ENERGY GeO Hackathon
Society of Petroleum Engineers

SPE International
SPE Europe Region

2023 SPE EUROPE ENERGY GEOHACKATHON

3. Seismic Data Processing and Imaging

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#DatafyingEnergy

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1992 University of Miskolc, Hungary

1992- 2002 GES Ltd, Hungary
Central-Europe, North Africa

2002-2003 Trafalgar Energy Ltd,
Project leader, West Africa, Middle East

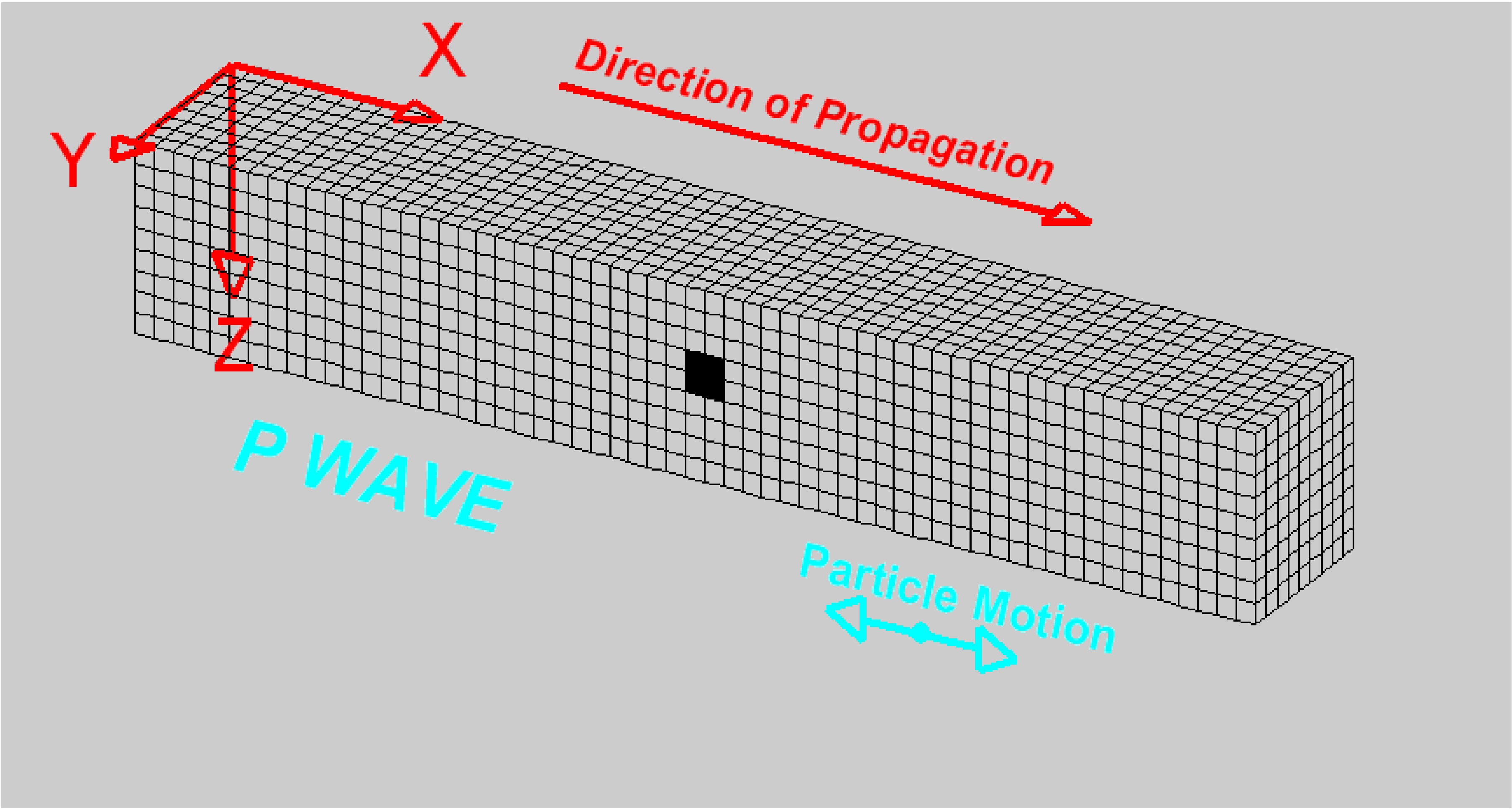
2003-2012 CGG,
2003-2004 Senior project Leader, Angola, Kazakhstan
2005-2008 Team Leader, Oman, Abu Dhabi
2009-2012 Technology Centre Manager Saudi Arabia
2012 Advisor, Netherland

2013- OMV
2013-2022 DM of Seismic Data Processing, Vienna
2023- DM of Seismic Shared Services, Bucharest, OMVPetrom

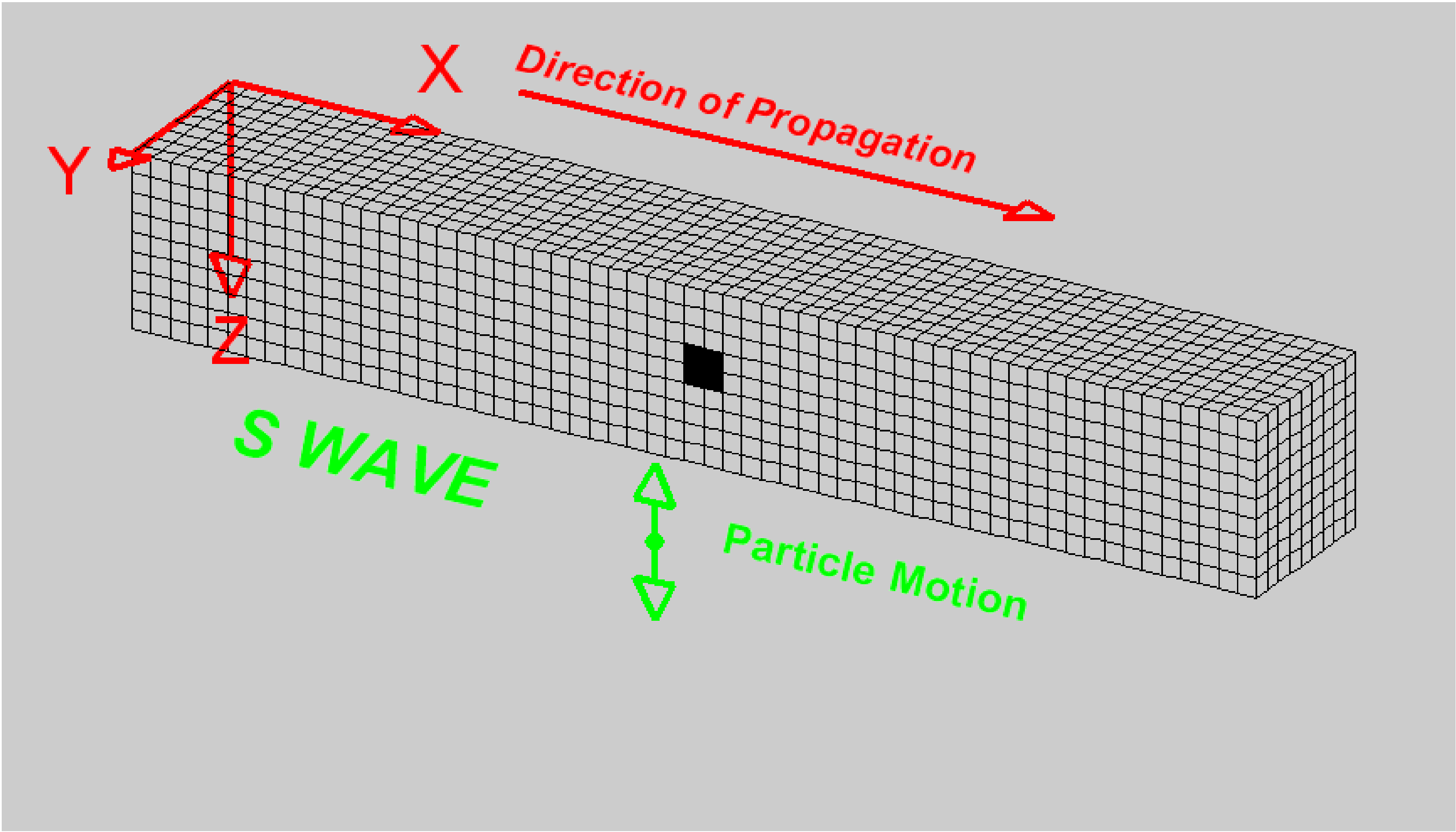
Agenda

1. Introduction
2. Pre-processing
   - I. Reformatting, Geometry, amplitude recovery
   - II. Noise attenuation, Filters
   - III. Deconvolution
   - IV. Common Midpoint gathers
   - V. Static corrections (mostly land)
   - VI. Dynamic correction (NMO), Mute
   - VII. Stack
   - VIII. Migration
3. Migration
   - I. Time migration
   - II. Depth migration

Introduction: P wave, S wave



- Primary waves - also referred to as compressional, longitudinal wave
- P-waves have higher velocities than S-waves
- P-waves are the predominant waves used in seismic exploration
- Vertical component geophones

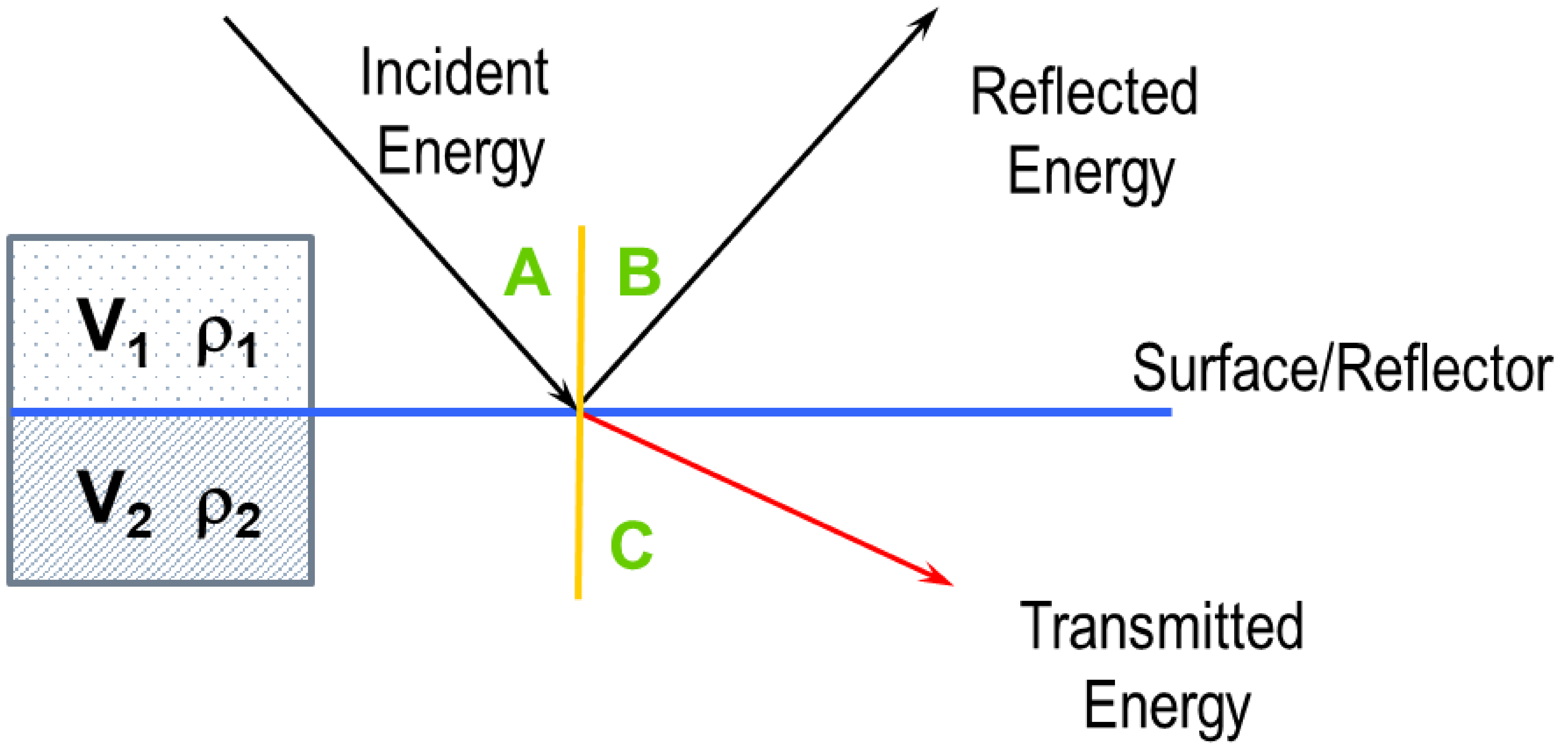


- Secondary waves – also referred to as shear, transverse wave
- Transverse particle motion
- Velocity is lower than P-wave velocity
- S-wave cannot propagate in fluids / gas
- Shear waves may be SV (vertical) or SH (horizontal particle motion)
- Horizontal component geophones

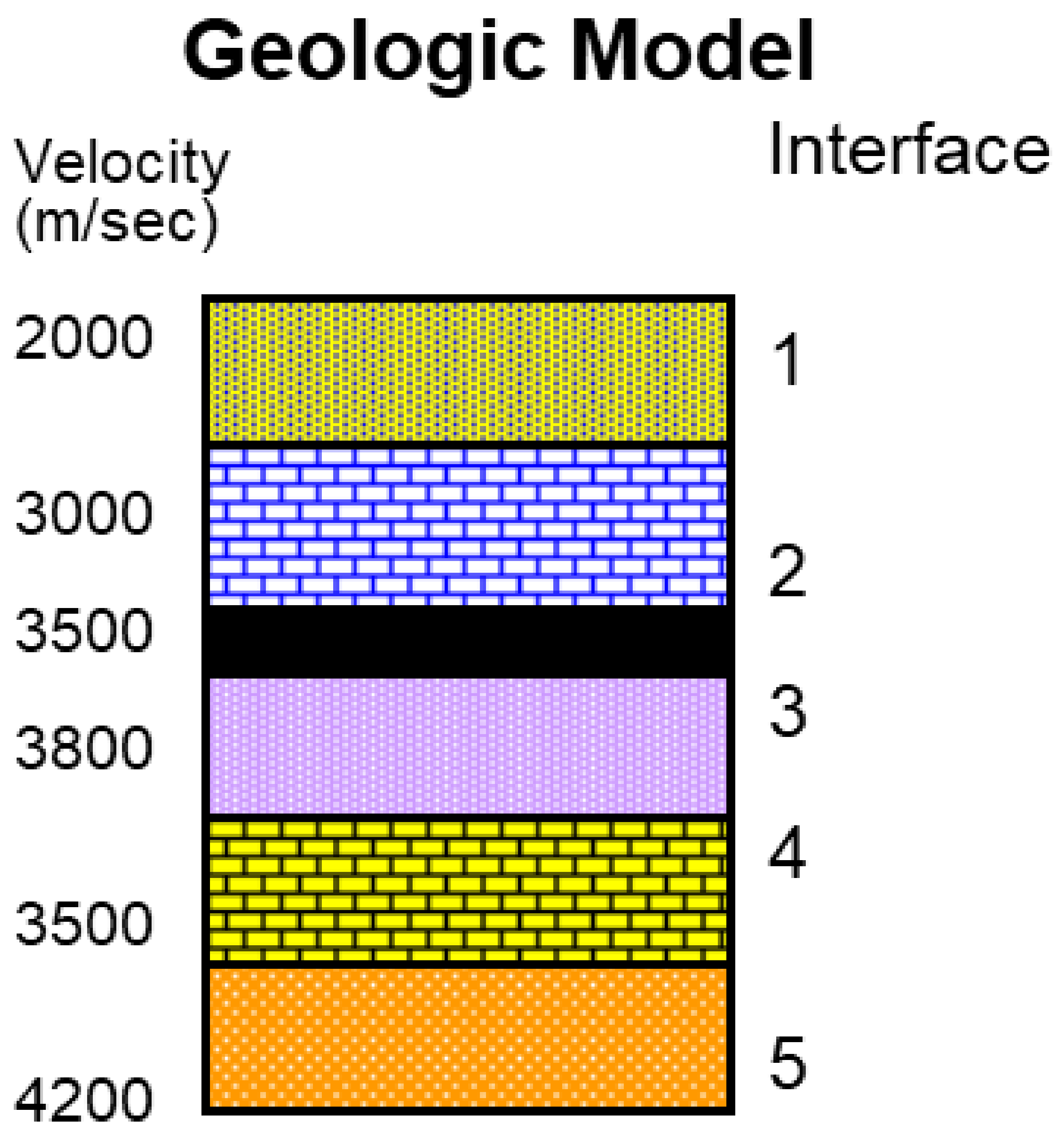
Introduction: Snell's law,

Angle of Incidence *A* = Angle of reflection *B*

Snell´s law $$\frac{\text{Sin } A}{\text{Sin } C} = \frac{V1}{V2}$$



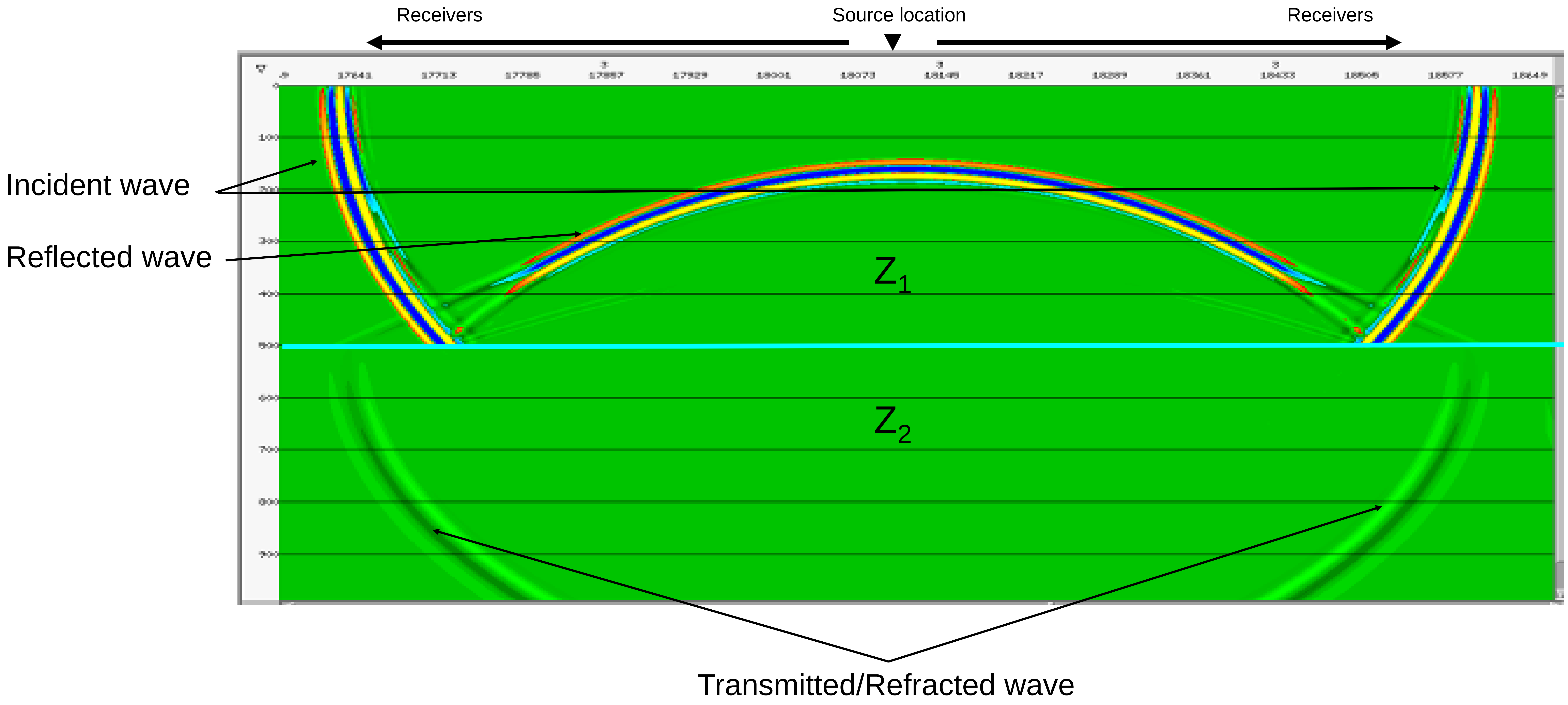
Introduction: Earth 'convolutional model'



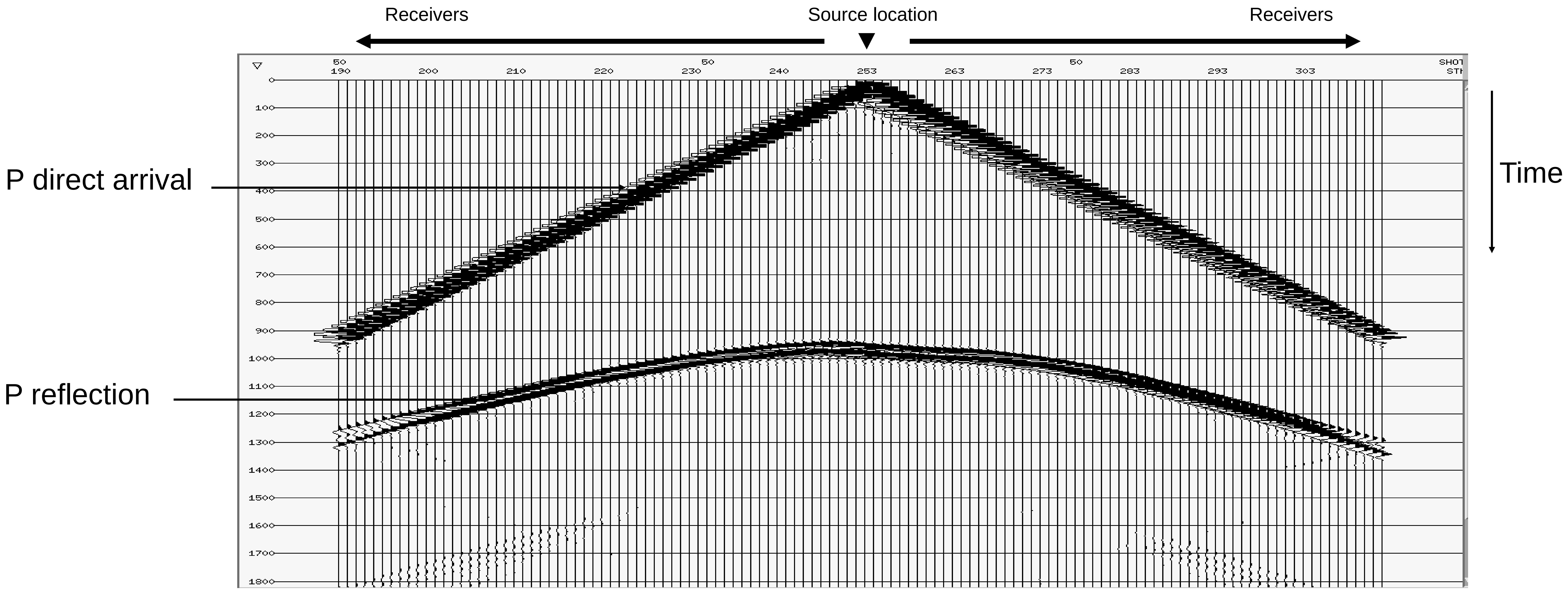
In theory, the seismic trace, (**s**), is obtained by the convolution of the reflection coefficient time series (**r**) with the wavelet (**w**)

$$\mathbf{s = (r * w)}$$

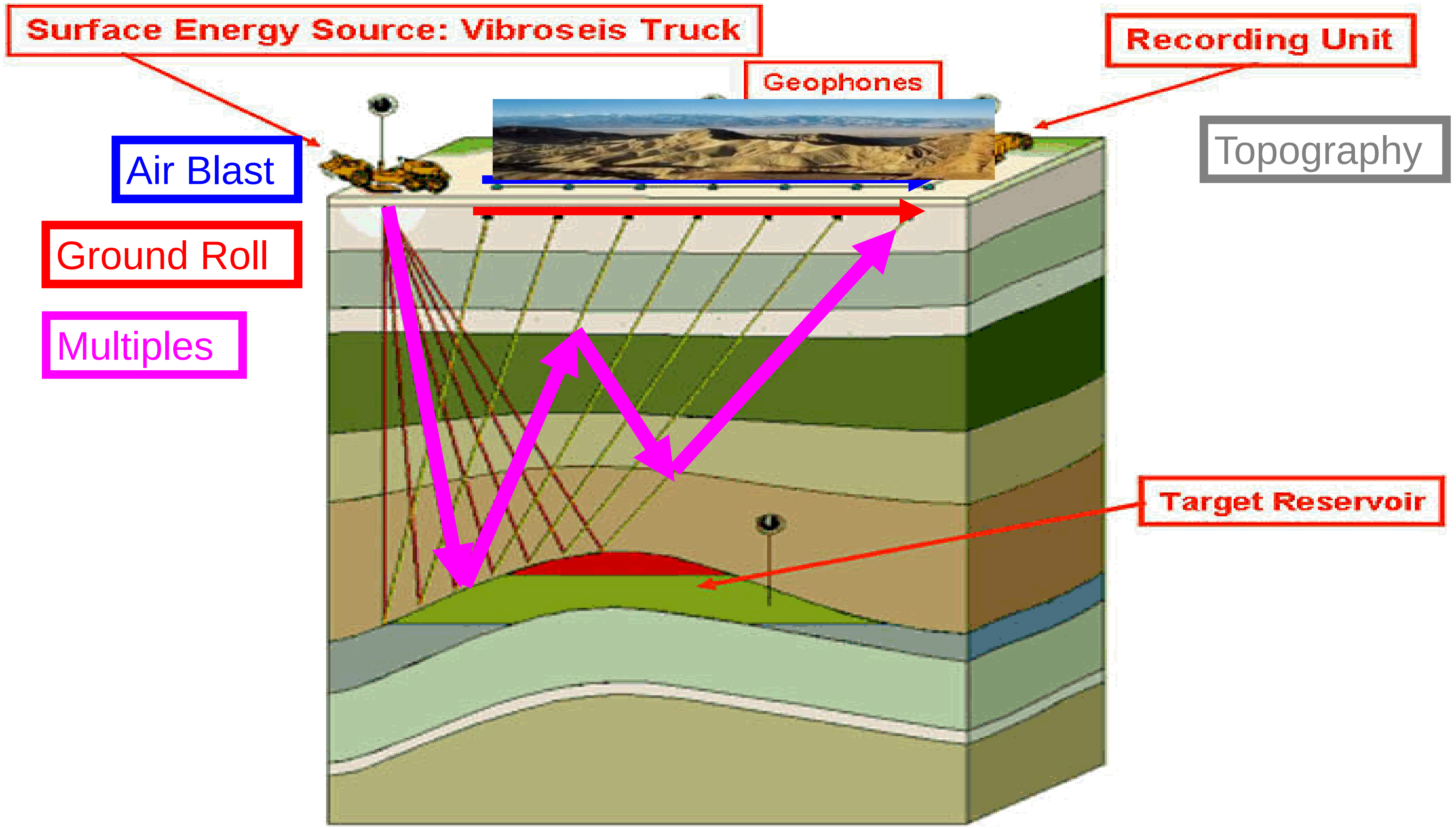
Introduction: P waves, reflection and transmitted



Introduction: P waves, recorded on surface

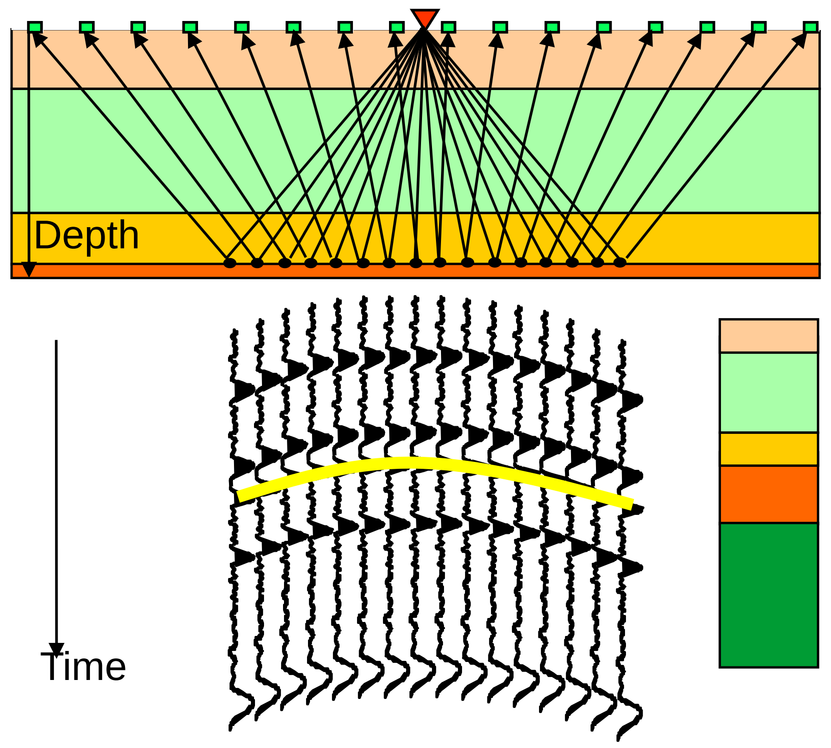


Introduction: The seismic experience, some unwanted effects

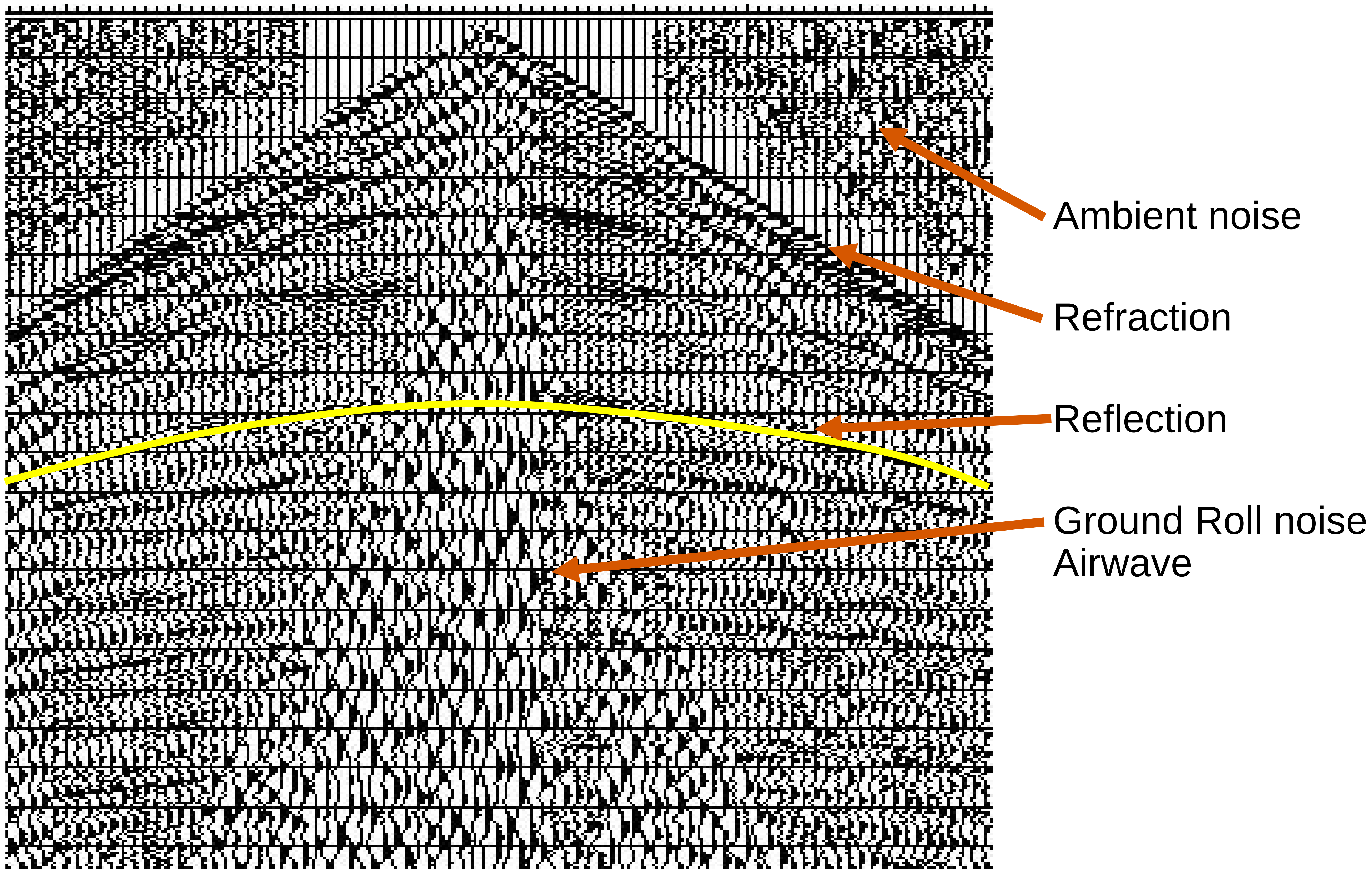


Introduction: Summary a seismic record

Theoretical shotpoint



Recorded shotpoint



Introduction: What is seismic data processing

Processing:
"Changing data, usually to improve the signal-to-noise ratio to facilitate interpretation. Processing operations include applying corrections for known perturbing causes, rearranging the data, filtering it according to some criteria, combining data elements, transforming, migrating, measuring attributes, display, etc."

[Sheriff: Encyclopedic Dictionary of Applied Geophysics (4 ed)]

The seismic data processing consists of a suite of tasks to:

- Improve resolution

- Improve signal to noise ratio

- Obtain an accurate reflection time and position

- Keep amplitude fidelity

Processing flow

Reformatting, geometry, amplitude recovery

⇩

Noise attenuation, filters

⇩

Deconvolution

⇩

Common Mid Point gather

⇩

Static corrections (mostly lands)

⇩

Dynamic (NMO) corrections and Mutes

⇩ ← Multiple attenuation

Stack

⇩

Migration

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Processing flow

Reformatting, geometry, amplitude recovery

↓

Noise attenuation, filters

↓

Deconvolution

↓

Common Mid Point gather

↓

Static corrections (mostly lands)

↓

Dynamic (NMO) corrections and Mutes

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Stack

↓

Migration

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Pre-processing: Reformatting, geometry,

- Reformat the data from international exchange format (SEG – D,Y) to in-house format.

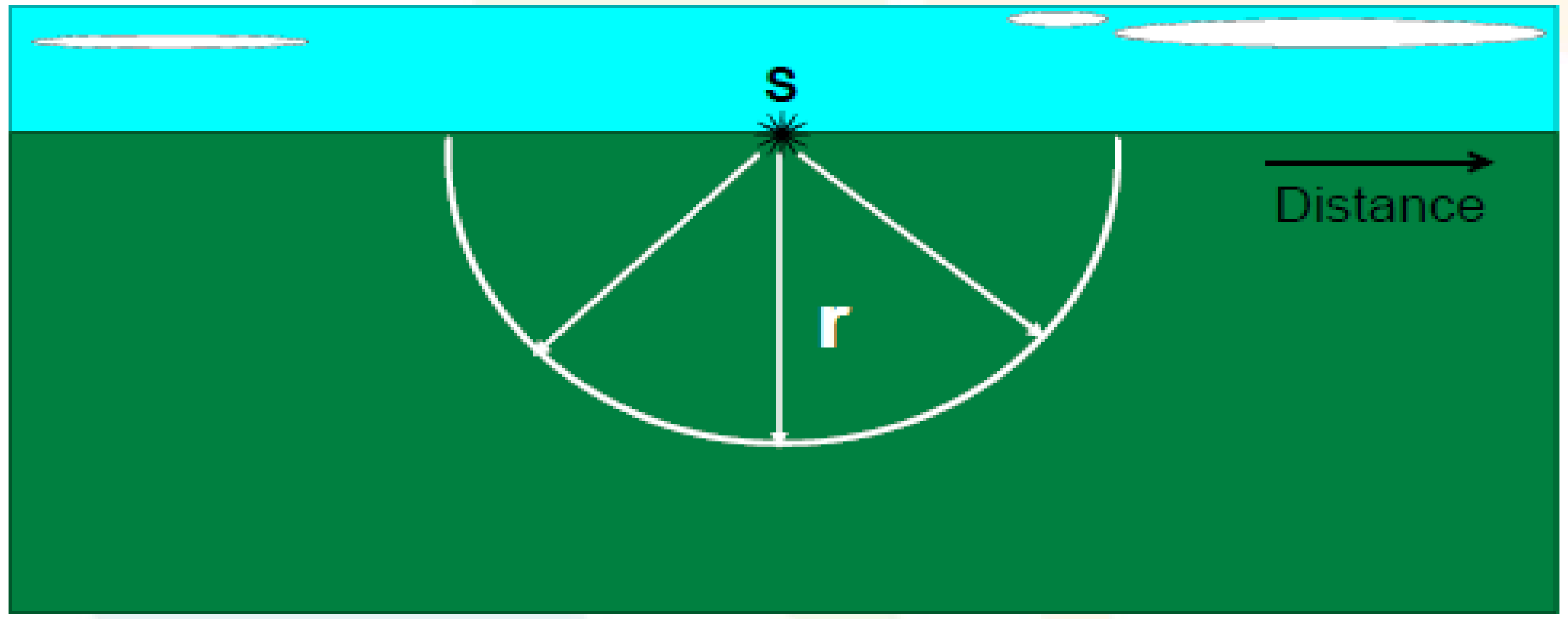
- Geometry is described in the exchange format for the recent data,

  Earlier the geometry was described in the support navigation files and had to be

  assigned with the seismic data after reformatting

Pre-processing: Amplitude recovery

The seismic energy is distributed over a spherical surface of increasing area as the wave propagates away from the source

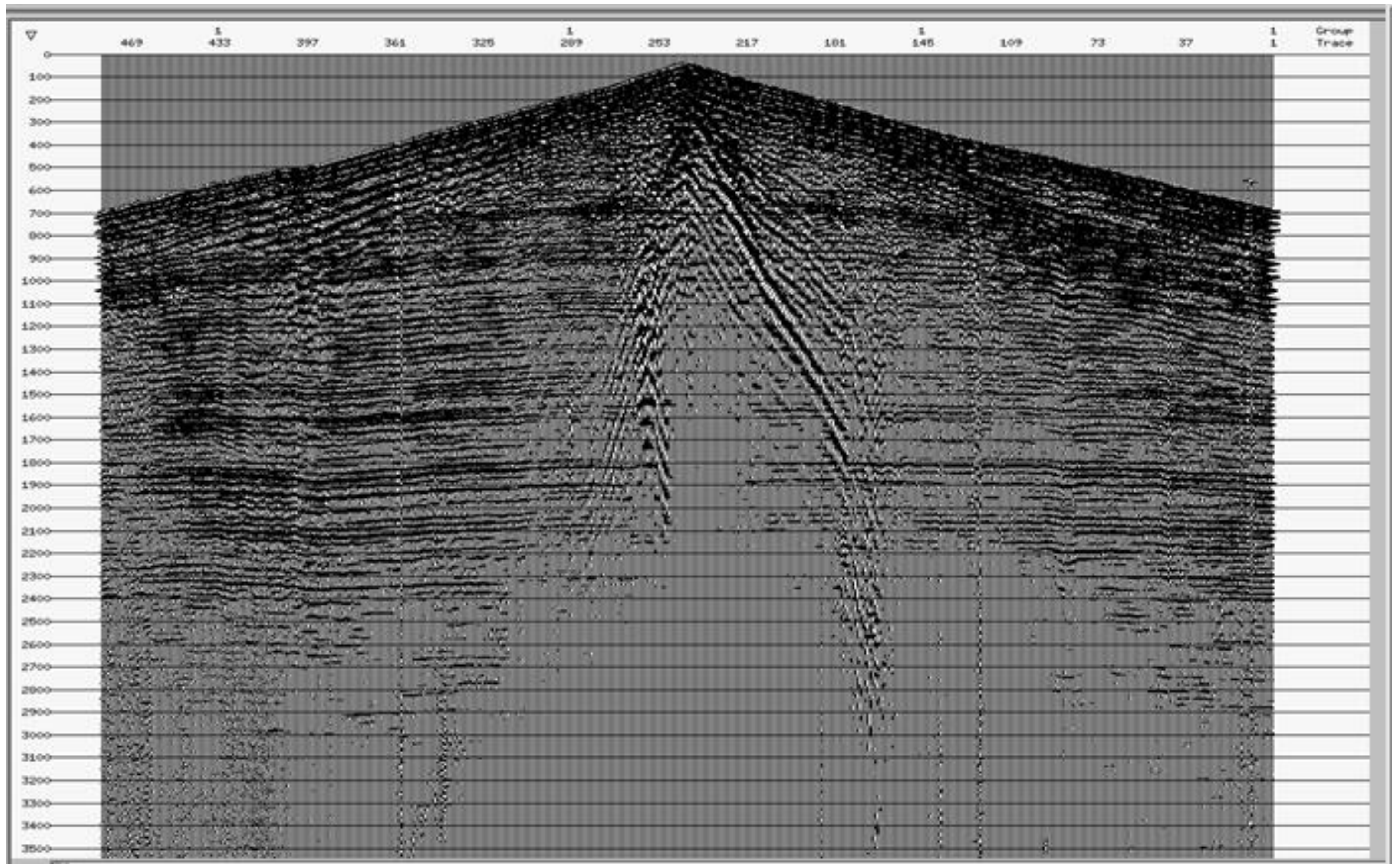


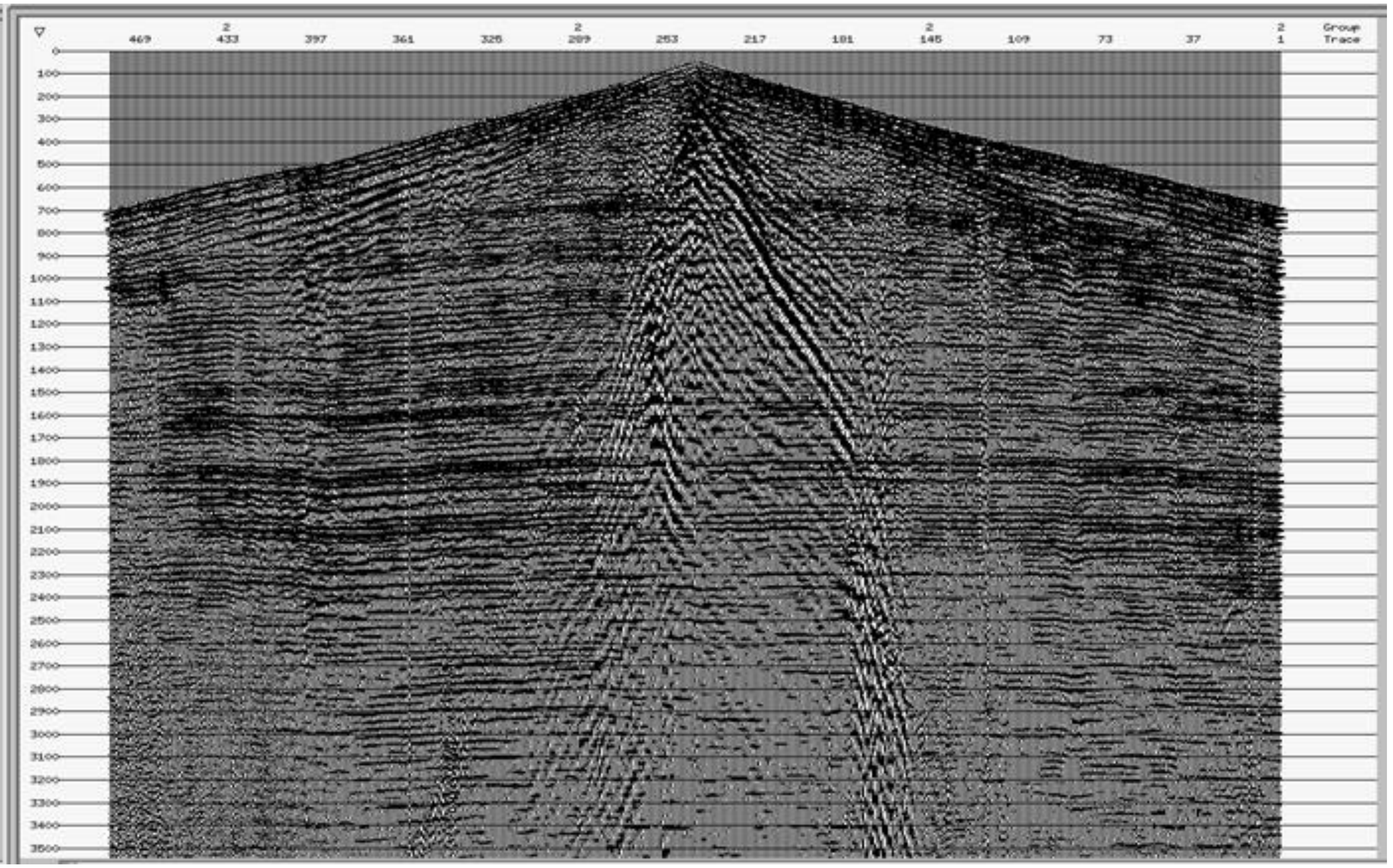
Amplitudes decrease as 1/r when r is the radius of the half sphere.

Pre-processing: Amplitude recovery,

Shot gather before amplitude recovery

Shot gather after amplitude recovery
(spherical divergence correction)





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Processing flow

Reformatting, geometry, amplitude recovery

↓

Noise attenuation, filters

↓

Deconvolution

↓

Common Mid Point gather

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Static corrections (mostly lands)

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↓ ← Multiple attenuation

Stack

↓

Migration

Pre-processing: Noise attenuation, filter

One of the main objective of seismic data processing is the attenuation of noise

Without noise attenuation:

- Signal may be distored
- Signal may be masked
- Noise may be spread across data sets if using multi-channel processes (migration, tau-p, etc.)

Definitions:

SIGNAL – that part of the data which is required

- Normally primary reflection information

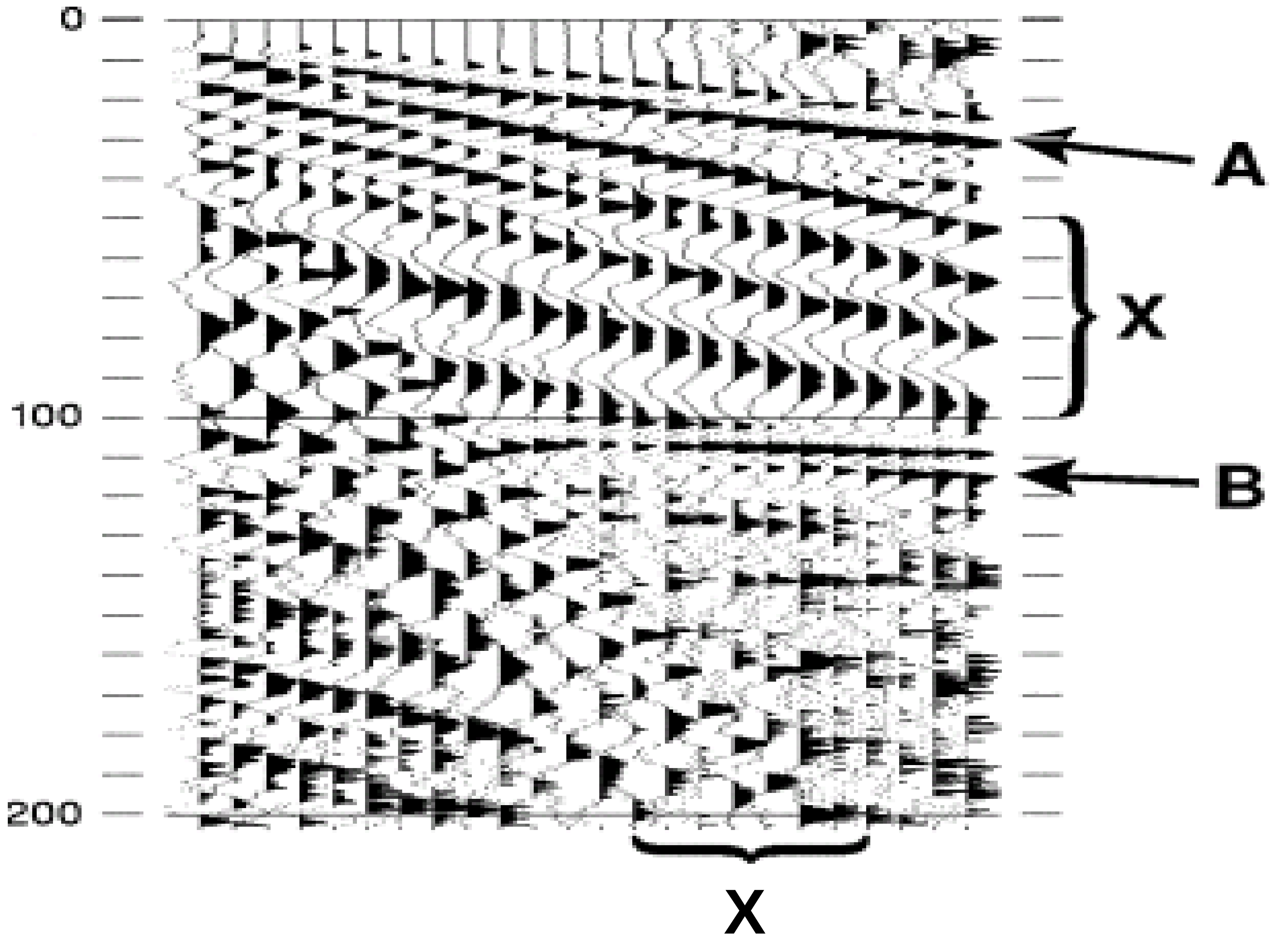
NOISE – Everything else!

- Random
- Coherent

Pre-processing: Noise attenuation, filter

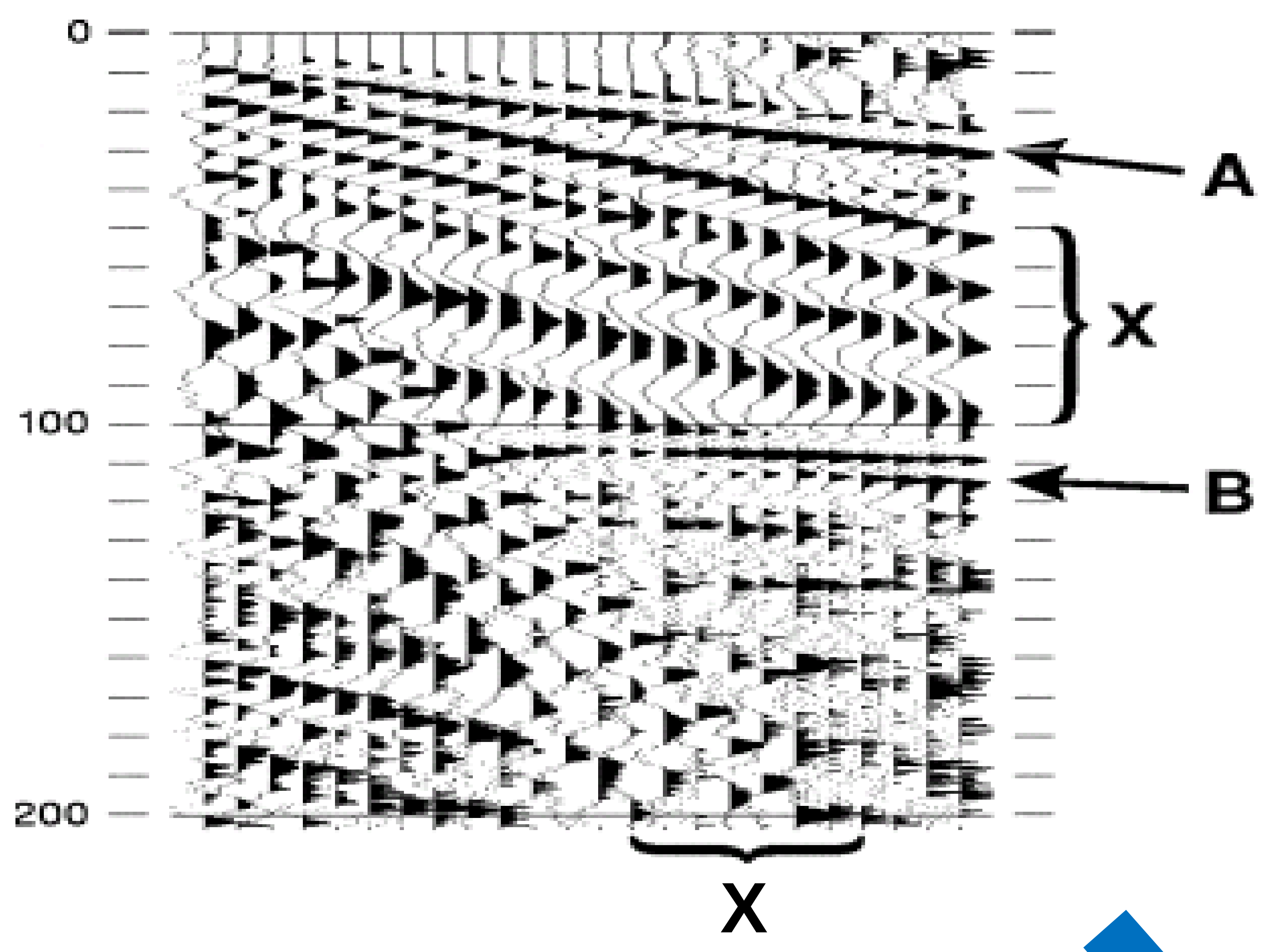
Main steps for noise attenuation:

- Recognition of noise content of the data
- Separation of the noise and signal in the right domain
- Attenuation of the noise content without attenuating or distorting the signal

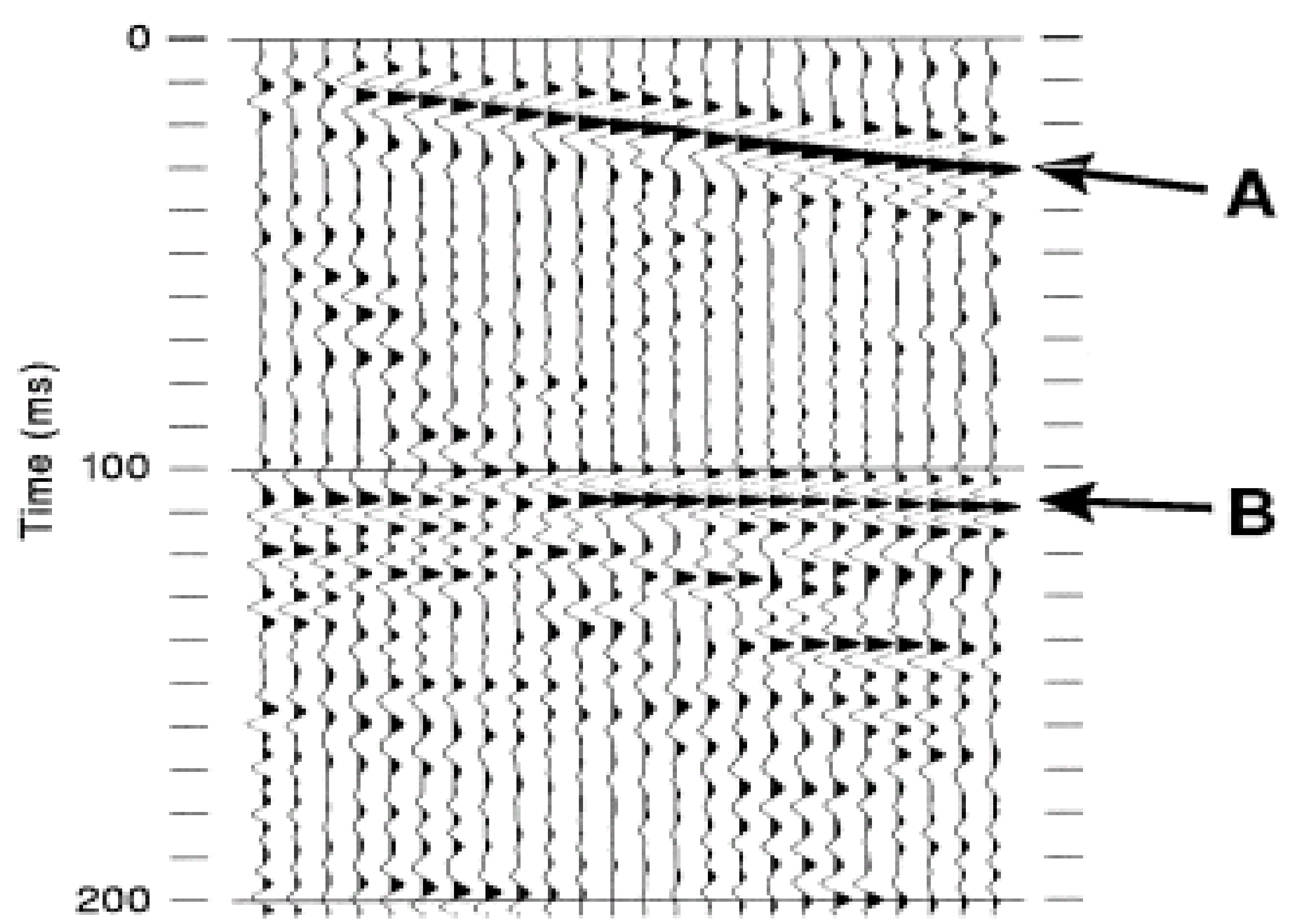


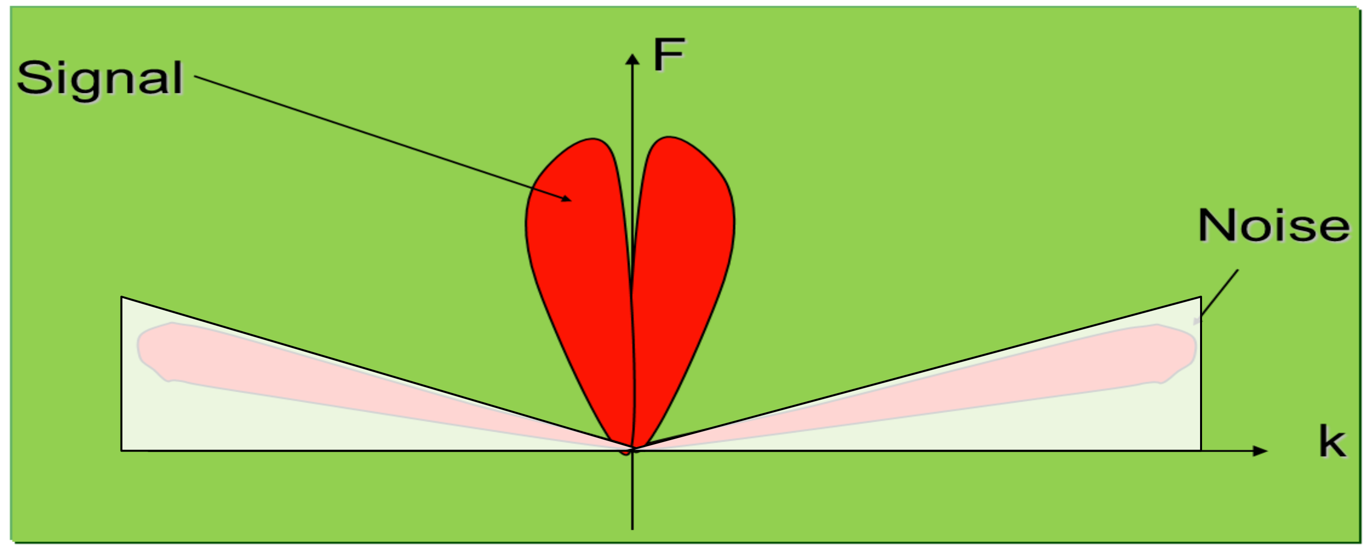
- A, B signal to be preserved
- X noise to be removed

Pre-processing: Noise attenuation, filter



- A, B signal to be preserved
- X noise to be removed





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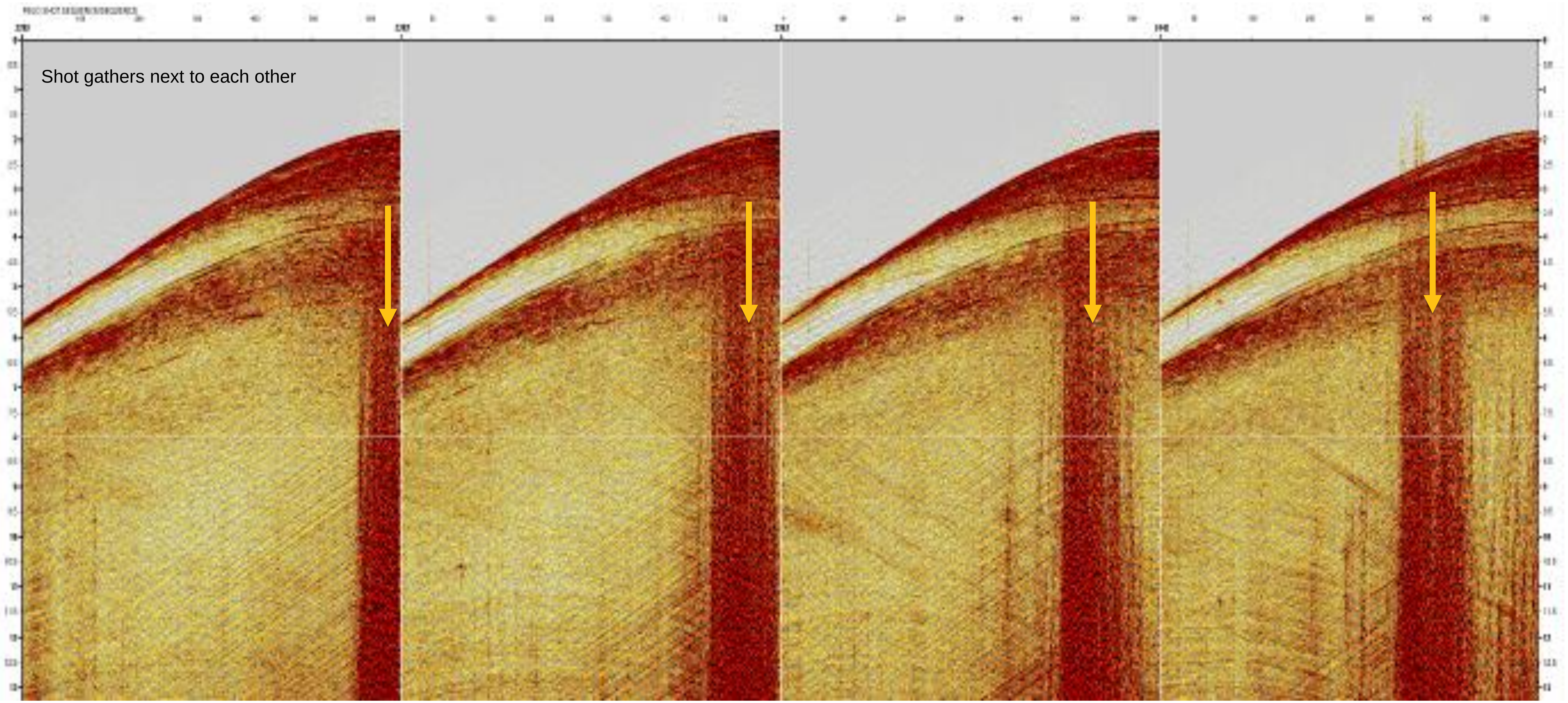
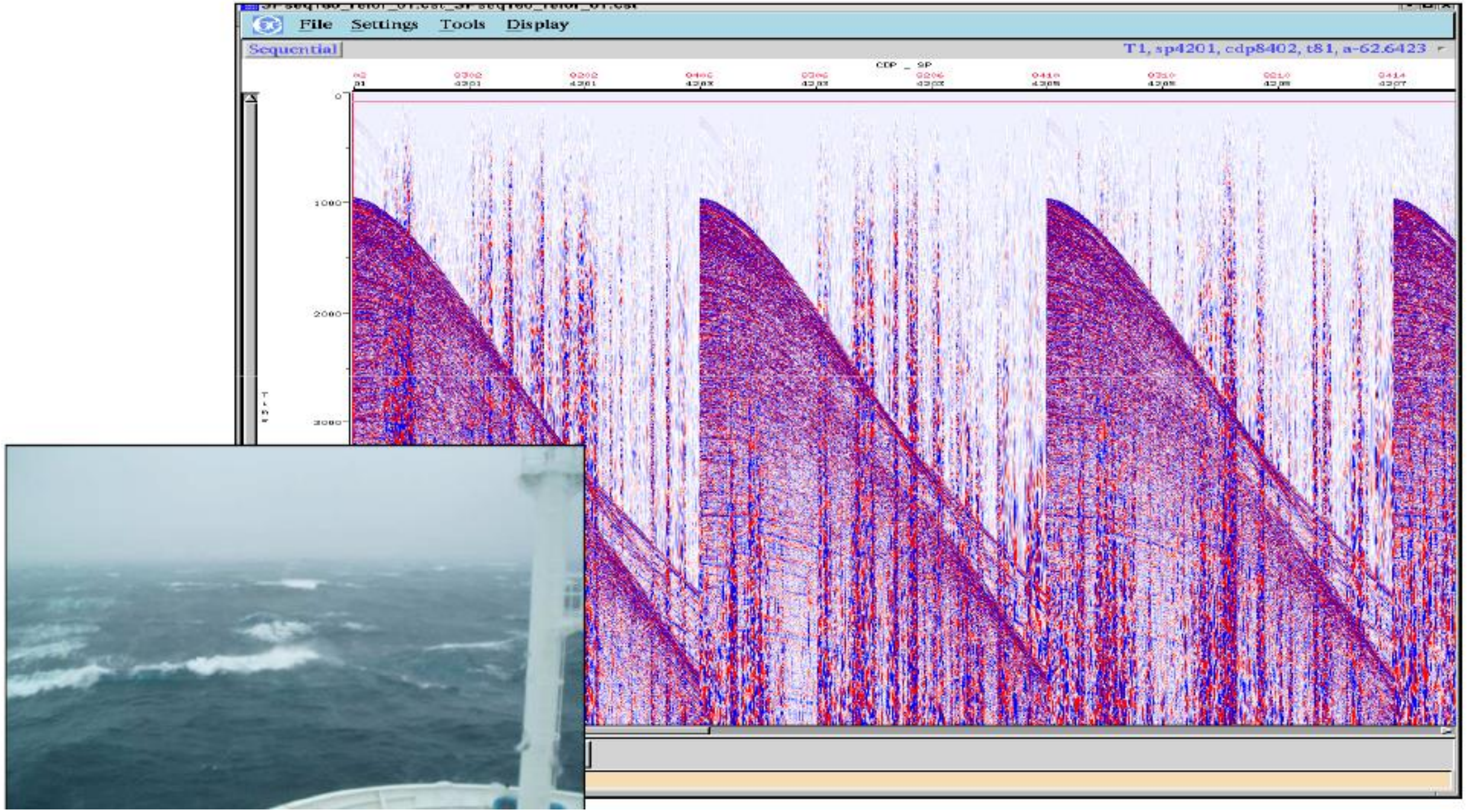
Pre-processing: Noise examples

Noise generated in a fix surface position



Pre-processing: Noise examples

Bad Weather

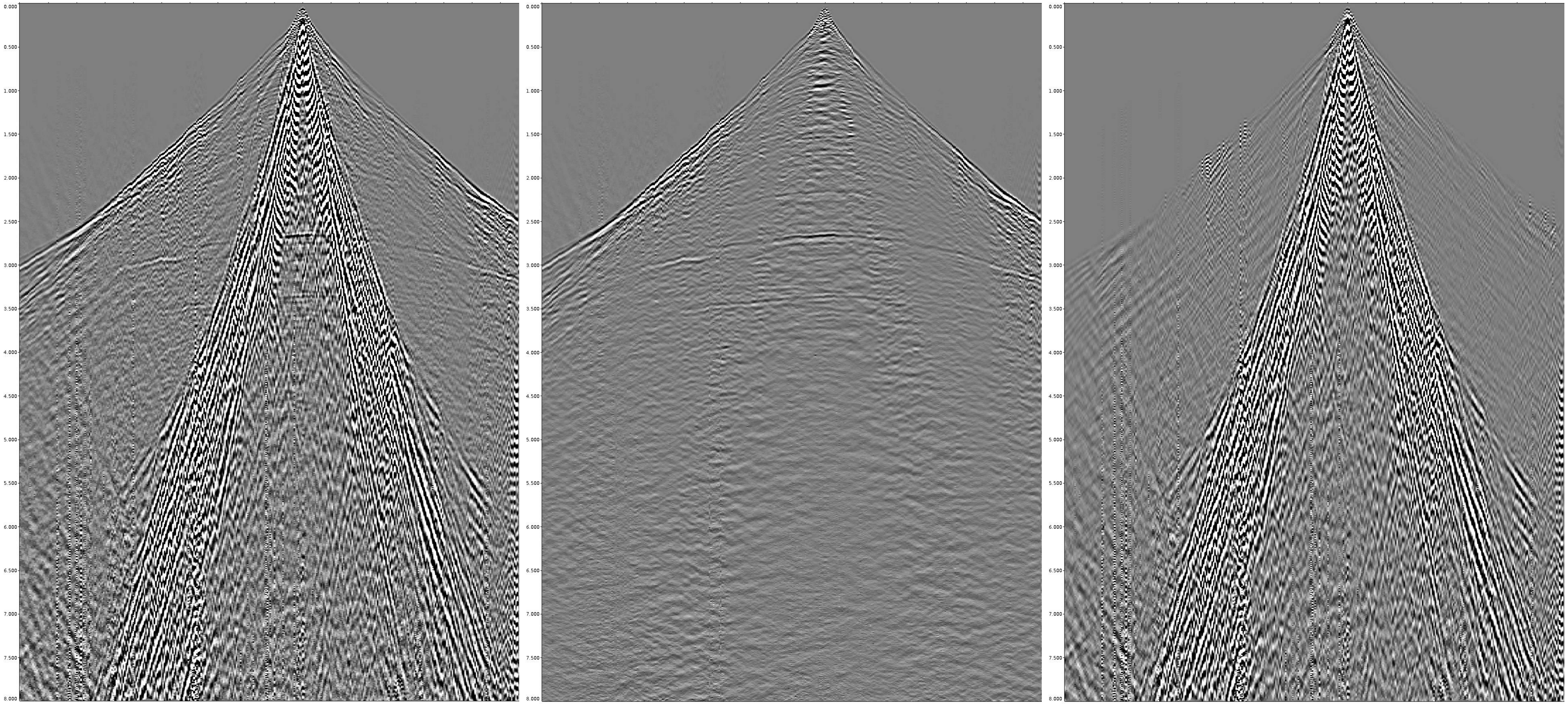


Pre-processing: Noise examples

Land shot gather
before noise attenuation

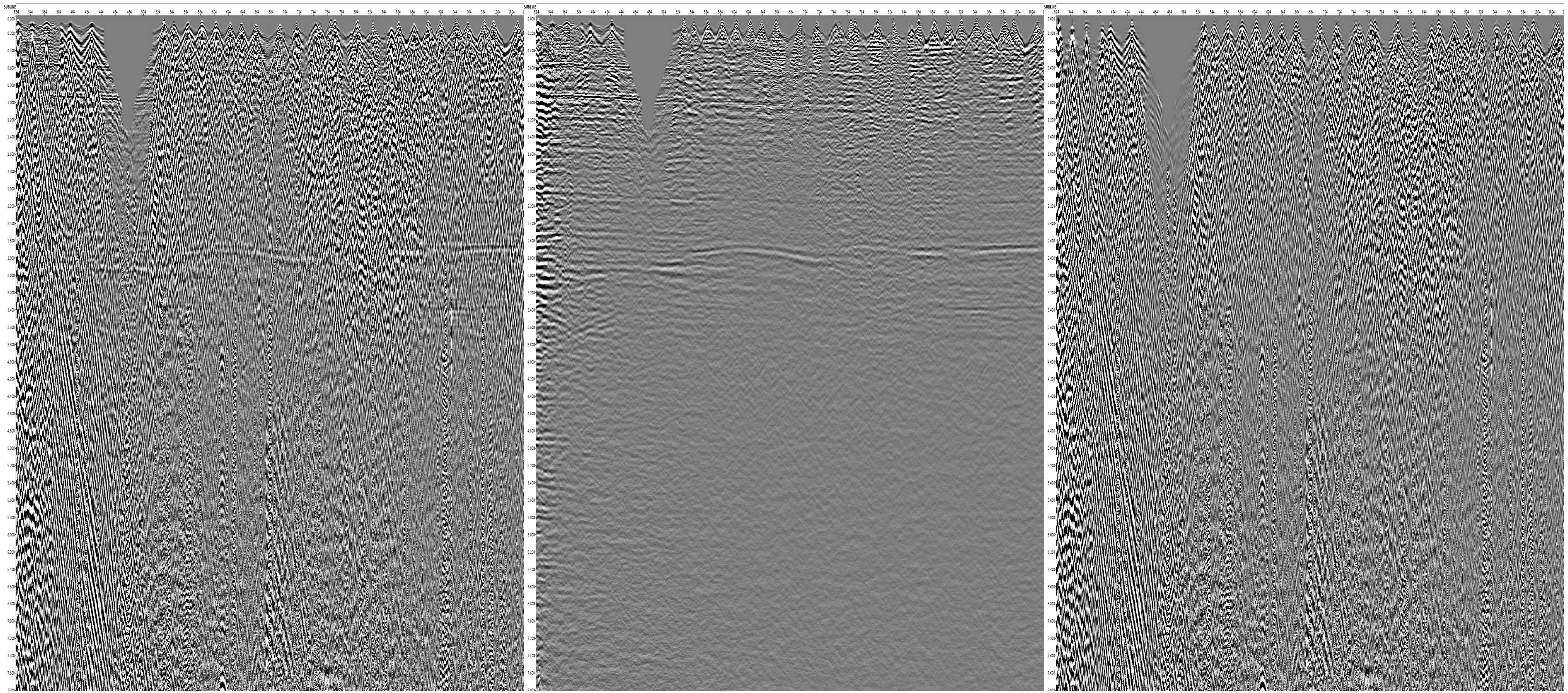
Land shot gather
after noise attenuation

Difference



Pre-processing: Noise examples

Land stack before noise attenuation | Land stack after noise attenuation | Difference



Processing flow

Reformatting, geometry, amplitude recovery

⇩

Noise attenuation, filters

⇩

Deconvolution

⇩

Common Mid Point gather

⇩

Static corrections (mostly lands)

⇩

Dynamic (NMO) corrections and Mutes

⇩ ← Multiple attenuation

Stack

⇩

Migration

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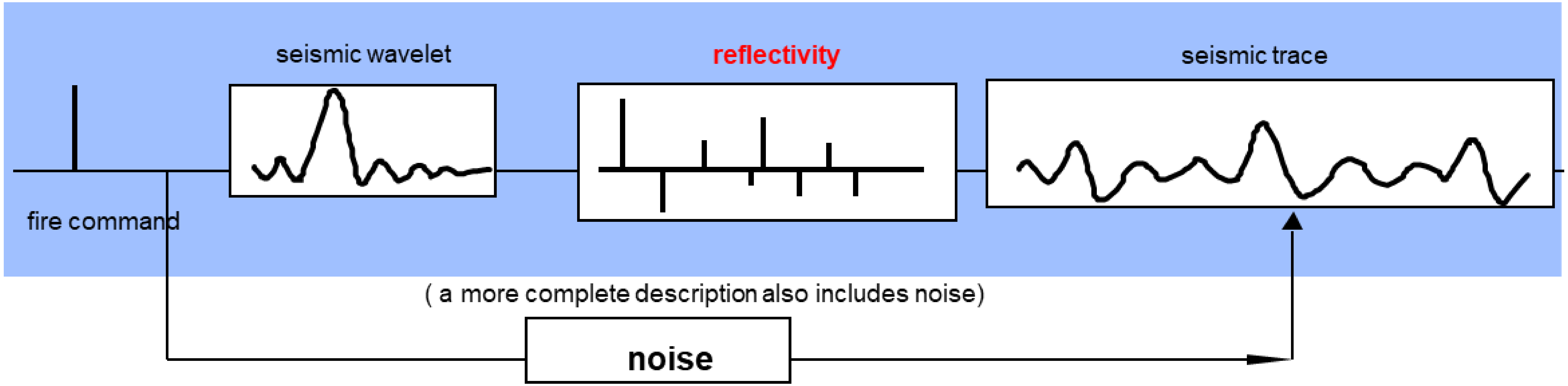
Pre-processing: Deconvolution

- seismic wavelet: response of the filters in the seismic system (except reflectivity)

- seismic trace: reflectivity convolved with the wavelet plus noise

$$s = (w * r) + n$$



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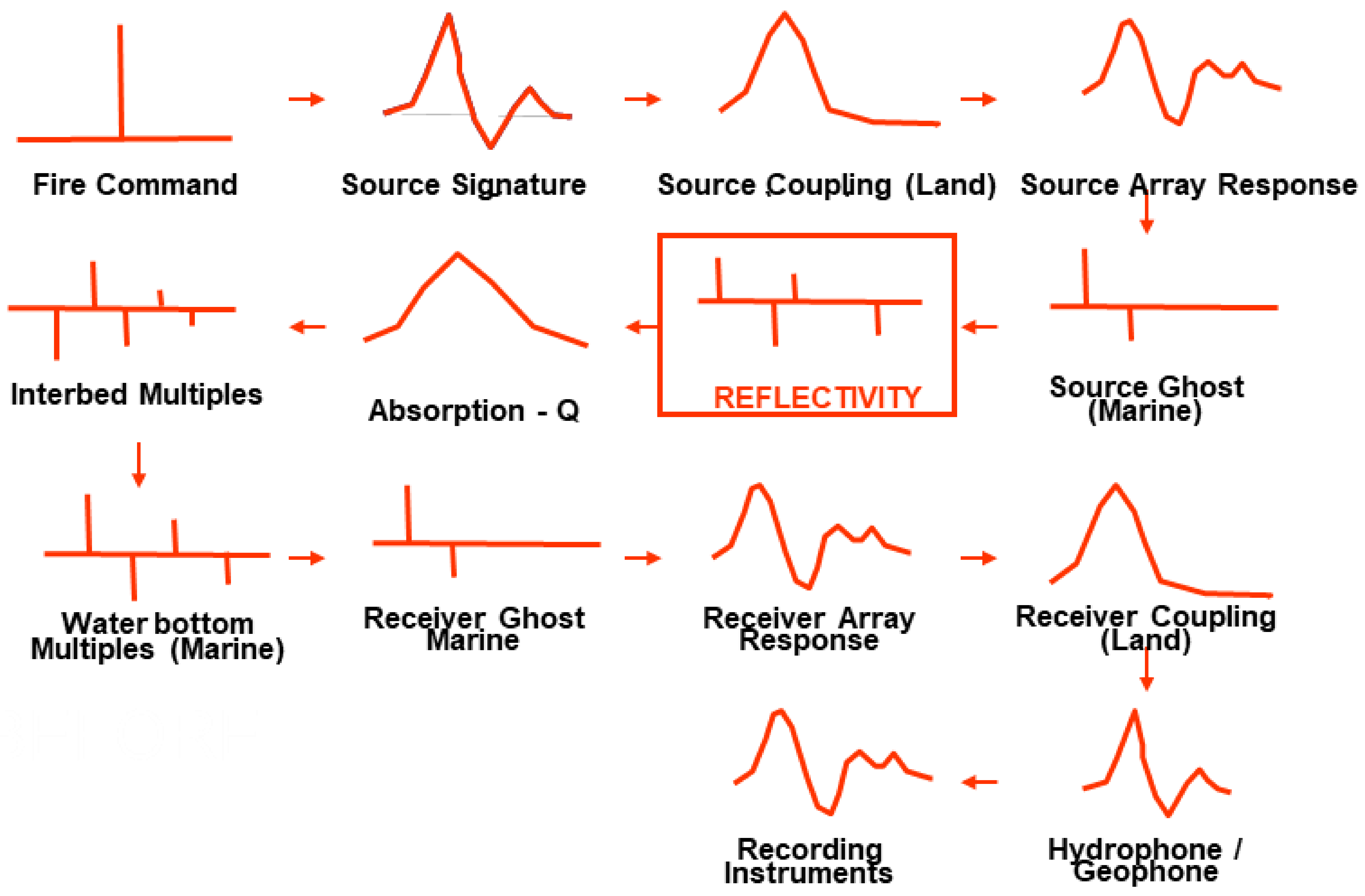
Pre-processing: Deconvolution

The seismic trace is the output of a cascaded series of filters in response to an input spike

Each physical component of the seismic system (e.g. source, receiver, recording instrument etc.) can equivalent to a filter ‘black box’

ONLY THE REFLECTIVITY SERIES IS THE INTEREST OF THE INTERPRETER



Pre-processing: Goals of deconvolution

Retrieve the Earth reflectivity function:

1. Compress the seismic wavelet
2. Attenuate multiples
3. Compensate for source and receivers effects

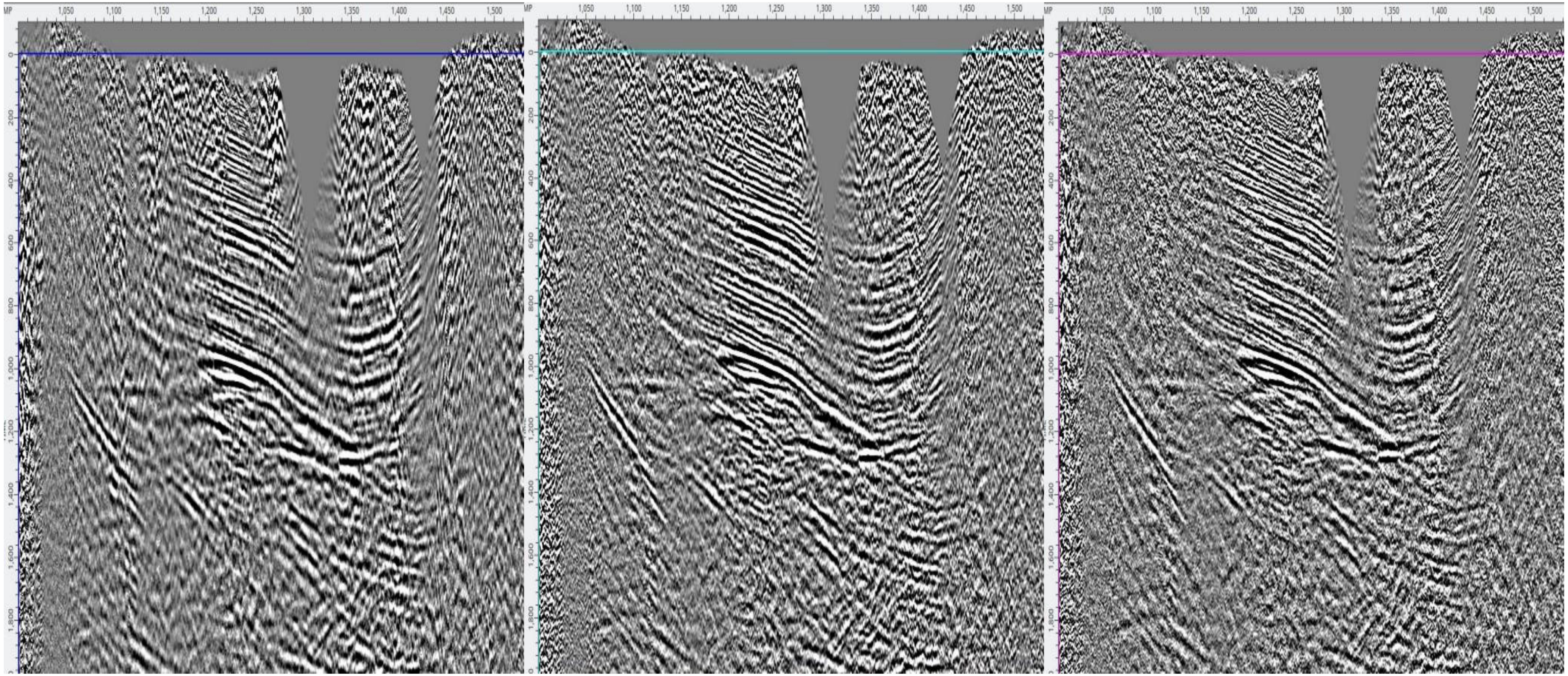
- **Predictive deconvolution**
  Statistical
  Phase is not manipulated
  Multiples attenuated

- **Spike deconvolution**
  Statistical,
  Min. phase input zero phase output
  Support to merge datasets with different sources

- **Source signature deconvolution**
  Deterministic
  Based on far field signature
  Zero phase output

Pre-processing: Deconvolution example

Input | Predictive (gap) deconvolution | Spike deconvolution



Processing flow

Reformatting, geometry, amplitude recovery

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Noise attenuation, filters

↓

Deconvolution

↓

Common Mid Point gather

↓

Static corrections (mostly lands)

↓

Dynamic (NMO) corrections and Mutes

↓ ← Multiple attenuation

Stack

↓

Migration

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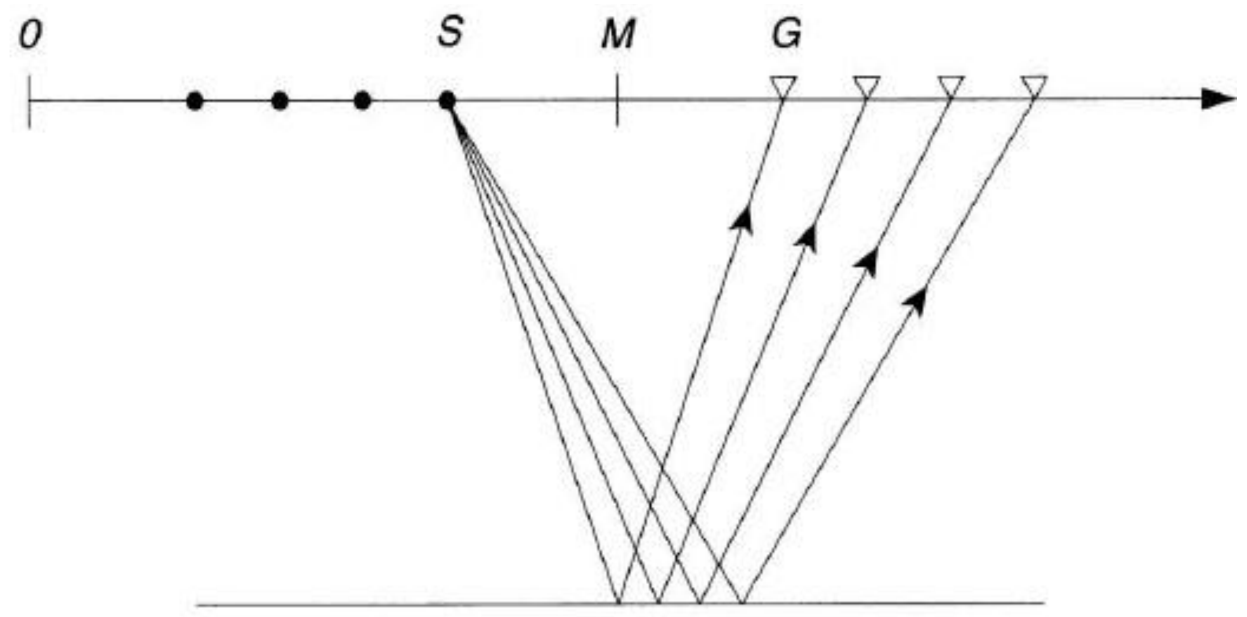
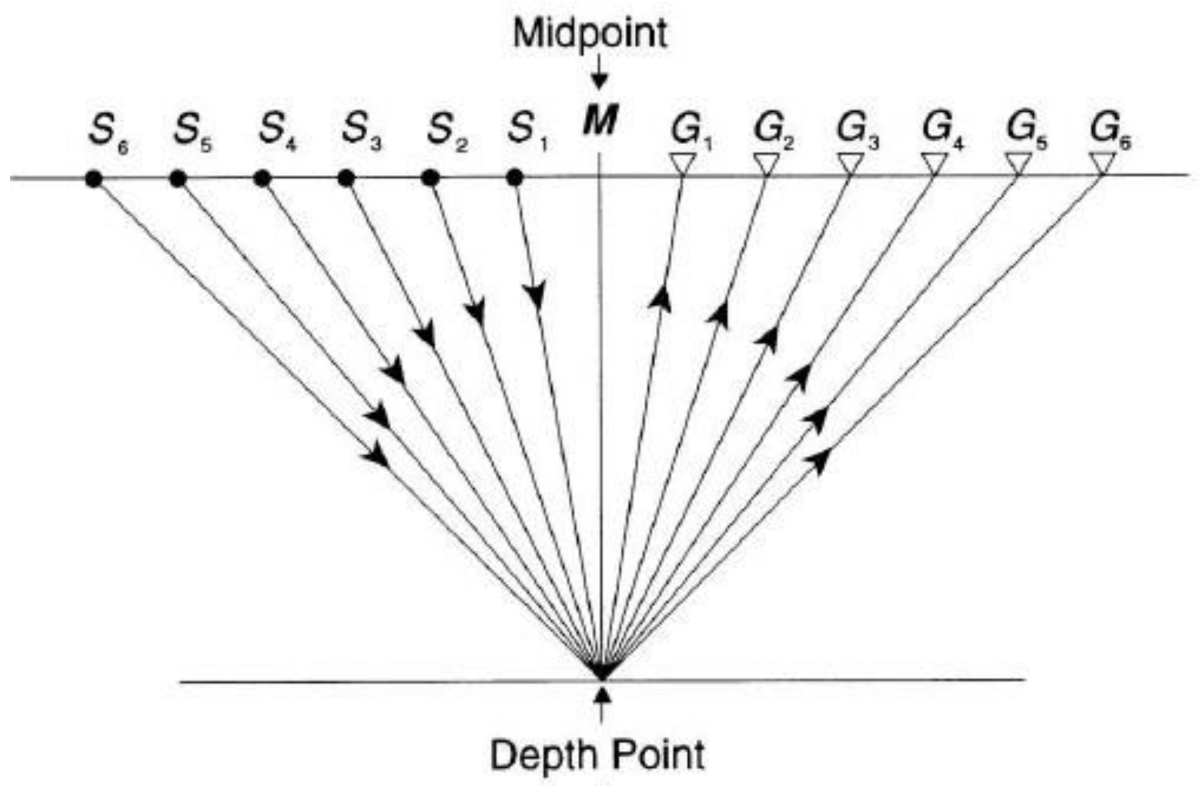
Pre-processing: Common Midpoint gathering



a



b

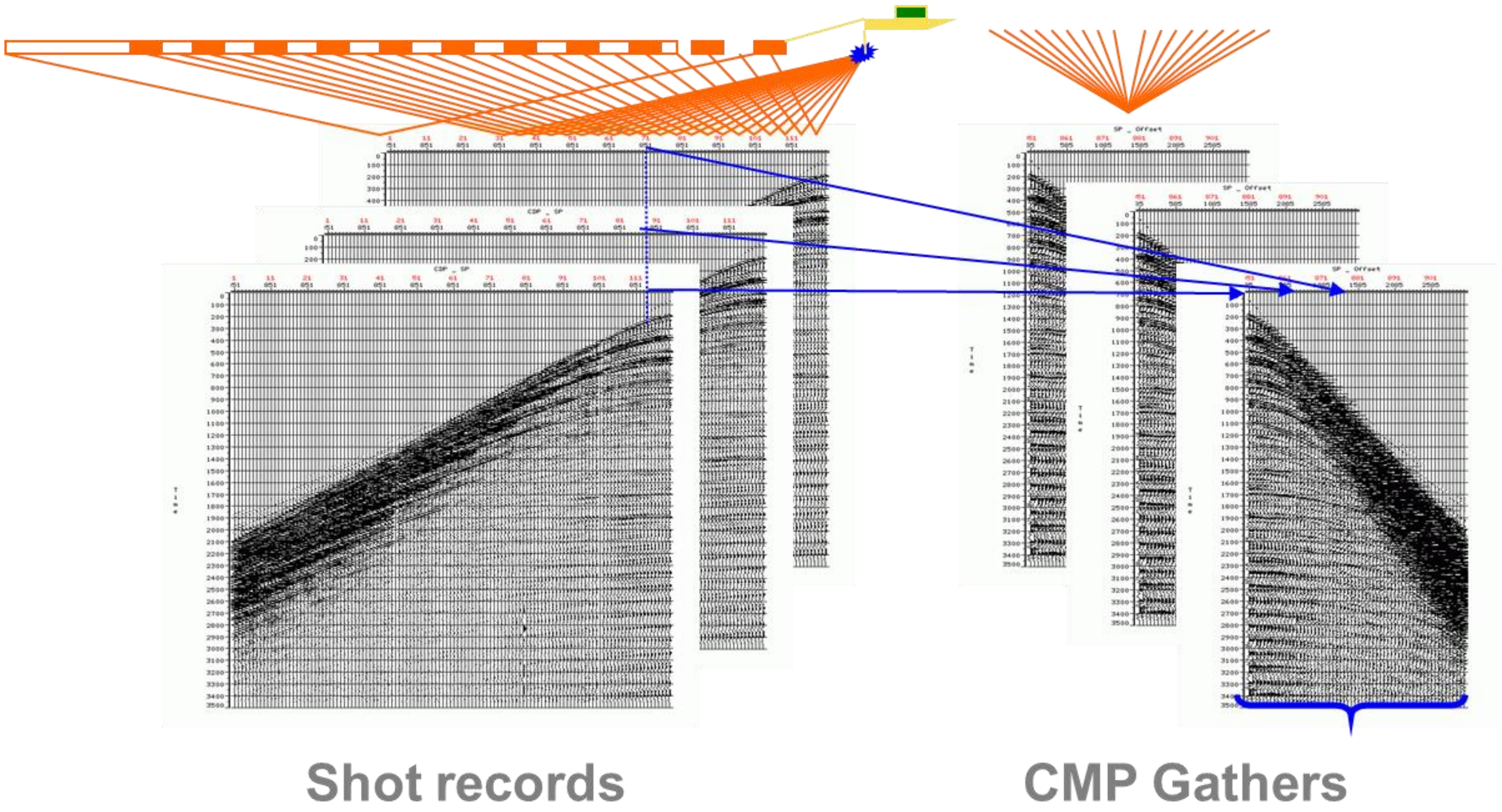
Seismic data acquisition with multifold coverage is done in shot-receiver (*s, g*) coordinates. Figure (a) is a schematic depiction of the recording geometry and ray paths associated with a flat reflector.

Seismic data processing, on the other hand, conventionally is done in midpoint-offset coordinates. The required coordinate transformation is achieved by sorting the data into CMP gathers, Fig (b). Based on the field geometry information, each individual trace is assigned to the midpoint between the shot and receiver locations associated with that trace.

Those traces with the same midpoint location are grouped together, making up a CMP gather. Albeit incorrectly, the term *common depth point* (CDP) and *common midpoint* (CMP) often are used interchangeably.

From SEG-WIKI

Pre-processing: Common Midpoint gathering



Processing flow

Reformatting, geometry, amplitude recovery

⇩

Noise attenuation, filters

⇩

Deconvolution

⇩

Common Mid Point gather

⇩

Static corrections (mostly lands)

⇩

Dynamic (NMO) corrections and Mutes

⇩ ← Multiple attenuation

Stack

⇩

Migration

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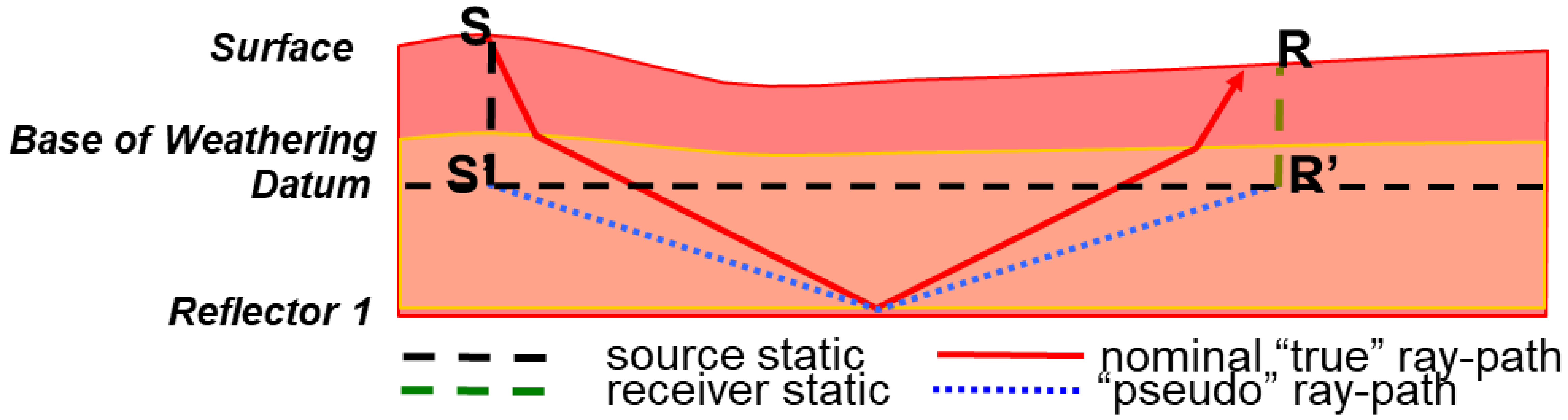
Pre-processing: Static correction



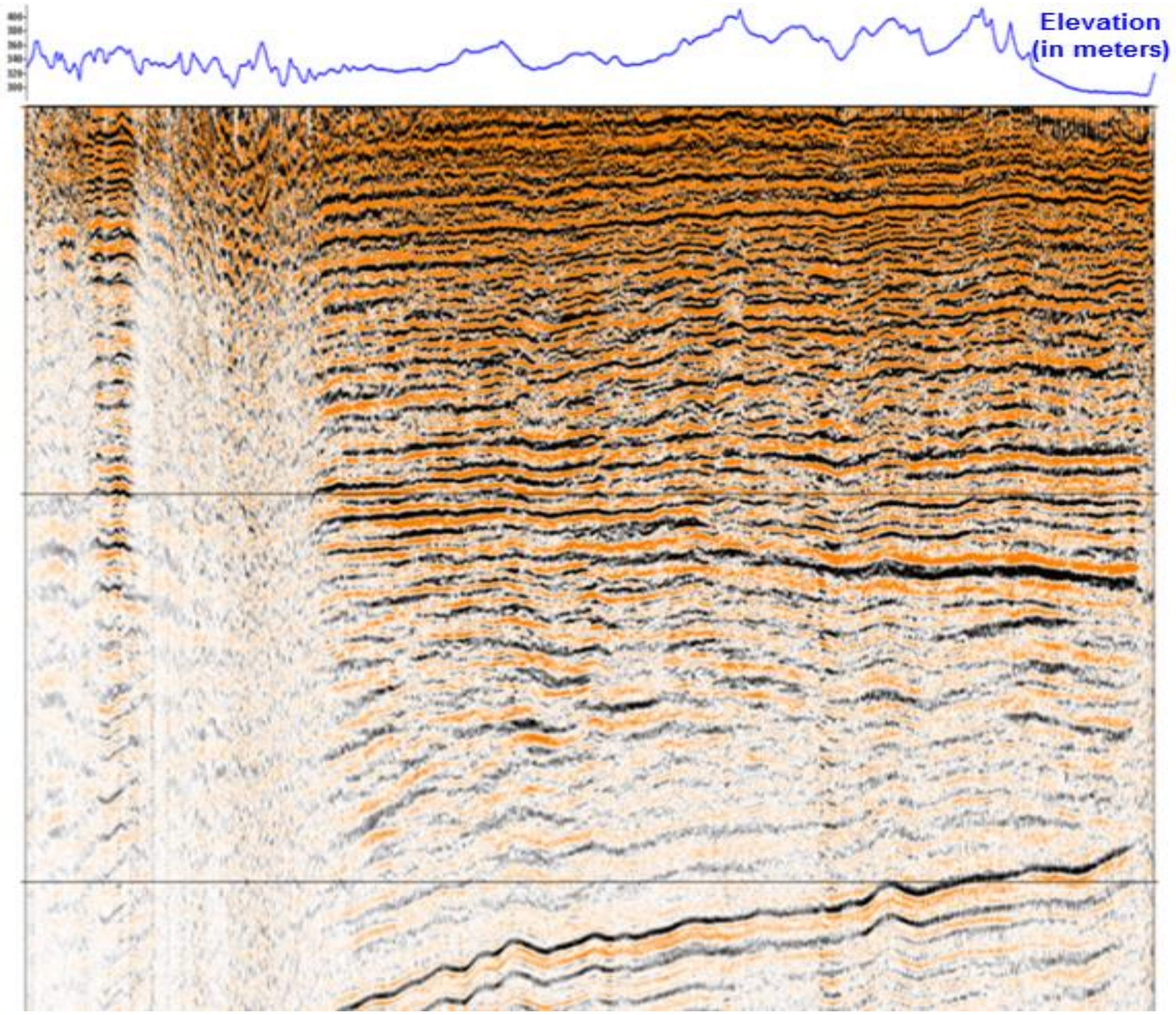
Remove unwanted, near surface, time delays due to:

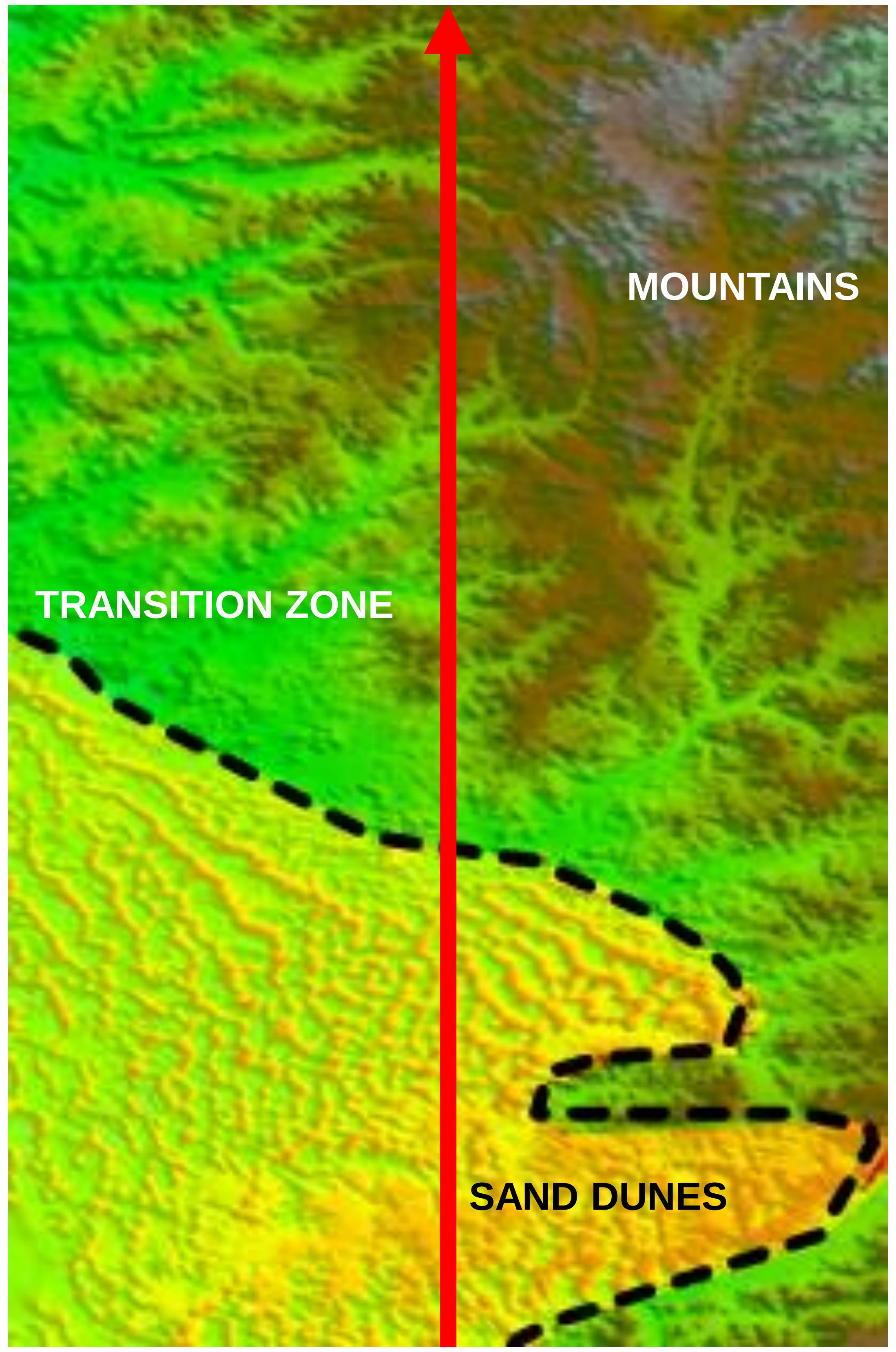
- variable receiver and source elevations
- variable weathered layer velocities and thicknesses
- other near surface layer velocity anomalies

All time measurements from a defined « datum plane »

Pre-processing: Static example

FIELD STATIC





Processing flow

Reformatting, geometry, amplitude recovery

⇩

Noise attenuation, filters

⇩

Deconvolution

⇩

Common Mid Point gather

⇩

Static corrections (mostly lands)

⇩

Dynamic corrections (NMO) and Mutes

⇩ ← Multiple attenuation

Stack

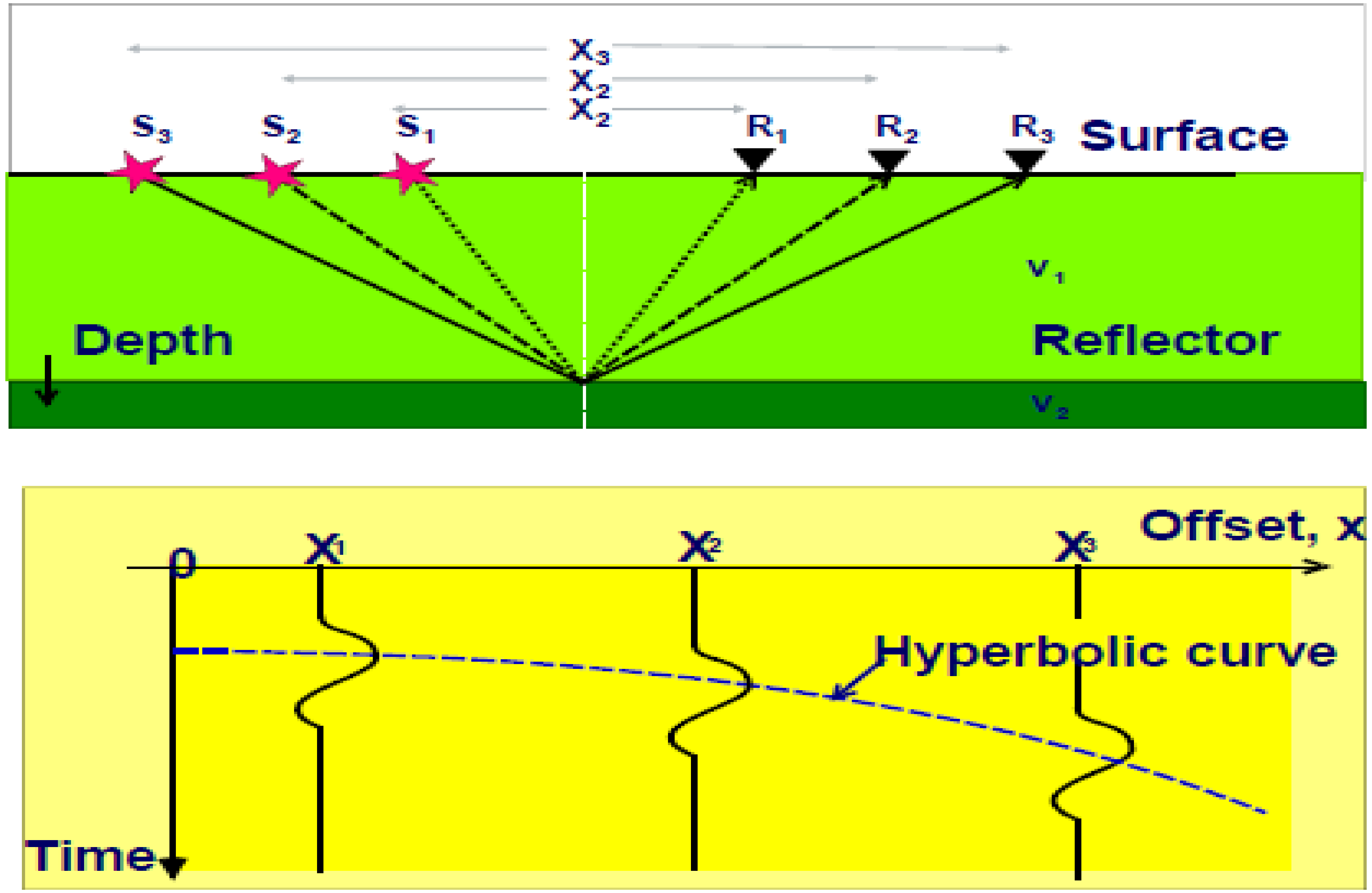
⇩

Migration

OMV Petrom

Pre-processing: Dynamic correction (NMO)

Velocity from seismic



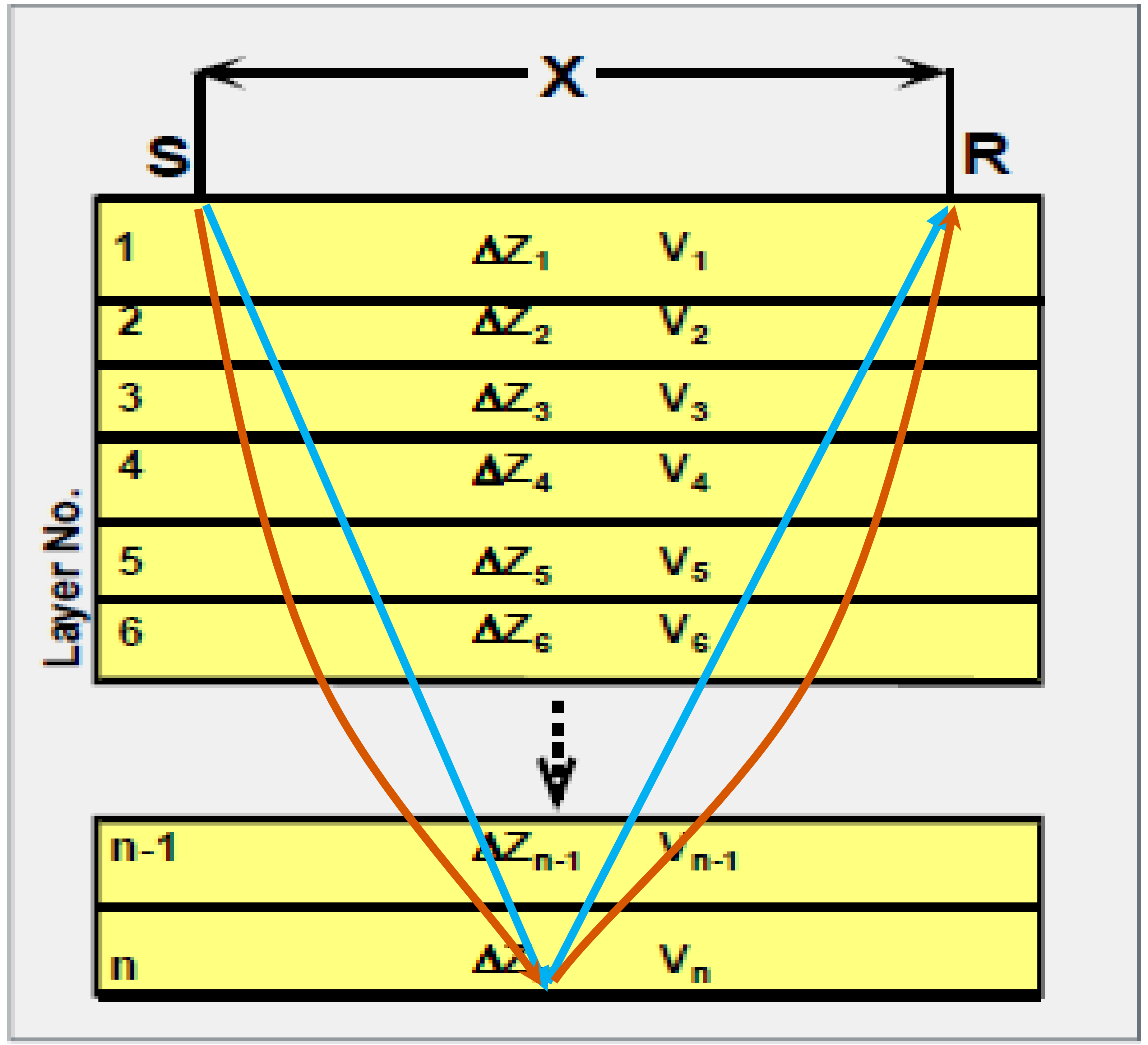
One layer:

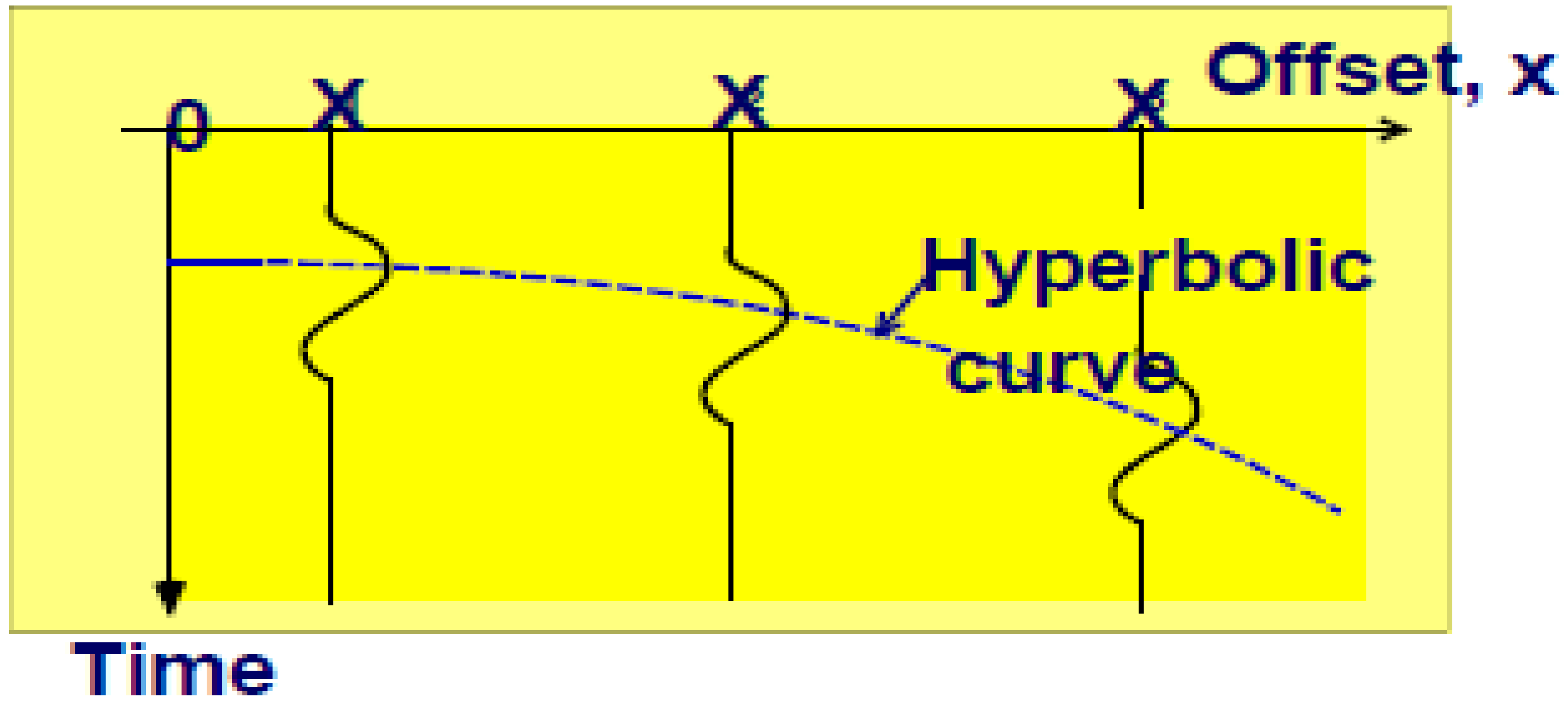
$$T_X^2 = T_0^2 + \frac{X^2}{V^2}$$

$V = V_1$

Pre-processing: Dynamic correction (NMO)

Velocity from seismic





N layers

$$T_X^2 \approx T_0^2 + \frac{X^2}{V^2}$$

These are not true geological velocities.

What is V ?

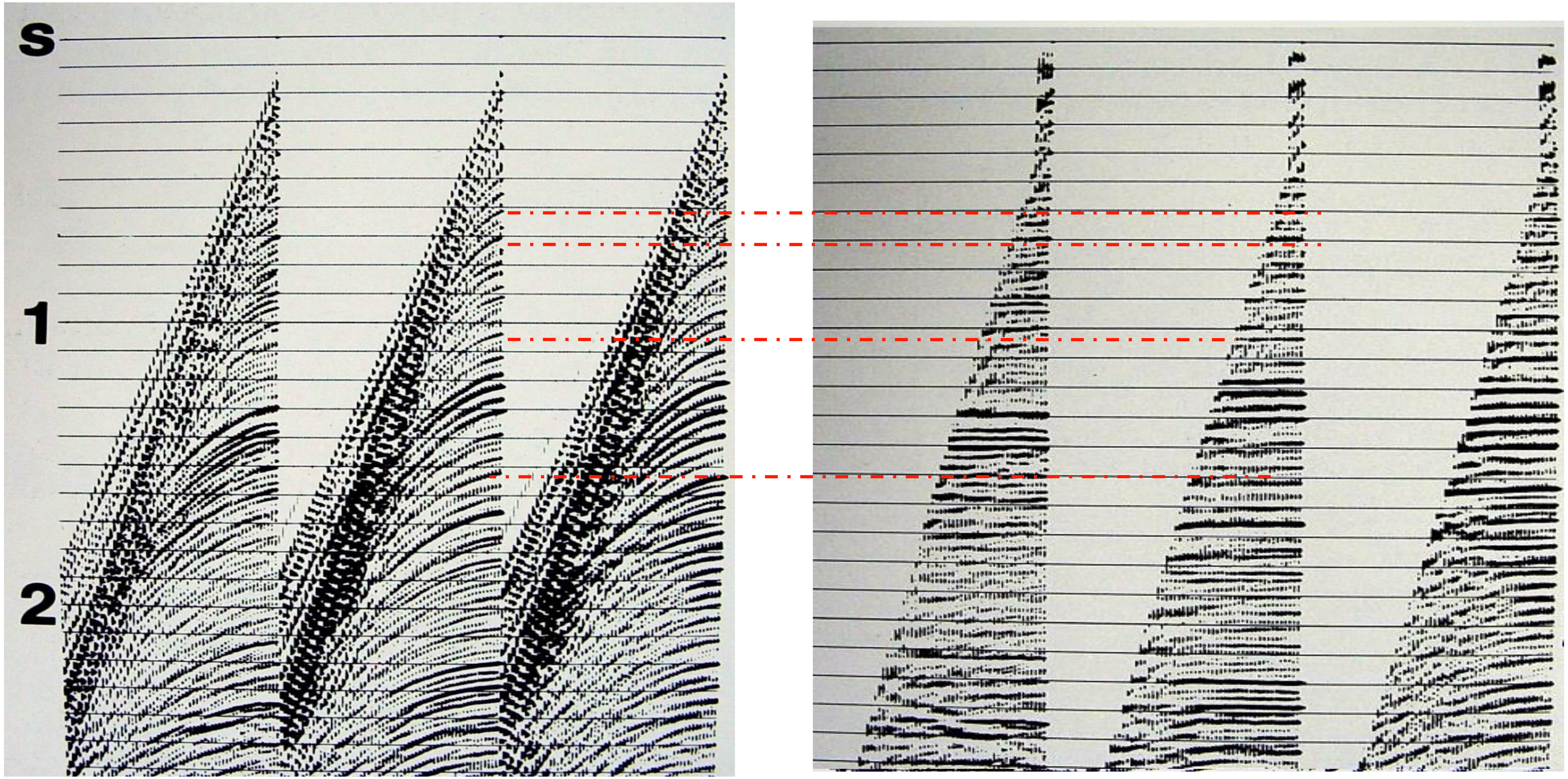
Actual curved raypath is replaced by a straight raypath

RMS velocity (V) is a replacement velocity, when the multiple layers replaced by a single layer

Pre-processing: Dynamic correction (NMO), Mute

CMP gathers without Dynamic correction

CMP gathers with Dynamic correction + mute



After Yilmaz

Processing flow

Reformatting, geometry, amplitude recovery

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Noise attenuation, filters

↓

Deconvolution

↓

Common Mid Point gather

↓

Static corrections (mostly lands)

↓

Dynamic corrections (NMO) and Mutes

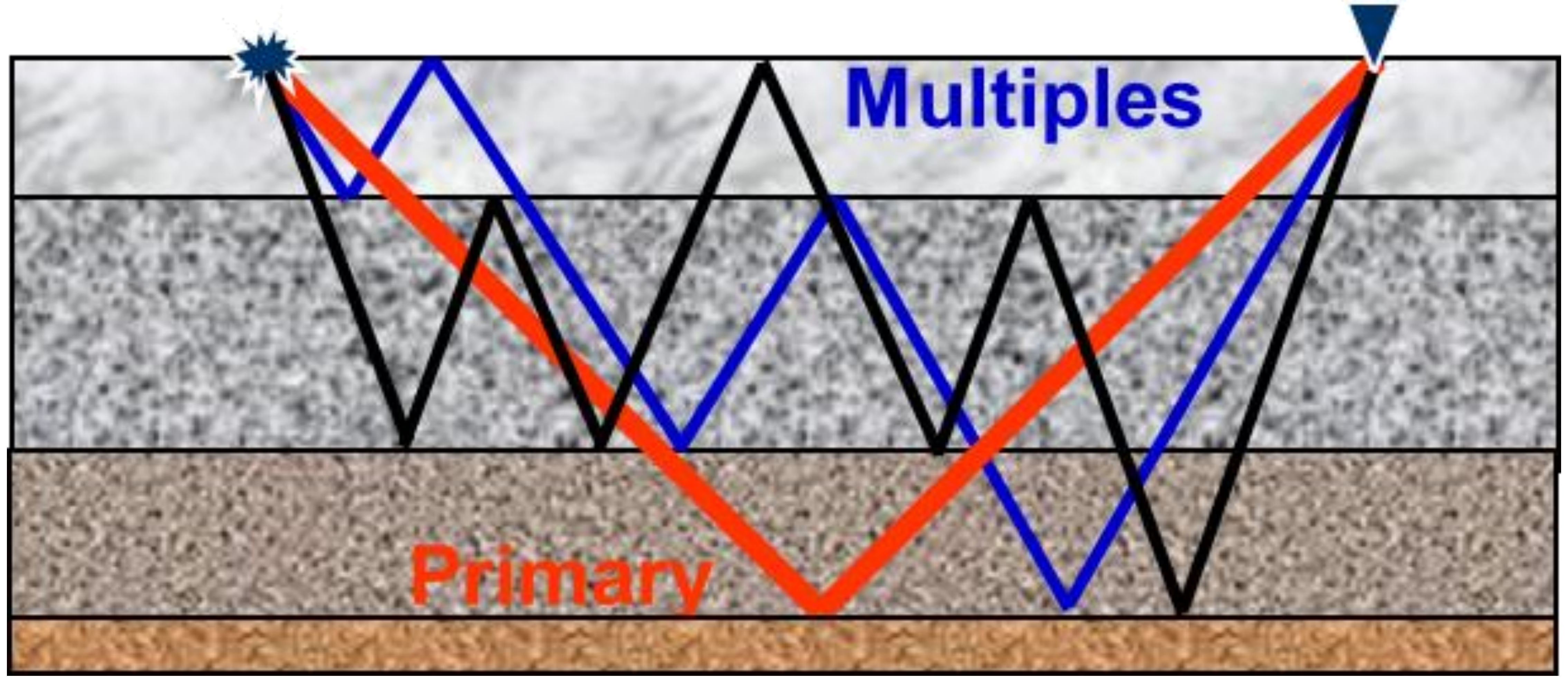
↓ ← Multiple attenuation

Stack

↓

Migration

Pre-processing: Multiple attenuation



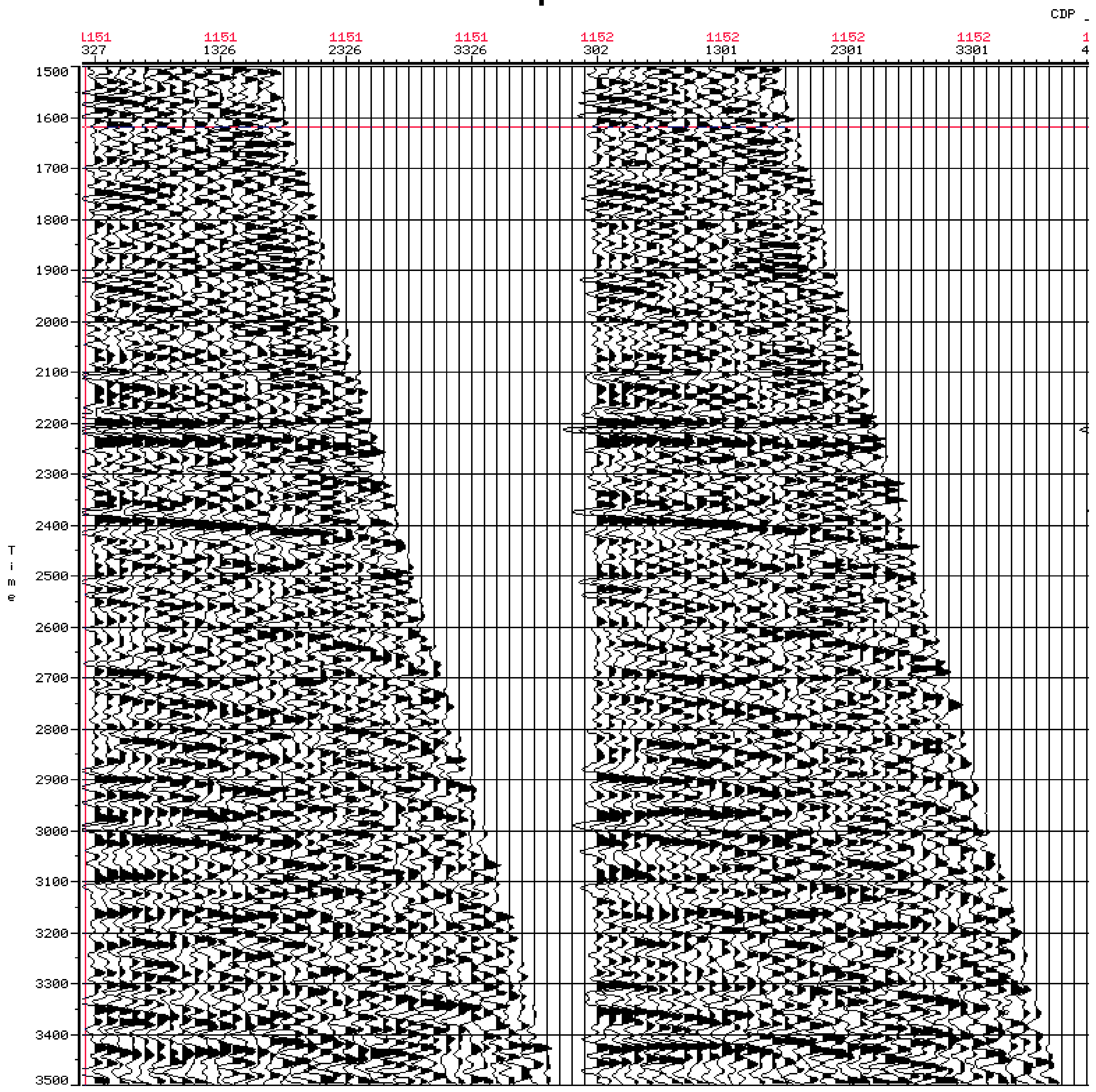
Definition: A Multiple is energy which has more than one reflection in its travel path

General Properties of the multiple:

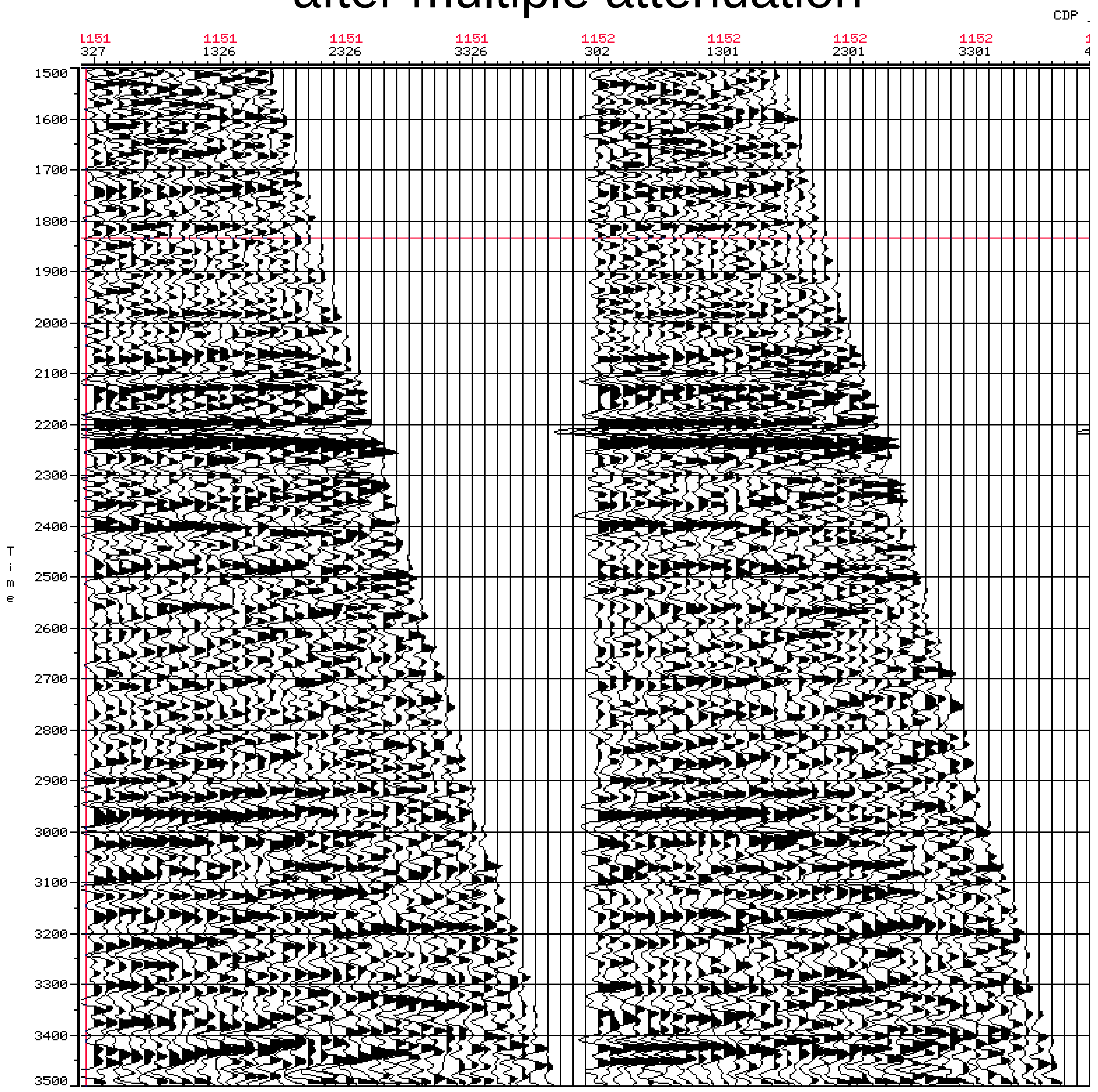
- Low velocity (high moveout), Velocity increases with depth
- High amplitude, Less geometric spreading
- Periodic, Repeated cycles with horizontal layers
- Predictable from primaries

Pre-processing: Multiple attenuation examples

Gathers after dynamic correction and mute
before multiple attenuation



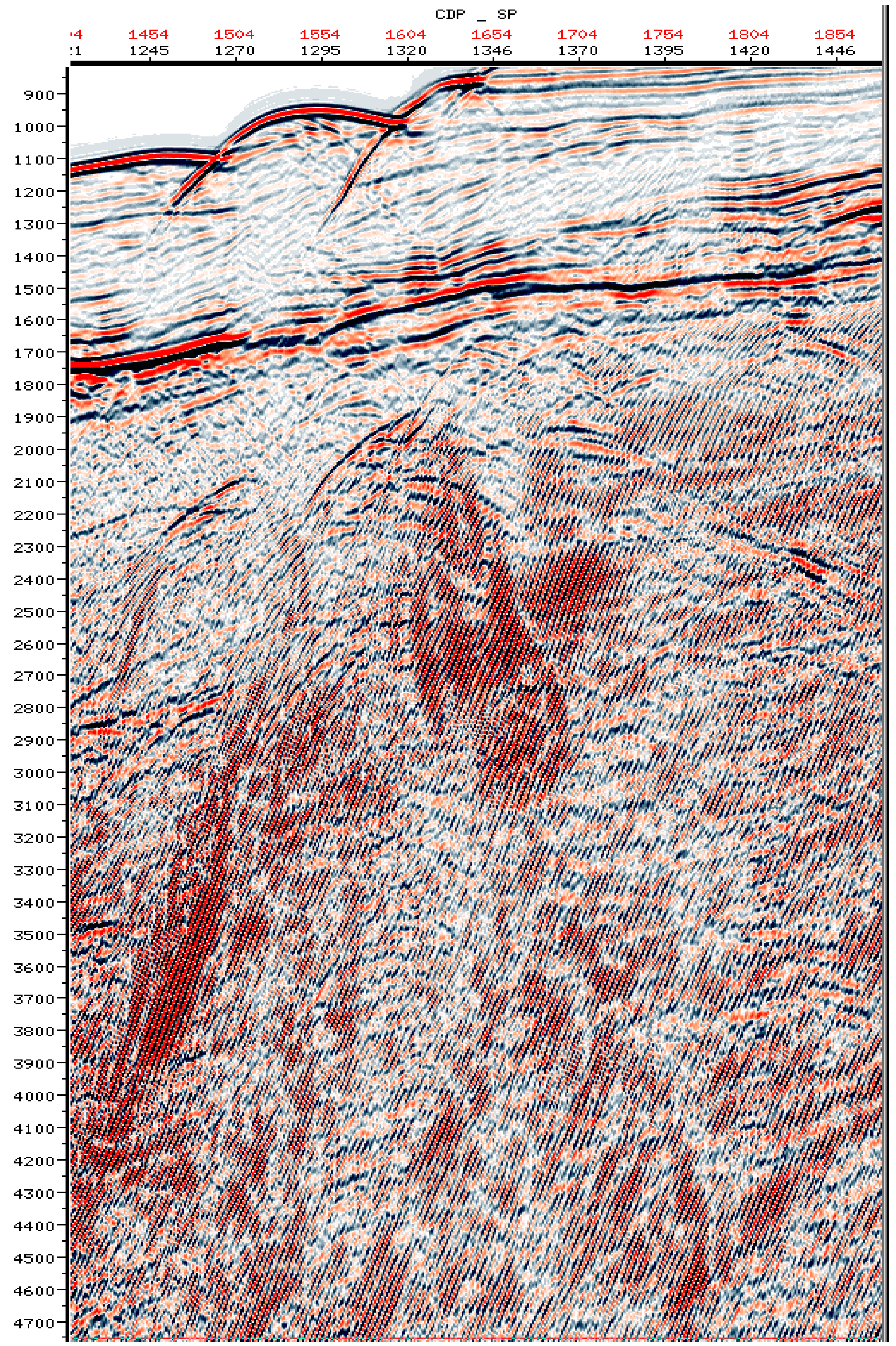
Gathers after dynamic correction and mute
after multiple attenuation



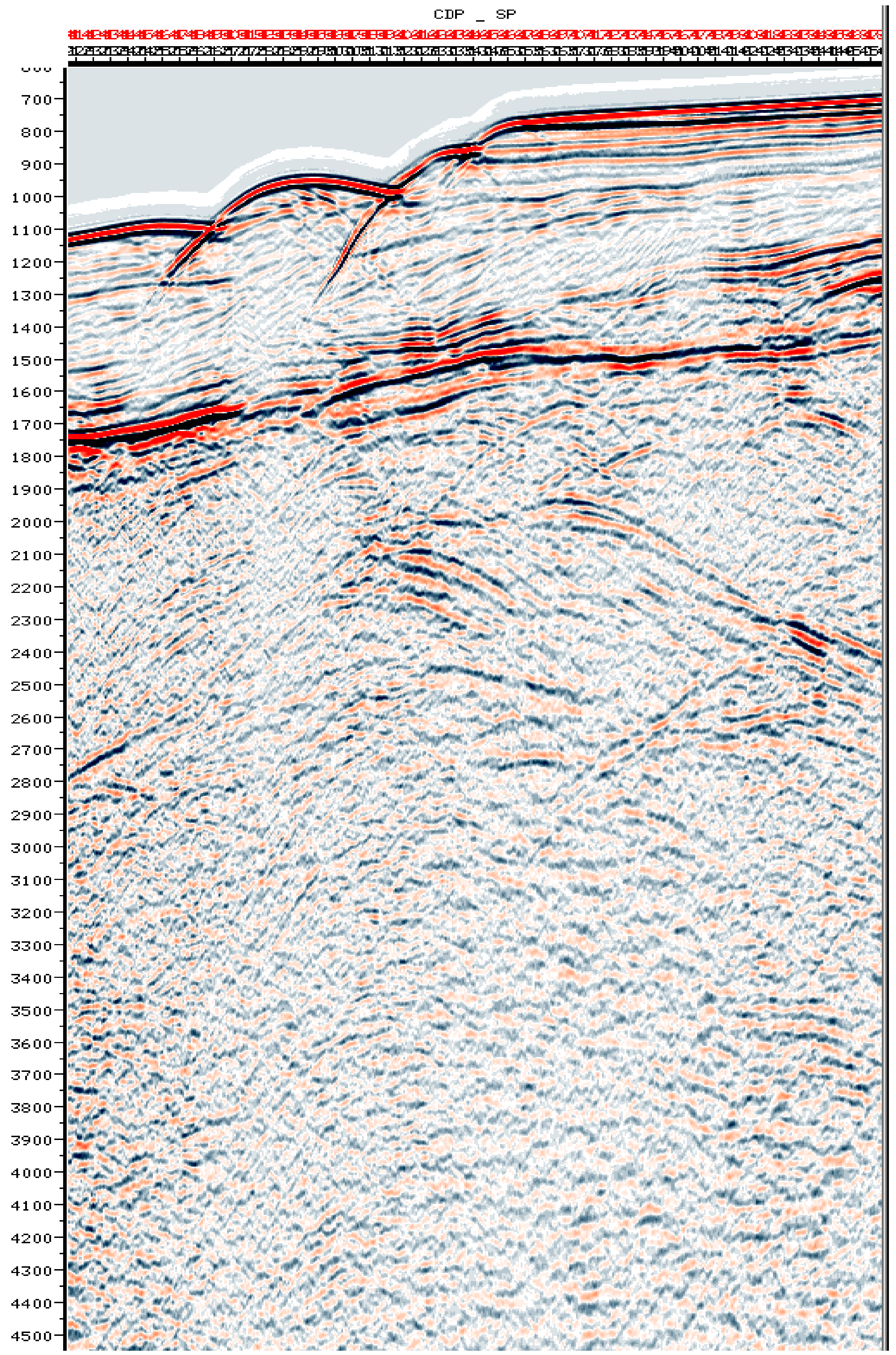
- Multiples are interfere with, or may be falsely interpreted as primaries
- Multiples are adversely effect imaging processes (which assume multiple free data)
- Multiples are contaminate AVO calculations

Pre-processing: Multiple attenuation examples

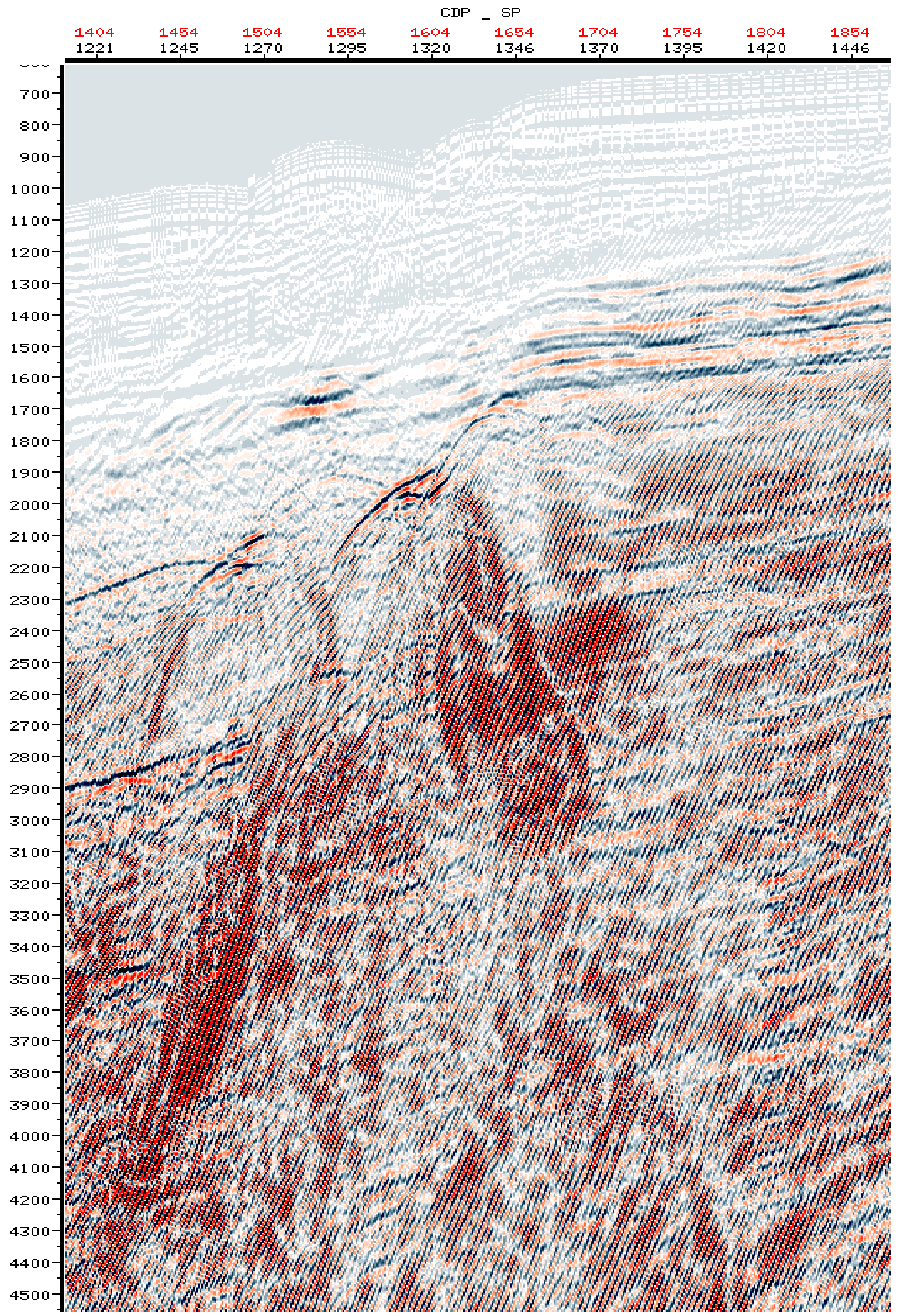
Stack before multiple attenuation



Stack after multiple attenuation



Difference



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Processing flow

Reformatting, geometry, amplitude recovery

⇩

Noise attenuation, filters

⇩

Deconvolution

⇩

Common Mid Point gather

⇩

Static corrections (mostly lands)

⇩

Dynamic corrections (NMO) and Mutes

⇩ ← Multiple attenuation

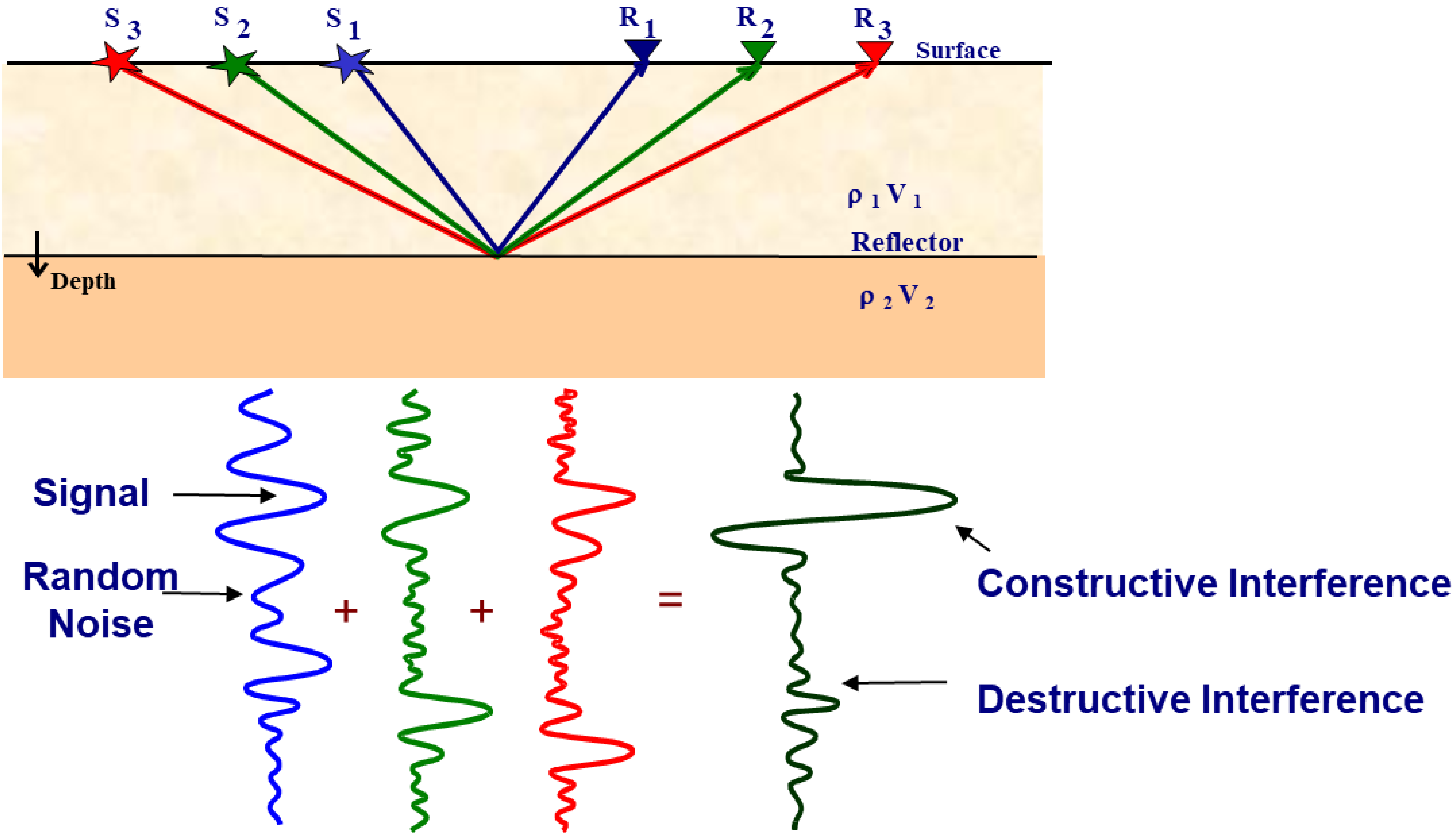
Stack

⇩

Migration

OMV Petrom

Pre-processing: Stack



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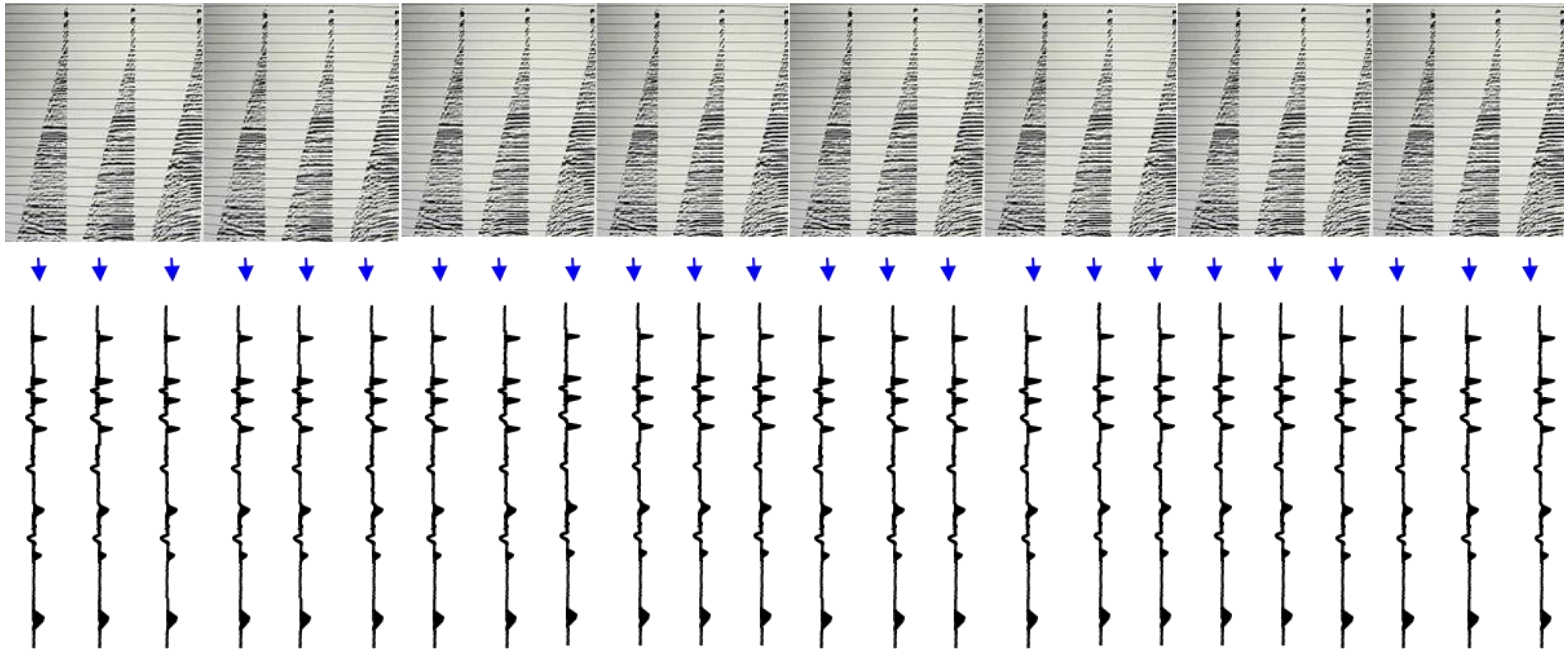
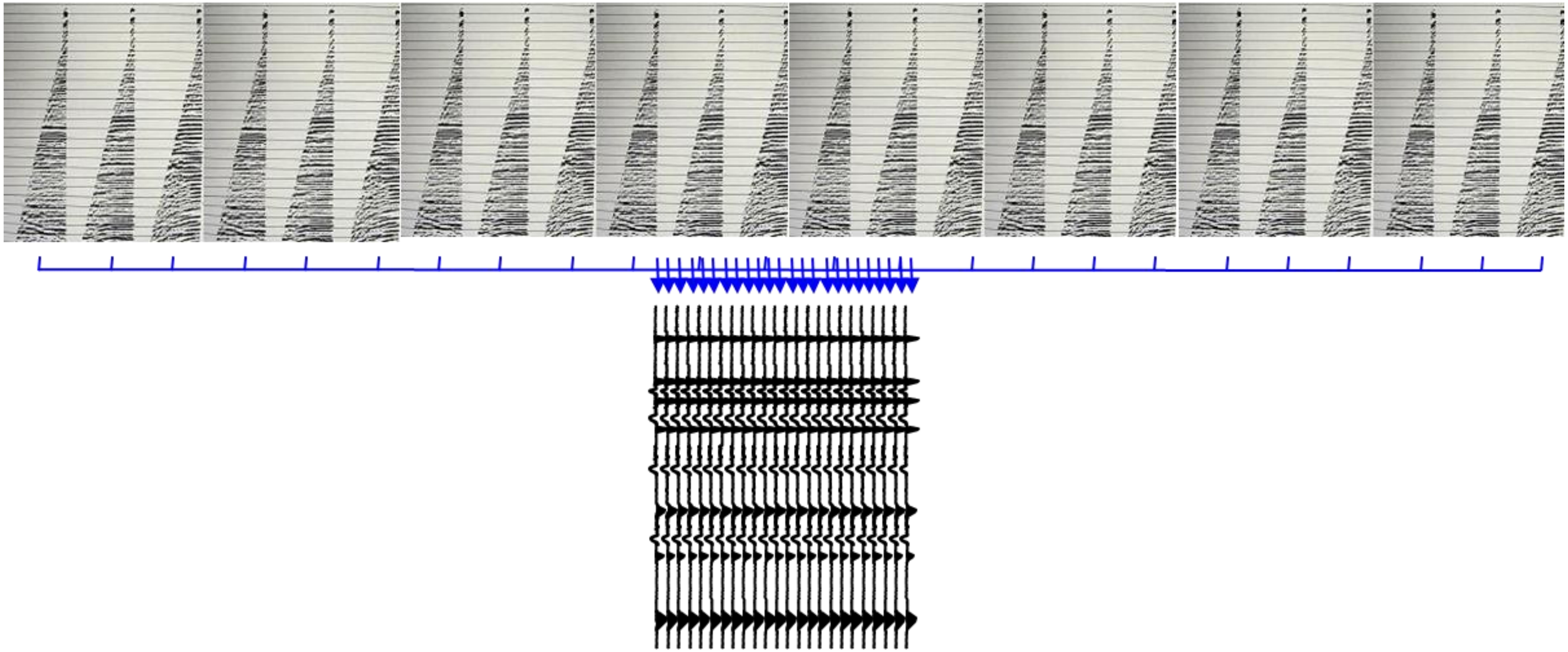
Pre-processing: Stack



After Yilmaz

Pre-processing: Stack



After Yilmaz

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⇩ ← Multiple attenuation

Stack

⇩

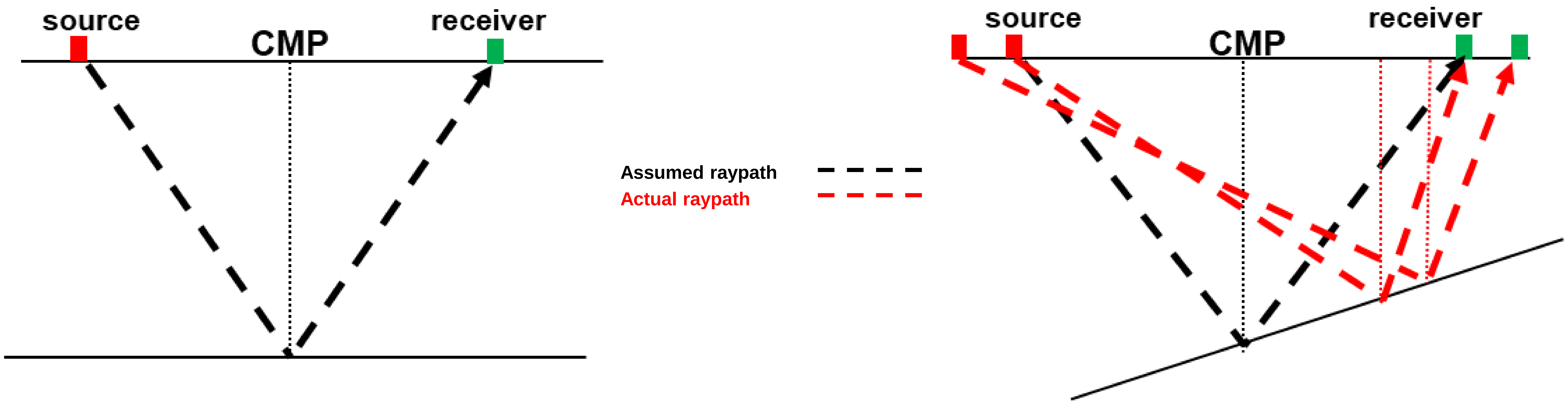
Migration

Migration

- Seismic data records the traveltime of reflectors, not their spatial positions

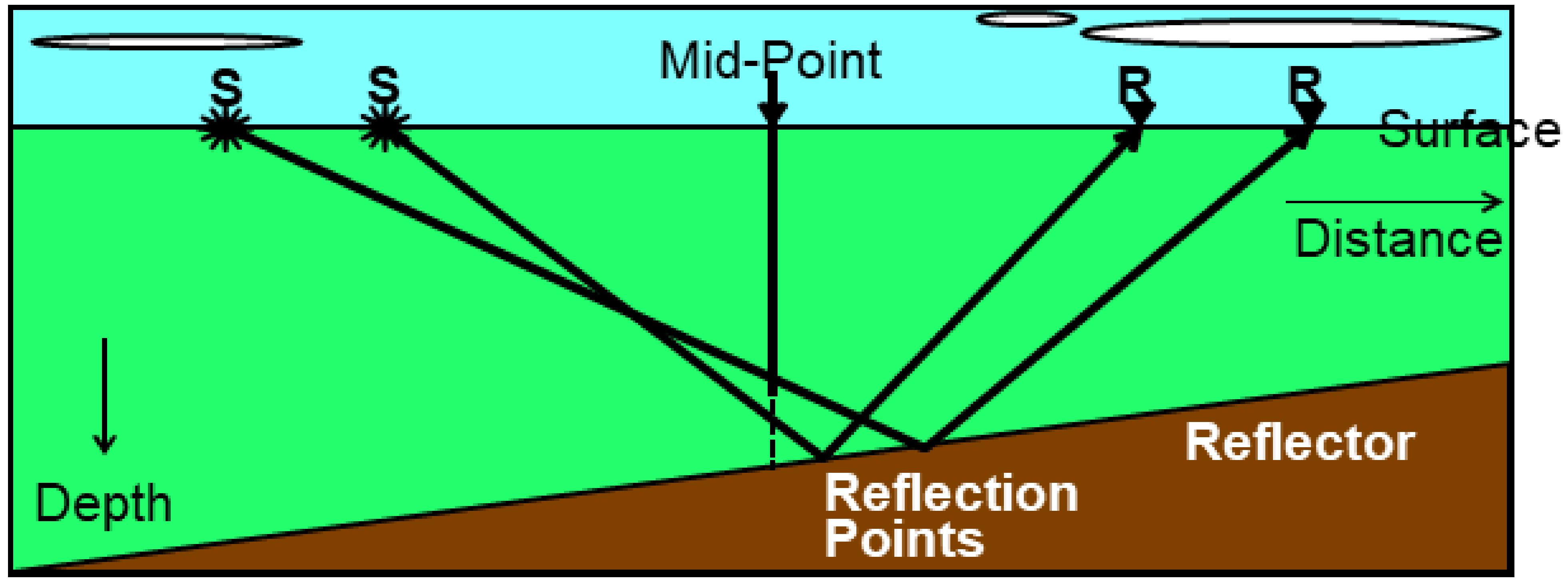
- For inhomogeneous, non-horizontally layered model, reflectors are not in their true location in stacked data

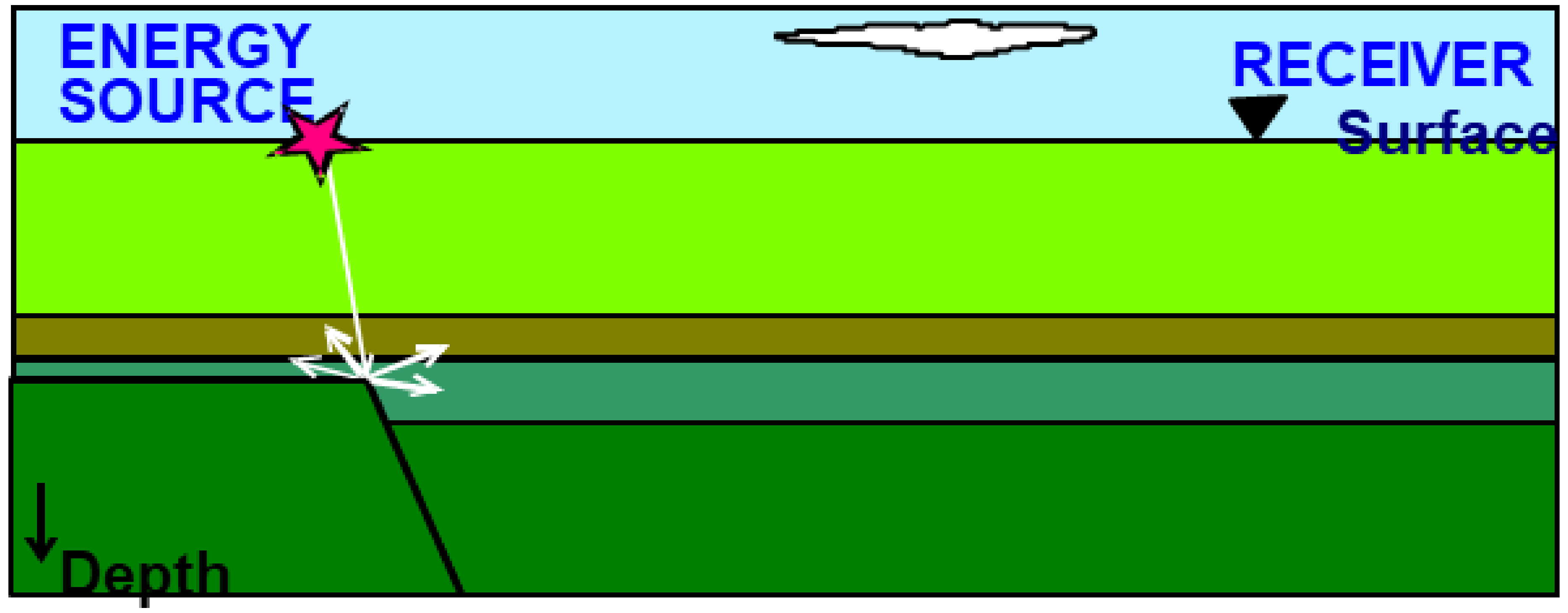
- Migration needed to move the seismic events to their correct geometric position



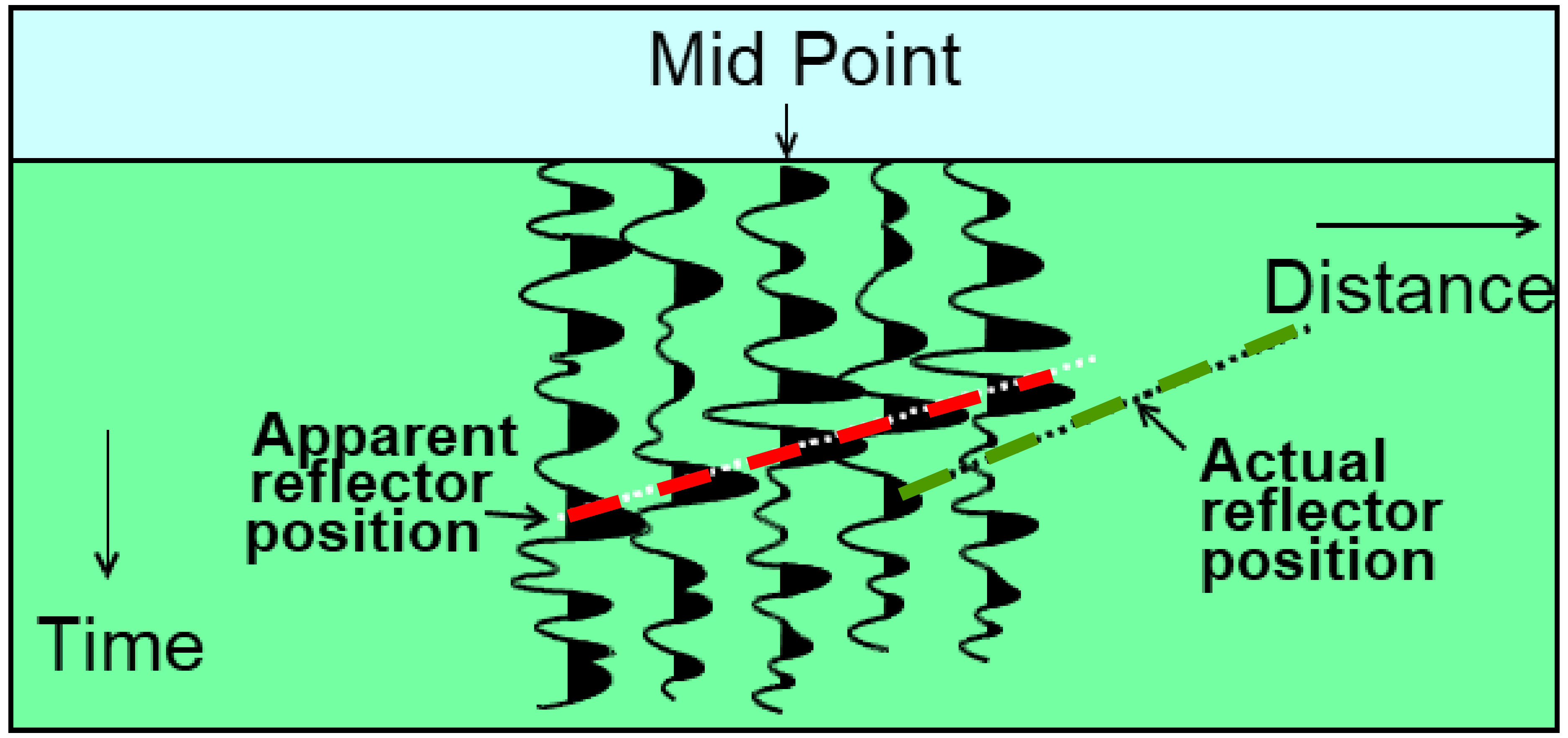
Migration: Necessity of migration

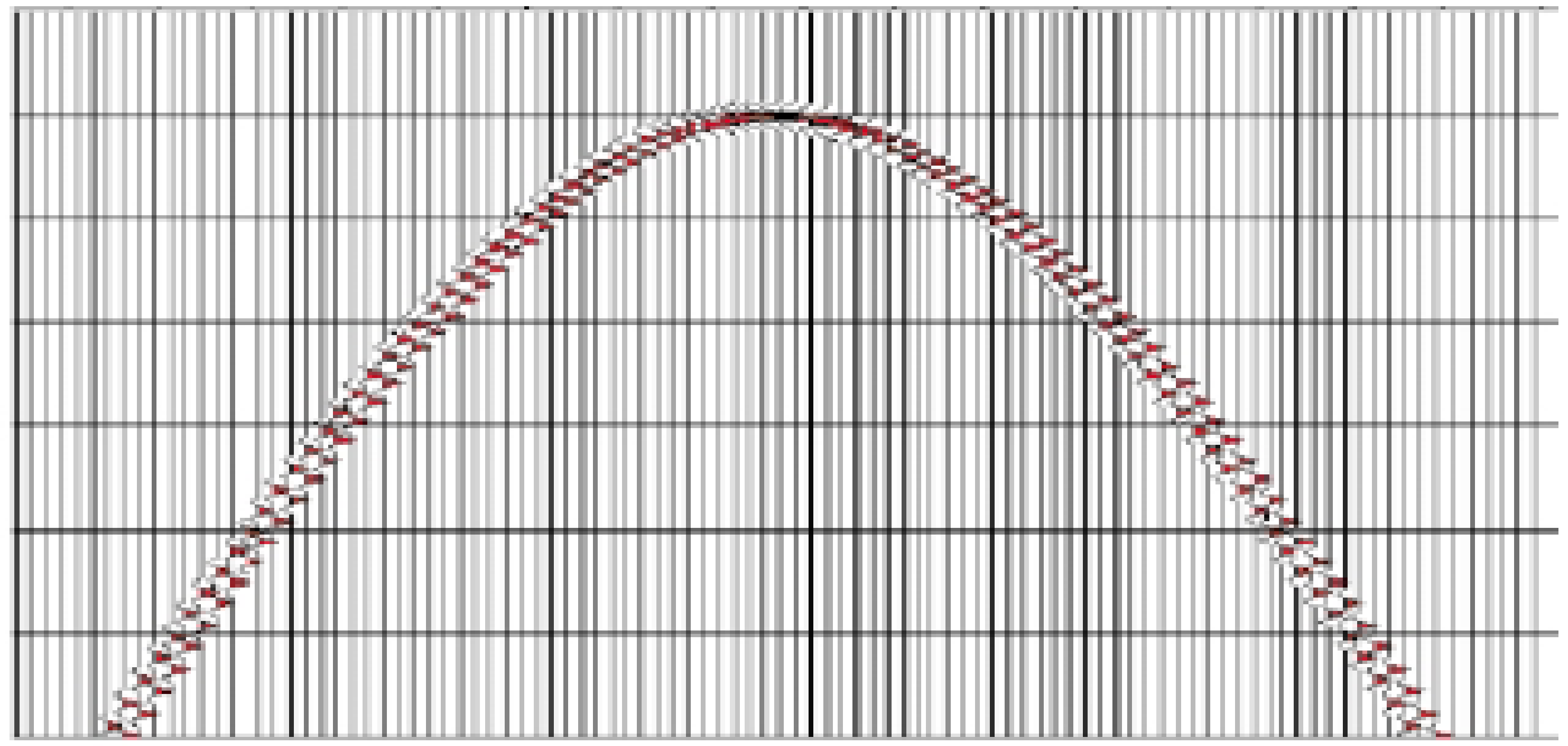
Accuracy of reflection position



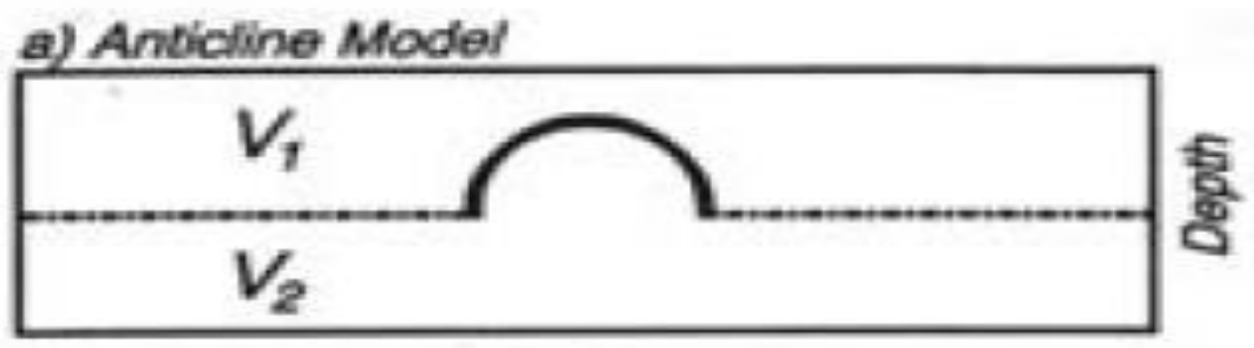


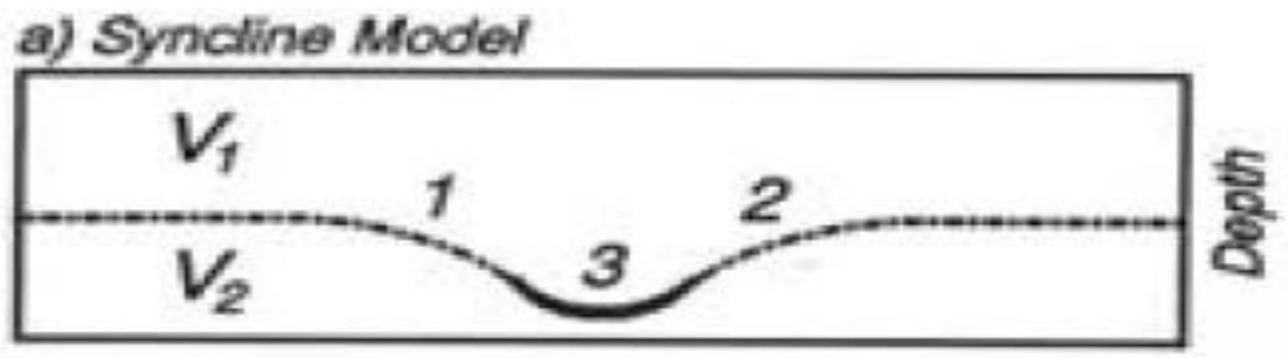
Reflector are not flat and horizontal !





Migration: Anticlines and synclines

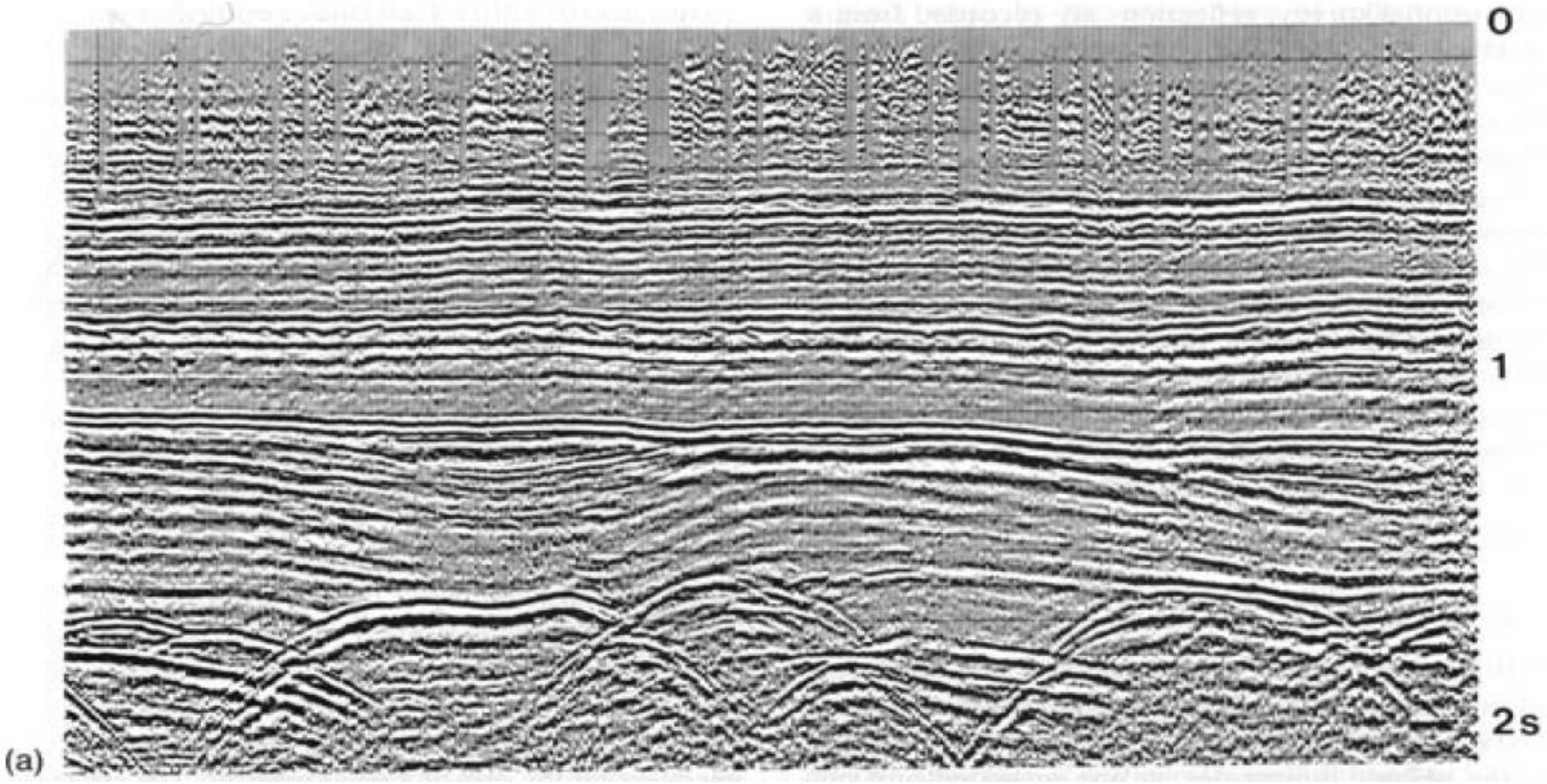




Source: seismo.berkeley.edu

Migration: Examples

Non-migrated section

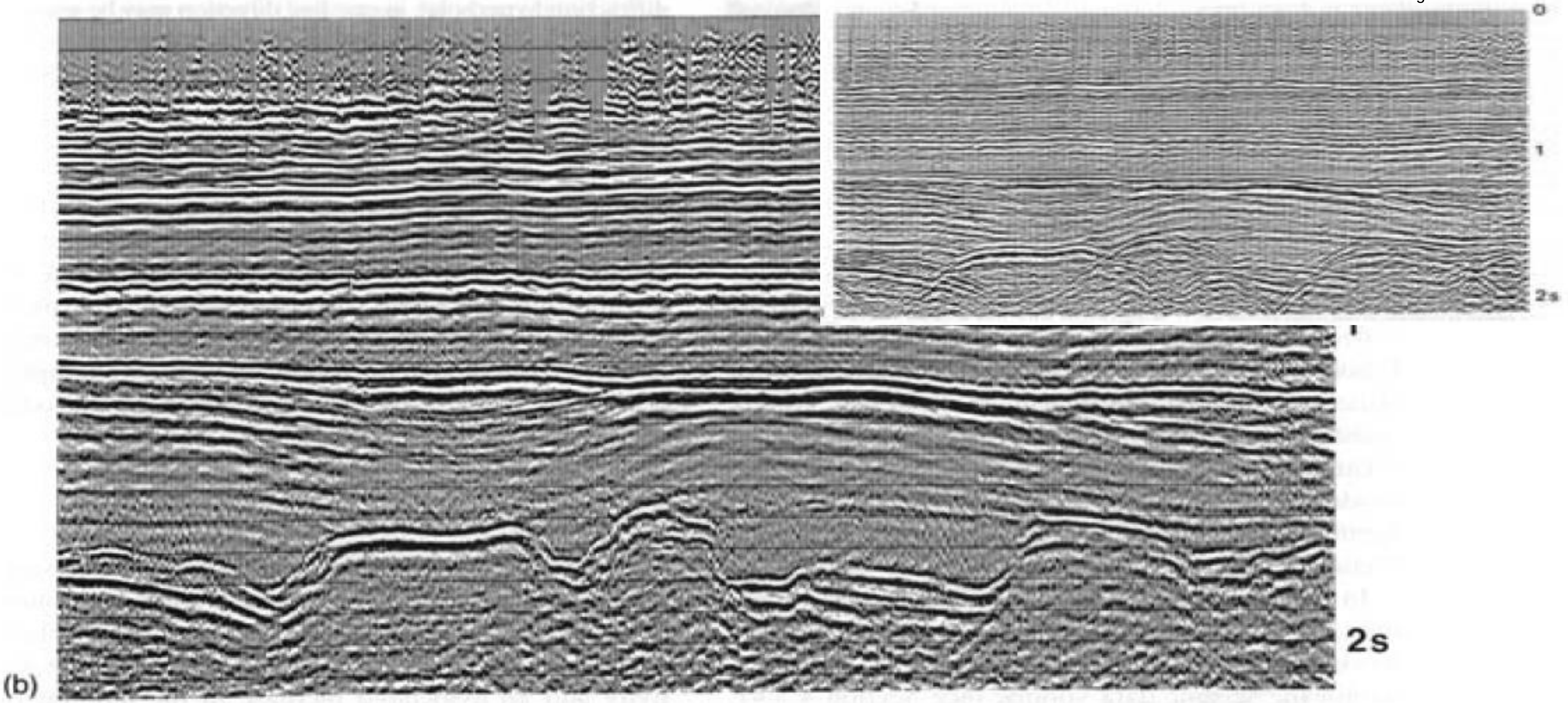


Source: seismo.berkeley.edu

Migration: Examples

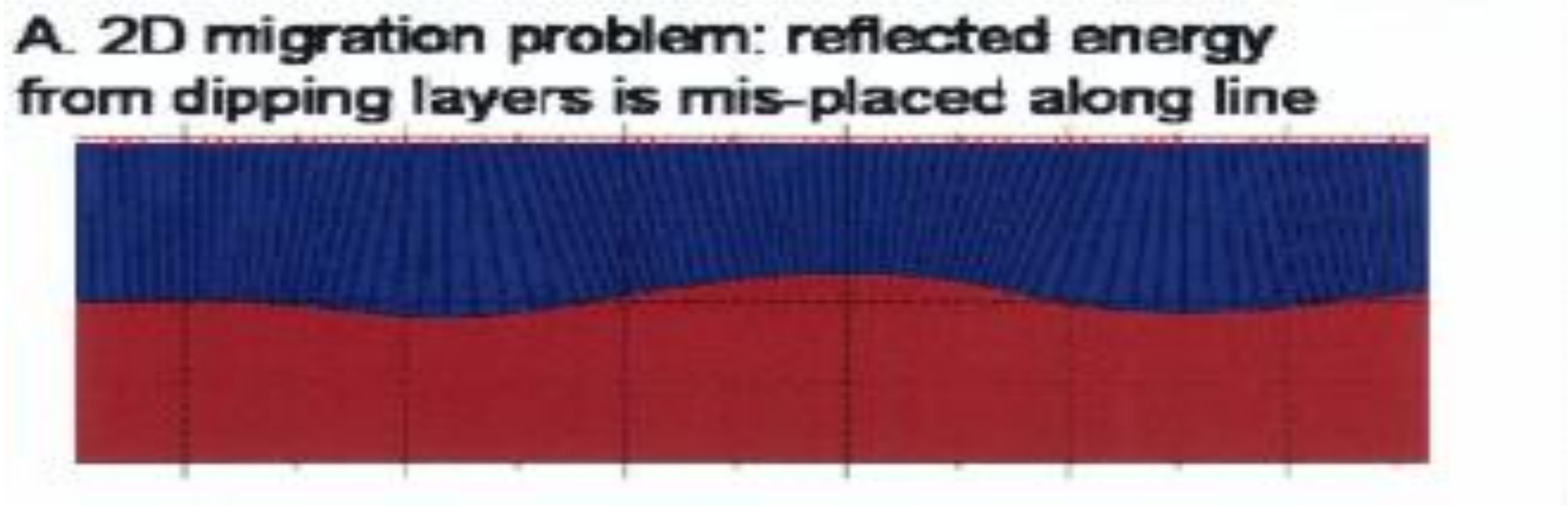
Migrated section

Non-migrated section



Source: seismo.berkeley.edu

Migration: 2D vs 3D migration



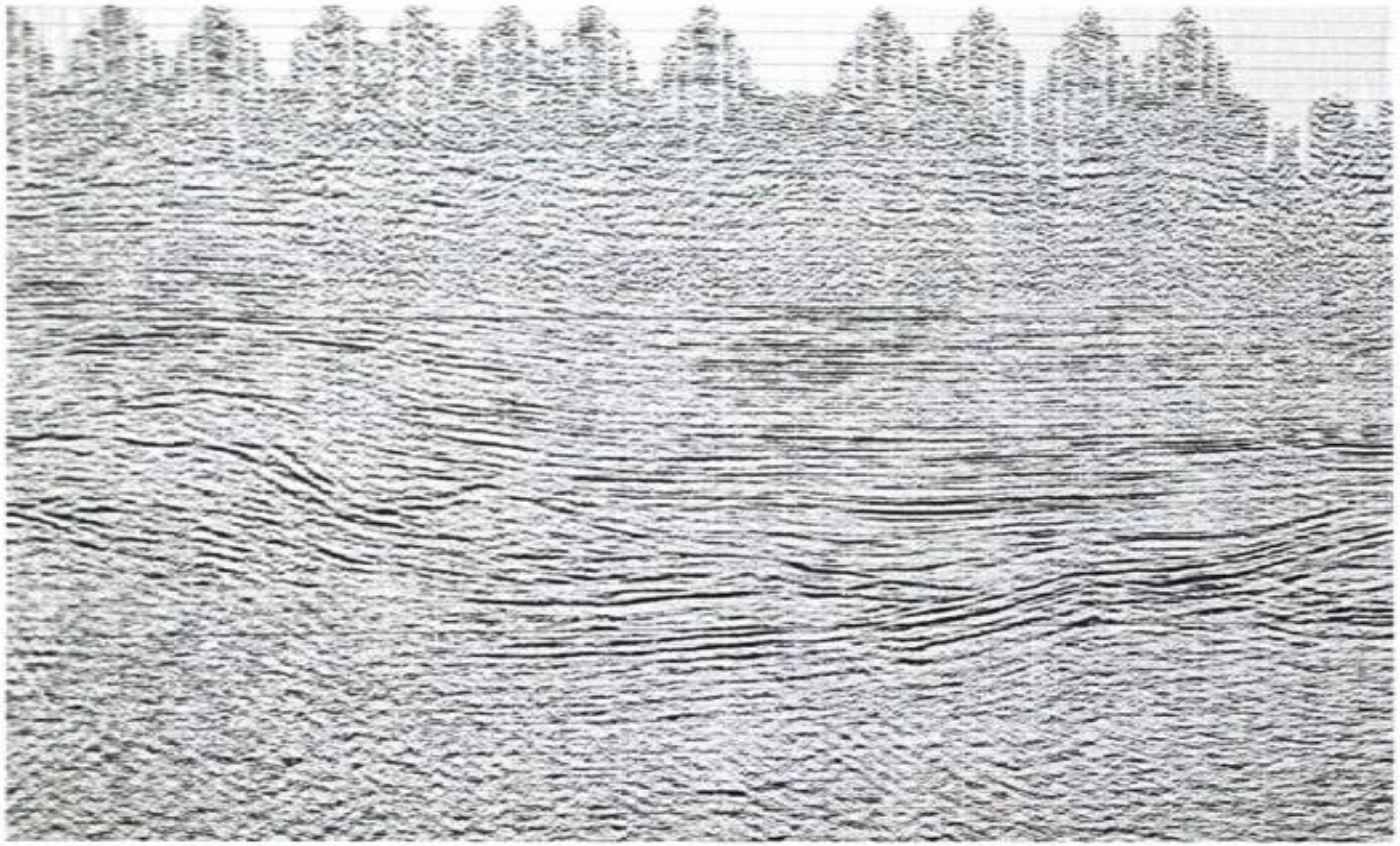
- 2D migration can correct only those positioning errors due to apparent dip and velocity changes occurring in the plane of the 2D lines

- Structural anomalies located a considerable distance away from the plane of the 2D line can still have a significant effect on the 2D profile

- 3D migration is required to resolve such imaging issues

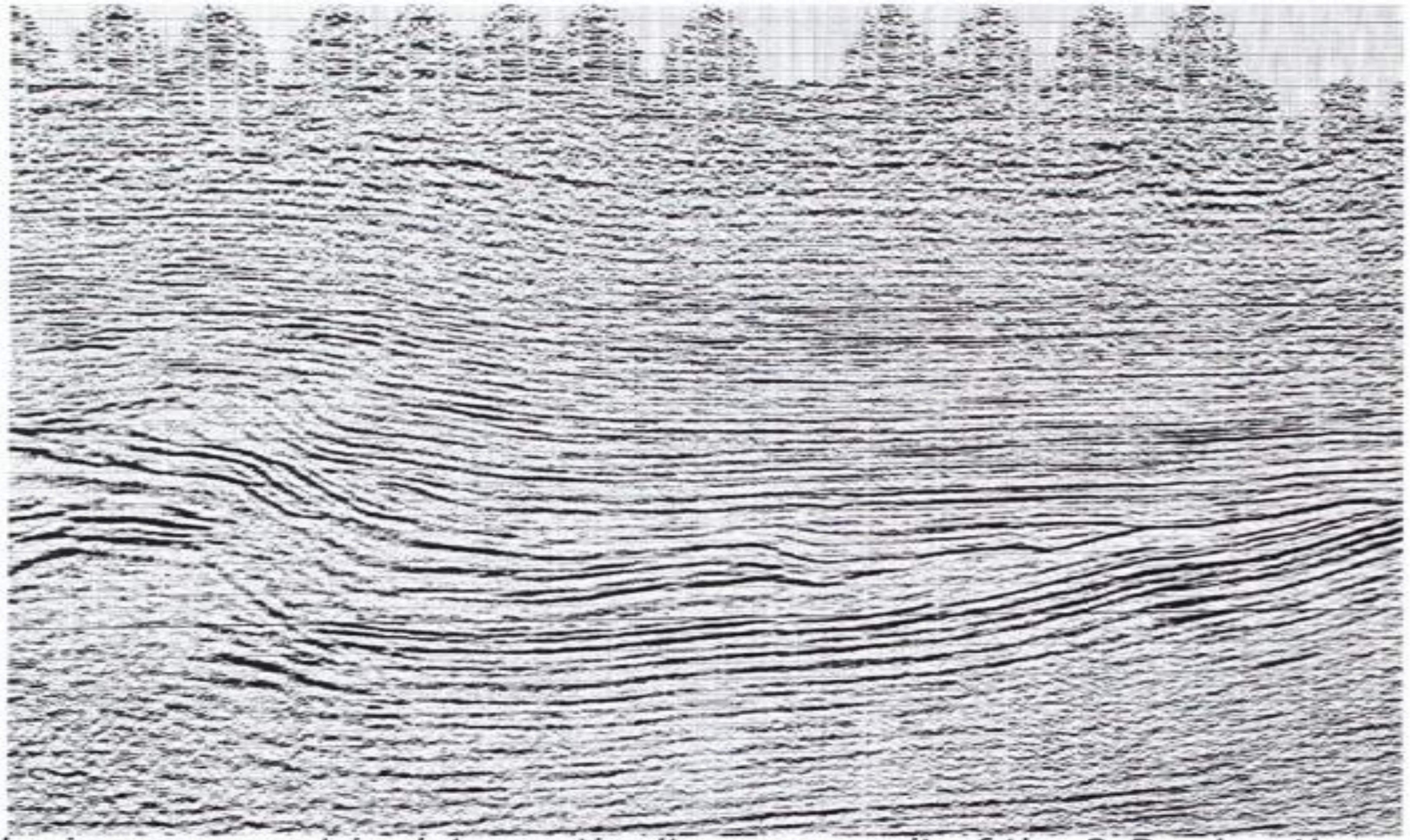
Courtesy Western Geophysical

Migration: 2D migration



Courtesy Western Geophysical

Migration: 3D migration



Note the improvement in data continuity as a result of the 3-D migration. This is a major reason why lower 3-D fold is required to equal the quality of 2-D data.

Courtesy Western Geophysical

Migration: Time vs Depth migration

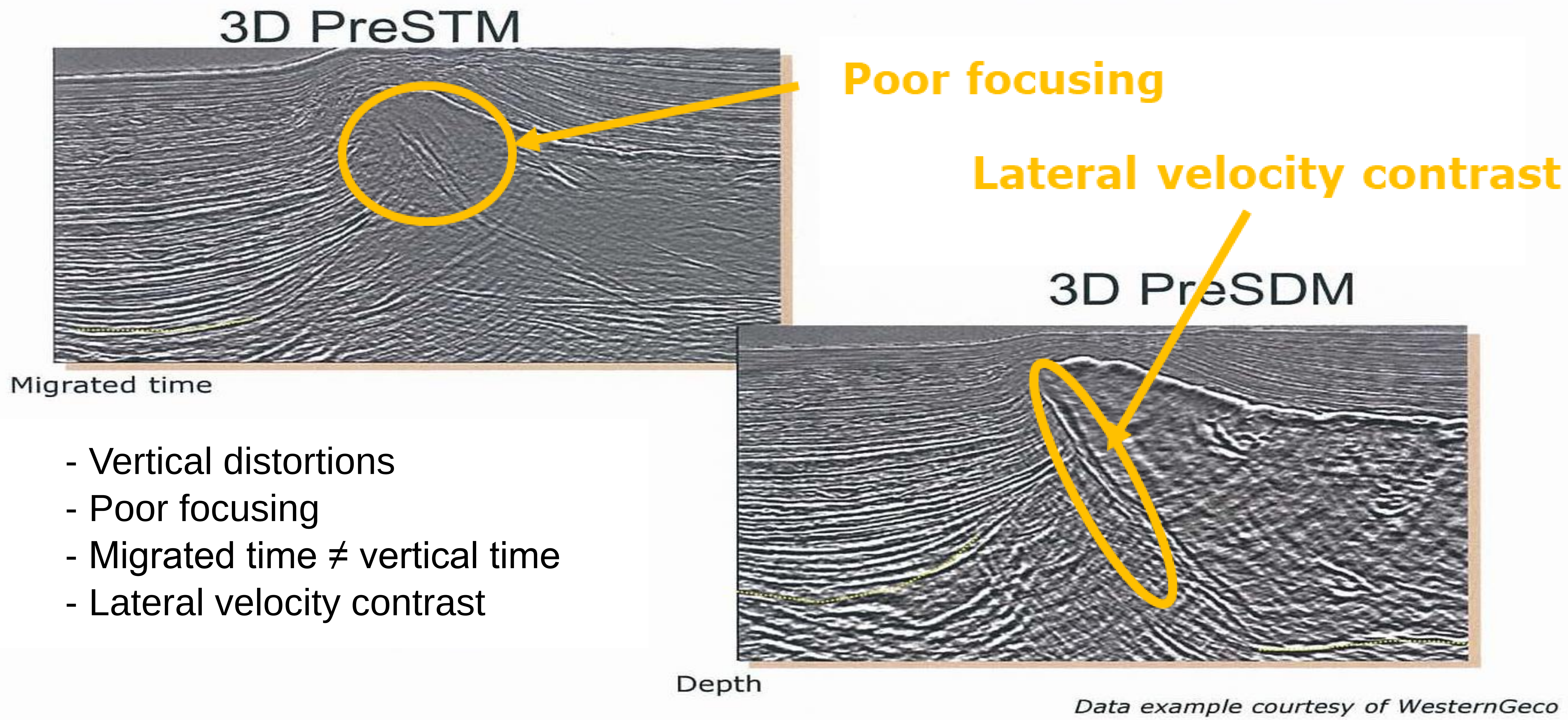
Time migration (PSTM):

- Velocities are less geologic and have low spatial resolution.
- Lateral velocity variations produce mis-imaging.
- Time migration is strictly valid only for vertically varying velocity; it does not account for ray bending at interfaces.

Depth migration (PSDM):

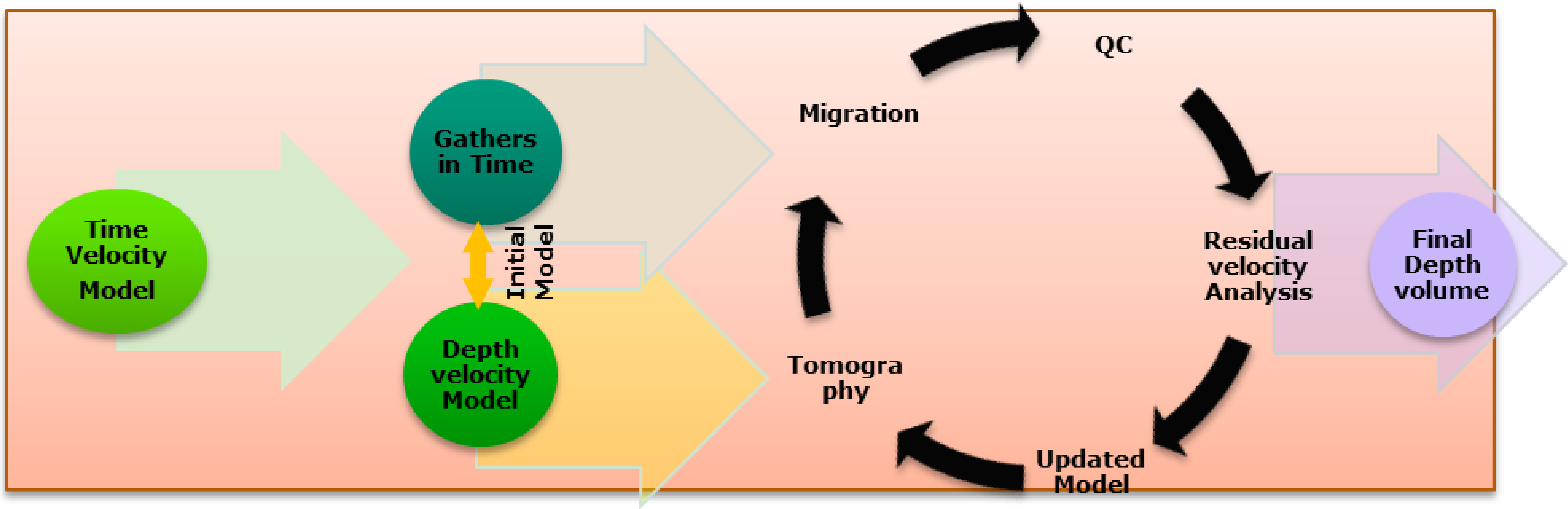
- Velocities are more geologic with higher spatial resolution.
- Algorithmic accuracy results in better focusing and stable phase in the data.
- Depth migration accounts for ray bending at interfaces but requires an accurate velocity model.

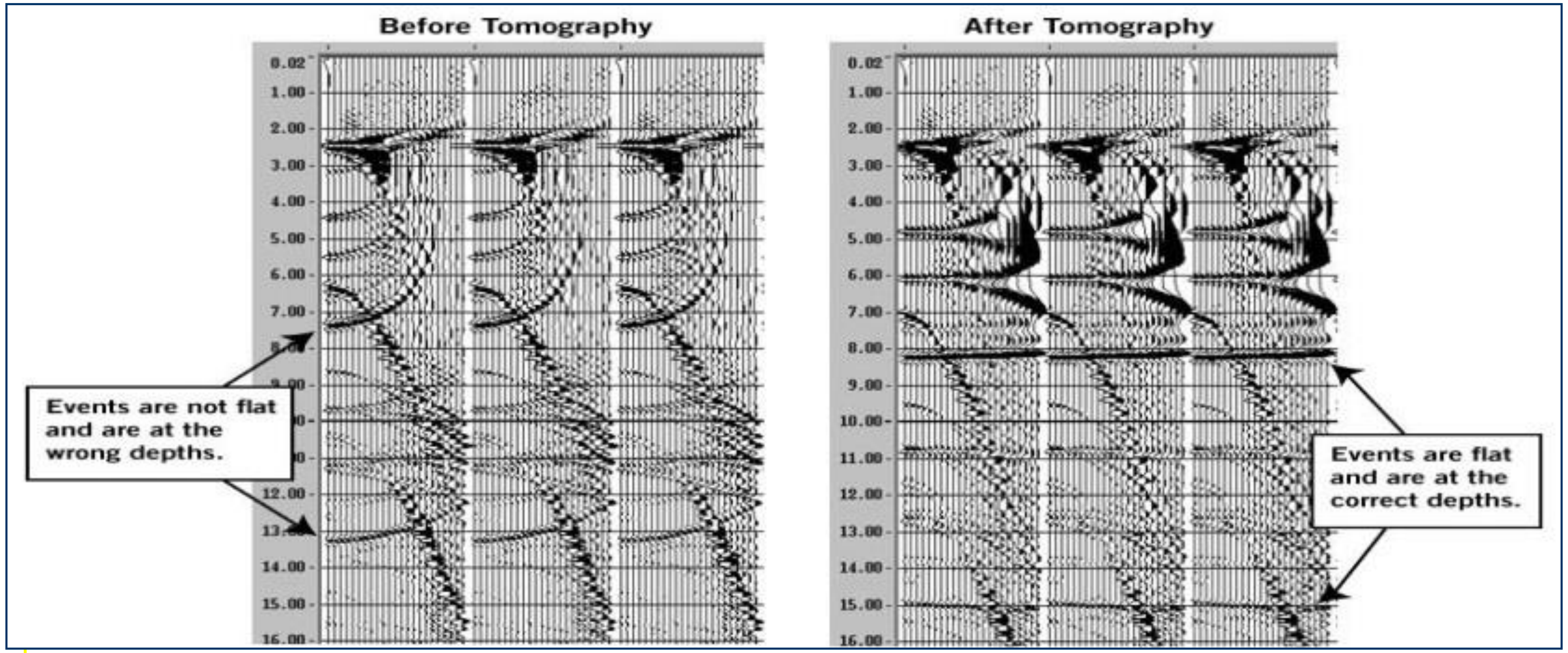
Migration: Time vs Depth migration



- Vertical distortions
- Poor focusing
- Migrated time ≠ vertical time
- Lateral velocity contrast

Migration: Depth migration workflow



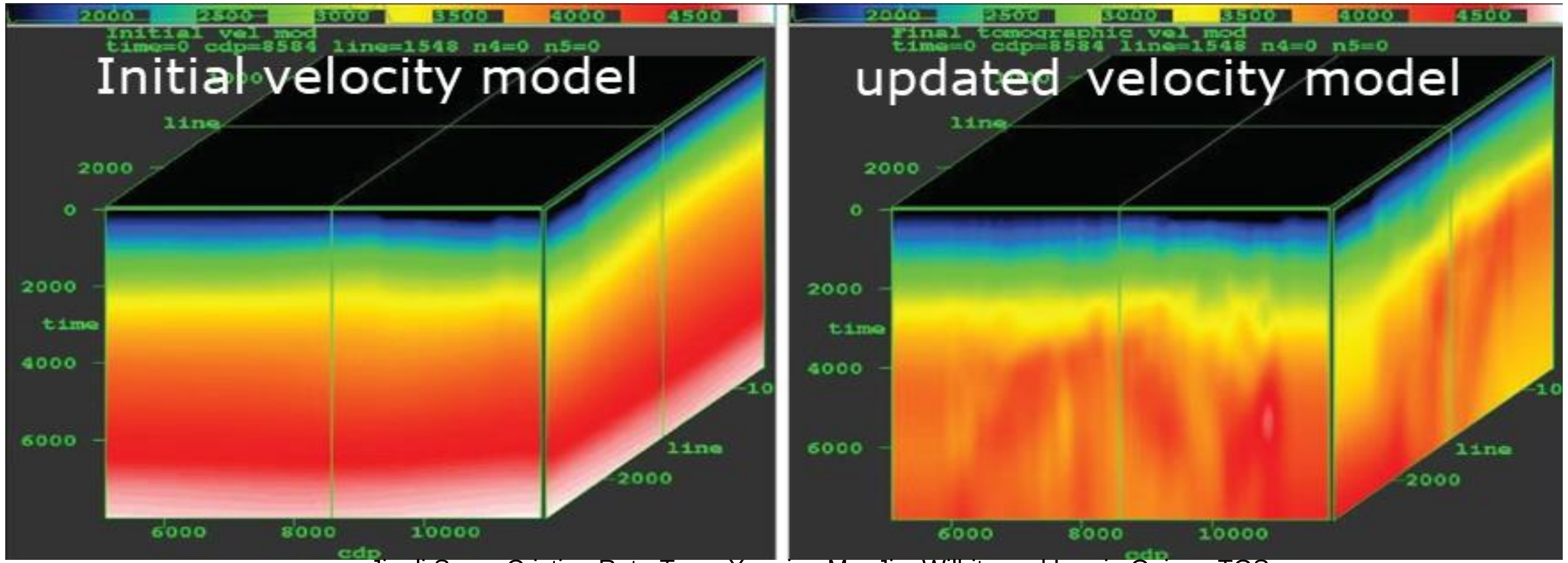


Picture from Geotrace

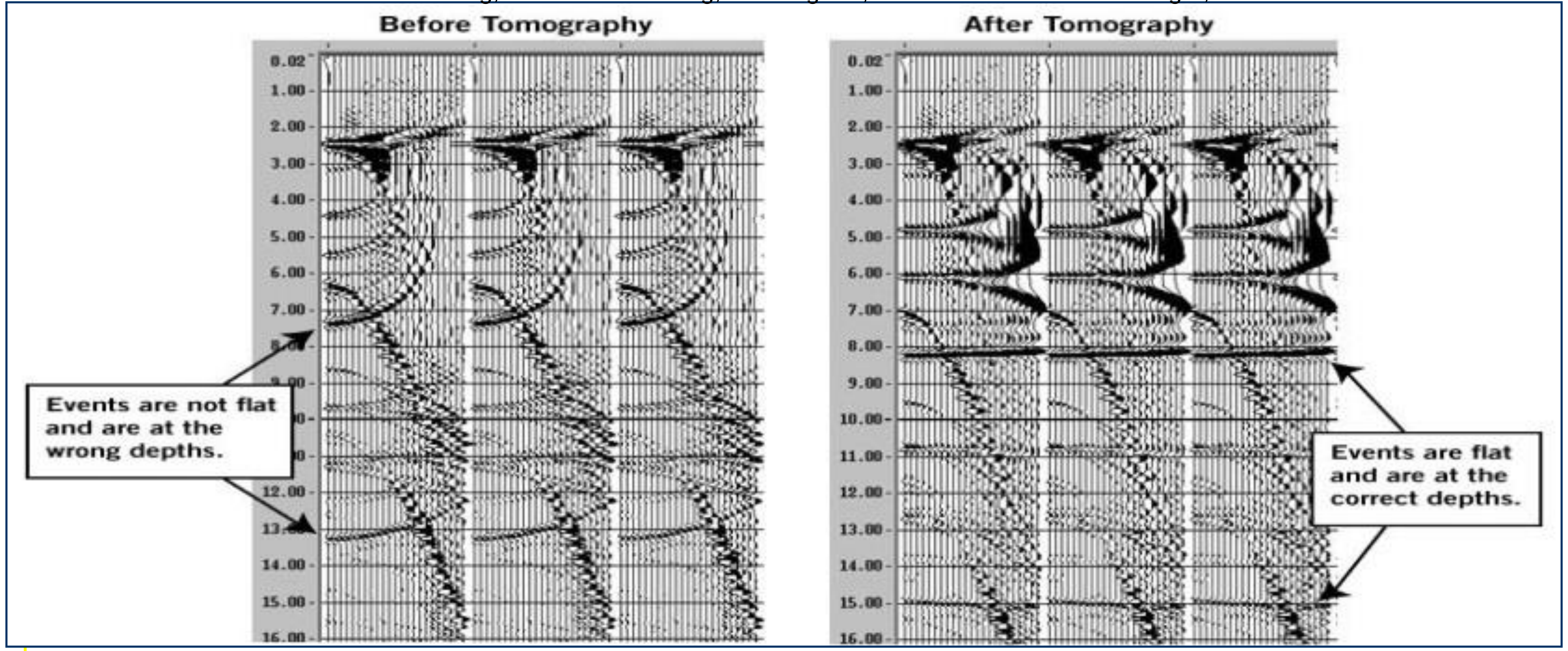
- PSDM is a model-based seismic imaging methodology that works well for complex geological structures.

- PSDM in comparison with PSTM is more expensive and time consuming but is more likely to precisely determine the structure of the reservoirs.

Migration: Depth migration workflow – tomography result



Jianli Song, Cristina Reta-Tang, Xuening Ma, Jim Wilhite and Laurie Geiger, TGS

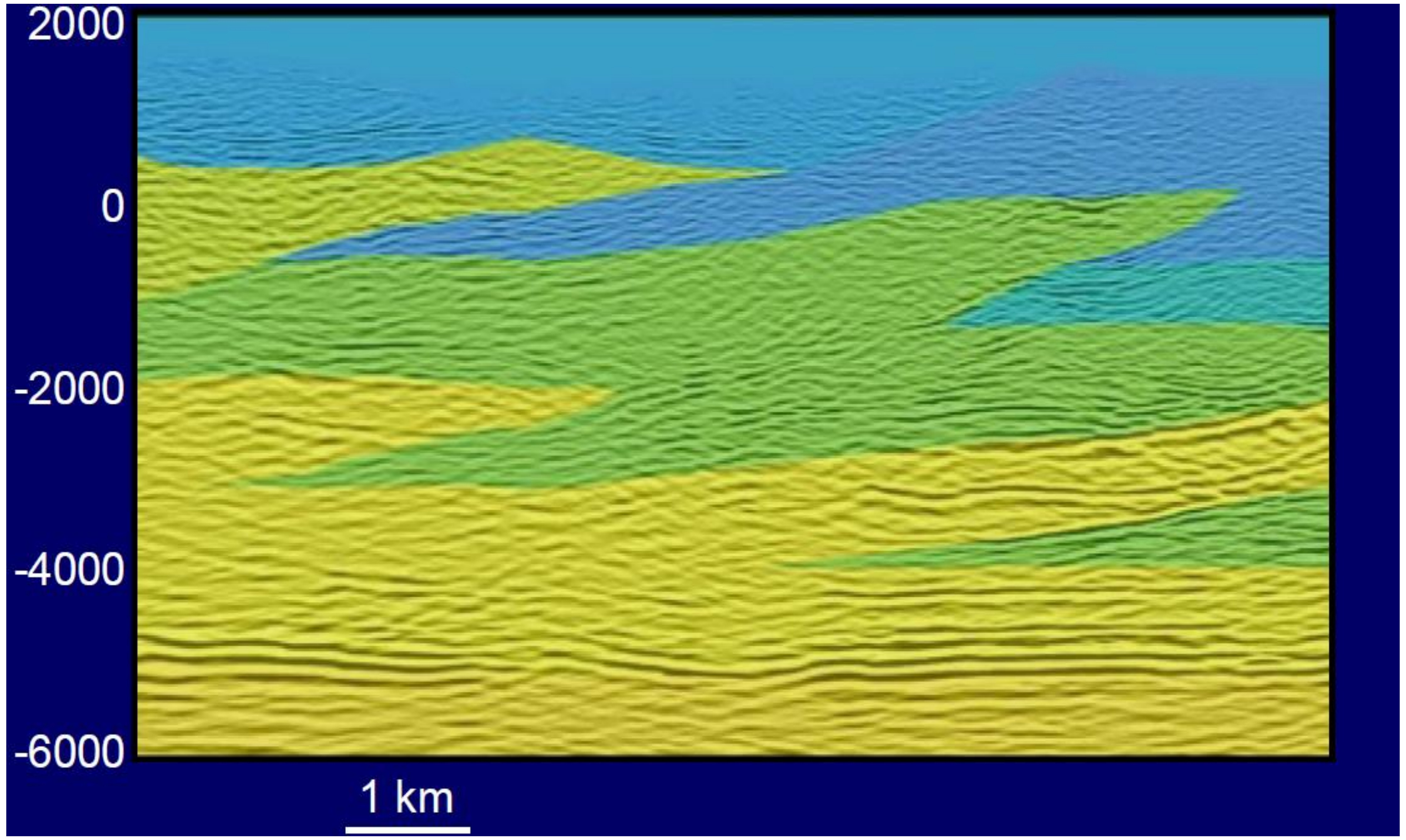


Picture from Geotrace

- PSDM is a model-based seismic imaging methodology that works well for complex geological structures.

- PSDM in comparison with PSTM is more expensive and time consuming but is more likely to precisely determine the structure of the reservoirs.

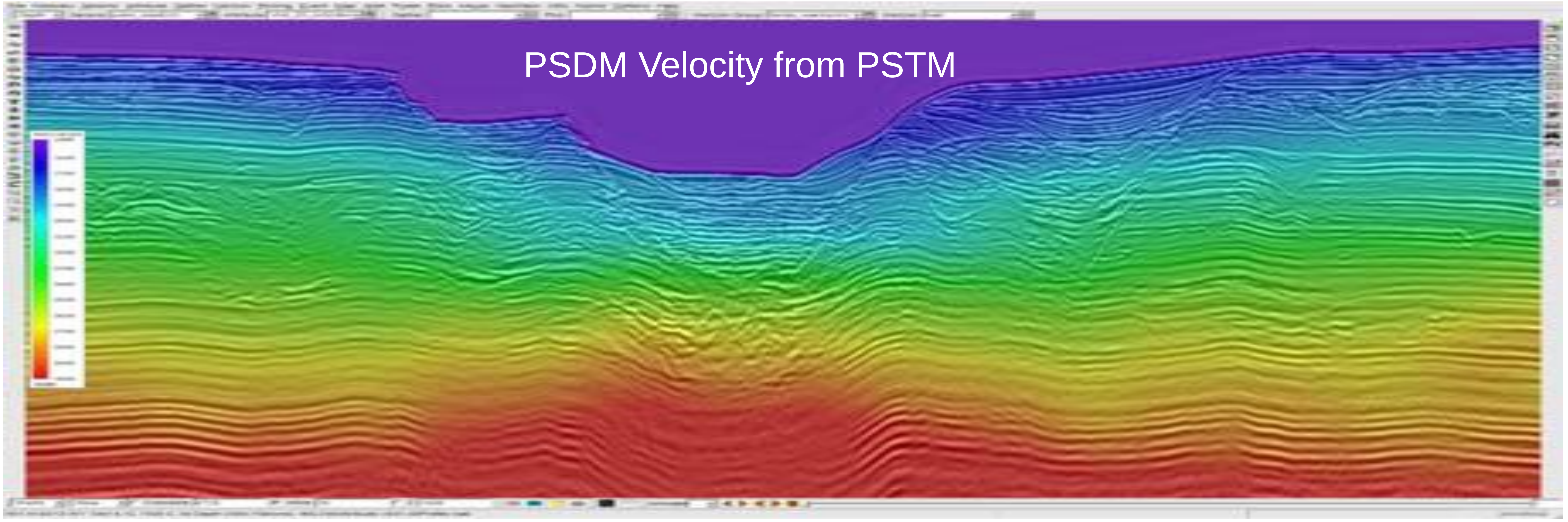
Migration: Depth migration workflow – velocity constrains

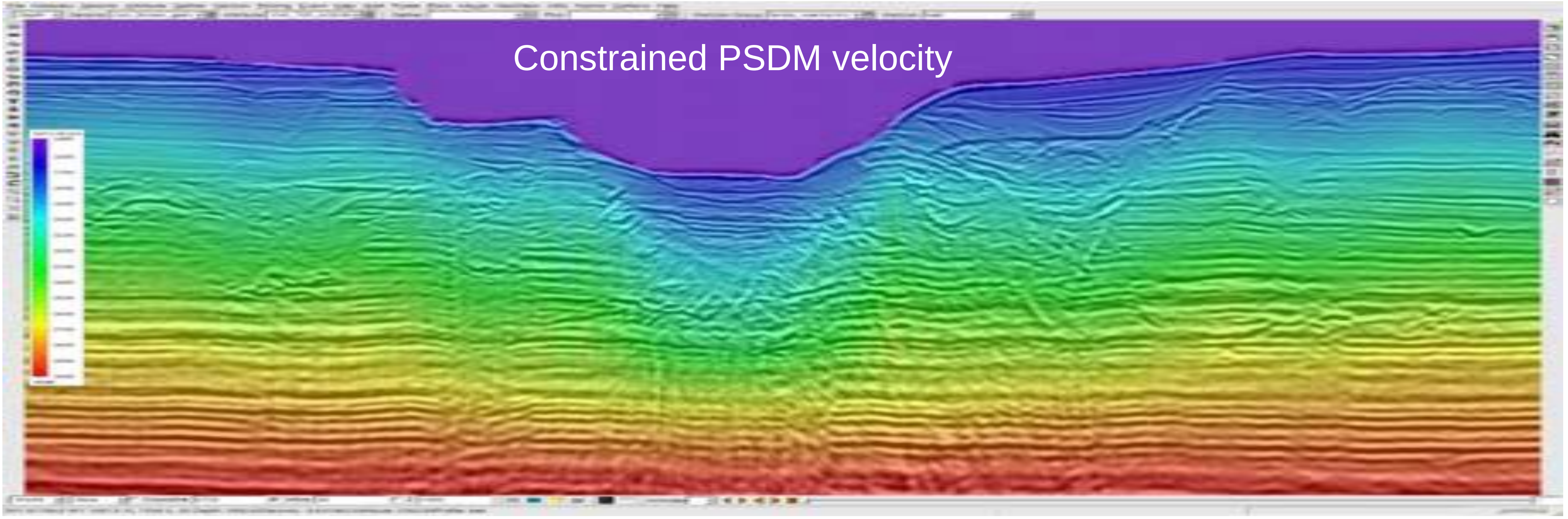


Helen Isaac and Don Lawton, AAPG 2009

- Depth velocity is not unique
- Improving the depth velocity model:
  - geological maps, geological cross-sections,
  - well formation tops,
  - sonic interval velocities,
  - near-surface velocities from refraction statics,
  - location of pitfalls such as pull-up on time sections

Migration: Depth migration example - Submarine canyons





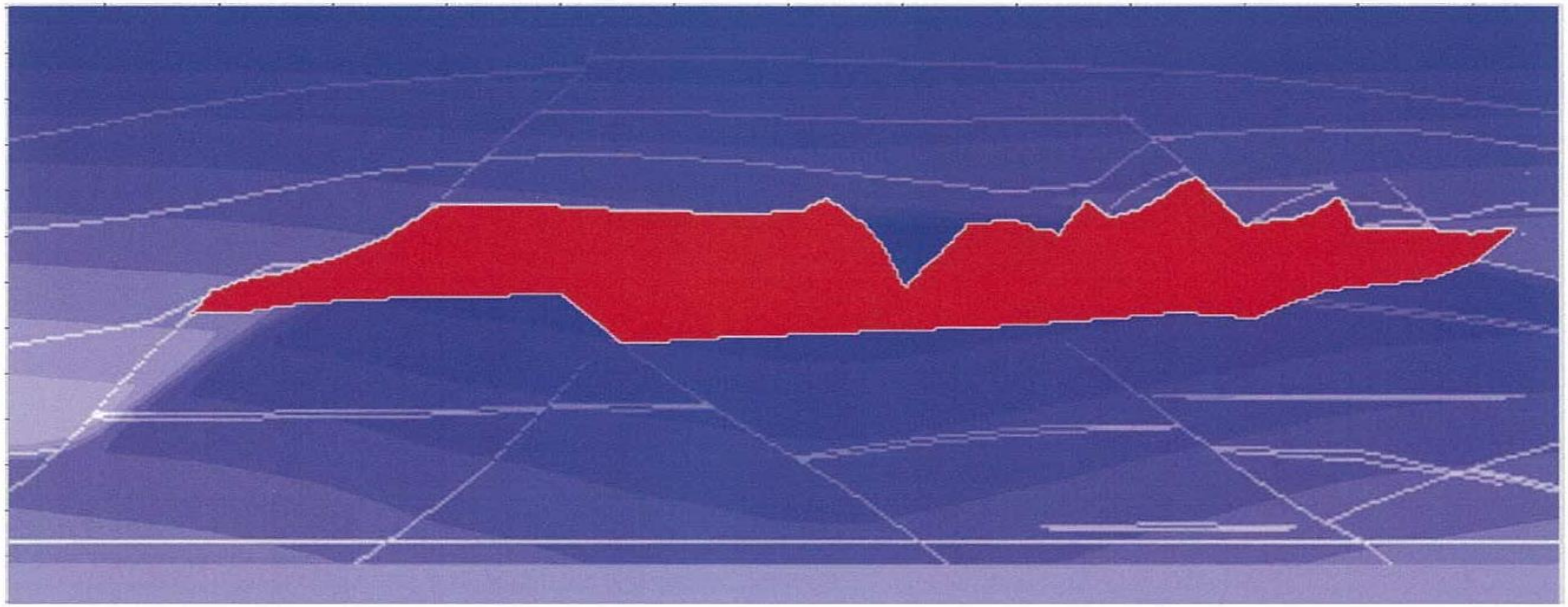
Jorge Sánchez Littau and Marcelo Koremblit, CGGVeritas Argentina

Migration: Depth imaging tools

Ray Based methods, Kirchhoff migration
- Focus of diffractions
- Fast
- Consistent with tomography
- Amplitude preserved
- Limitation: Ray tracing in complex mode. Multi-pathing

Wavefield extrapolation based methods, Reverse time migration (RTM)
- No limitation in complexity of models
- Handles turning and prism waves
- Costly, higher frequencies are expensive
  8-20 Hz: x1, 8-40 Hz: x16, 8-80 Hz: x256
- Possible to create angle gathers, ~10x more cost

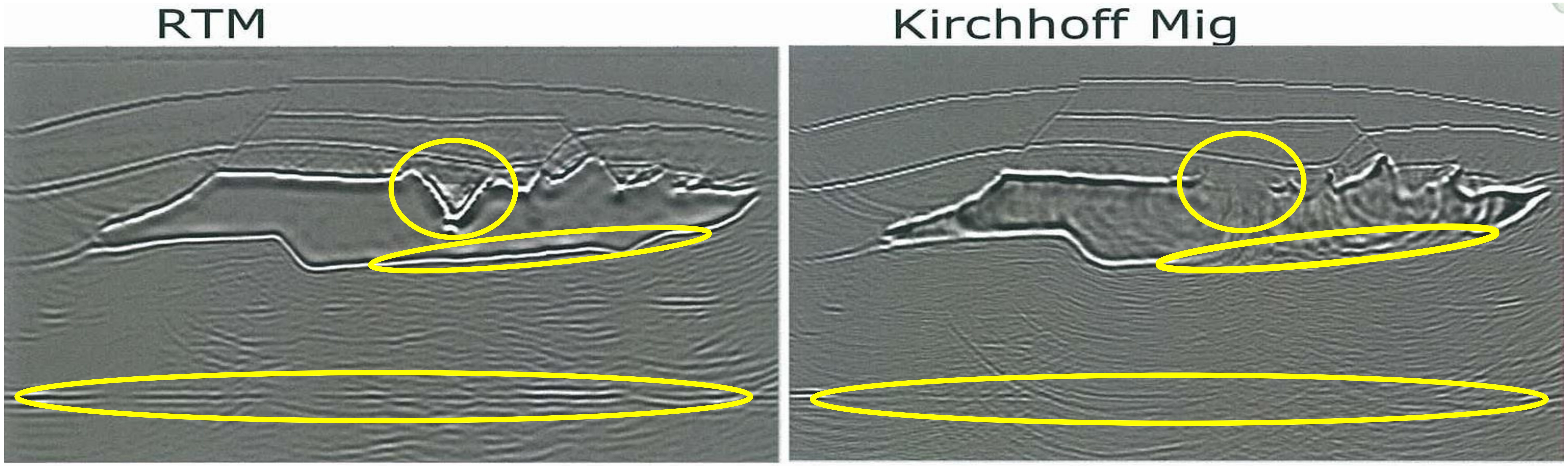
Migration: Depth imaging tools



EAGE- SEG Salt Model: Crossline 348

Example Courtesy of H. Guan, Total HGRG

Migration: Depth imaging tools



EAGE – SEG Salt model: Crossline 348, Example Courtesy of H. Guan, Total HGRG

RTM:

Pro:

- No limitation in complexity of the models
- Handles turning and prism waves
- Improved subsalt imaging

Cons:

- Loss of resolution (cost issue)
- Phase fidelity ?

Kirchhoff migration:

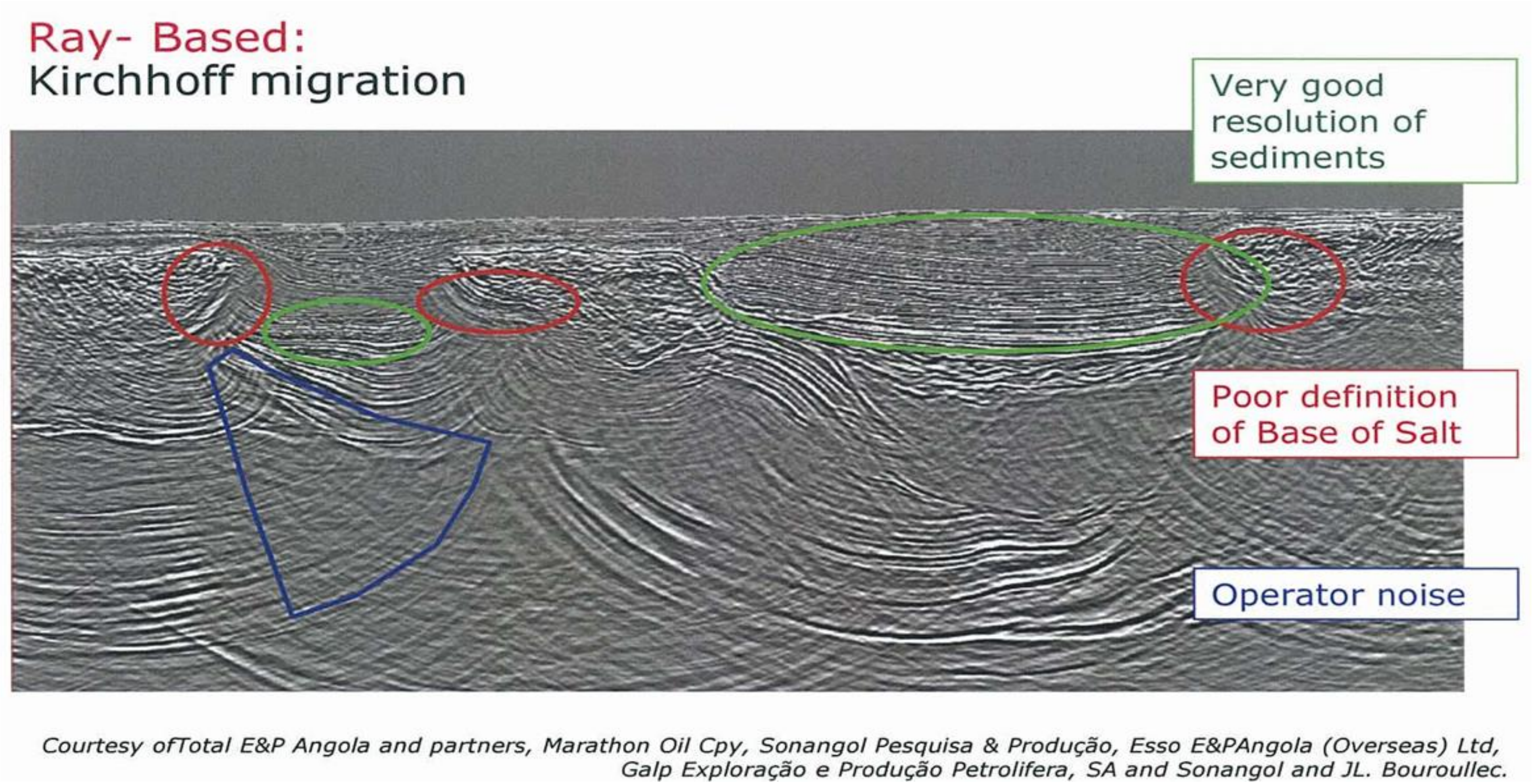
Pro:

- Fast, cheap
- Amplitude preserved

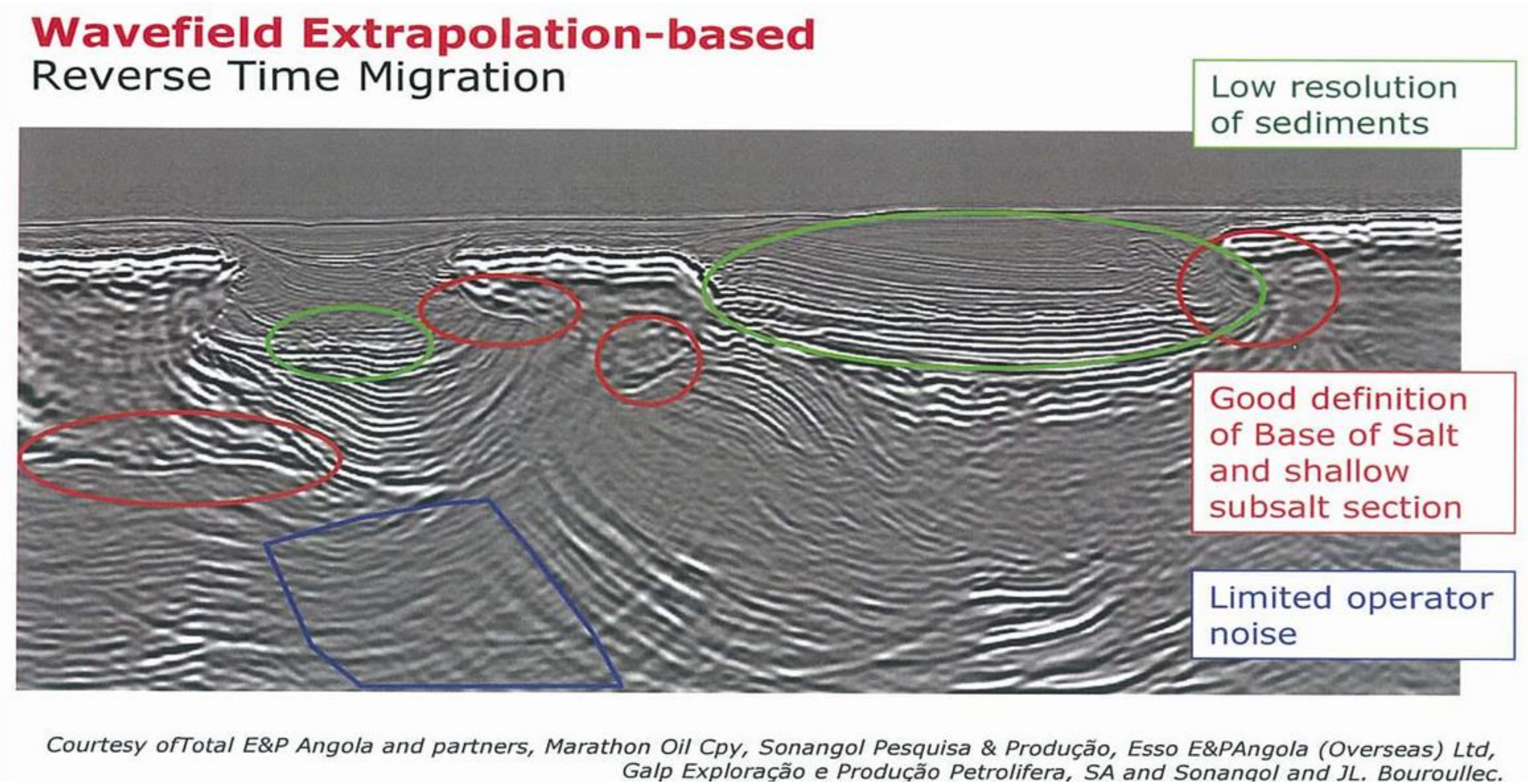
Cons:

- Ray tracing in complex mode, Multi-pathing
- Subsalt image is poor

Migration: Depth imaging tools - example



Migration: Depth imaging tools - example



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