Australian Government

Geoscience Australia

ANSIR NATIONAL RESEARCH FACILITY FOR EARTH SOUNDING

2005 TANAMI SEISMIC SURVEY: Acquisition, Processing & Pitfalls

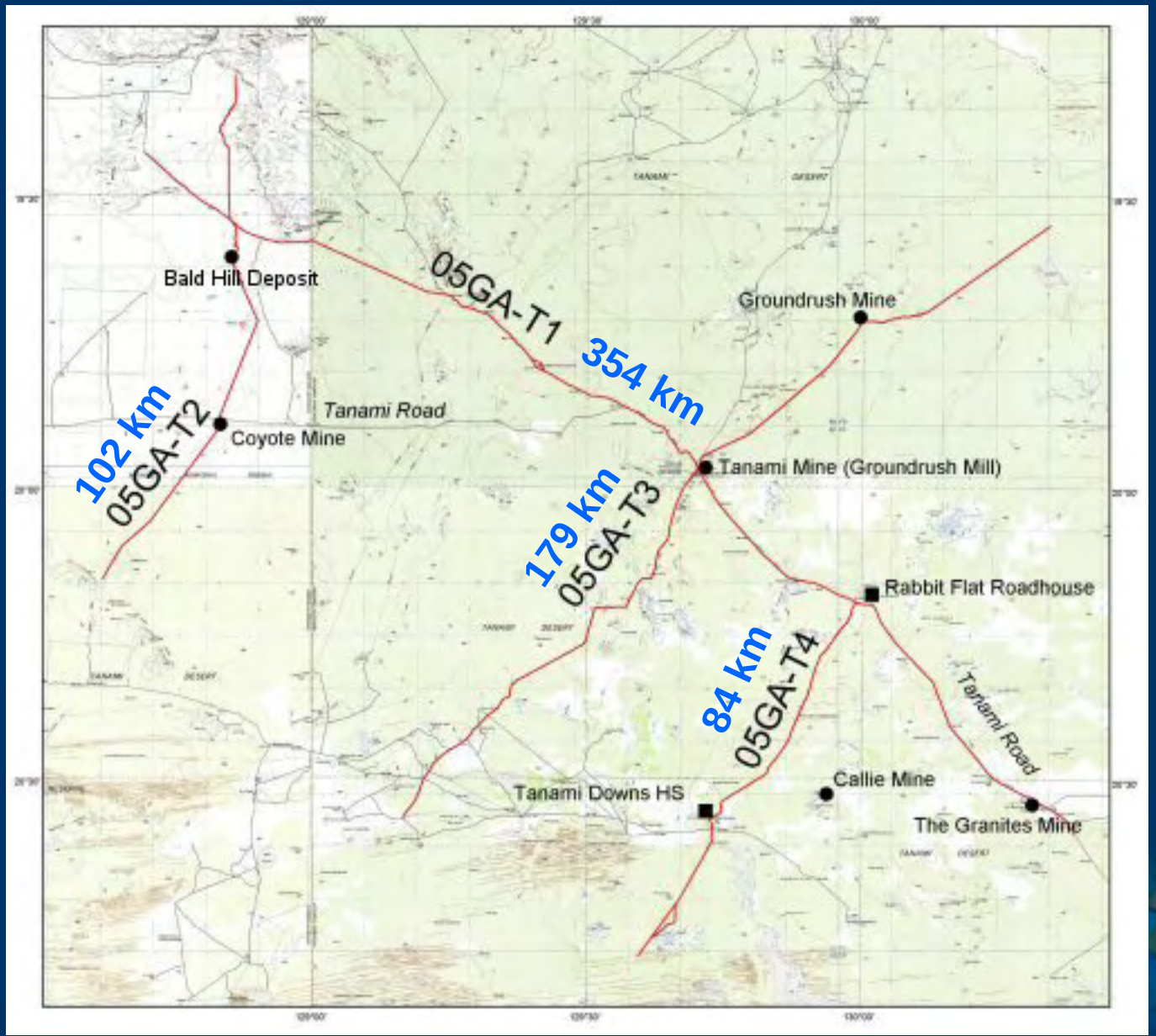
Leonie Jones & Bruce Goleby

Acquisition: Leonie Jones, David Johnstone, Tim Barton & Tanya Fomin

Processing: Leonie Jones, Bruce Goleby & David Johnstone

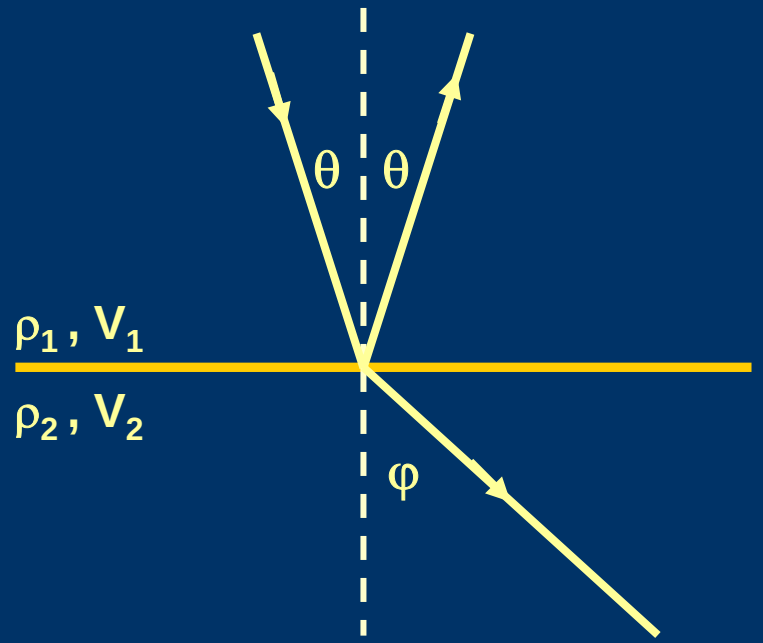
Evolution and Metallogenesis of the North Australian Craton – Seismic Workshop – June 2006

Tanami Seismic Survey – Line Locations

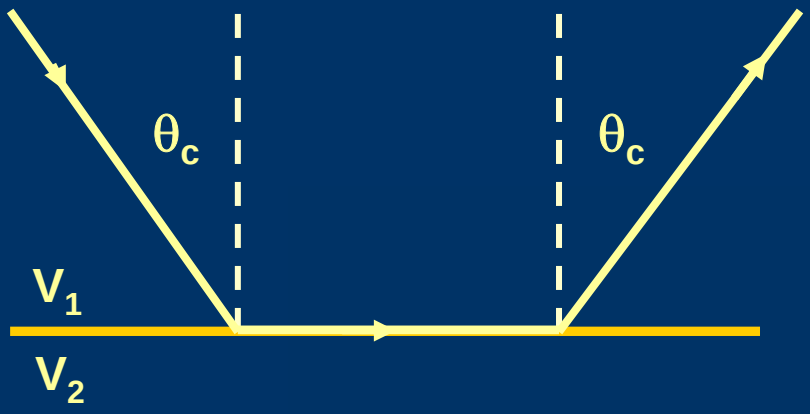


Behaviour of Seismic Waves at an Interface

Reflection



Critical Refraction



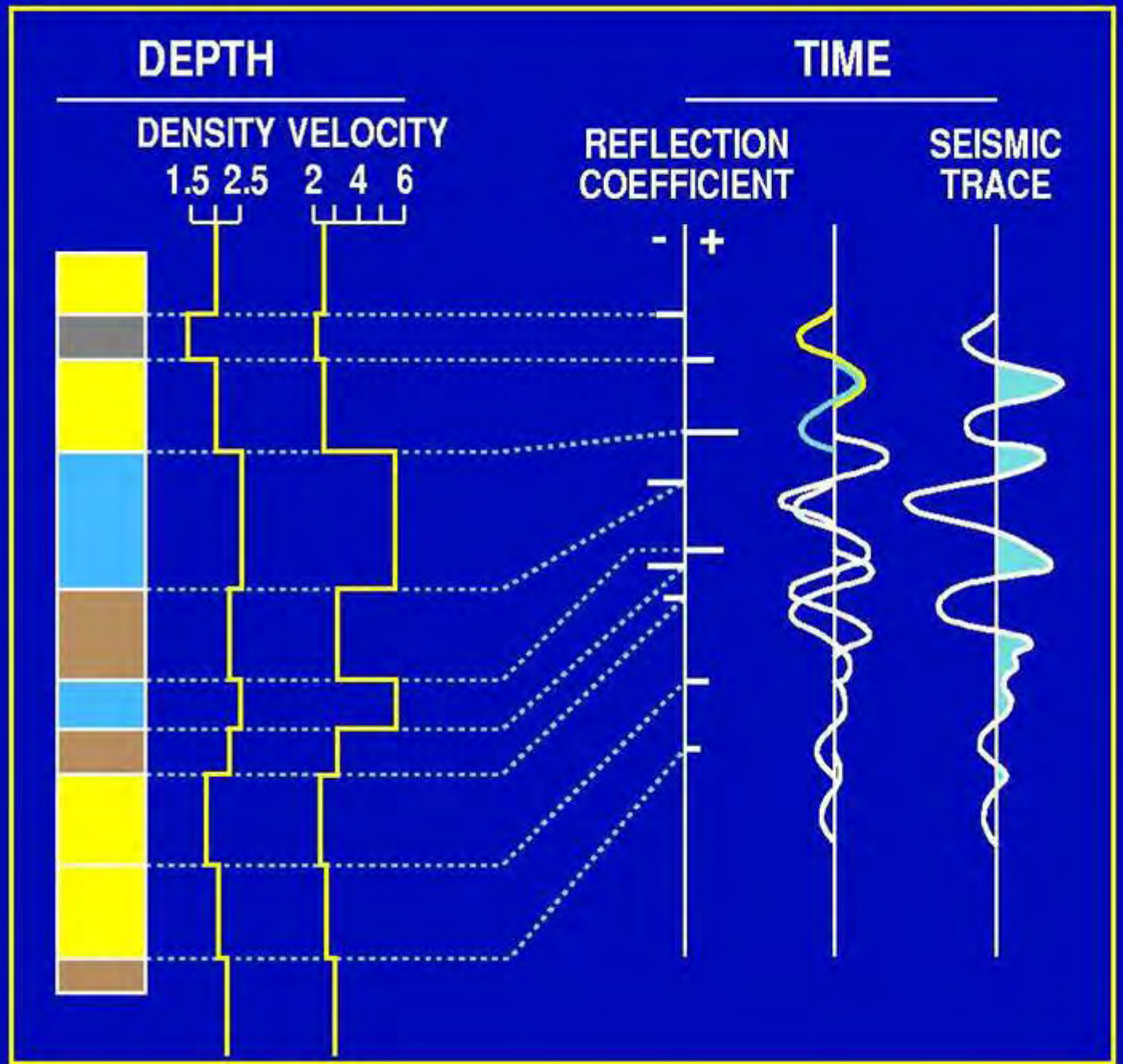
$\sin \theta_c = V_1/V_2$ for $V_2 > V_1$

Snell's Law $\sin \theta / \sin \varphi = V_1/V_2$

Amplitude of reflected waves governed by the reflection coefficient given by:

$$RC \equiv \frac{\rho_2 V_2 - \rho_1 V_1}{\rho_2 V_2 + \rho_1 V_1}$$

- Reflections caused by density contrasts, since hard rock velocity approximately proportional to density.
- Typical reflection coefficients are small, e.g. mafic - felsic contacts up to +/- 0.075
- Negative reflection coefficients result in 180° phase change, i.e. the reflected wavelet is “flipped”



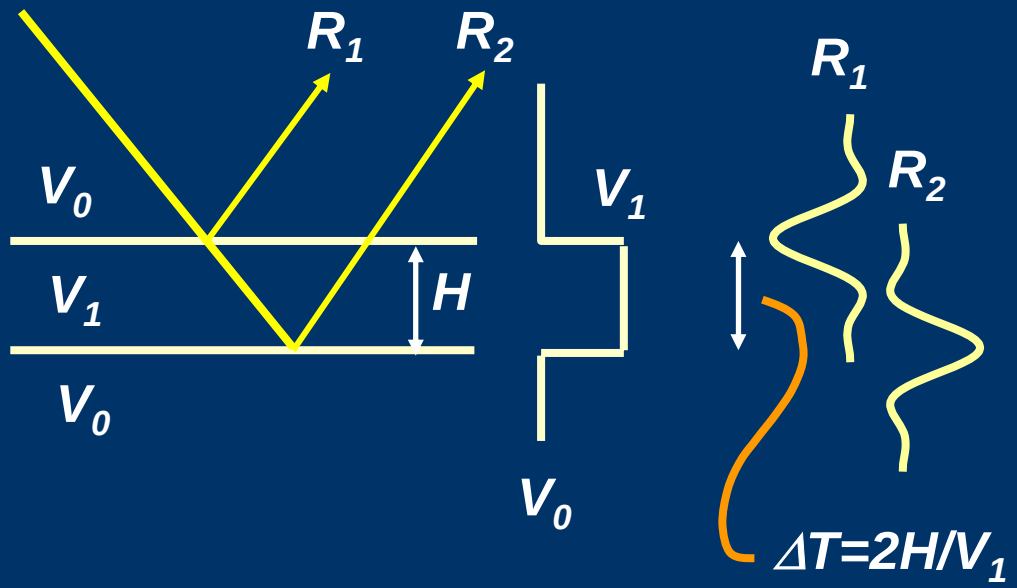
$$\text{REFLECTION COEFFICIENT} = \frac{\rho_2 V_2 - \rho_1 V_1}{\rho_2 V_2 + \rho_1 V_1}$$

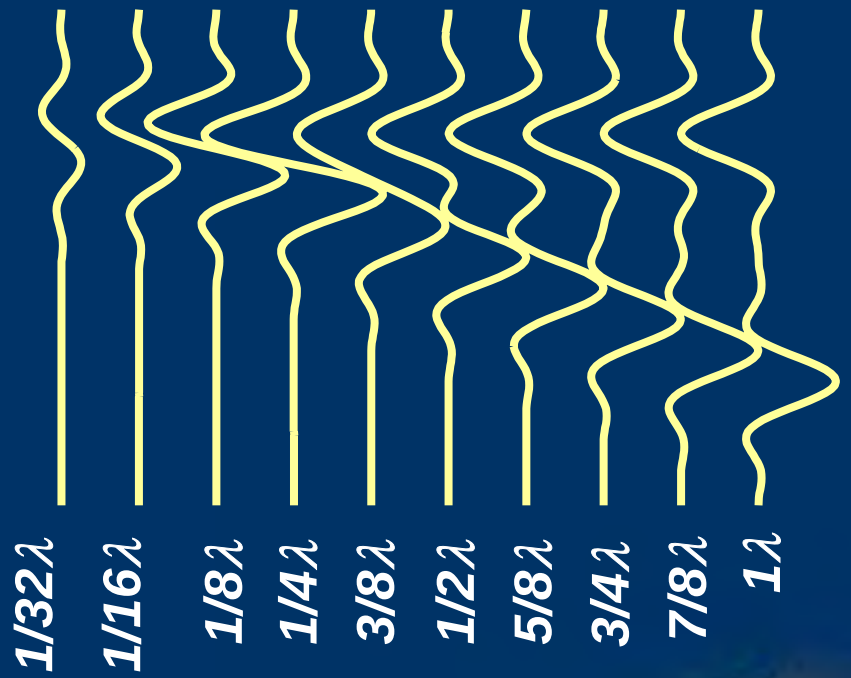
INPUT WAVELET

AGSO

01/263

Vertical Resolution



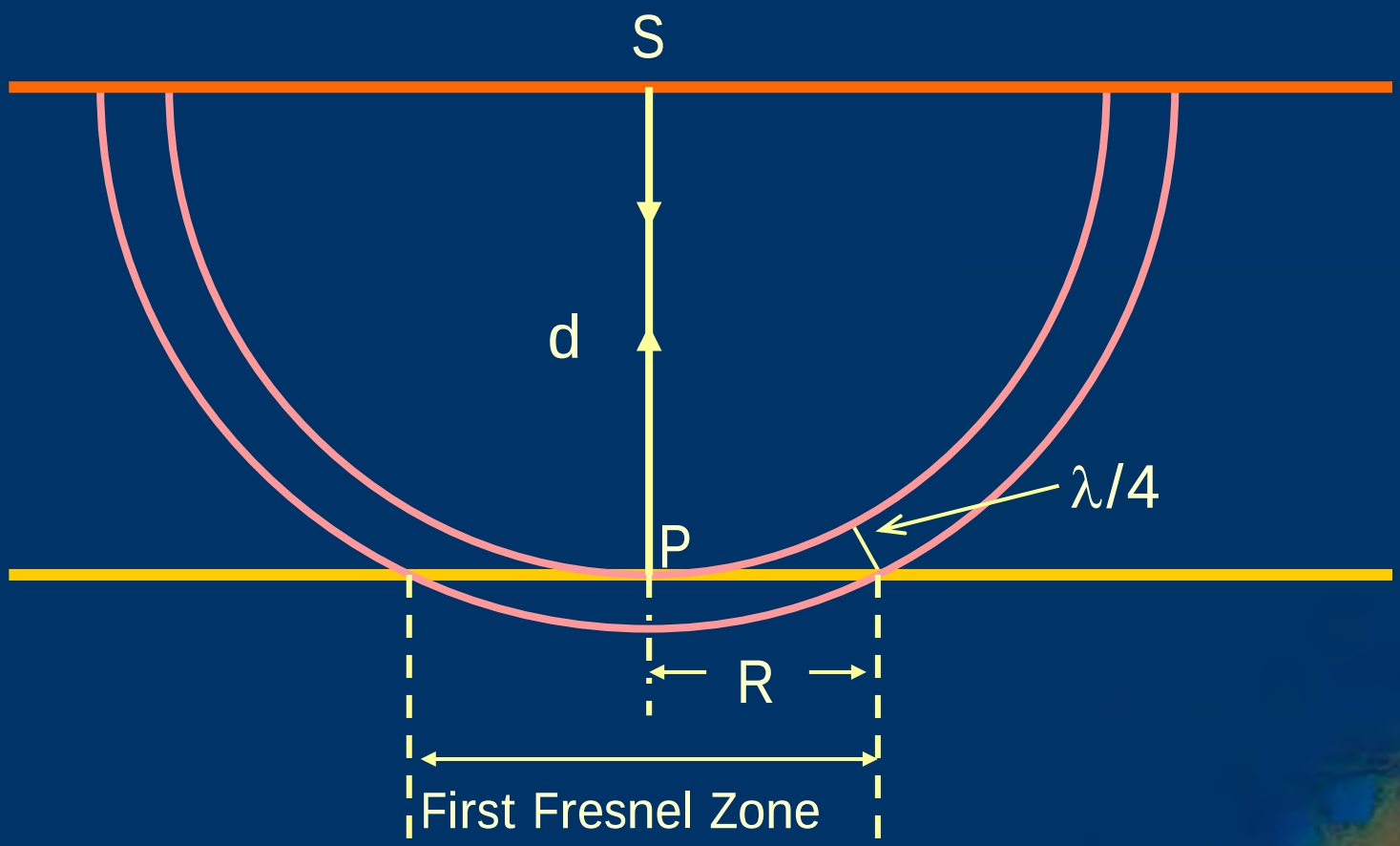


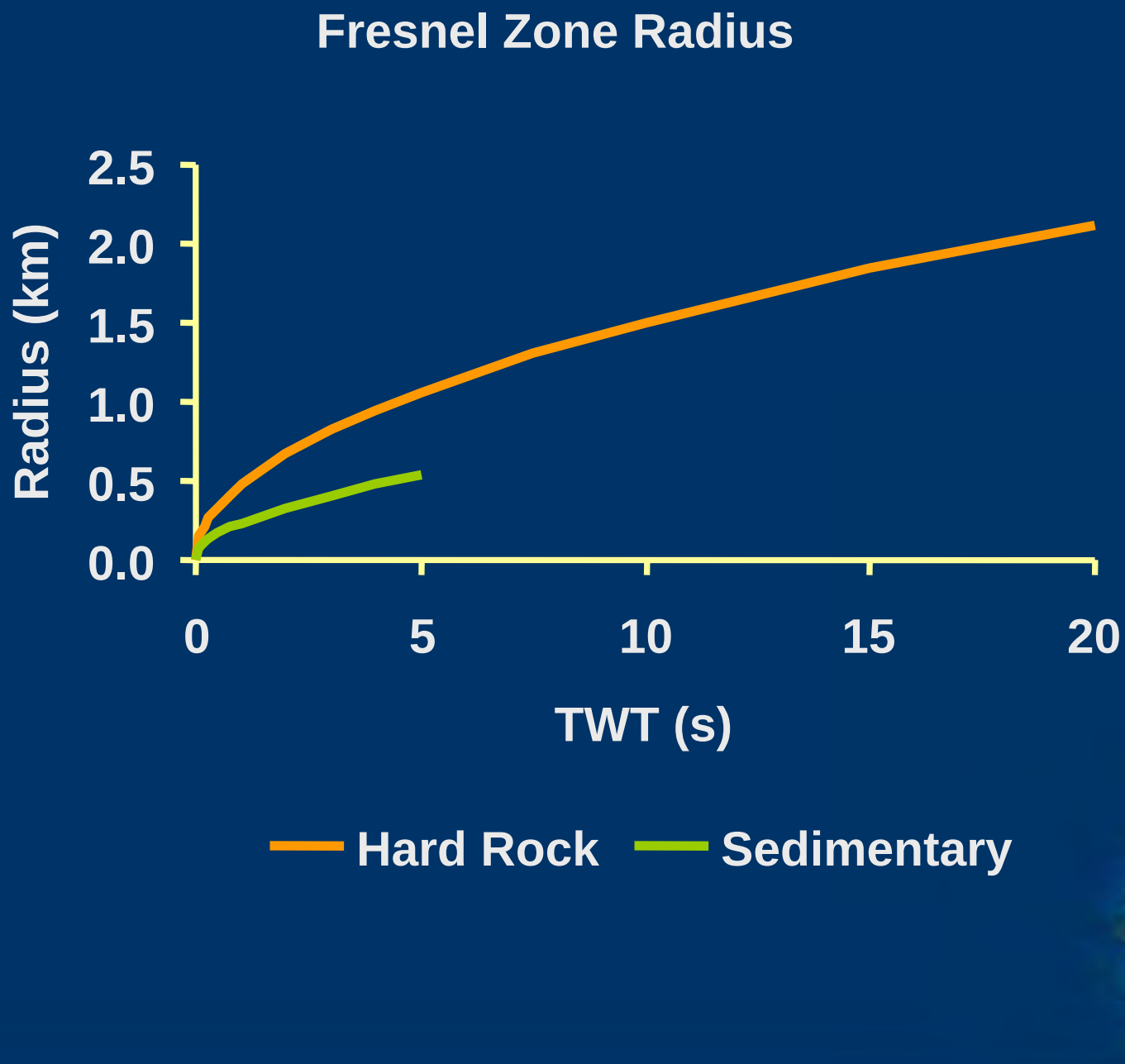
For a 50 Hz Wavelet

$V = 2{,}500 ms^{-1}, \lambda = 50m$

$V = 5{,}000 ms^{-1}, \lambda = 100m$

Horizontal Resolution




Fresnel Zone Radius
Radius (km)
2.5
2.0
1.5
1.0
0.5
0.0
0
5
10
15
20
TWT (s)
Hard Rock
Sedimentary

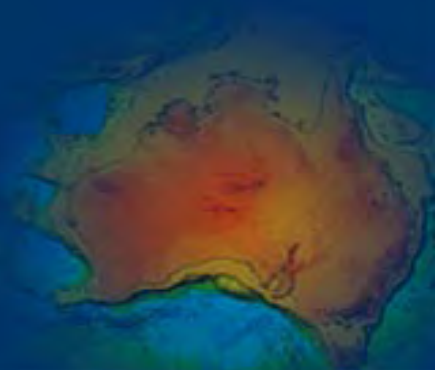
Comparison of Hard Rock & Sedimentary Basins

Resolving power depends on wavelength $\lambda = V/f$

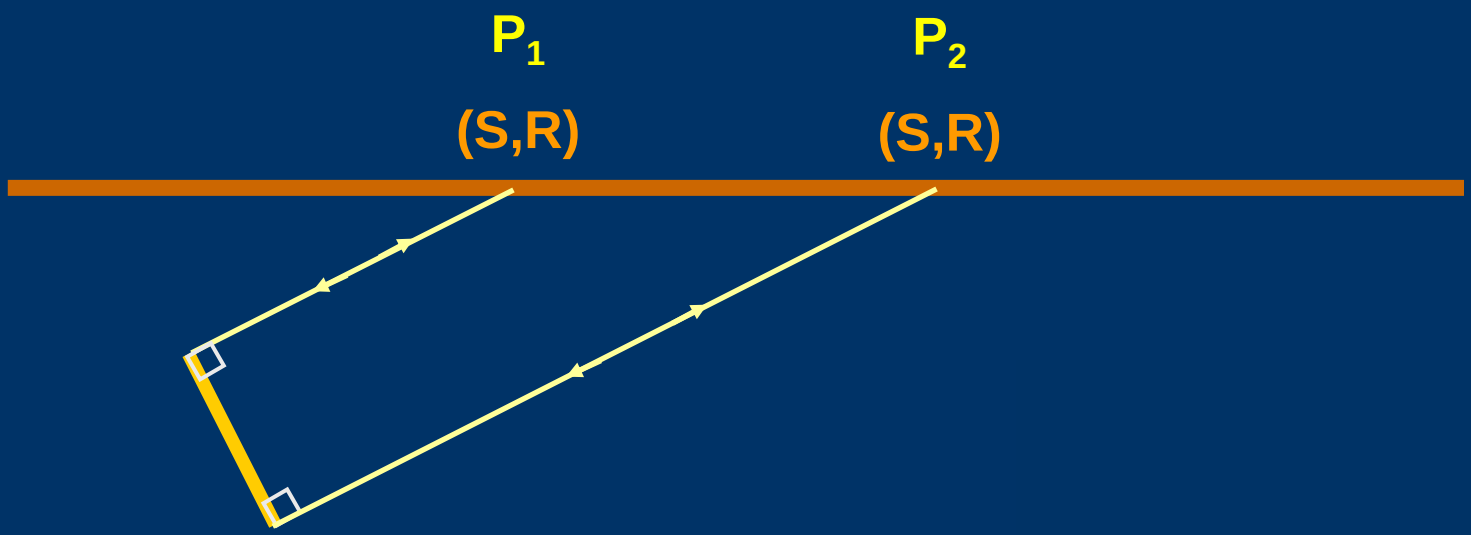
Hard rock	Sedimentary
f = 40 Hz	f = 40 Hz
V= 6000 m/s	V= 3000m/s
λ = 150 m	λ = 75 m

In hard rock, vertical resolution is only half as good.

Horizontal resolution is about 70% as good as for sedimentary basins (for the same depth).

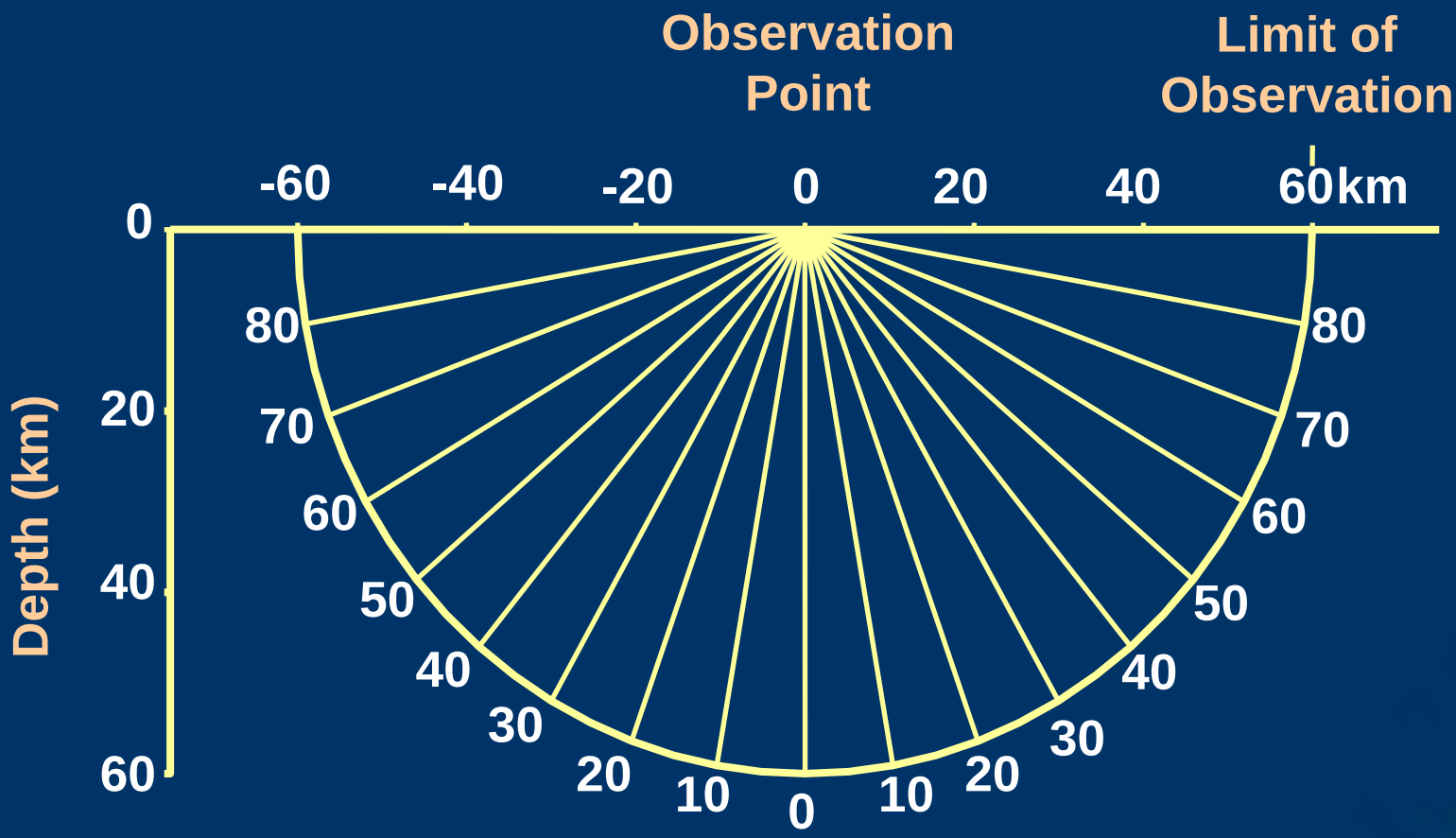


Dipping Reflector



- The seismic line must be long enough to include the observation points and the reflector.
- The recording time must be long enough for seismic waves to travel to and from the reflector.

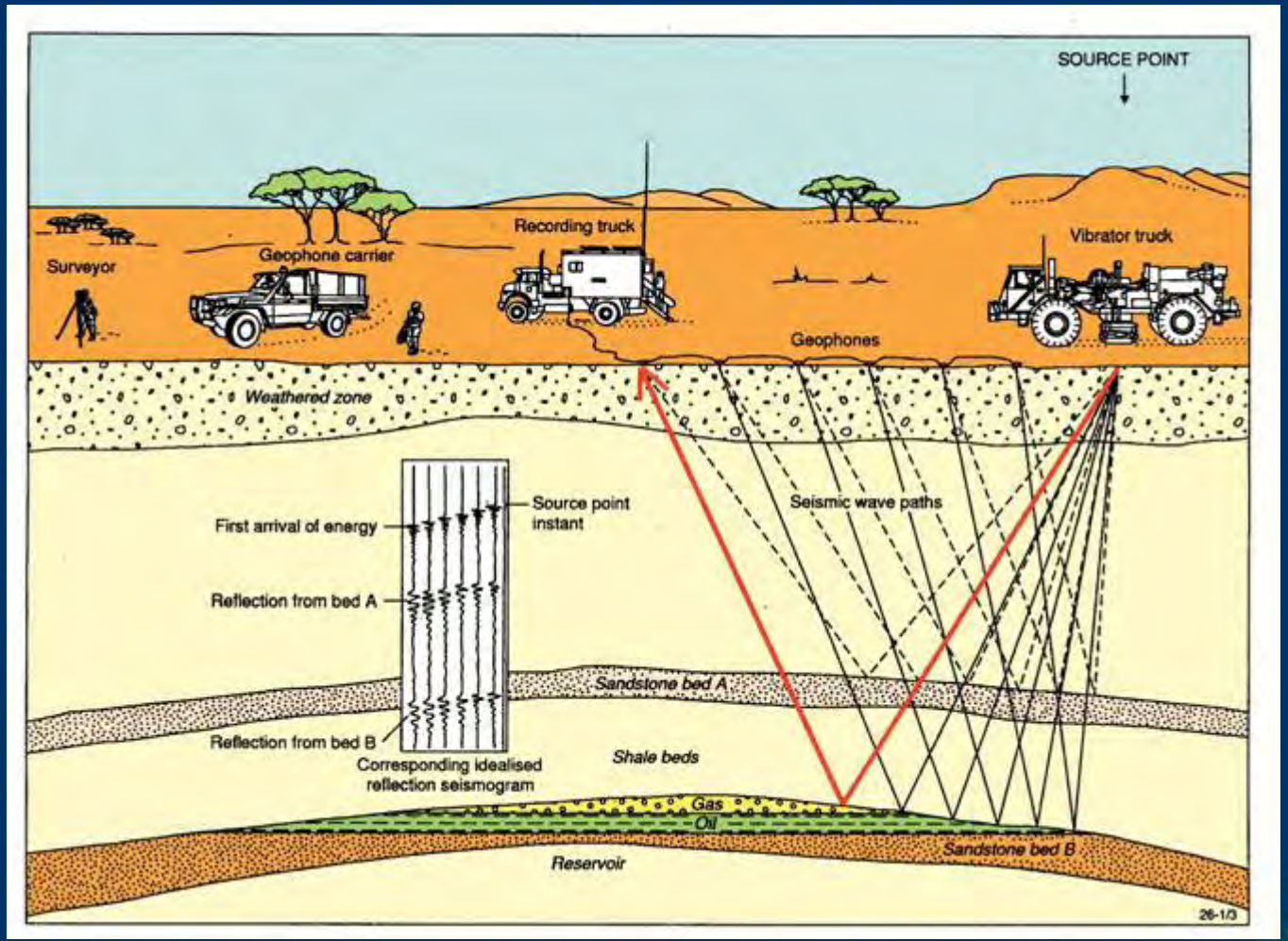
Dip Resolution



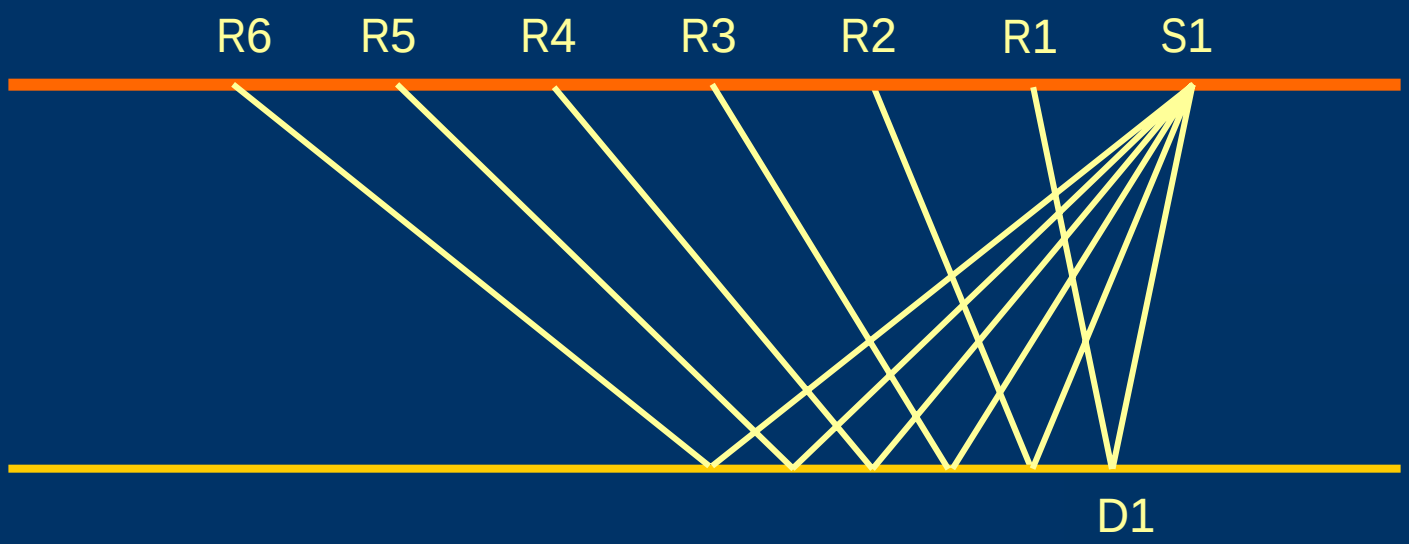
Velocity = 6.0 km/s

Max Record Time = 20s

Seismic Reflection Method

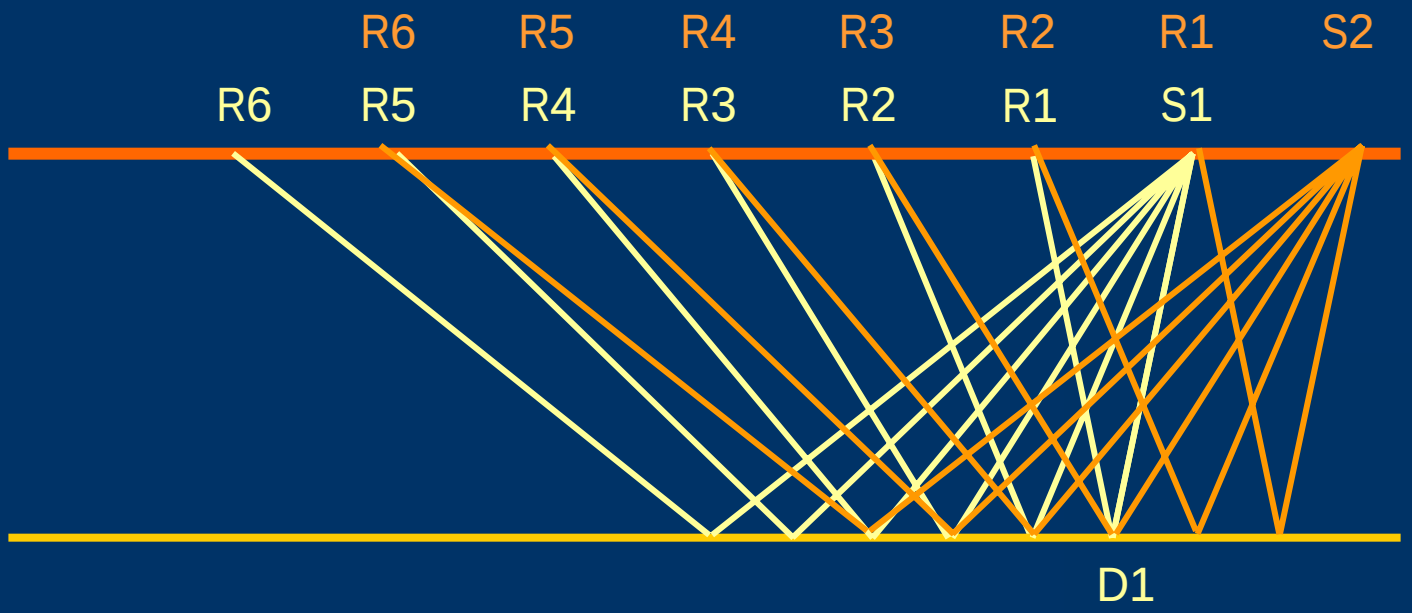


CDP (Common Depth Point) Method



Reflecting points on the reflector are separated by half the receiver spacing.

CDP (Common Depth Point) Method



Depth point D1 is sampled by R1 for Shot 1 and R3 for Shot 2. Fold is the number of times a depth point is sampled.

Front Crew


Laying cable


Dropping geophone strings


Unclipping phones


Connecting takeout

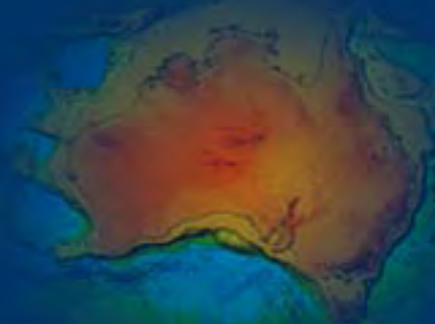

Stomping geophone

Back Crew

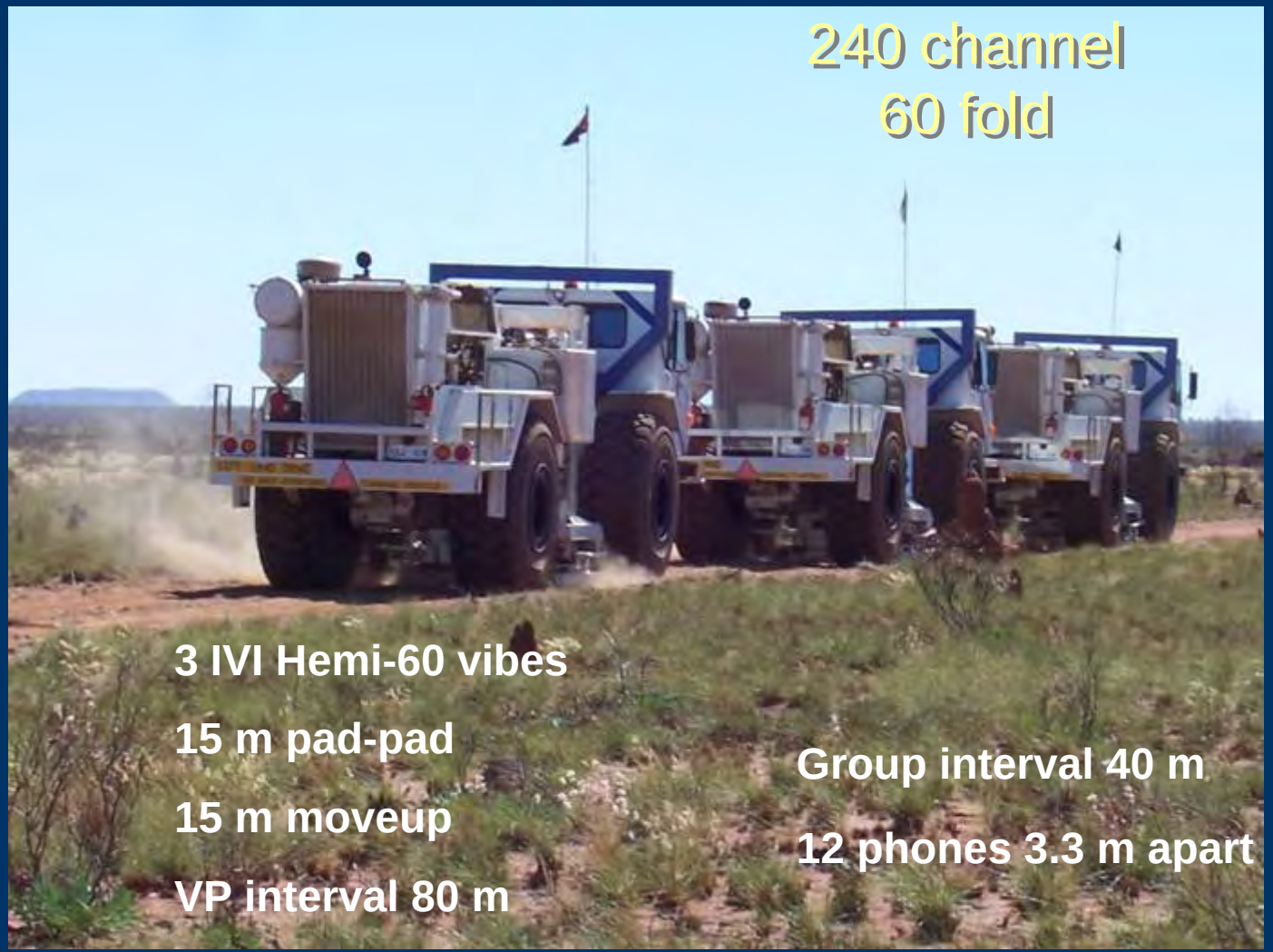

Pinning geophones


Dropping clip


Pulling in cable



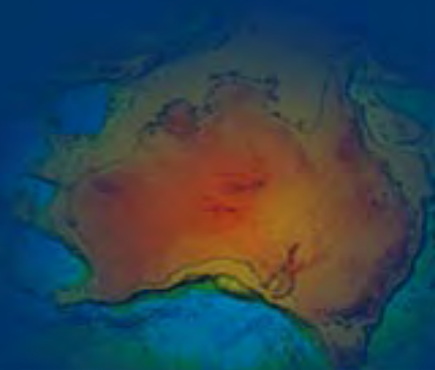
Acquisition Parameters I



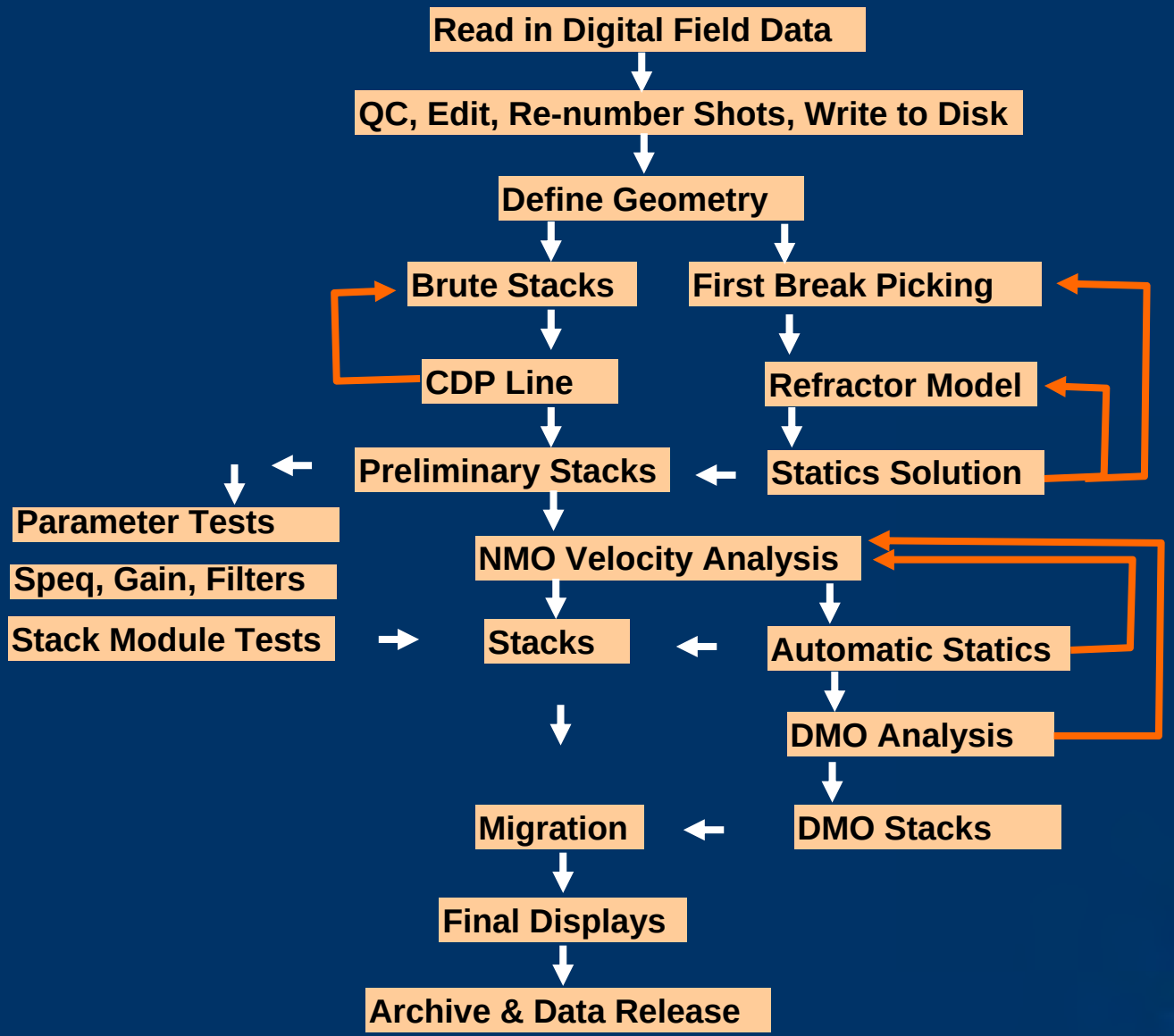
Acquisition Parameters II

Seismic Processing

Overall goal is to produce an image of the sub-surface by enhancing and correctly positioning reflections and reducing undesired energy (noise)



Seismic Processing



Key Processing Steps

Crooked line geometry definition - including CDP line

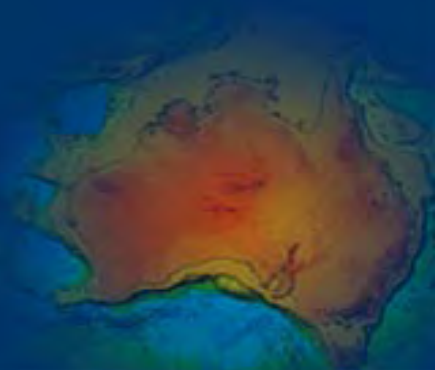
Statics correction - for variable time delays in regolith

Spectral equalisation - suppresses low f noise

CDP sort - collects traces with common mid point

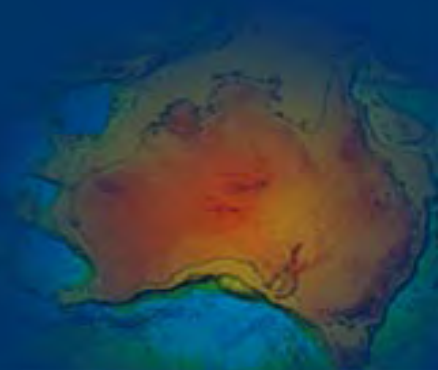
Velocity analysis - corrects for normal & dip moveout

Migration - moves reflectors to correct positions

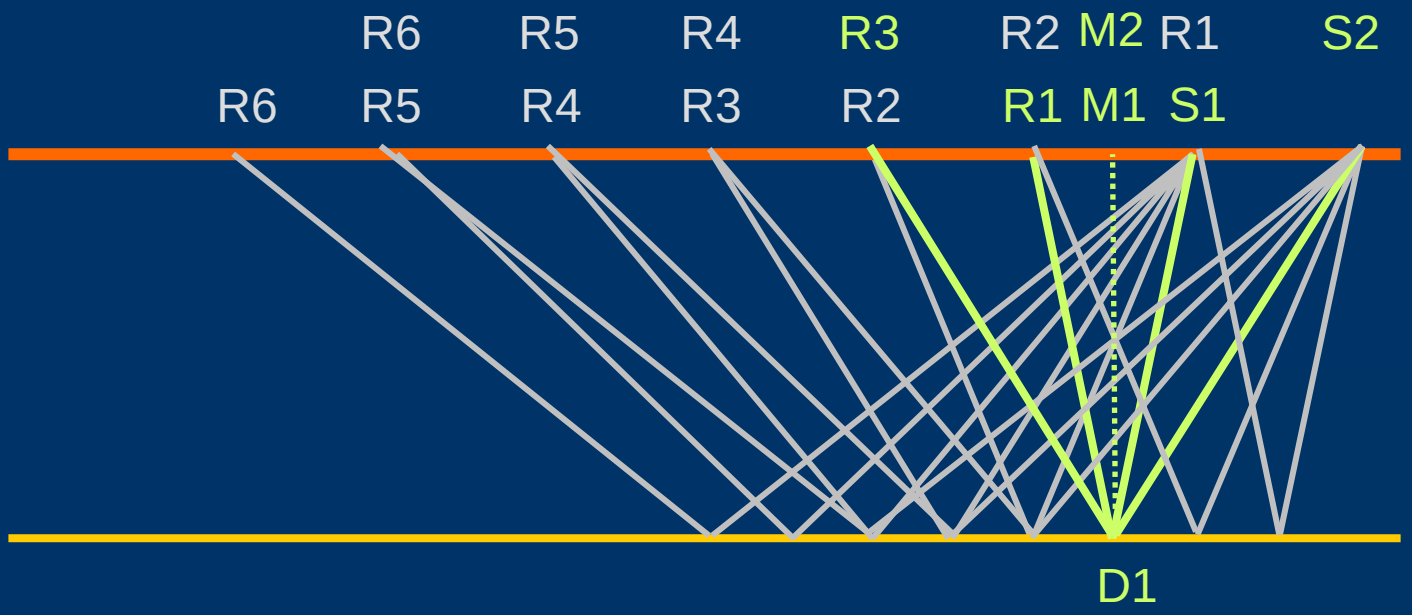


Geometry Definition

Locates sources and receivers and defines the CDP line

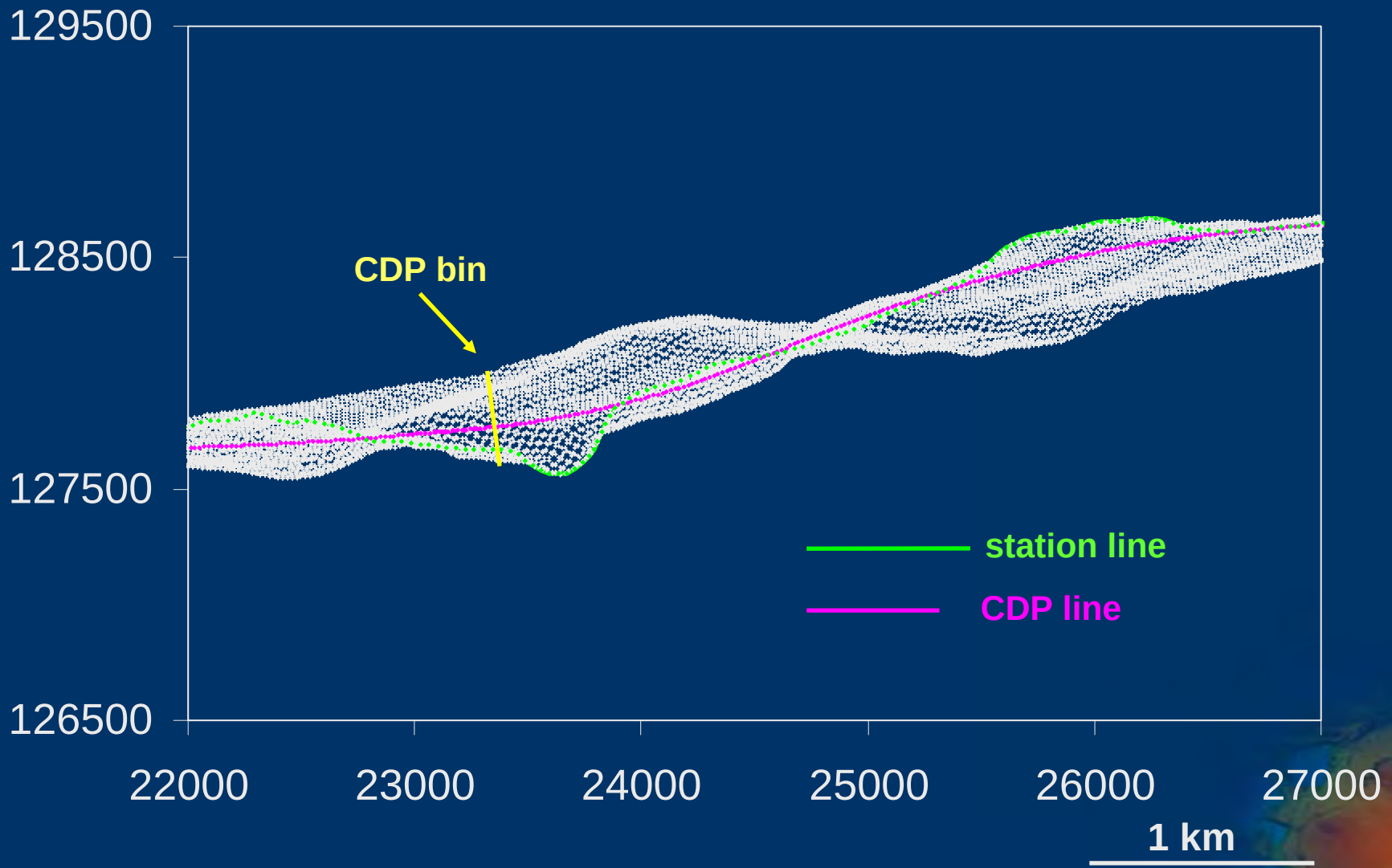


CDP (Common Depth Point) Binning

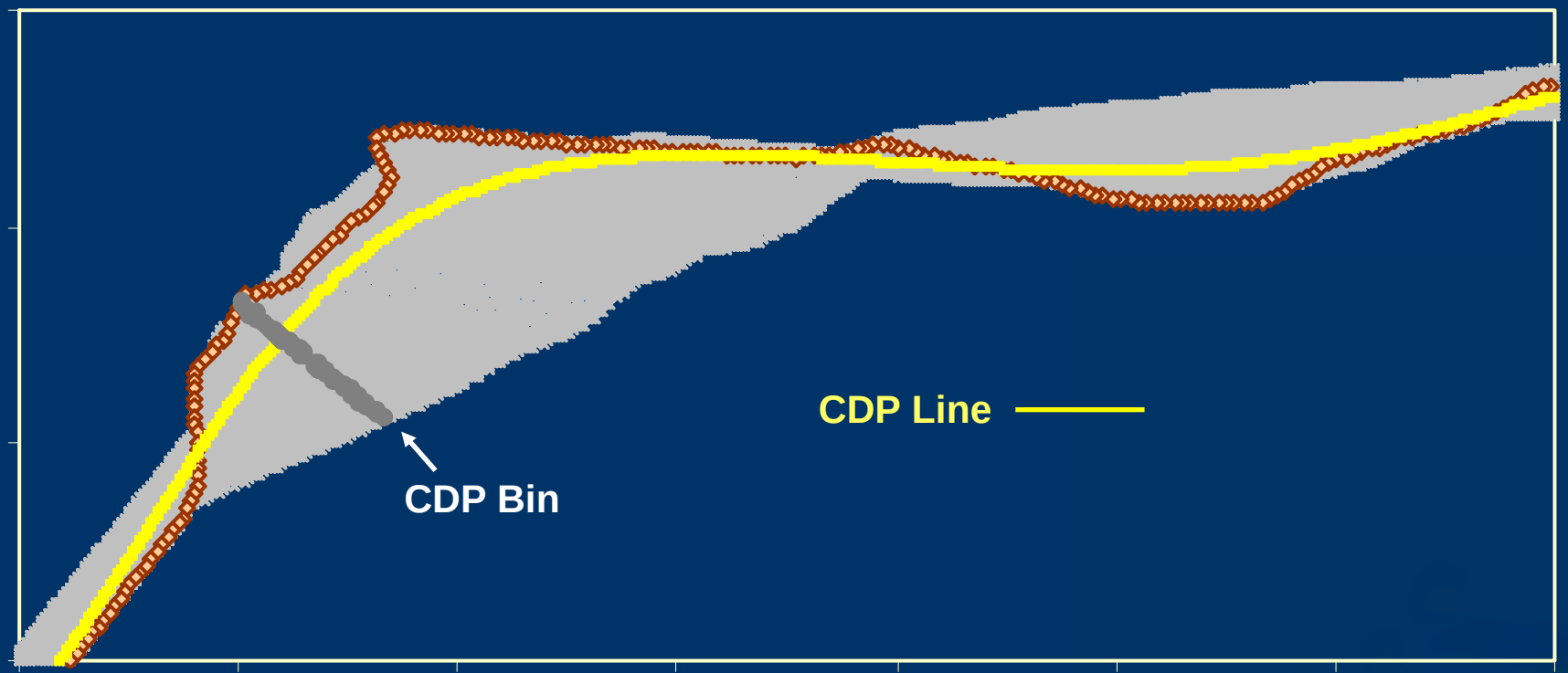


Assigns shot-receiver midpoints (M1 and M2) to common depth point D1

Crooked Line Geometry



Crooked Line Geometry

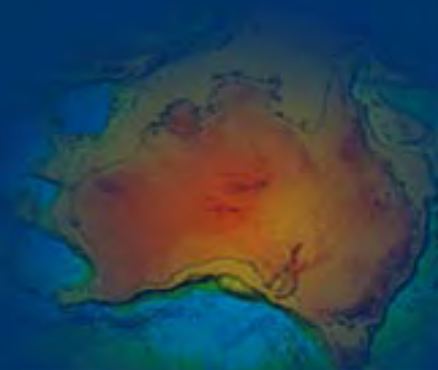


Refraction Statics Calculation

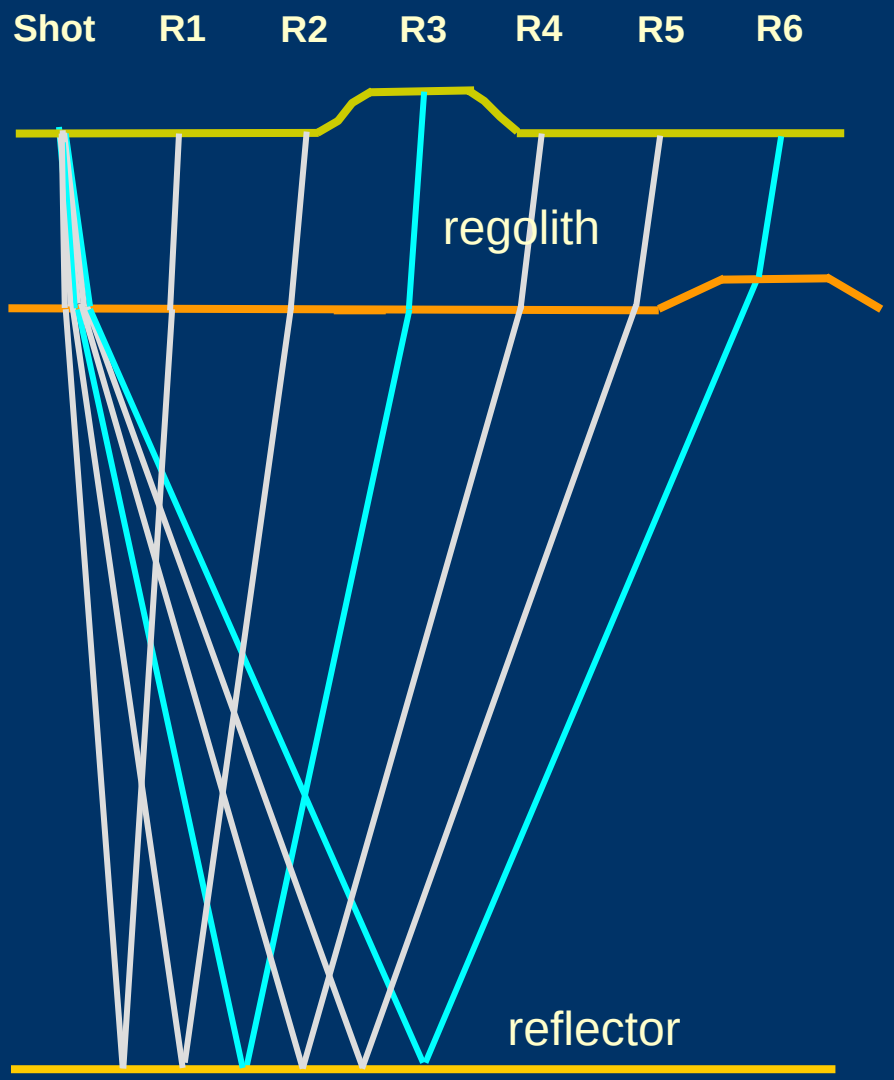
Corrects for varying travel times due to varying surface elevation and regolith thickness, else

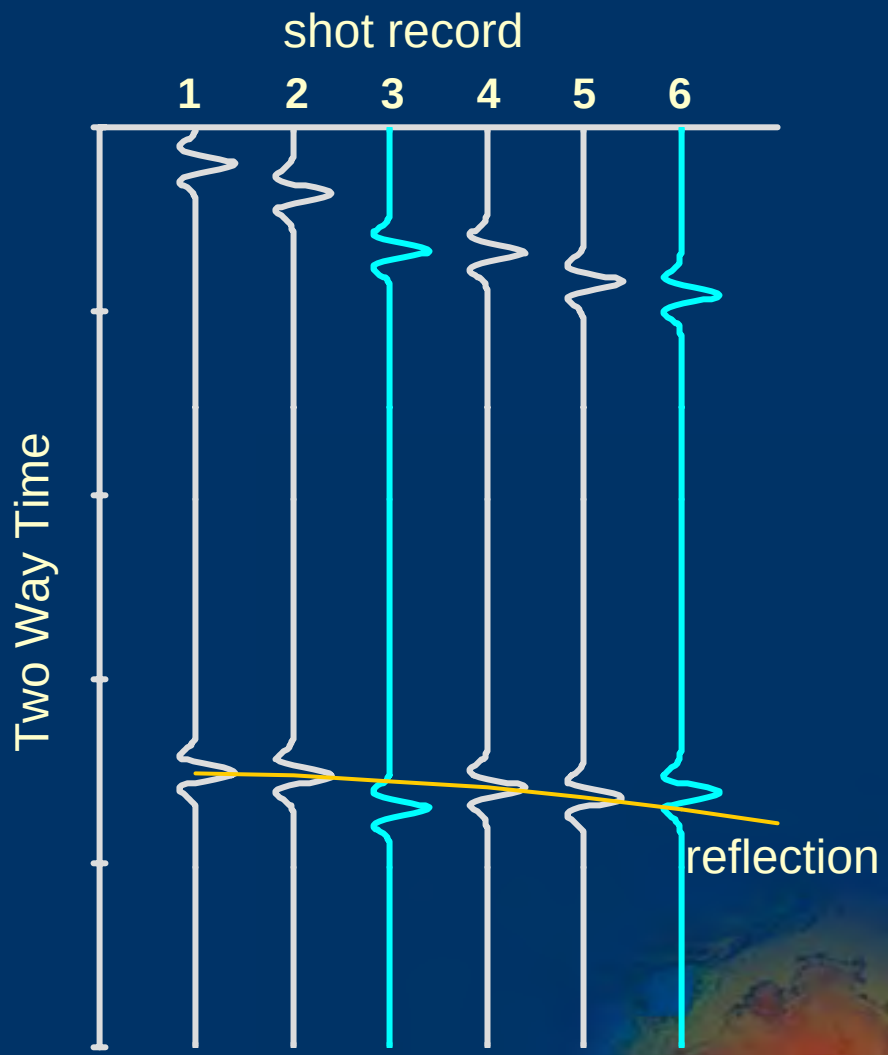
False structures can occur

Data won’t stack correctly



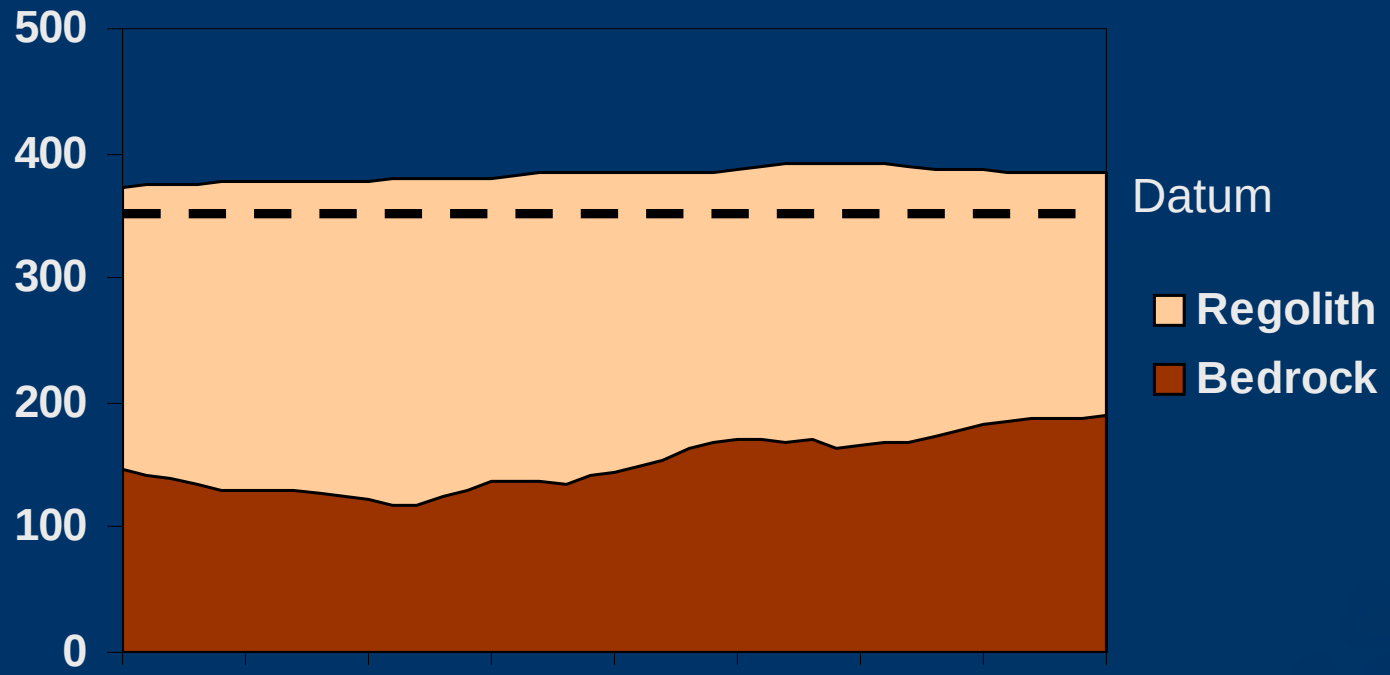
Statics Corrections needed for elevation and regolith





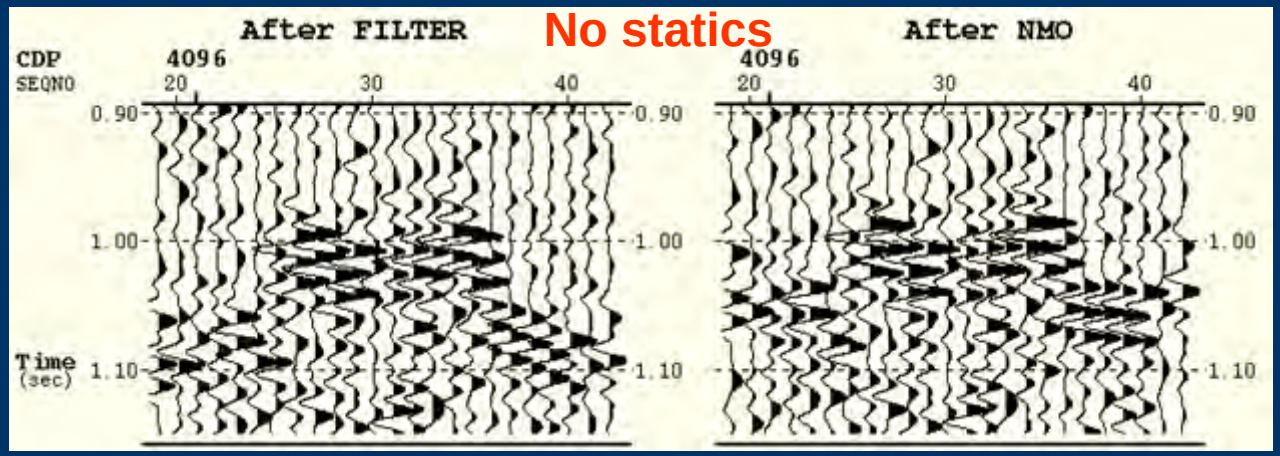
Statics Correction

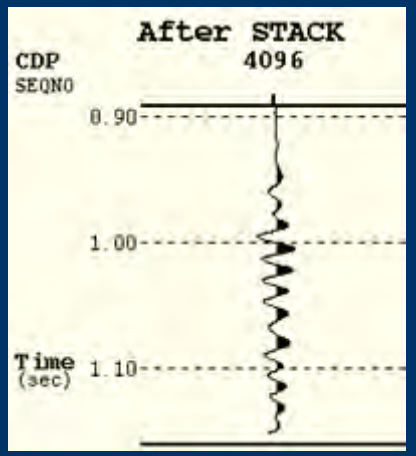
- subtracts travel time in lower velocity regolith
- adds travel time between bedrock & datum at bedrock velocity

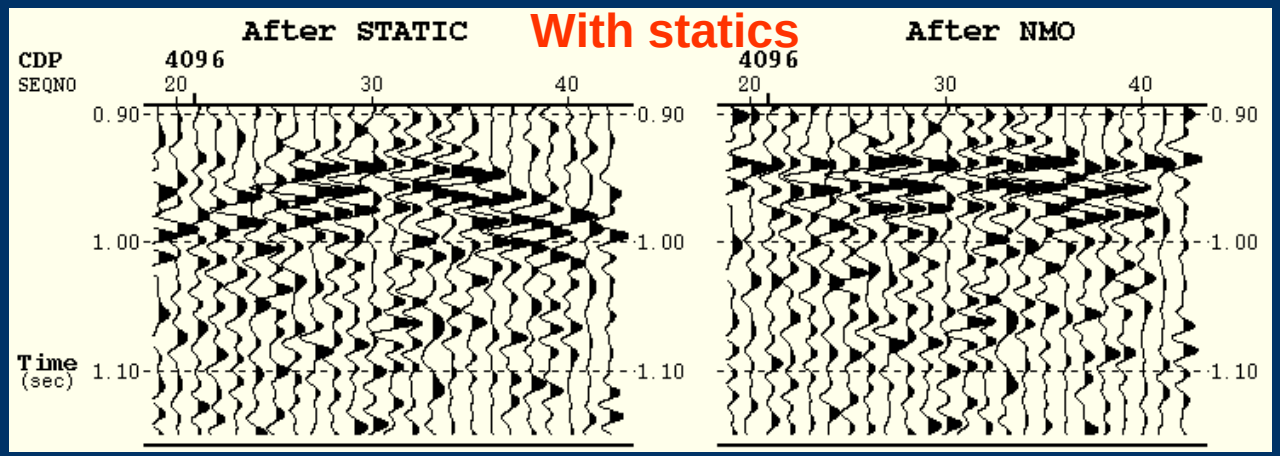


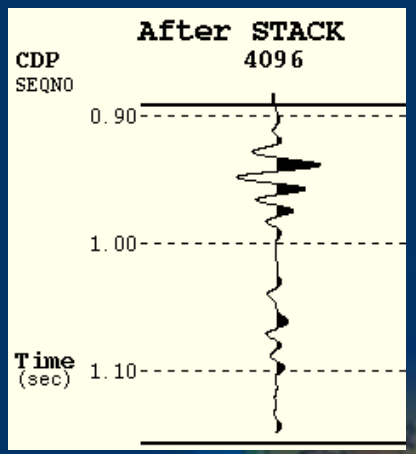
- Therefore, need a model for regolith/bedrock interface
- Note that static shift depends on chosen datum

Effect of Statics Correction

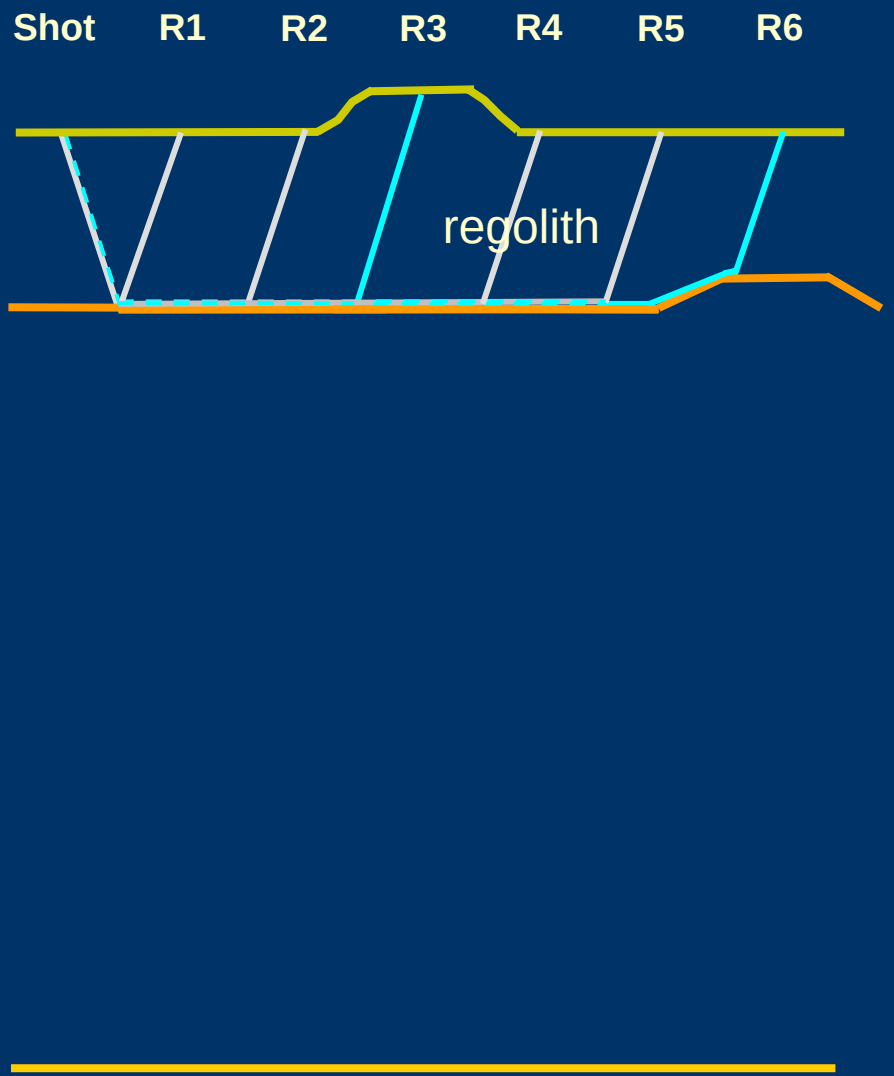


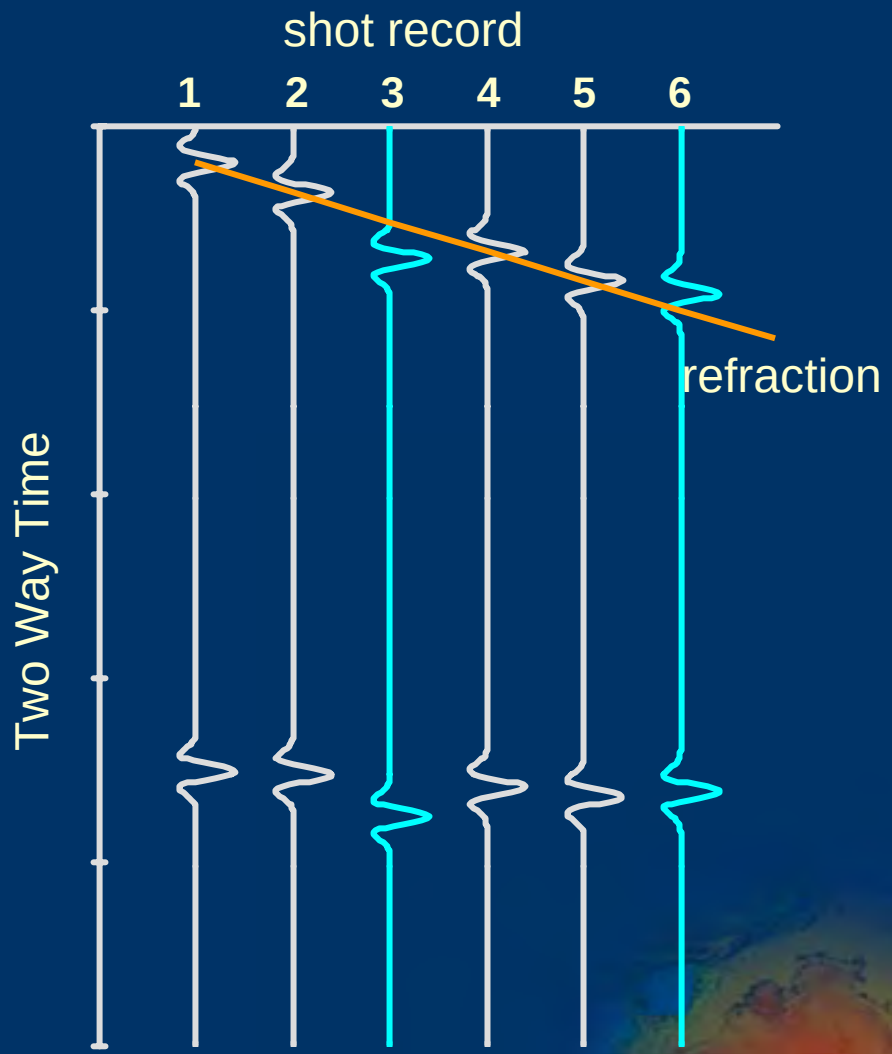




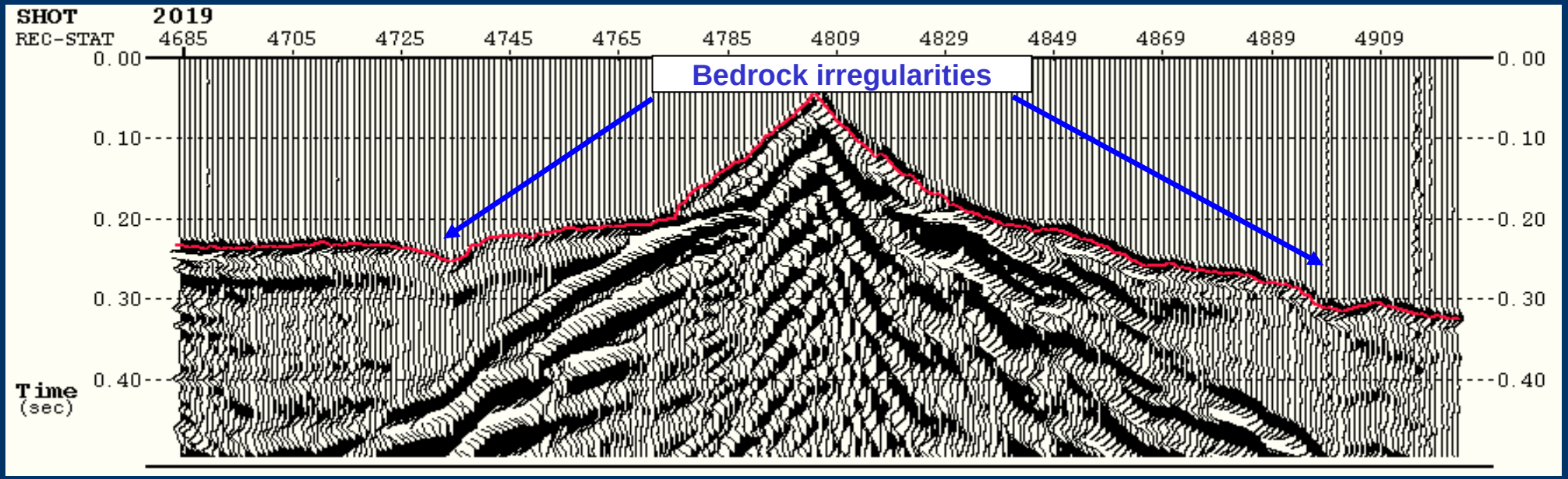


First arrivals (refracted waves) are used for statics calculations





First break (first arrival) picking

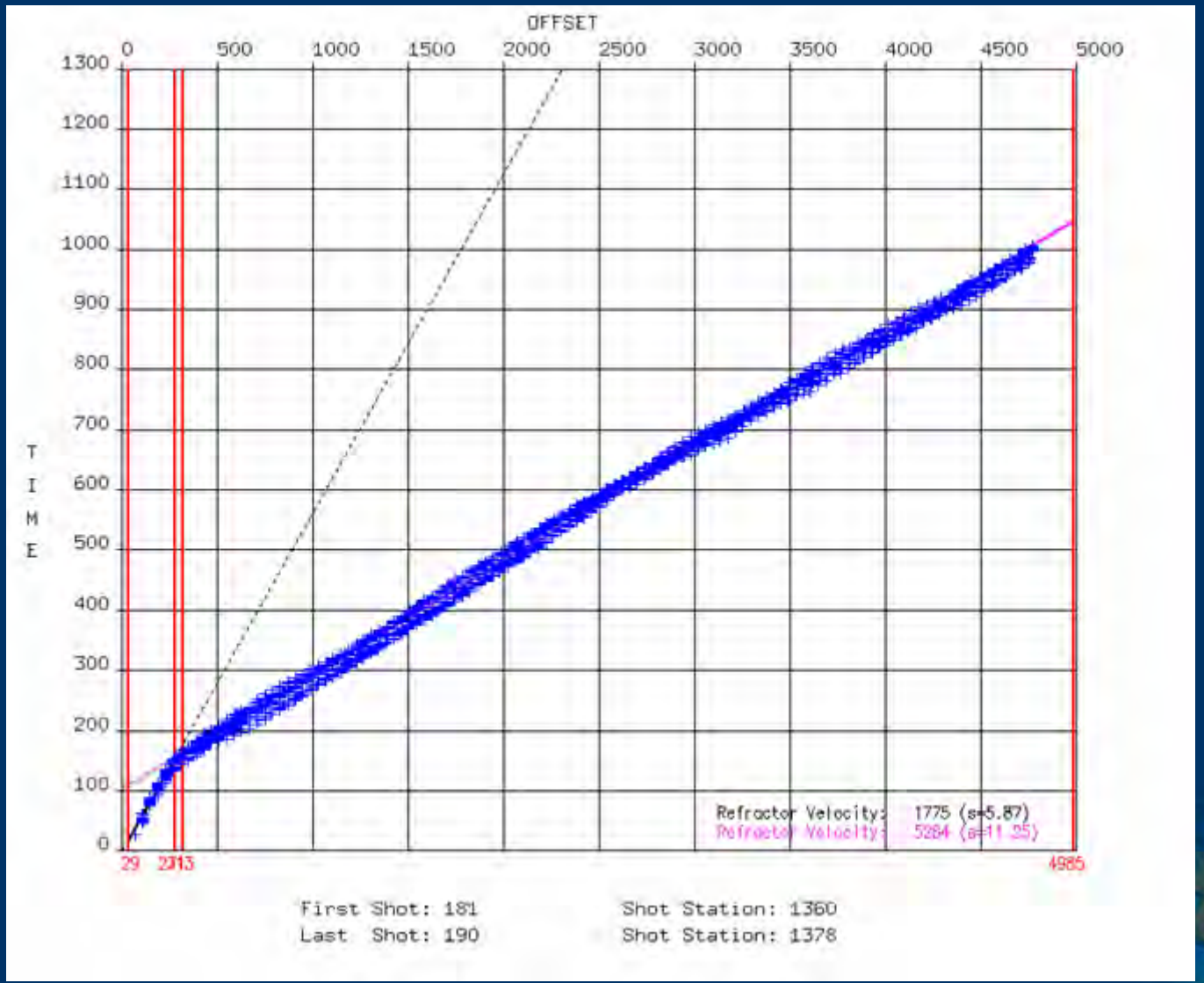


TIME-CONSUMING TASK:

Pick first arrival for each shot record (240 traces) for

05GA-T1 - 4429 shots
05GA-T2 - 1402 shots
05GA-T3 - 2361 shots
05GA-T4 - 1097 shots

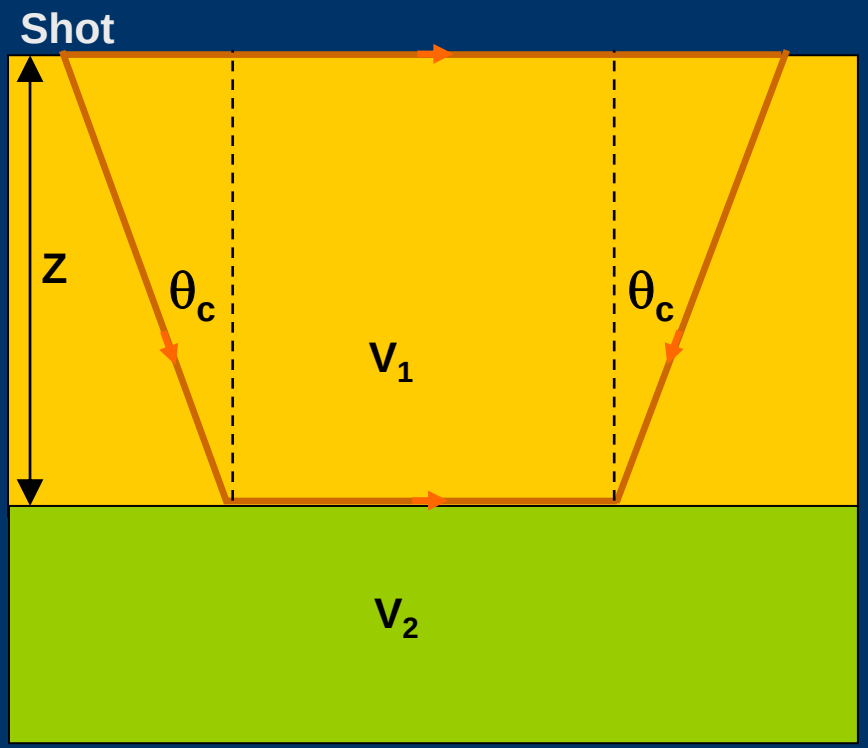
Use plot of first arrival time vs offset (distance) to identify refractor branch for refraction solution software

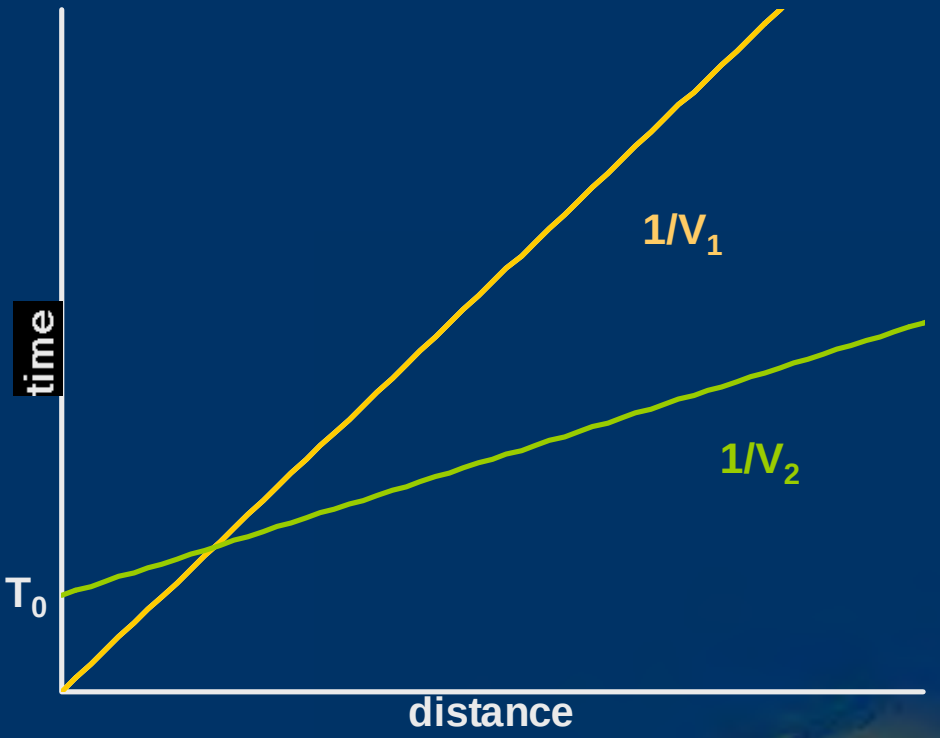


One-refractor model

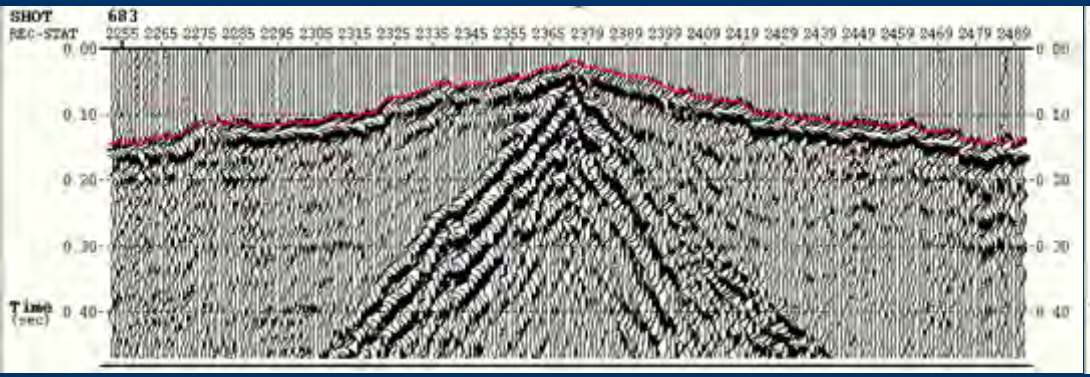
$\sin \theta_c = V_1/V_2$

$T_0 = 2\ Z \cos \theta_c / V_1$

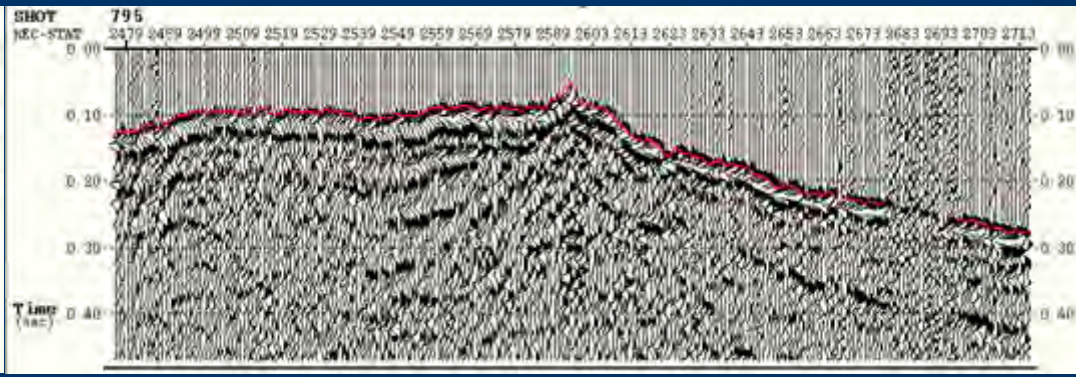




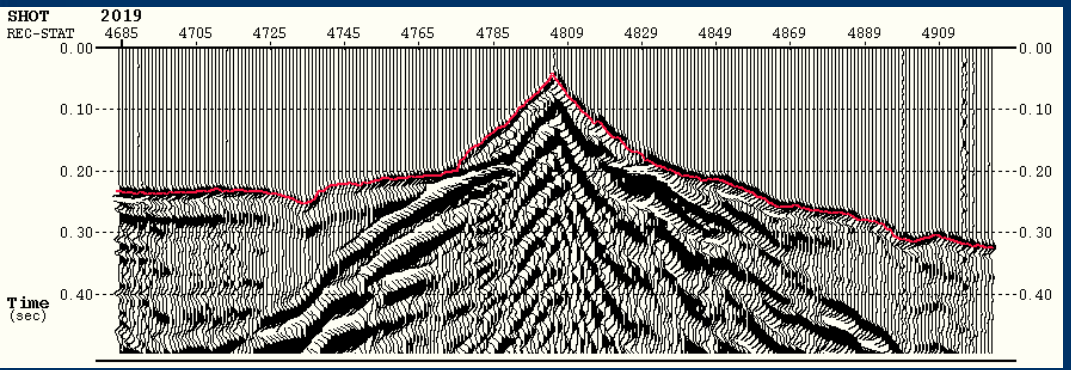
Characteristic shot records



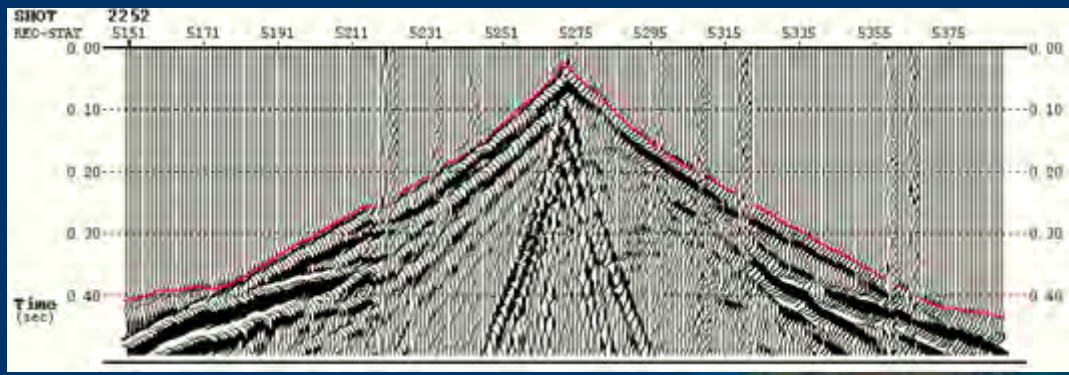
Near outcrop in hard rock



Approaching broad channel

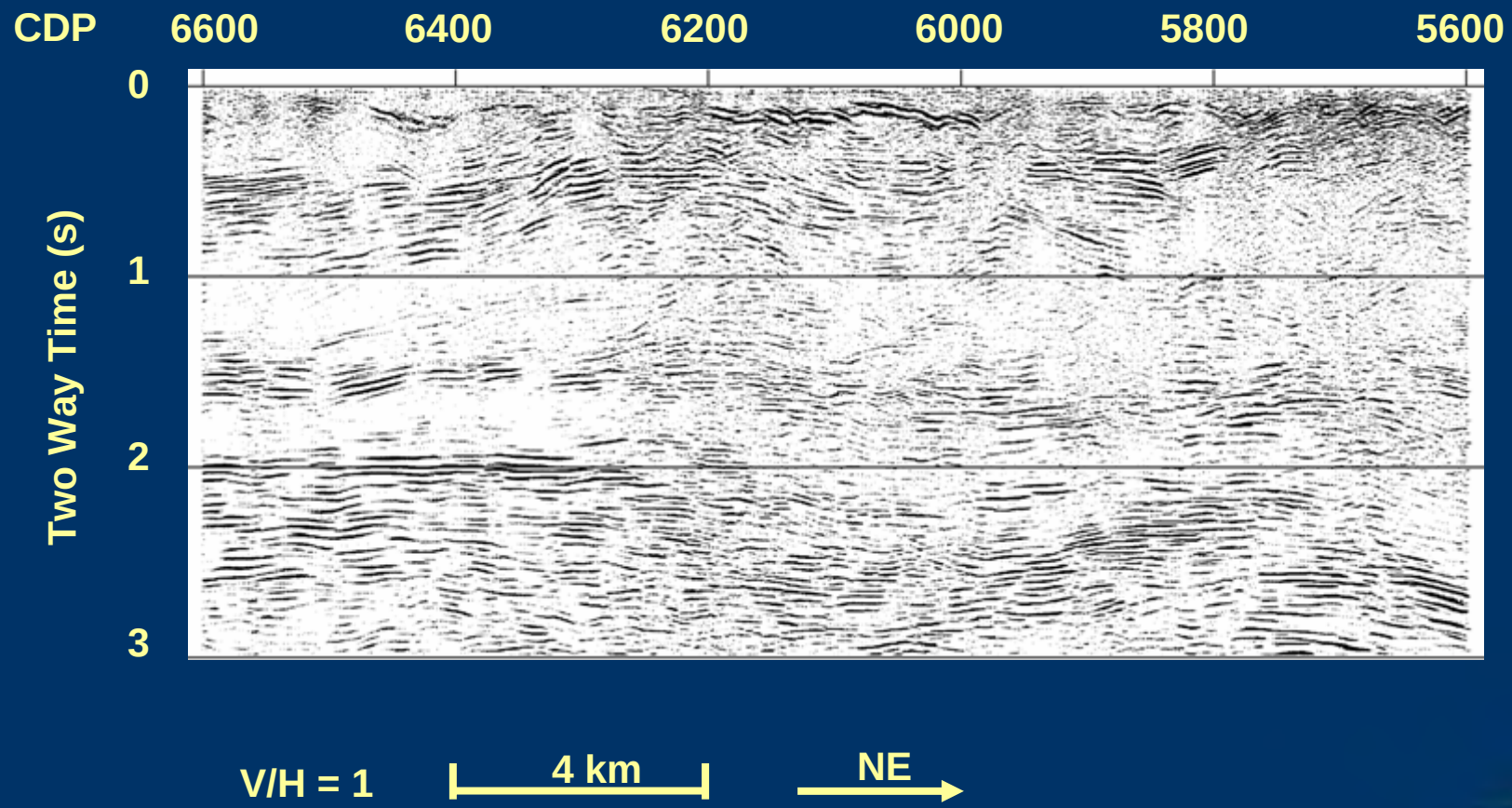


Thin Permian sediments over basement

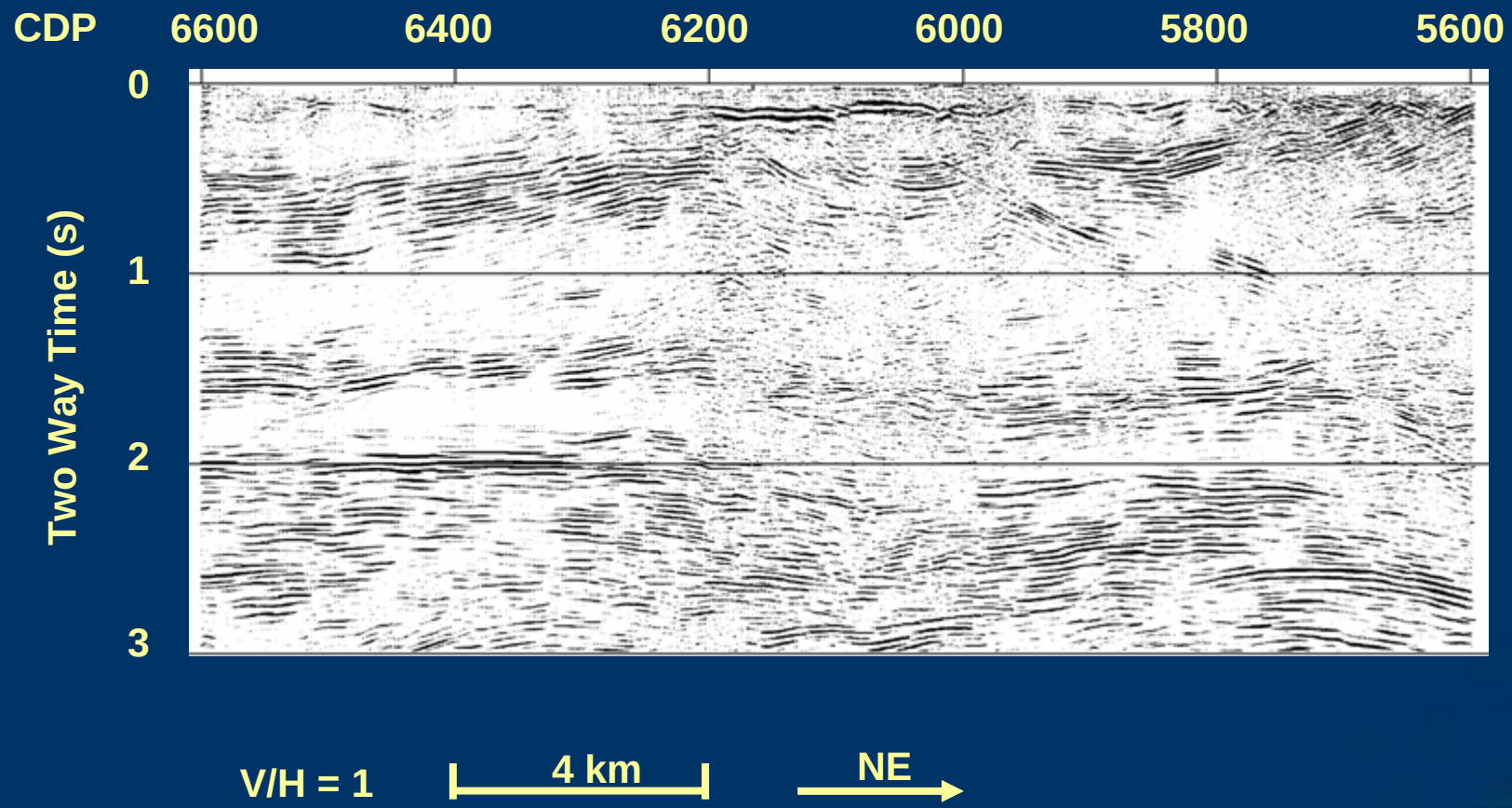


Thick Permian sediments over basement

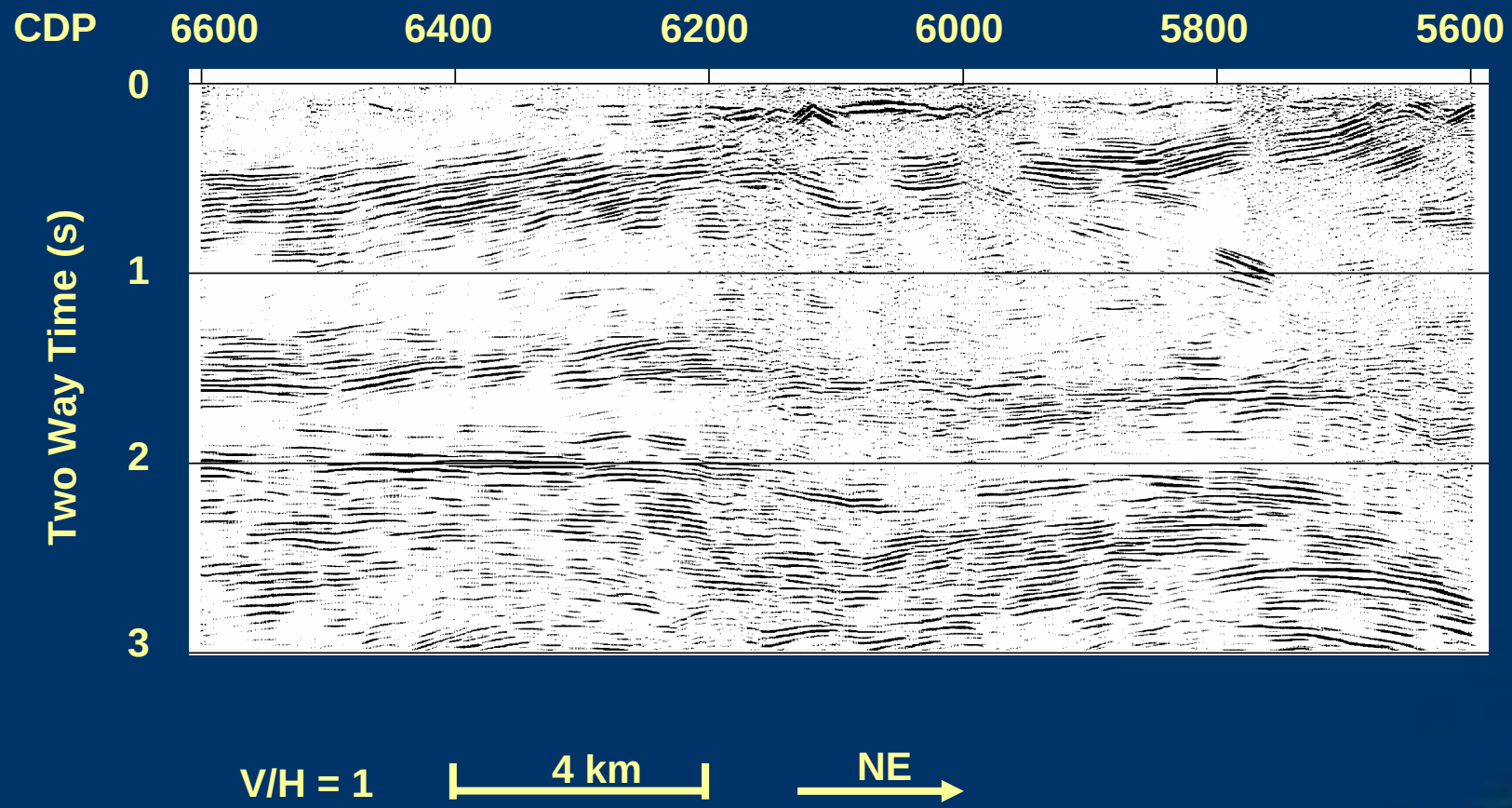
Line 05GA-T3 – No statics



Line 05GA-T3 – Refraction statics

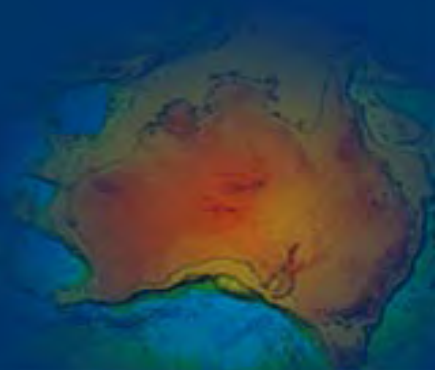


Line 05GA-T3 – Plus autostatics

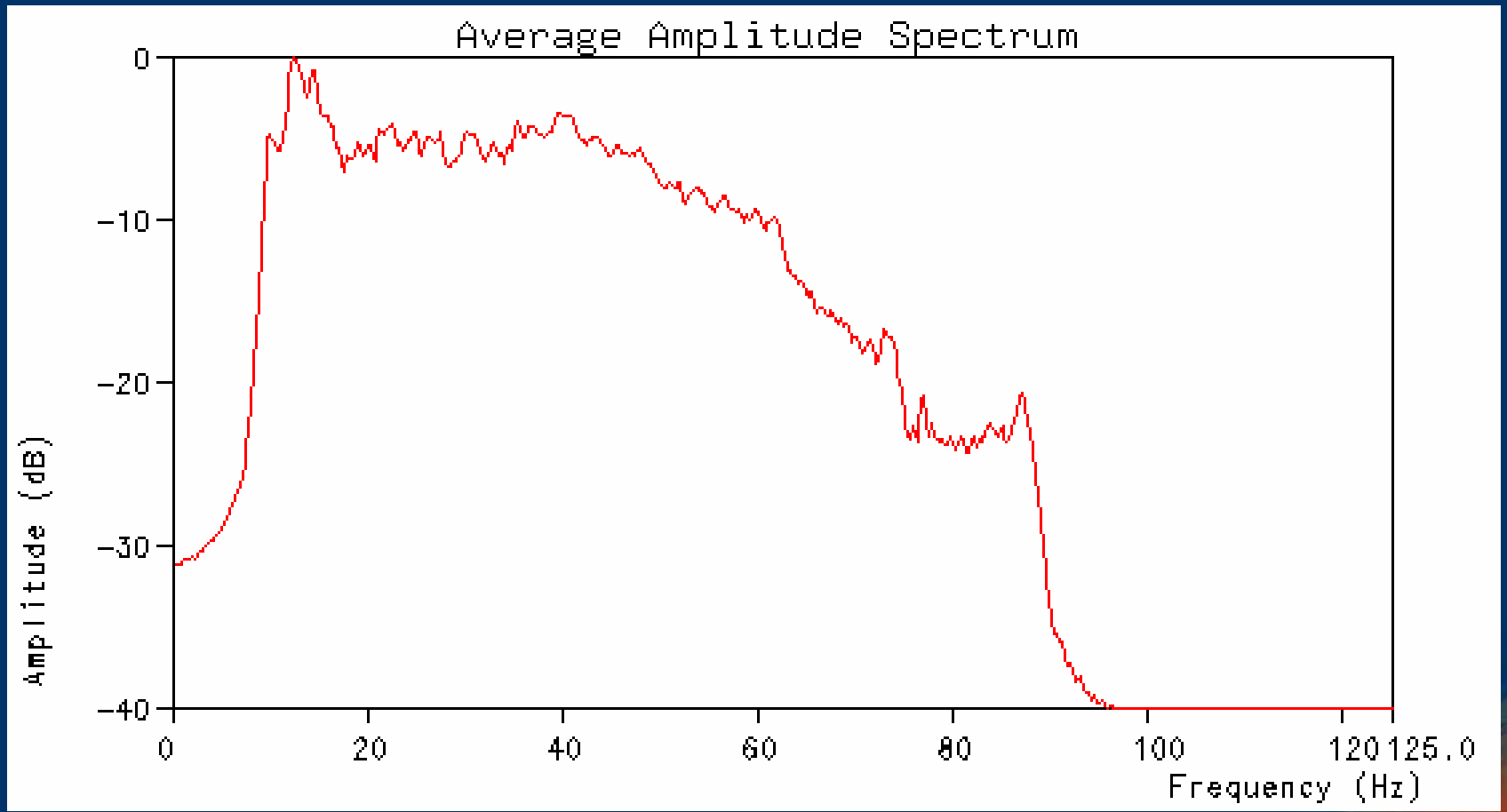


Spectral Equalisation

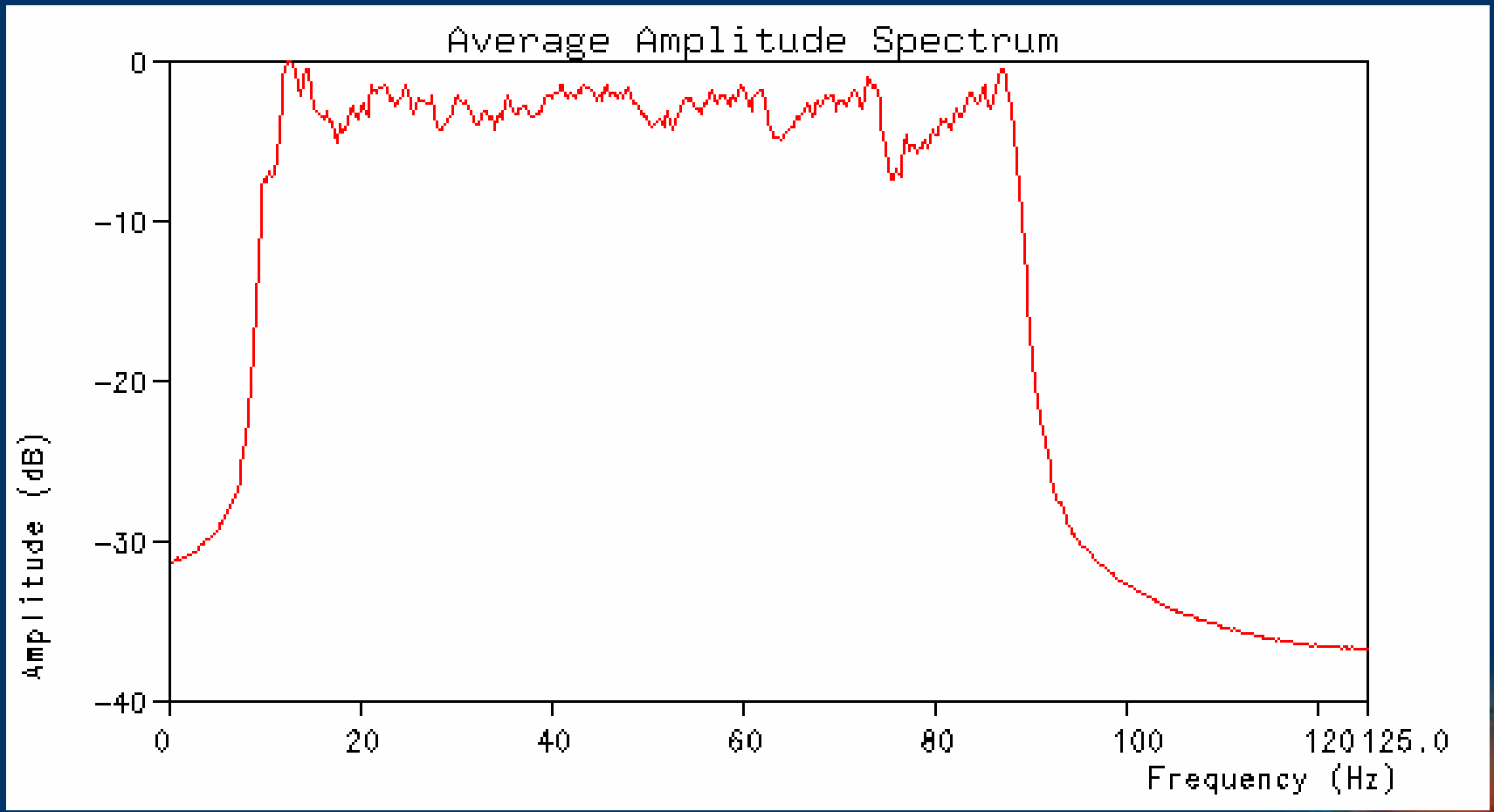
Boosts high frequencies relative to low frequencies, thus suppressing low frequency source generated noise



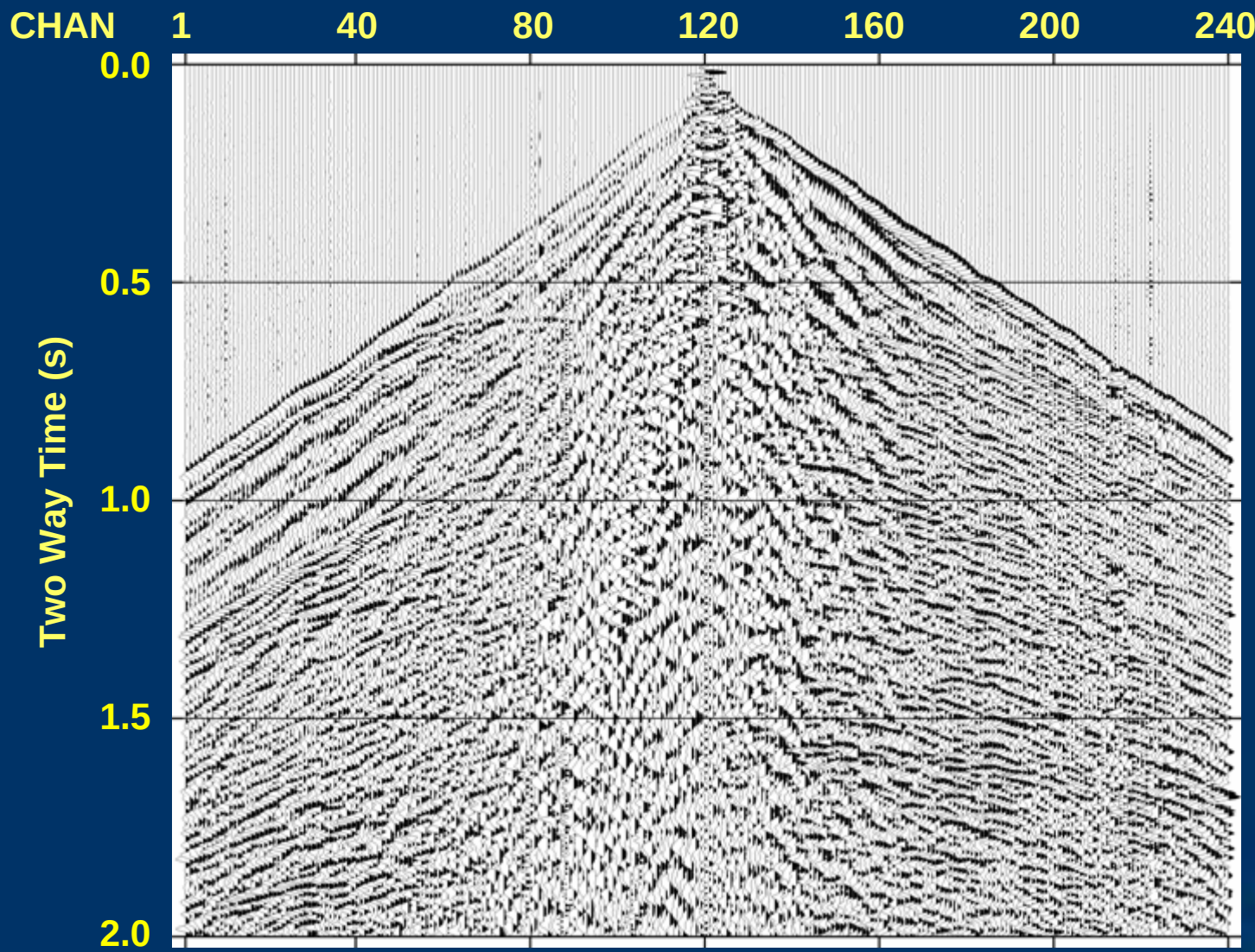
Frequency Spectrum - Pre speq



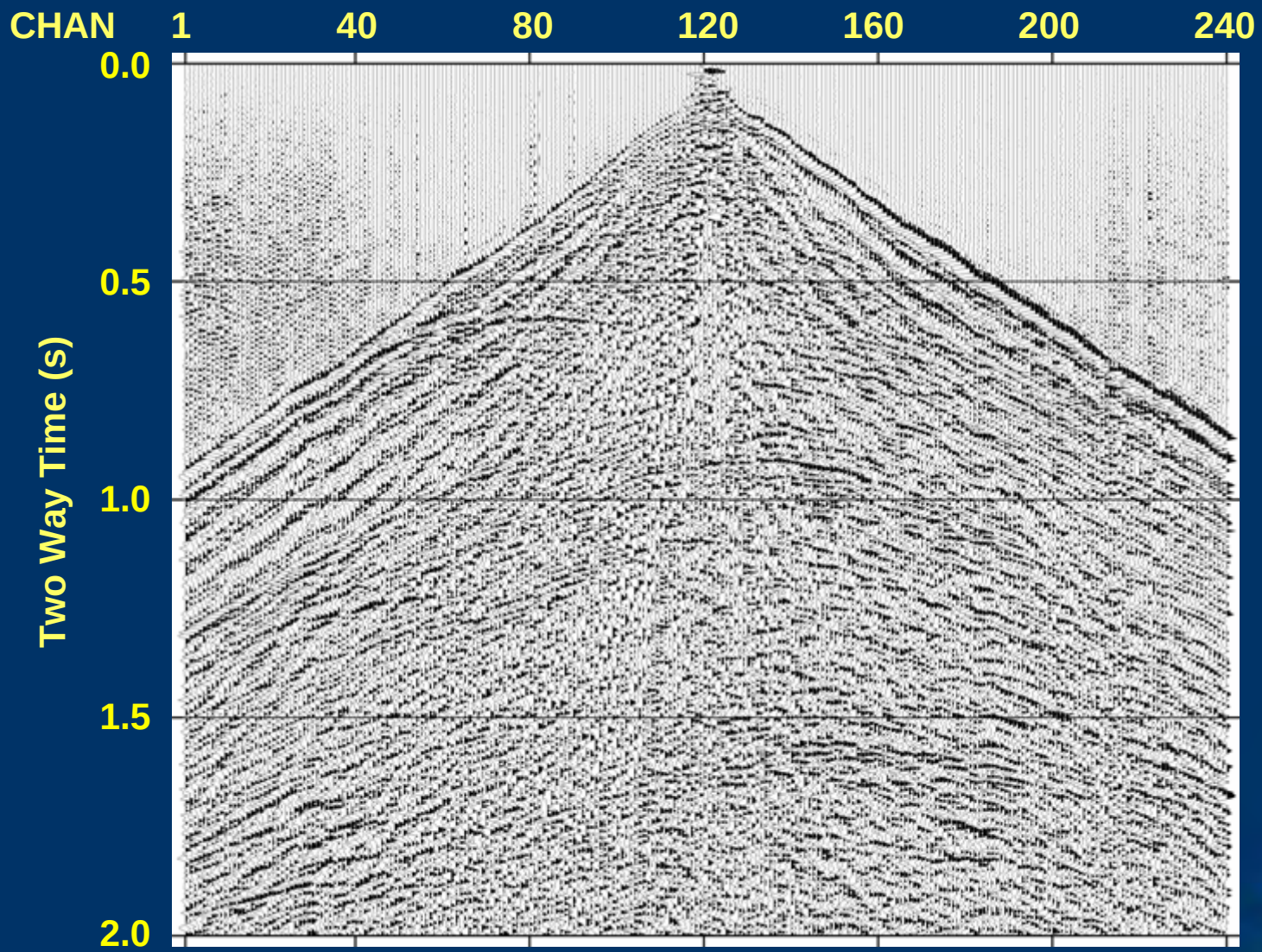
Frequency Spectrum - Post speq



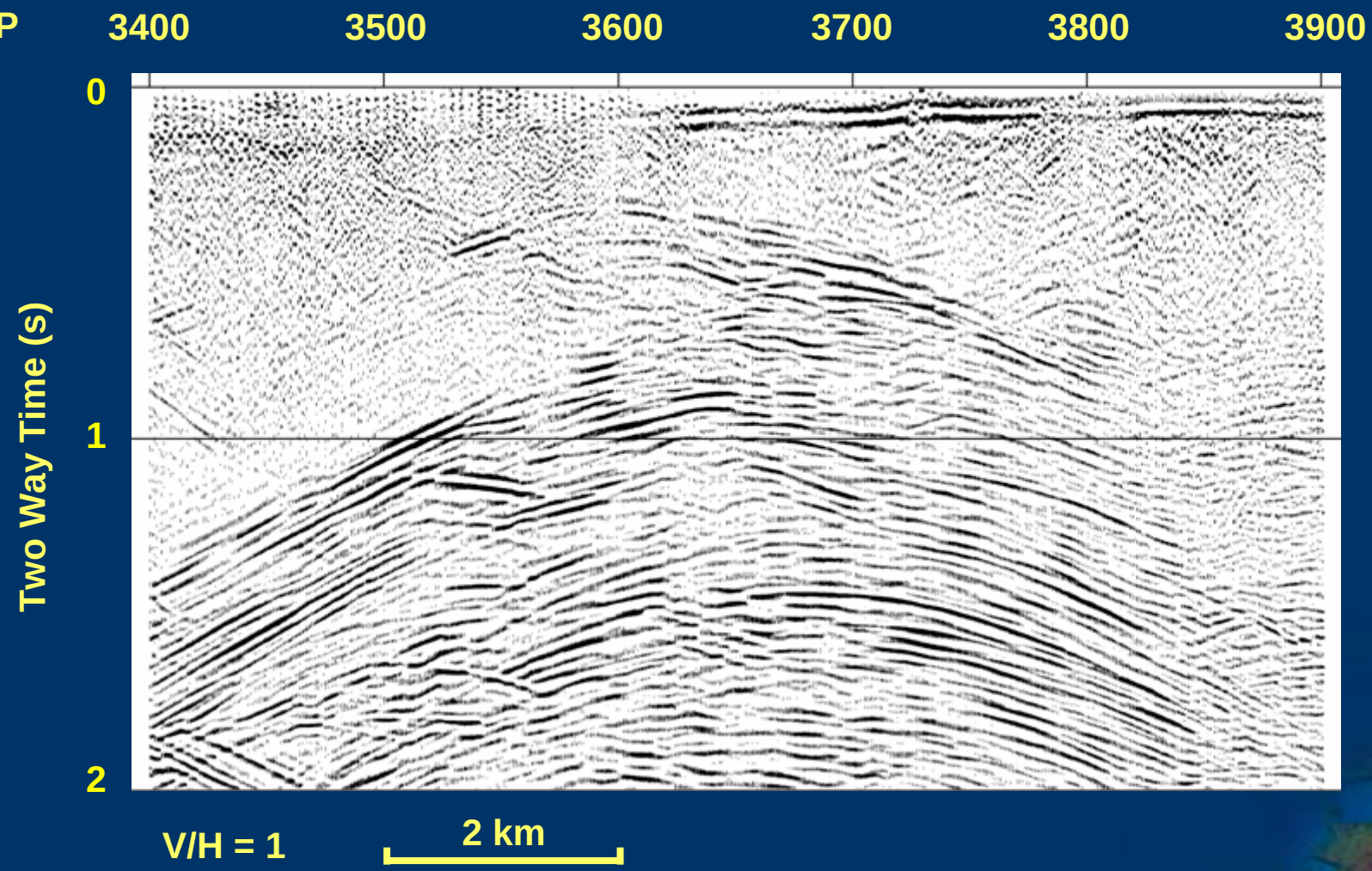
Shot Record - Pre speq



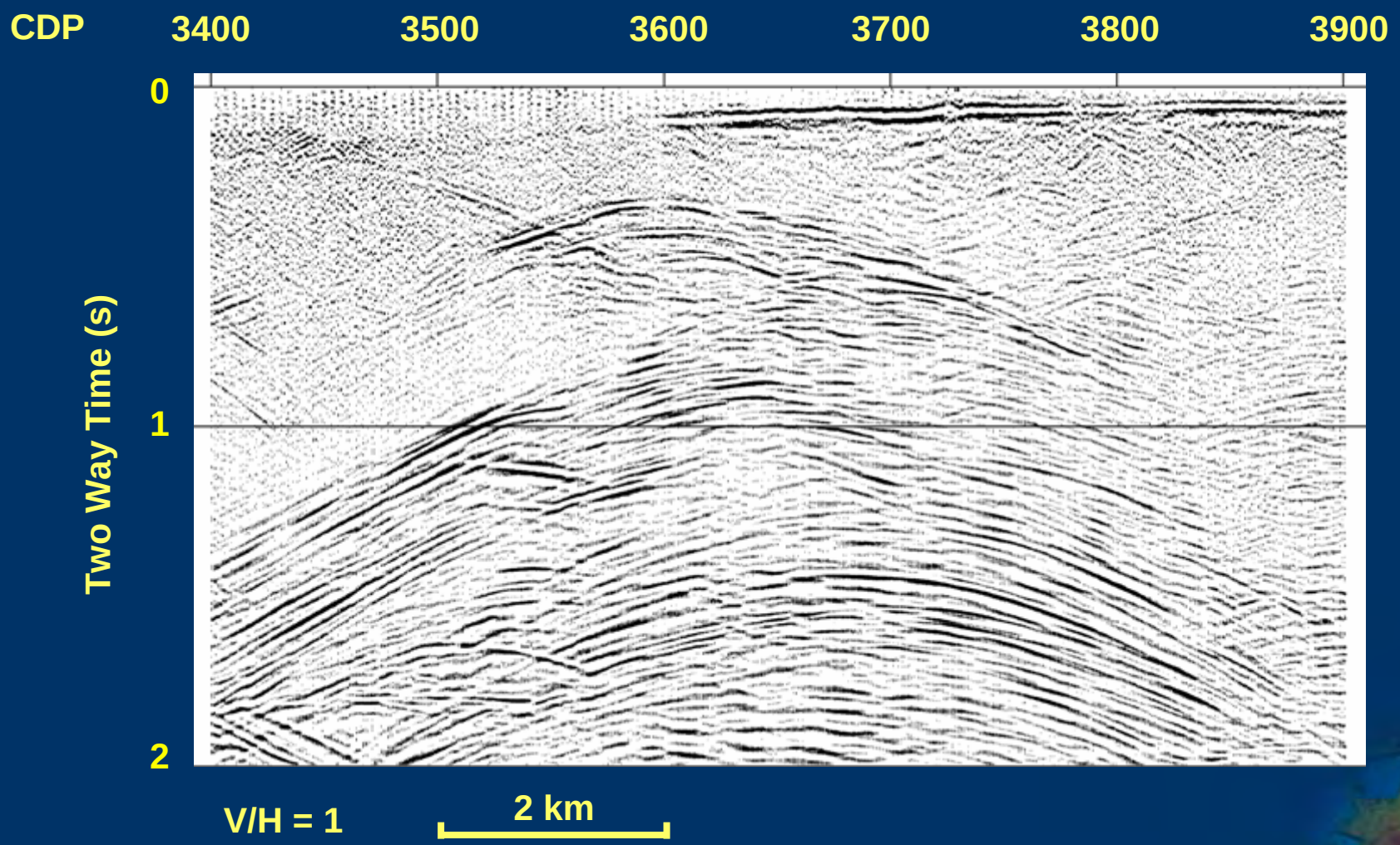
Shot Record - Post speq



Stack Section - Pre speq



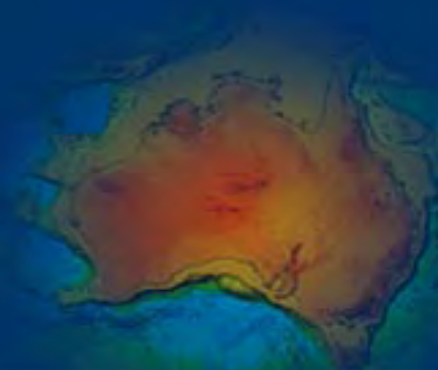
Stack Section - Post speq



Stacking (NMO) Velocity Analysis

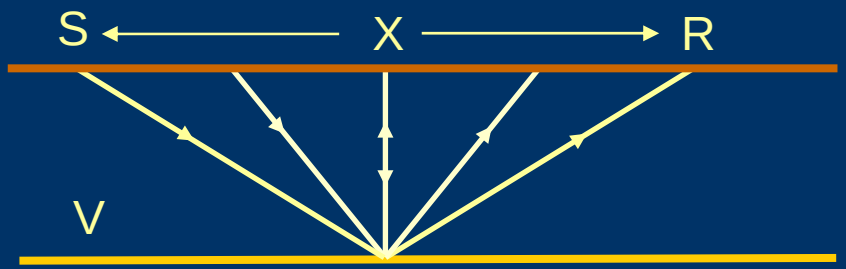
NMO correction corrects for non-coincidence of source and receivers

Stacking velocity is the velocity producing optimum stack across a CDP gather



Normal Moveout (NMO) Correction

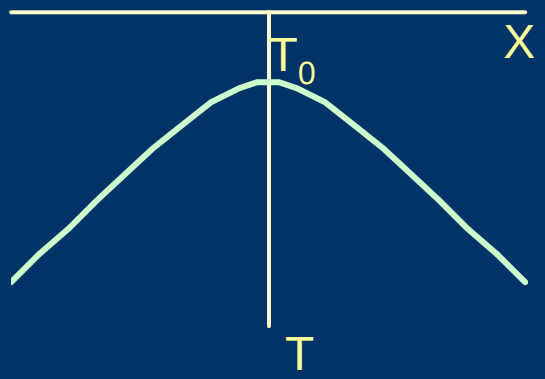
Horizontal reflector



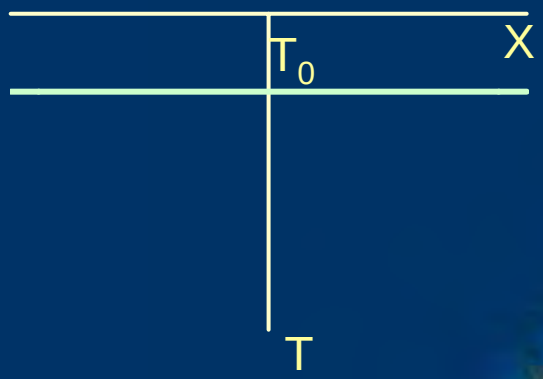
Moveout relationship

$$T^2 = T_0^{\,2} + X^2 / V^2$$

Uncorrected CDP gather

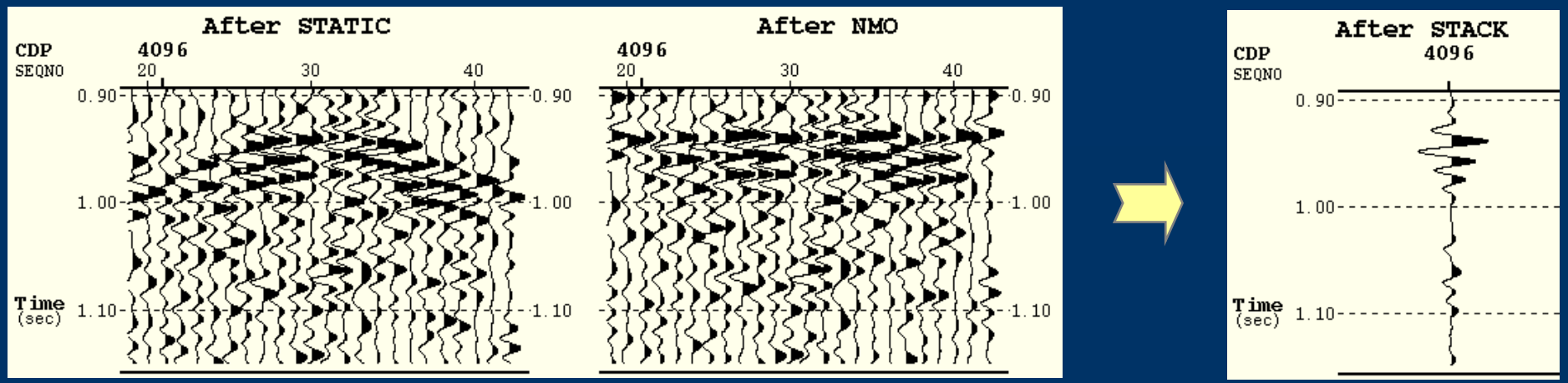


Corrected CDP gather



Normal Moveout (NMO) Correction and Stack

Uncorrected CDP gather **Corrected CDP gather** **Stacked seismic trace**



Stacking improves signal to noise by √n, where n is the fold

n	10	60	120
√n	3	8	11

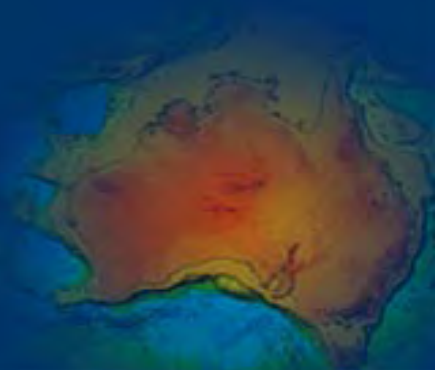
Stacking velocities in hard rock

Higher velocity means less moveout, so easier to stack at TWT > 2 s, but can't convert to depth!

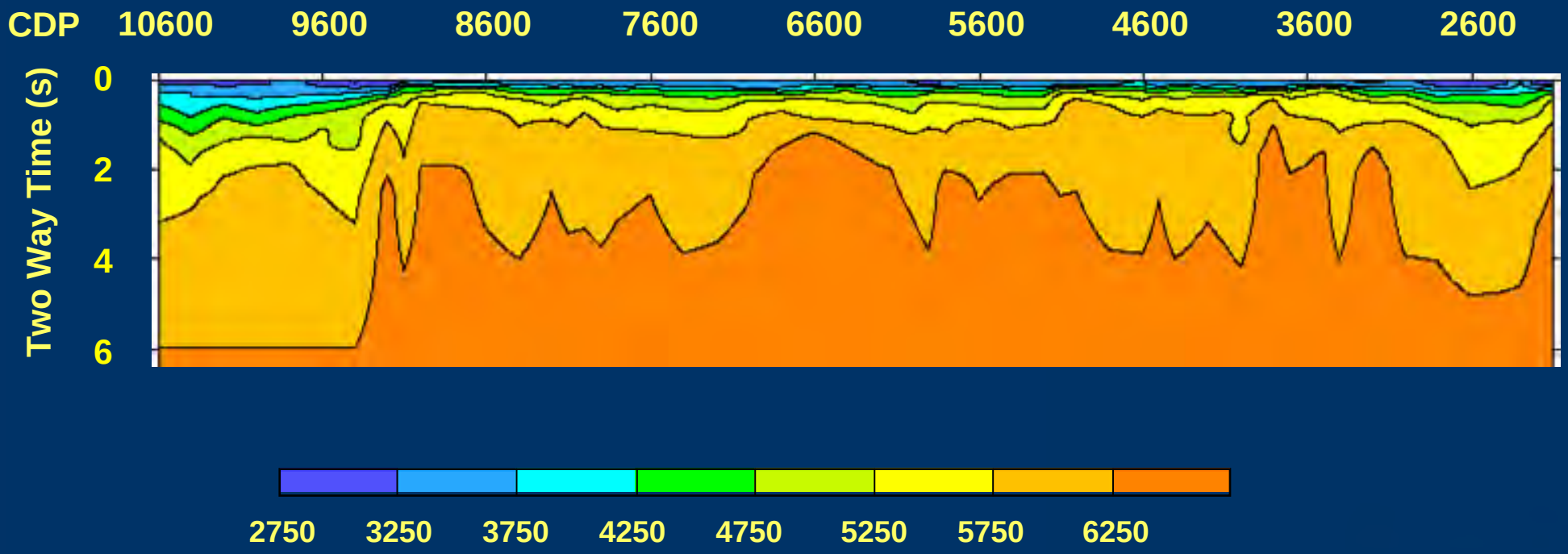
Velocity analysis is most critical (& difficult) in the top ½ second where moveout is greatest (& fold lowest).

Velocity is sensitive to

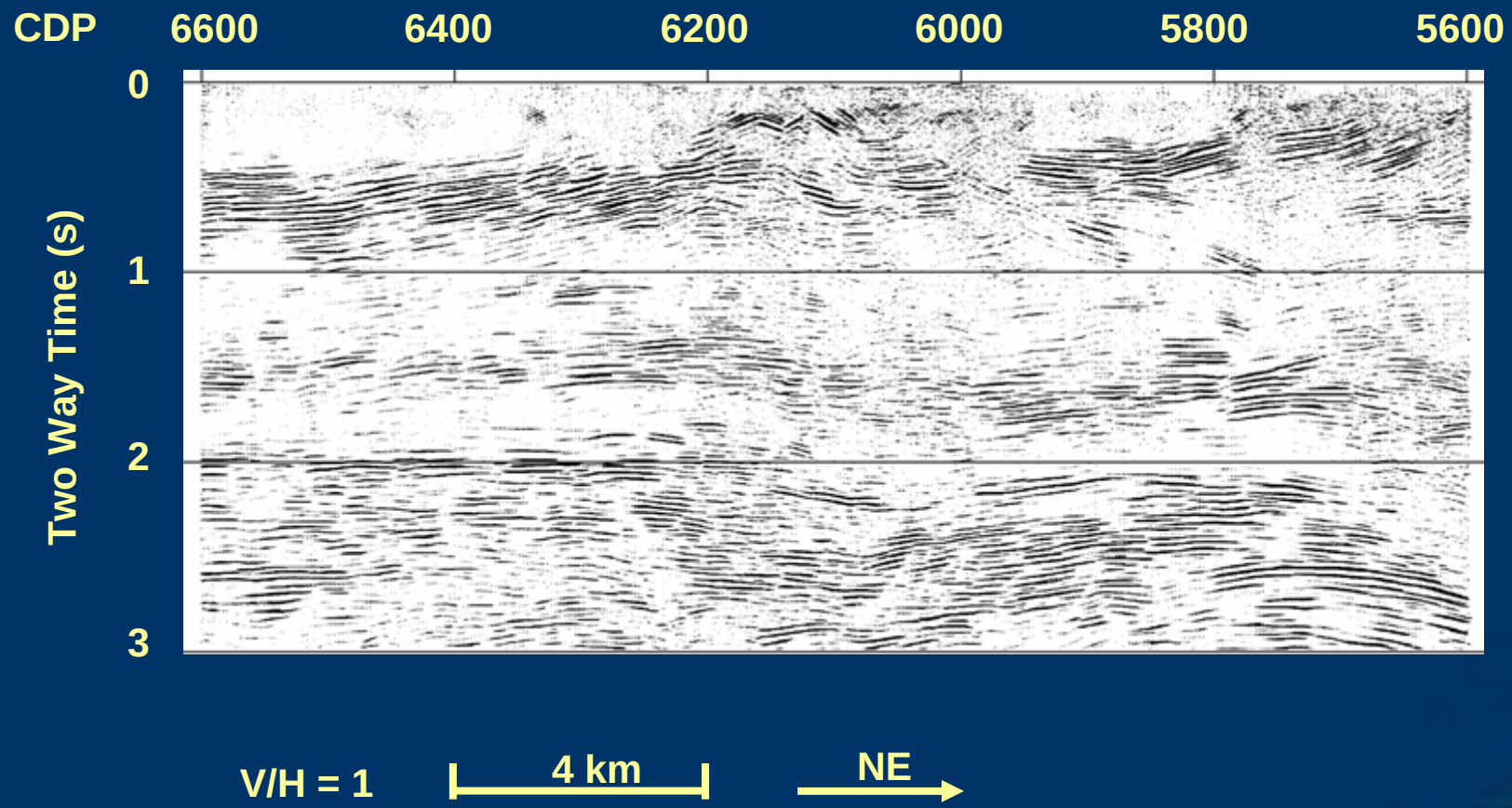
- Overlying low velocity layers
- Amount of static shift
- Dip of reflectors



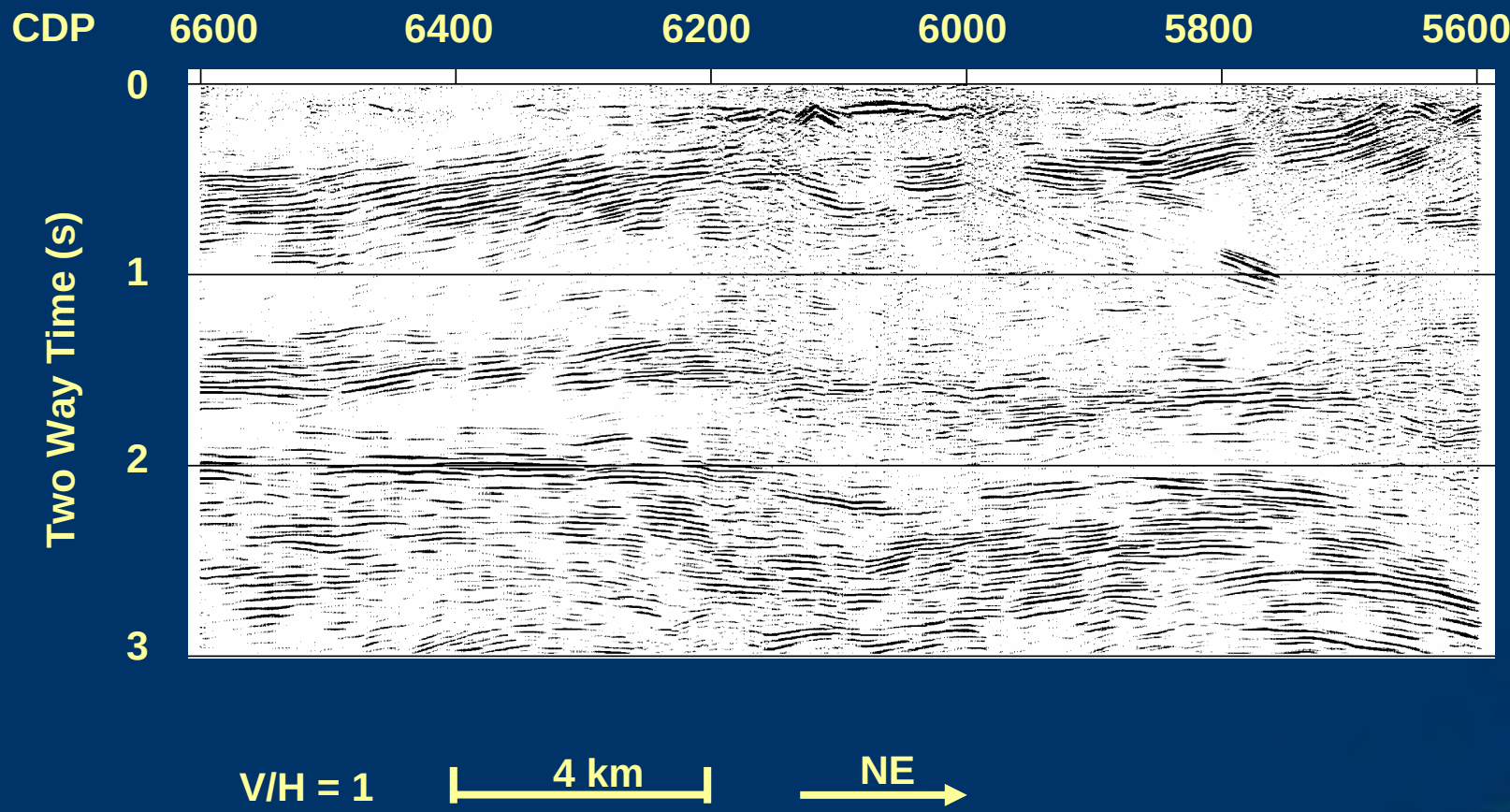
Normal Moveout (NMO) Velocity for 05GA-T3



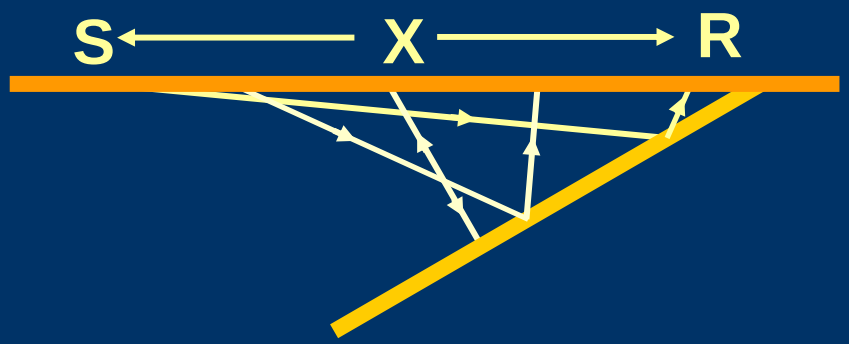
Line 05GA-T3 – Single velocity function

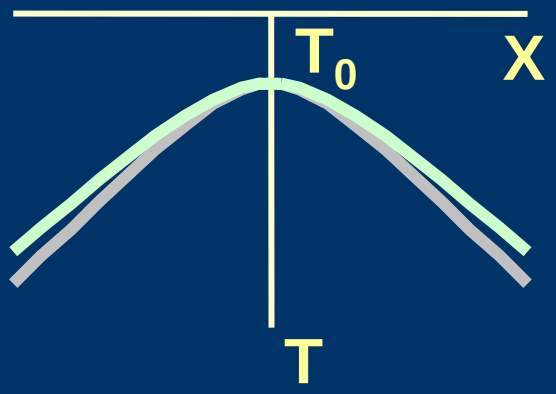


Line 05GA-T3 – Detailed velocity analysis

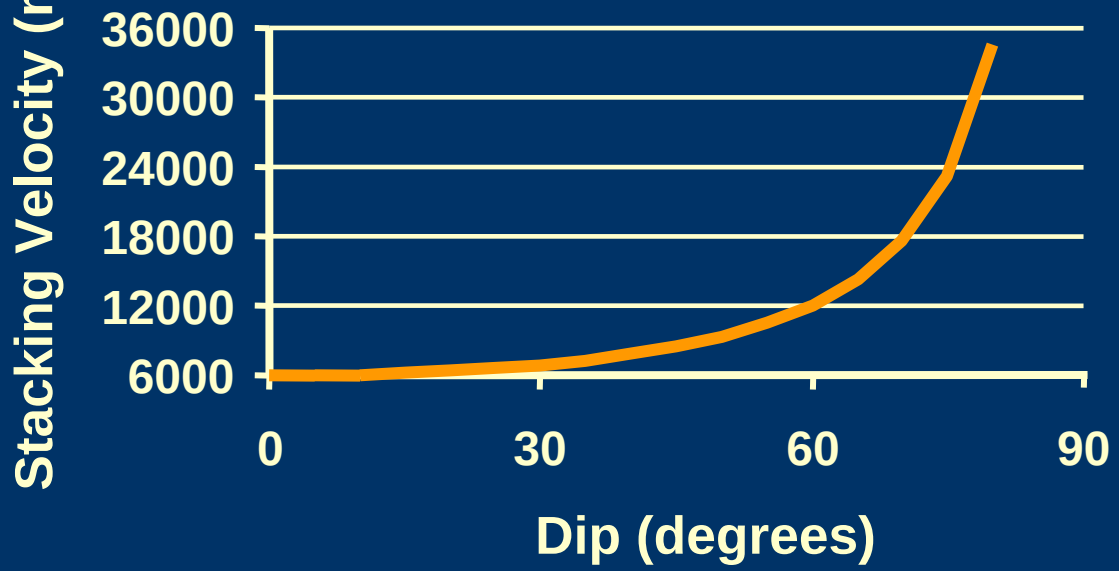


Effect of Dip on Stacking Velocity

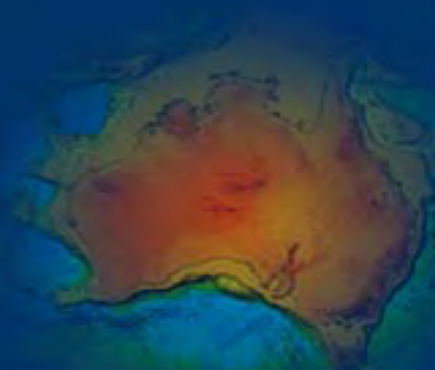




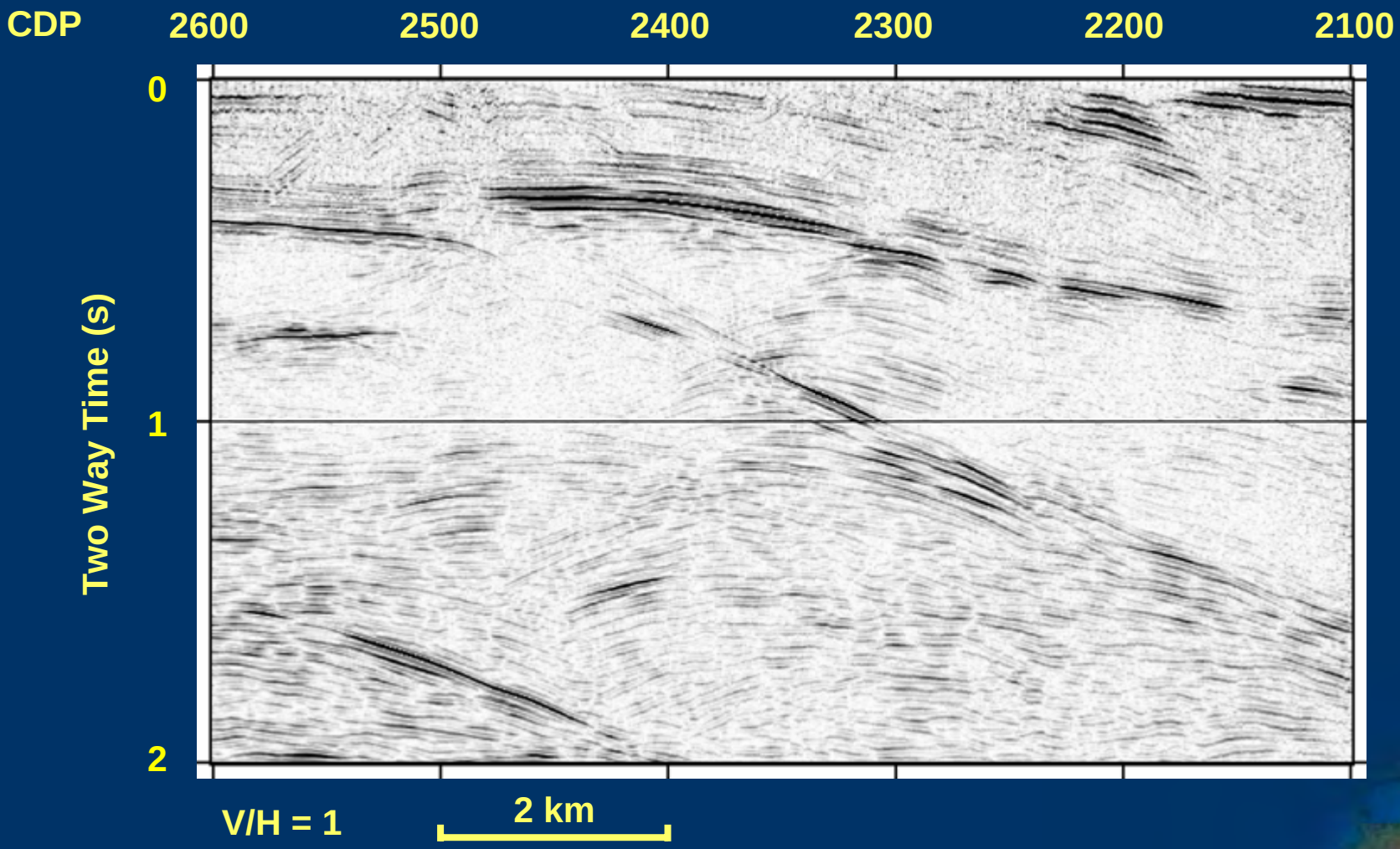
$$T^2 = T_0^2 + X^2 \cos^2 \alpha / V^2$$



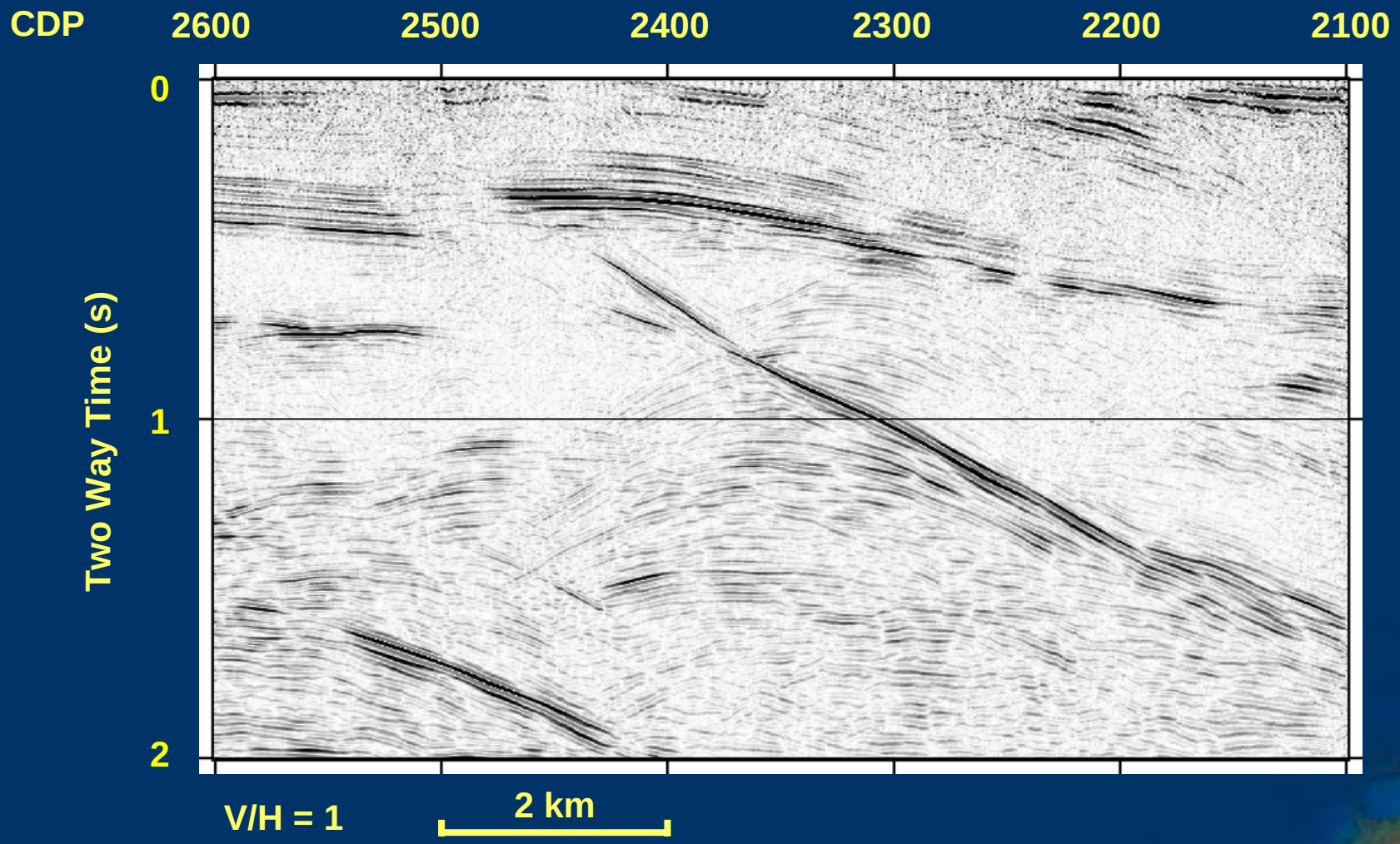
Need Dip Moveout Correction (DMO)



05GA-T3 - Stack

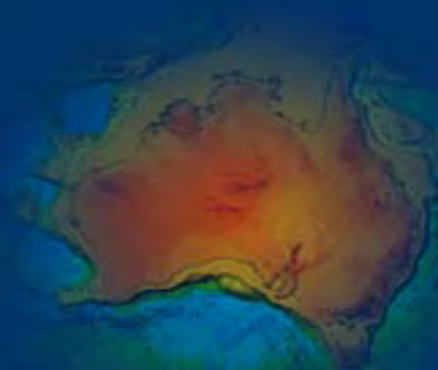


05GA-T3 - Stack with DMO

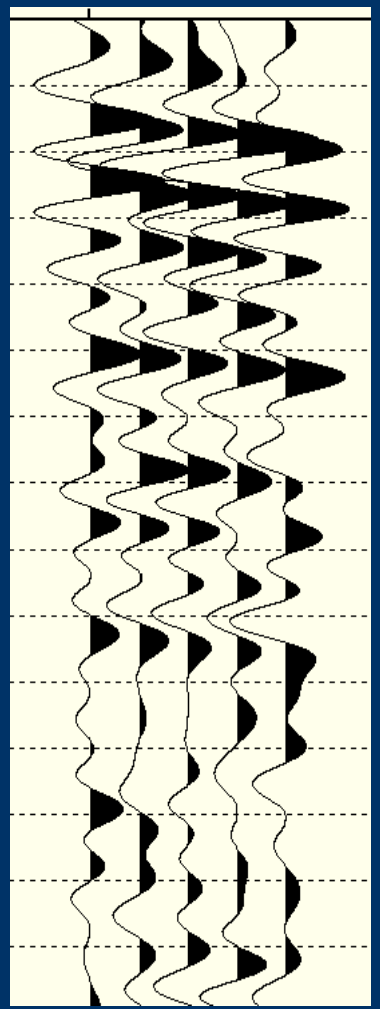


Migration

Moves reflectors to their correct positions



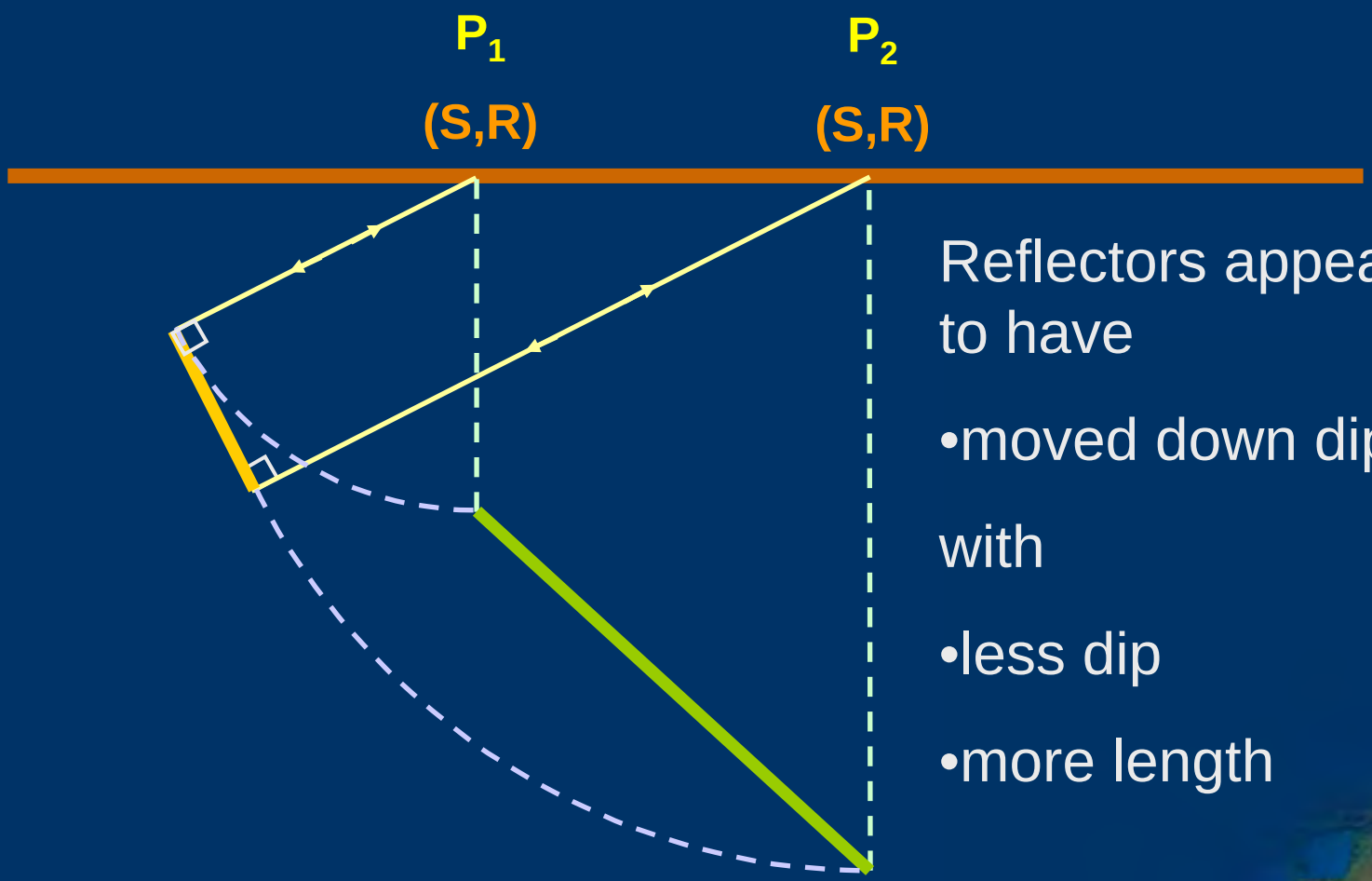
Seismic Section - Set of Stacked Traces



But ….

Seismic data are recorded in (two-way travel) time and the traces are displayed vertically with time increasing downwards

Imaging of Dipping Reflectors on Stack Section



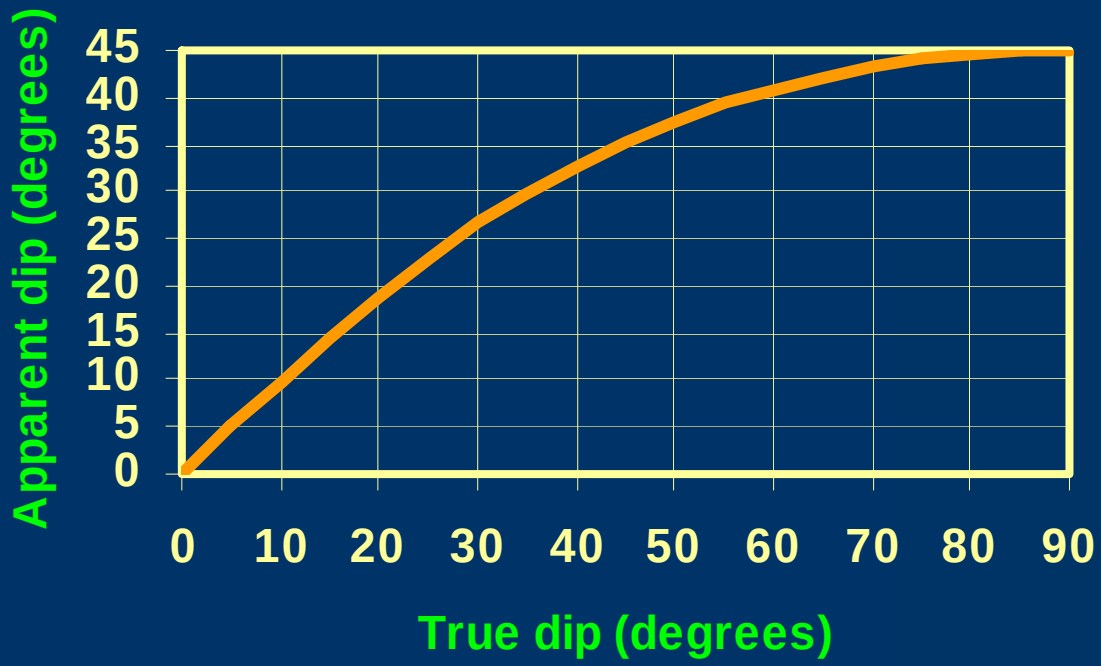
Reflectors appear to have

- moved down dip

with

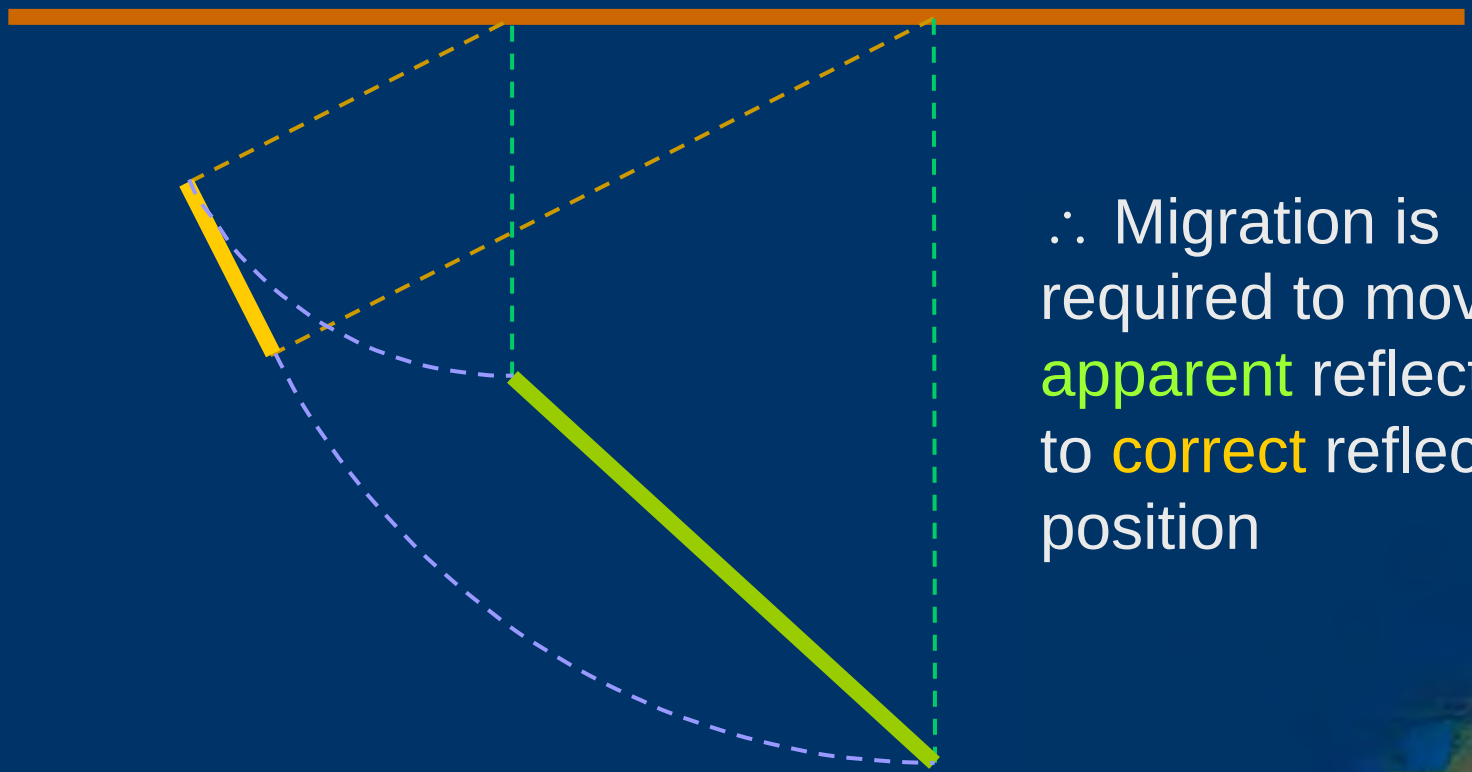
- less dip
- more length

Apparent Dips on Un-migrated Stack Sections



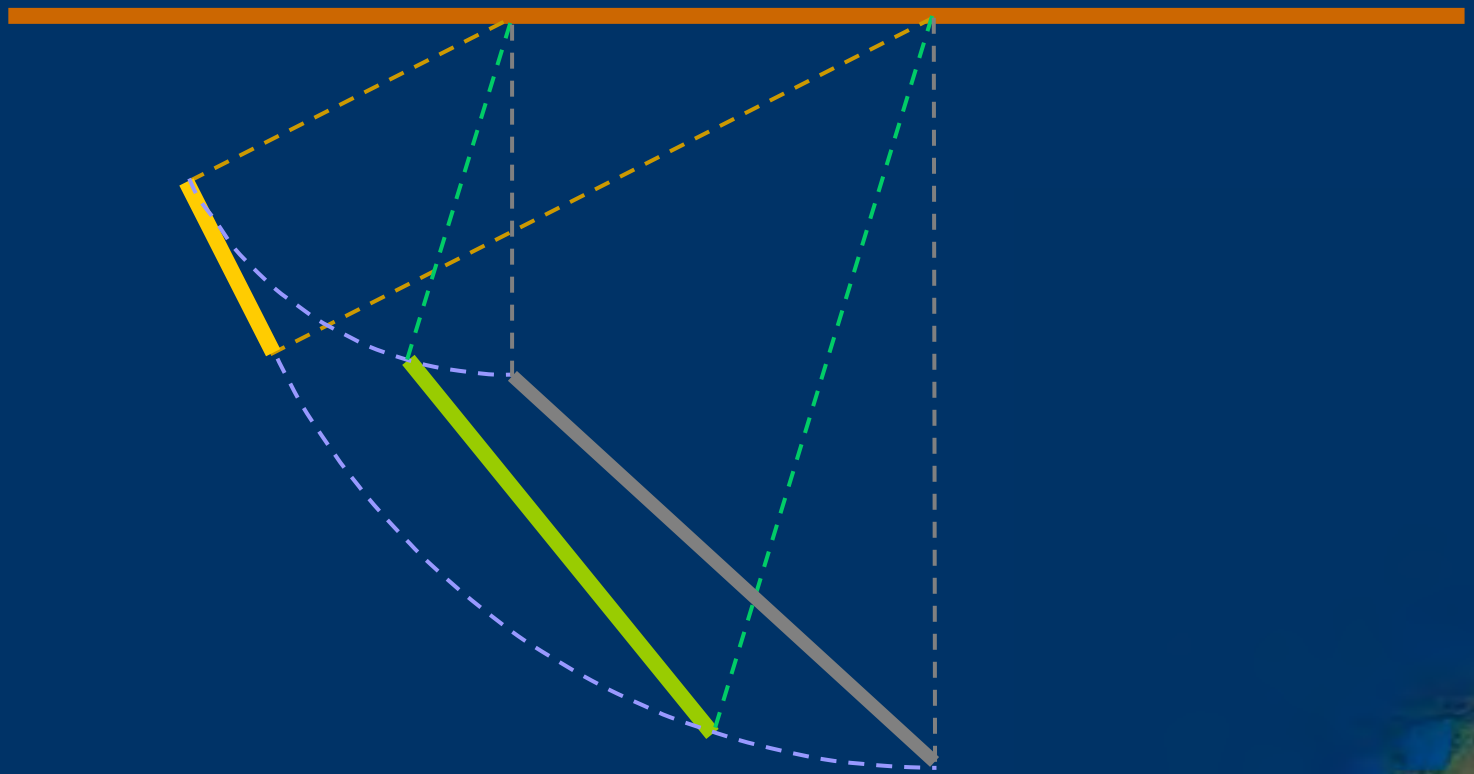
Note that the apparent dip will not exceed 45°

Migration of Dipping Reflector

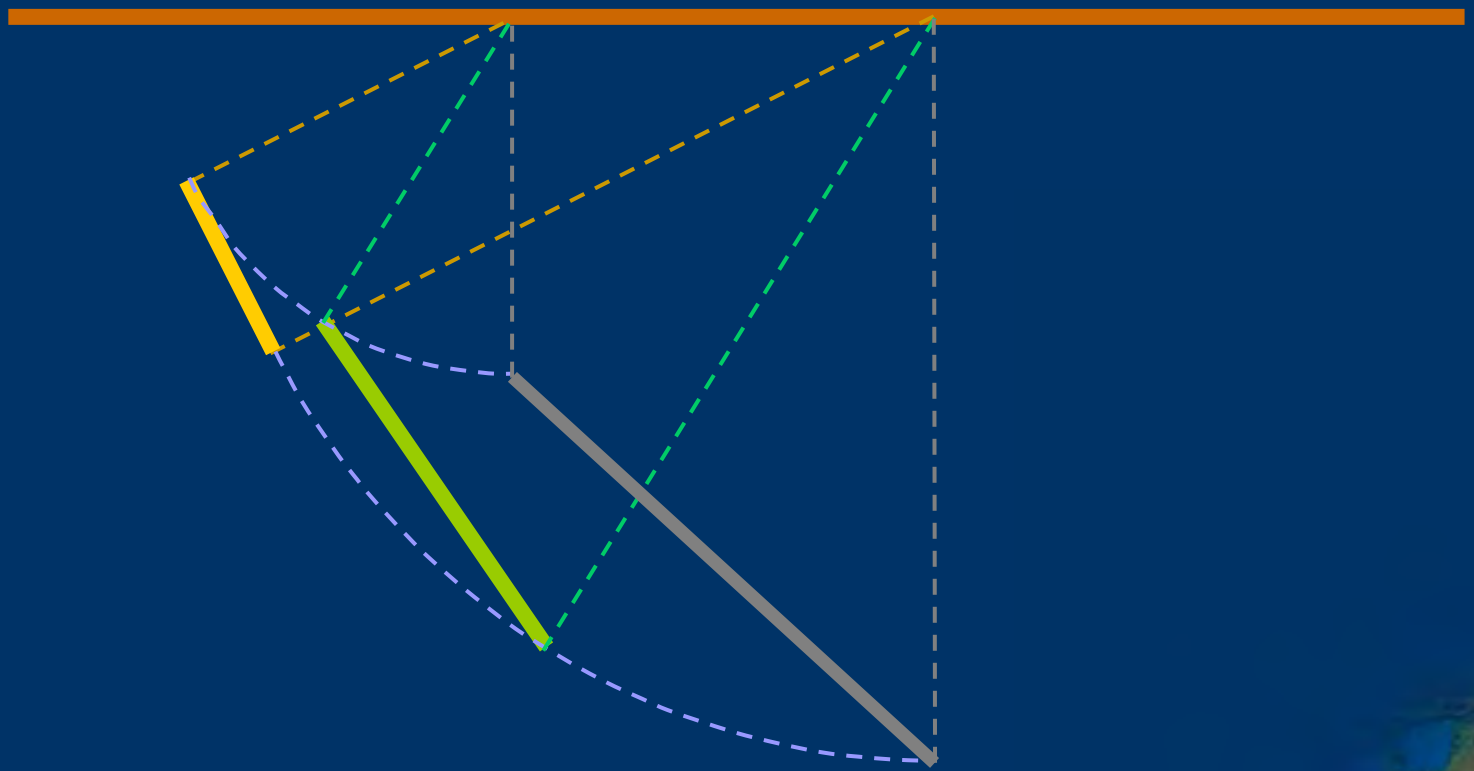


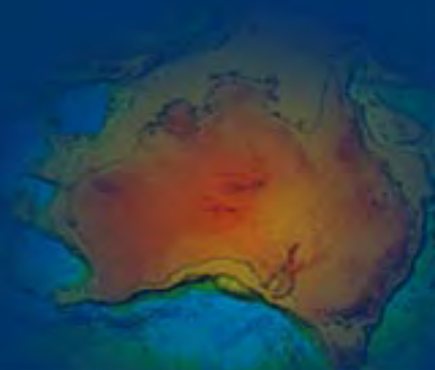
∴ Migration is required to move apparent reflector to correct reflector position

Migration of Dipping Reflector

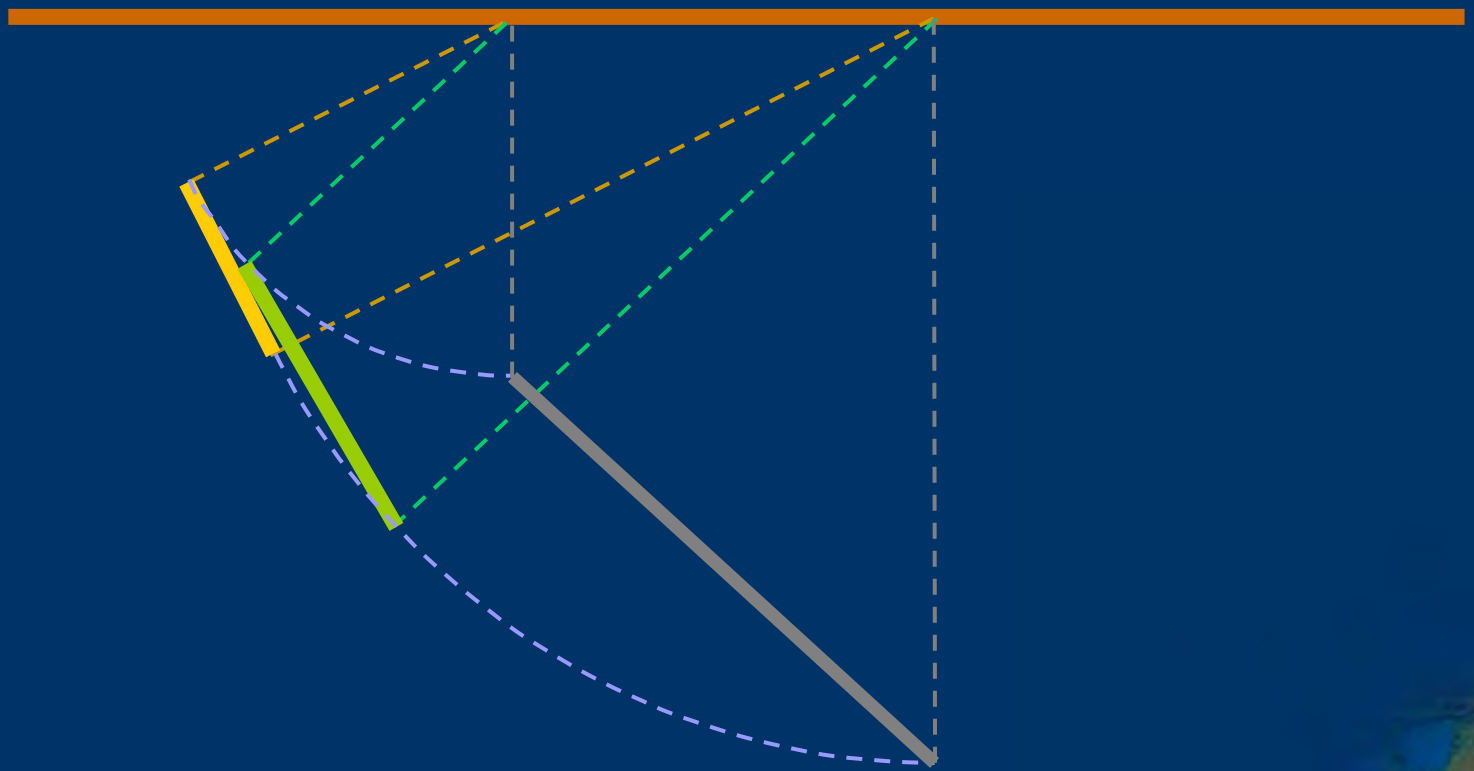


Migration of Dipping Reflector

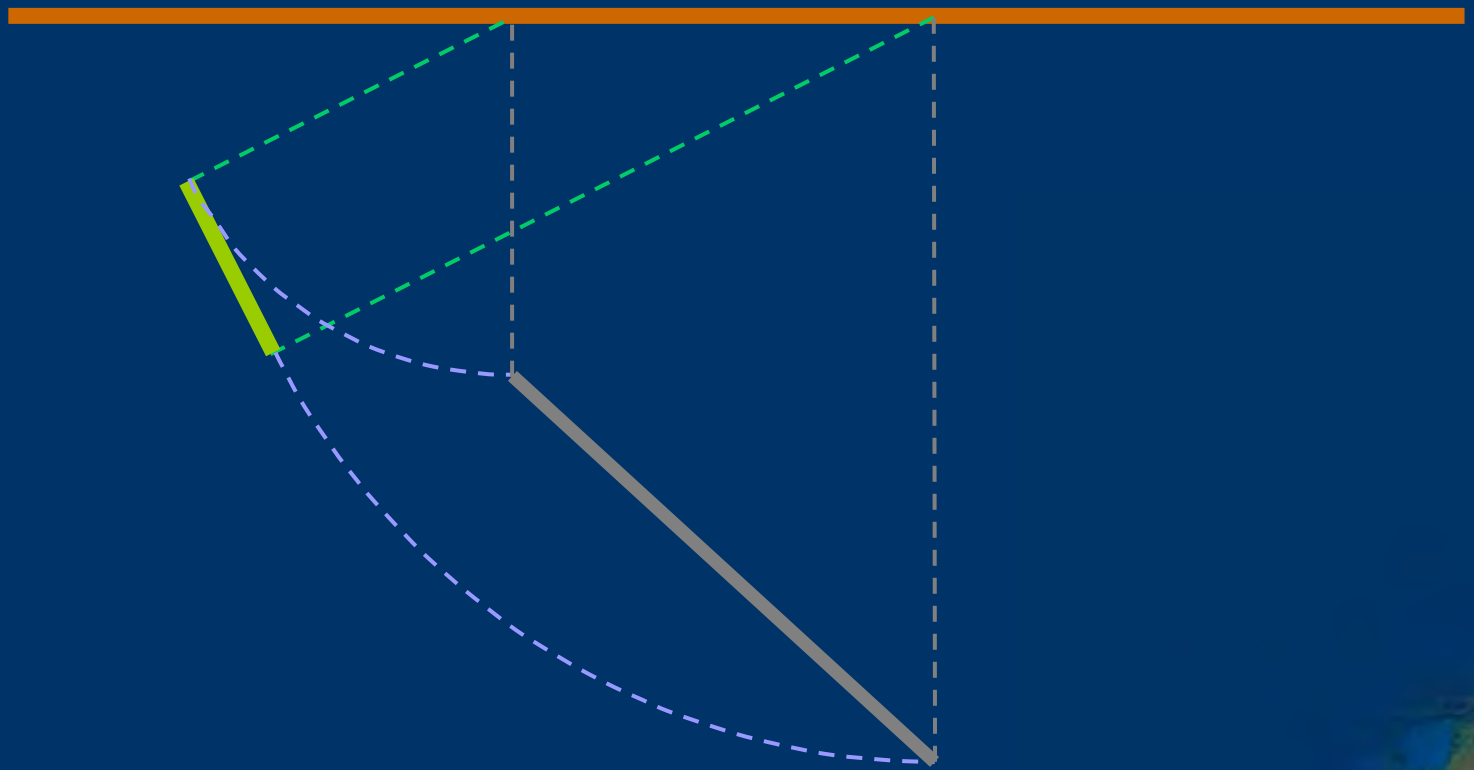


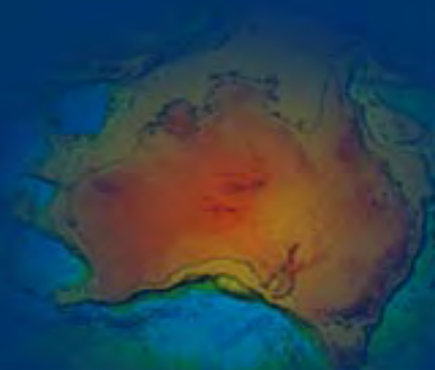


Migration of Dipping Reflector

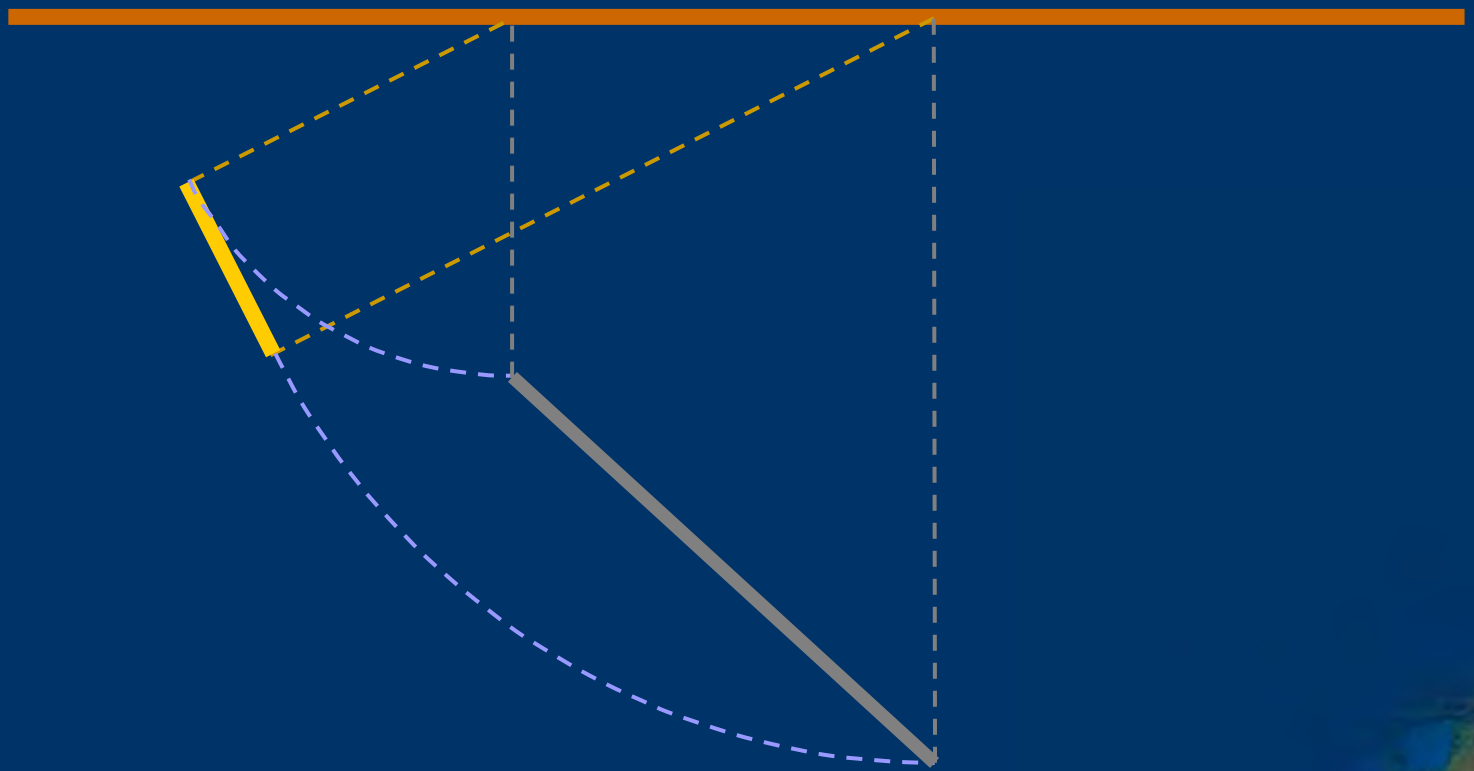


Migration of Dipping Reflector

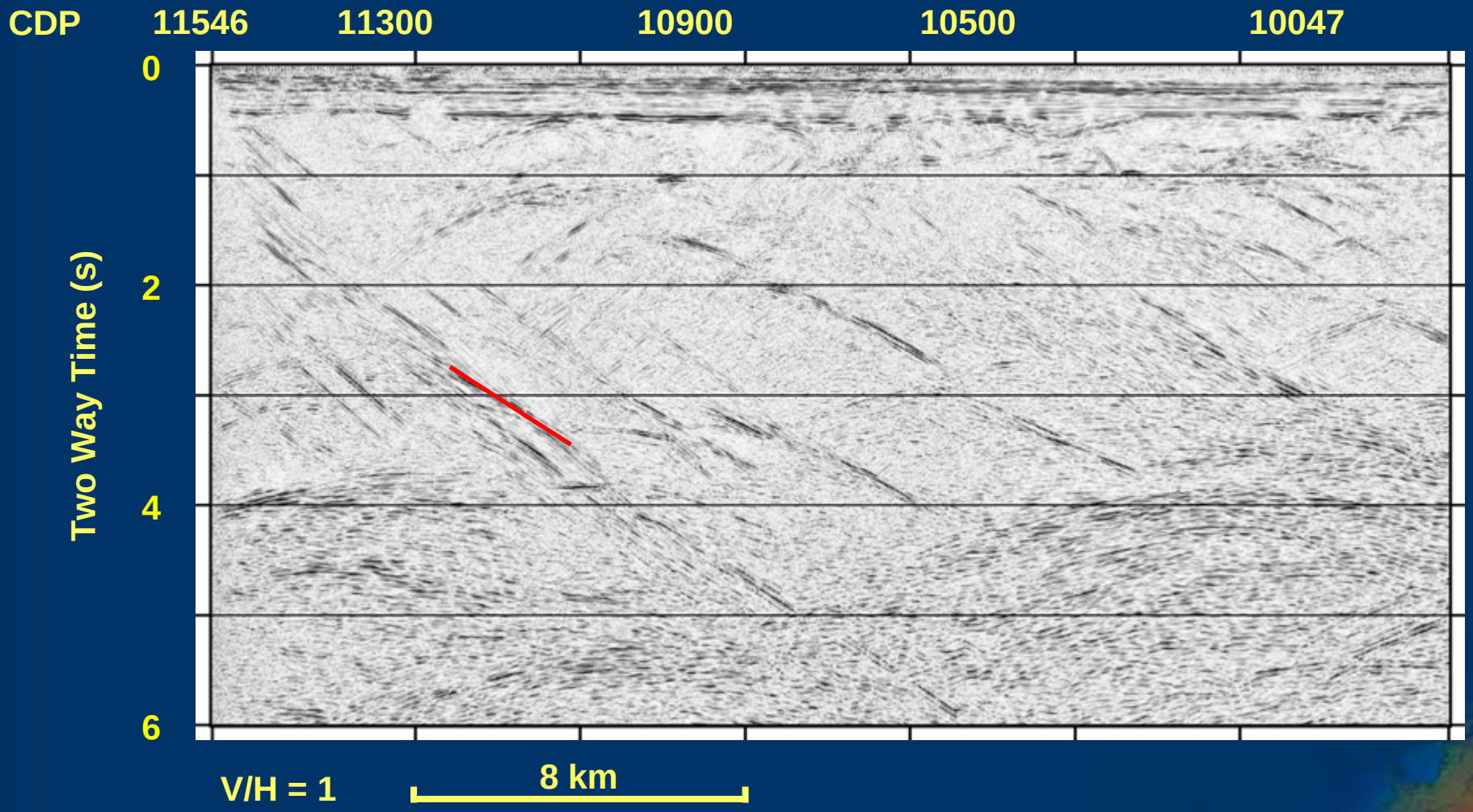




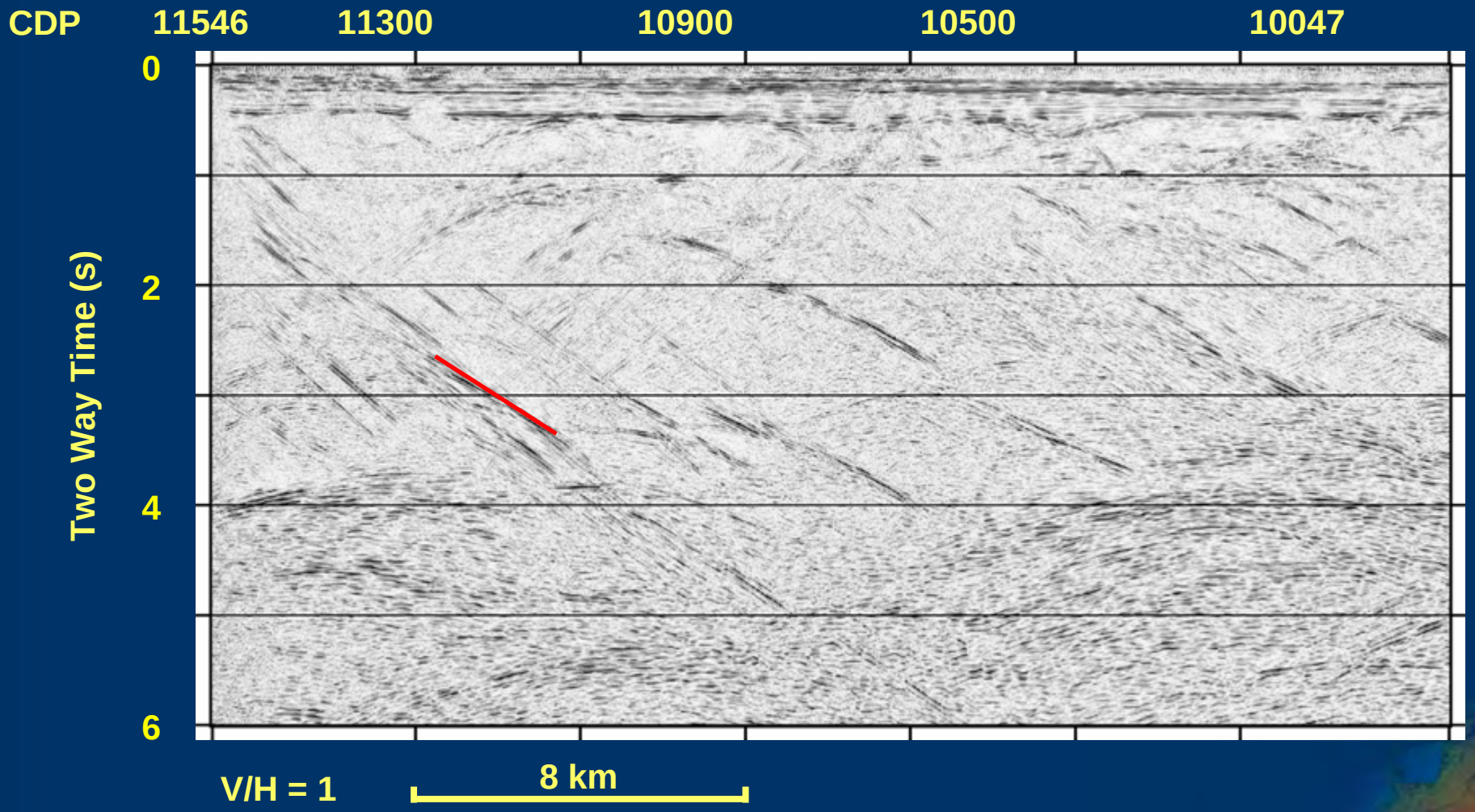
Migration of Dipping Reflector



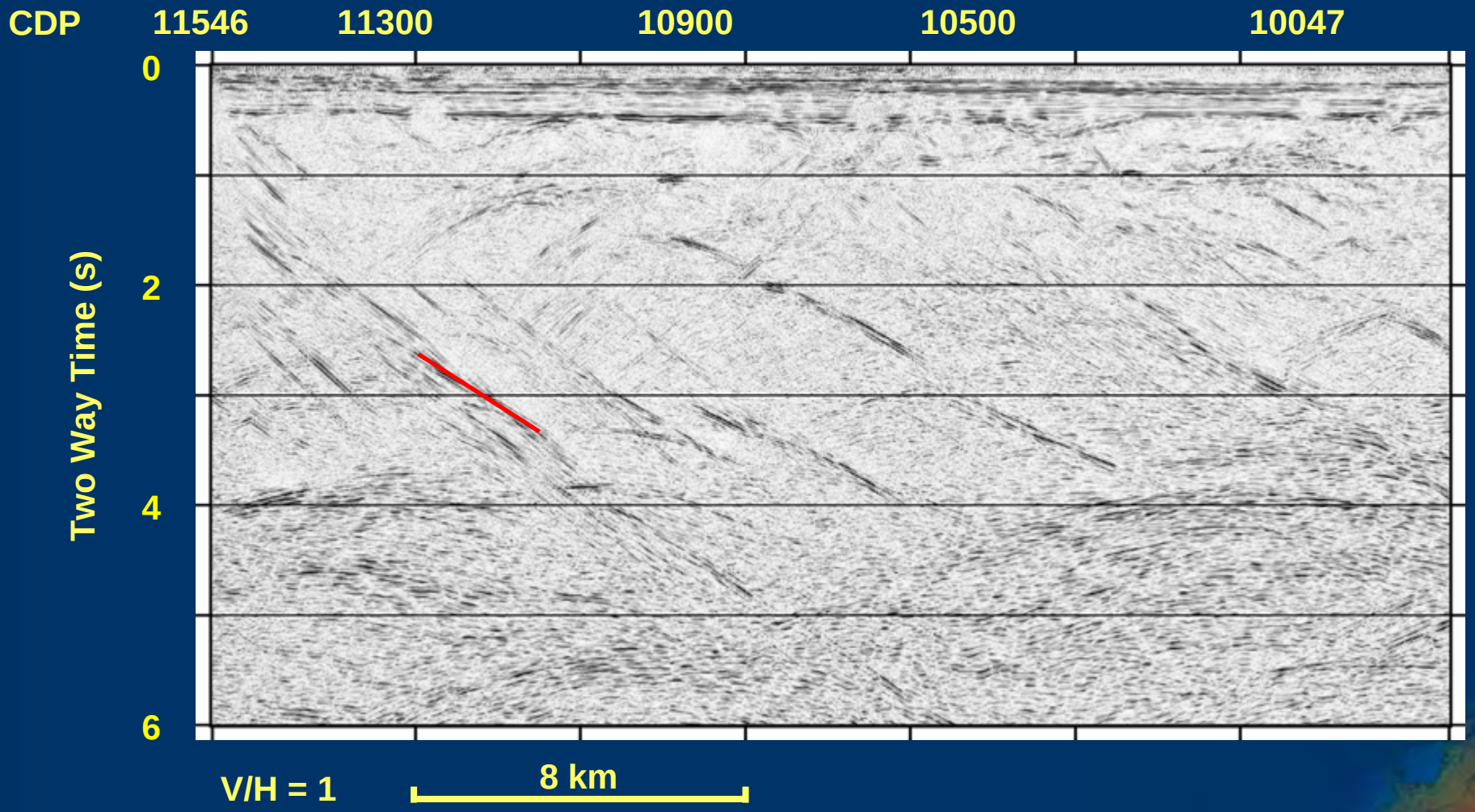
Examples: Migration 03GA-OD1



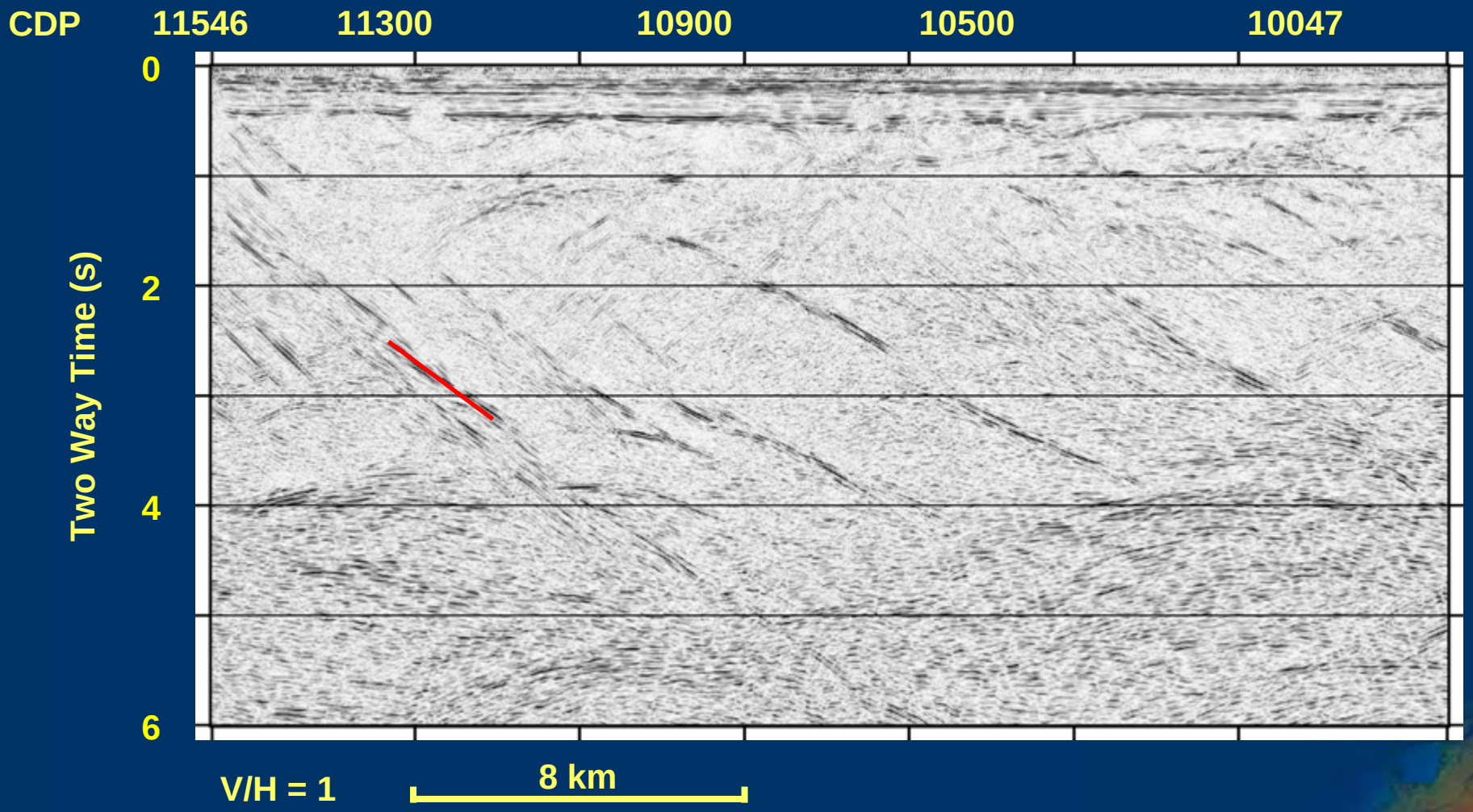
Examples: Migration 03GA-OD1



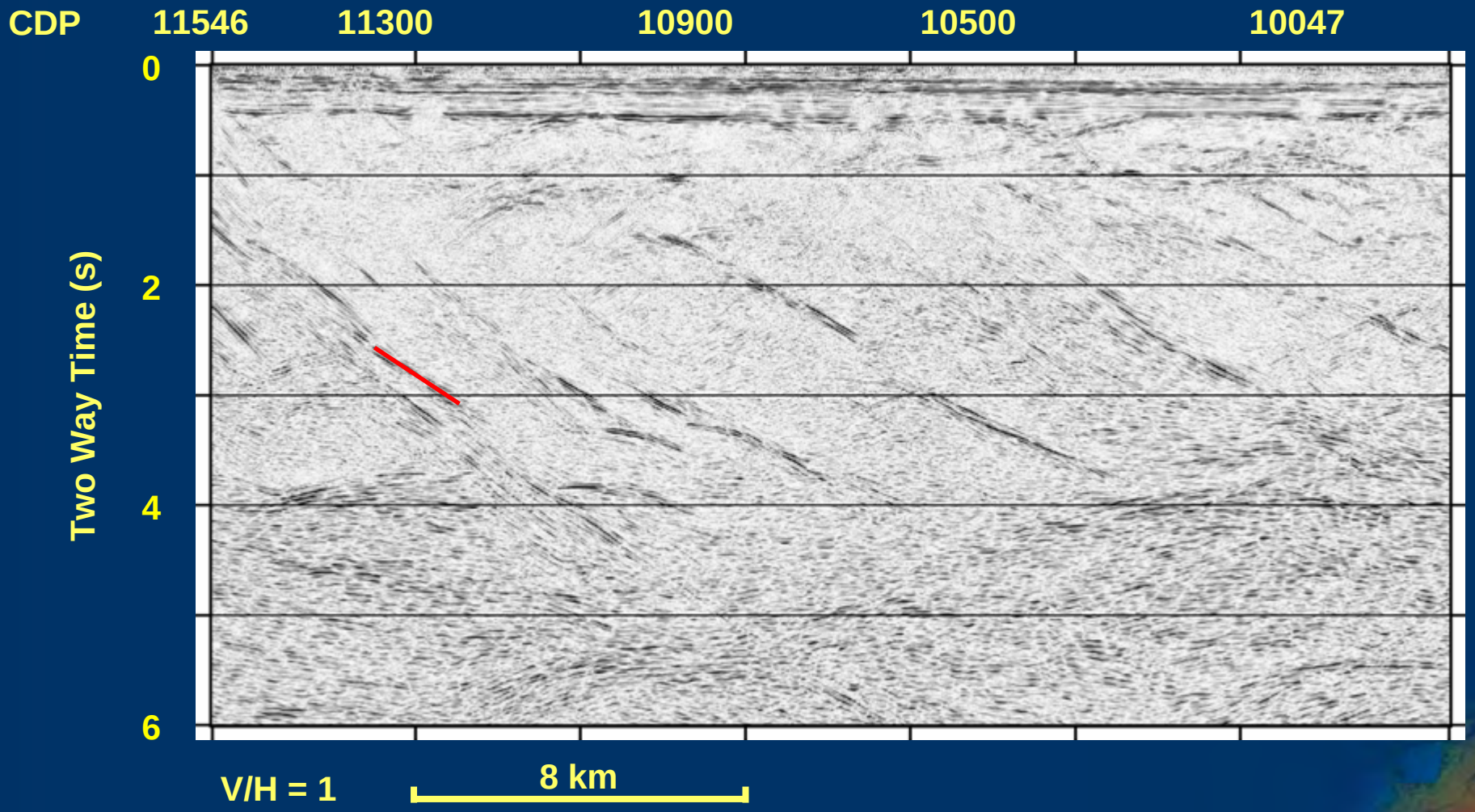
Examples: Migration 03GA-OD1



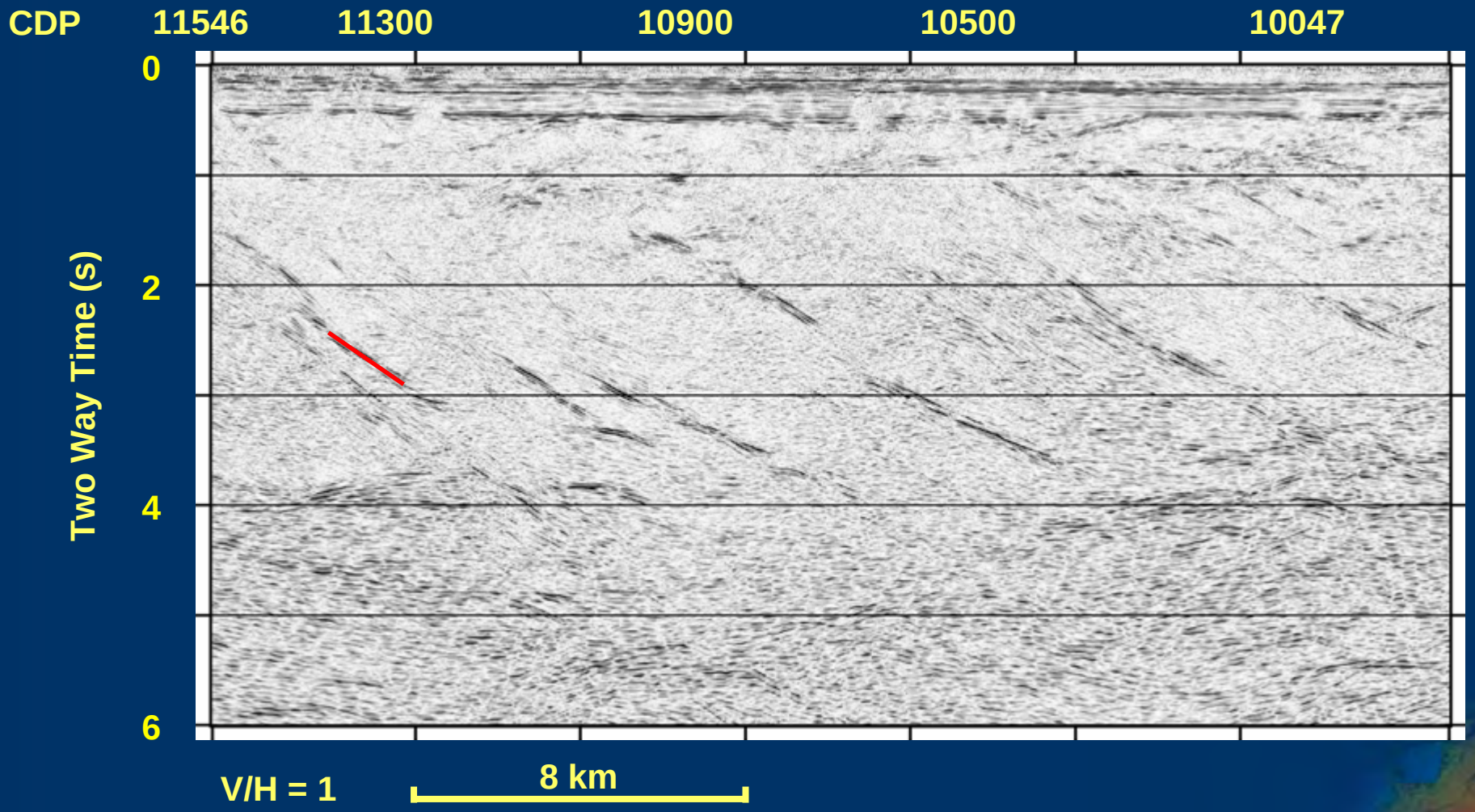
Examples: Migration 03GA-OD1



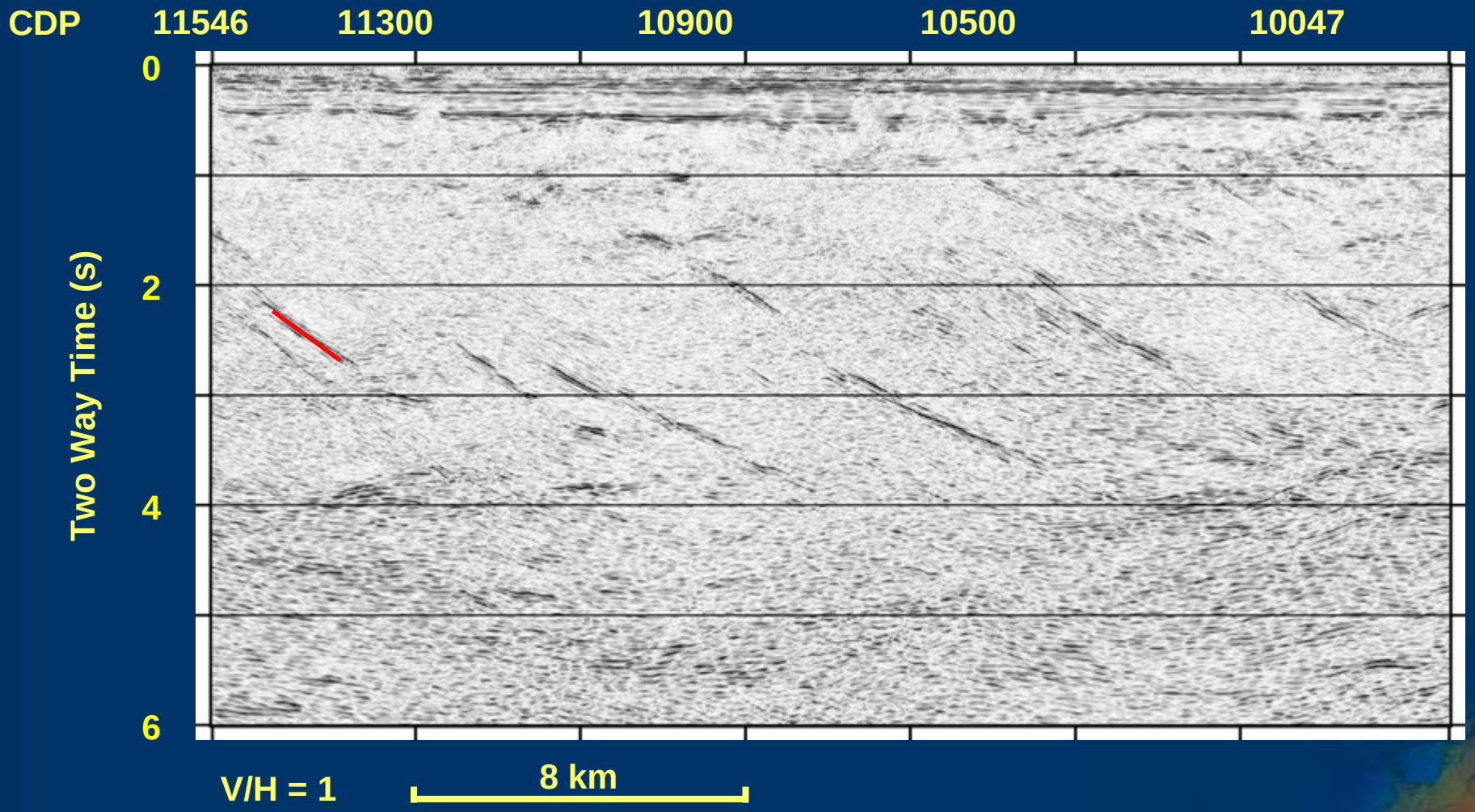
Examples: Migration 03GA-OD1



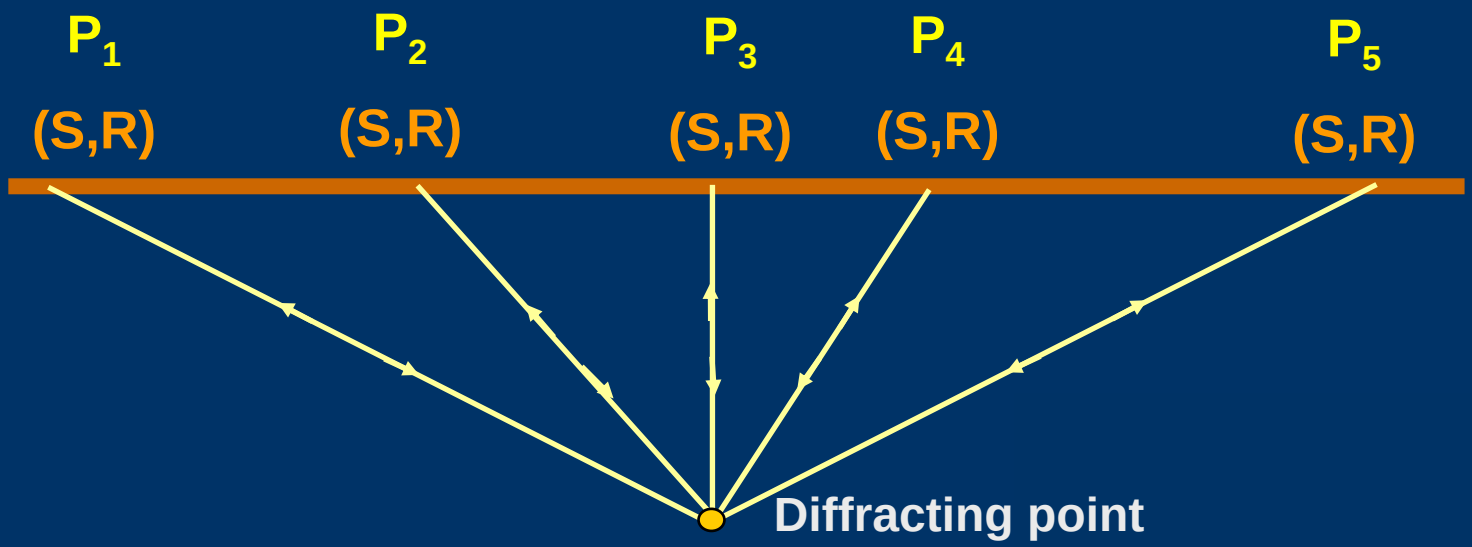
Examples: Migration 03GA-OD1



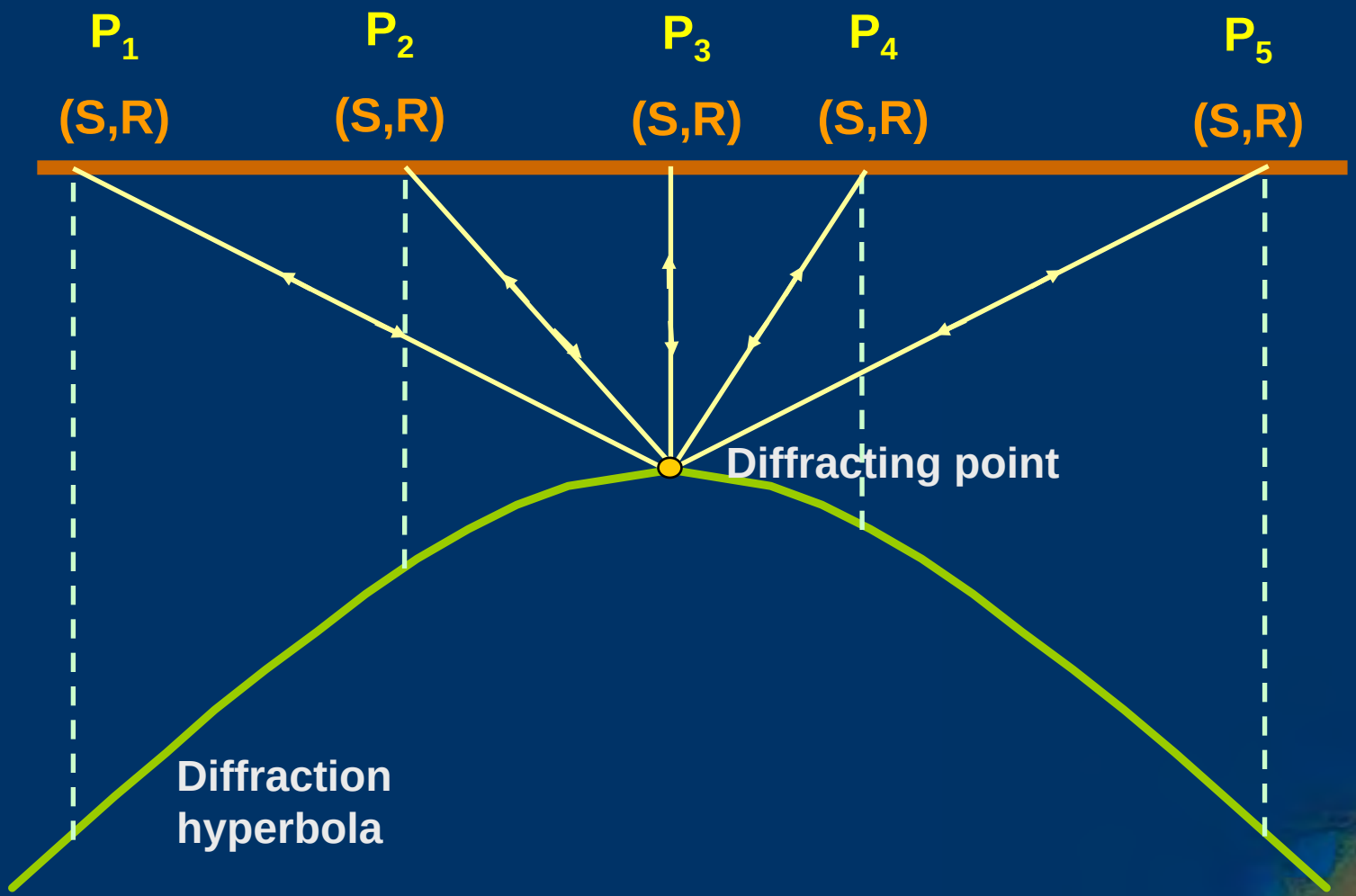
Examples: Migration 03GA-OD1



Generation of Diffractions



Generation of Diffractions

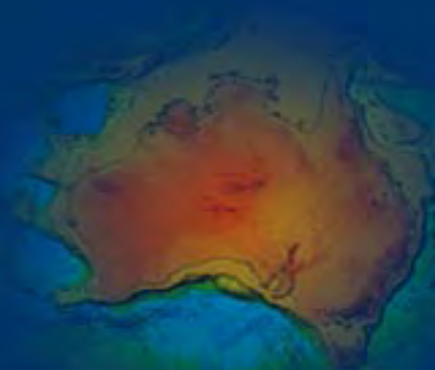


Migration improves a seismic image by

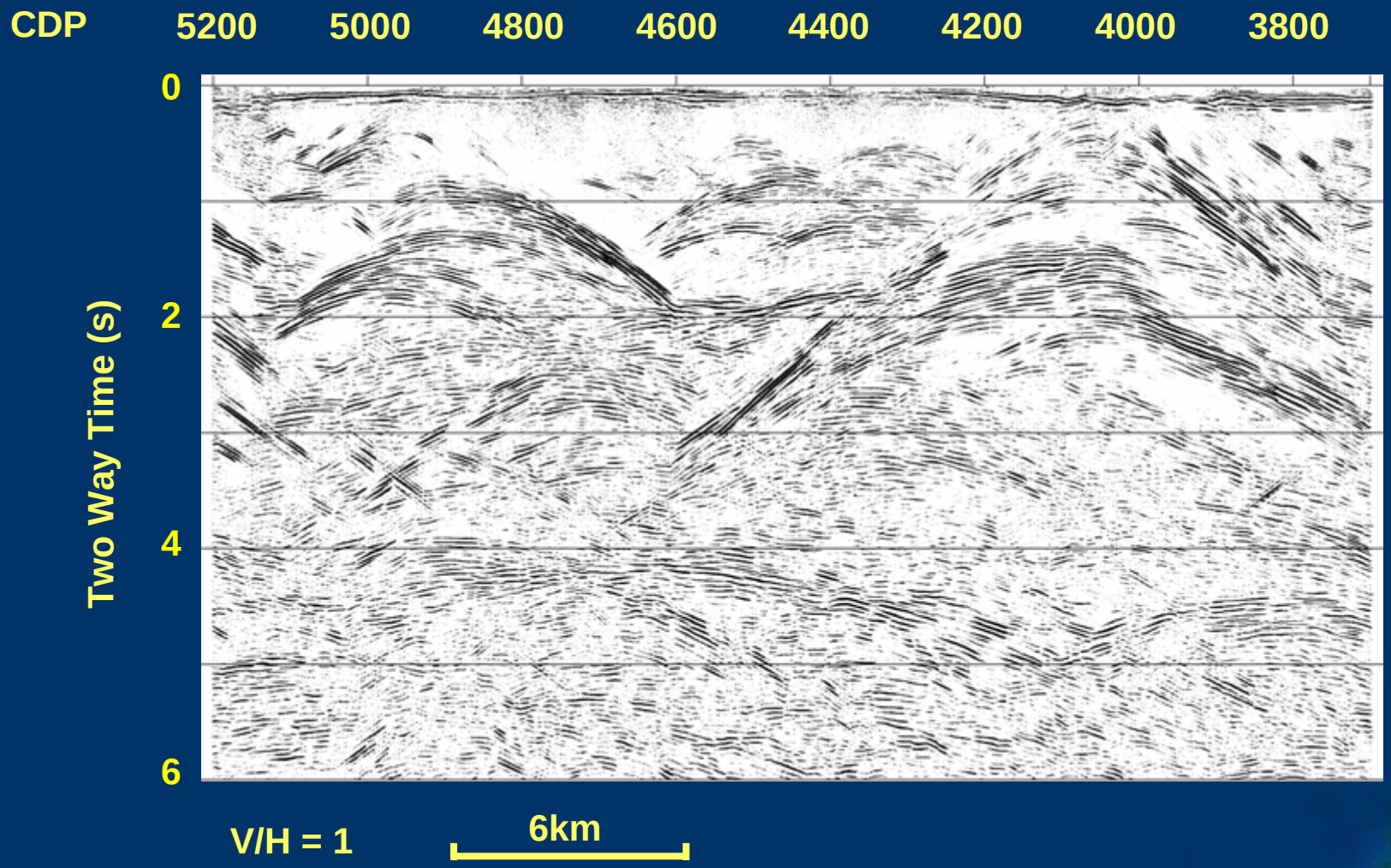
- moving reflectors to their correct positions
- steepening the dip of dipping reflectors
- collapsing diffractions

Migration can be evaluated by

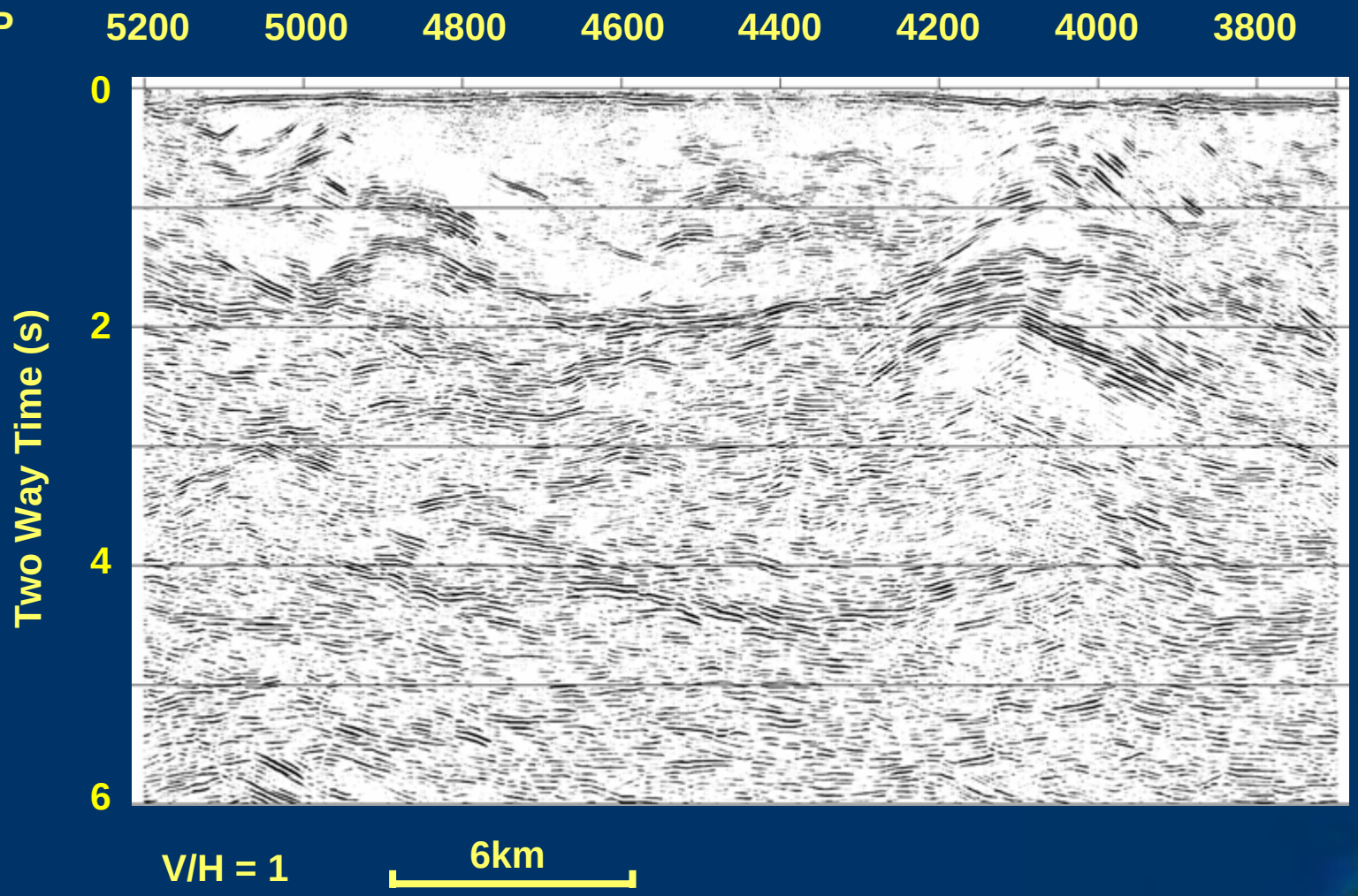
- appearance of diffractions (curves vs ‘smiles’)
- juxtaposition of reflectors of different dip



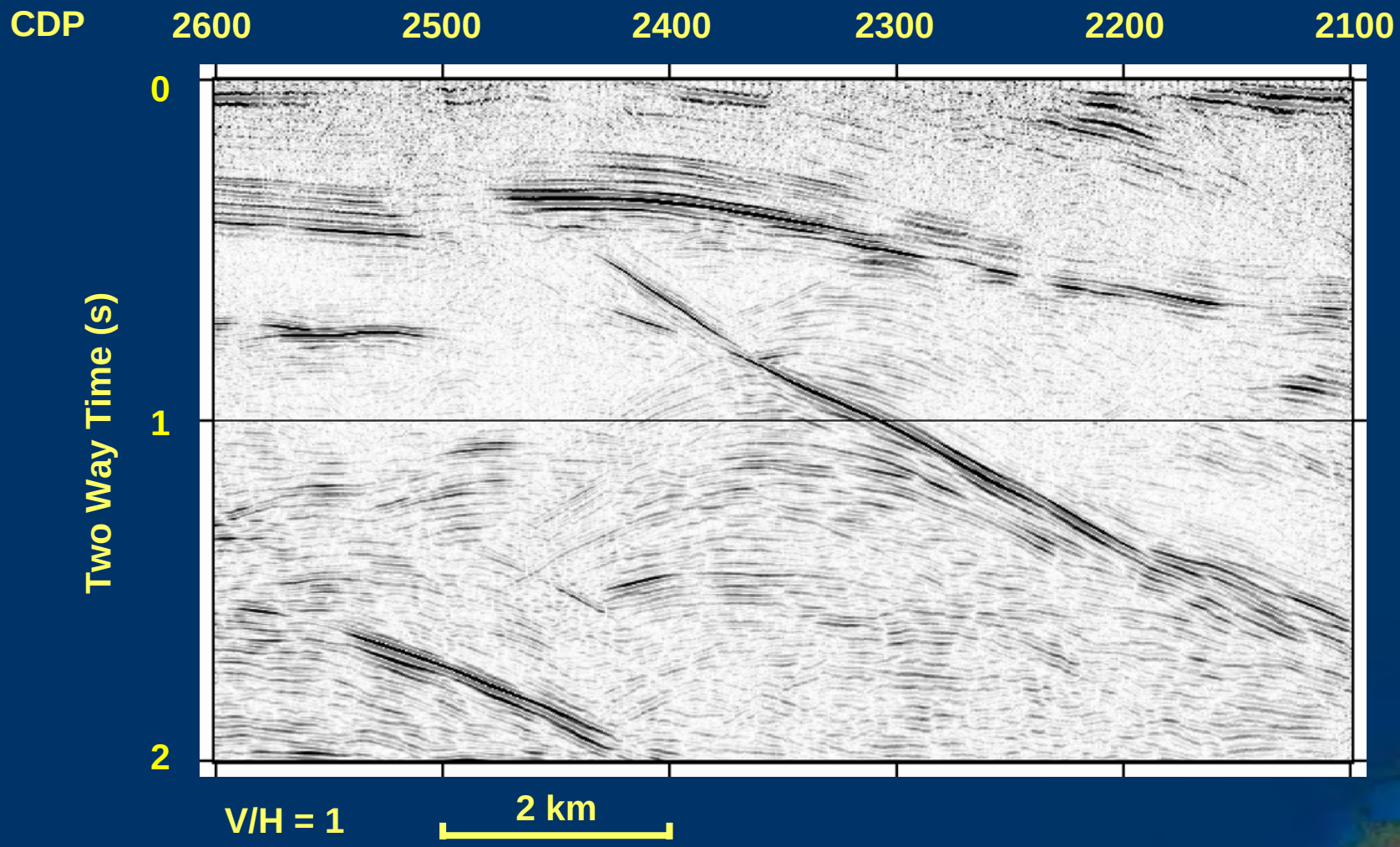
05GA-T3 - Pre Migration



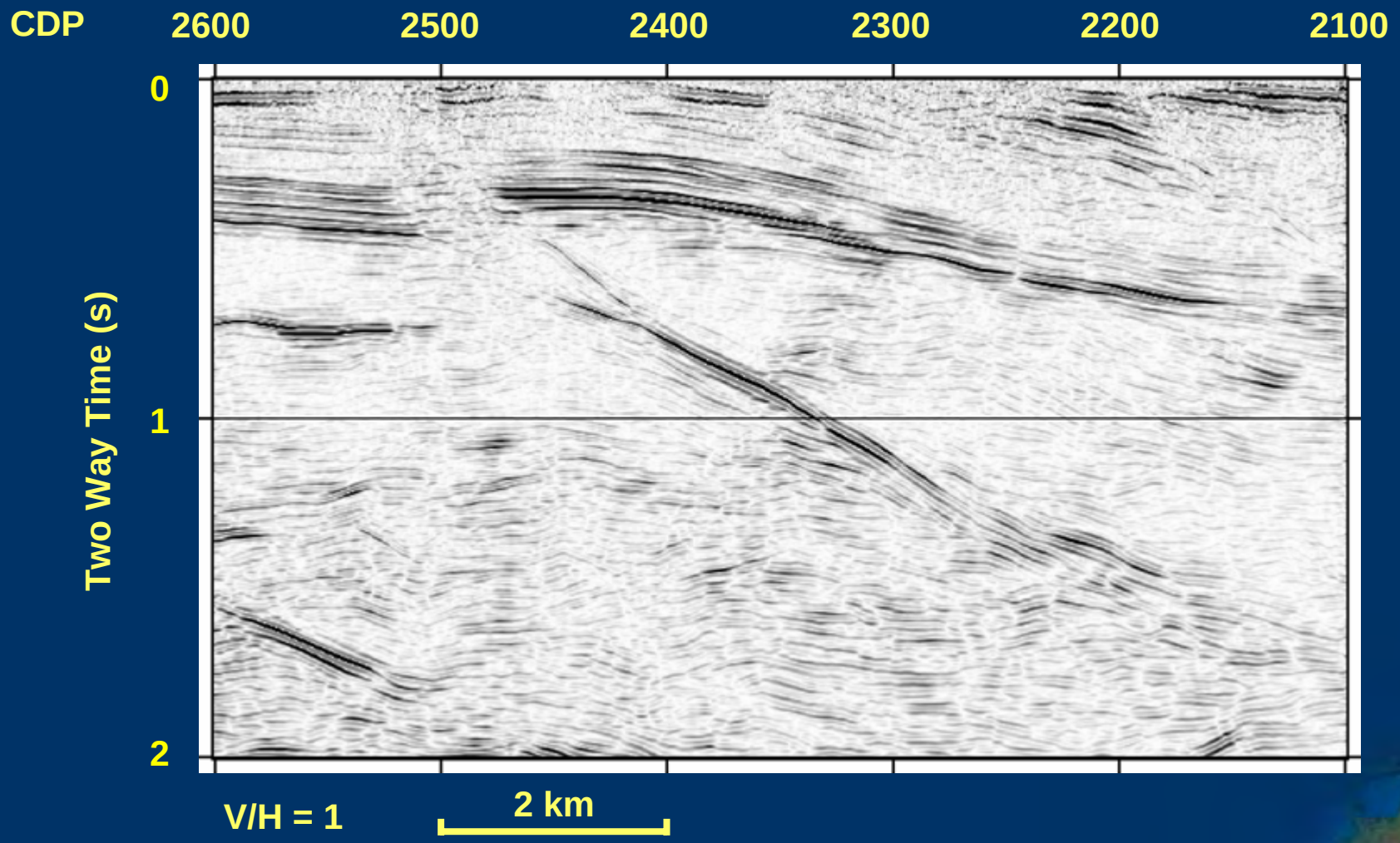
05GA-T3 - Post Migration



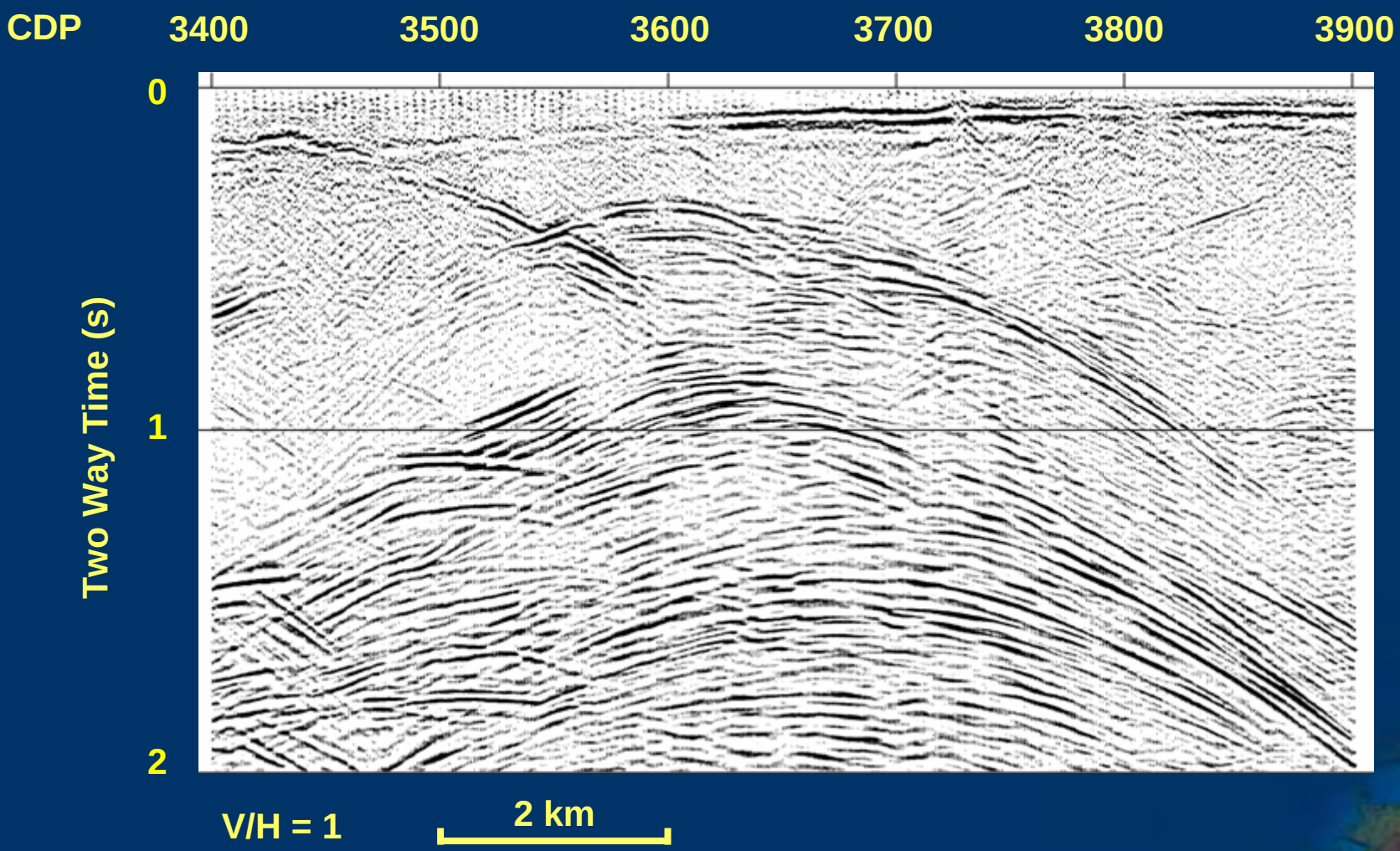
05GA-T3 - Pre Migration



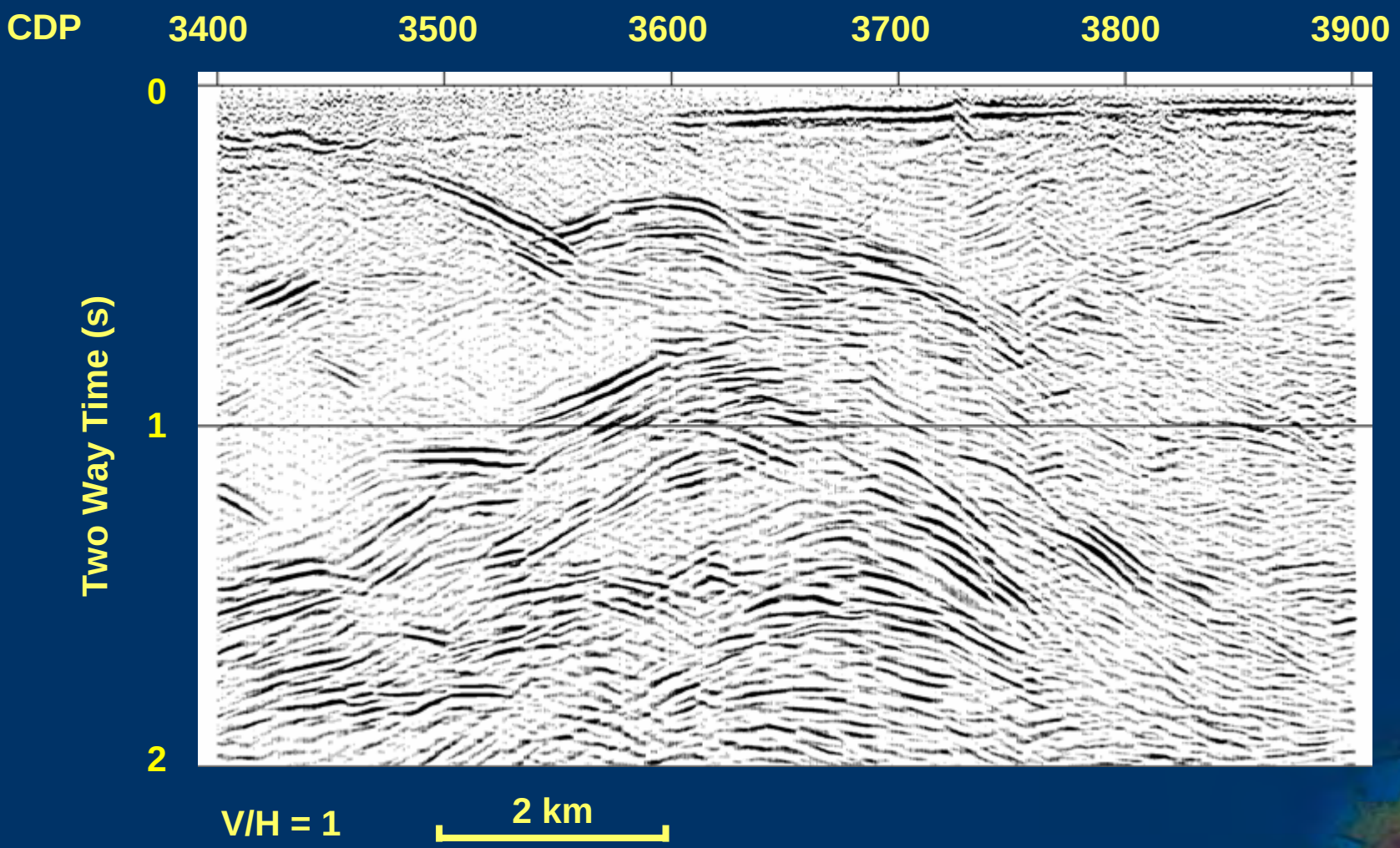
05GA-T3 - Post Migration



05GA-T2 - Pre Migration



05GA-T2 - Post Migration

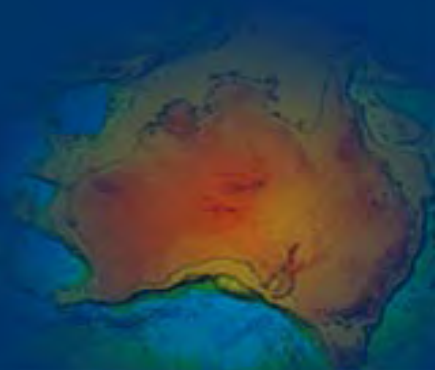


Migration improves a seismic image by

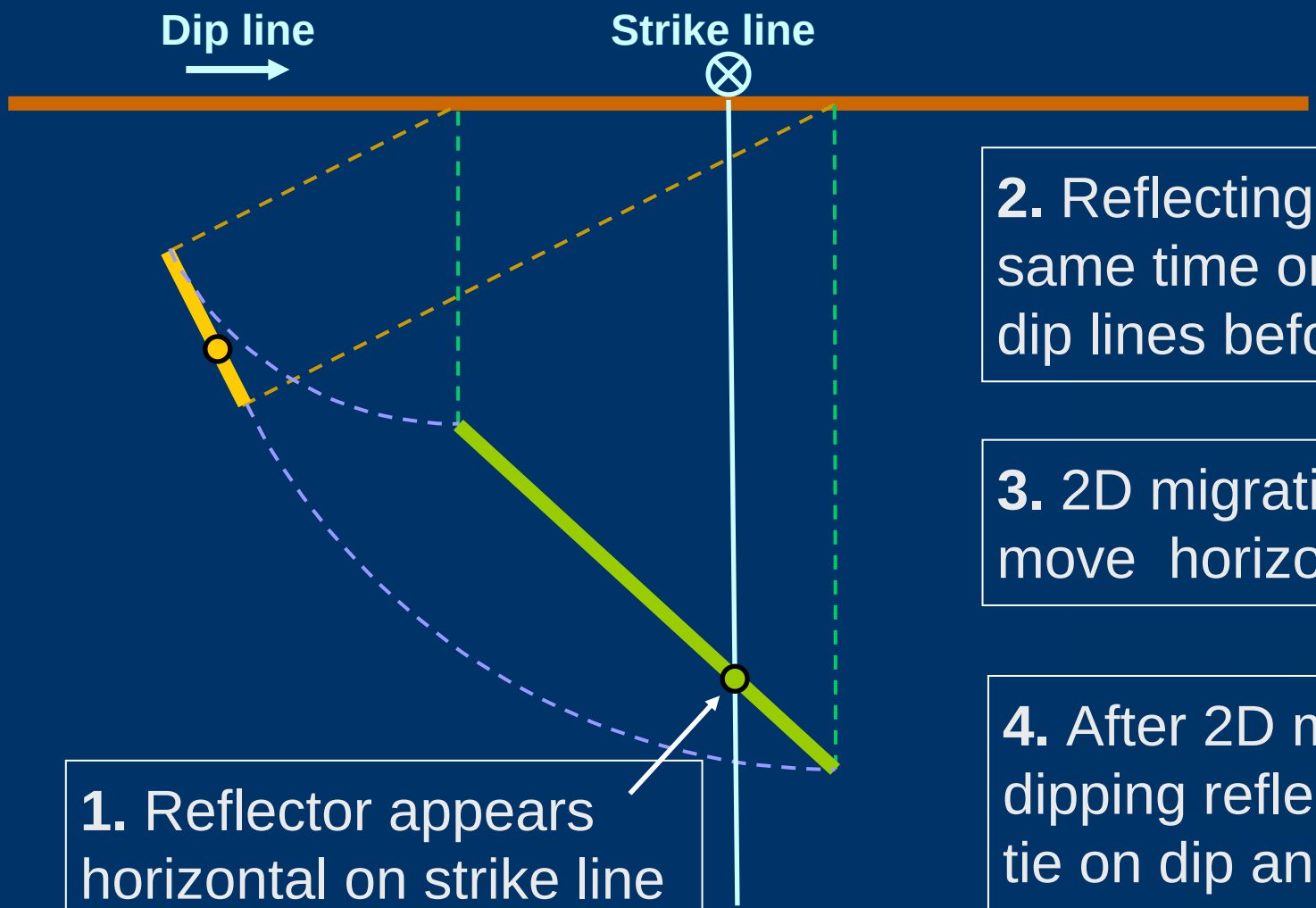
- moving reflectors to their correct positions
- steepening the dip of dipping reflectors
- collapsing diffractions

Migration can be evaluated by

- appearance of diffractions (curves vs ‘smiles’)
- juxtaposition of reflectors of different dip



Limitation of 2D Migration



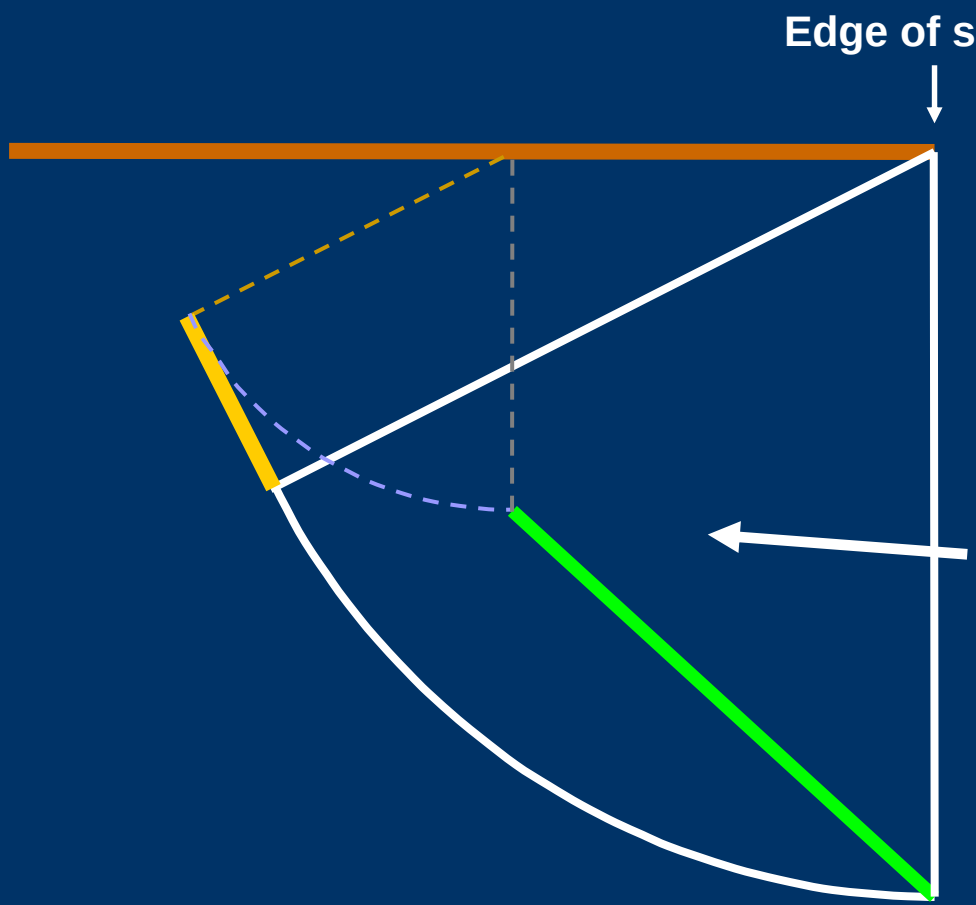
1. Reflector appears horizontal on strike line

2. Reflecting point ties at same time on strike and dip lines before migration

3. 2D migration will not move horizontal events

4. After 2D migration, dipping reflectors will not tie on dip and strike lines

Edge effects - Migration Aperture



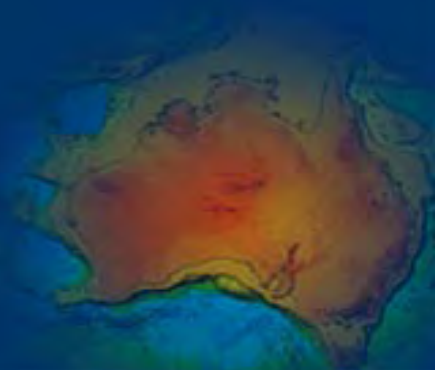
1. Can't migrate energy from dipping reflectors into section past edge of data coverage.

2. Therefore a zone occurs where dipping reflectors won't be imaged – broader with increasing dip.

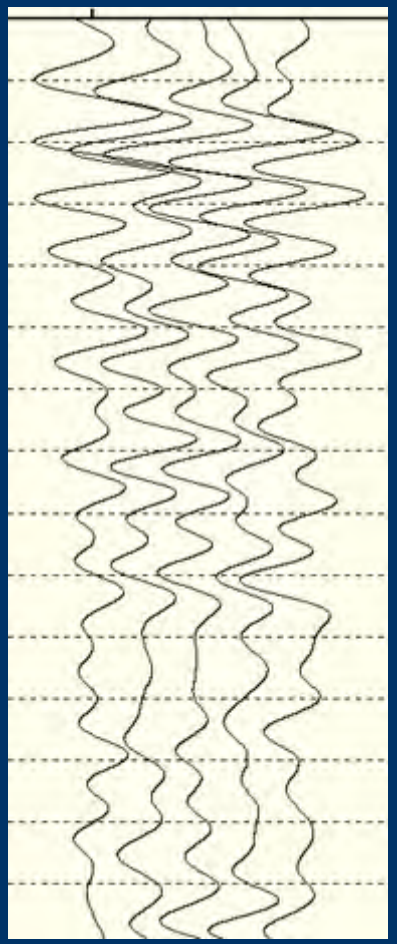
Display of seismic data

Important for interpretation and presentation

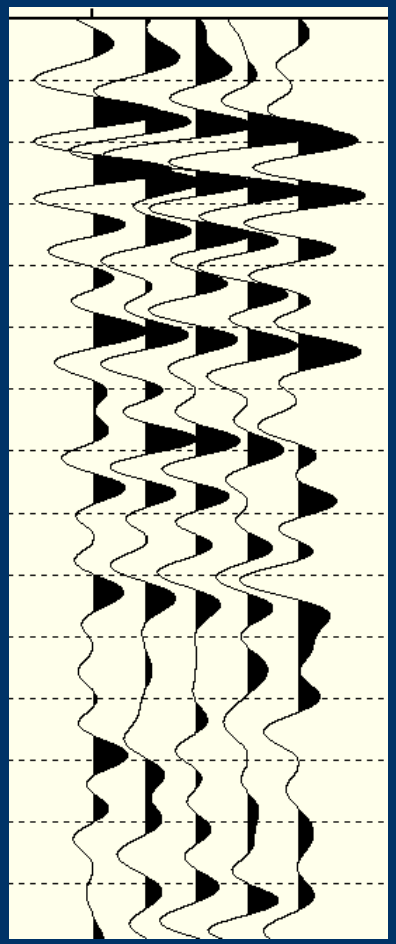
NB: Displayed in two way rime not depth



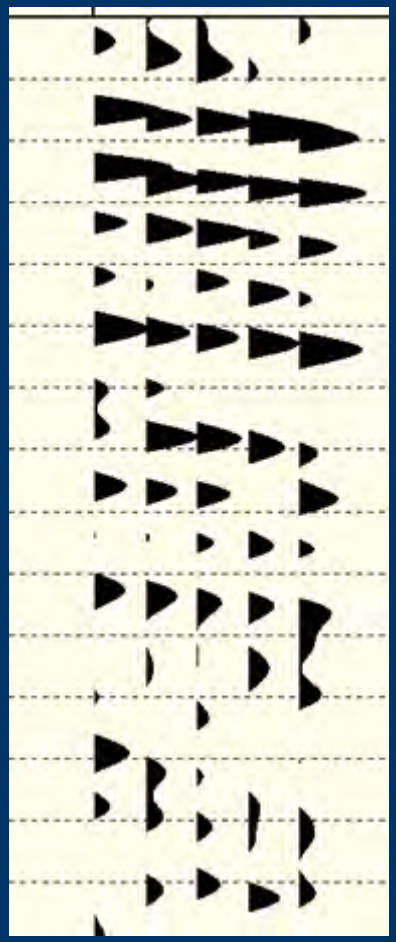
Types of B/W Seismic Displays



Wiggle Trace



Variable Area
Wiggle Trace



Variable Area

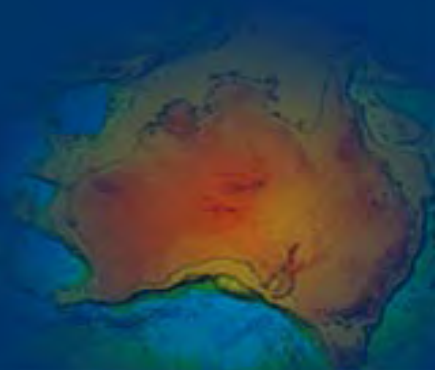
Australian Government

Geoscience Australia

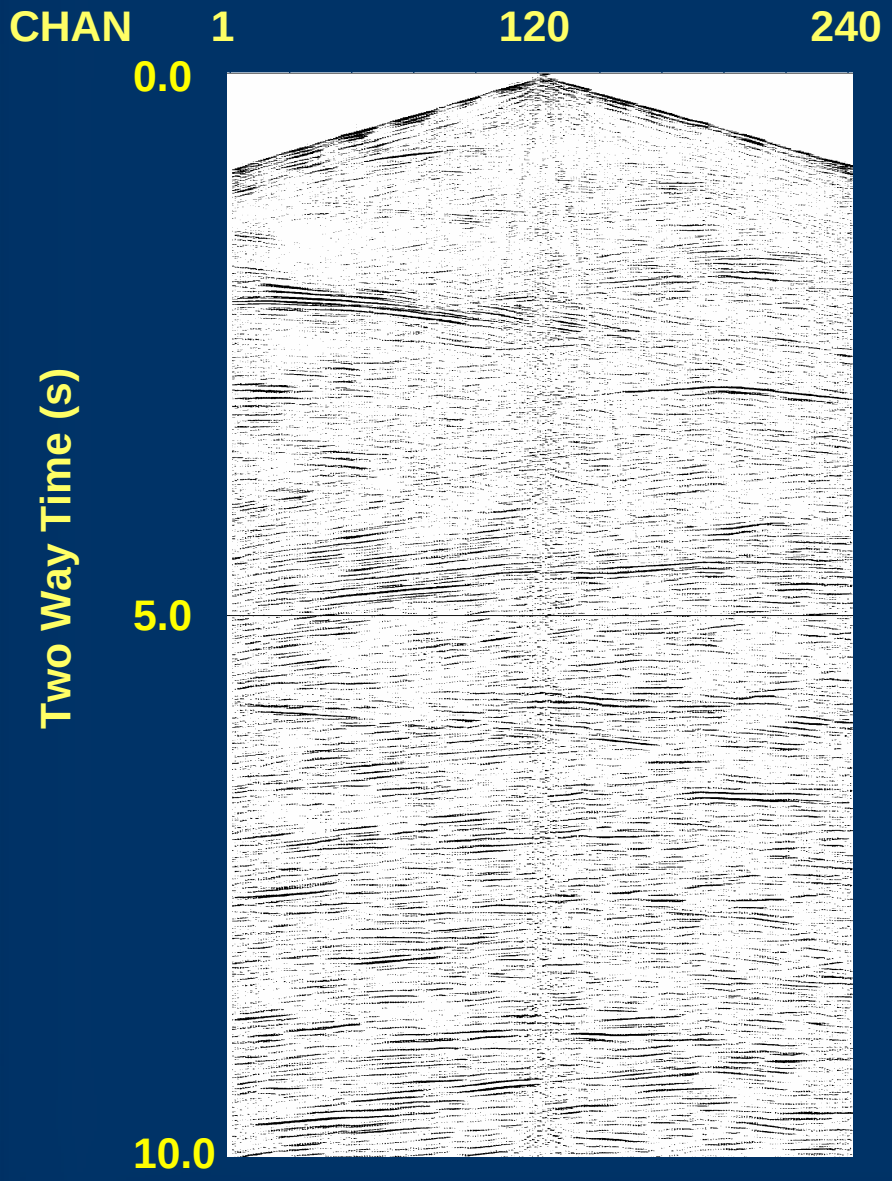
ANSIR NATIONAL RESEARCH FACILITY FOR EARTH SOUNDING

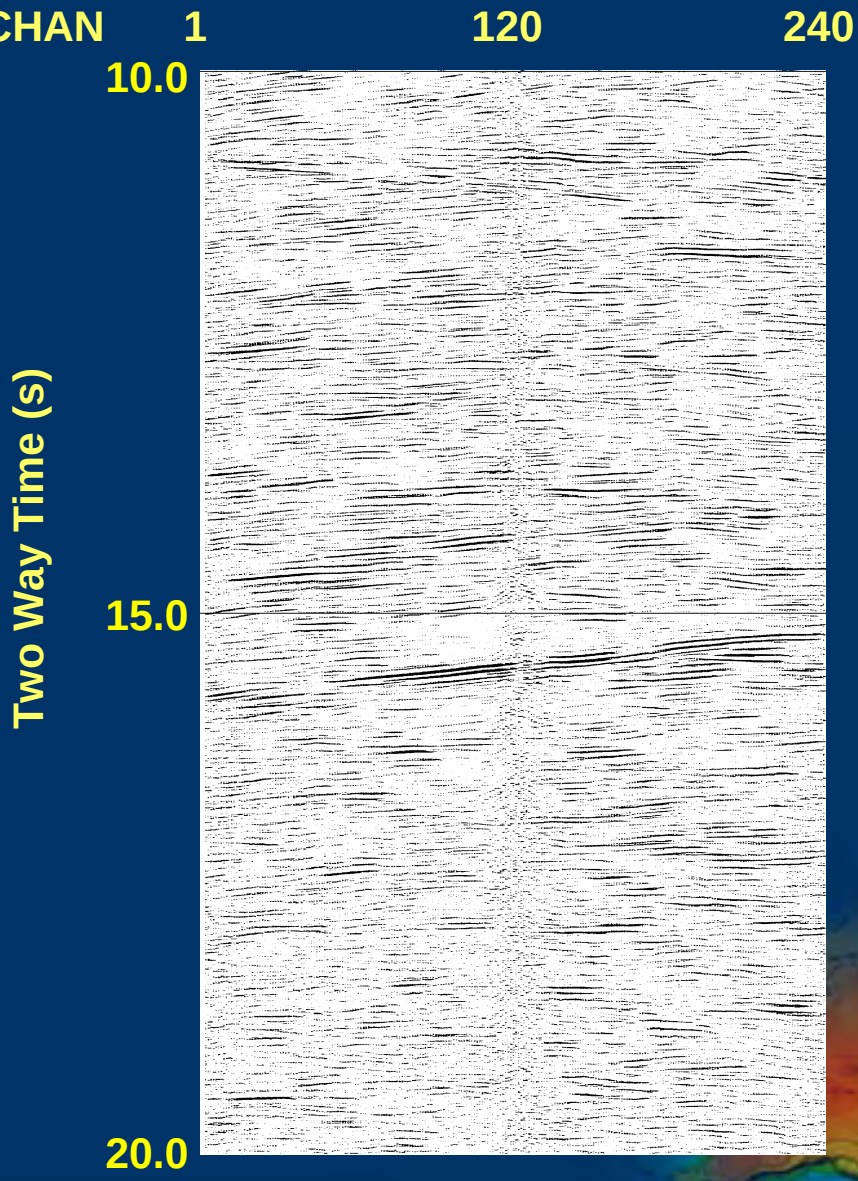
- 720 km of high-fold deep seismic reflection data acquired
- Acquisition and processing parameters designed to enhance reflections and allow for imaging steep dips
- Migration of seismic data essential in complex structures
- Caveats: Need impedance contrast and some continuity
  Resolution less than for young sedimentary basins
  Earlier deformation might be masked by later
- Seismic sections provide crustal scale framework for geological interpretation of the Tanami Province

- **Extra slides for answering questions**



Example of shot record (enhanced)



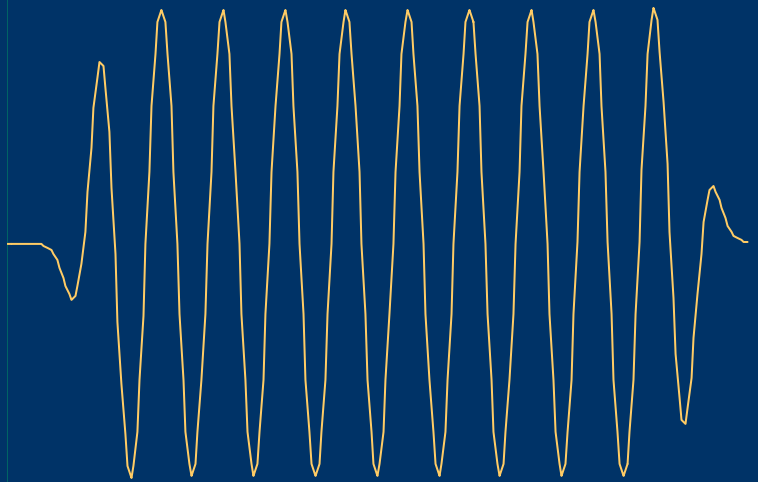


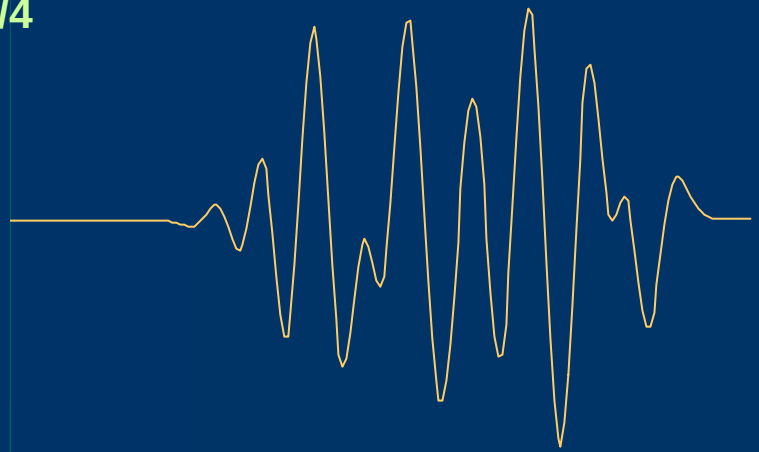
Reflectivity of Shear Zones - 20 layers

Uniform thickness

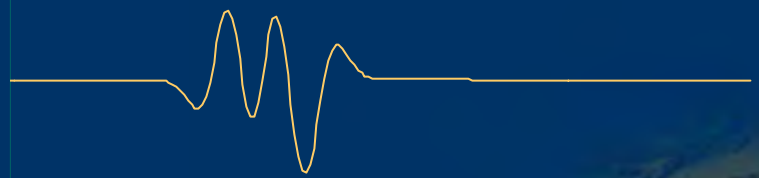
Random thickness

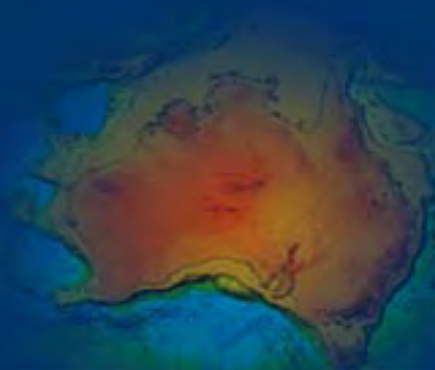
Wavelength/4





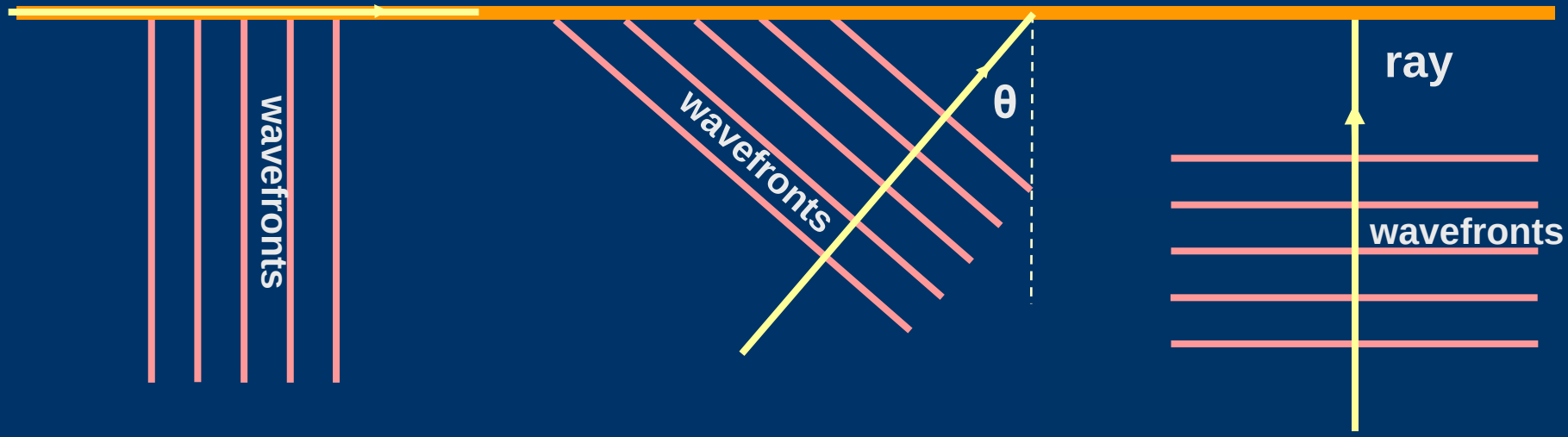
Wavelength/20





Apparent Wavelength

$$\lambda_a = \lambda / \sin\theta = V / f \sin\theta$$



Horizontal incidence

- true wavelength

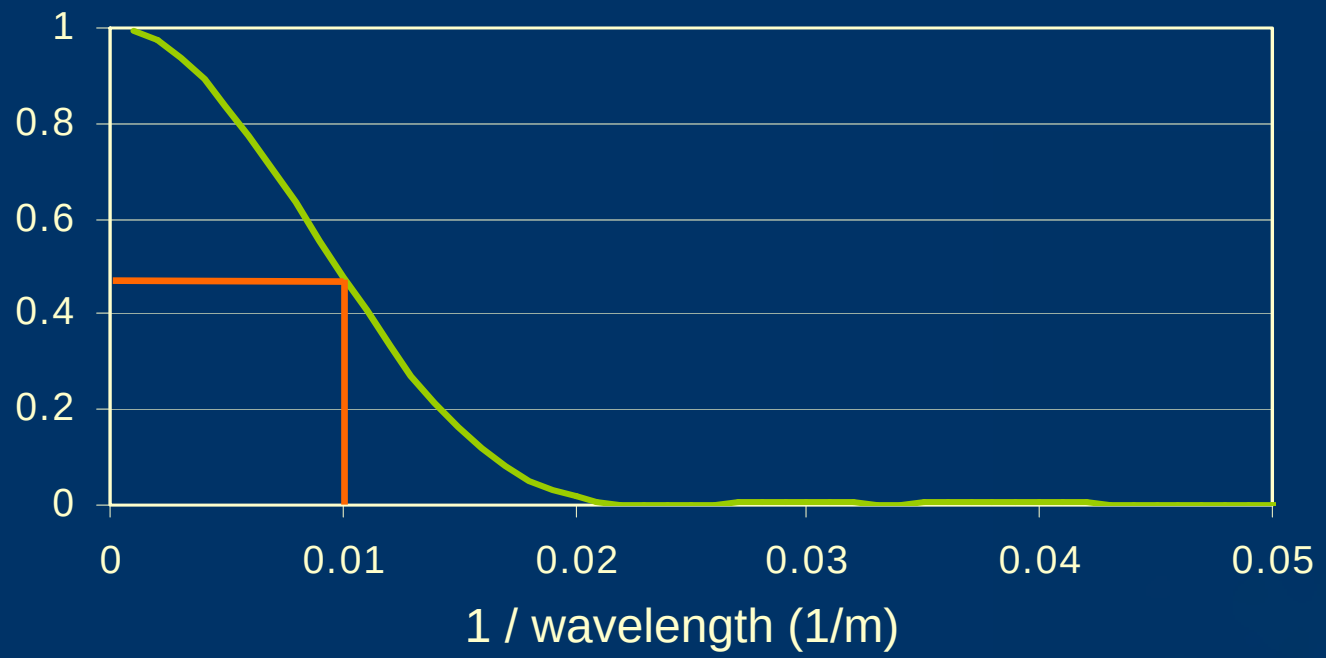
Vertical incidence

- infinite wavelength

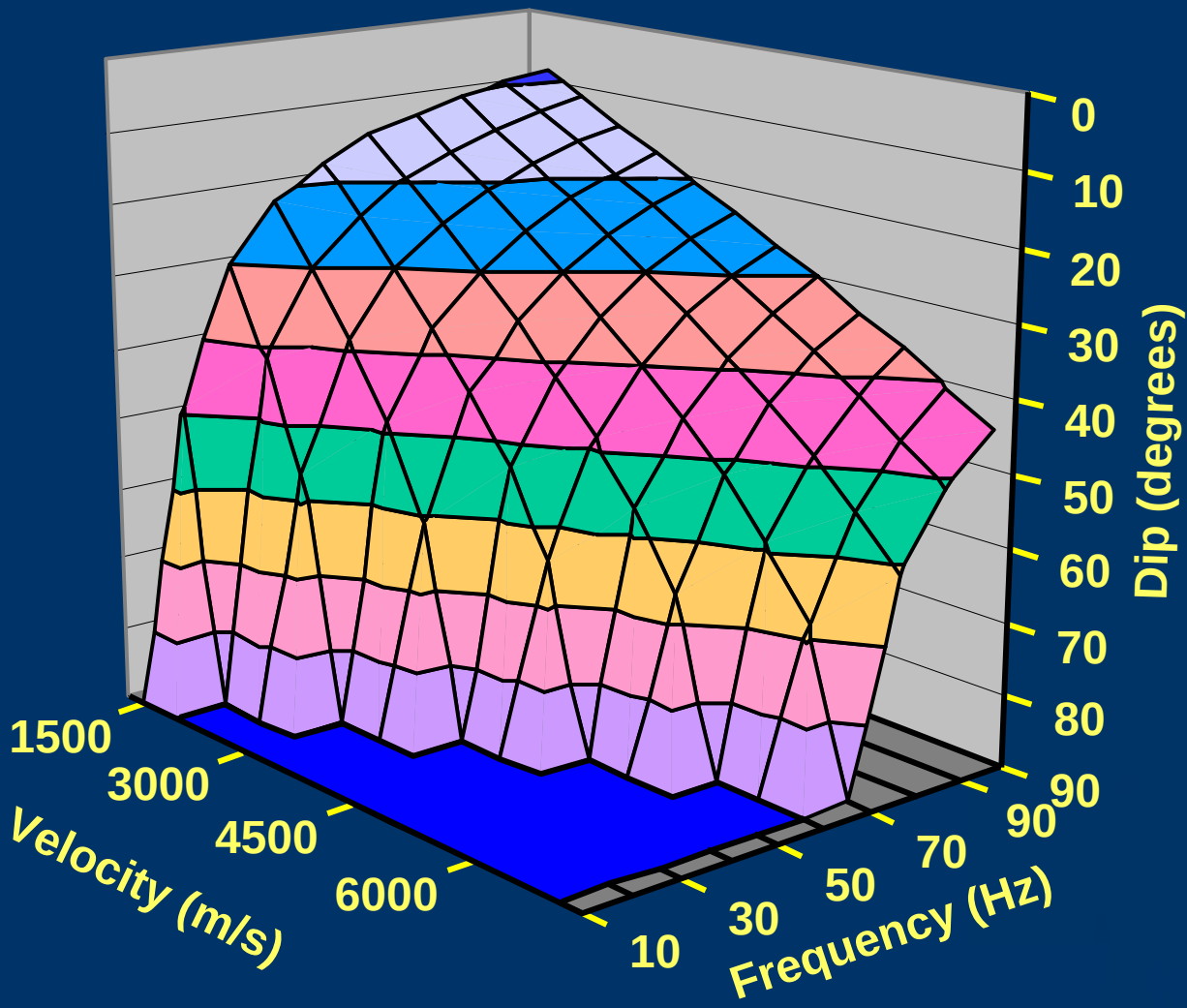
Combined Array Response

3 IVI Hemi-60 vibrators, 15 m pad-pad, 10 m moveup

12 geophones in-line over 40 m

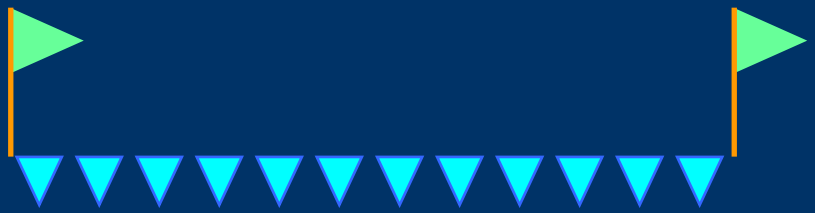


Dips recorded for a typical survey



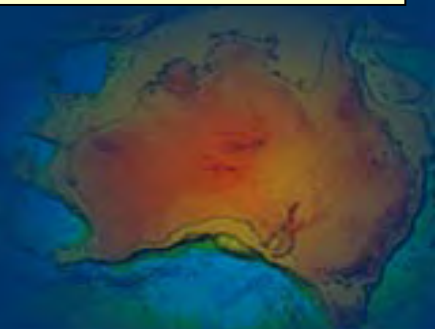
Line and Source Geometry

Receiver groups centred between pegs



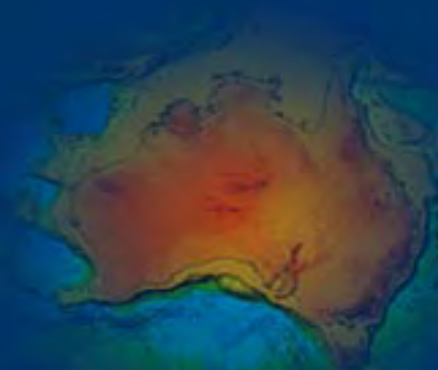
Source array centred on peg

- Take surveying coordinates for stations (pegs)
- Subtract “bias” for E & N
- Interpolate for processing station
- Locate “shots” on peg
- Define spread pattern to associate each channel for each shot with a station

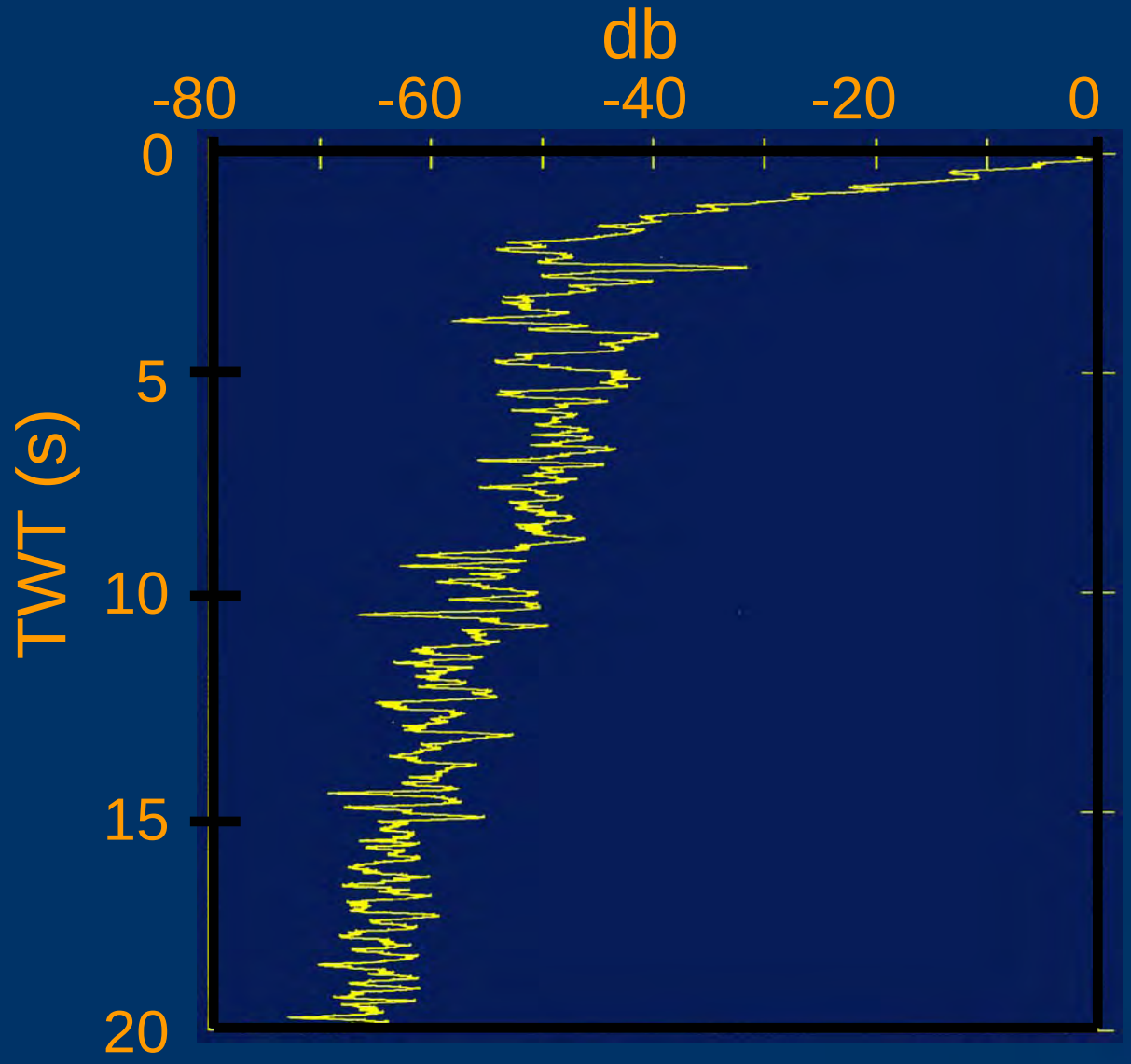


Gain Recovery

Compensates for energy loss at later two-way travel times due to spherical spreading and intrinsic attenuation of seismic waves.

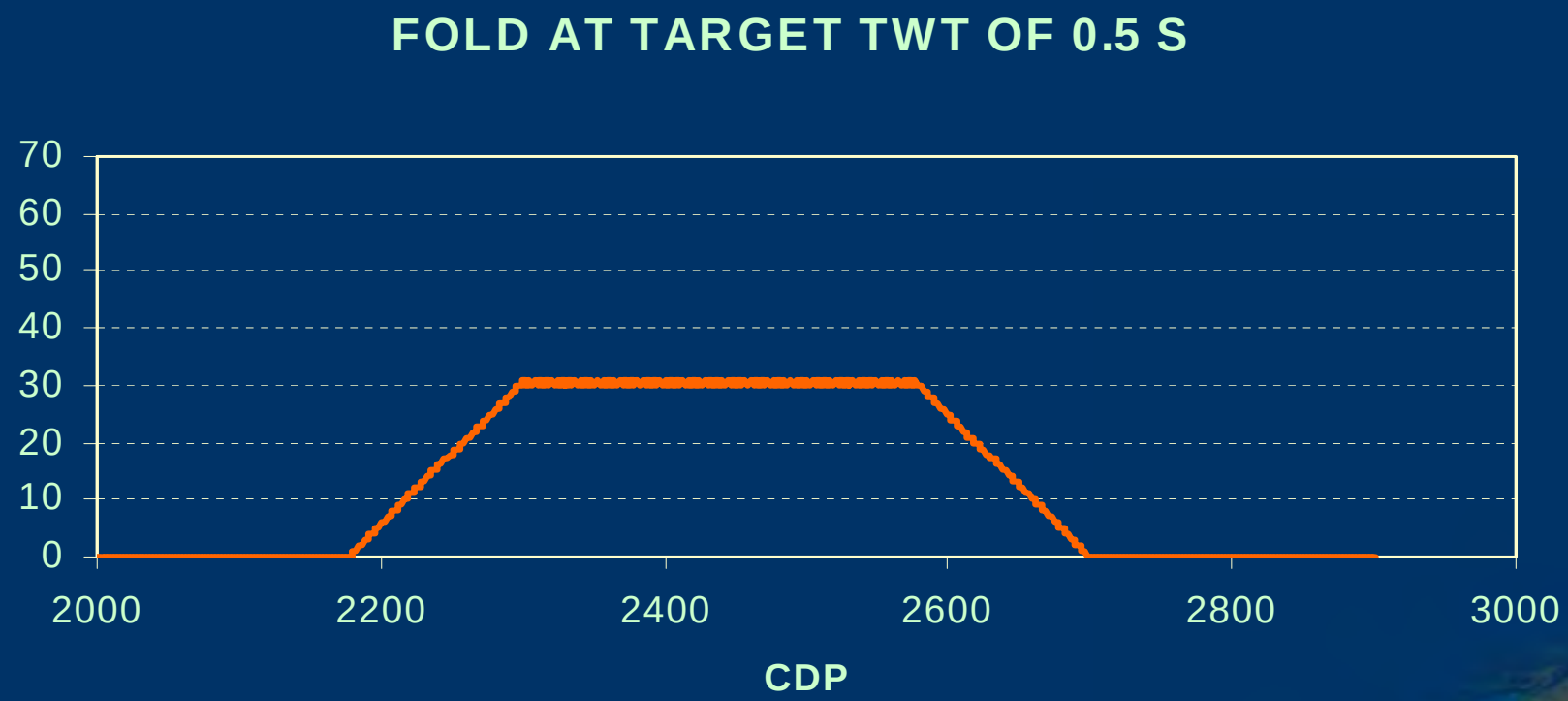


Reflector Strength



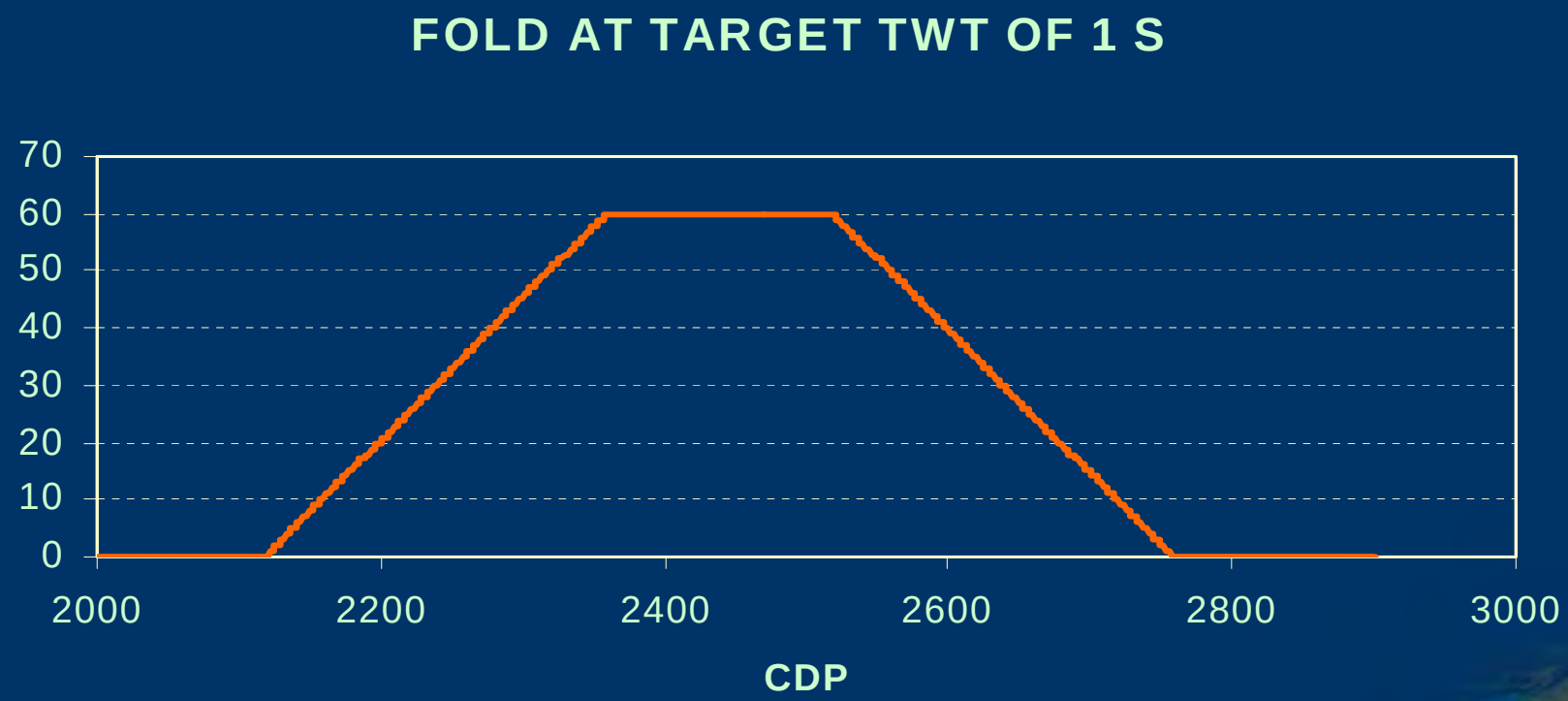
Why is stack quality generally lower in top ½ second?

Effective fold is lower due to muting of outside traces to remove first arrivals and excessive moveout stretch



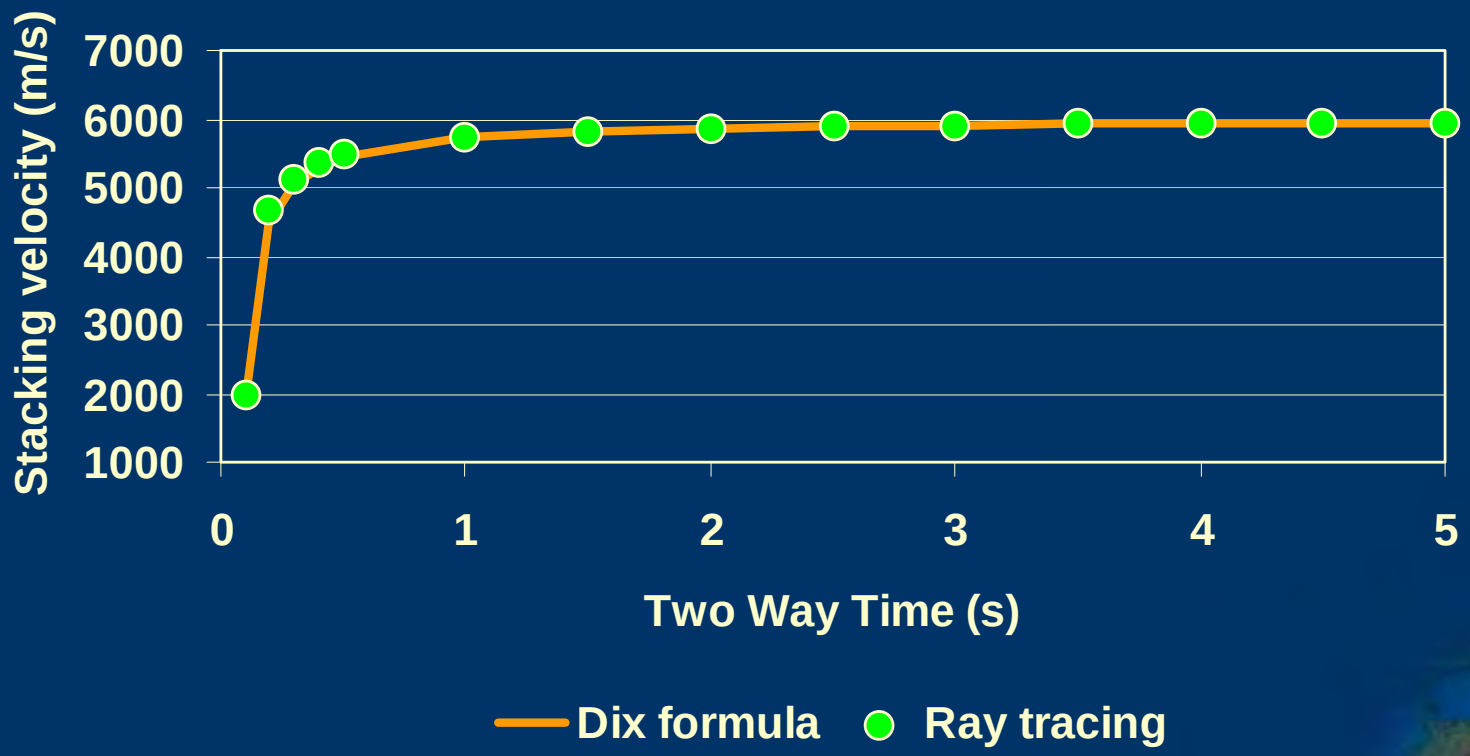
Why is stack quality generally lower in top ½ second?

Effective fold is lower due to muting of outside traces to remove first arrivals and excessive moveout stretch



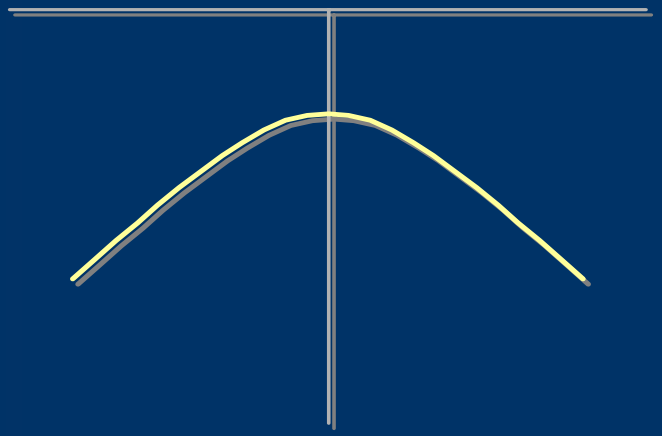
Effect of Regolith on Stacking Velocity

100 m regolith layer (2000 m/s) overlying bedrock (6000 m/s)



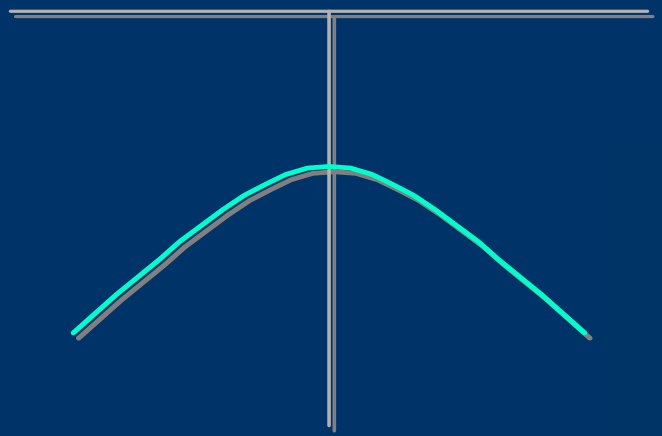
Effect of Static Shifts on Stacking Velocity

No shift



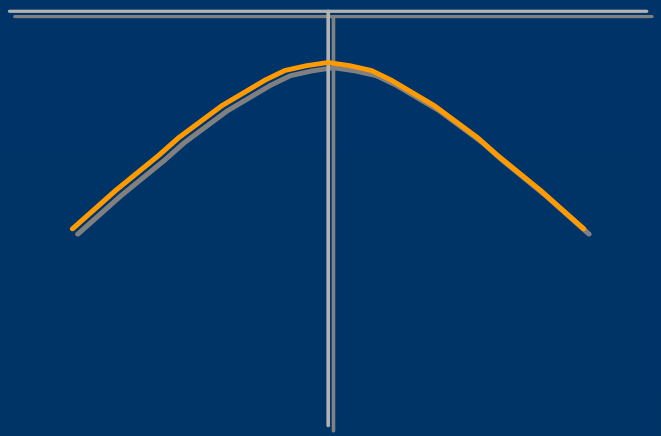
No change

+ve shift



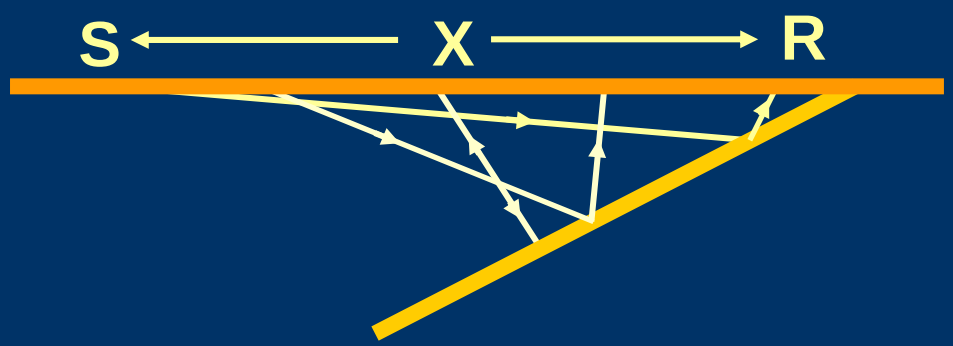
Too much curvature for new time → lower stacking velocity

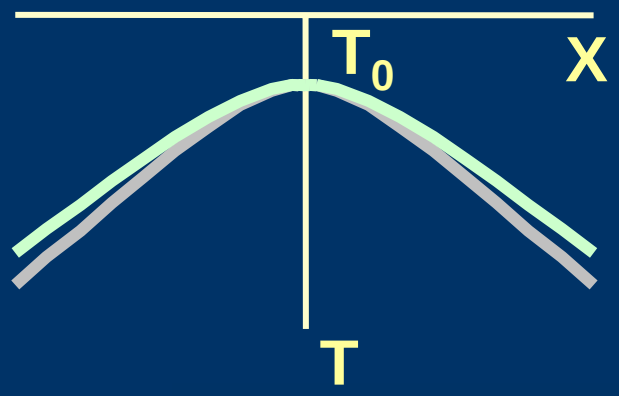
-ve shift



Too little curvature for new time → higher stacking velocity

Dip Moveout Correction (DMO)





DMO corrects

- reflecting point smear
- moveout velocity for dip

DMO

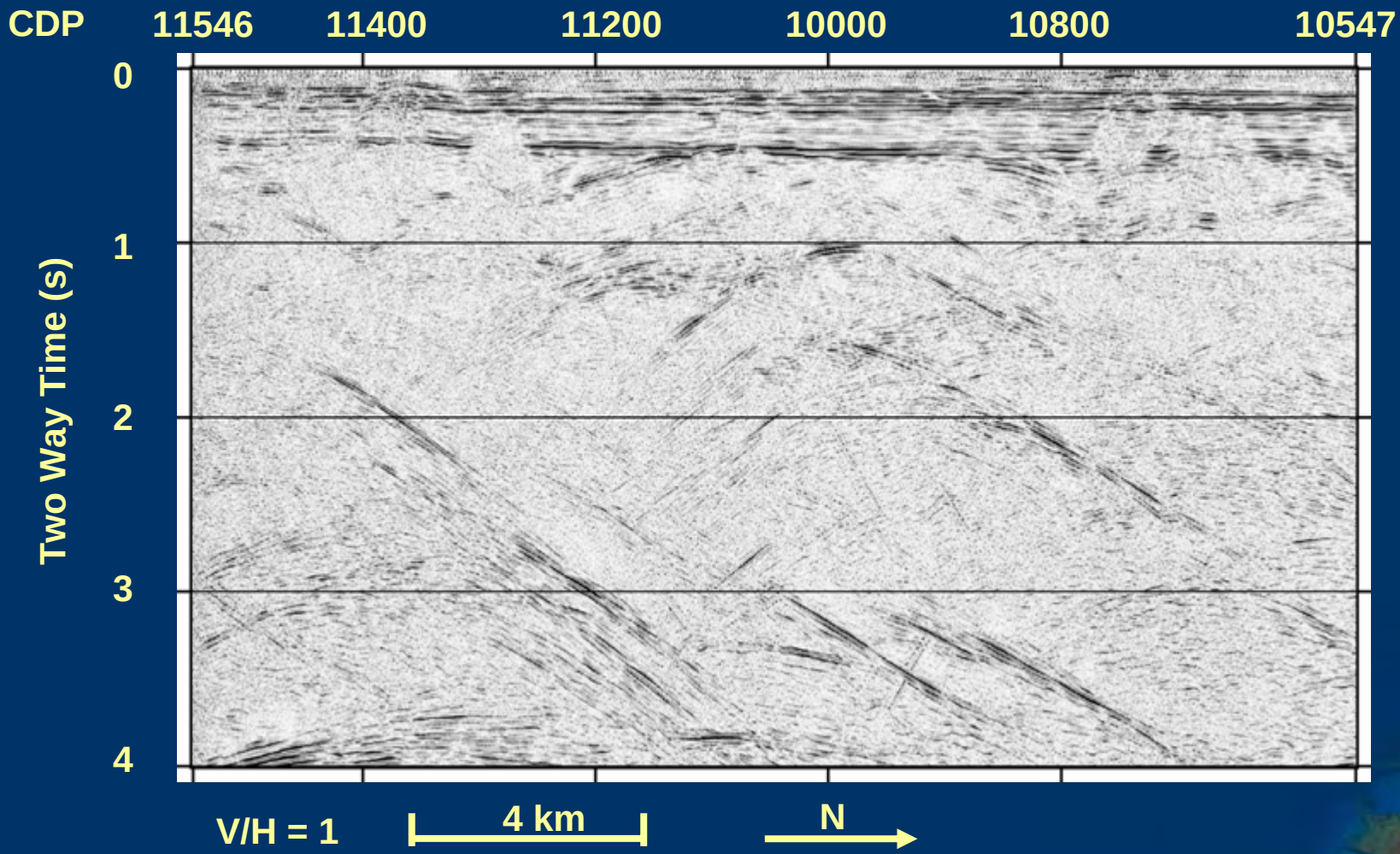
- is partial pre-stack migration
- needs common offset sections

$$T^2 = T_0^2 + X^2 \cos^2 \alpha / V^2$$

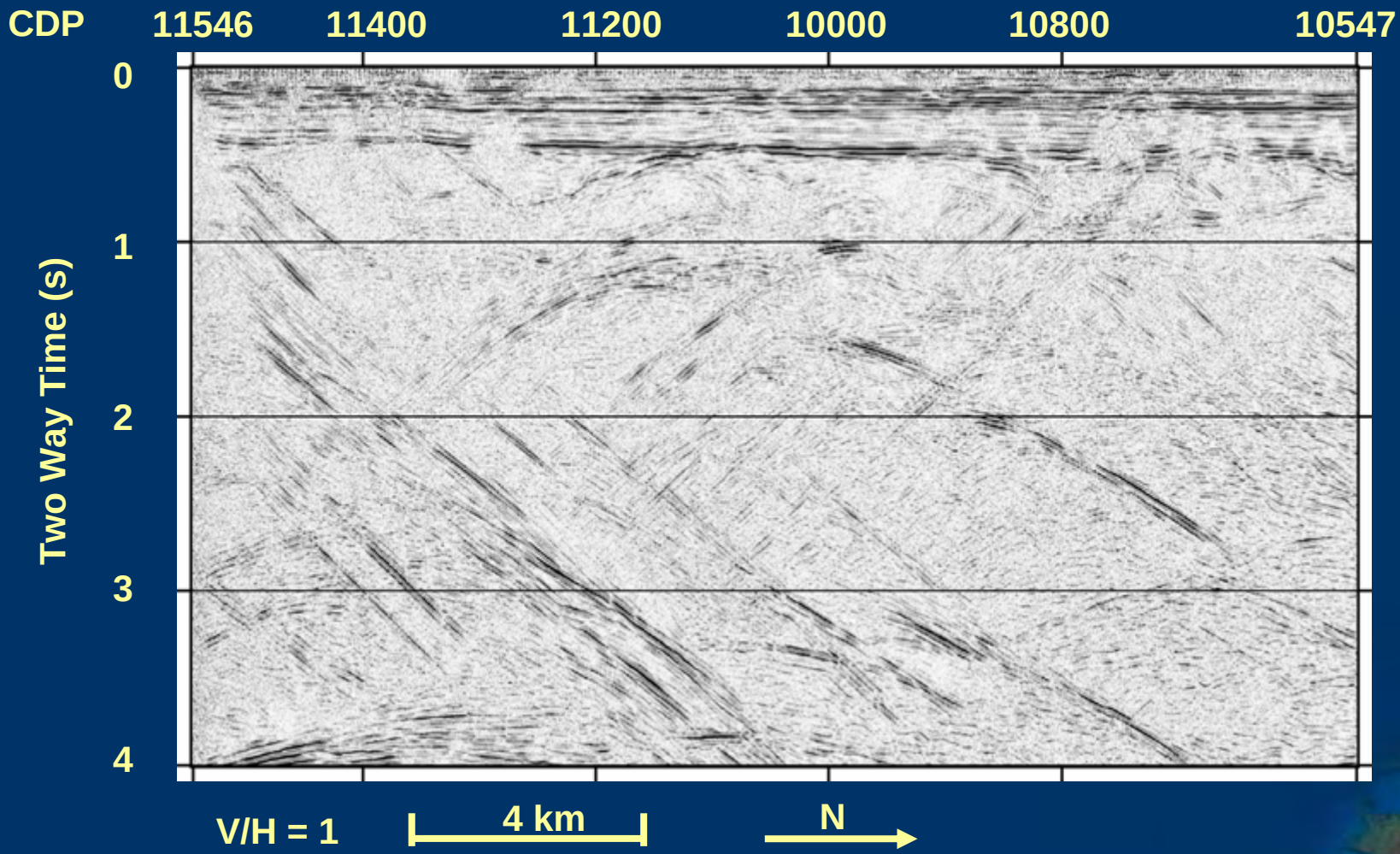
$$= T_0^2 + X^2 / V^2 - X^2 \sin^2 \alpha / V^2$$

normal moveout **dip moveout**

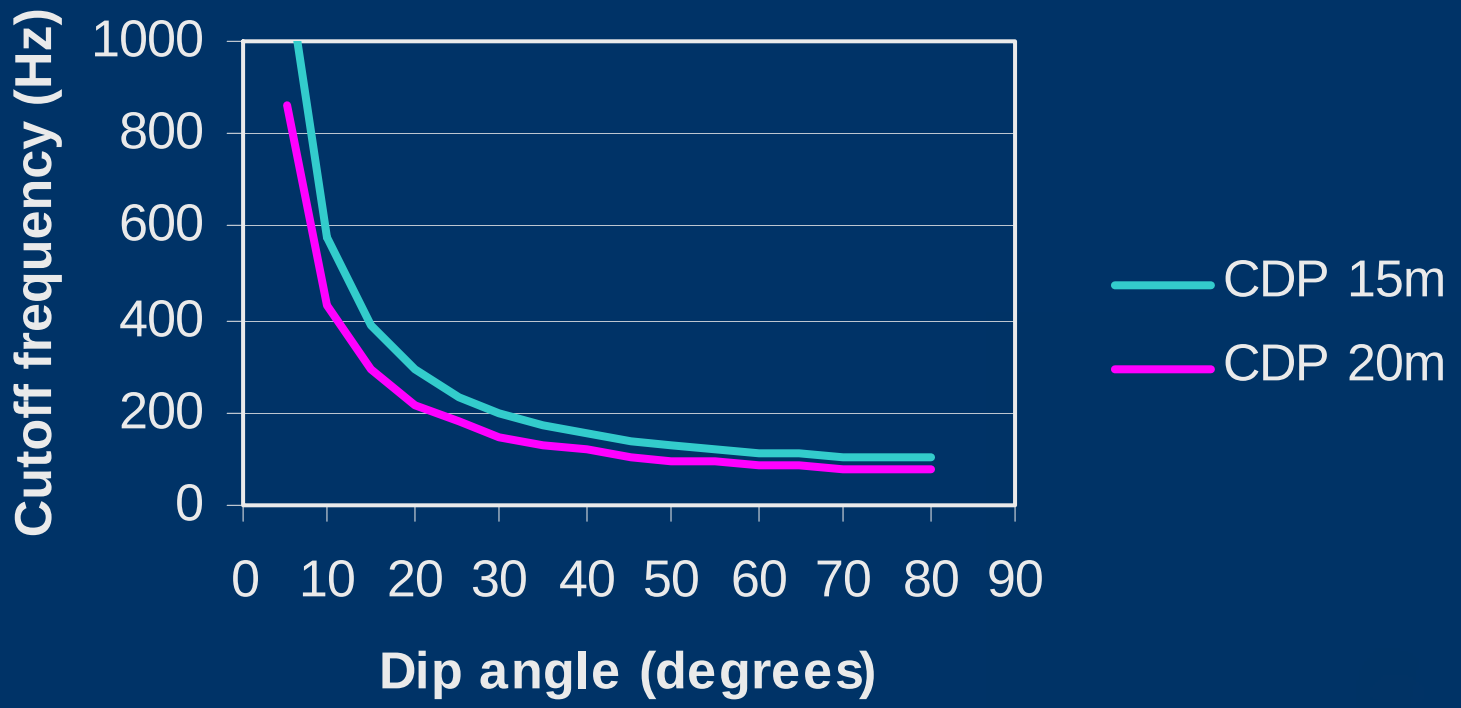
Gawler Line 03GA-OD1 - Before DMO



Gawler Line 03GA-OD1 - After DMO



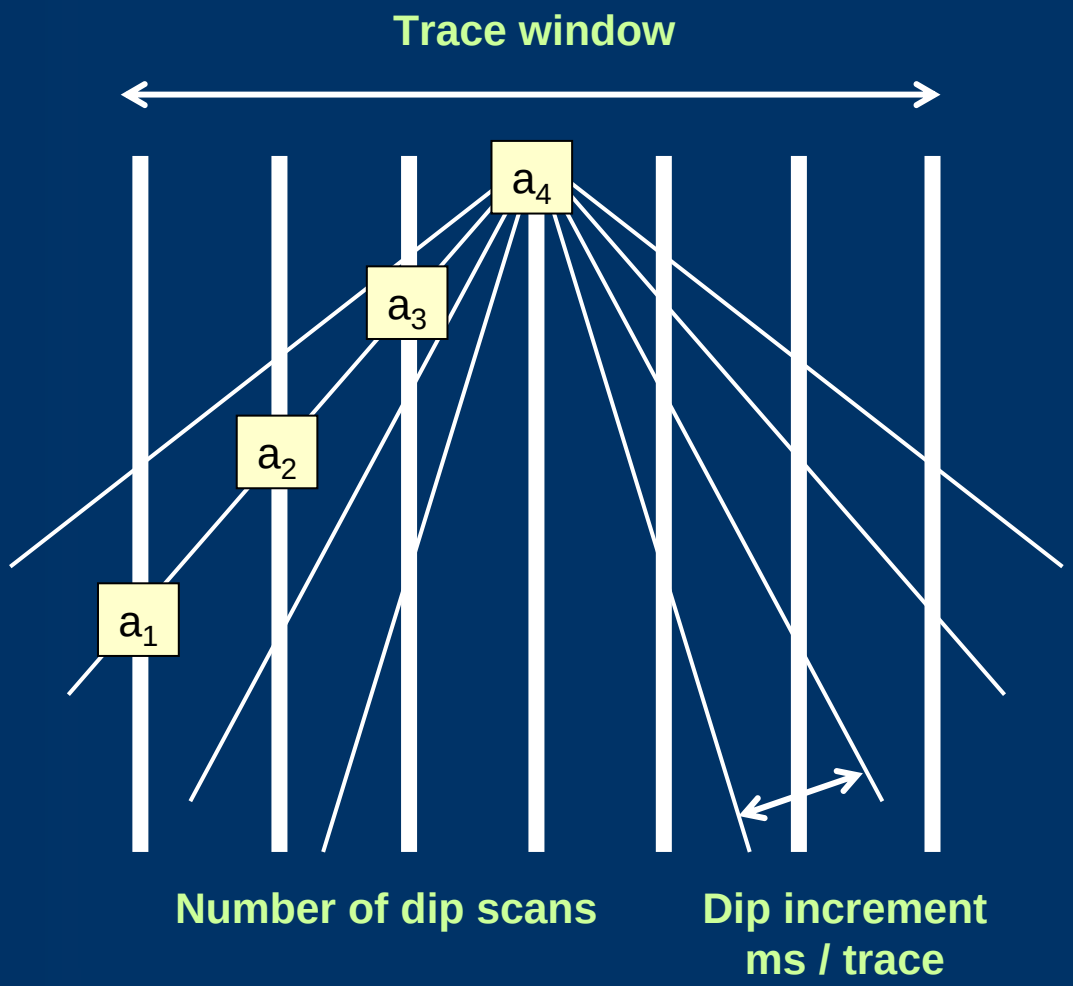
Migration - Spatial Aliasing



Frequencies below curves will not be aliased

Semblance Coherence Filtering

(total incoherence) 0 < Semblance < 1 (complete coherence)



4 step process

- Compute semblance across window along each dip

  $(\Sigma a_i)^2/N\Sigma(a_i)^2$ (Here N = 7 traces)
- Compute coherence as power of semblance
- Smooth data in direction of maximum semblance
- Filter data using coherence weights

Semblance Filtering (*improving the image*)