Seismic exploration of shallow cover

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with

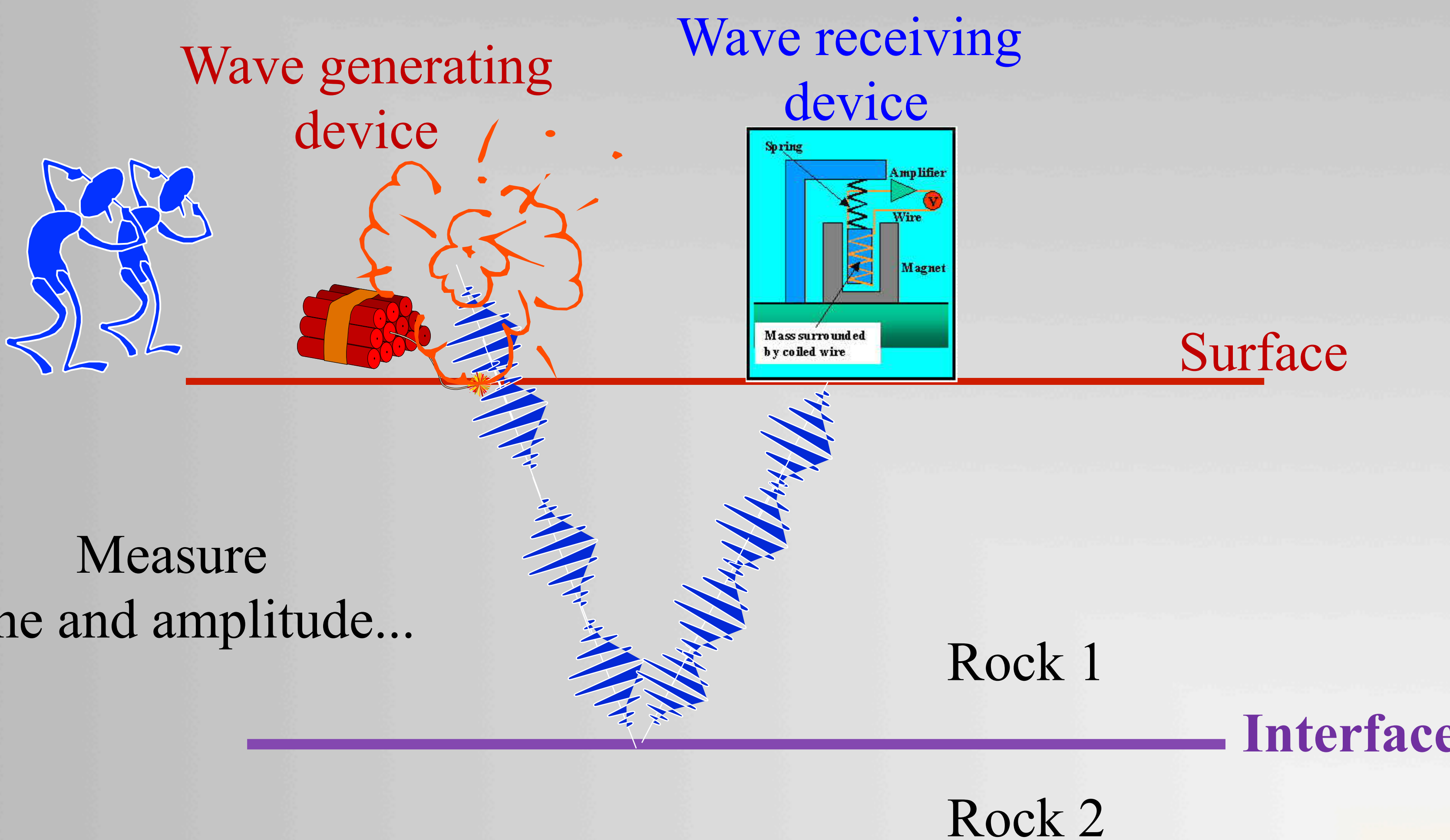
Contribution from

Researchers from the Department of Exploration Geophysics

and HiSeis Pty Ltd

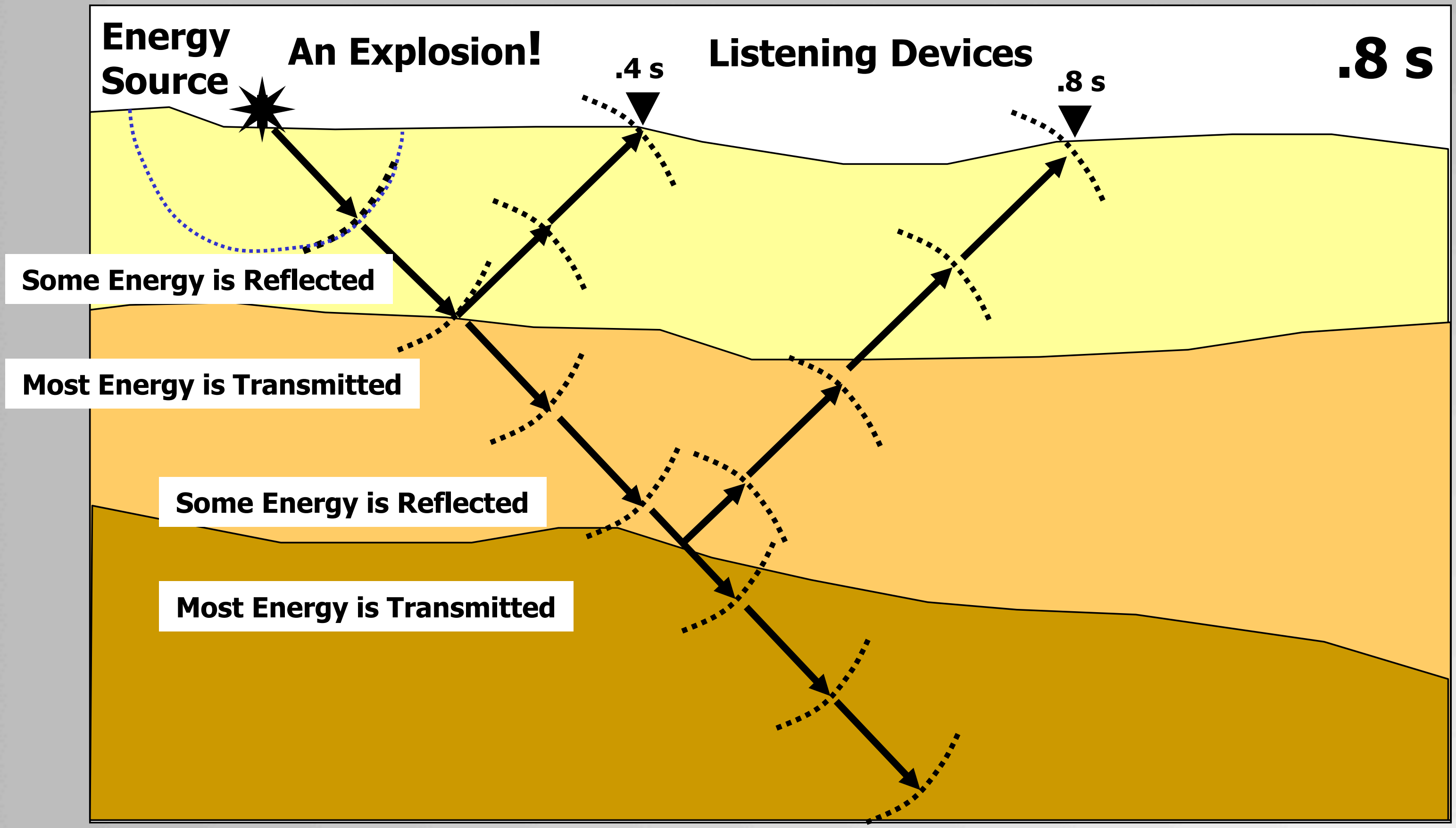
UNCOVER, April 2-3, Adelaide

Seismic methods – how does it work



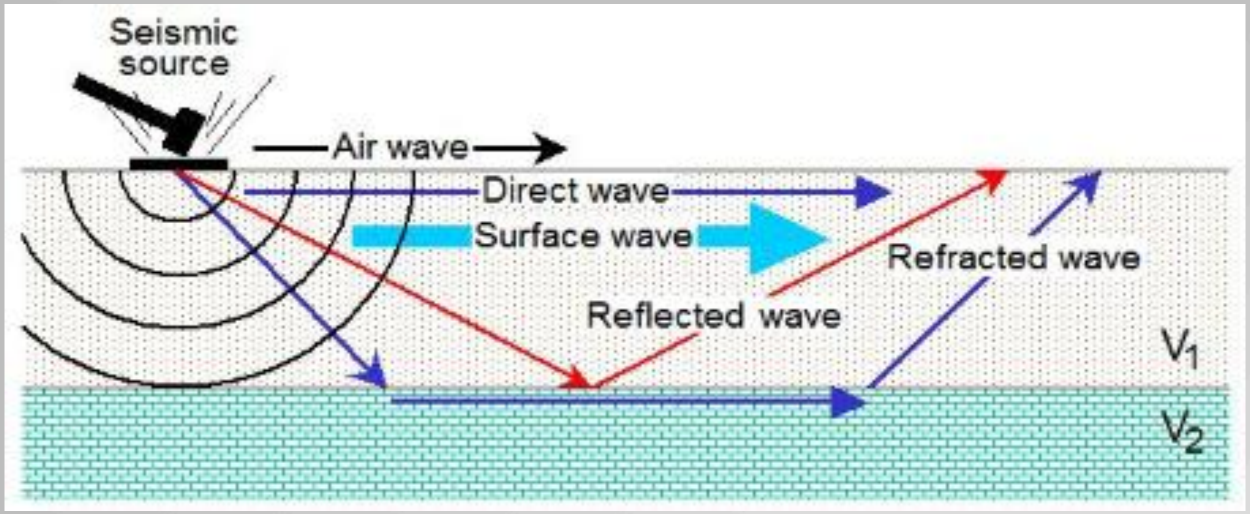
Measure
Time and amplitude...

Seismic reflection methods



Courtesy of ExxonMobil

Wave types generated by a source



$$V = \sqrt{\frac{M}{\rho}}$$

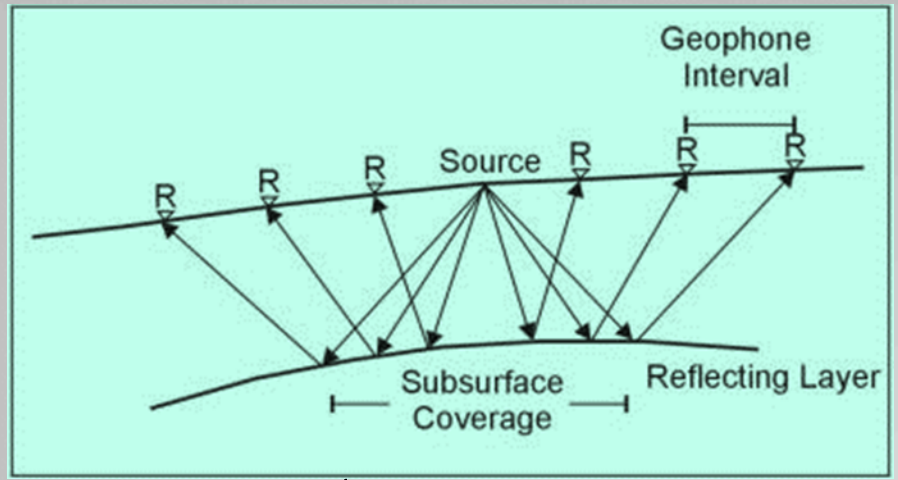
$$V_p = \sqrt{\frac{K + \frac{4}{3}\mu}{\rho}}$$

$$V_R \sim 0.9 V_S$$

$$V_s = \sqrt{\frac{\mu}{\rho}}$$

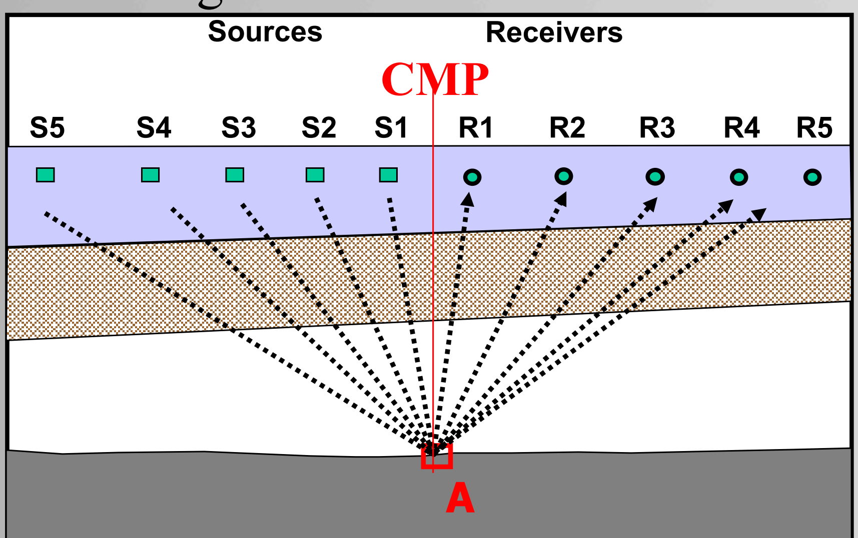
Modified from: www.google.com.au/search?q=seismic+reflection+method&rlz

Seismic reflection methods (CMP)



Common shot gather

Common mid-point gather



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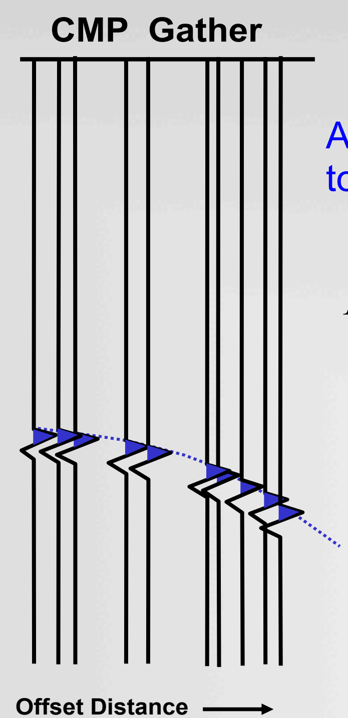
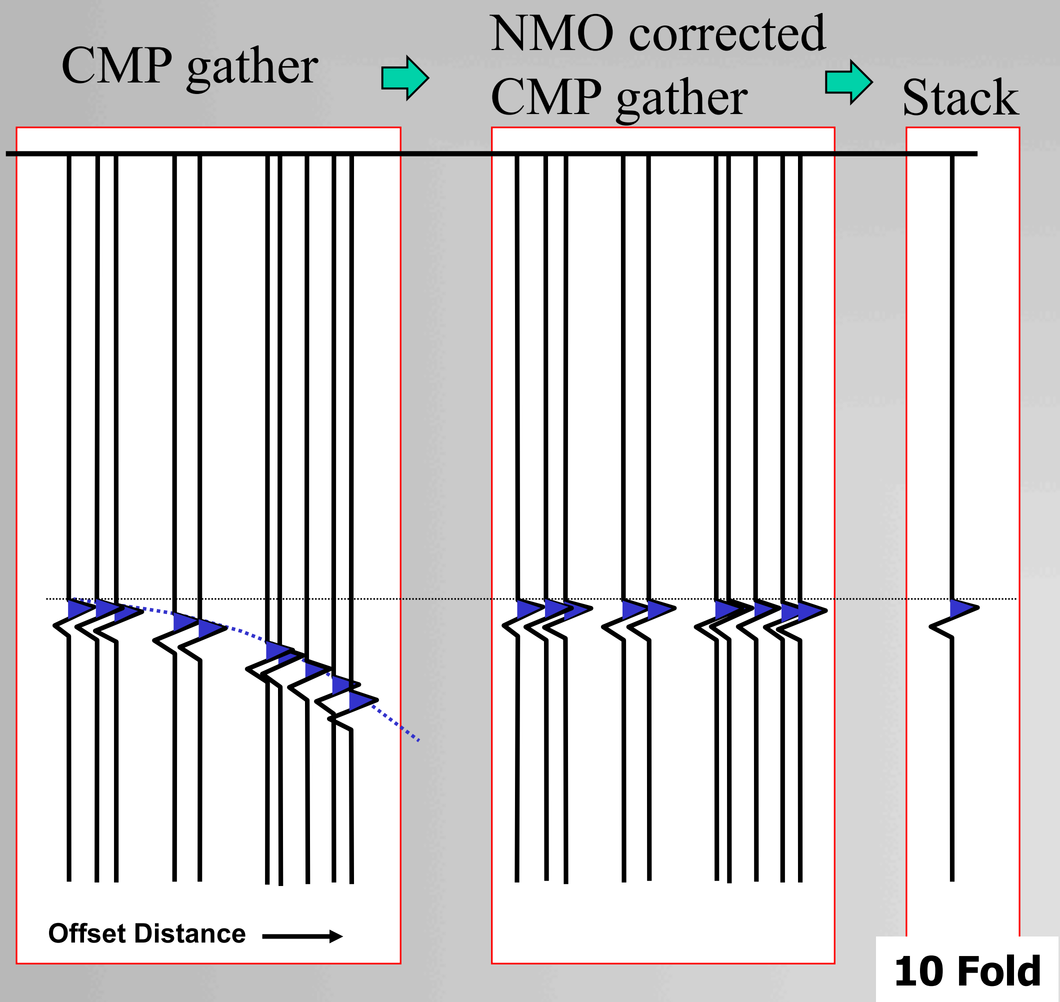


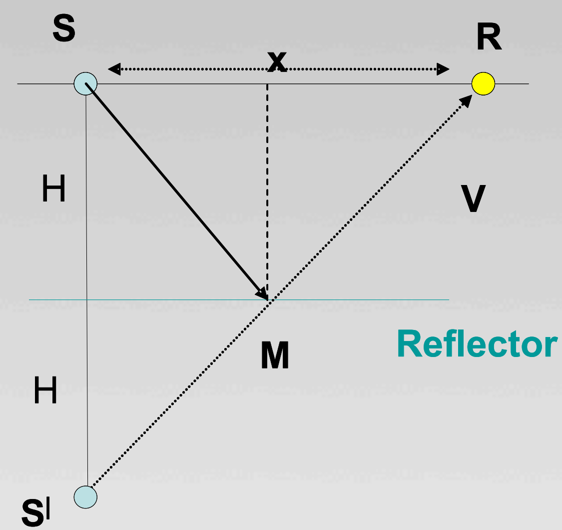
Amplitude is proportional to Reflection Coefficient (R)

$$R = \frac{Z_2 - Z_1}{Z_2 + Z_1}; \quad Z = V \cdot \rho$$

The curvature of this hyperbola is a function of $V_{average}$ to A

Seismic reflection stack (image)





$$T = \sqrt{\frac{x^2}{V^2} + \frac{4H^2}{V^2}}$$

What can we “see” with seismic

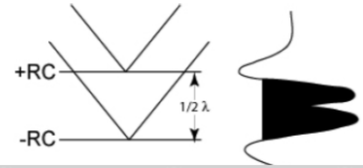
How small?

How deep?

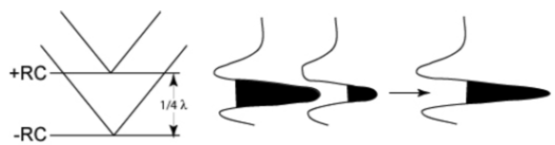
How complex?

Seismic resolution - “Vertical”

Beds thicker than 1/2 wavelength are interference free

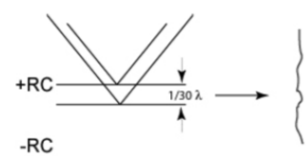


Maximum constructive interference occurs at 1/4 wavelength (tuning)



Amplitude decreases between 1/4 and 1/8 wavelength. Below 1/8 wavelength waveshape is indistinguishable from that produces by a single bed

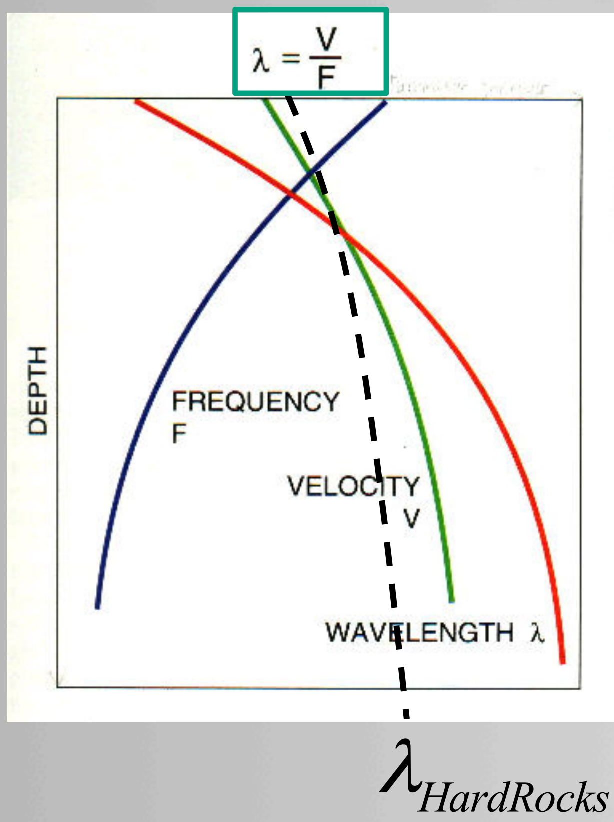
At about 1/30 λ interference destroys the reflection no matter how large the reflection coefficient



HR tuning thickness ~ 25m

Hard Rock Seismic

Seismic has much higher resolution and depth of penetration than any other geophysical technique



Hard rocks: High velocities → Long wavelet → Low resolution

Complex structures (high scattering but no absorption)

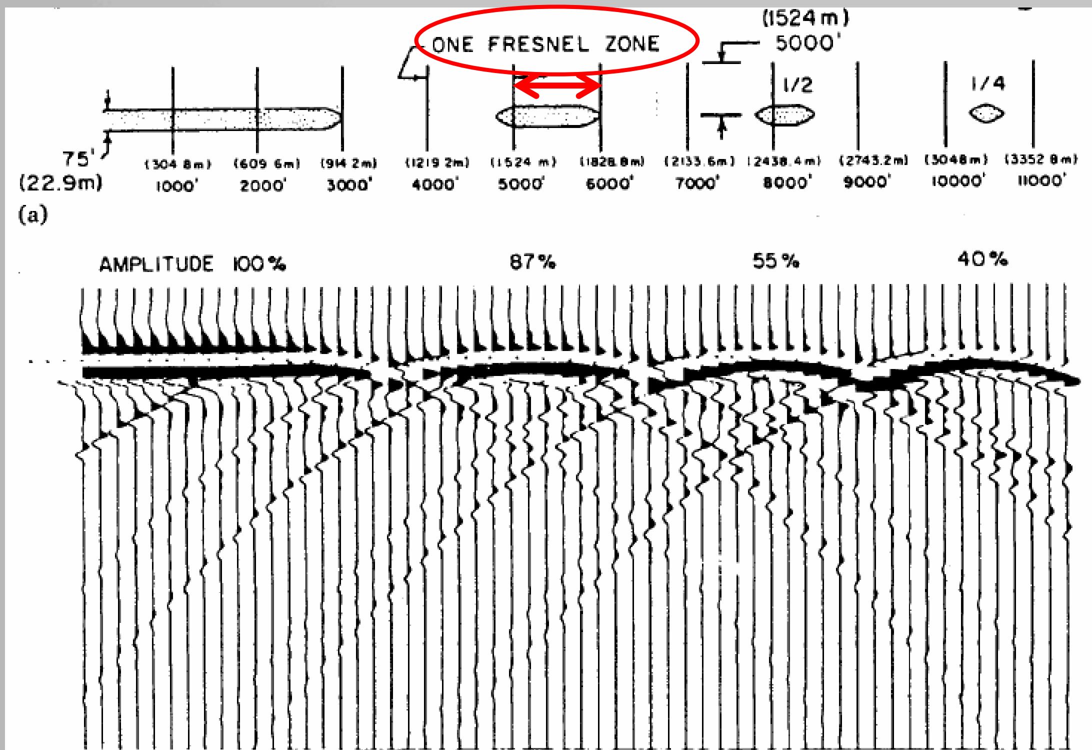
Discrete interfaces but with transitions (alteration zones)

No compaction "depth" trend

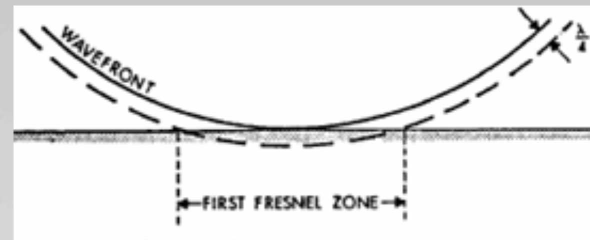
Modified from Brown, Alistair, 1999

What can we “see” with seismic

Seismic resolution - “Horizontal”



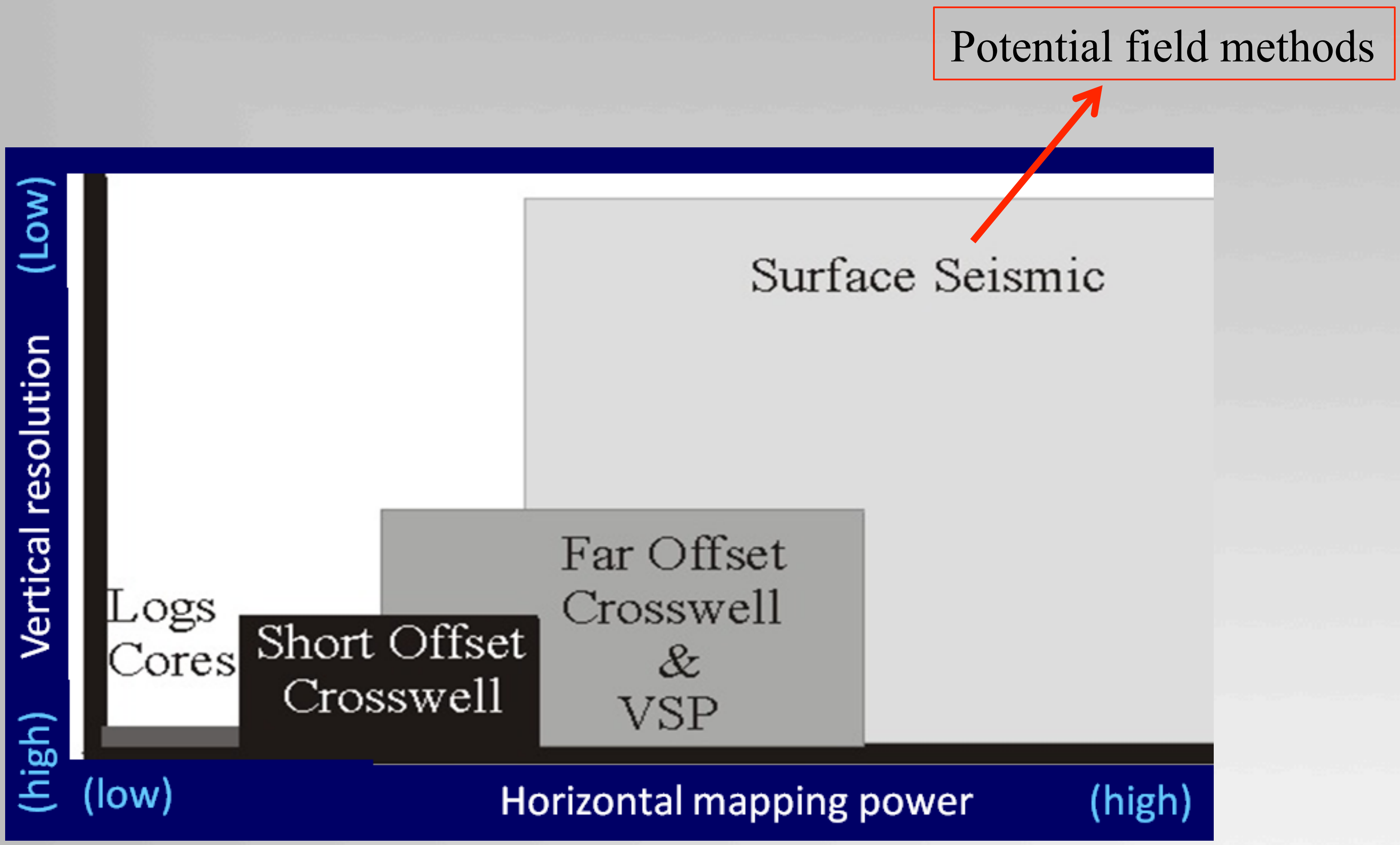
(b) Wave-theory model response for sandstone bodies of varying lateral extents illustrating significance of Fresnel zone size.



$$R_{Fresnel} = \left(\left(\frac{V}{2}\right) \cdot \left(\frac{t}{f}\right) \right)^{\frac{1}{2}}$$

HR Fresnel zone ~ 250m

Resolution power for different seismic methods



Seismic exploration of mineral resources

Seismic has unmatched penetration power and resolution

Can delineate very complex structures

Characterise the rock

Provide new drilling targets

It performs at all scales

Seismic for mineral exploration

Intrinsic difficulties

- Performance affected by heterogeneous regolith
- Excessively complex geology (scattering)
- Highly variable and/or weak, reflectivity
- Intrinsically low S/N ratio (scattering, excessive ambient noise)
- Access restrictions
- Other (more subjective)

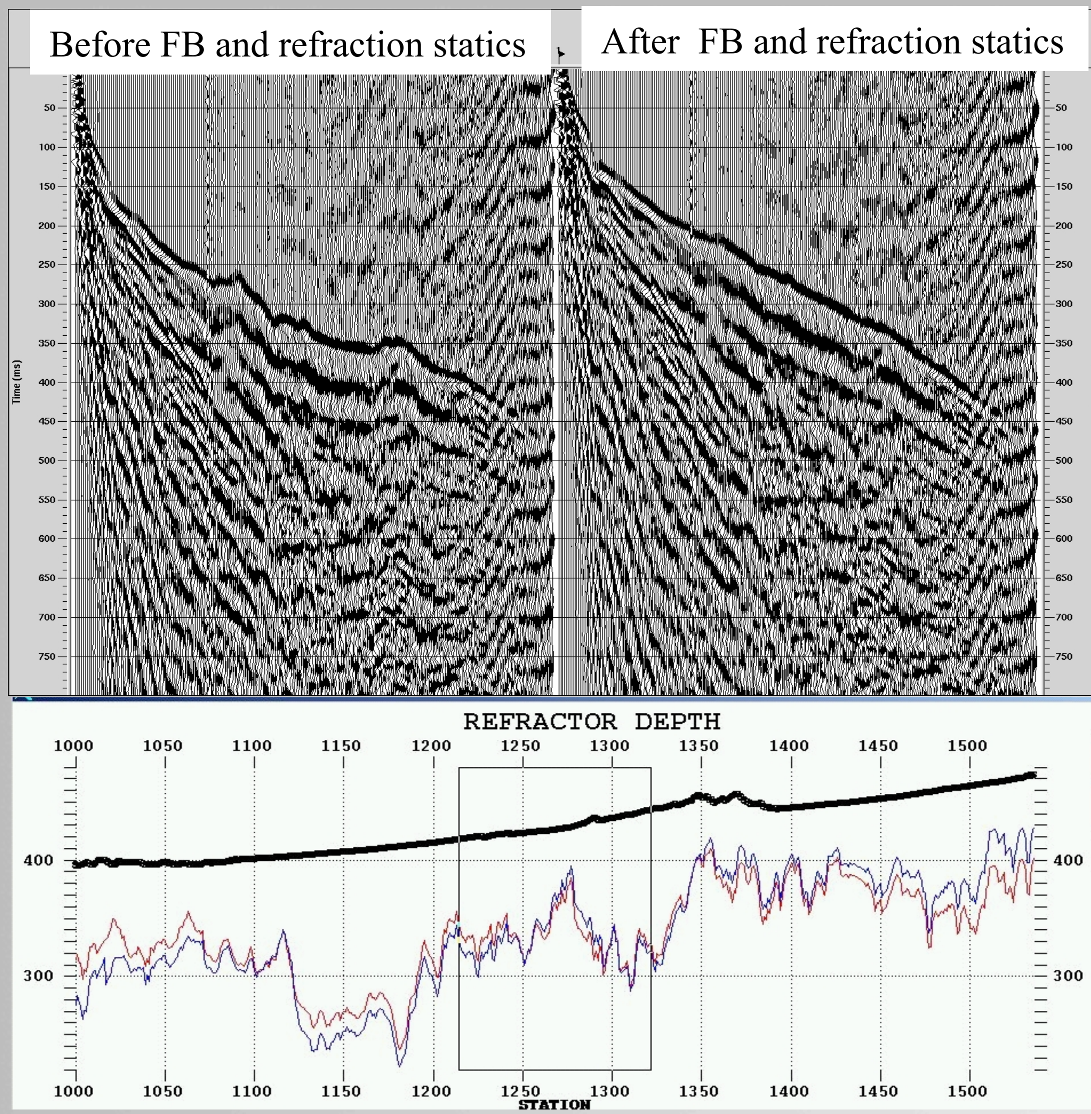
“Seismic cover”

- Cover = Regolith

- Regolith = most annoying slab of the rock that destructs our images

(and affects our profit)

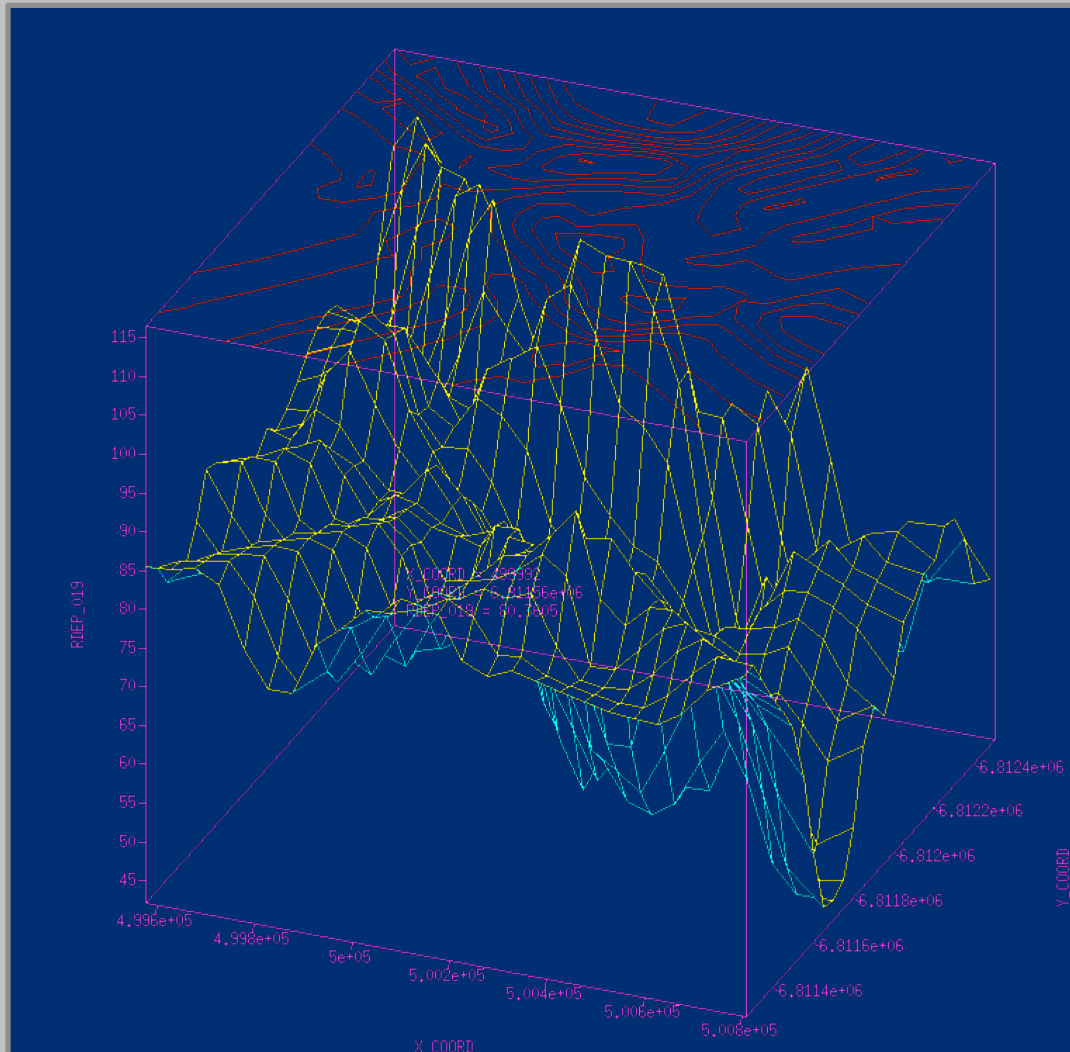
Typical regolith complexity – Yilgarn



Cover thickness 120 m +

Compute: Refraction statics, relative refractor depth

WA – North

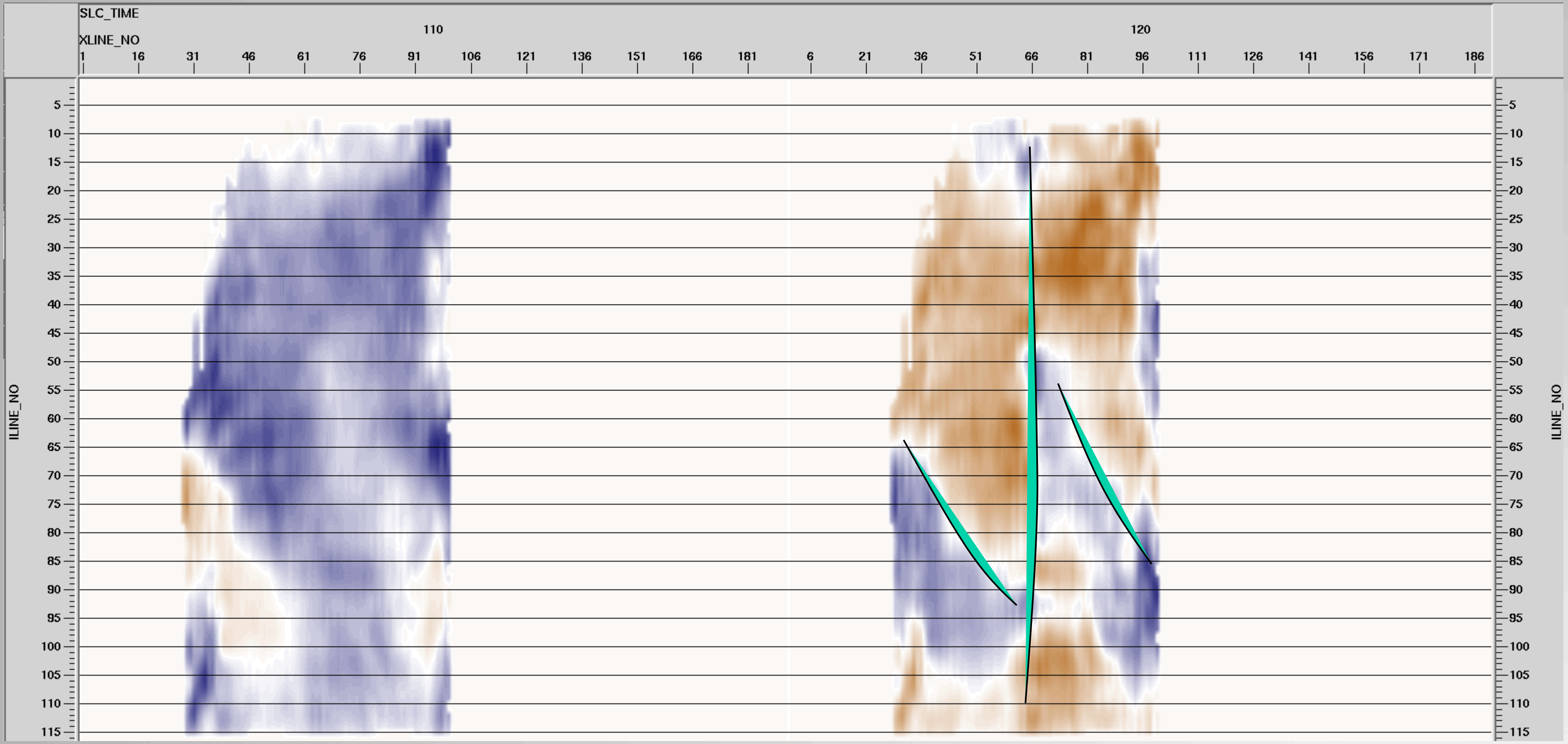


Cover
0-120 m

Golden Grove

Estimated regolith depth, also of interest to engineering

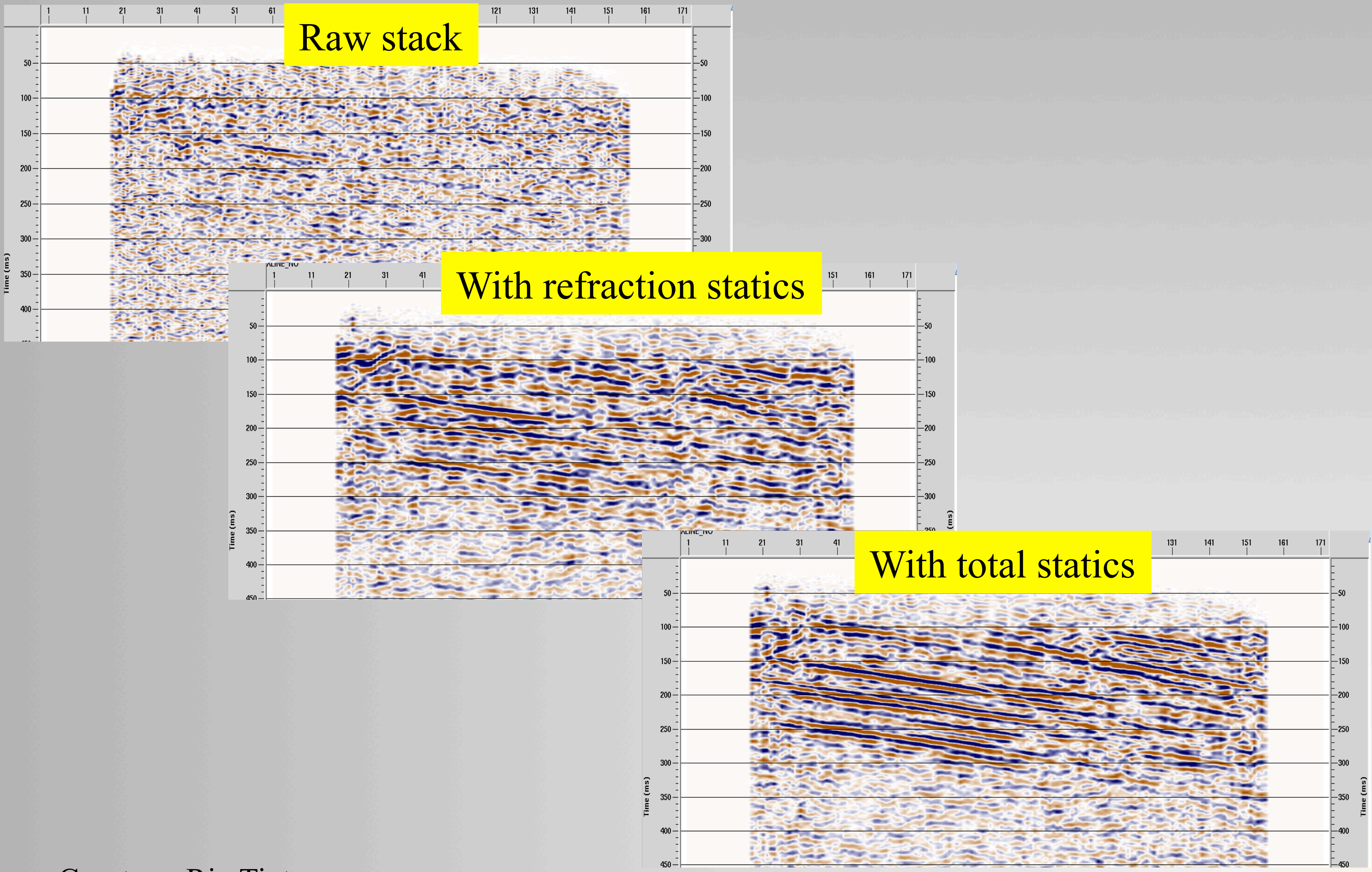
Alternative approach: time slices through 3D LMO cube



Get time delays …also fault traces at shallow depth

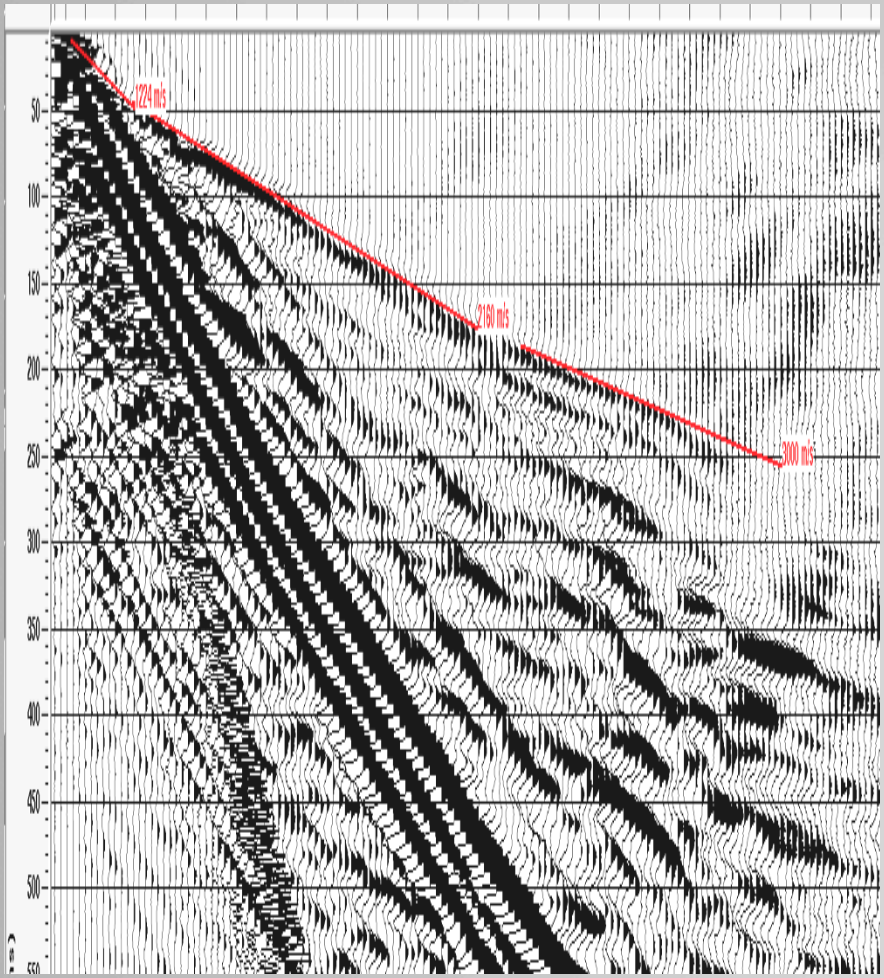
Courtesy, IGO, - Nickel, WA

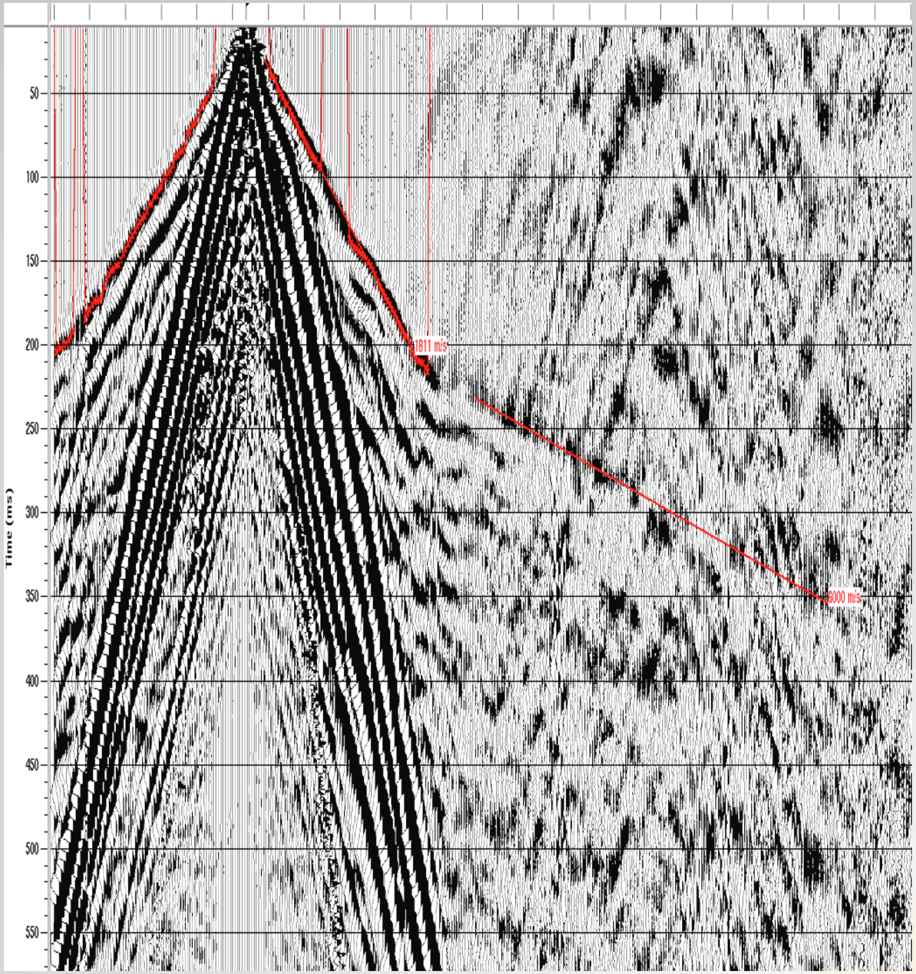
Effect of regolith on stack quality



Courtesy, Rio Tinto

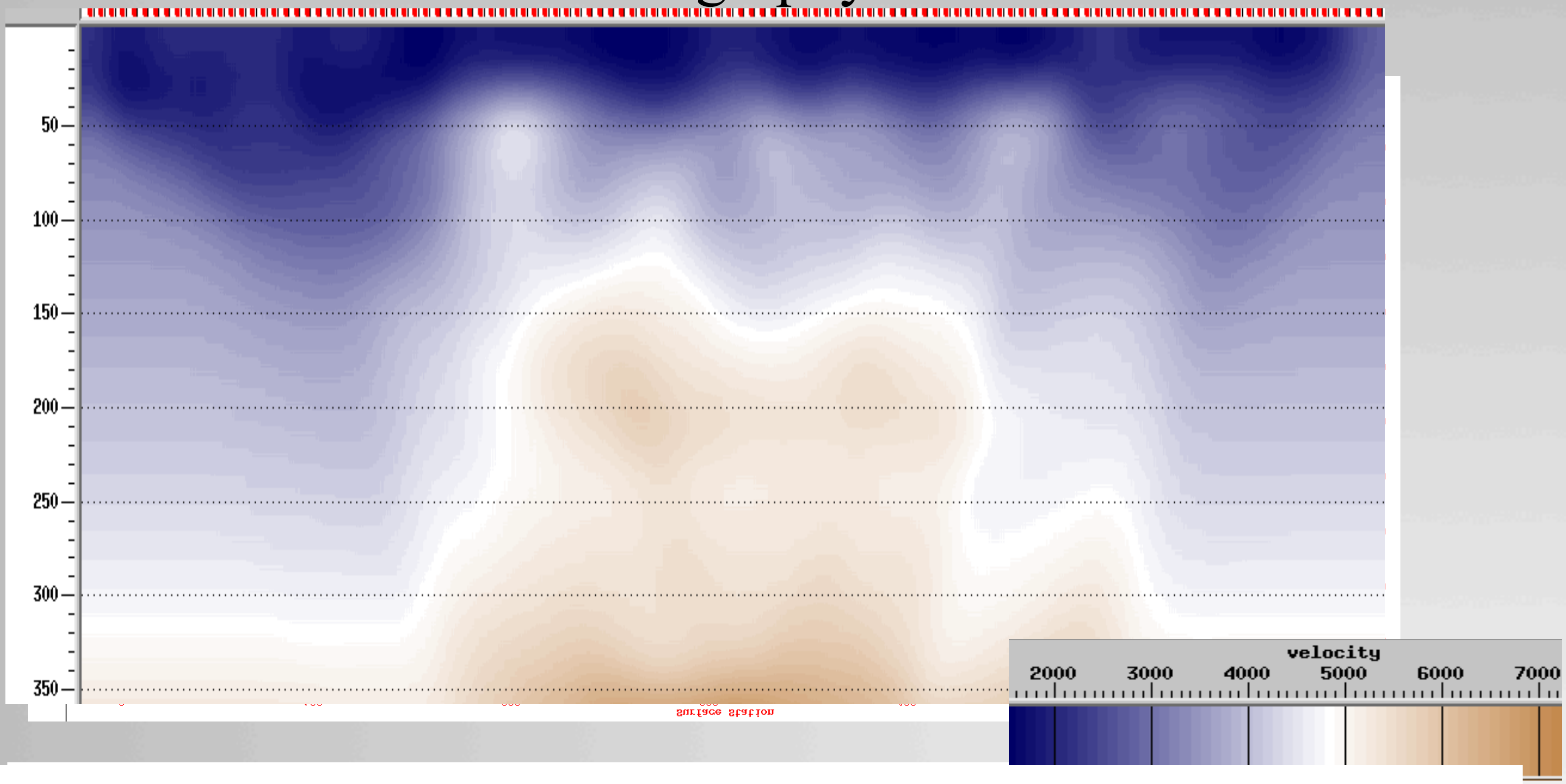
Excessively heterogeneous near surface





Depth to the fresh rock from FB

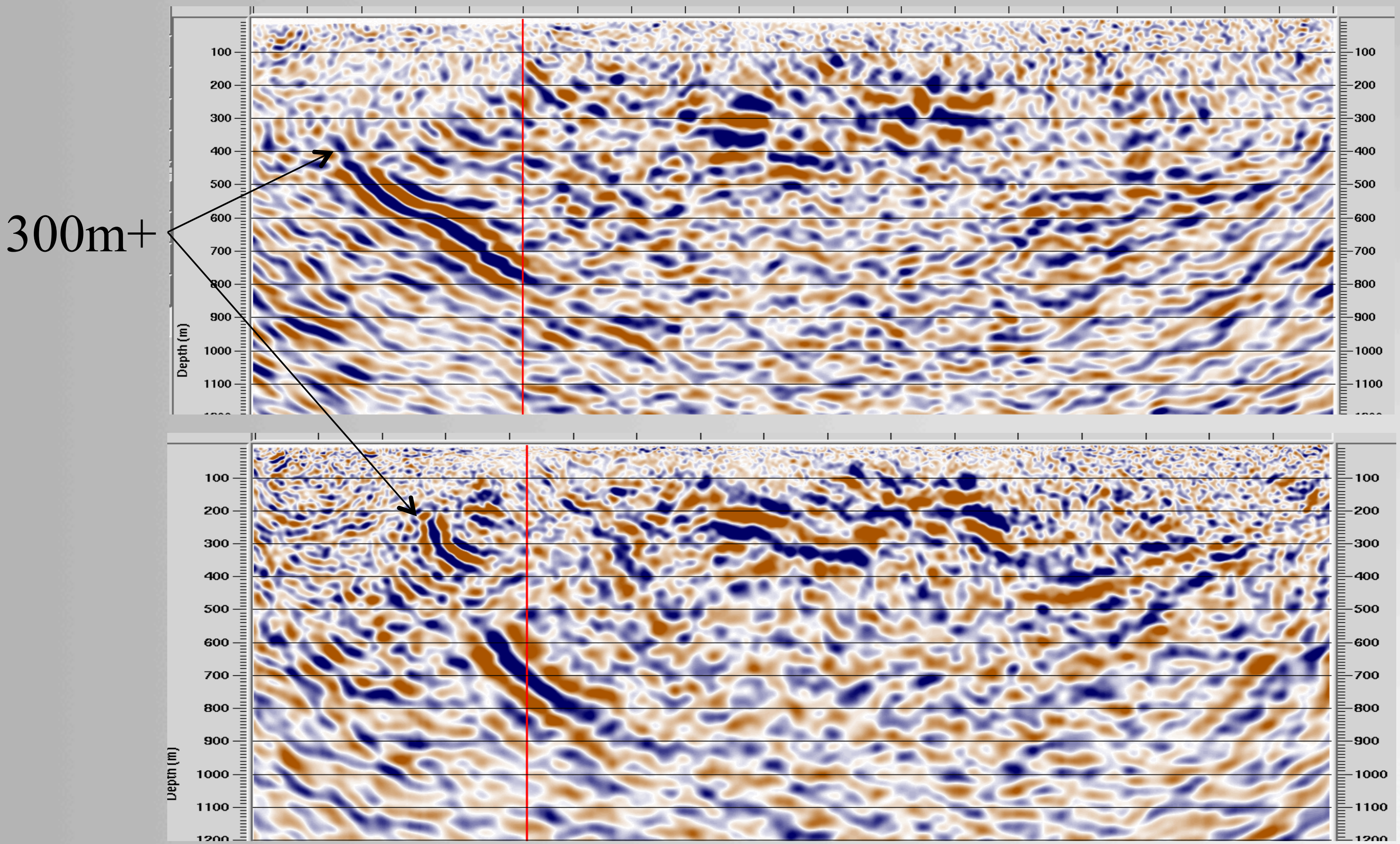
Tomography



Good quality tomographic inversion –for time delays and imaging

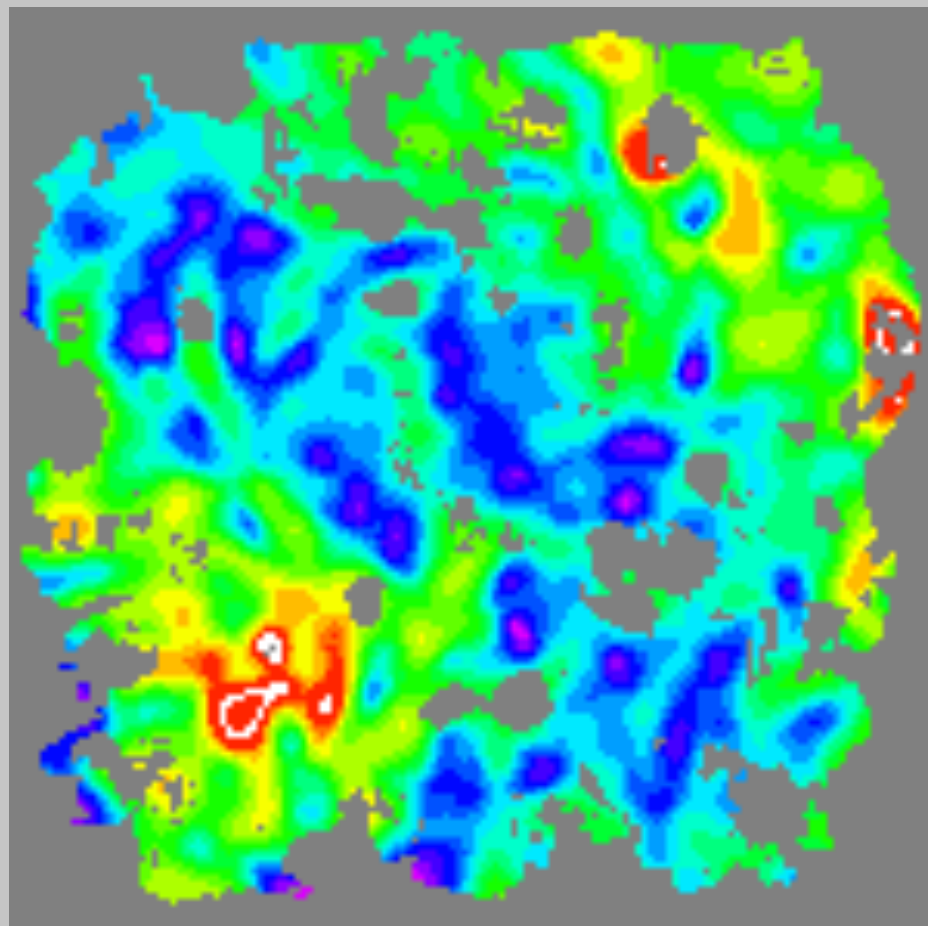
WA, NE, Courtesy, HiSeis

Standard and imaging with tomo-velocities

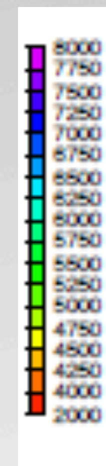


Courtesy, HiSeis

Kevitsa 3 tomography



Slope stability

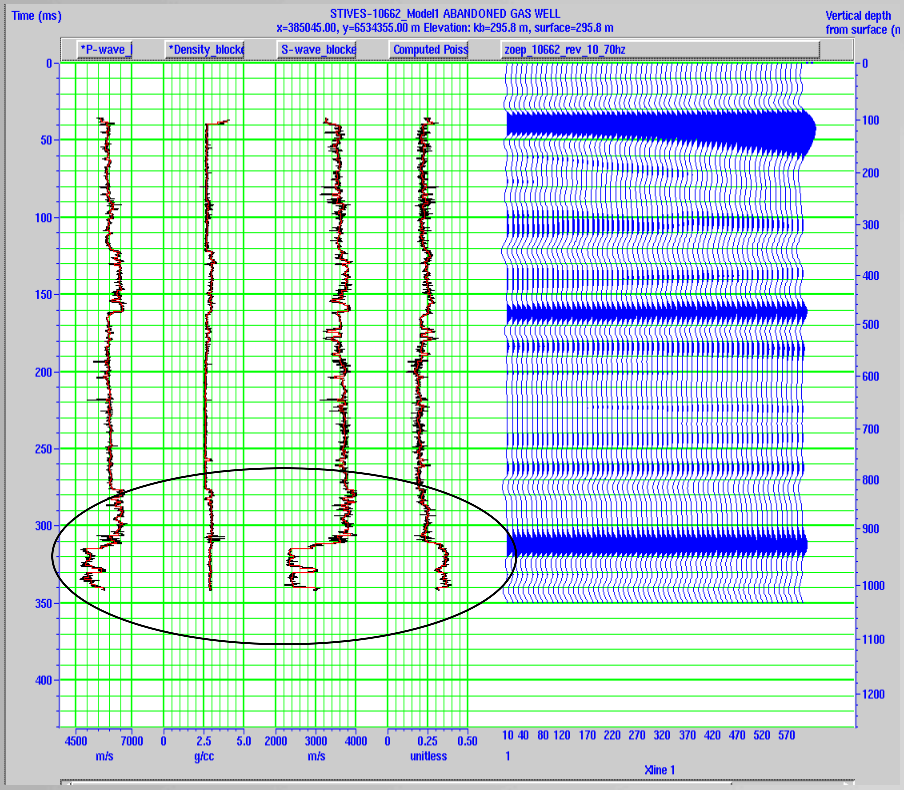


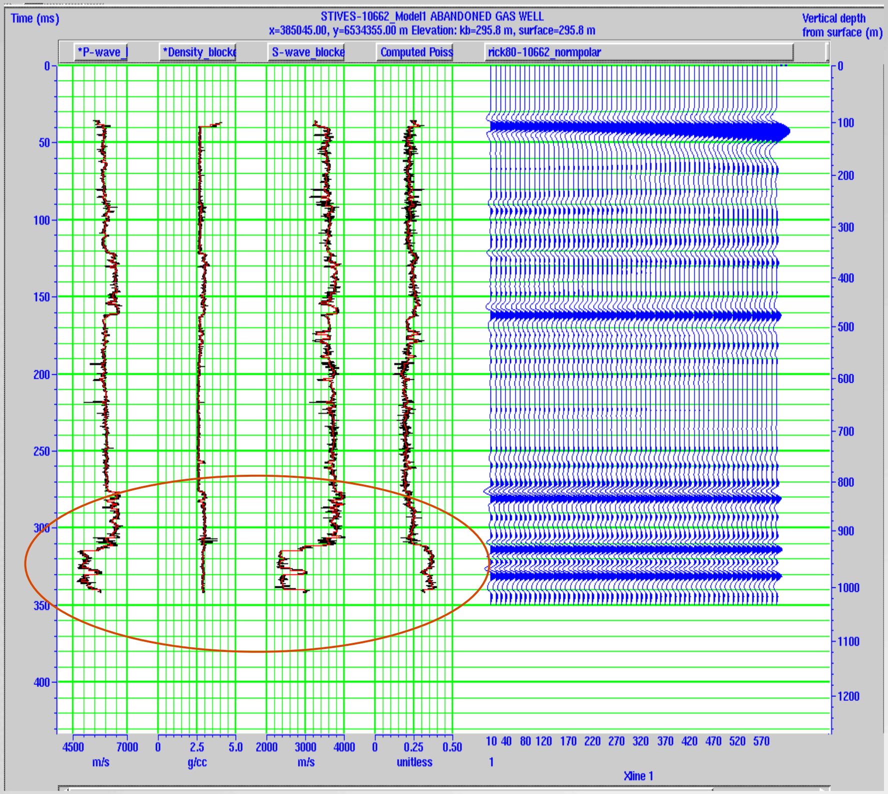
Courtesy, First Quantum

Effect of cover on resolution– simple modelling

Thick and absorptive

Thin and transmissive



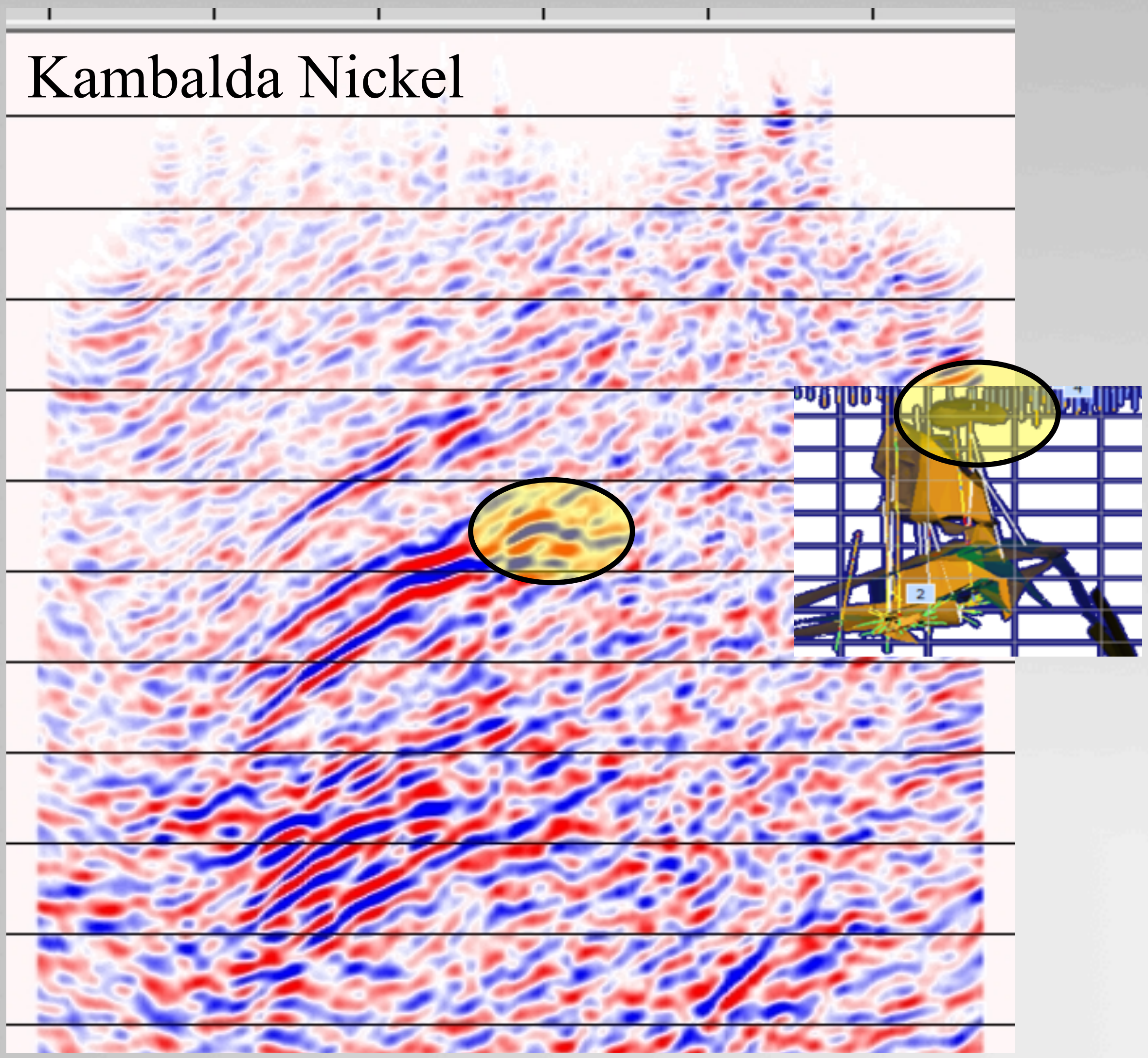


Trace the contact

Estimate reserves

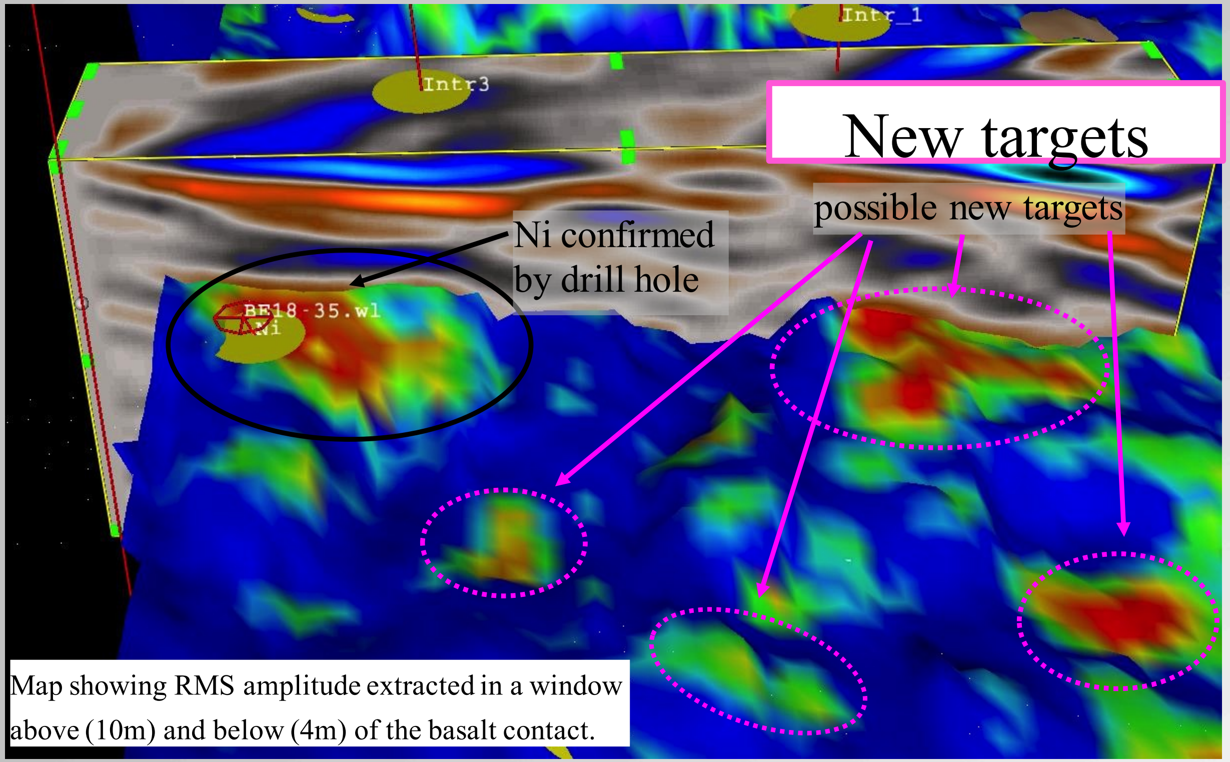
Courtesy, Gold Fields

Thin and transmissive cover delineate even very complex structures

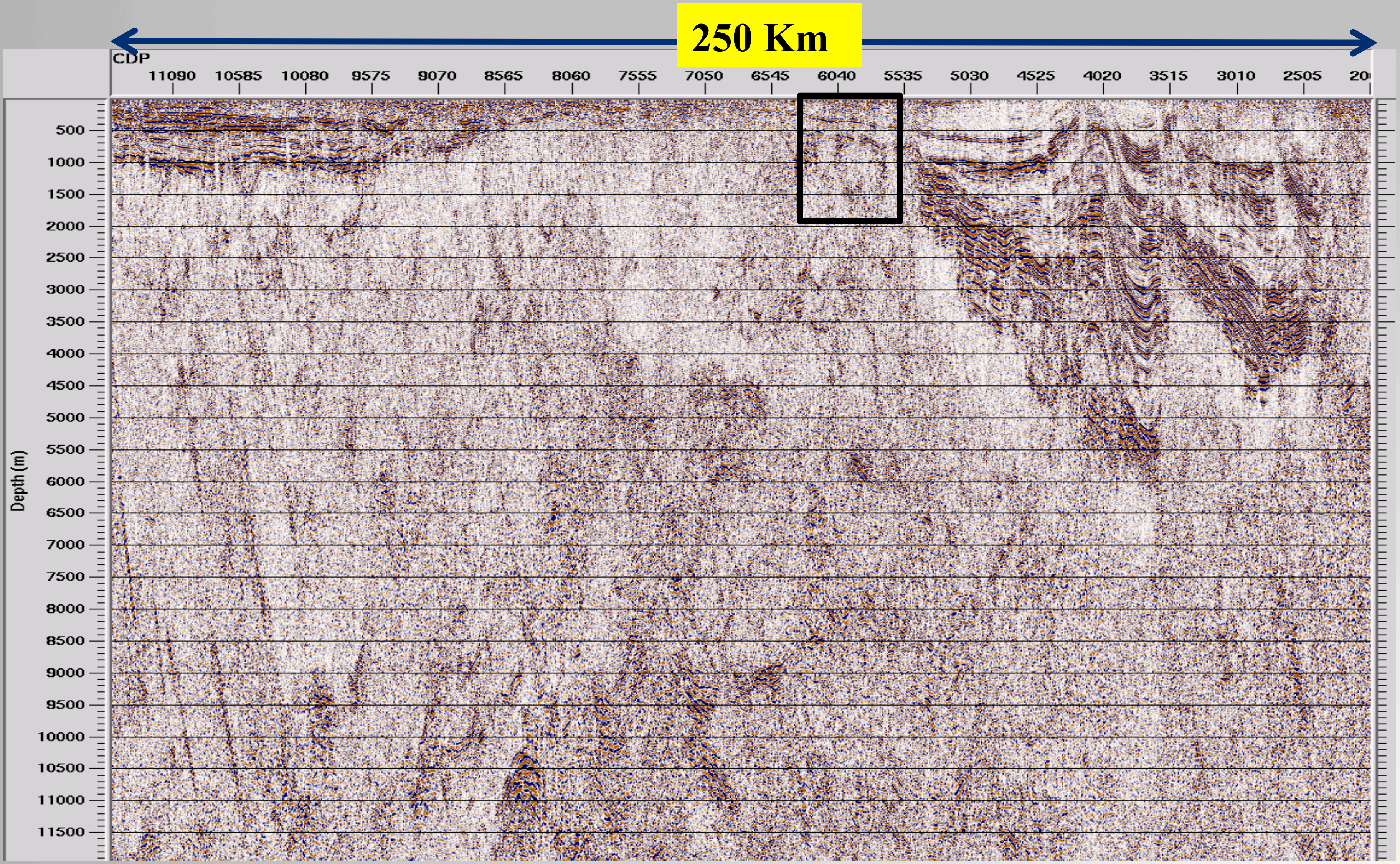


Courtesy, CSM

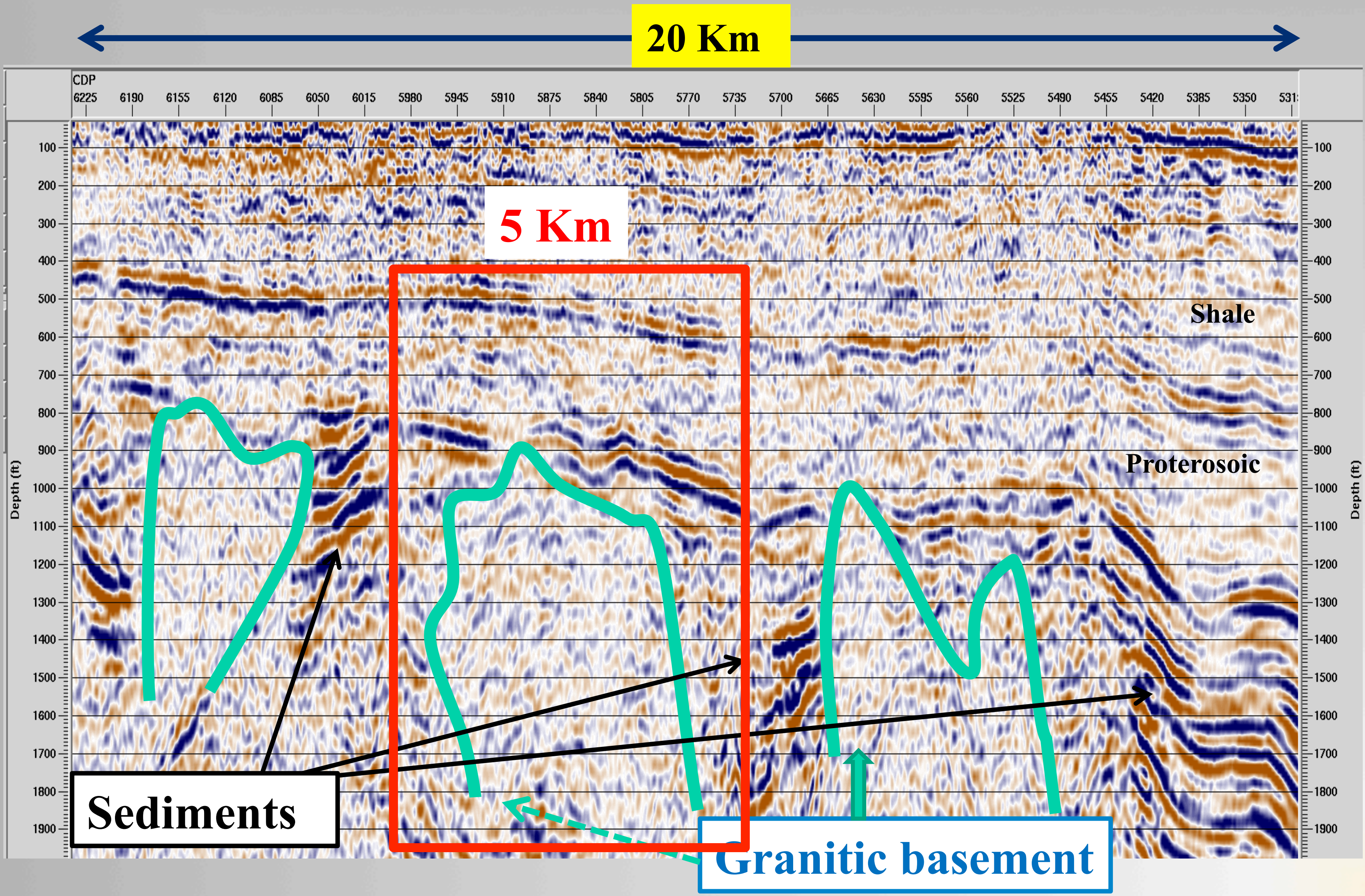
We can use seismic to propose new drilling targets



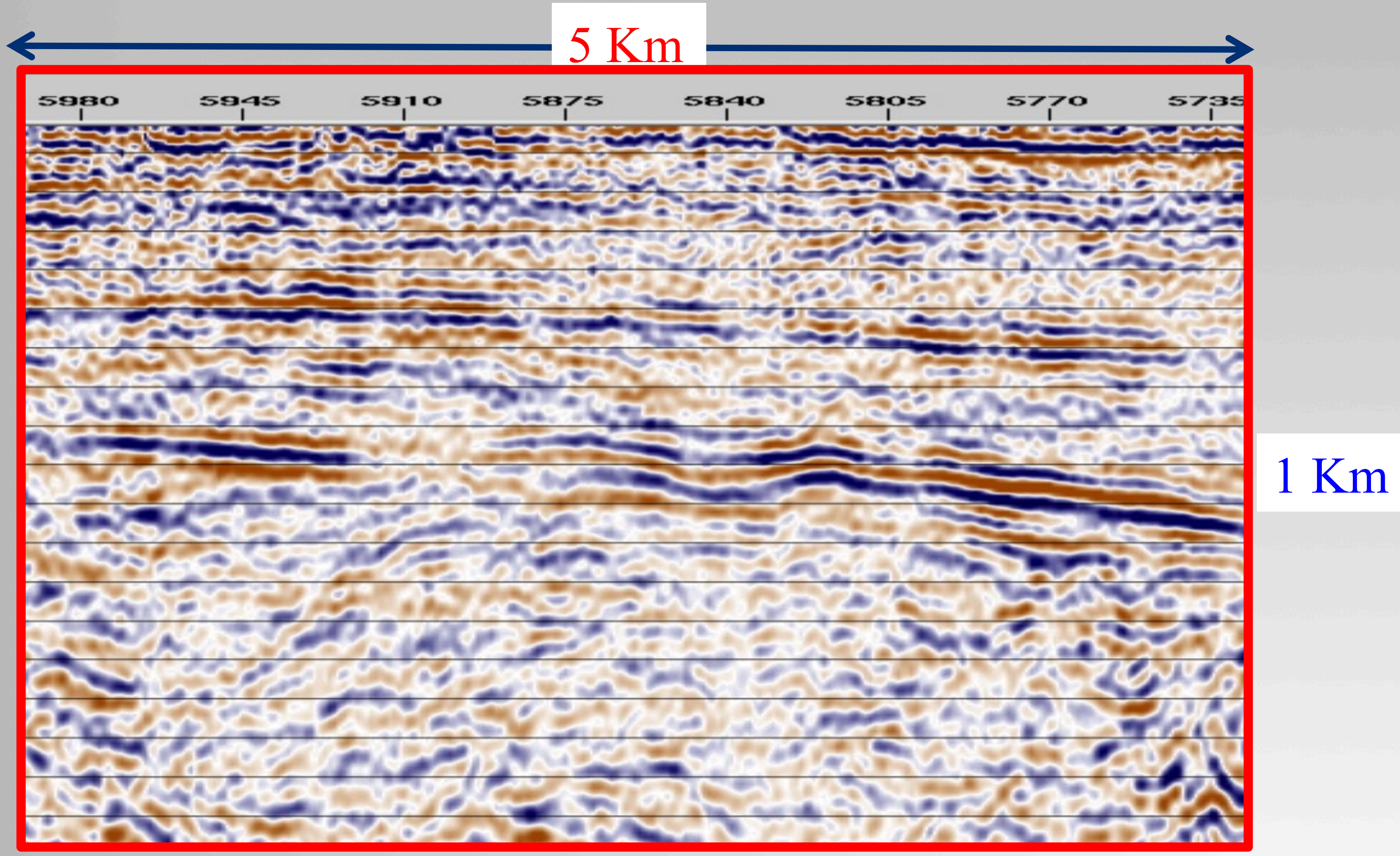
Thick cover- across Stuart shelf



Tenement scale



Prospect scale



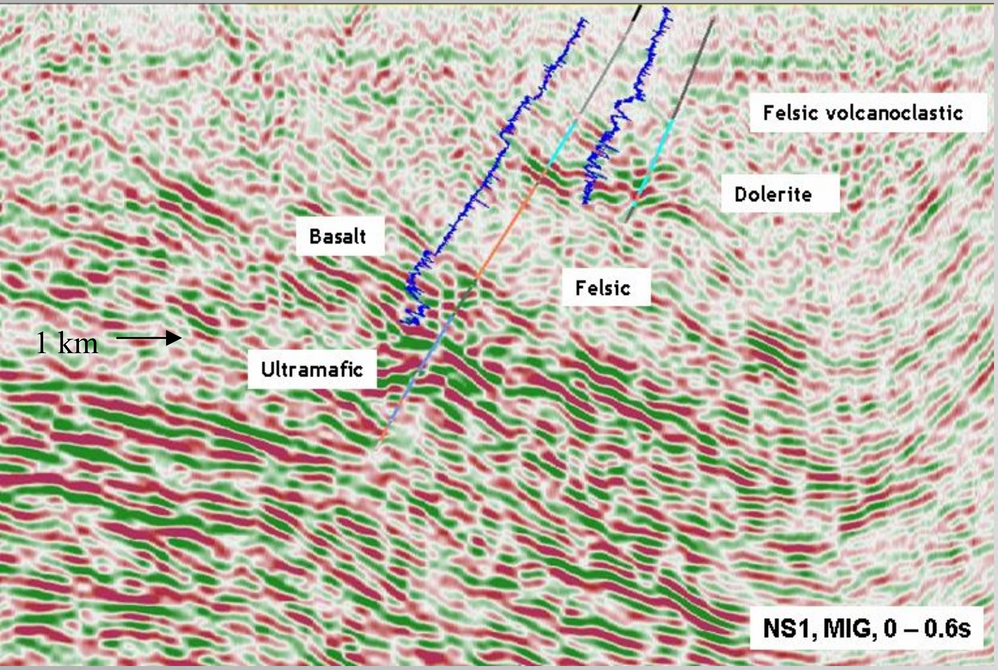
Is 5 km enough ?

Seismic exploration in practice: main issues

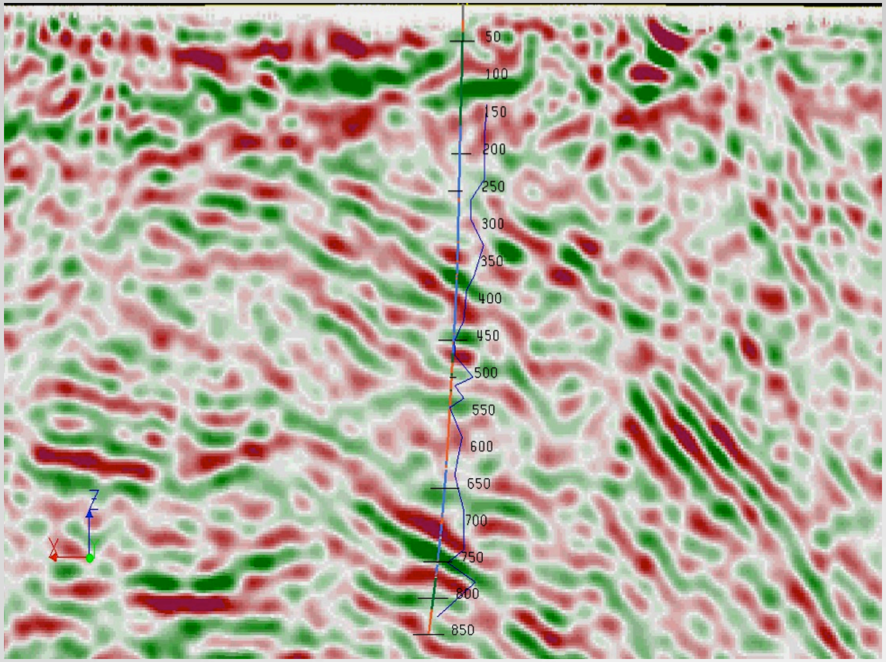
Lack of correlation of seismic images

Cost…particularly shallow targets

No correlation, no geological interpretation



1 km →



0.9 km

Courtesy of Gold fields

Cost of a seismic survey

Inversely proportional to the target depth

Directly proportional to the target complexity

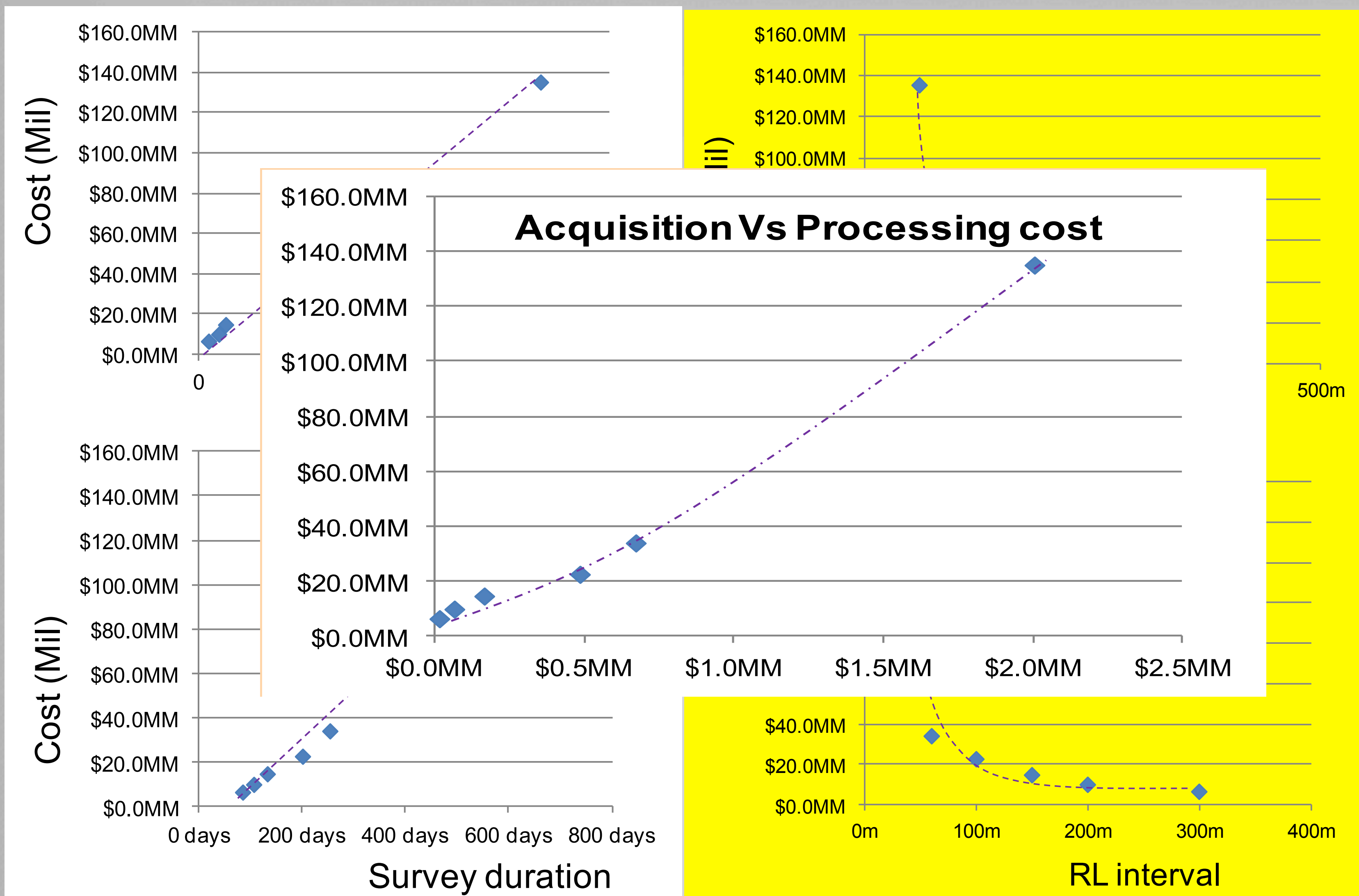
Affected by survey conditions (terrain and noise), survey design, technology (S,R), crew size, survey size

3D seismic cost crude estimate

	3D area	target depth(M)	Cost/Km^2	S/R-density/Km^2
Oil	> 100 Km^2	> 1500	\$80,000 \$60,000 \$30,000	80 60 20
	20-25 Km^2	$\leq$ 1000	\$100,000 \$120,000 \$130,000	100 150 200
Minerals	4-9 Km^2	500 - 1000	\$110,000 – 150,000	200 - 600
coal	0.5-2 Km^2	0 - 500	\$140,000 - \$1,000,000	500 - 1500

Modified from DETCRC, Caloundra

100 Km^2 3D seismic survey cost



DETCRC, Caloundra

Cost savings

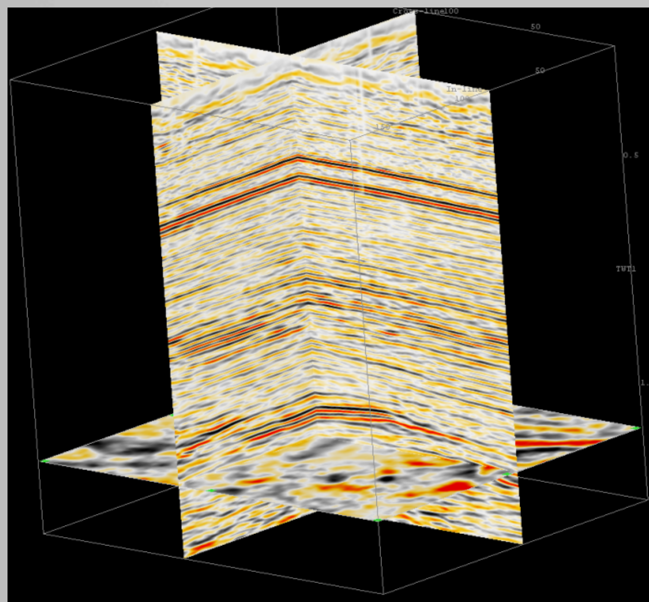
Crew size, equipment,

Selection of source, receiver

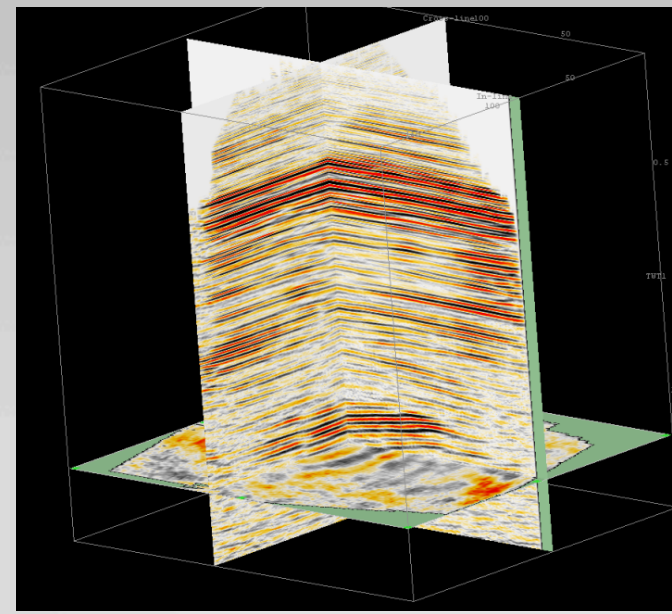
Survey design

Standard and alternative seismic

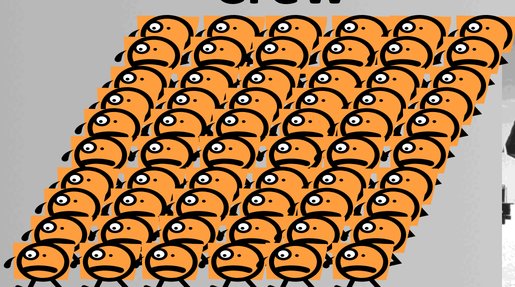
Standard



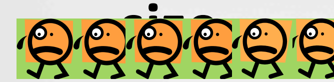
Alternative



Crew



Crew

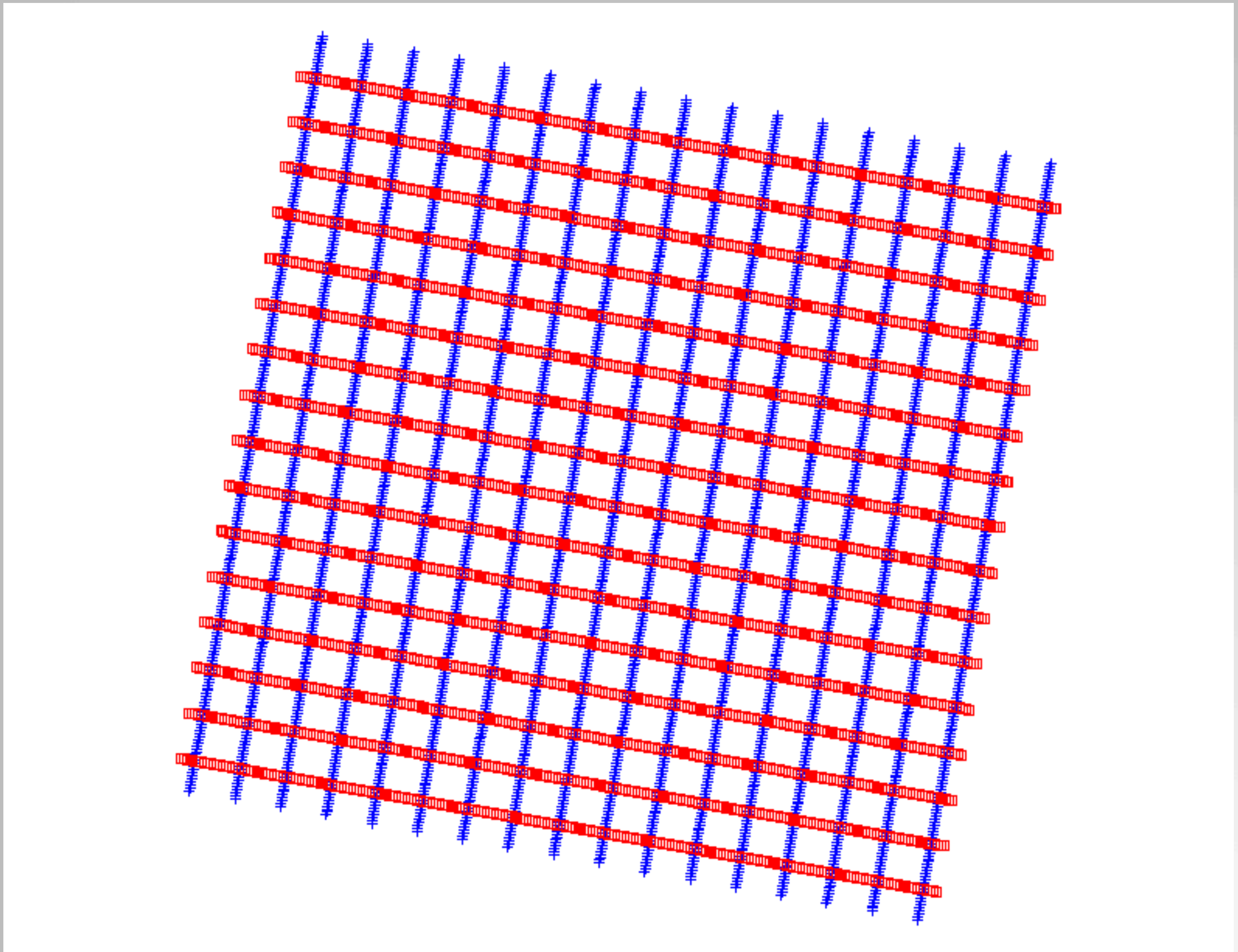


More alternative sources.....

Nomad 90 (Sercel)

Electrodynamics
hammer

Design - 25 Km^2 of Seismic



Survey statistic

Sources | Receivers | Marine | Project

Source Information

Source Lines:	16
Total Sources:	4000
Live Sources:	4000
Fired Sources:	0
Median Source Spacing:	20.00 m
Median Line Spacing:	300.00 m
Source Order Length:	Not calculated
Total Line Length:	79.68 km
Source Point Density:	122.61 / sq. km

Bin Information

Bin Grid Area	24.90 sq. km
Bin Width	10.00 m
Bin Height	10.00 m
Bin Inline Extent	4.99 km
Bin Crossline Extent	4.99 km

Receiver Information

Receiver Lines:	17
Total Receivers:	4250
Live Receivers:	4250
Unused Receivers:	4250
Median Rec Spacing:	20.00 m
Median Line Spacing:	300.00 m
Total Line Length:	84.66 km
Receiver Density:	130.27 / sq. km

Extent Definition

Currently Using: XY Extent

Area Extent: 32.62 sq. km

- (•) XY Extent
- ( ) User-Defined Extent
- ( ) Exclusion Zone Extent
- ( ) Bin Grid Extent — Default Bin Grid

[Calculate Density]

Target Parameters

Min Recoverable Freq	6
Max Recoverable Freq	100
Interval Velocity at Target	6000
Max Expected Dip (inline)	50
Max Expected Dip (crossline)	50
Horizon Time (ms)	1000
Nominal Desired Fold	16.709

Bin Size

Max Bin Size (inline dip)	19.581
Max Bin Size (xline dip)	19.581

Vertical Res: 15.96 m < Vr < 31.91 m

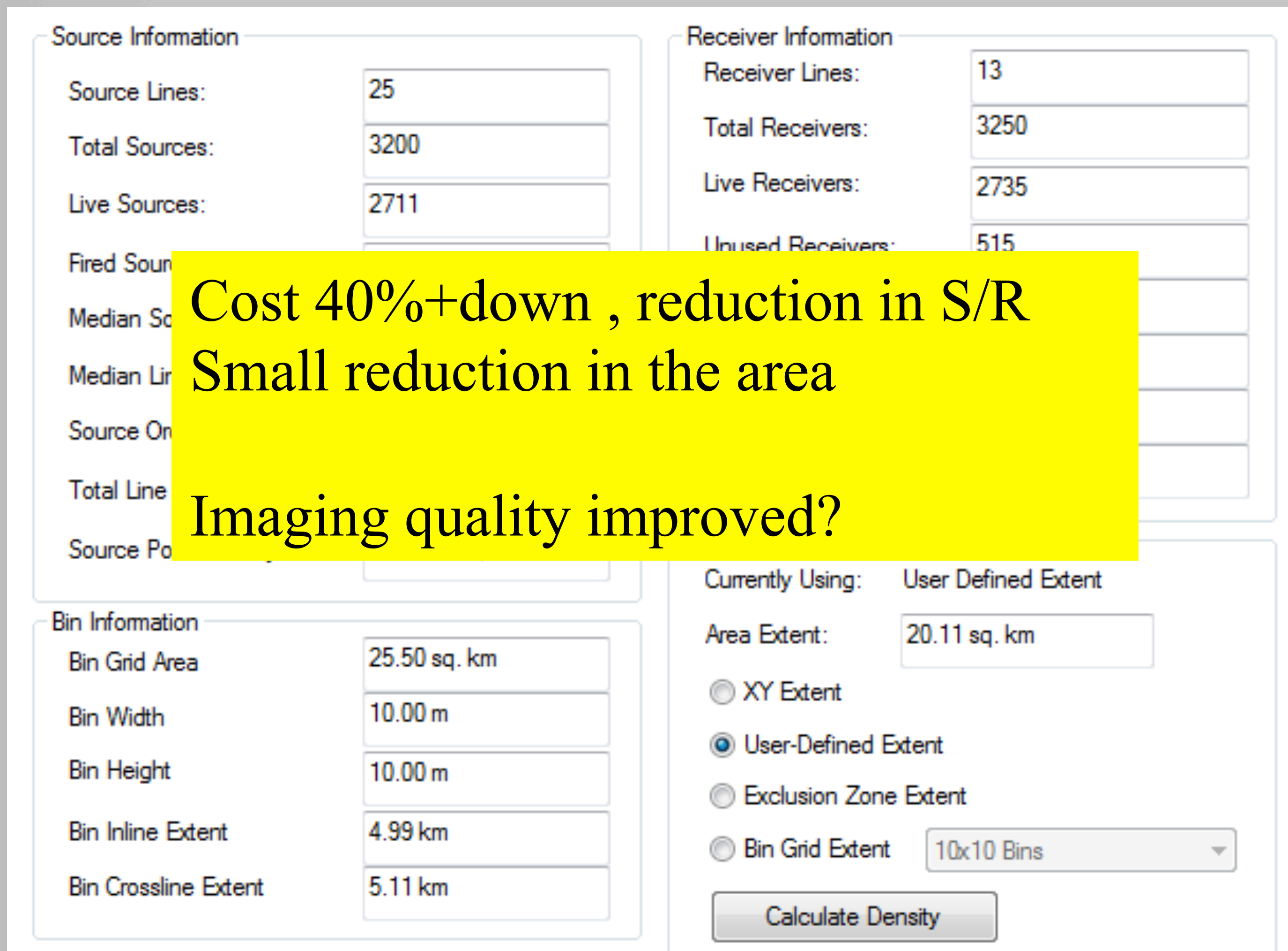
Lateral Res: 62.49 m < Lr < 124.99 m

Permitting Costs:	235525
Surveying Costs:	20188
Source Costs:	200000
Crew Costs:	700000
Equipment Costs:	100000
Clearing Costs:	100000
Processing Costs:	800000
Misc. Costs:	250000
Contingency Factor(%):	5
Total Cost:	2525998

Oil rate

Very high fold if all receivers active

Circular area

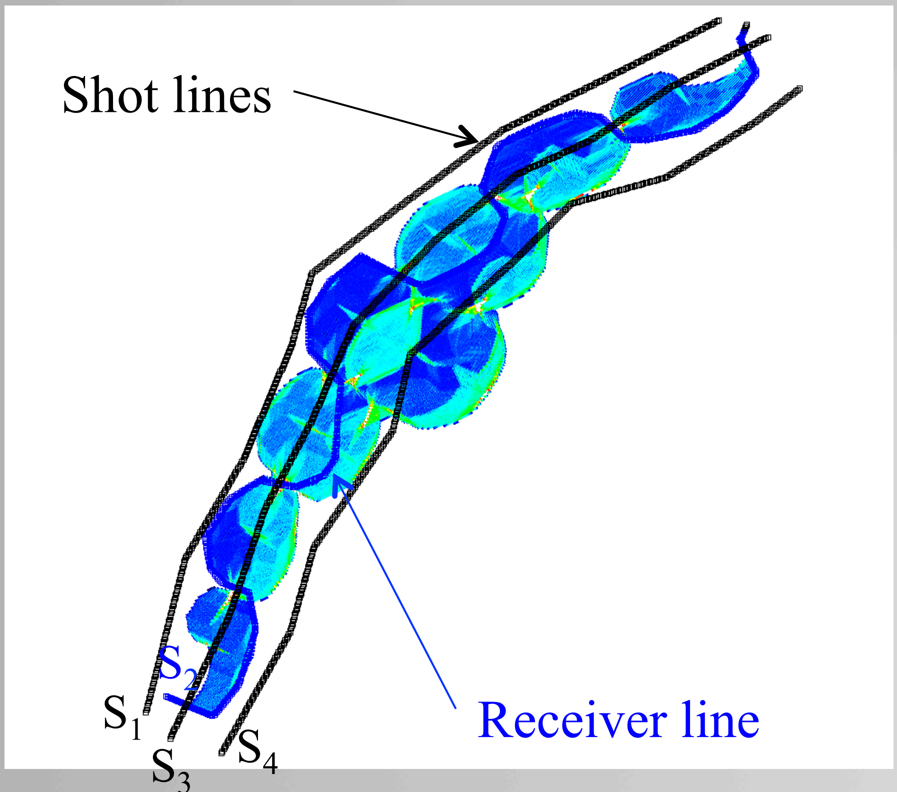


Cost 40%+down , reduction in S/R
Small reduction in the area

Imaging quality improved?

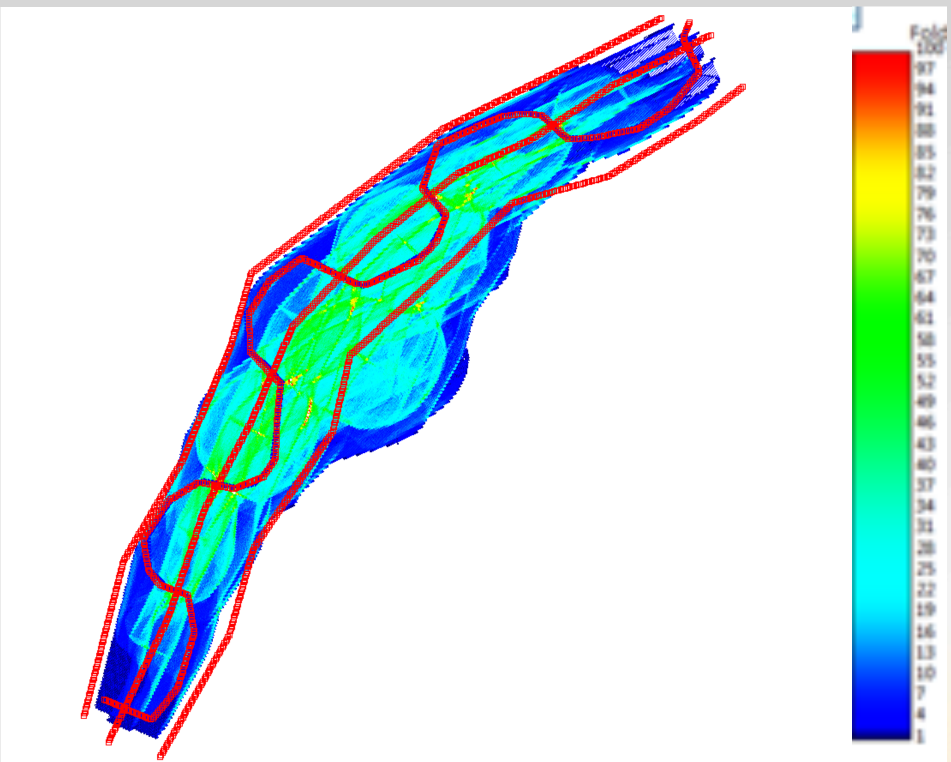
Alternative geometries to cover large area

Mapping a shear zone

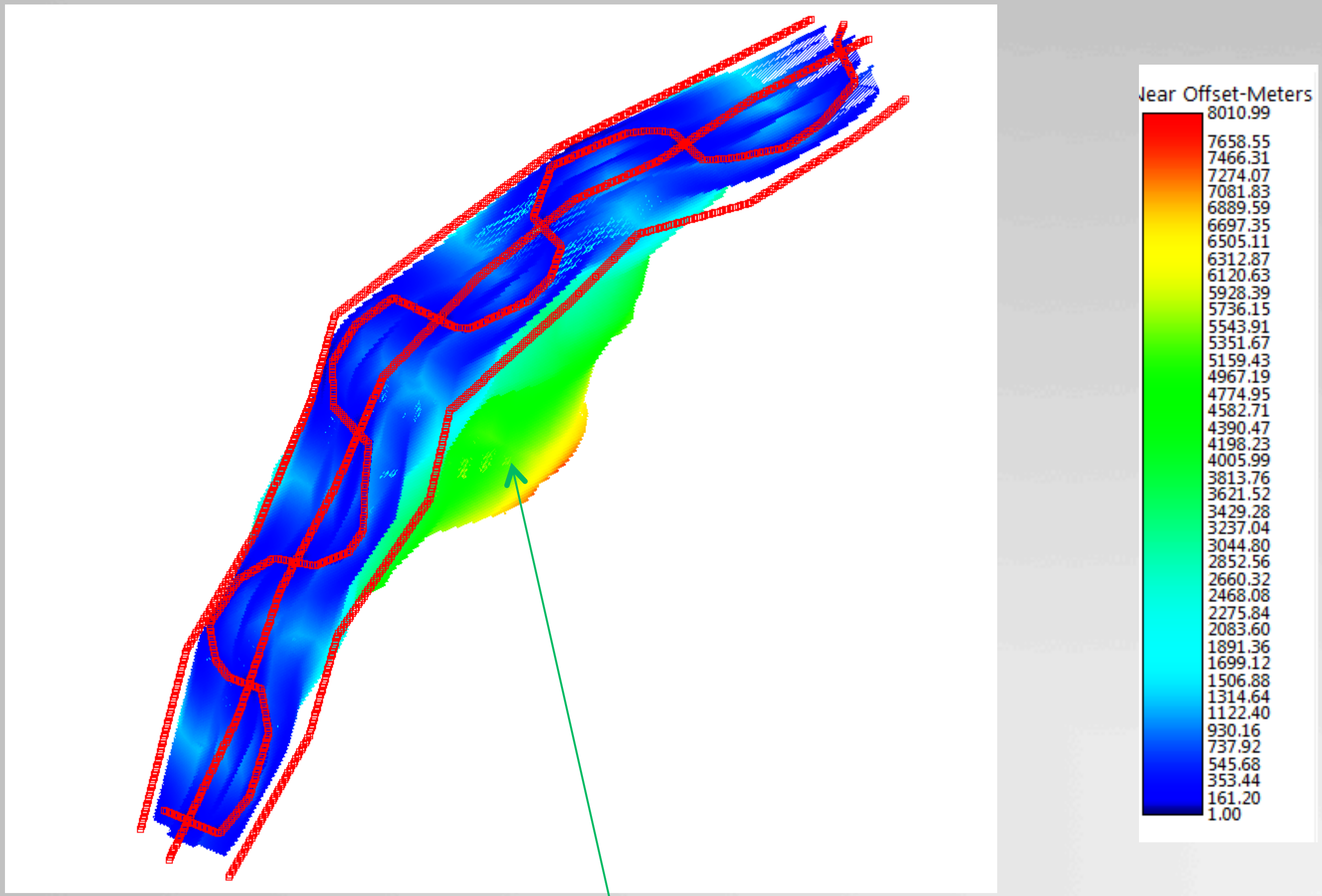


Fold for 1 pass flip-flop shooting

Flip-flop/dual pass



Offset distribution



Uniform distribution except very large offsets – eliminate in processing

Survey statistics for shooting 4 lines using flip-flop technique

Receiver Information

Receiver Lines:	1
Total Receivers:	1120
Live Receivers:	1120
Unused Receivers:	0
Receiver Spacing:	10.00 m
Line Spacing:	0.00 m
Total Length:	11.19 km
Receiver Density:	63.65 /sq. km
Graphical Density:	Not Calculated

Survey

X-Extent:	8101.43 m
Y-Extent:	2172.00 m
Areal Extents:	
Bin Grid:	30.01 sq. km
Graphical:	Not Calculated

Calculate Extents Graphically

Source Information

Source Lines:	4
Total Source Points:	1817
Live Source Points:	1817
Fired Sources:	1817
Source Spacing:	20.00 m
Line Spacing:	309.87 m
Order Length:	Not Calculated
Total Length:	36.26 km
Source Point Density:	103.26 /sq. km

Template Size Information

Min Channels:	1120
Max Channels:	1120

Bin Size

Bin Width:	5.000
Bin Height:	20.000

Effective area covered ~ 18 Km^2

Conclusions

- Solve cover complexities to see under cover
- Undercover seismic delineation – variable degree of success and precision (type of the deposits) - still developing
- Diversify imaging technique (introduce new methodologies, suited to regolith and deposit type)
- Correlate images (then interpret, invert)
- Diversify acquisition geometries and strategies
- Need 3D modelling using real geological case

Acknowledgements

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dGB Earth Sciences