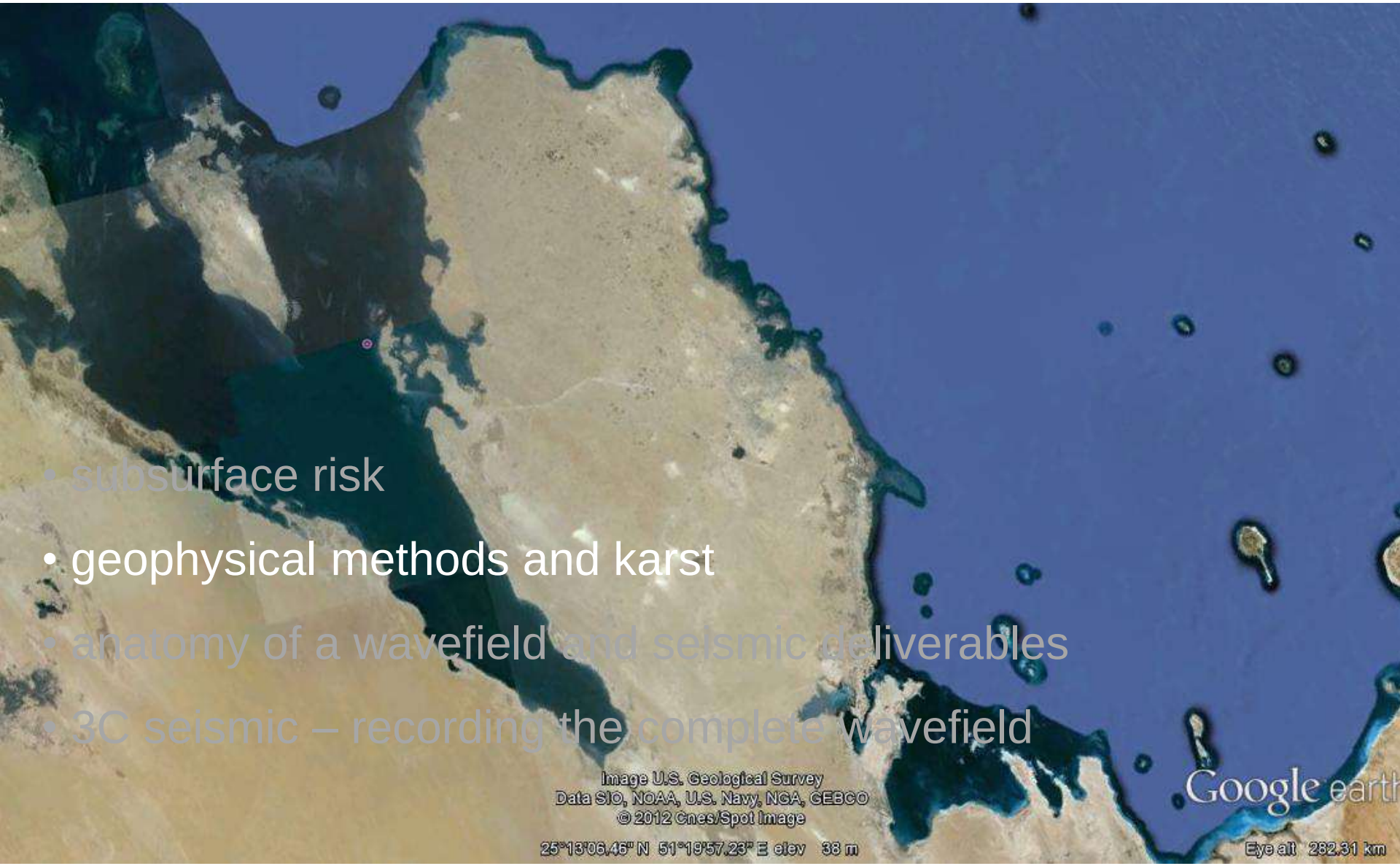
  geological
  geotechnical
  hydrogeological

- are well understood (benefits/limitations)?
- are appropriately deployed (best practice)?
- are optimally scheduled to help manage risk and reduce cost?

Capturing Experience



From a survey of 28 construction projects (Clayton, 2001)

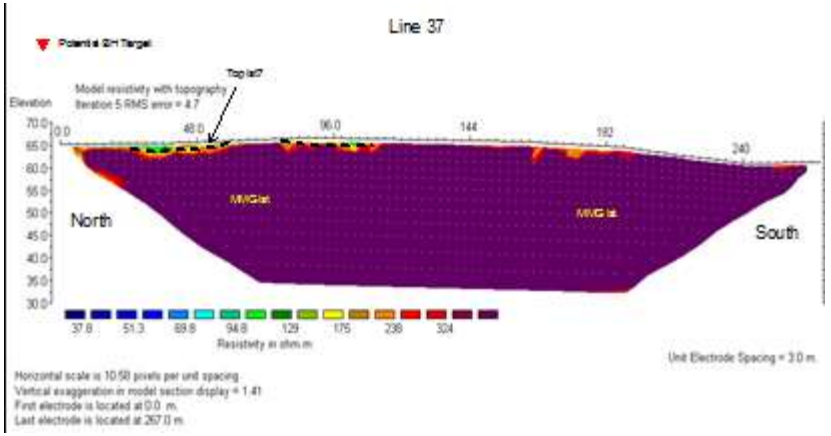


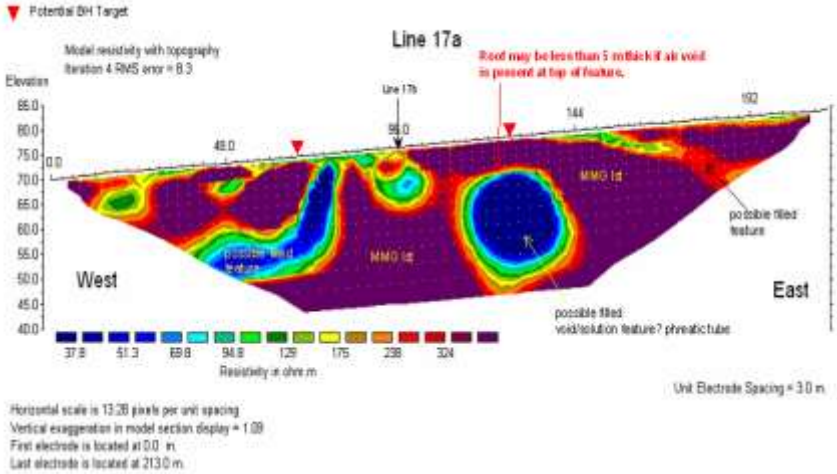
- subsurface risk
- geophysical methods and karst
- anatomy of a wavefield and seismic deliverables
- 3C seismic – recording the complete wavefield

Why Geophysics?

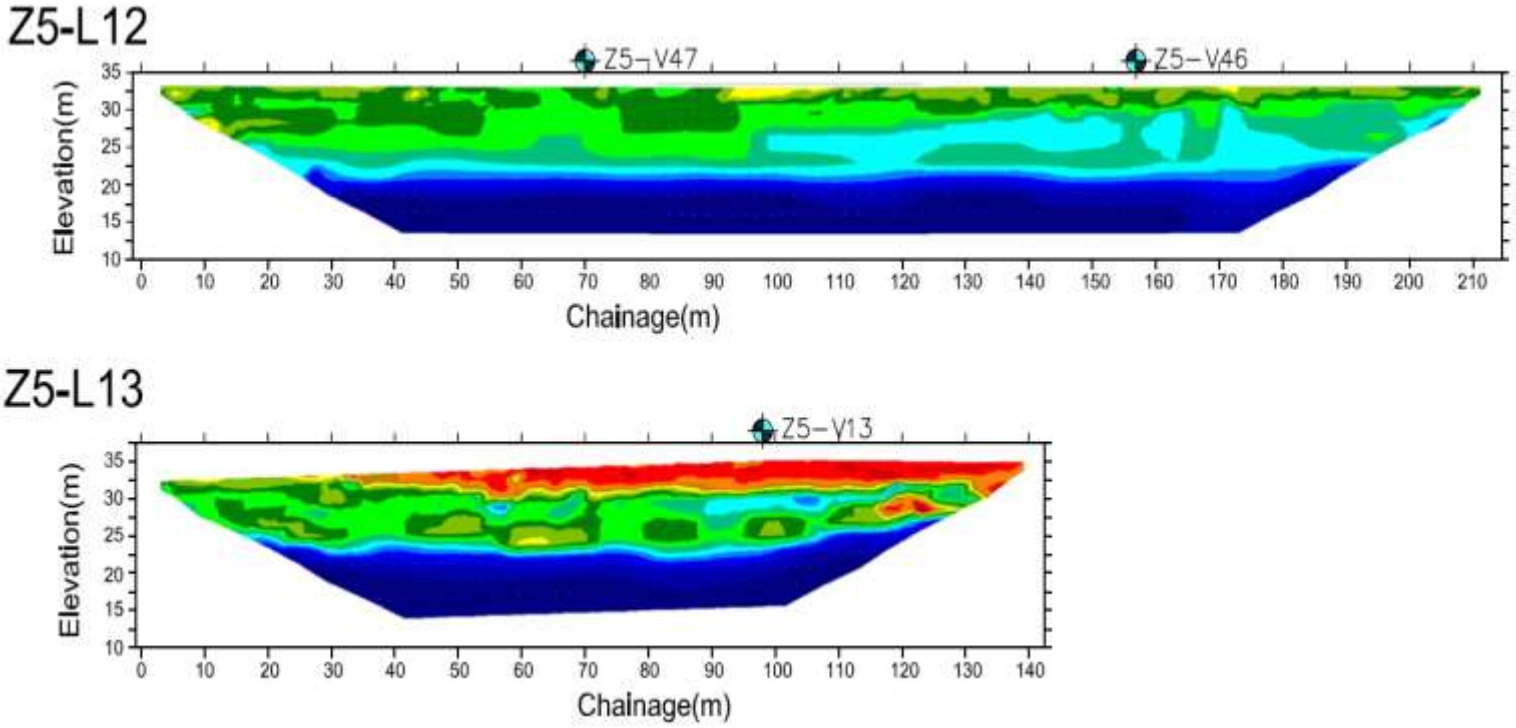
- relatively rapid screening for lateral and vertical variation
- effective targeting of intrusive programmes
- interpolation between controls
- appropriate phasing
- appropriate techniques
- appropriate execution

Electrical Resistivity Tomography (Europe – Karst)

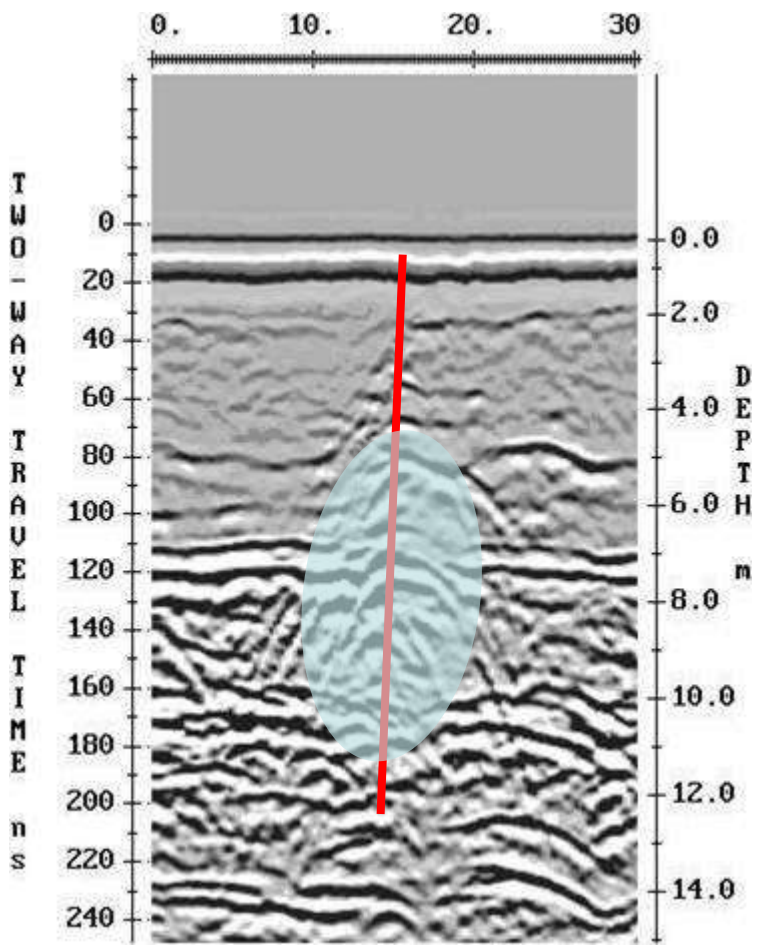


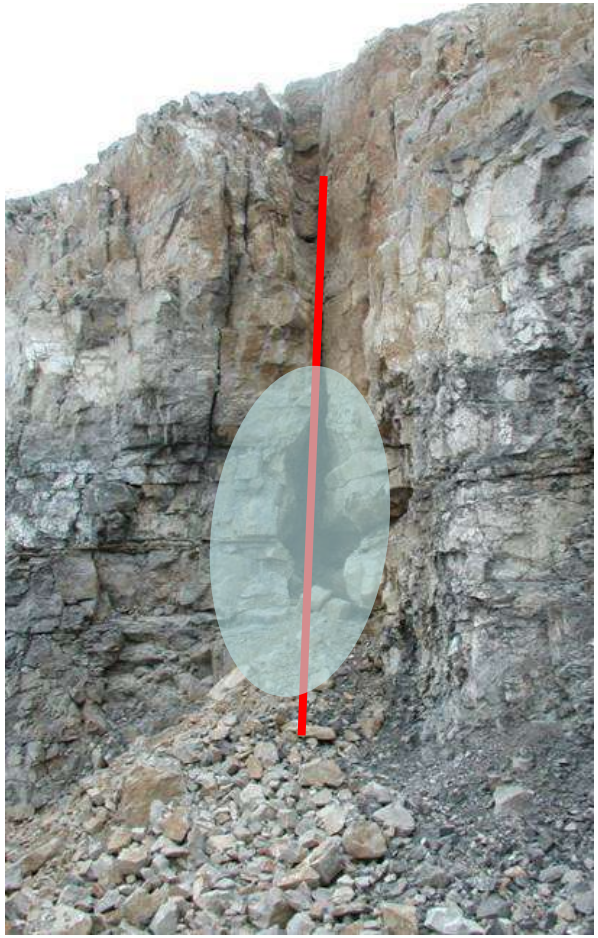


Electrical Resistivity Tomography (Doha – Karst)



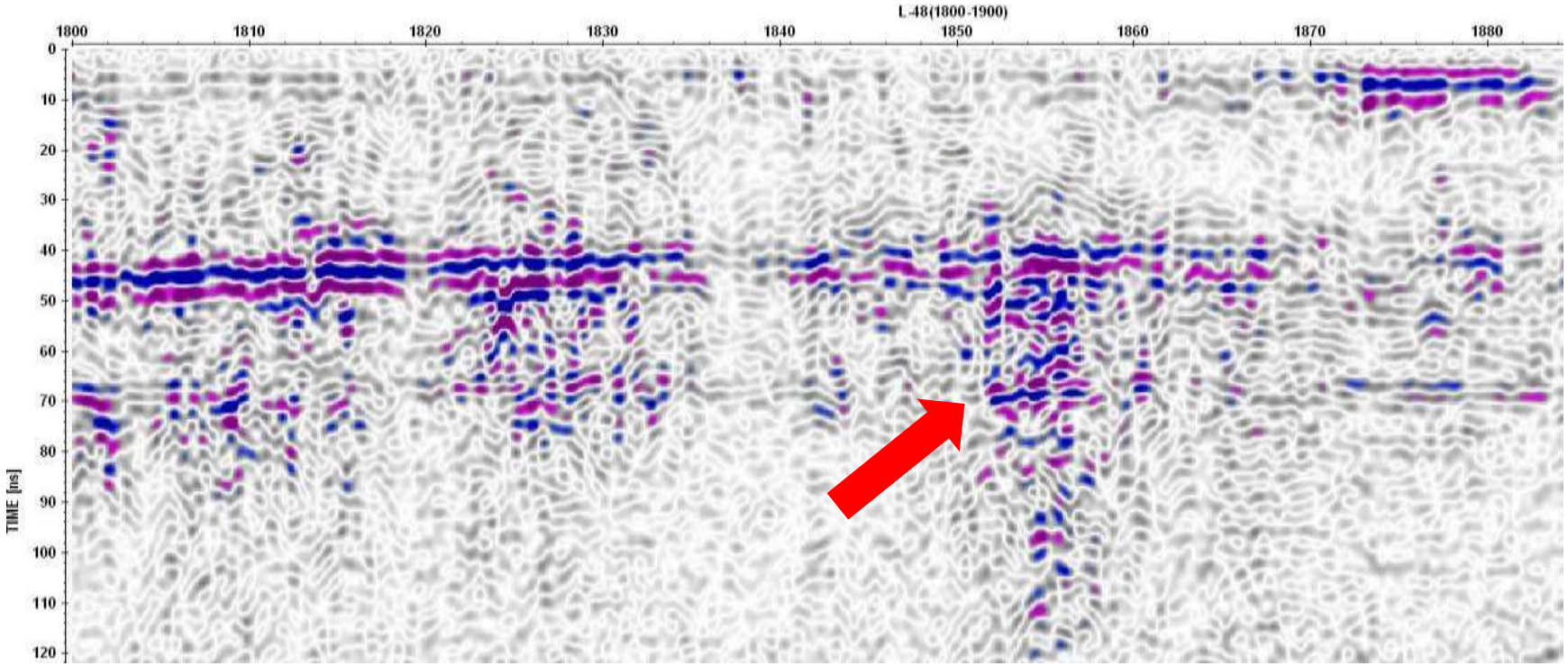
Ground Penetrating Radar (Europe - Karst)



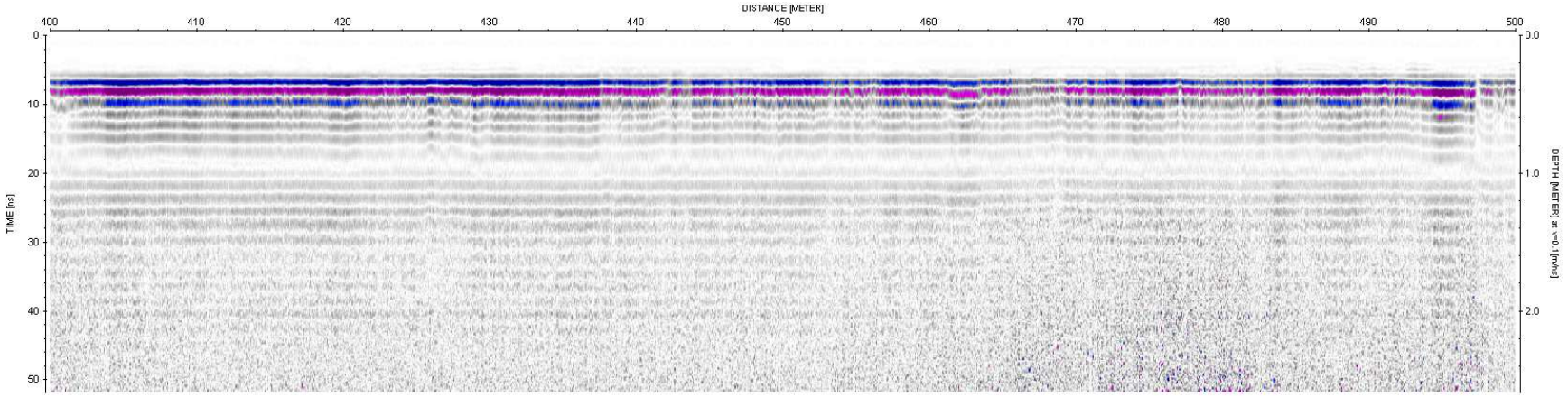


Ground Penetrating Radar (Oman-Karst)

Data Example



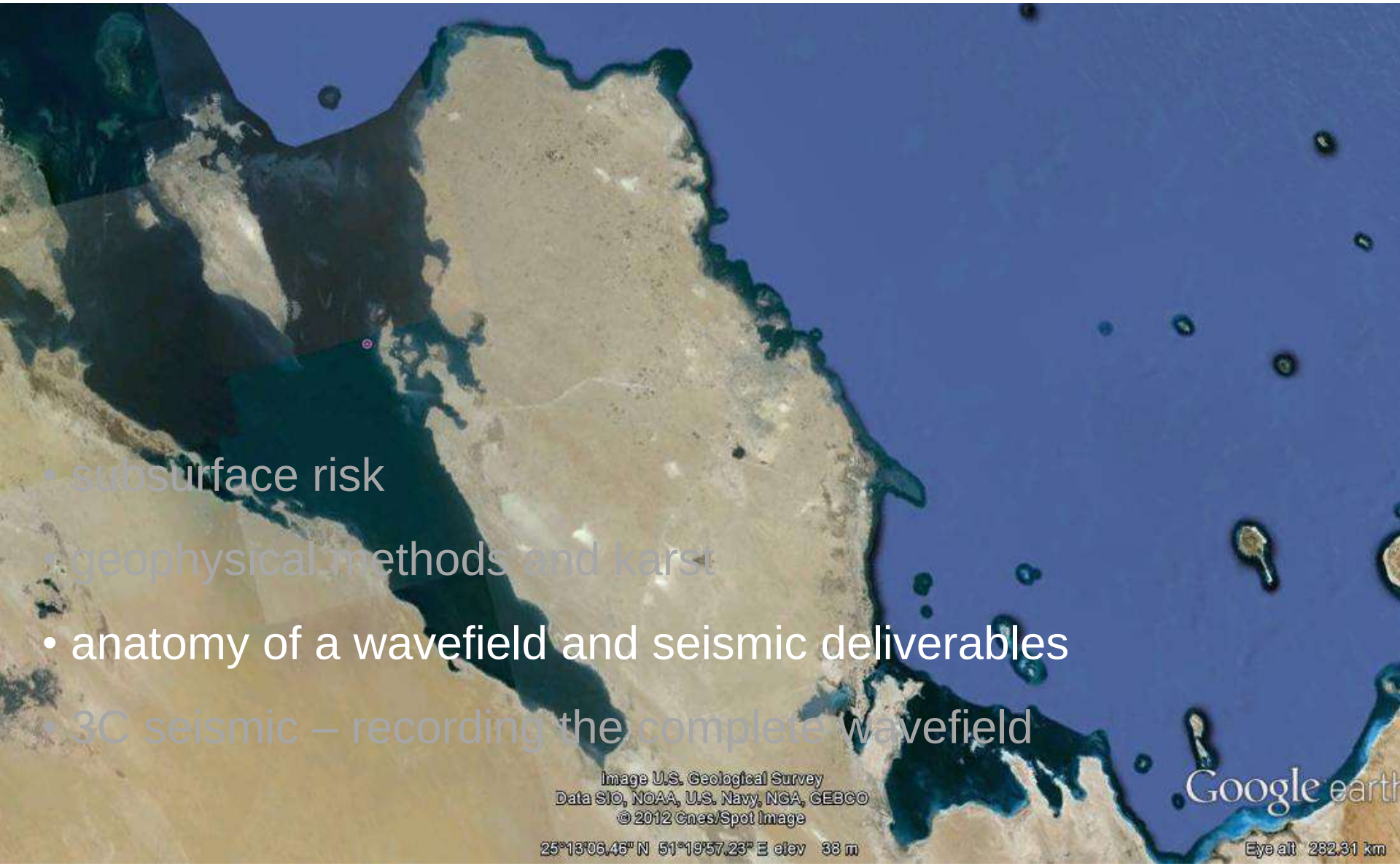
Ground Penetrating Radar (Doha)



Limiting Factors For Investigation

- **MASW –** dependent on frequency content/site conditions
- **Refraction –** velocity inversion below Simsima Lst
- **Microgravity –** depth/resolution
- **ERT –** masking due to saline conditions
- **GPR –** conductivity/saline ground conditions
- **EM** – depth/resolution

<u>Off the shelf</u> geophysical solutions may face significant limitations due to Qatar-specific site conditions



- subsurface risk
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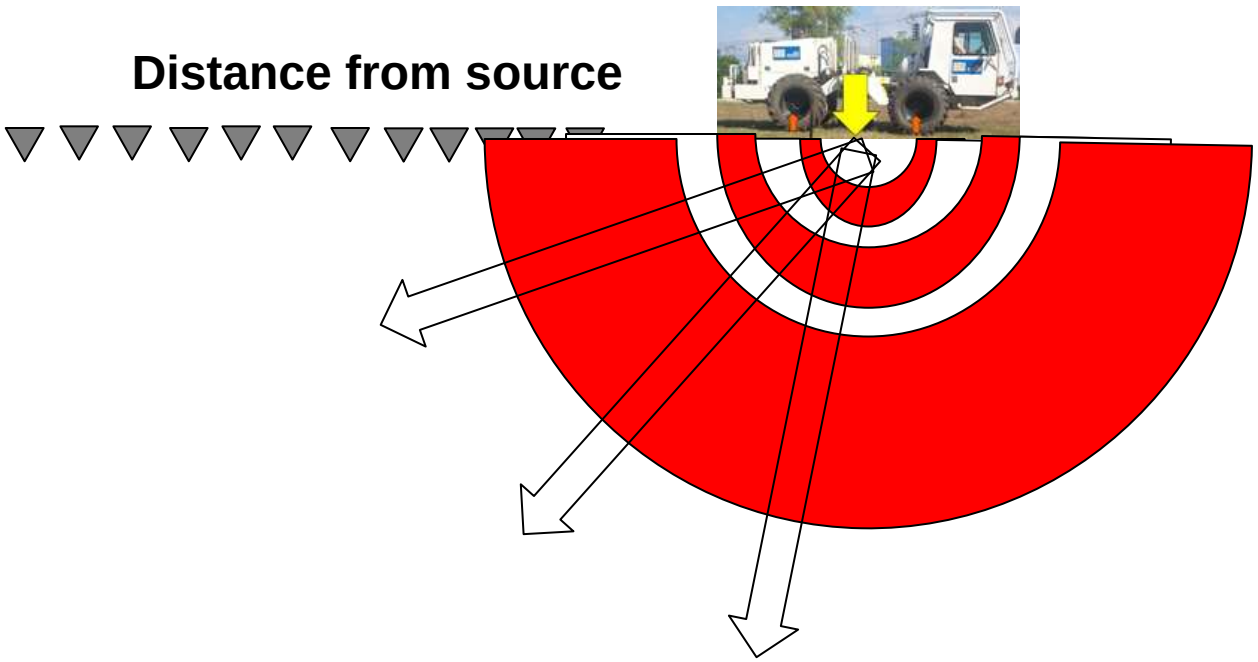
Field Configuration - Schematic

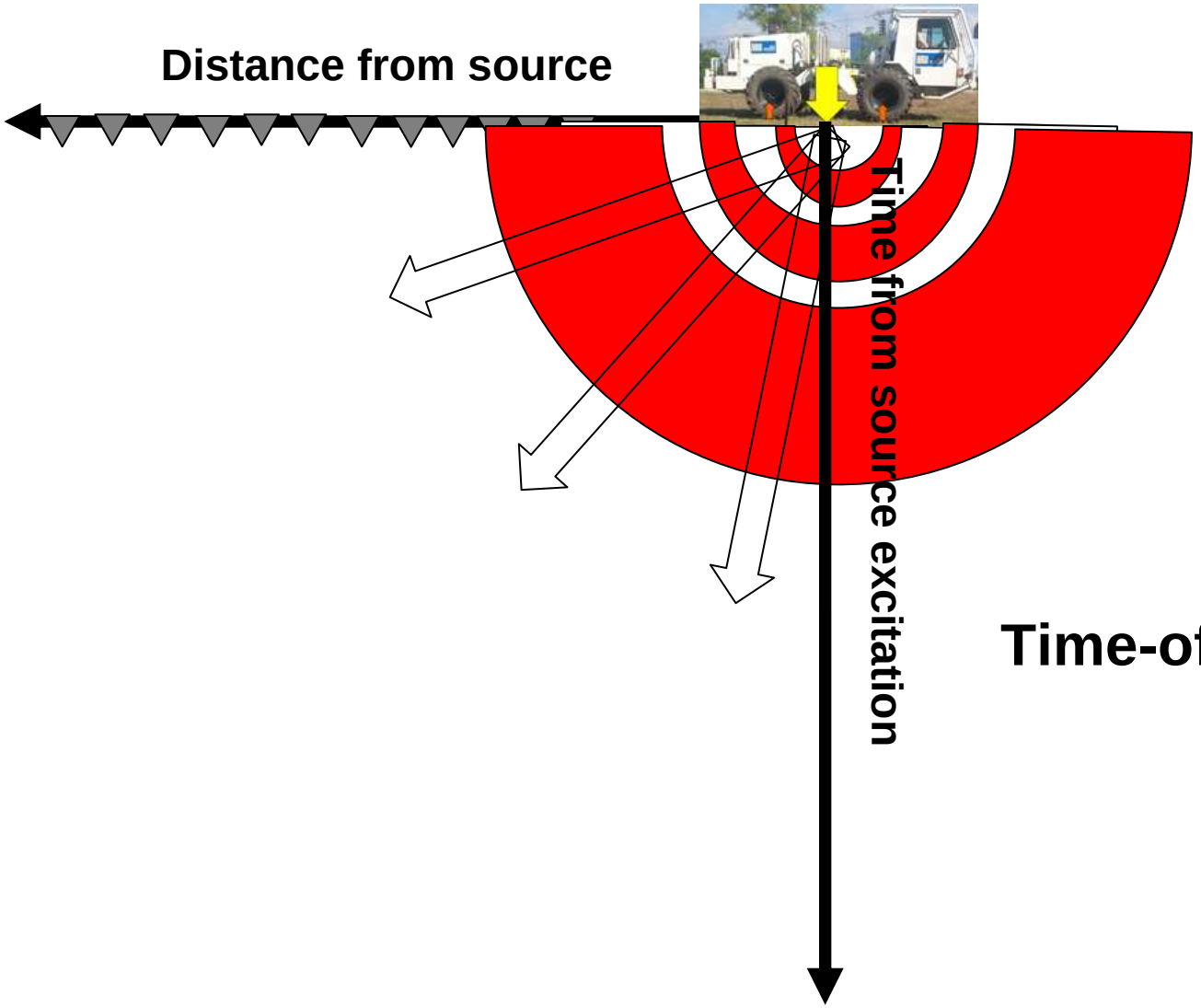
Receivers

Seismic Source

Anatomy of a Wavefield

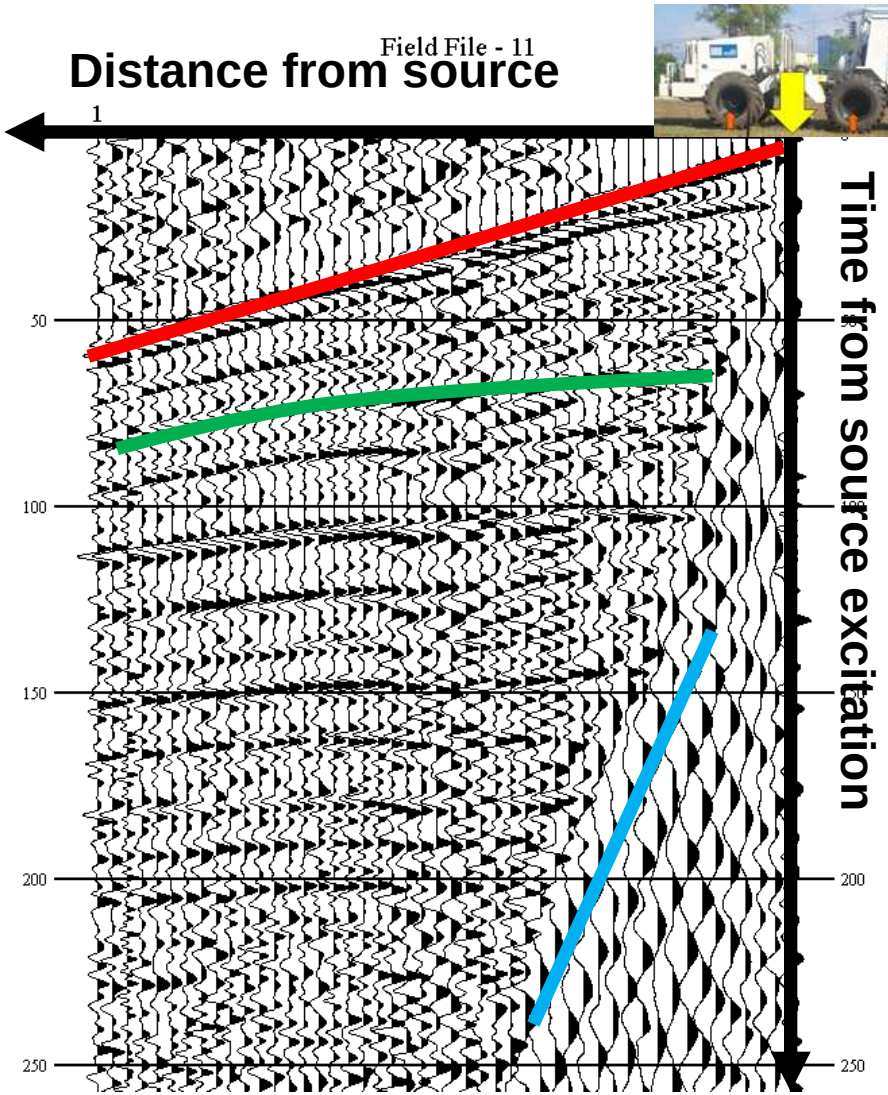


Anatomy of a Wavefield



Time-offset domain

Anatomy of a Wavefield

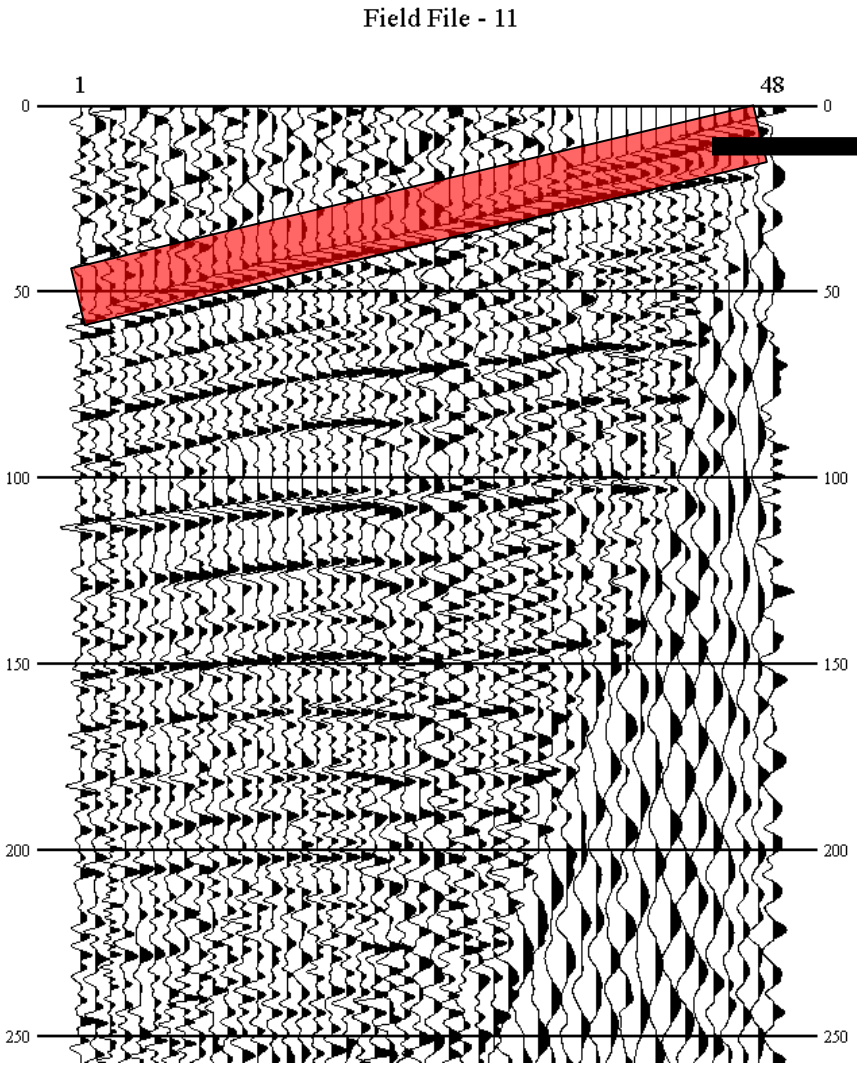


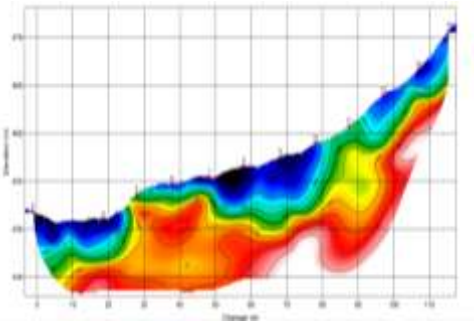
refracted waves

reflected waves

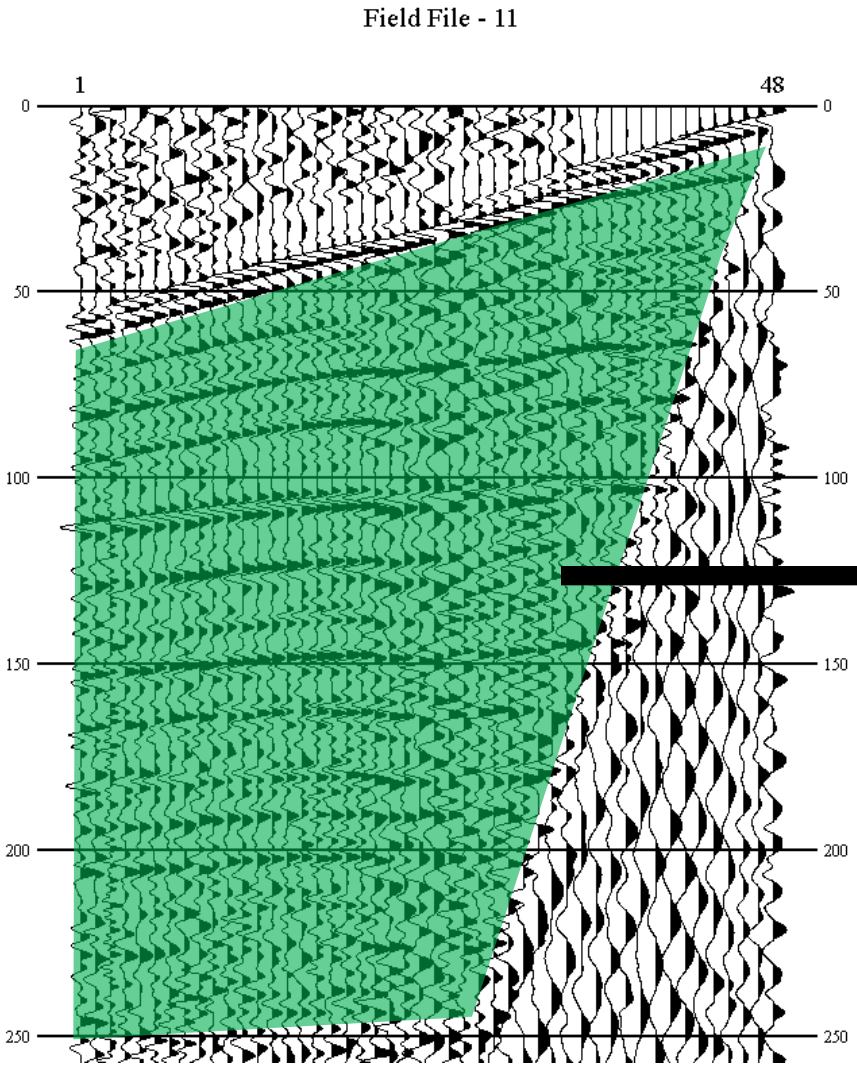
surface waves

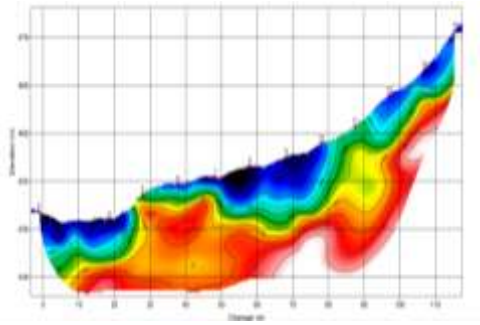
Seismic Deliverables: refraction

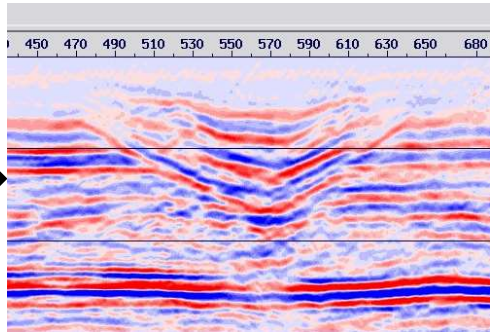




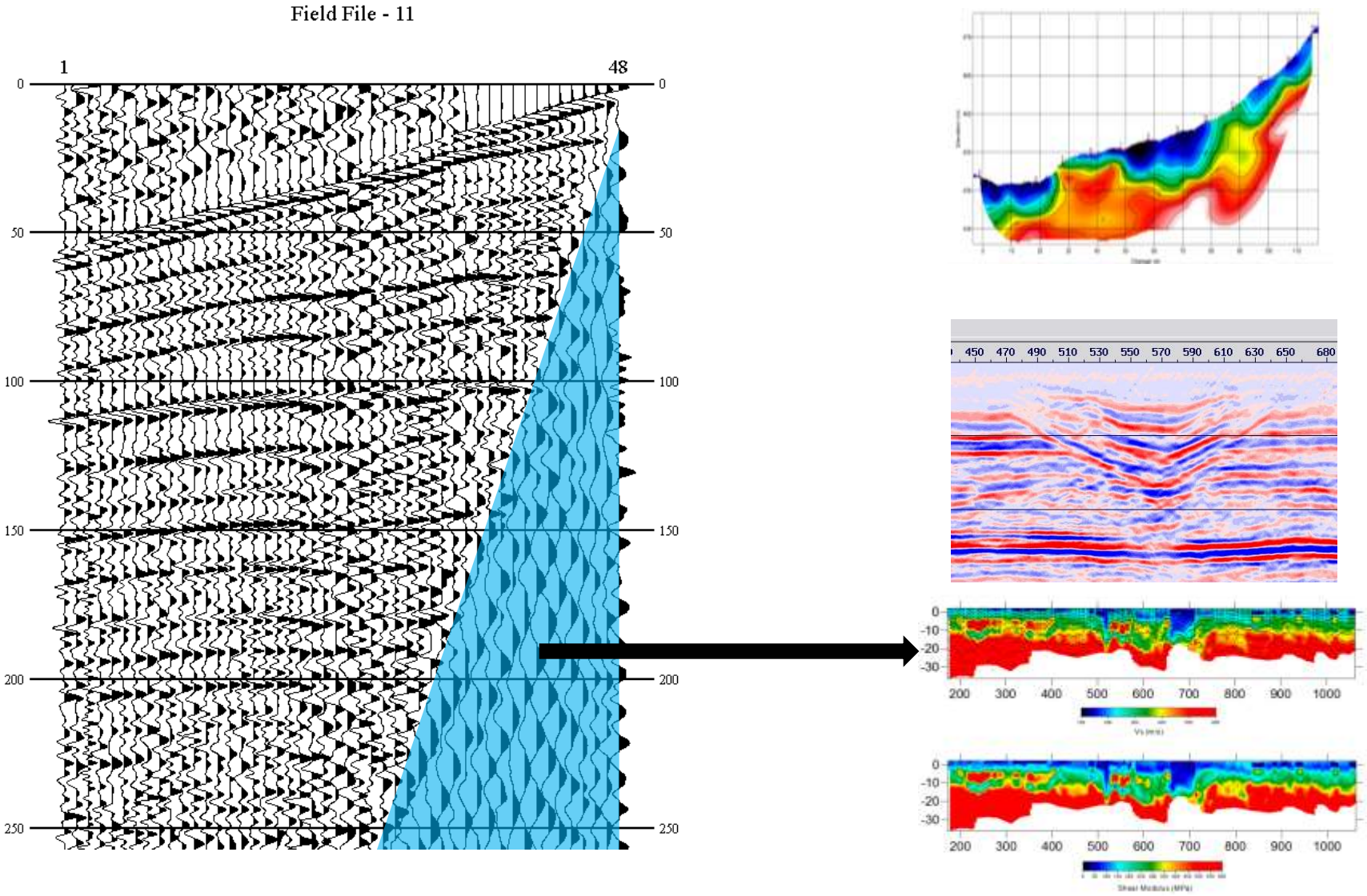
Seismic Deliverables: reflection



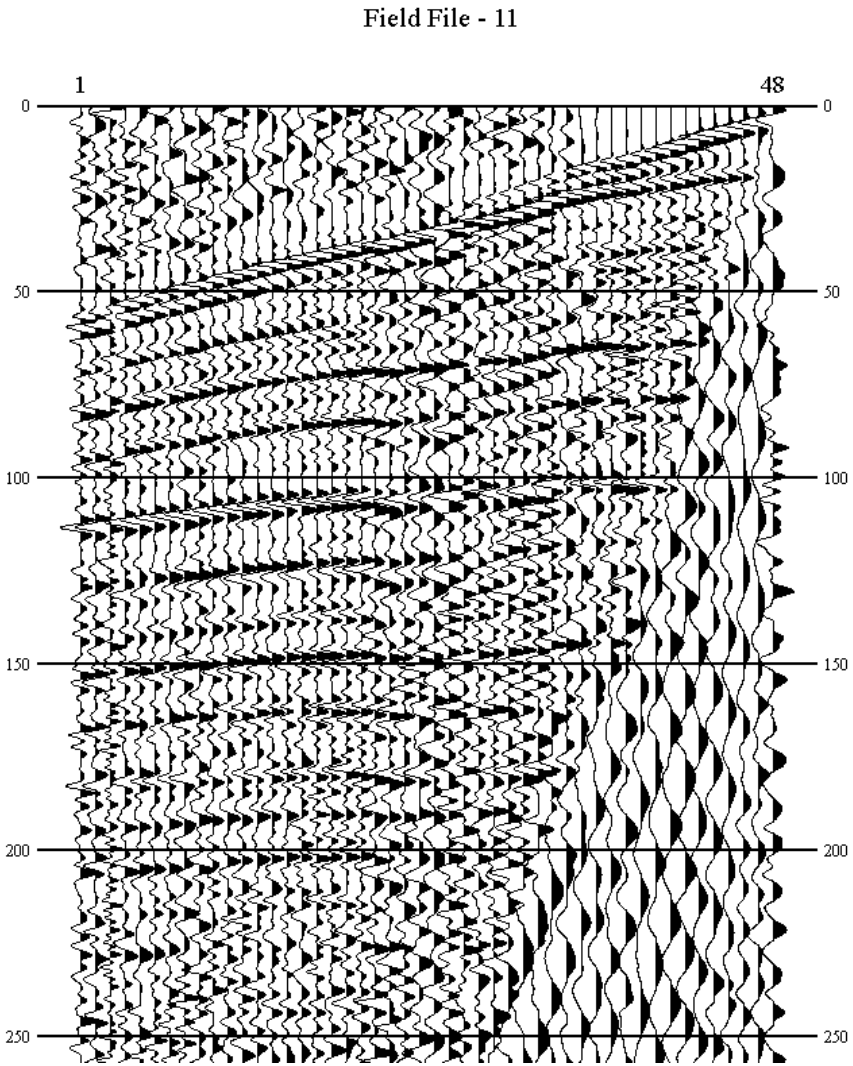




Seismic Deliverables: surface wave



Seismic Deliverables

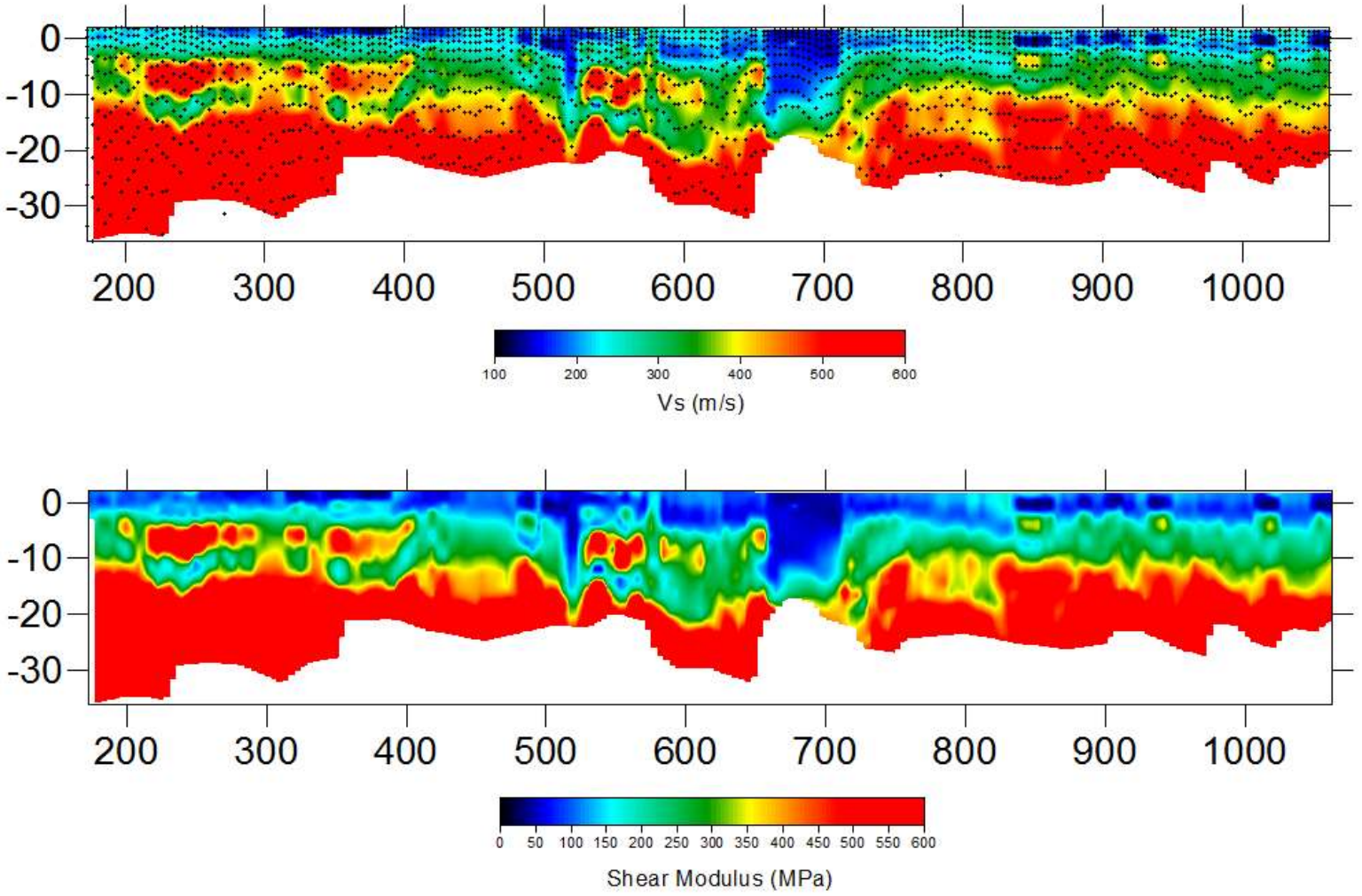


P-wave velocity distribution, layering, discontinuities

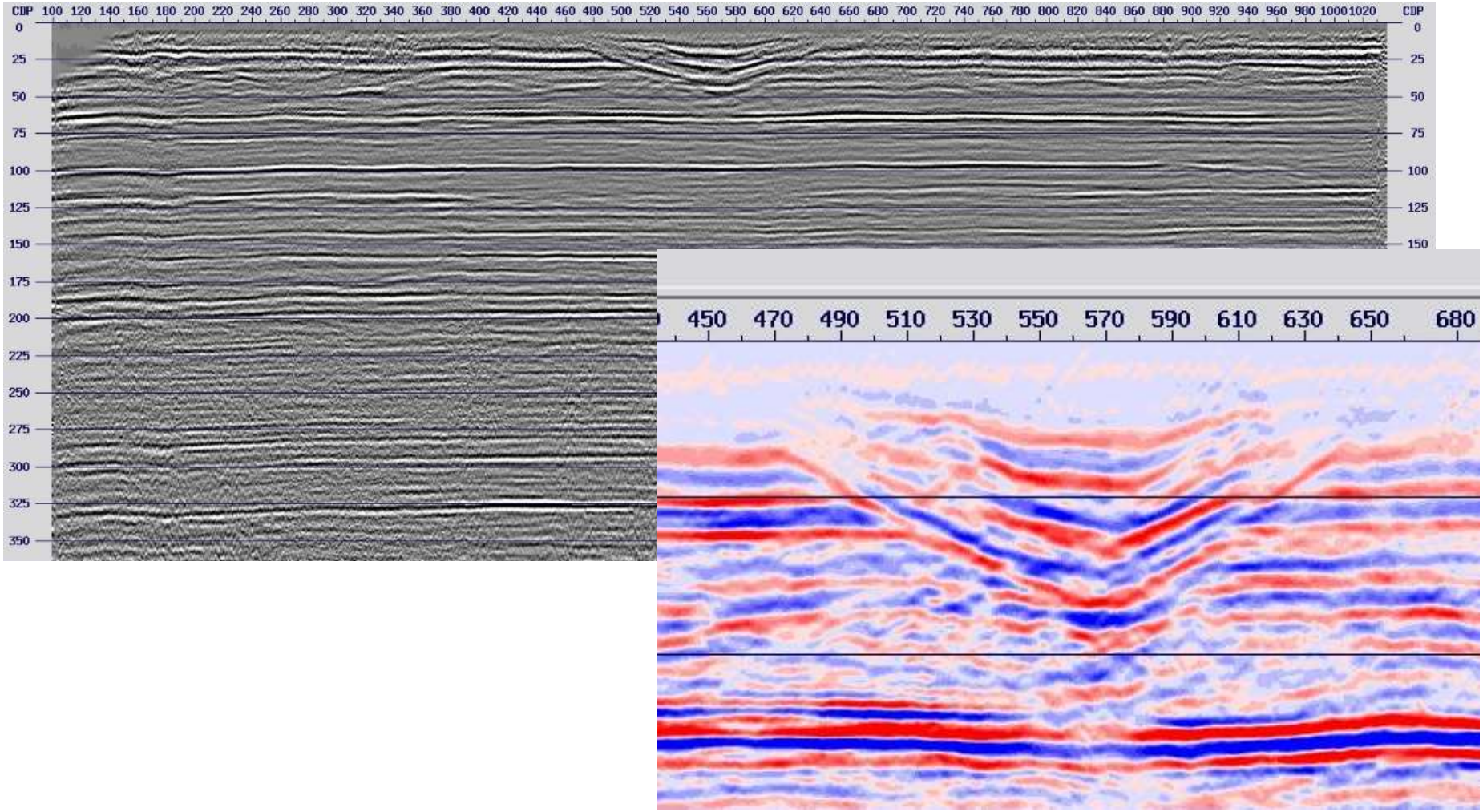
Seismic stratigraphy, discontinuities

S-wave velocity distribution, Gmax, layering, discontinuities

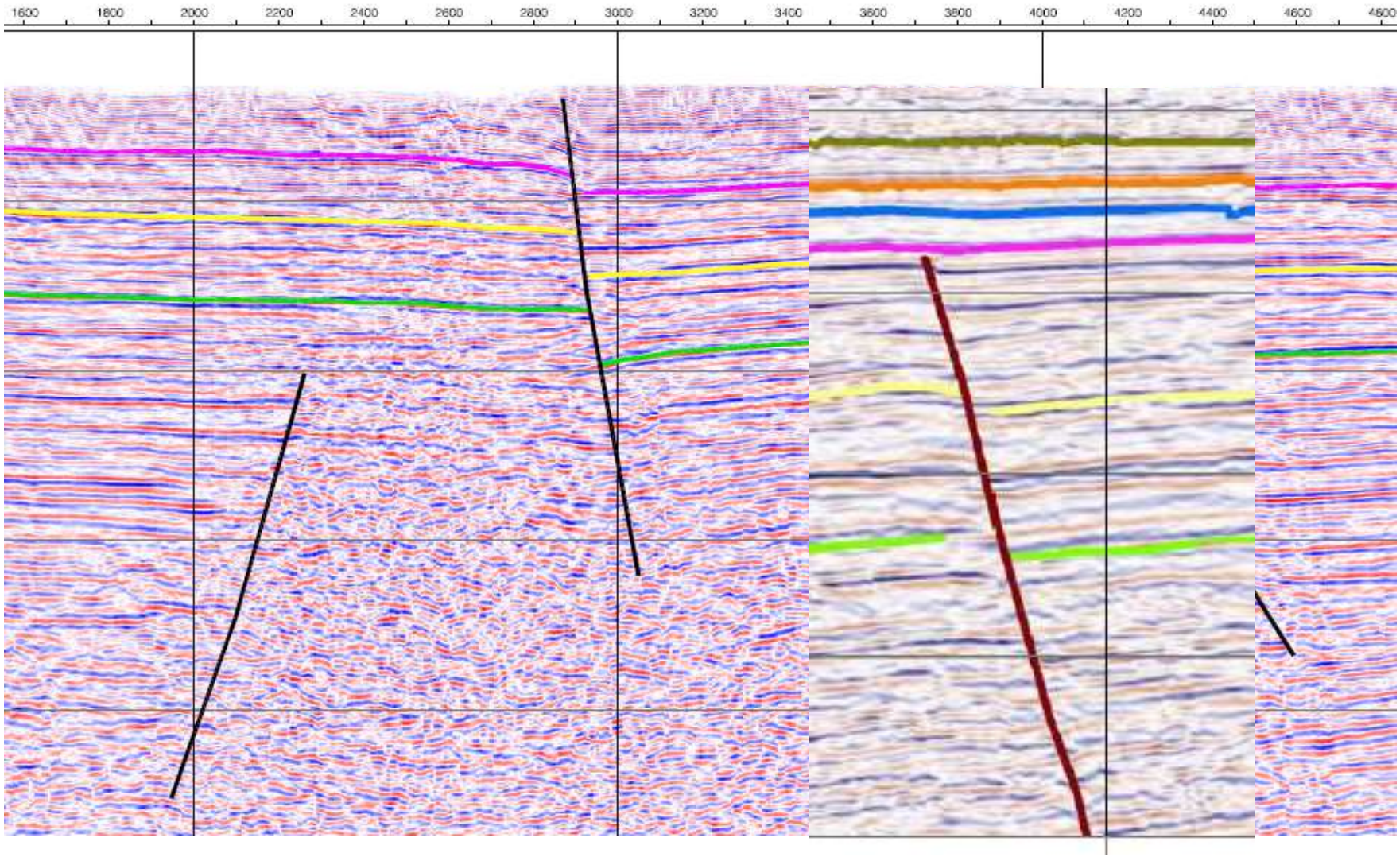
MASW


0
-10
-20
-30
200
300
400
500
600
700
800
900
1000
100
200
300
400
500
600
Vs (m/s)
0
-10
-20
-30
200
300
400
500
600
700
800
900
1000
0
50
100
150
200
250
300
350
400
450
500
550
600
Shear Modulus (MPa)

Seismic Reflection



Seismic Reflection

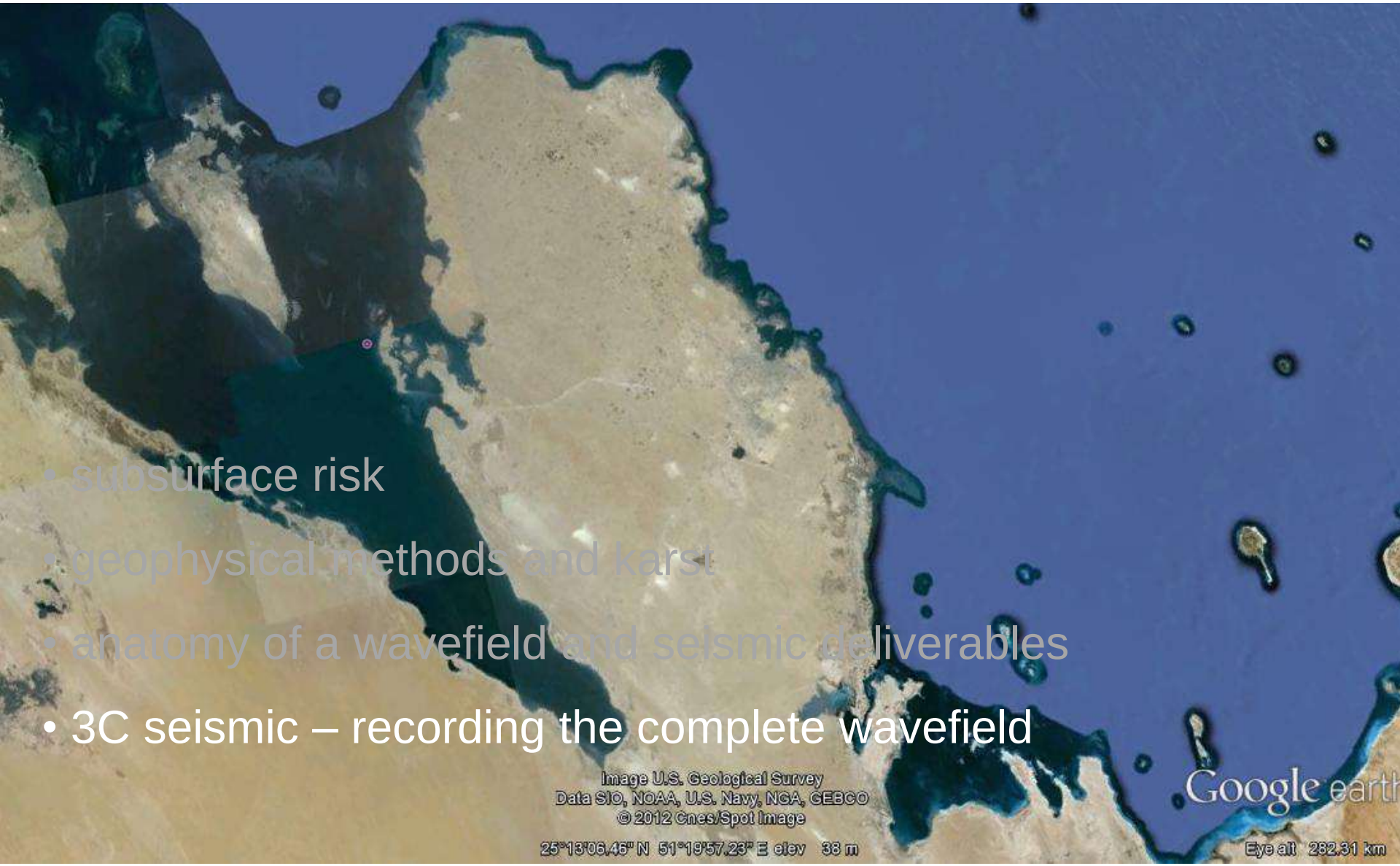


Under what conditions does seismic work best?

	These examples	Qatar
Low noise*	**8/10**	1/10 to 3/10
Good surface coupling	**9/10**	2/10 to 5/10
Saturated materials	**8/10**	2/10 to 8/10
Low velocity	**9/10**	2/10 to 8/10
Modest contrasts	**8/10**	2/10 to 5/10

*see next slide

Qatar Site Conditions



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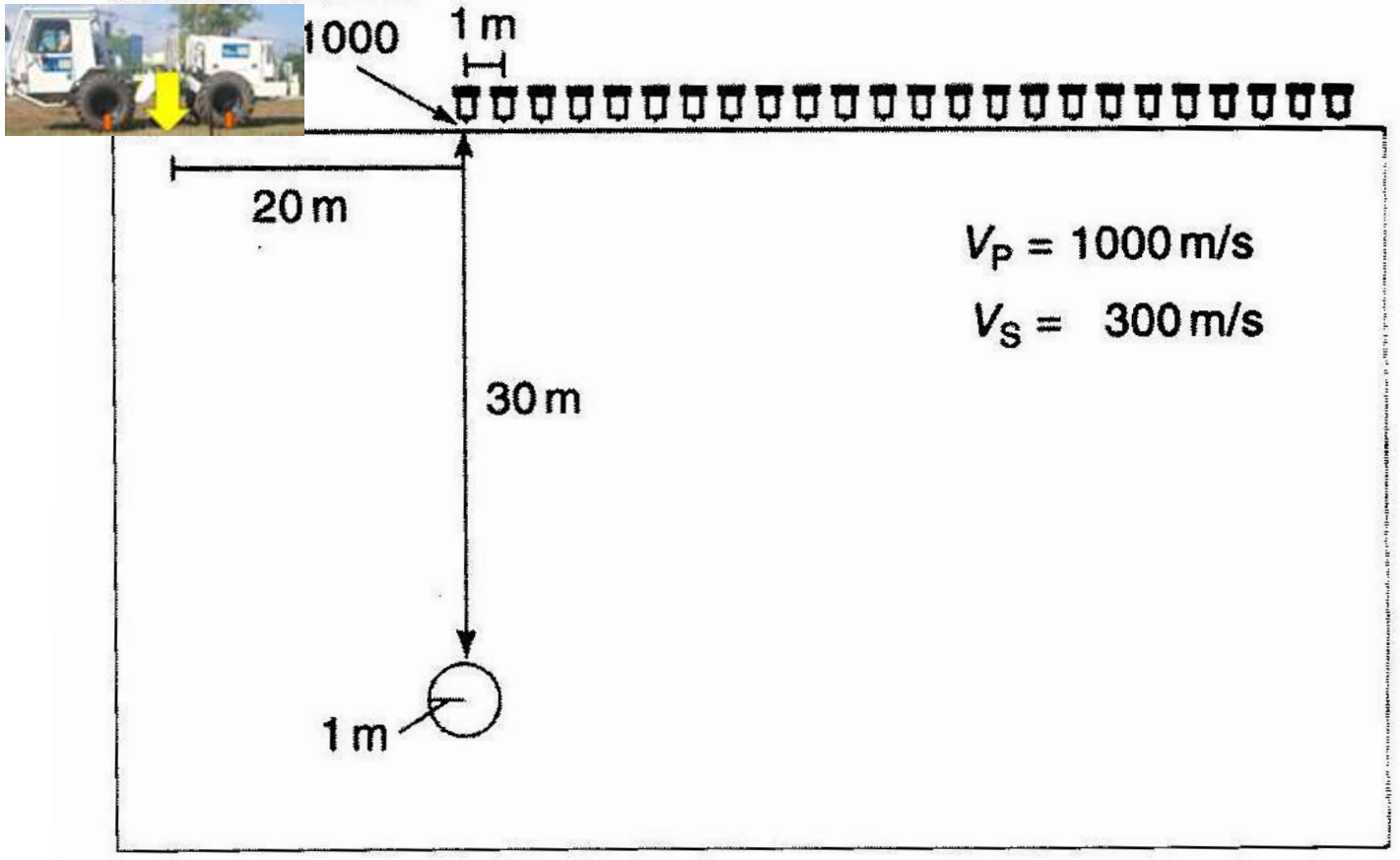
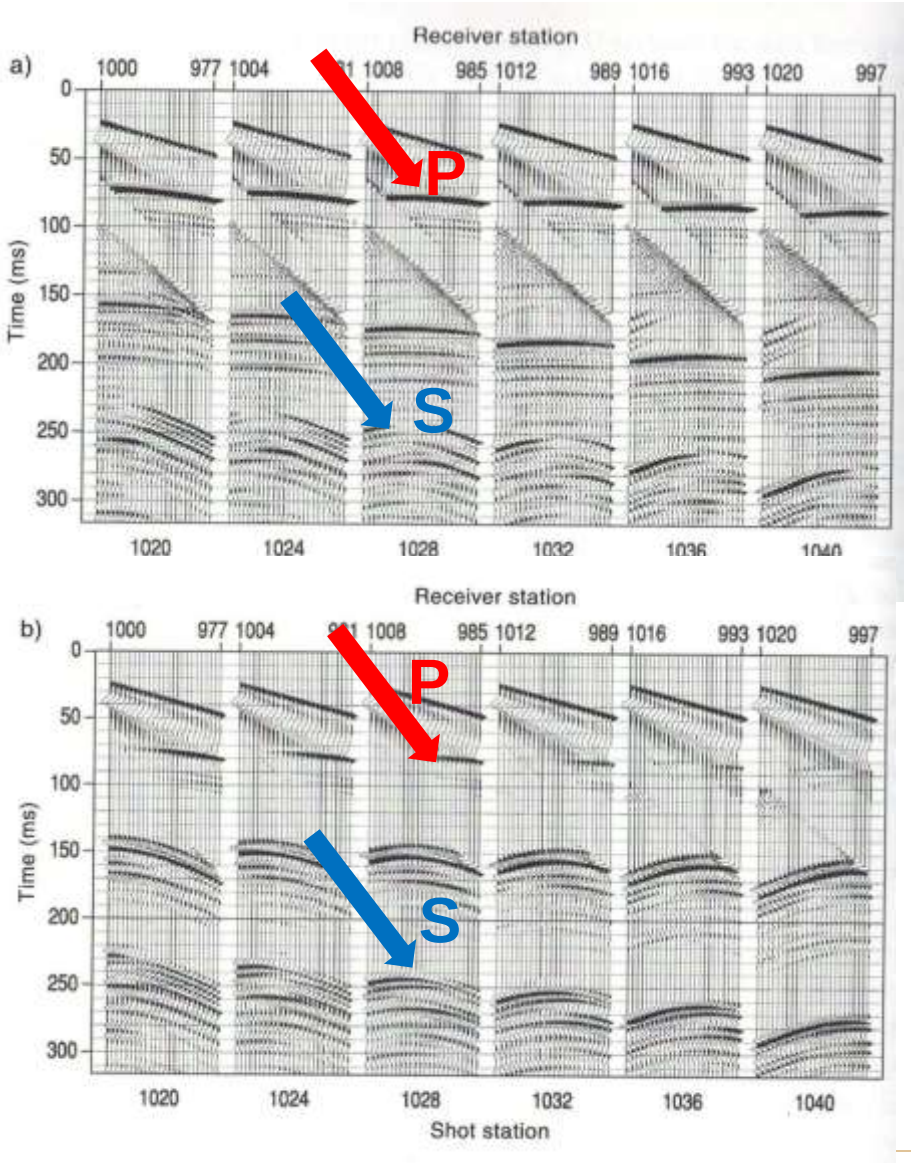
Model Void



Calculate V and H response

(Sloan et al 2010)

Vertical and Horizontal Diffraction Response

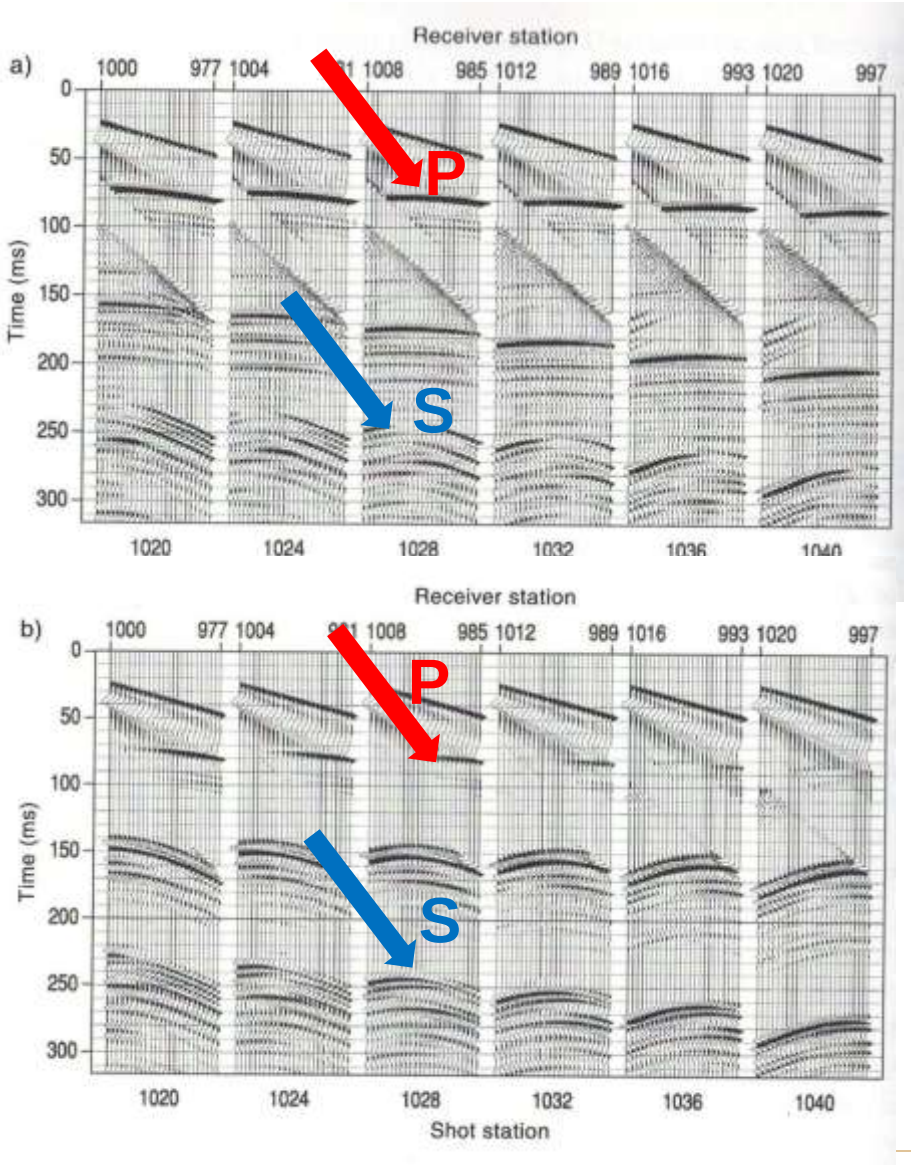


V

H

(Sloan et al 2010)

Vertical and Horizontal Diffraction Response

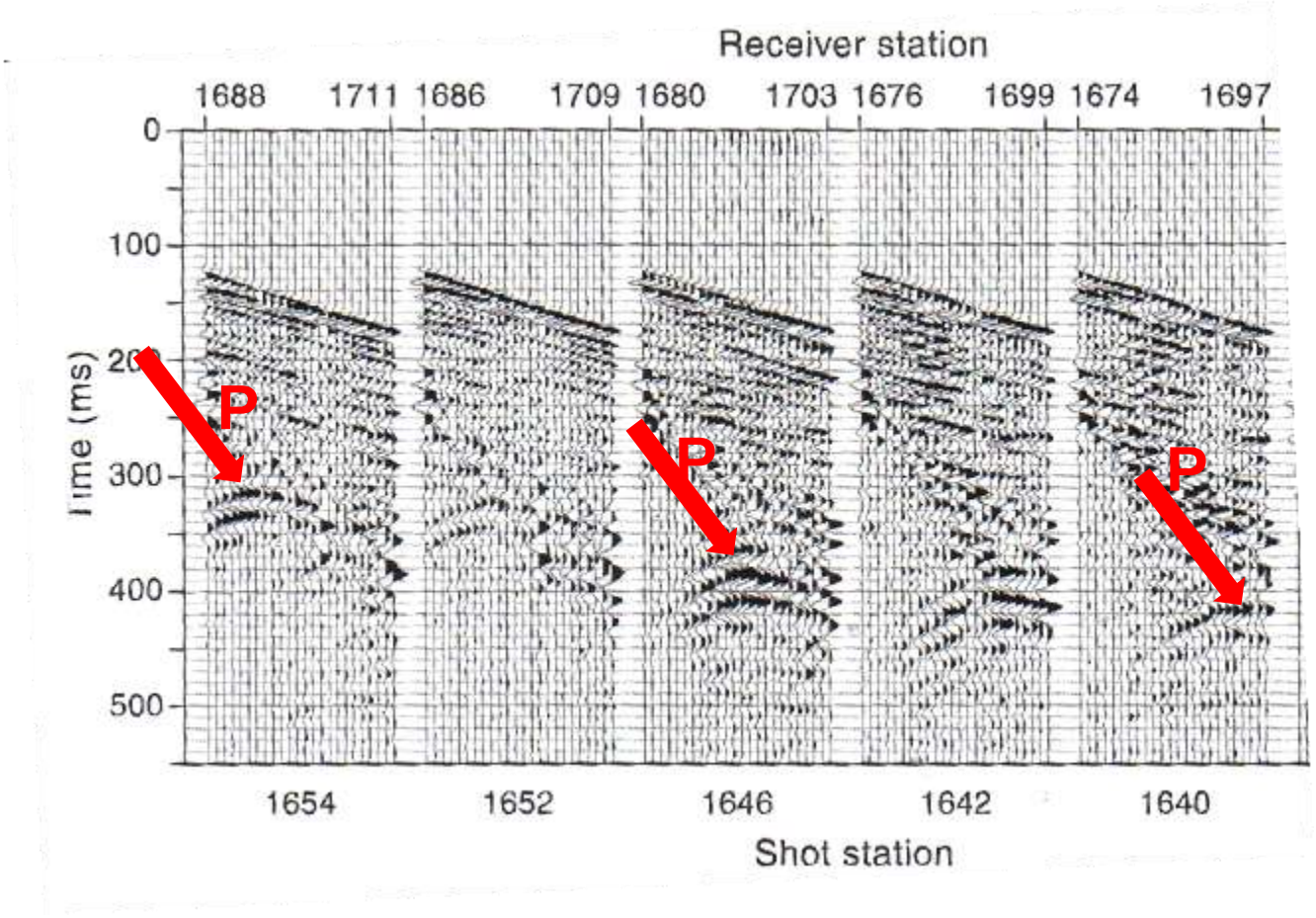


V

H

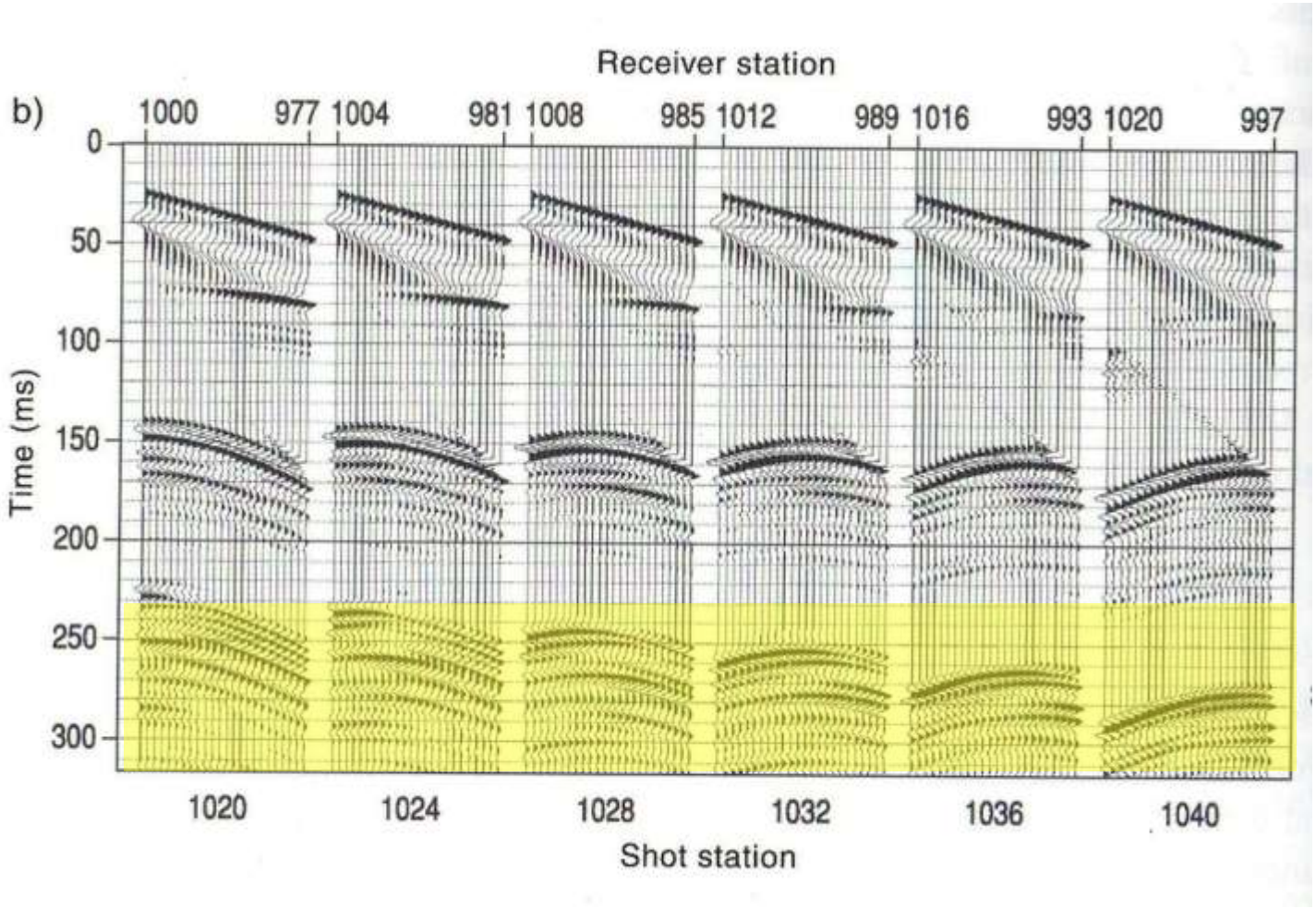
(Sloan et al 2010)

Actual Voiding – V Response



(Sloan et al 2010)

Resonance



(Sloan et al 2010)

Resonant Seismic Emission

GEOPHYSICS, VOL. 74, NO. 2 (MARCH-APRIL 2009); P. T47–T53, 13 FIGS.
10.1190/1.3068448

Resonant seismic emission of subsurface objects

Valeri Korneev[1]

Resonant Seismic Emission

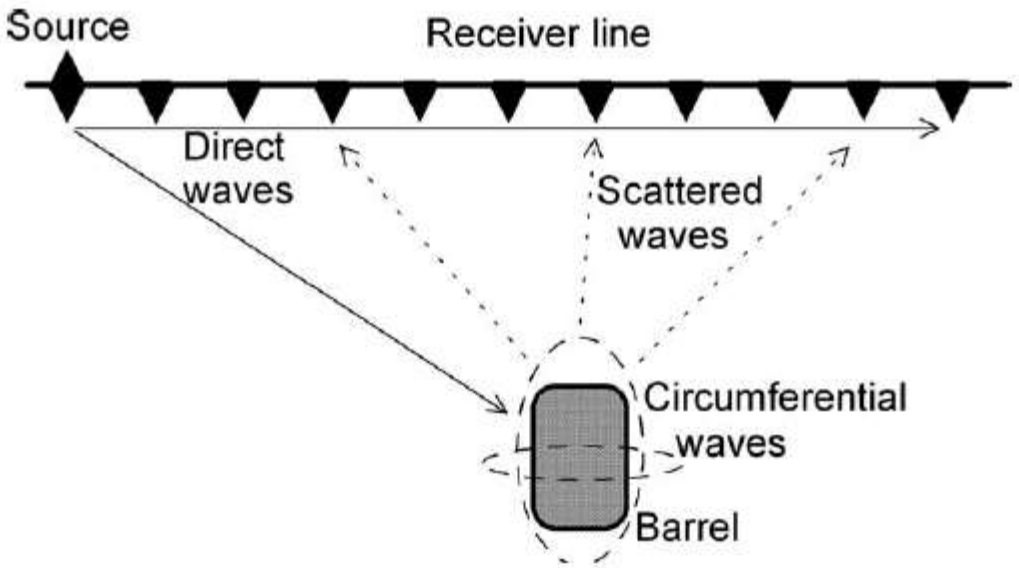
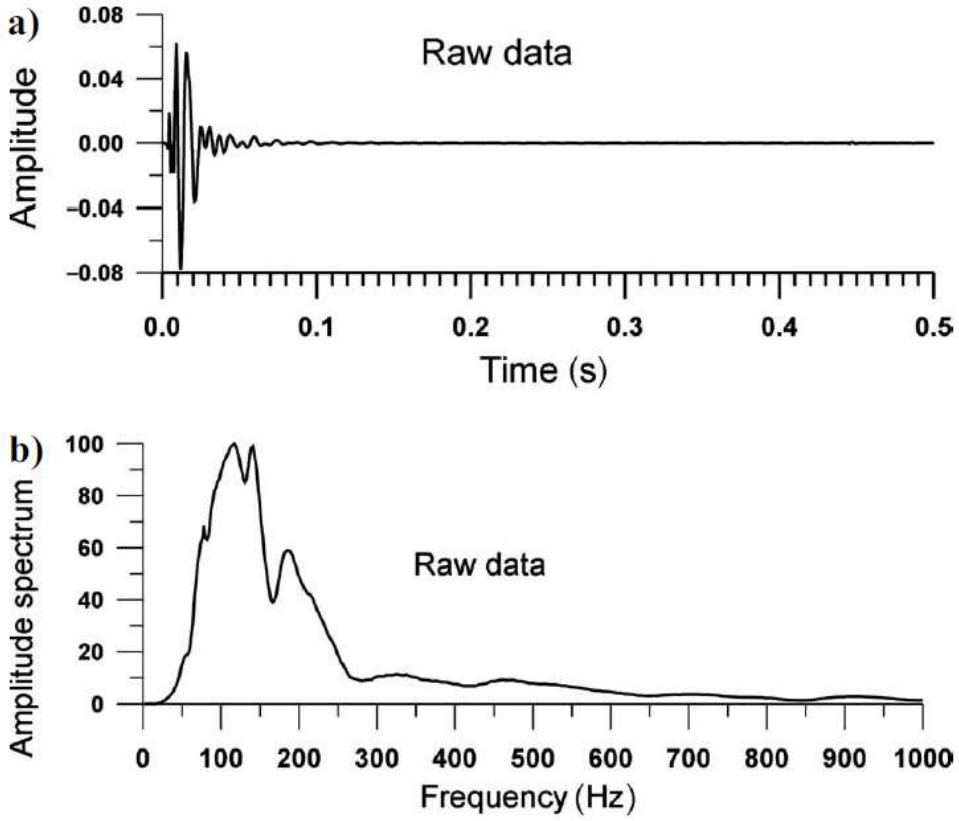


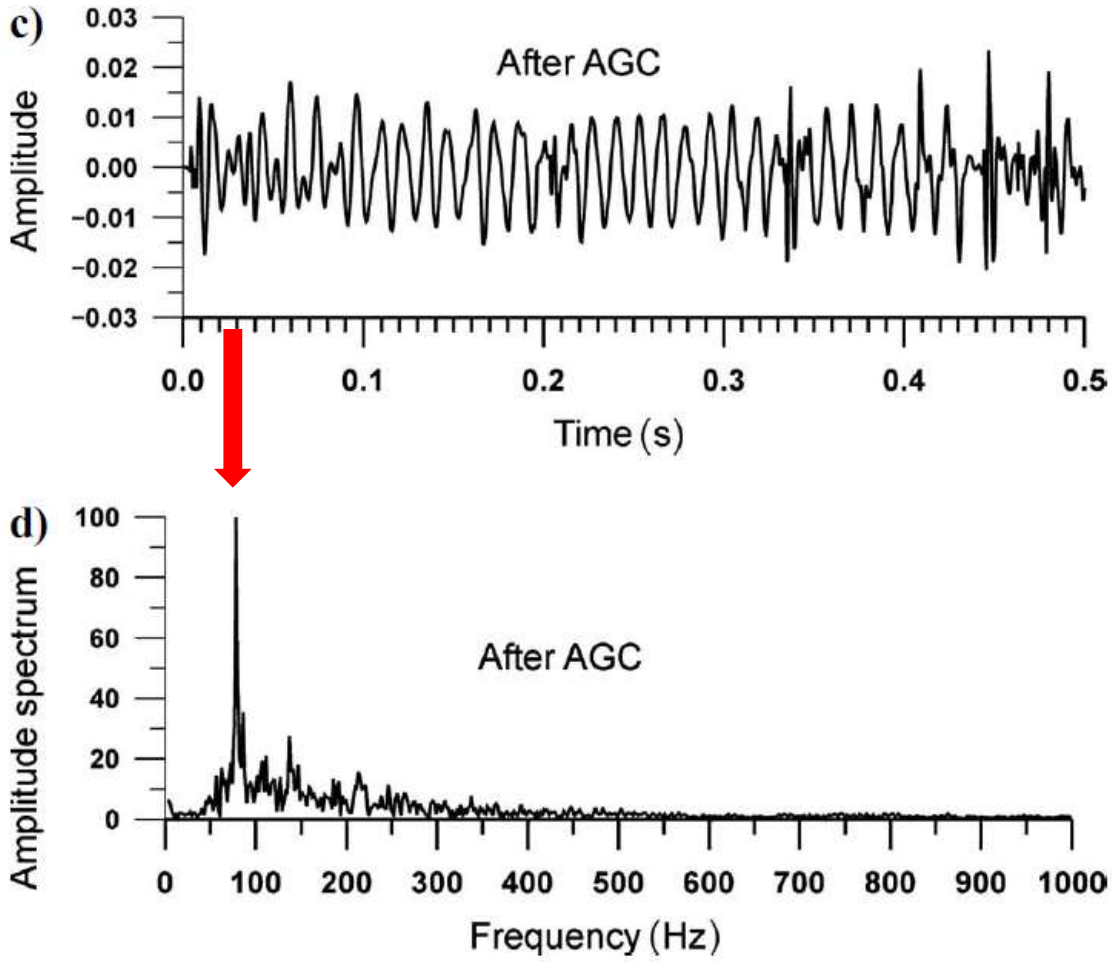
Figure 1. Geometry of the seismic experiment to locate a buried water-filled barrel. Solid lines, dashed lines, and dotted-line arrows indicate direct, circumferential, and scattered waves, respectively.

?tabular voiding

Resonant Seismic Emission



Resonant Seismic Emission



Objective diagnostics for voiding / filled cavities

1) Diffractions

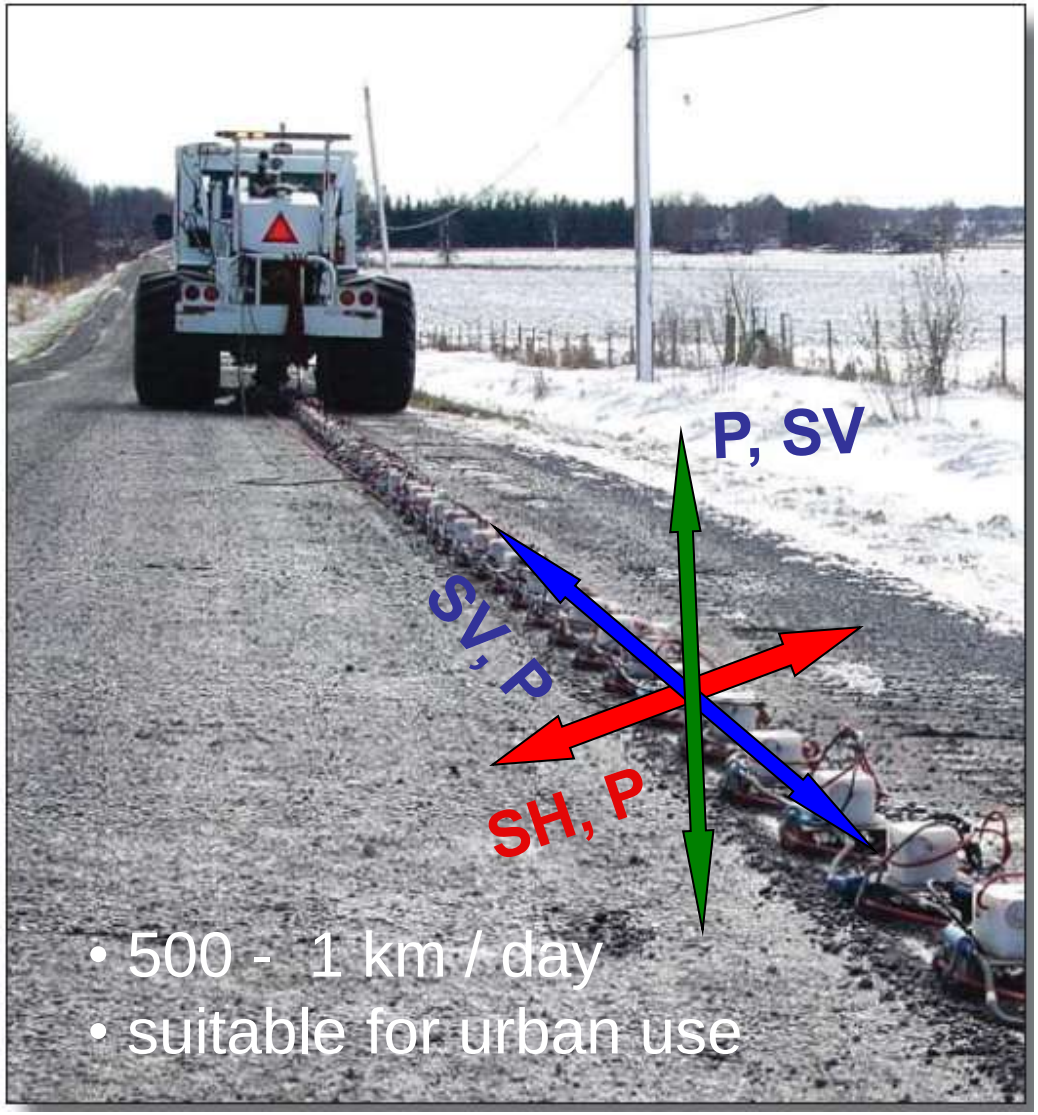
- V and H geometry
- V and H velocity behaviour
- V and H polarity behaviour
- consistent shot-to-shot response
- consistent line-to-line response

2) Resonance

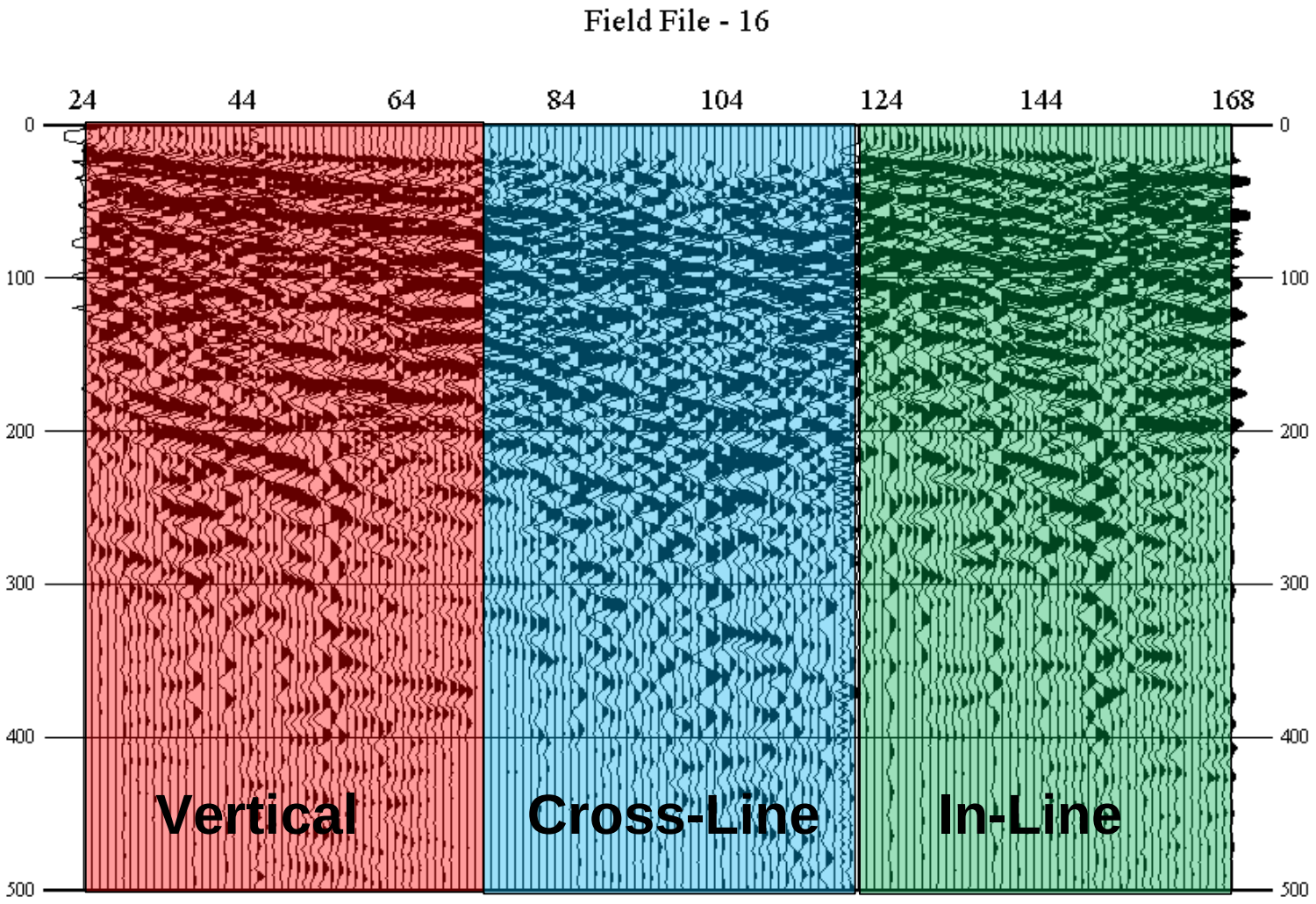
- monochromatic response

Important to capture the 3C wavefield

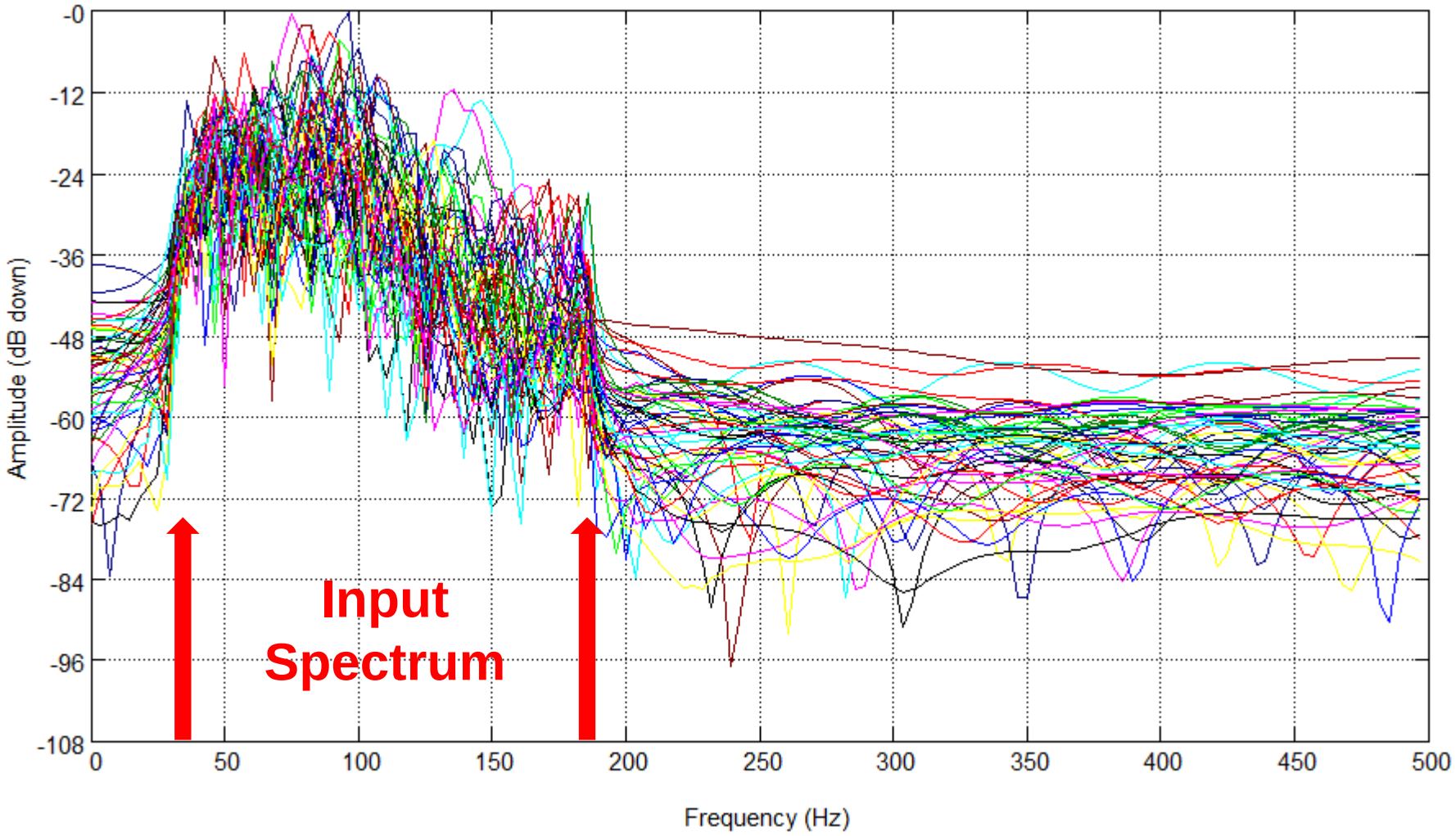
3C Land Streamer - Captured Wave Modes



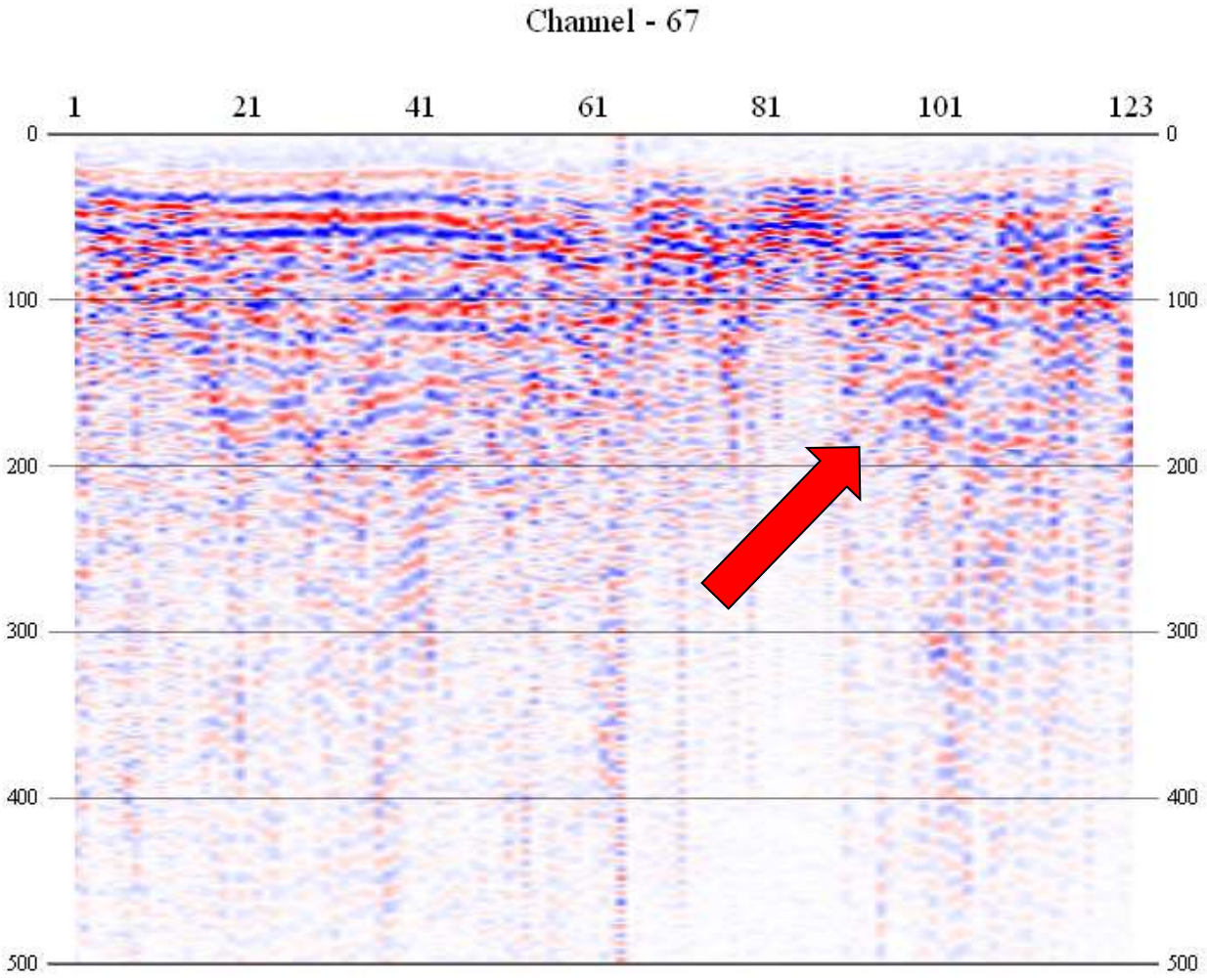
3C seismic (single) shot record



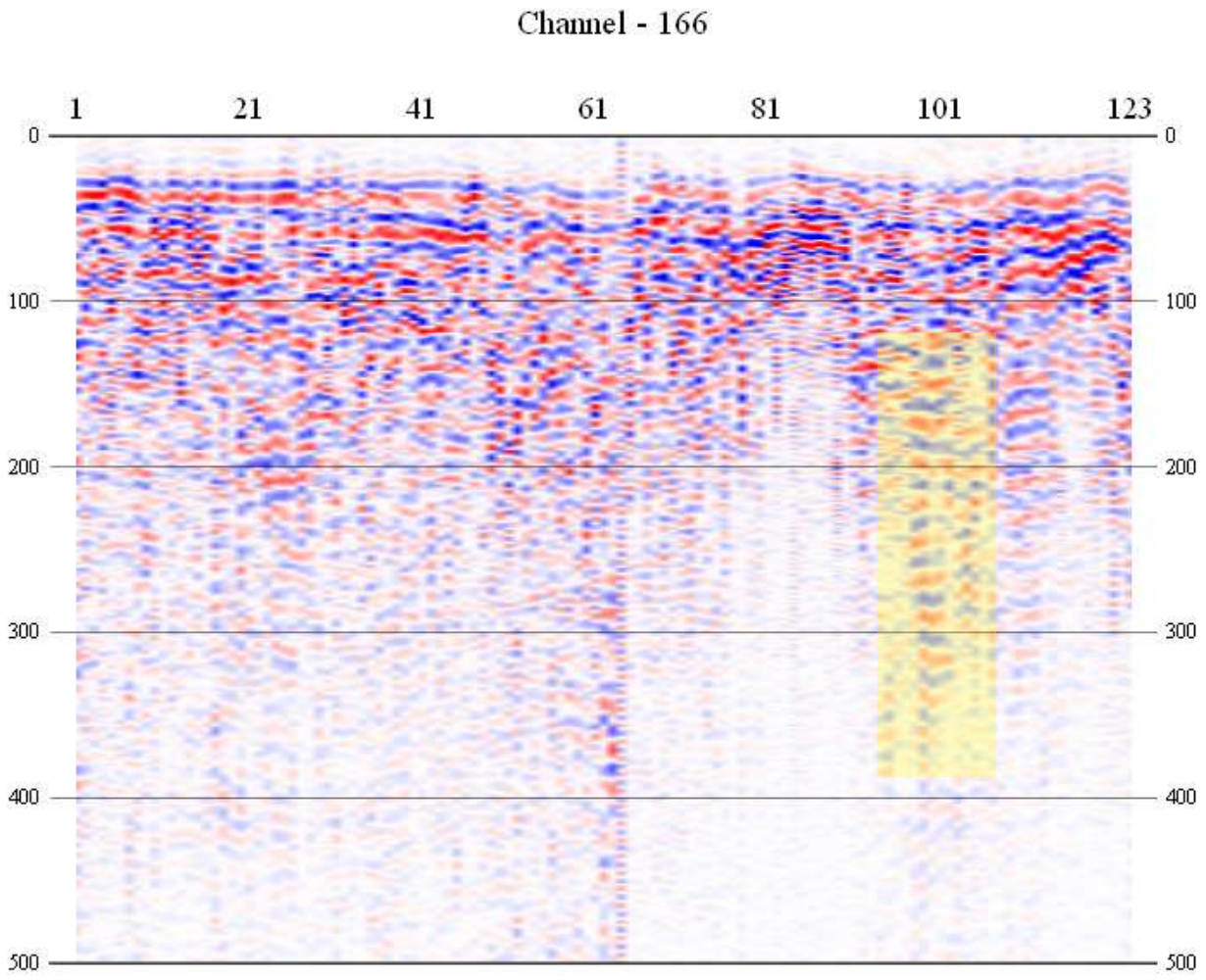
Whole Record Spectrum



V Response

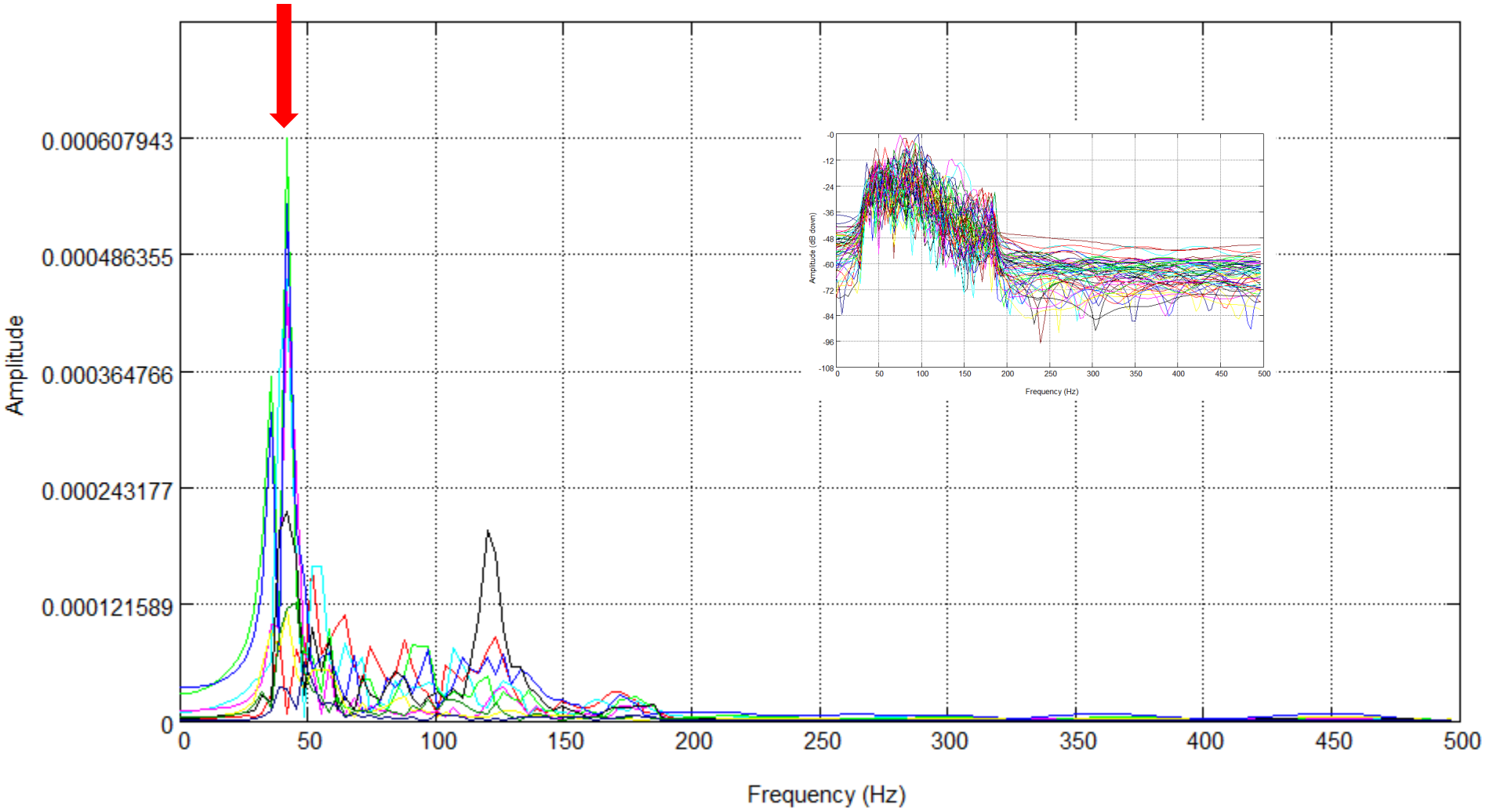


H Response

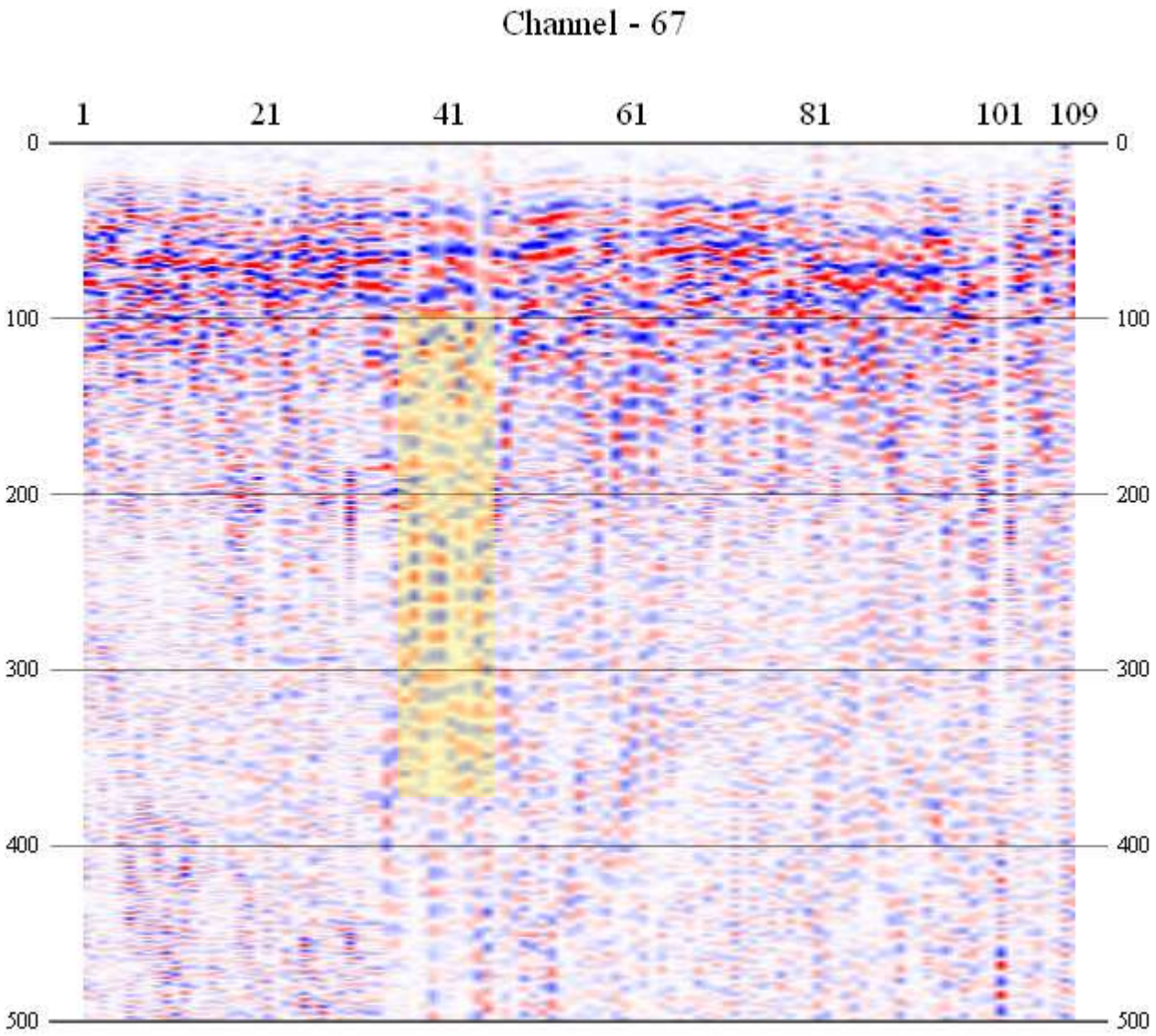


Spectrum: H Response

Resonance?

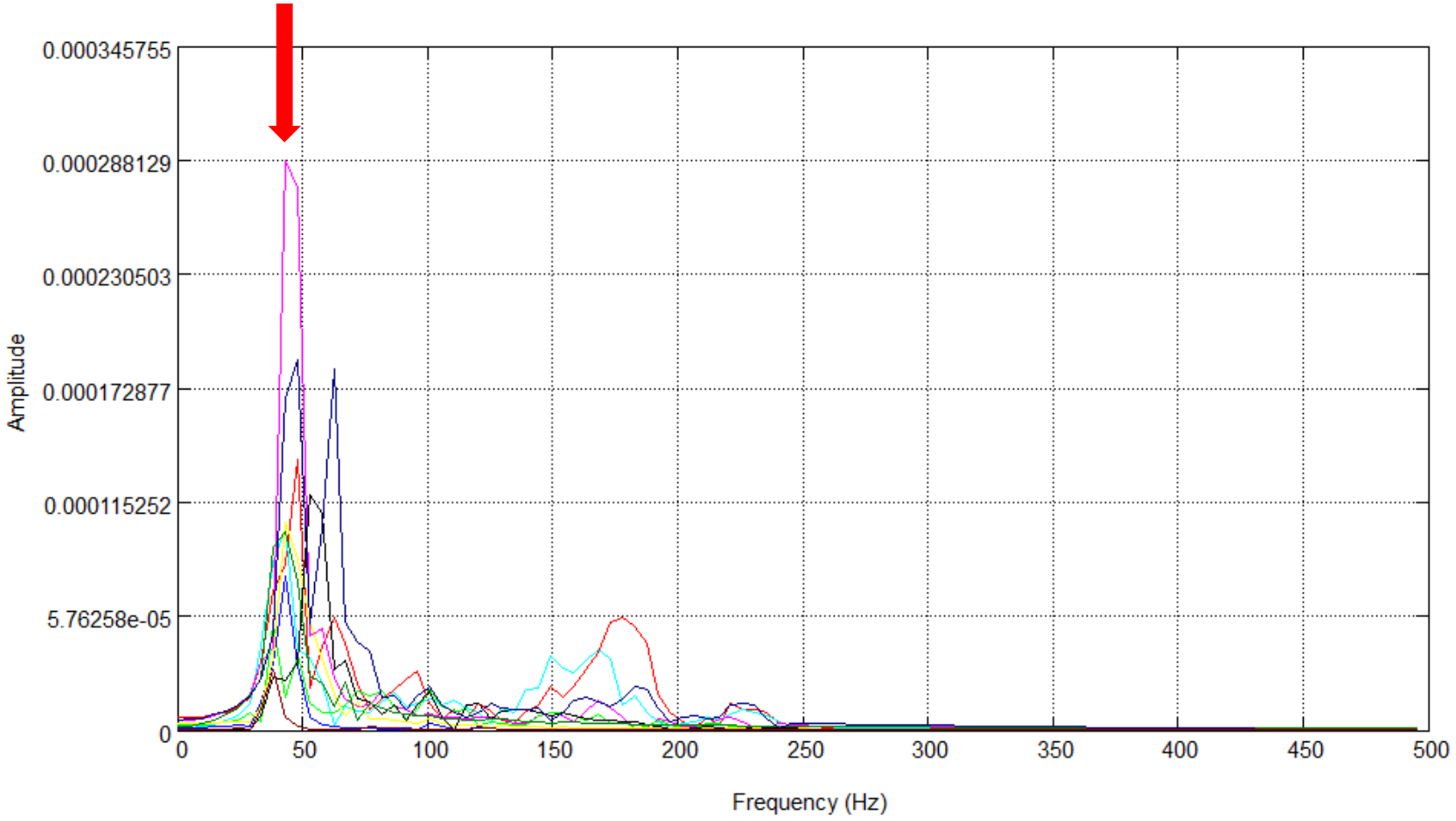


V Response

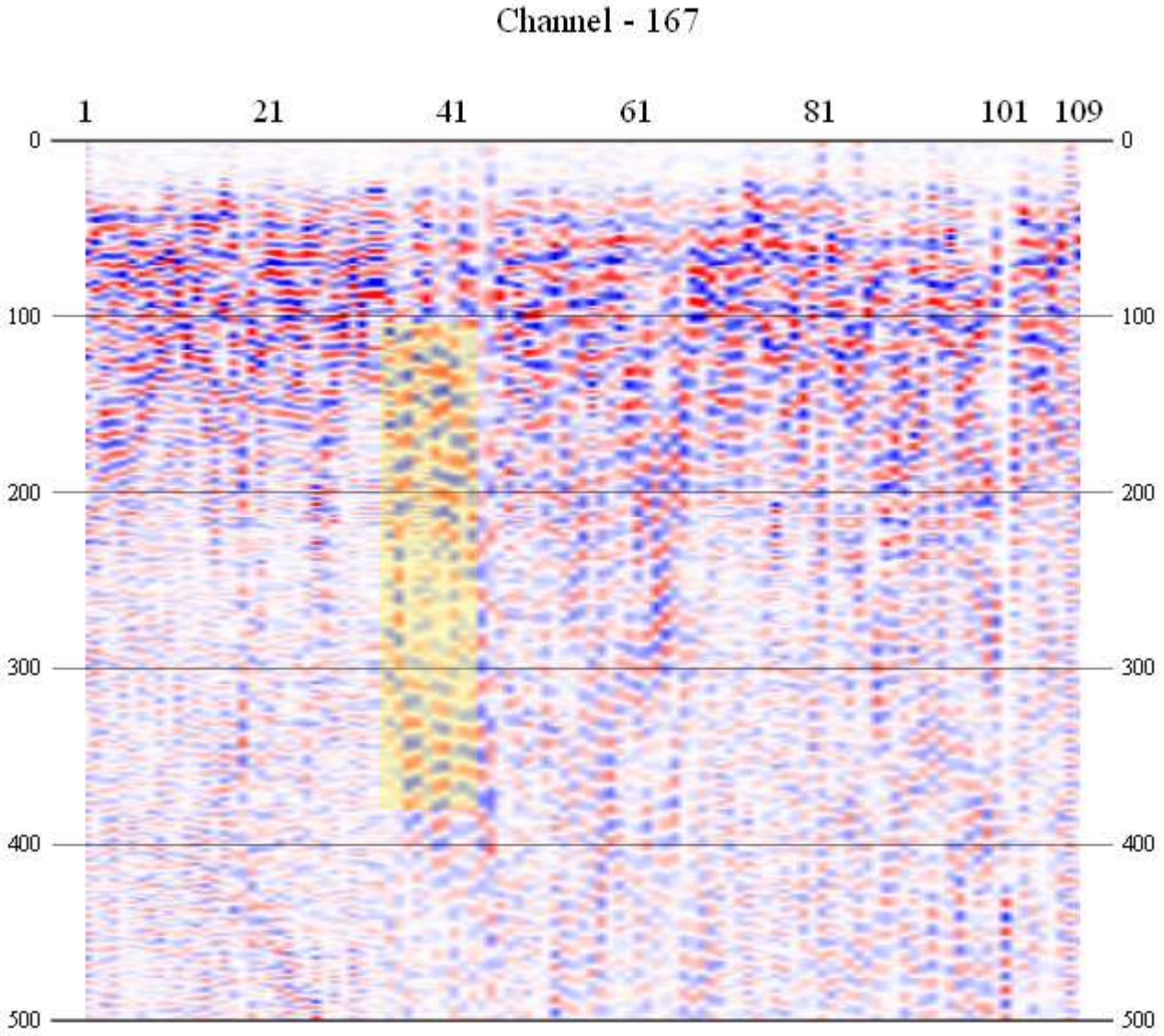


Spectrum: V Response

Resonance?

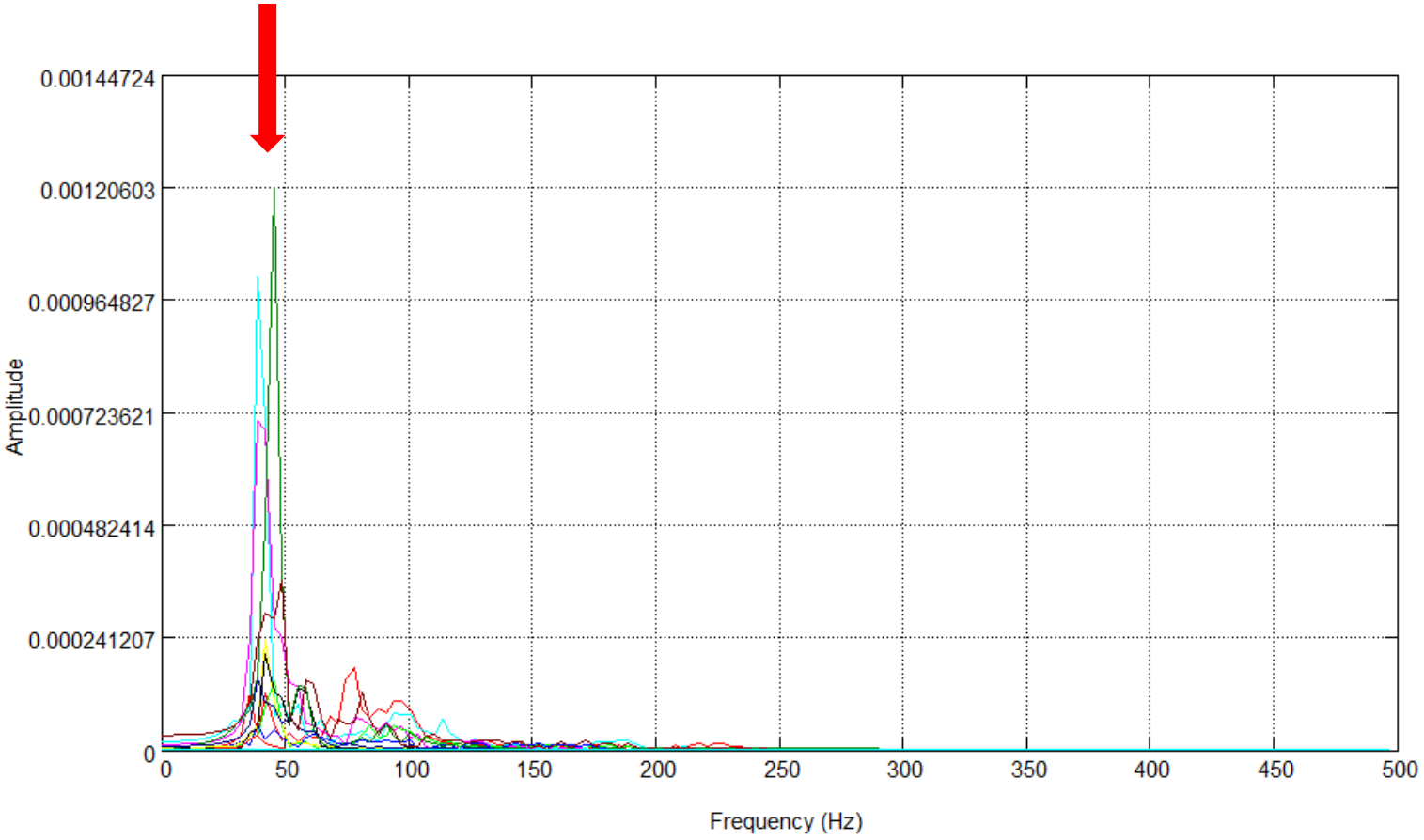


H Response

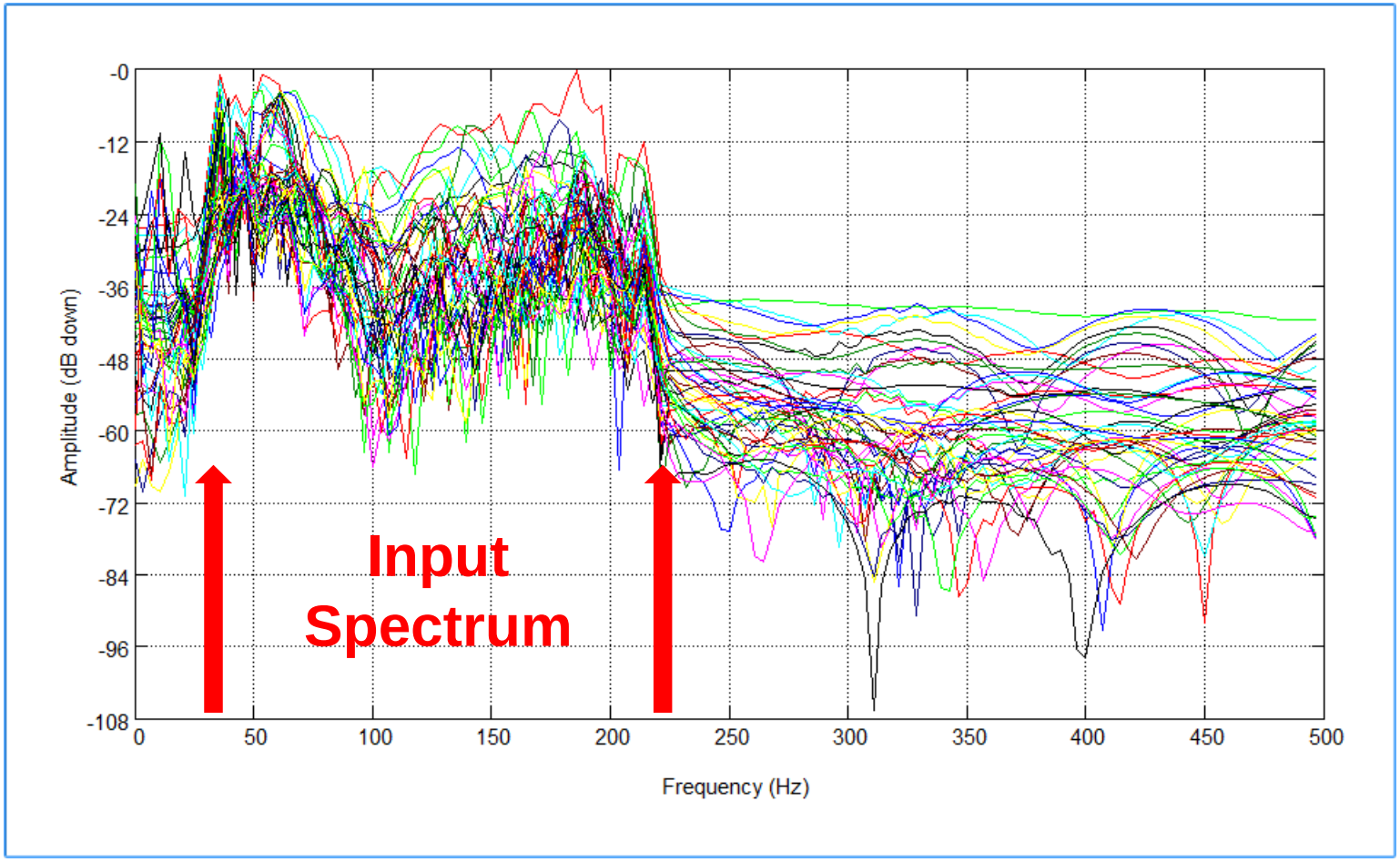


Spectrum: H Response

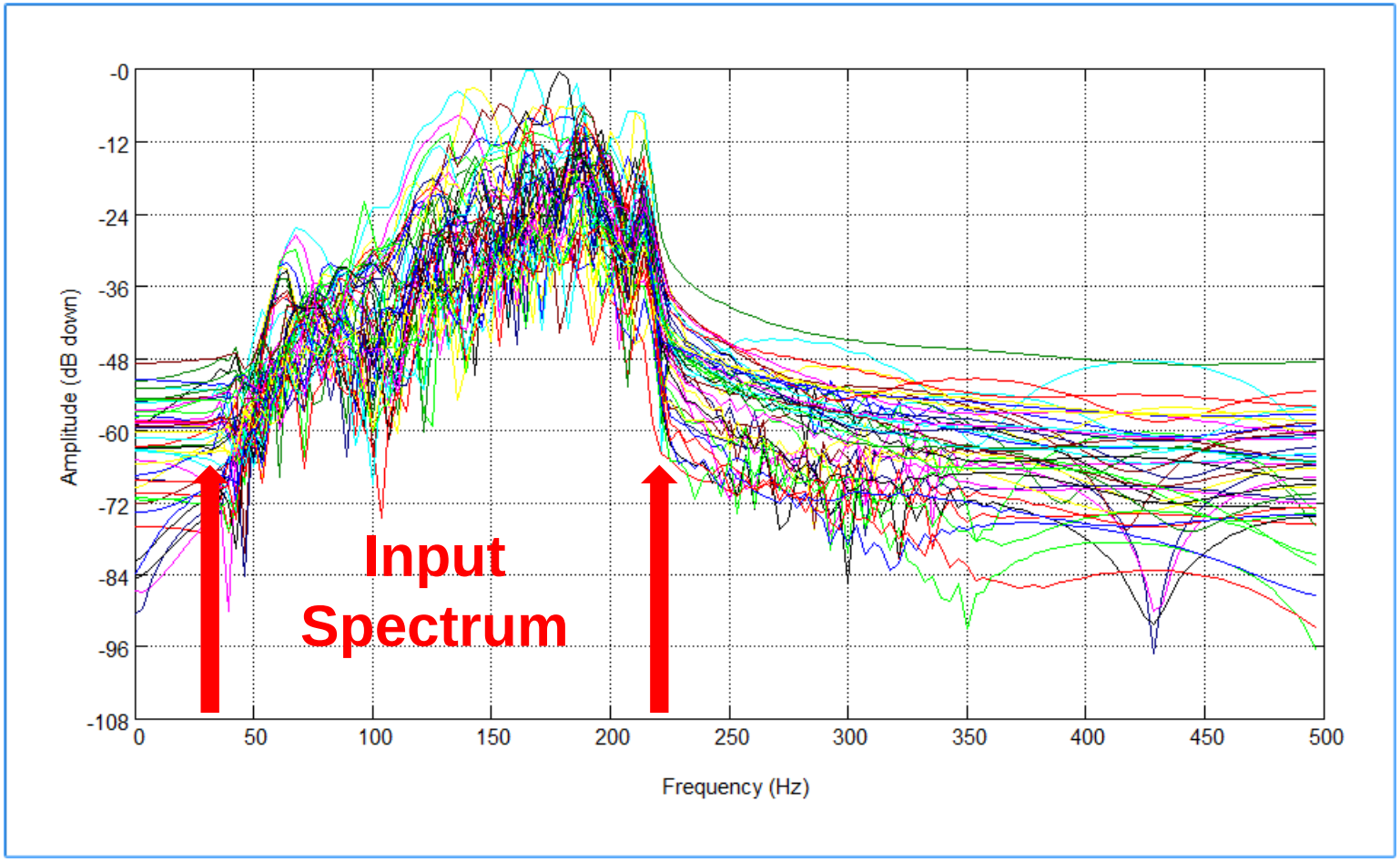
Resonance?



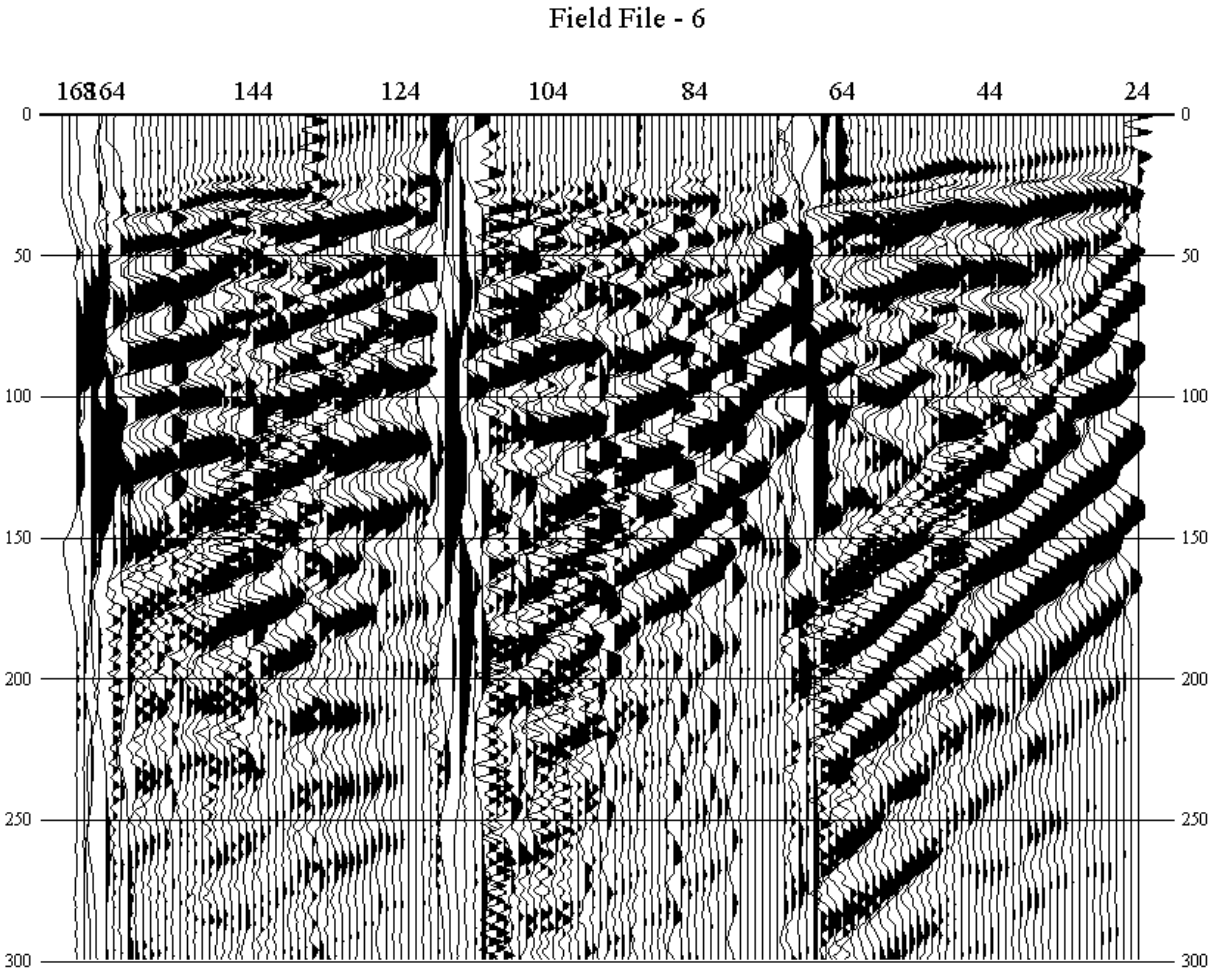
Spectrum: Full Wavefield



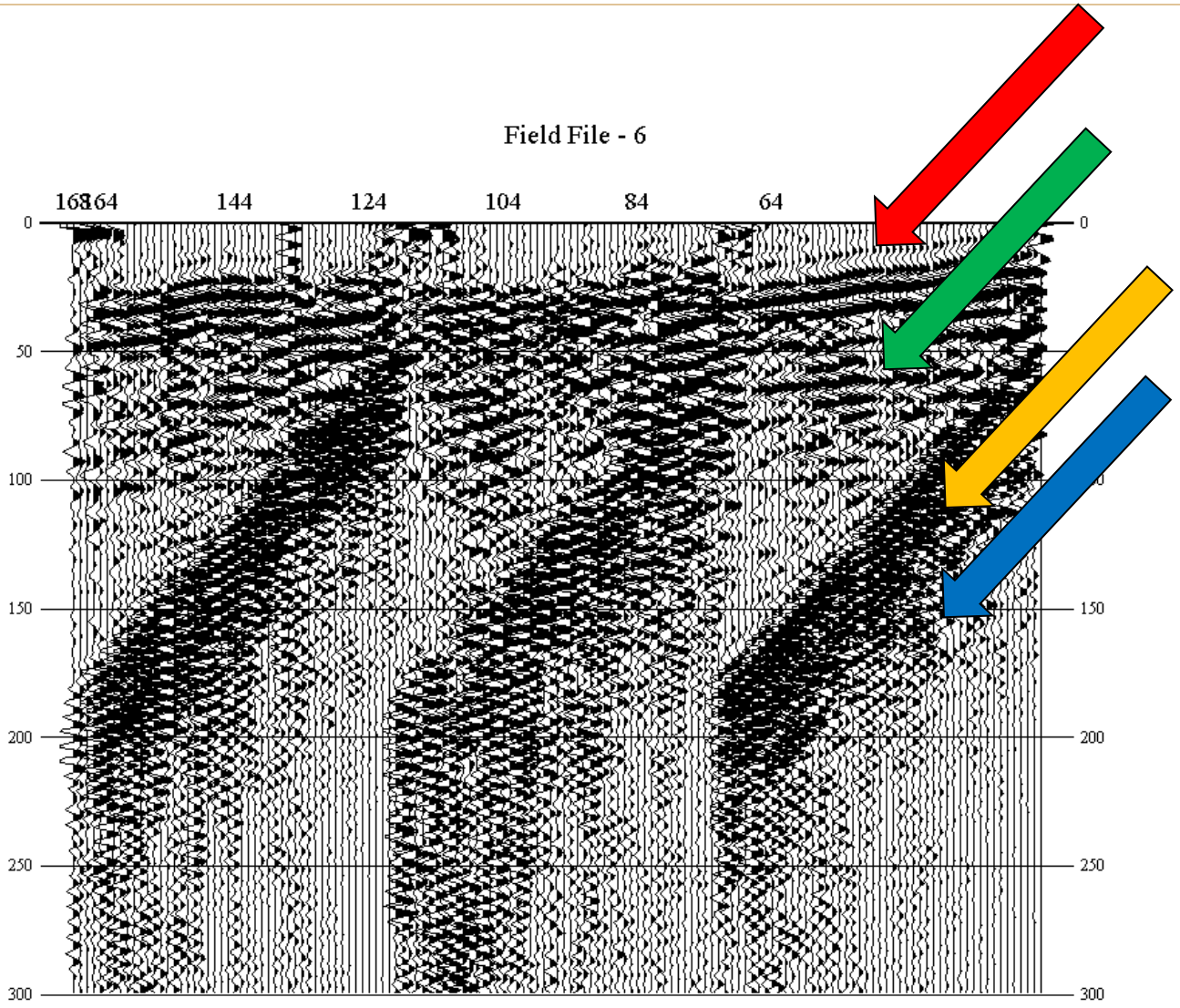
Spectrum: hi-pass filtered



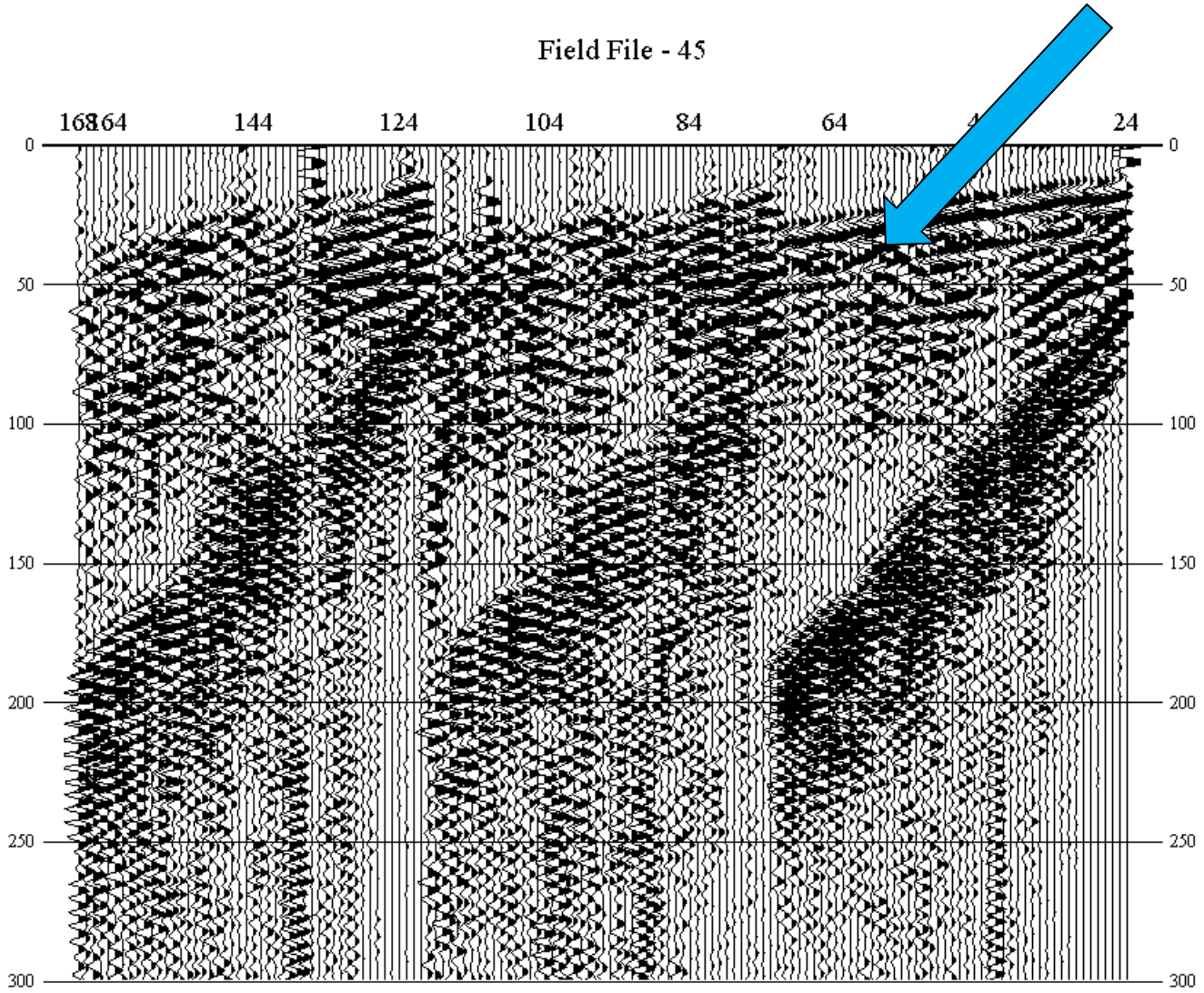
3C Full Wavefield Recording – no filters



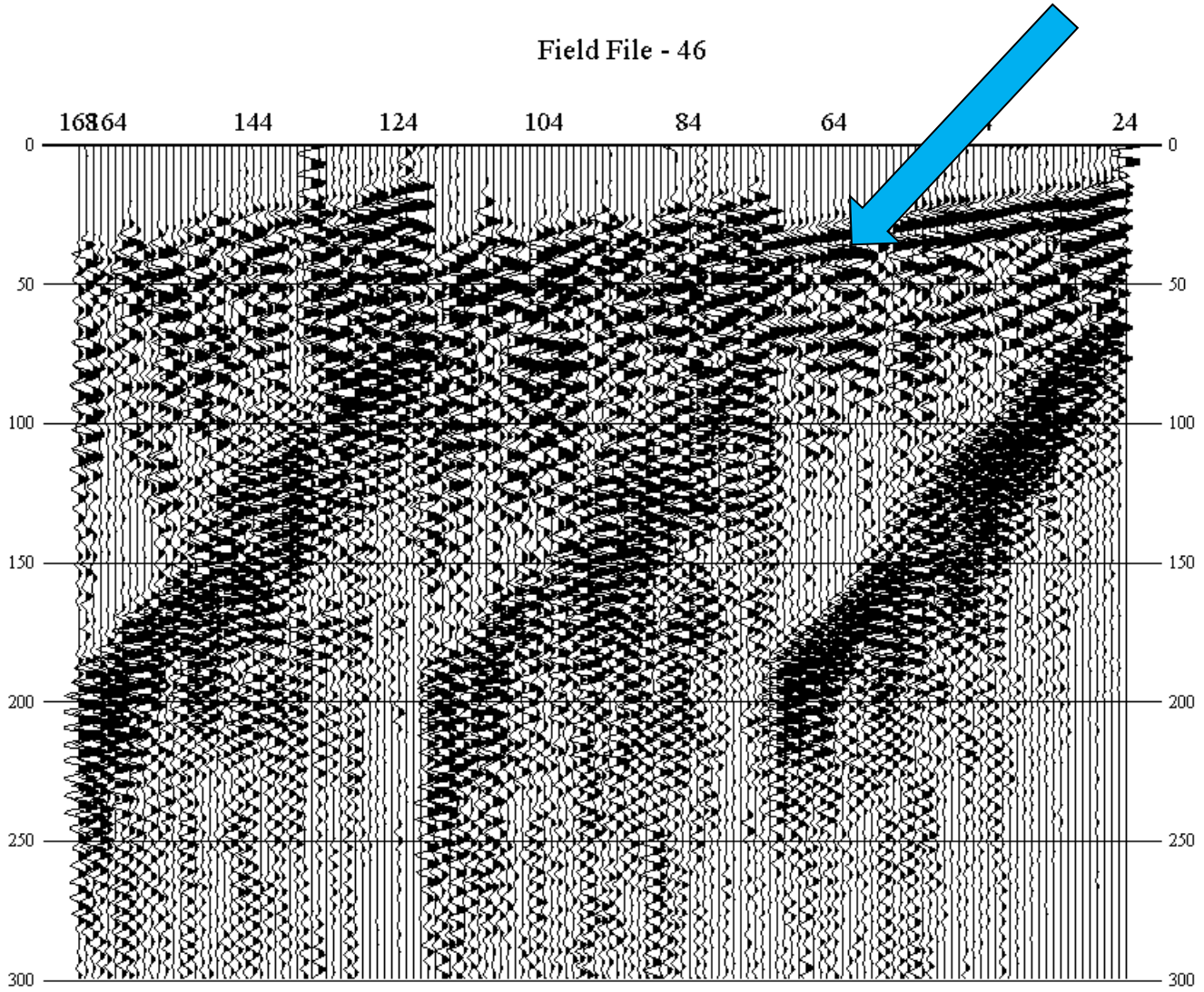
3C Full Wavefield Recording – hi pass filtered



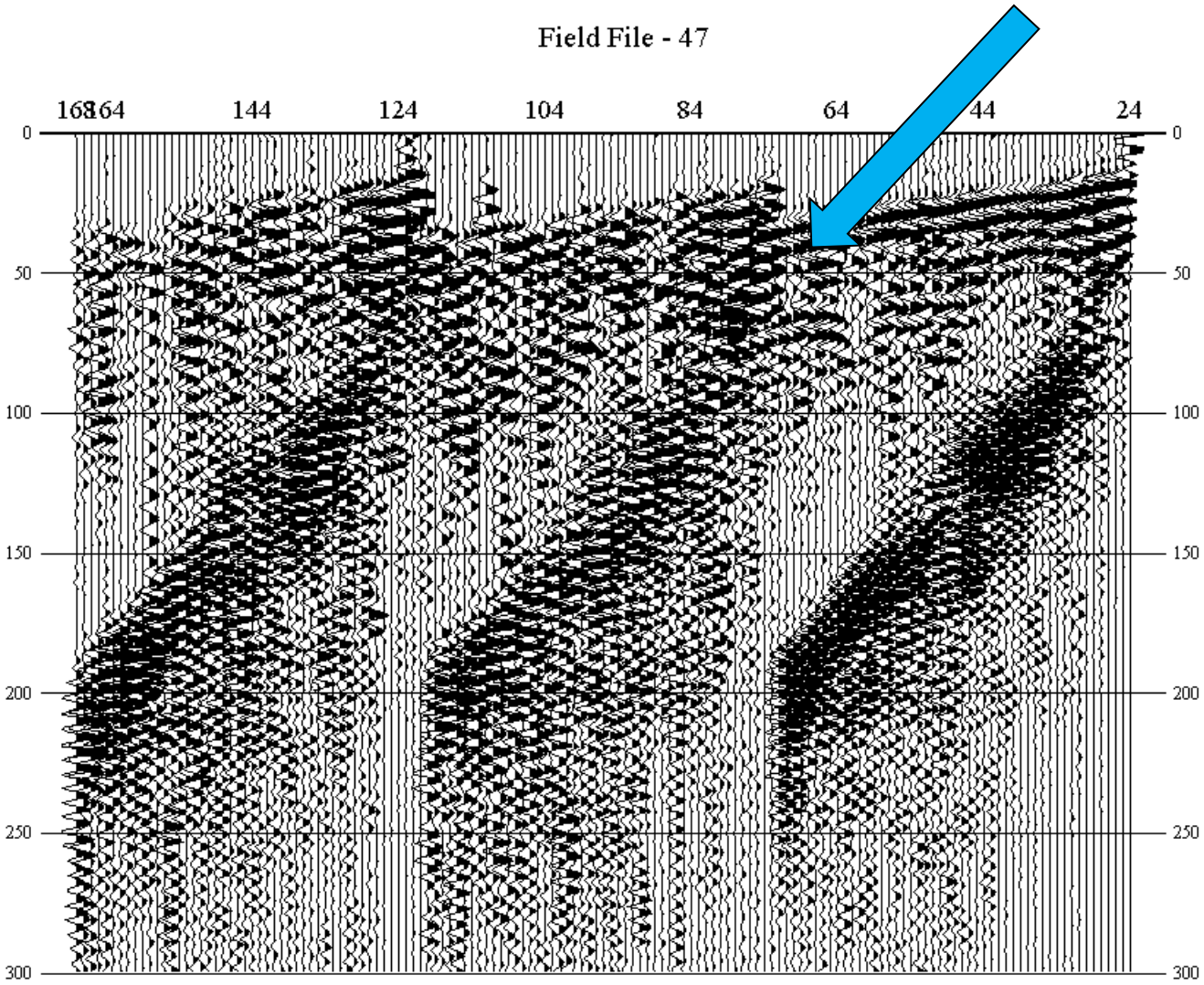
Hyperbolic/Reverse Move-Out Events



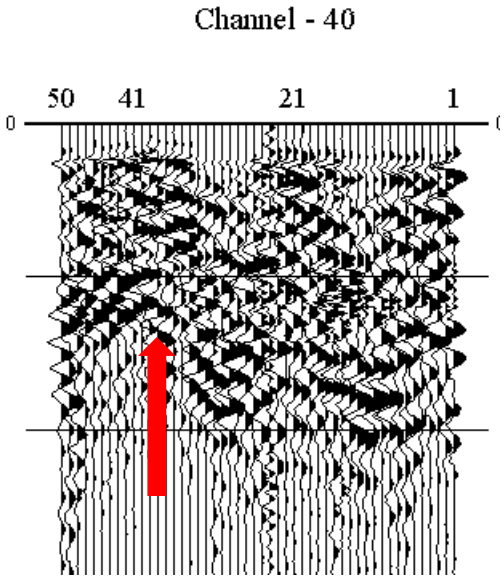
Hyperbolic/Reverse Move-Out Events

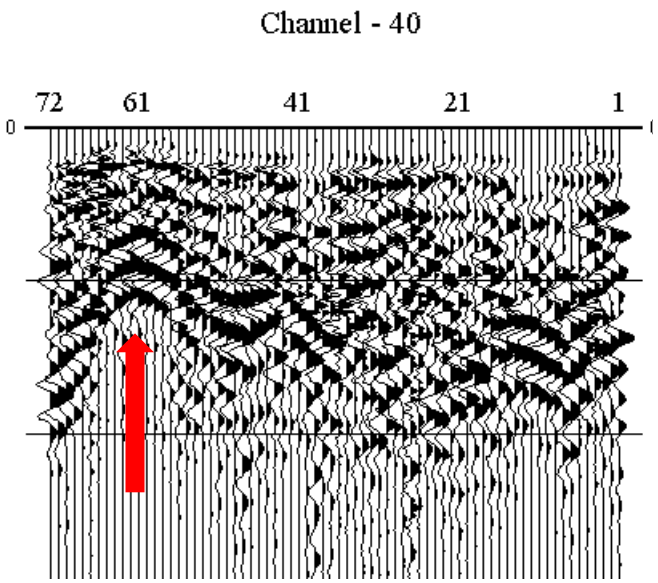


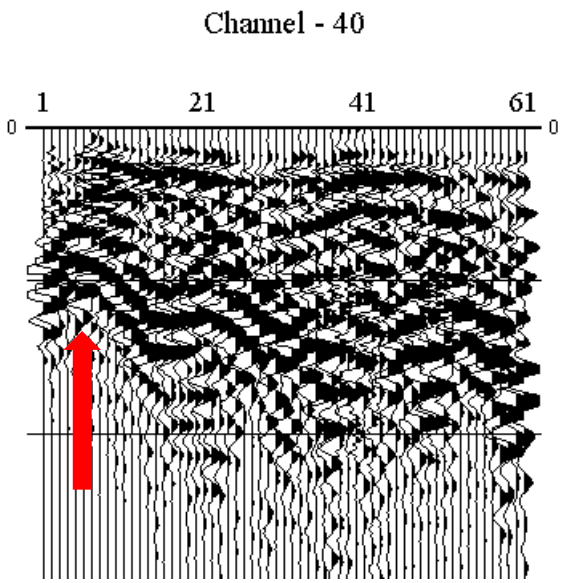
Hyperbolic/Reverse Move-Out Events



…and Surface Waves



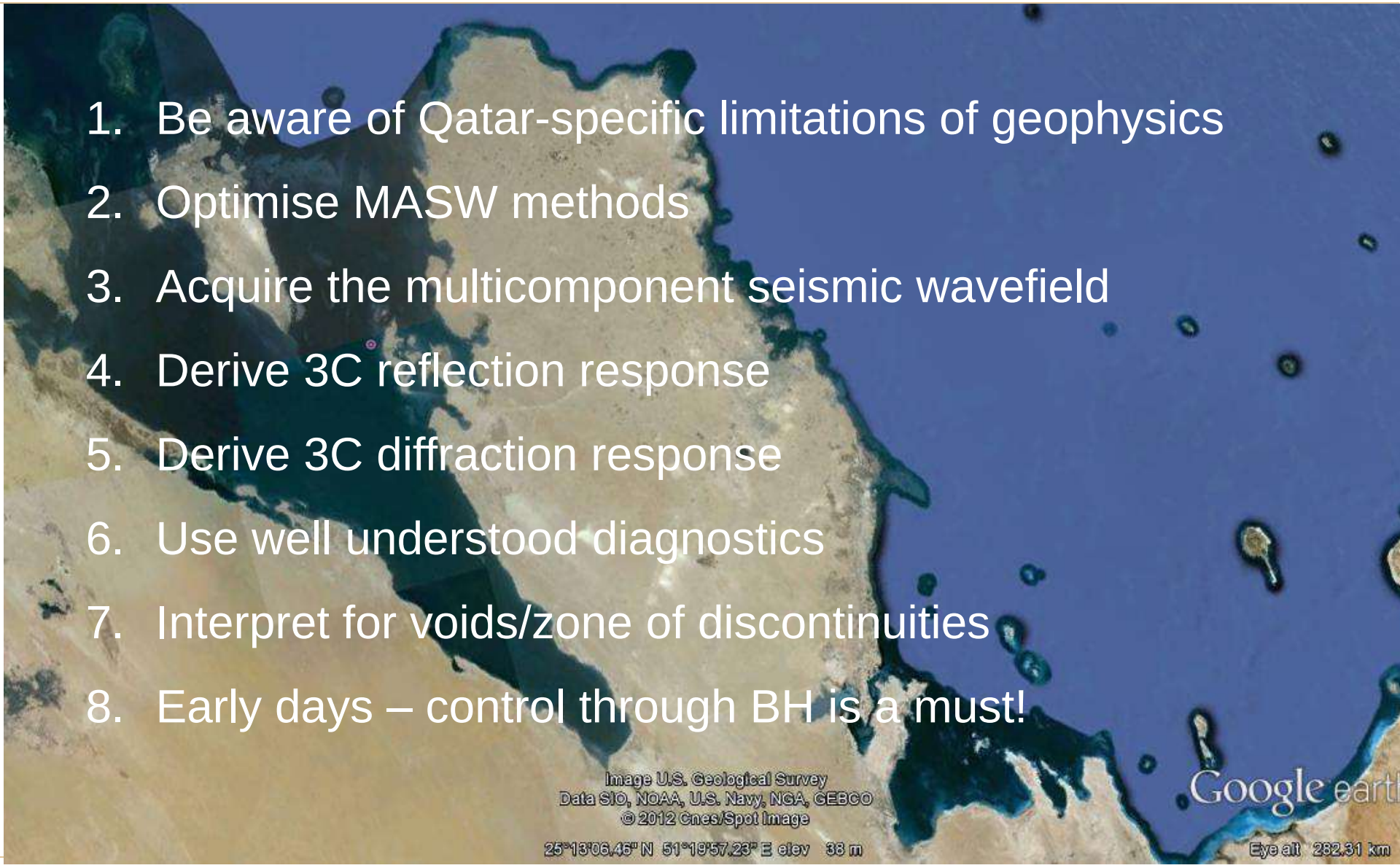




Tampa Bay Crosstown Expressway, April 13 2004

- Pier 97 collapse
- 3 m karst feature
- $350M project
- $100M fix

Possible Investigation Strategy for Qatar




Thank You