Refraction Seismic

–

Different layer cases

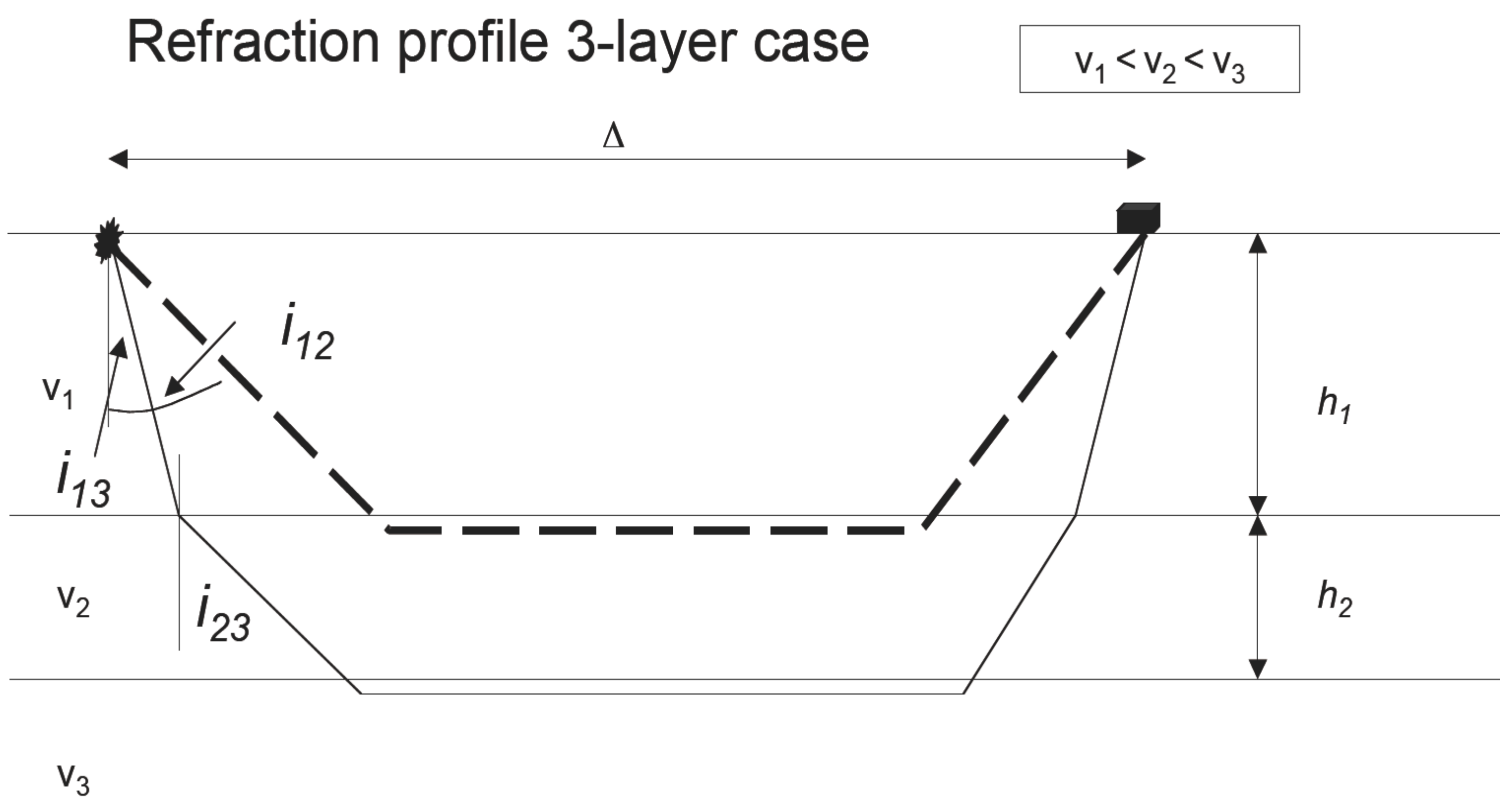
Refraction Seismics - Different layer cases

Multiple Refraction

- Several head waves.
- Evaluation becomes more complicated, but without principal problems.
- Important limitation: Only interfaces where the velocity increases towards to lower layer can be detected (also applies to the case of two layers).

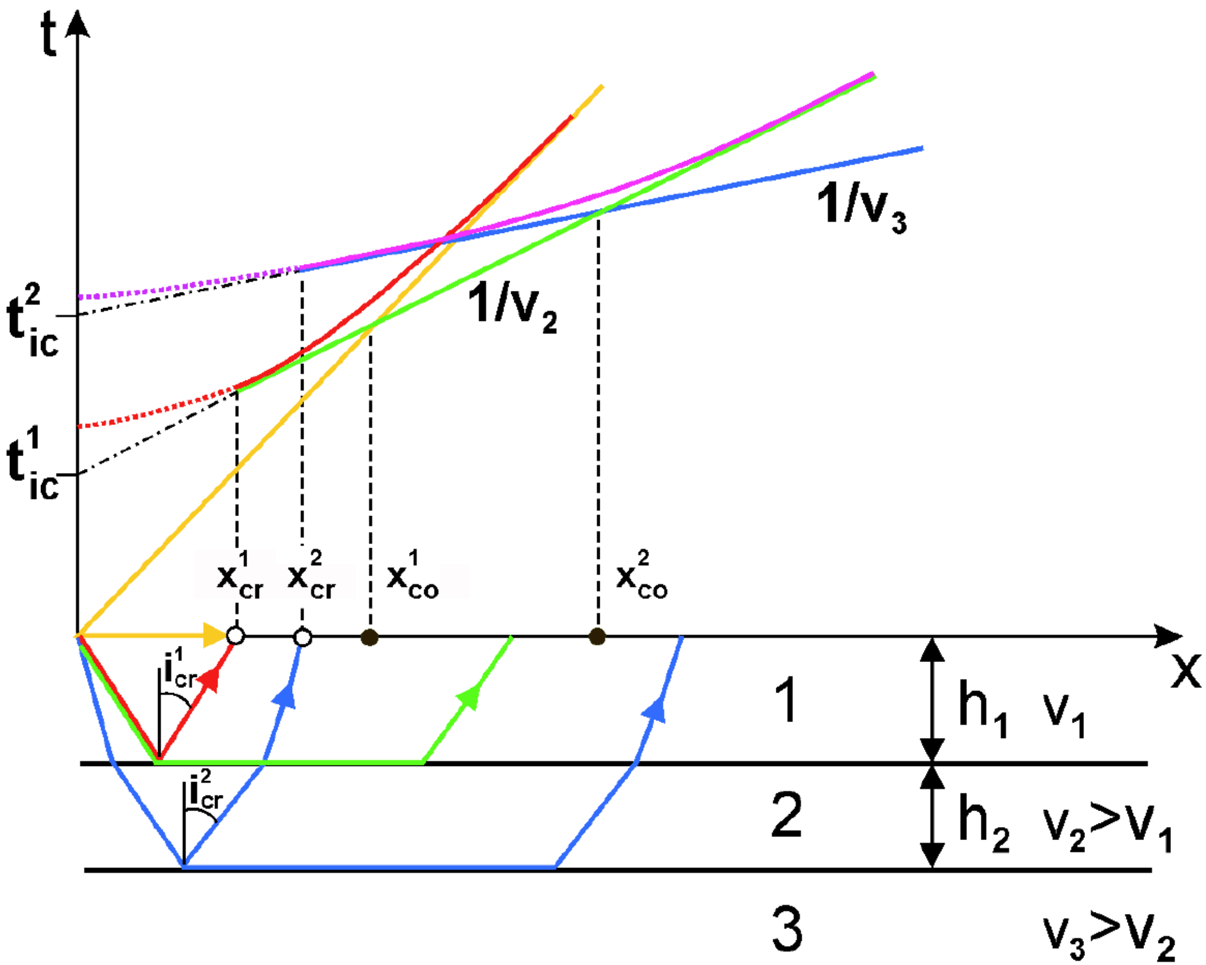
Refraction Seismics - Different layer cases

Geometry of 3-layer refraction



Refraction Seismics - Different layer cases

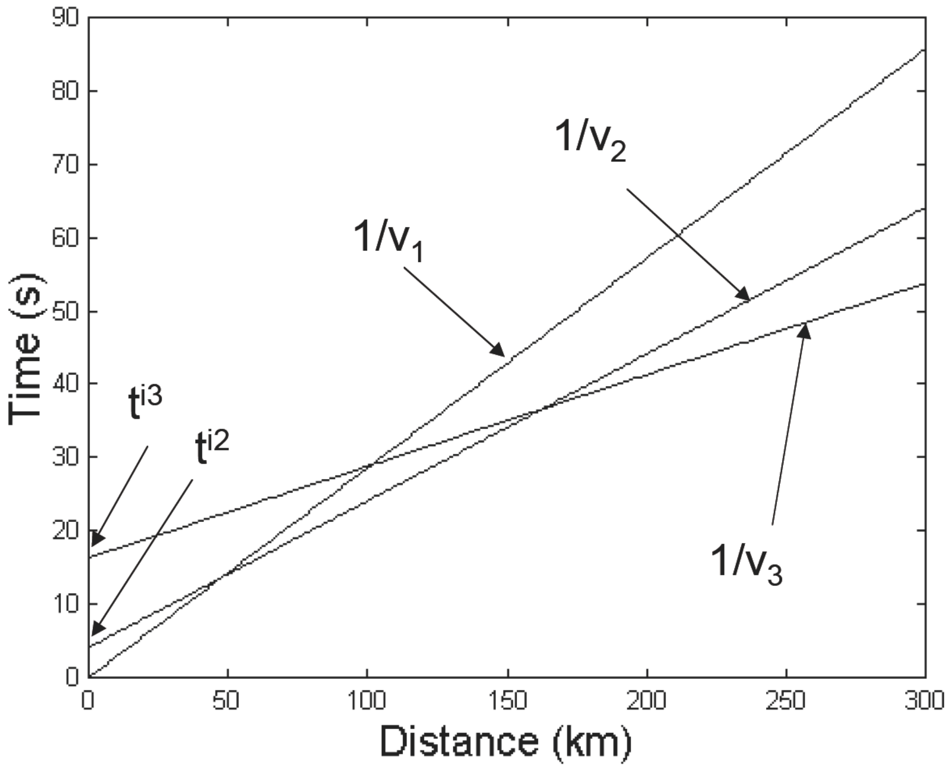
Multiple Refractions Seismogram



Refraction Seismics - Different layer cases

Multiple Refractions Two-Way Traveltimes

$$h_2 = \left(t^{i^3} - \frac{2h_1(V_3^2 - V_1^2)^{\frac{1}{2}}}{V_3 V_1}\right)\frac{V_3 V_2}{2\sqrt{(V_3^2 - V_2^2)}}$$

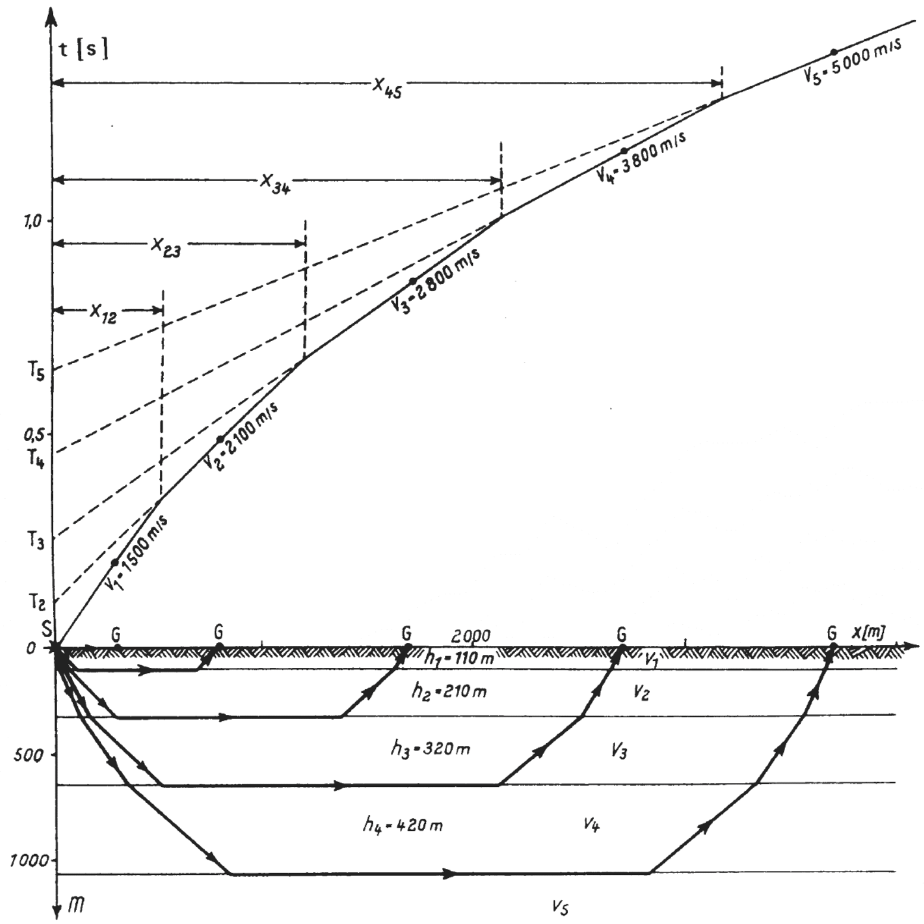


Refraction Seismics - Different layer cases

Multiple Refractions Two-Way Traveltimes

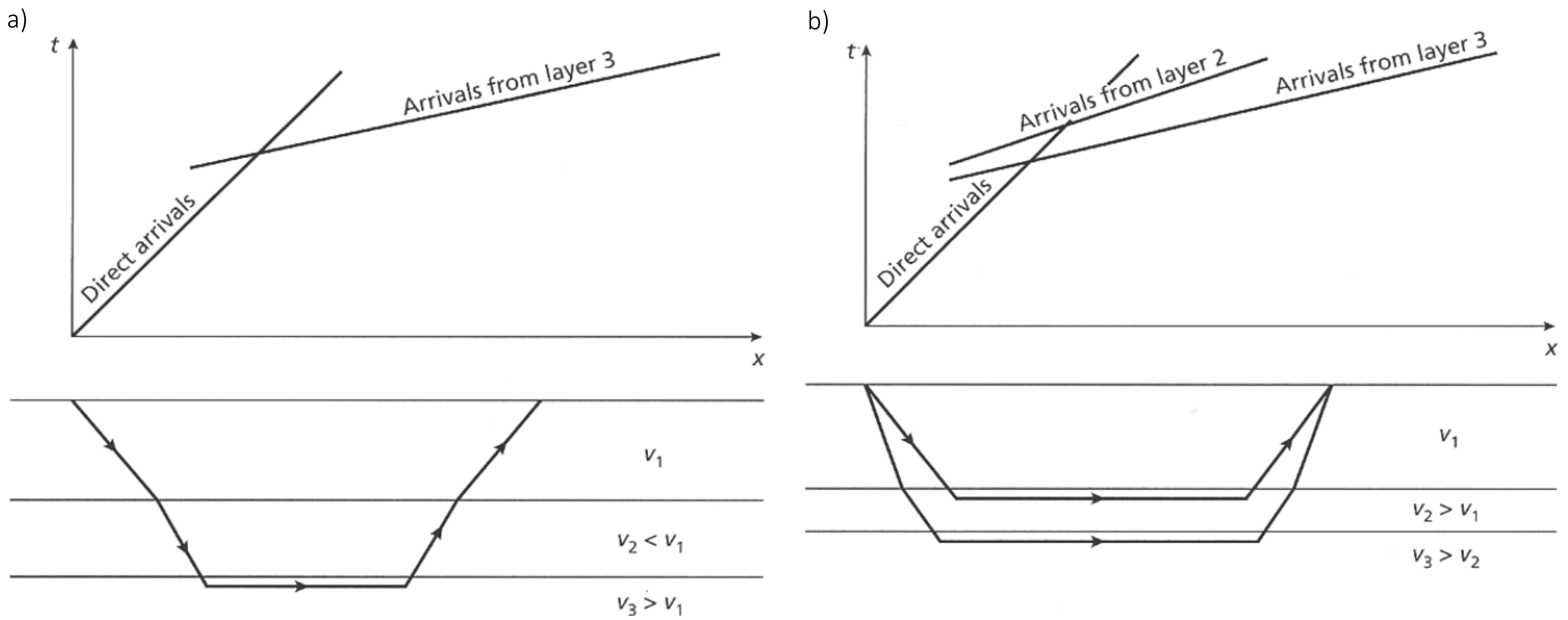
$$t_n = \frac{\Delta}{v_n} + \sum_{i=1}^{n-1} \frac{2h_i \cos i_{in}}{v_i}$$

$$i_{in} = \sin^{-1}\left(\frac{v_i}{v_n}\right)$$



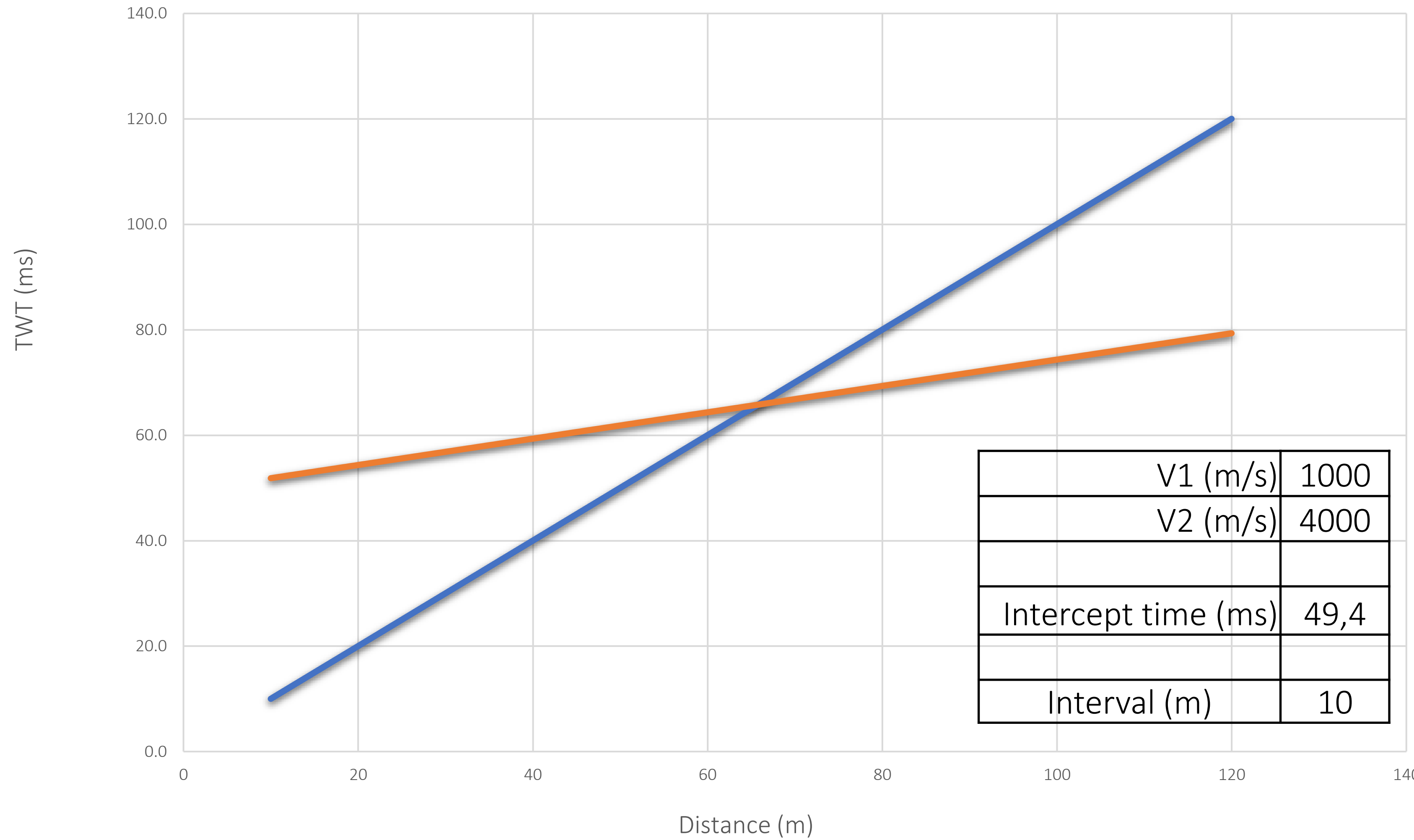
Refraction Seismics - Different layer cases

Multiple Refractions and Hidde Layers



Refraction Seismics - Different layer cases

a) Intermediate low-velocity layer

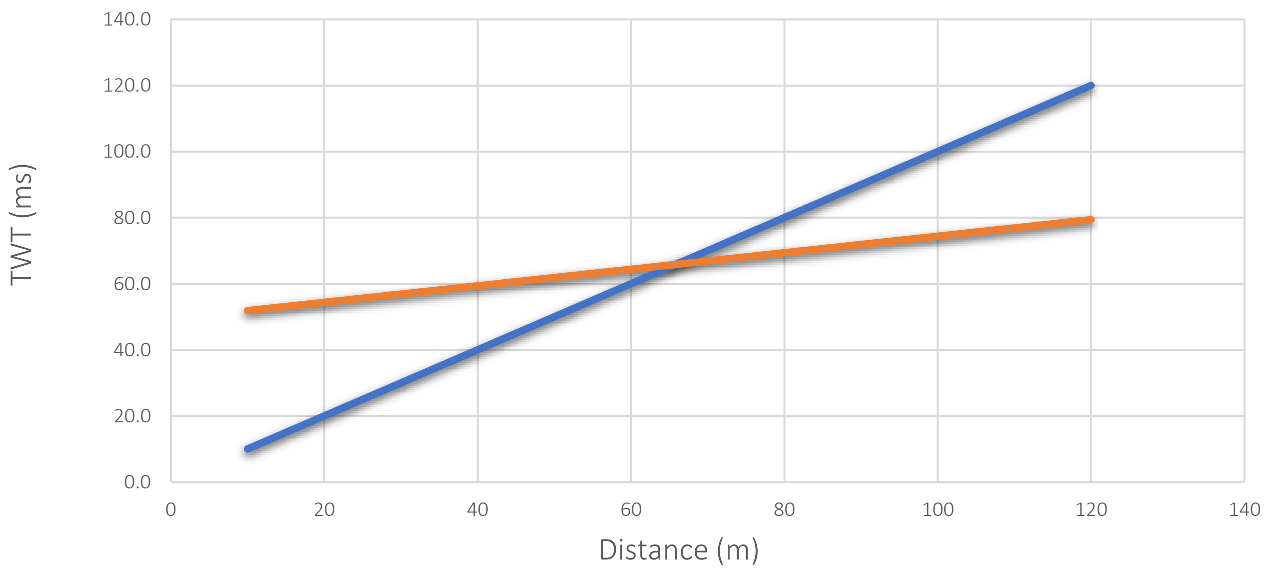


V1 (m/s)	1000
V2 (m/s)	4000
Intercept time (ms)	49,4
Interval (m)	10

Refraction Seismics - Different layer cases

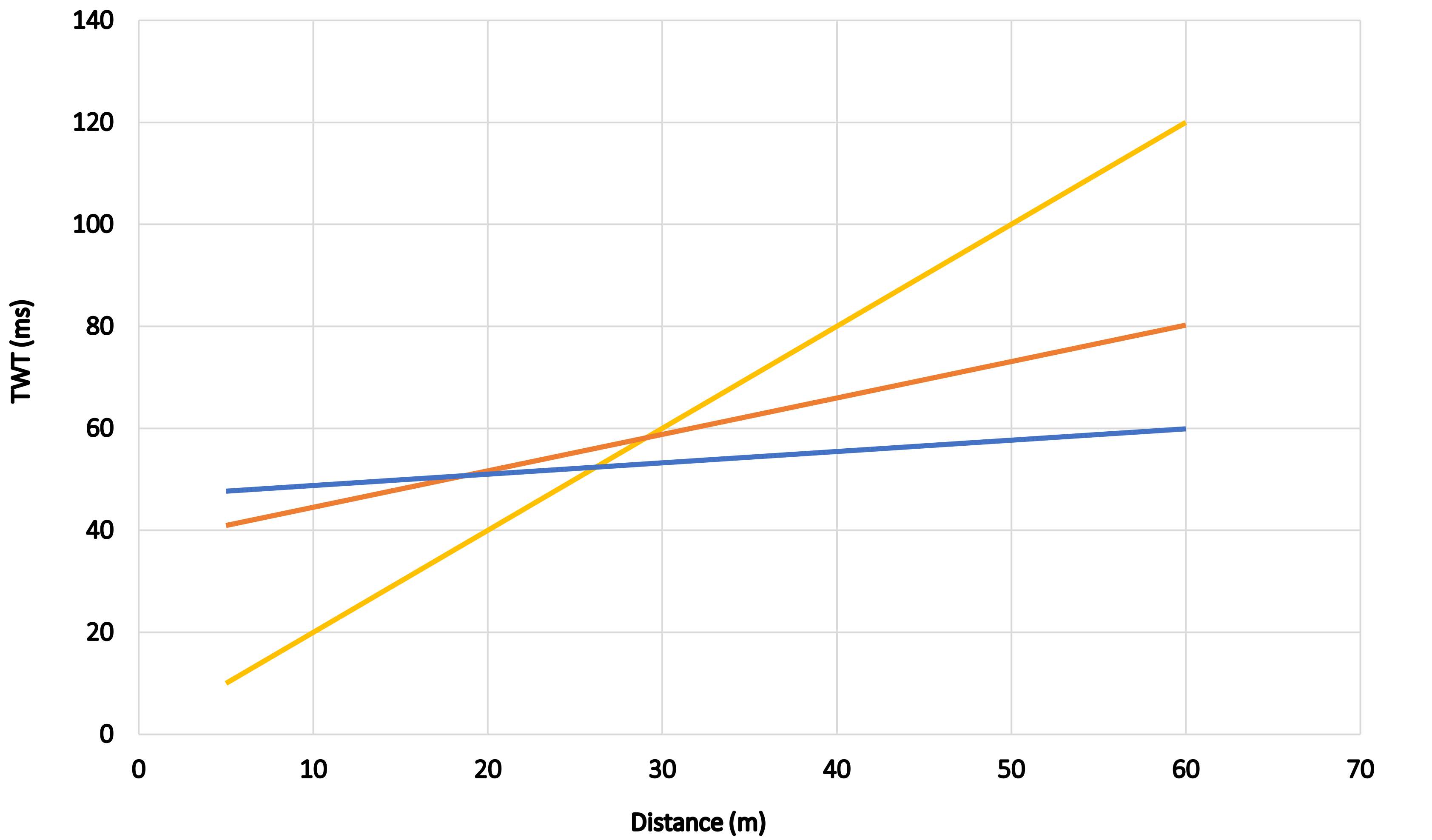
a) Intermediate low-velocity layer

Distance (m)	Direct wave (ms)	Interface 2 Refraction (ms)		
			V1 (m/s):	1000
			V2 (m/s):	500
10	10,0	51,9	V3 (m/s):	4000
20	20,0	54,4	h1 (m):	5
30	30,0	56,9	h2 (m):	10
...	...	...		
80	80,0	69,4	Interval (m):	10
90	90,0	71,9		
100	100,0	74,4	Intercept time (ms):	49,4
110	110,0	76,9		



Refraction Seismics - Different layer cases

b) Thin intermediate layer



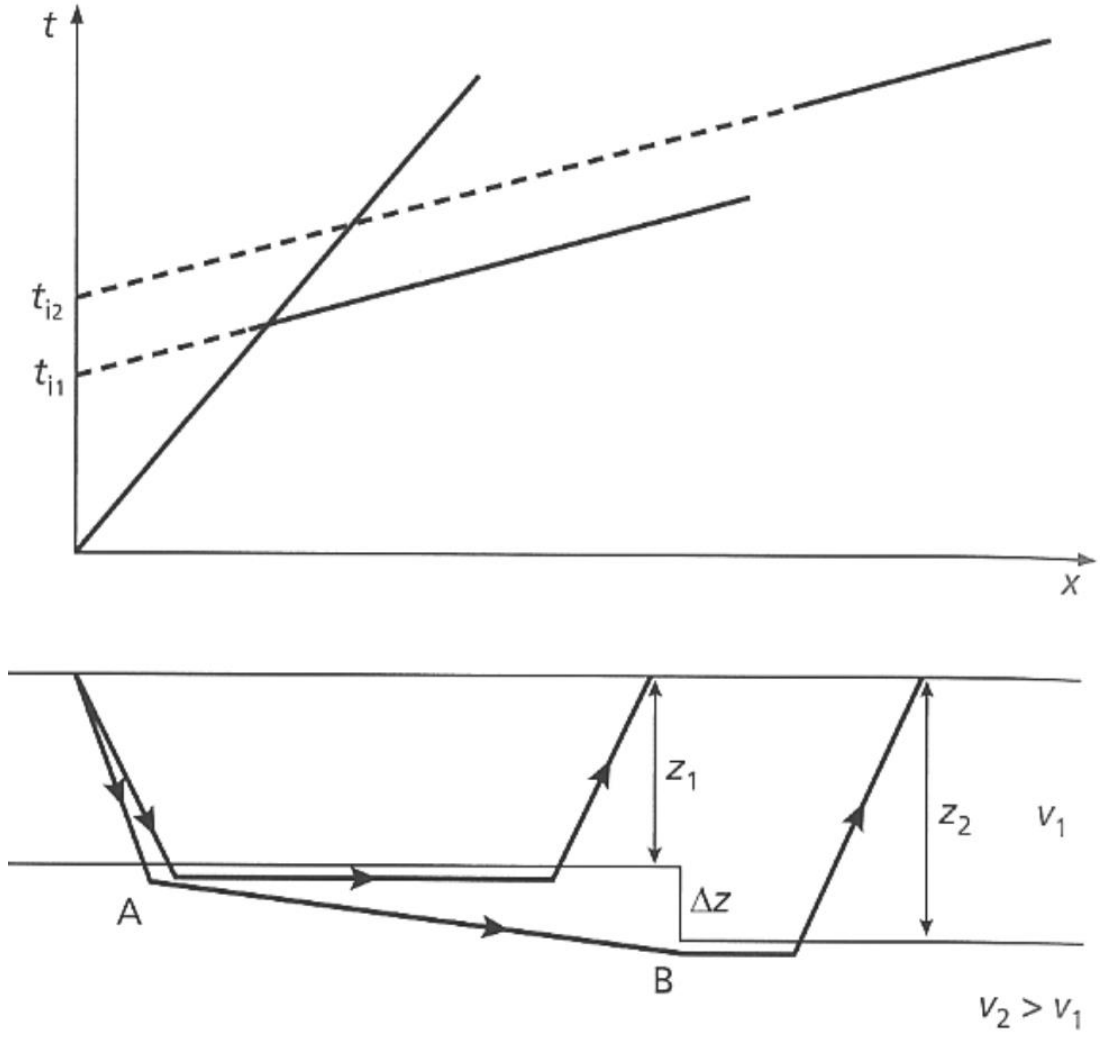
Refraction Seismics - Different layer cases

b) Thin intermediate layer

Distance (m)	Direct wave (ms)	Interface 1 Refraction (ms)	Interface 2 Refraction (ms)
5	10	40,93	47,65
10	20	44,50	48,76
15	30	48,08	49,87
20	40	51,65	50,99
25	50	55,22	52,10
30	60	58,79	53,21
35	70	62,36	54,32
40	80	65,93	55,43
45	90	69,50	56,54
50	100	73,08	57,65
55	110	76,65	58,76
60	120	80,22	59,87
V1 (m/s)	500		
V2 (m/s)	1400		
V3 (m/s)	4500		
h1 (m)	10		
h2 (m)	5		
Interval (m)	5		

Refraction Seismics - Different layer cases

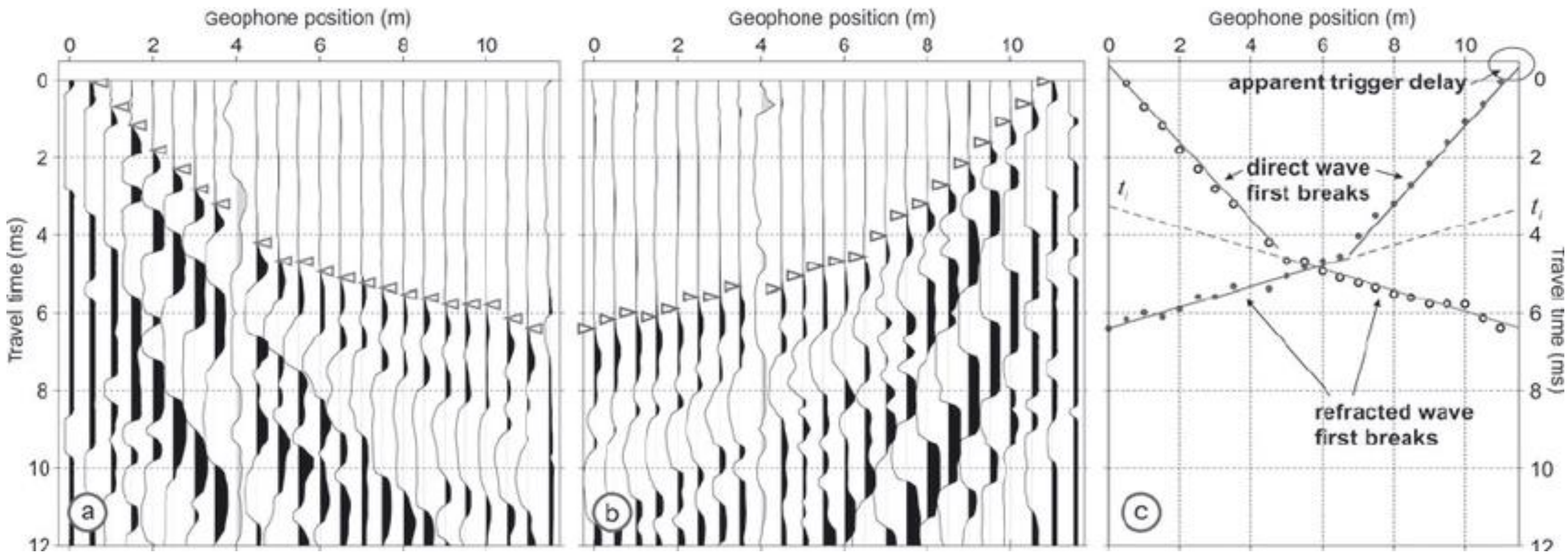
Lateral velocity changes



Refraction Seismic
–
Application

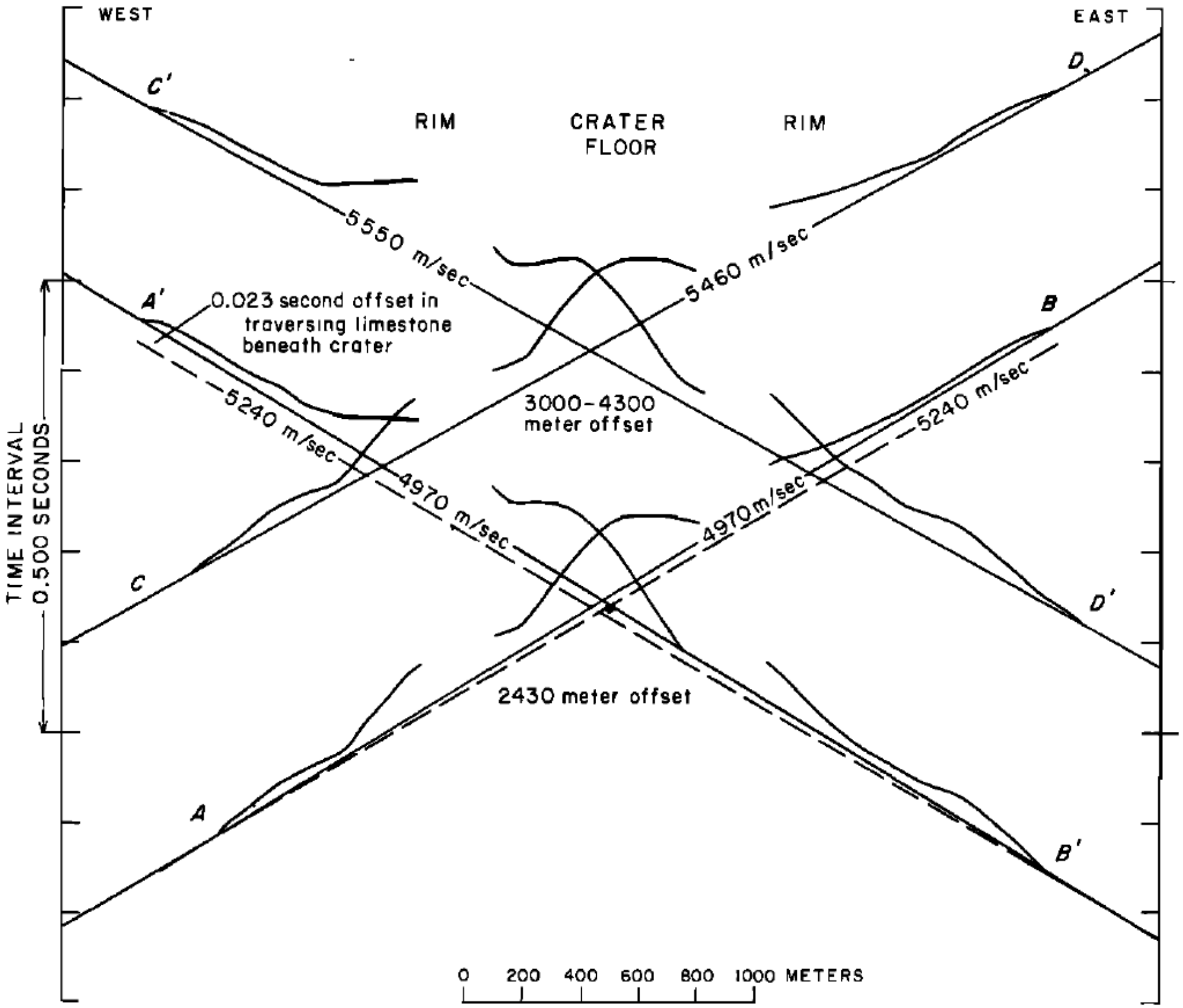
Refraction Seismics - Application

Interpretation of first picks



Refraction Seismics - Application

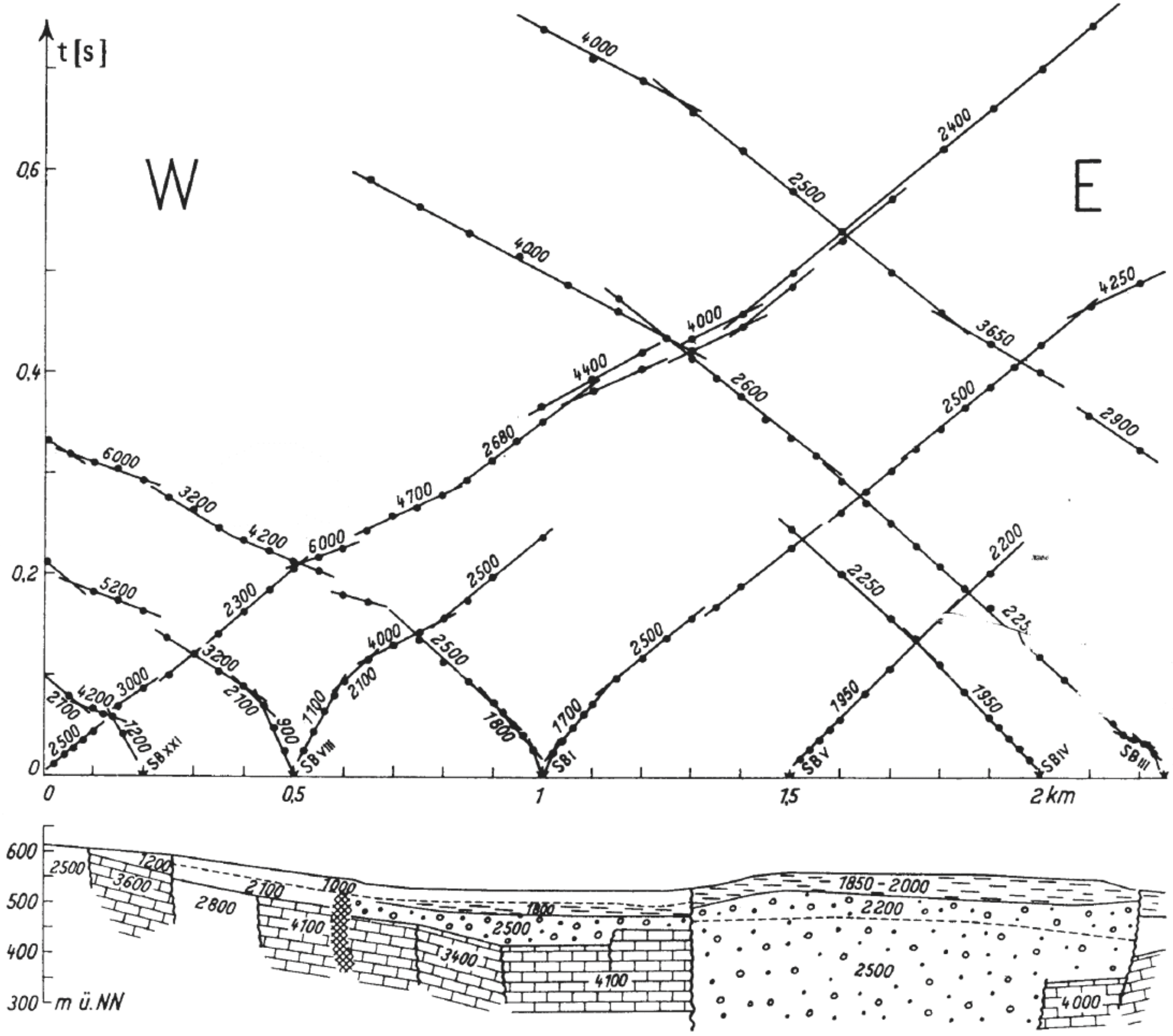
Interpretation of first picks



Ackermann et al. (1975)

Refraction Seismics - Application

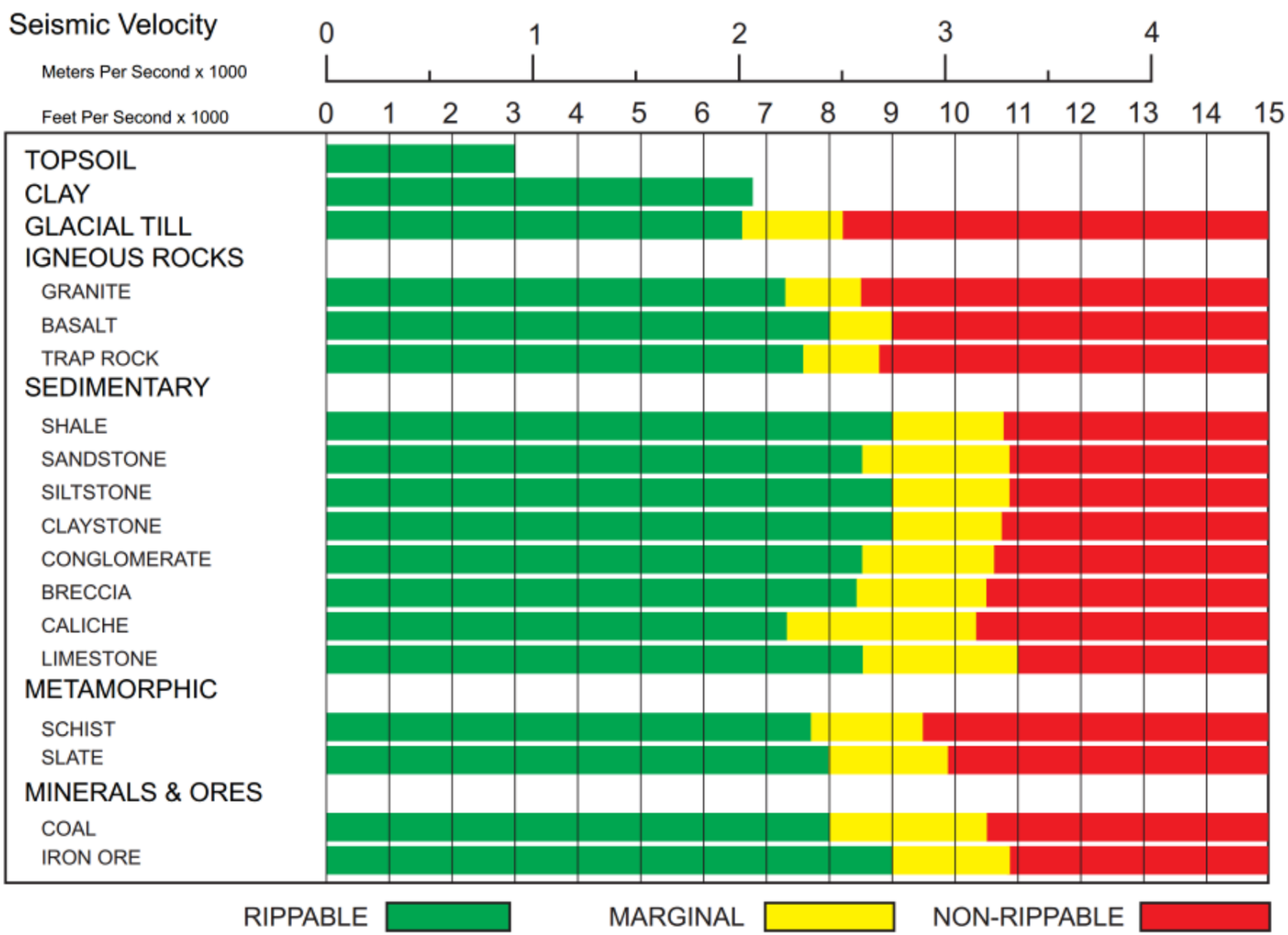
Interpretation of first picks



FU Berlin (2007)

Refraction Seismics - Application

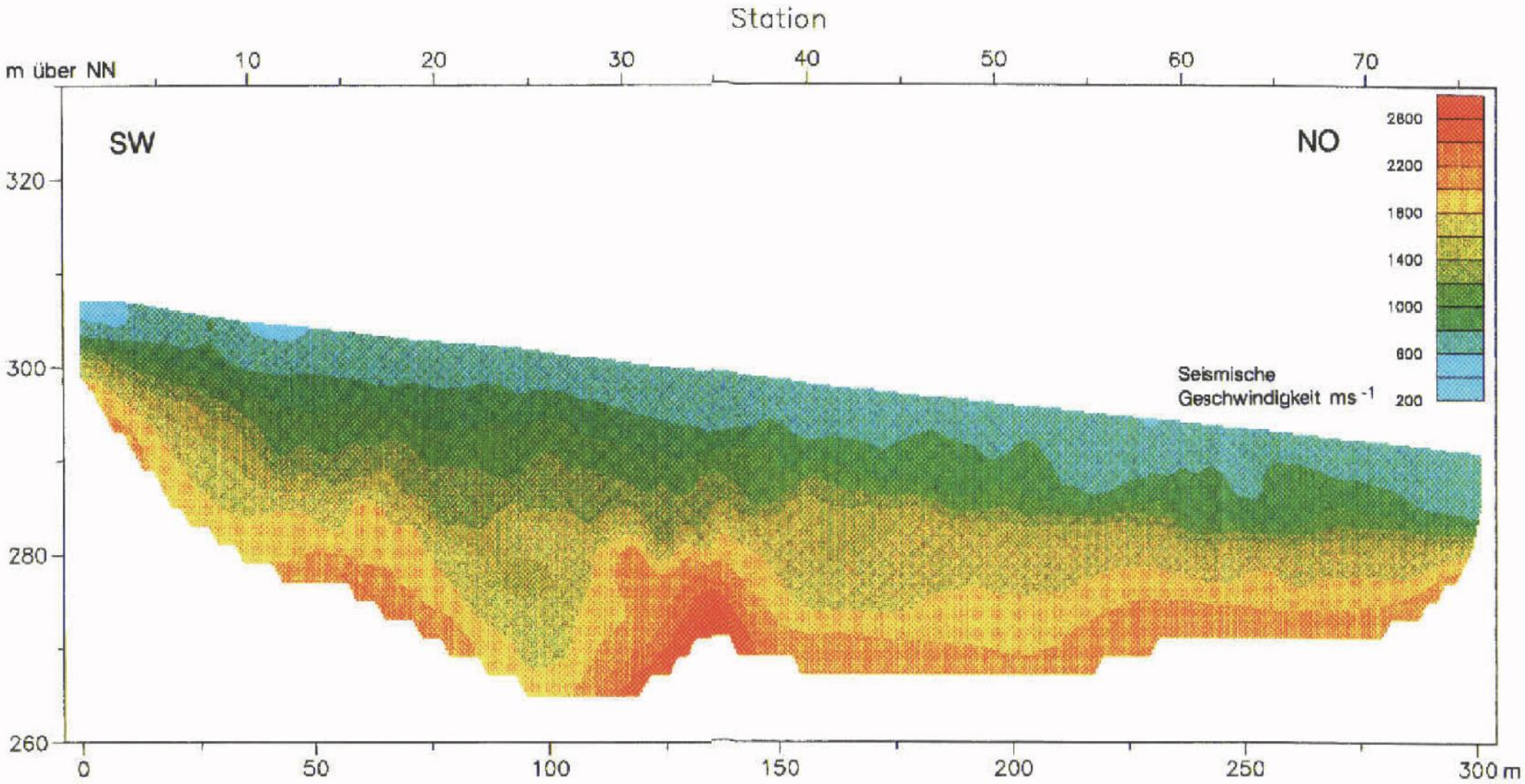
Translation into Geotechnical Subsurface Properties



Caterpilar (2001) Ripability Indexing

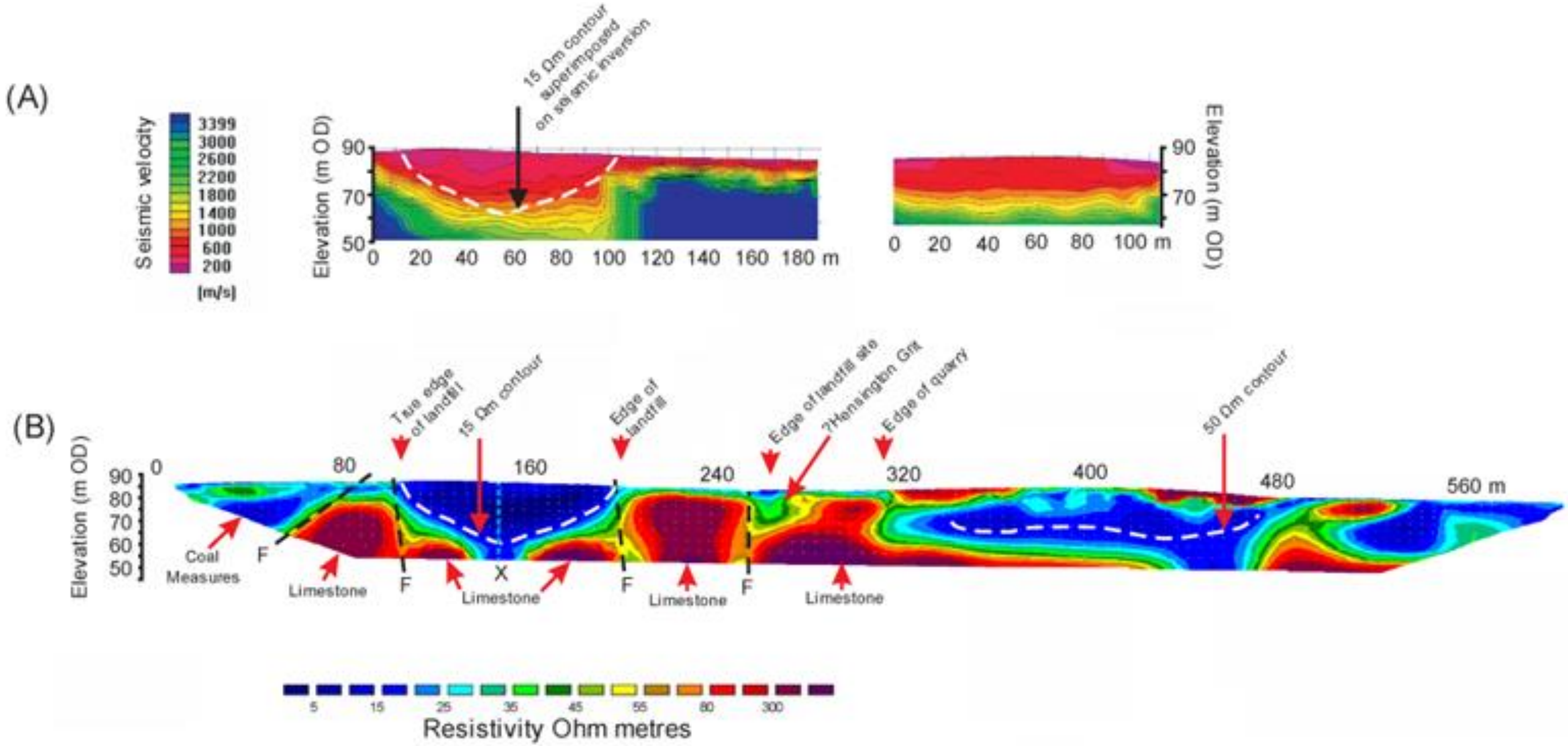
Refraction Seismics - Application

Translation into Geotechnical Subsurface Properties



Refraction Seismics - Application

Translation into Geotechnical Subsurface Properties



Reynolds (2011)

Reflection Seismic

–

Application

Reflection Seismics - Application

Editing and Muting

A) Head Wave

B) Reflection

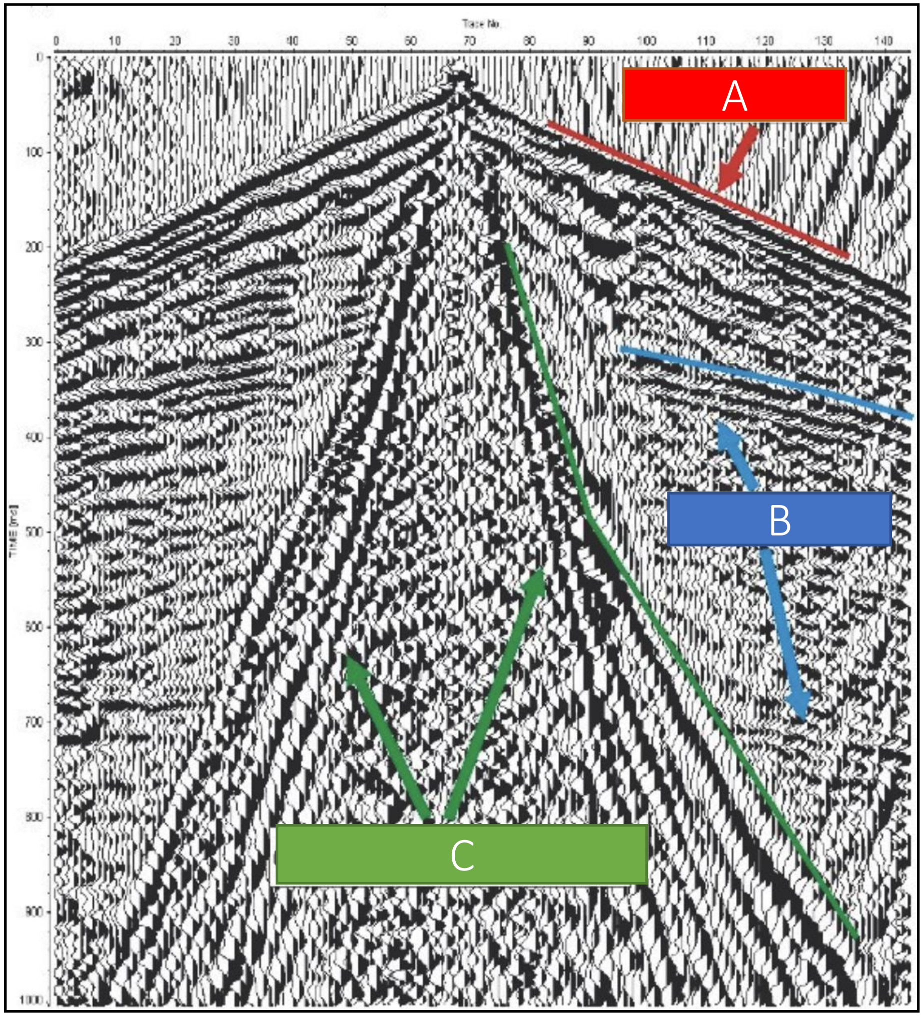
C) Ground Roll

Undesired signals

- Head wave and surface noise
- Ground roll

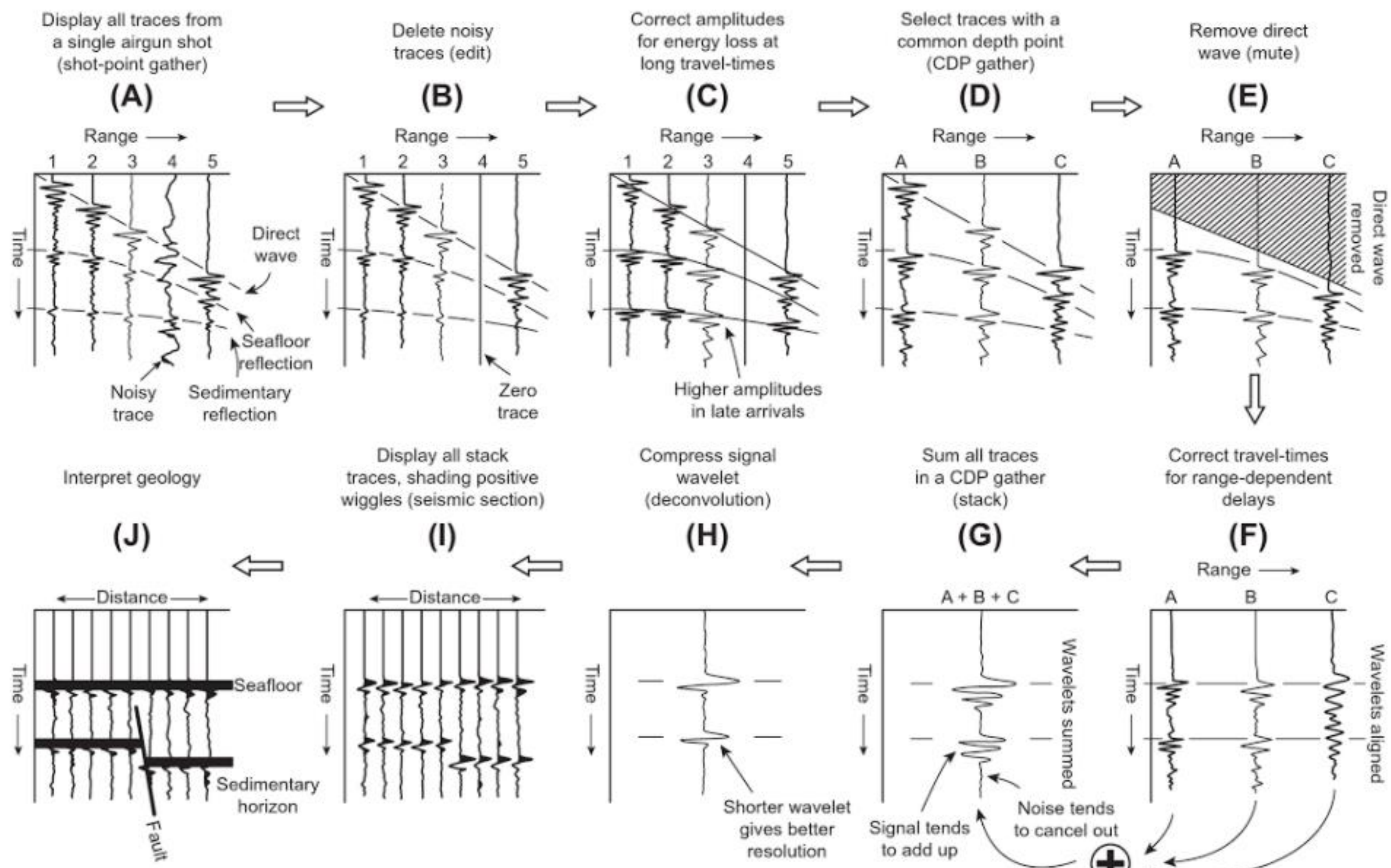
Desired signals

- Reflection hyperbola



Reflection Seismics - Editing

Editing Sequences



(source: Selley and Sonnenberg,1985)

Reflection Seismics - Application

Filters

- Seismic and SPS files merge, with minimum filter application through Autocorrelation with pilot sweep.
- Decay compensation by scaling of (T^2.2).
- Despiking for high amplitude noise bursts attenuation.
- Wavelet transform filter (WTF) for coherent noise sources attenuation.
- 3D FK filter .
- Normal Moveout correction NMO.
- Automatic Gain Correction AGC.
- Random Noise Attenuation , Minimum Noise Attenuation.
- Phase correction for Onshore data, and Time-Phase shift correction for Offshore data.
- Fourier Transfor Filter (FTF).
- Stacking.
- Zero Phase filter application.
- Low filter migration.
- Deconvolution.
- Depth moveout correction DMO.

Parameters

Parameter	Method
Sesimic, SPS files	Data Merge
Time, Amplitude	*Autocorrelation
Time, Amplitude	*Decay compensation
Time, Frequency	Despiking
Time, Amplitude	WTF
Time,Frequency	3D FK filter
Time, Frequency	NMO
Time, Amplitude	*AGC
Time, Frequency	Noise attenuation
Time,Frequency	*Fourier Transform
Time, Amplitude	Stacking
Time, Frequency	Zero Phase filte
Time, Frequency	*Low filter migration
Time, Frequency	Deconvolution
Depth	*Depth moveout correction DMO.

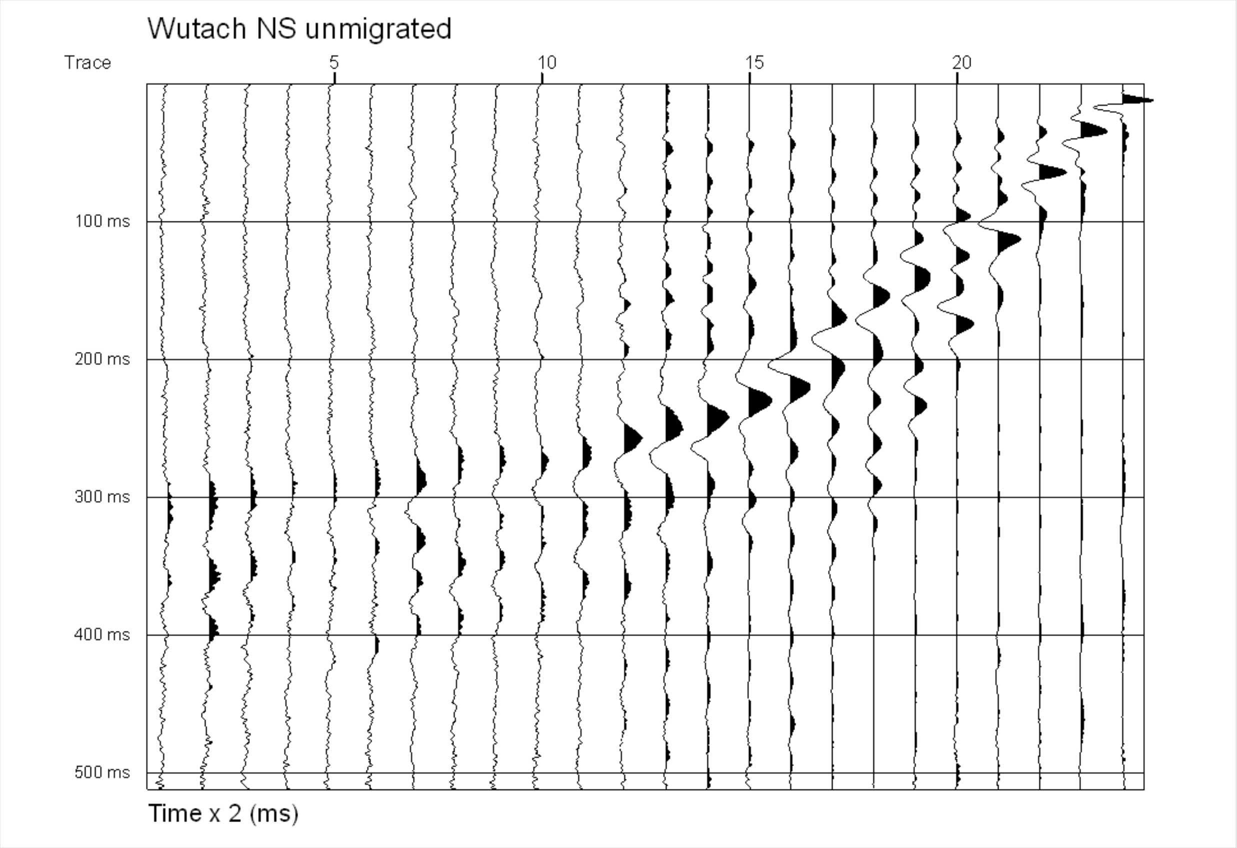
Reflection Seismics - Application

NMO Example

Noise:

- Air wave
- Rayleigh wave
- Ground roll
- Surface wave
- Refraction
- Head wave
- Multiple reflection
- Cultural noise

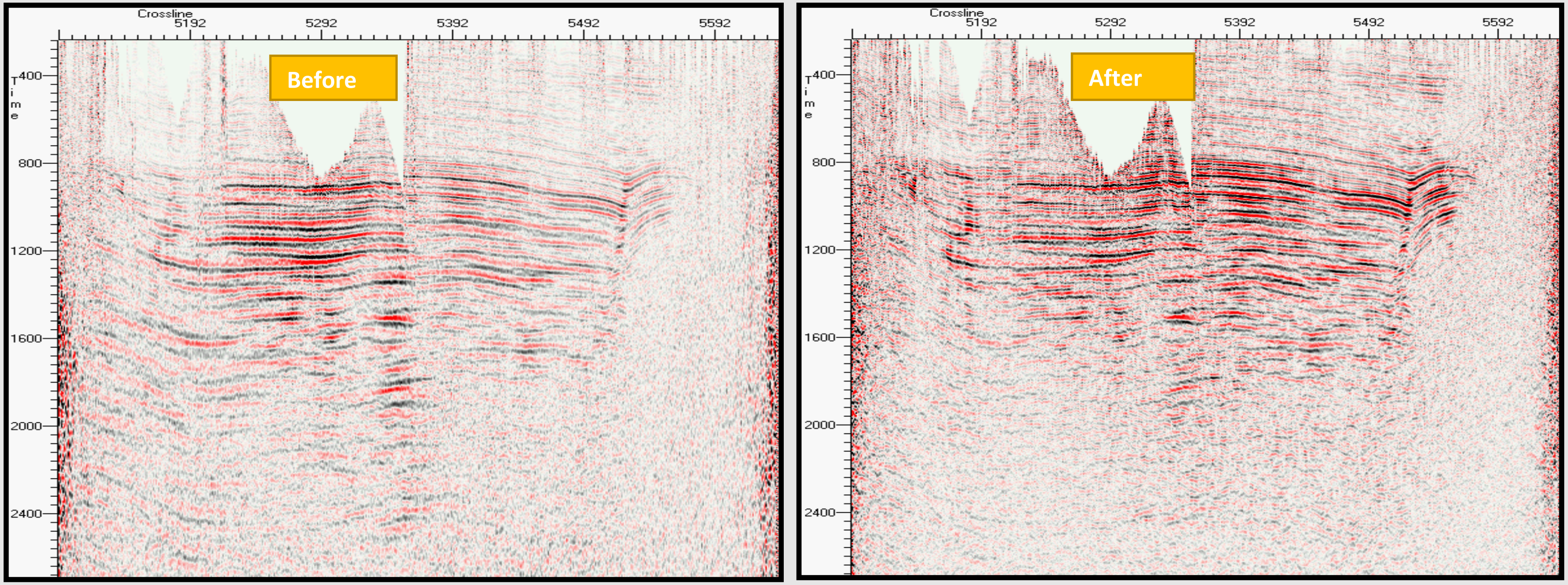
application of a high pass filter (above 380 MHz):



Reflection Seismics - Application

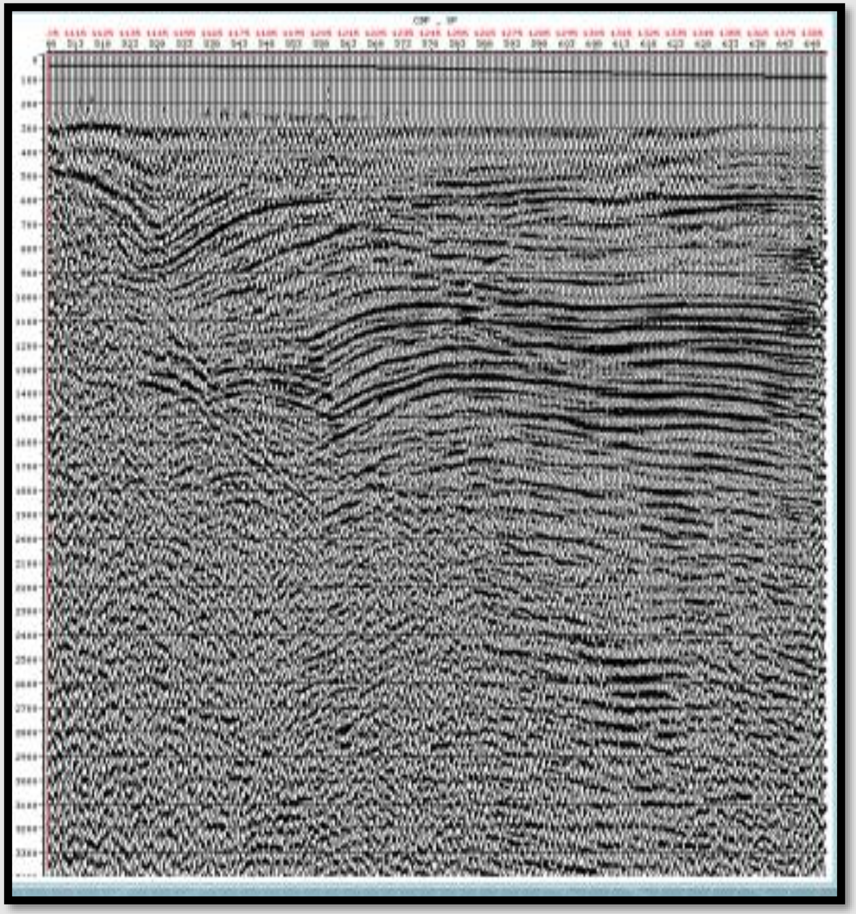
FK-Filter

- The aim of this process is to attenuate the low frequency ground roll energy.

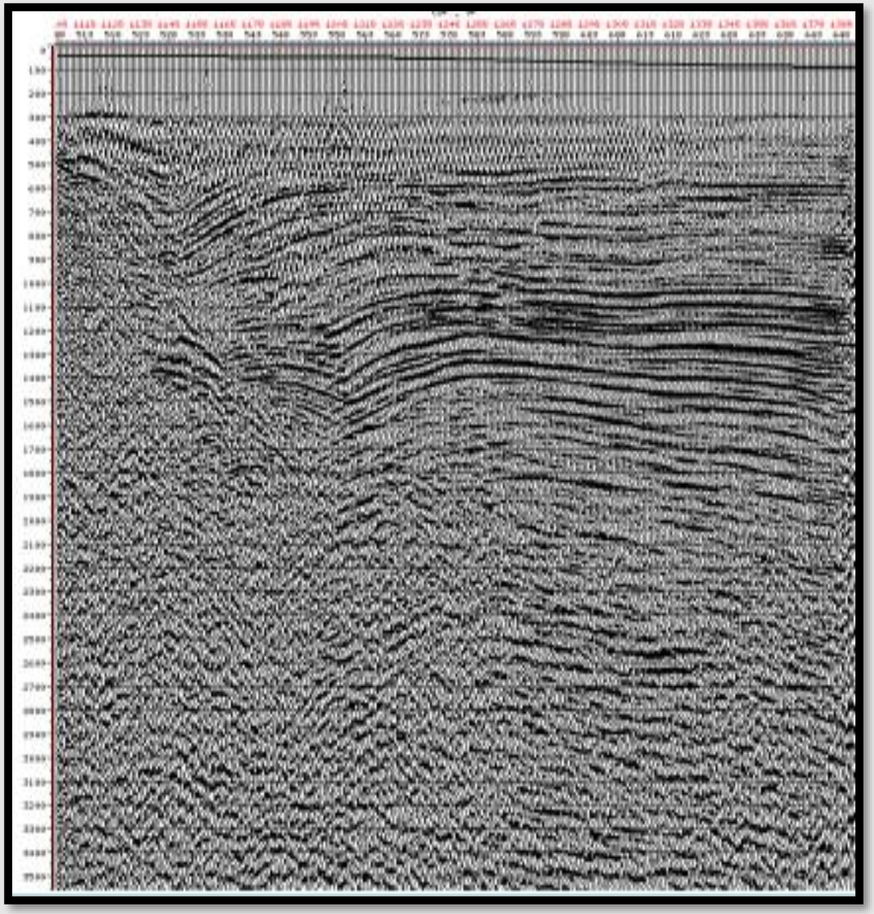


Reflection Seismics - Application

Raw Stack



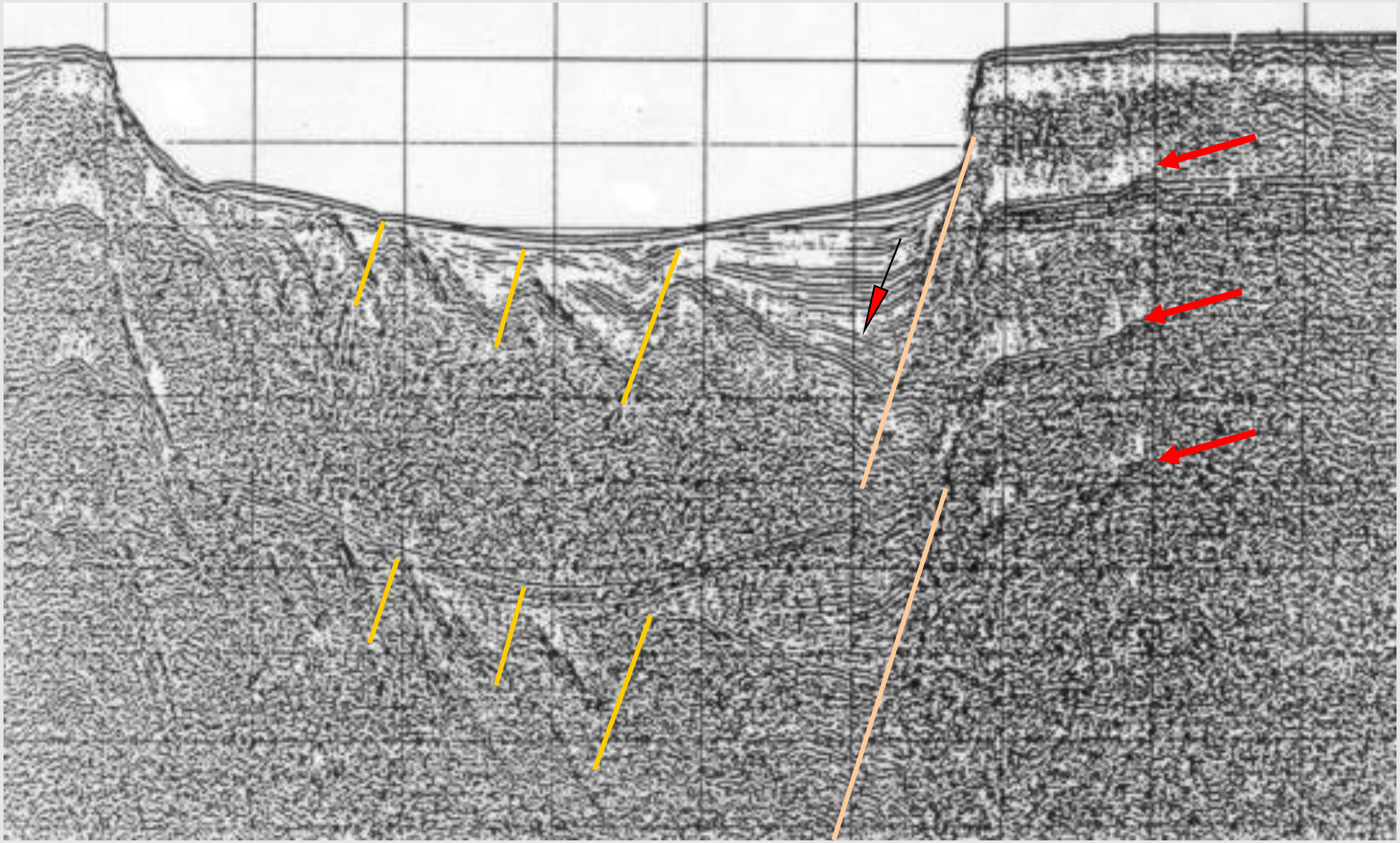
Deconvolution



Reflection Seismics - Application

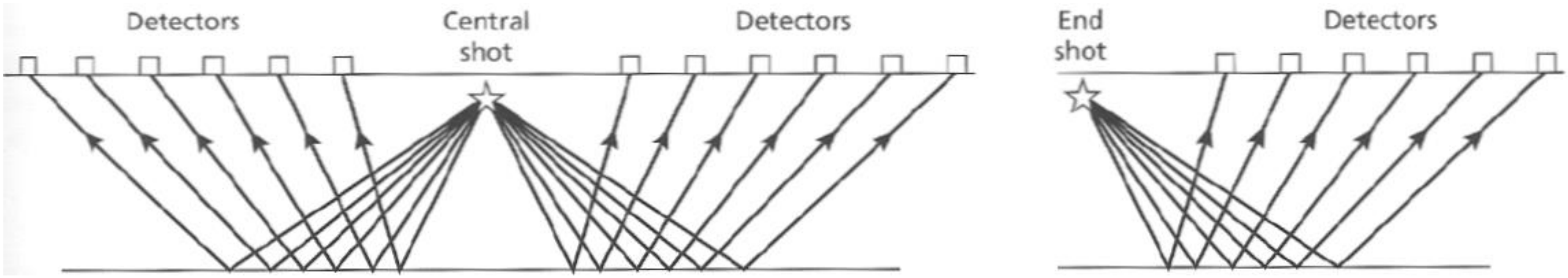
Deconvolution

- Multiples are considered “coherent” noise or unwanted signal



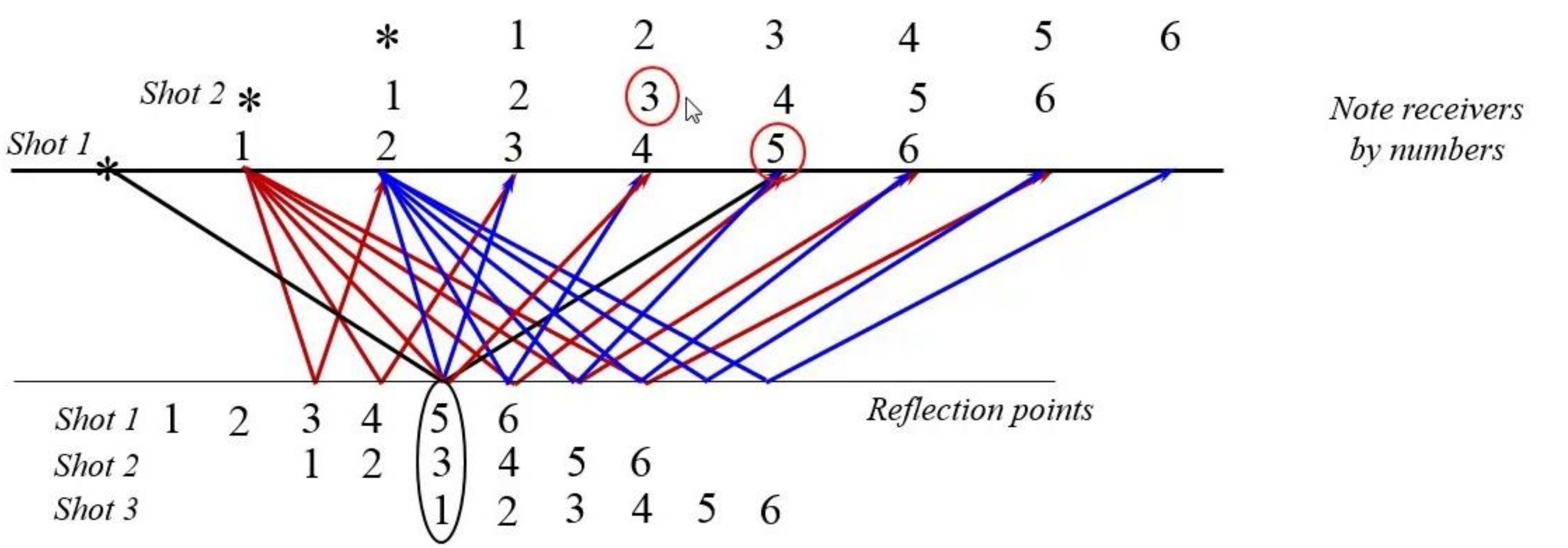
Reflection Seismics - Application

Spread Geometry and Shot Gathers



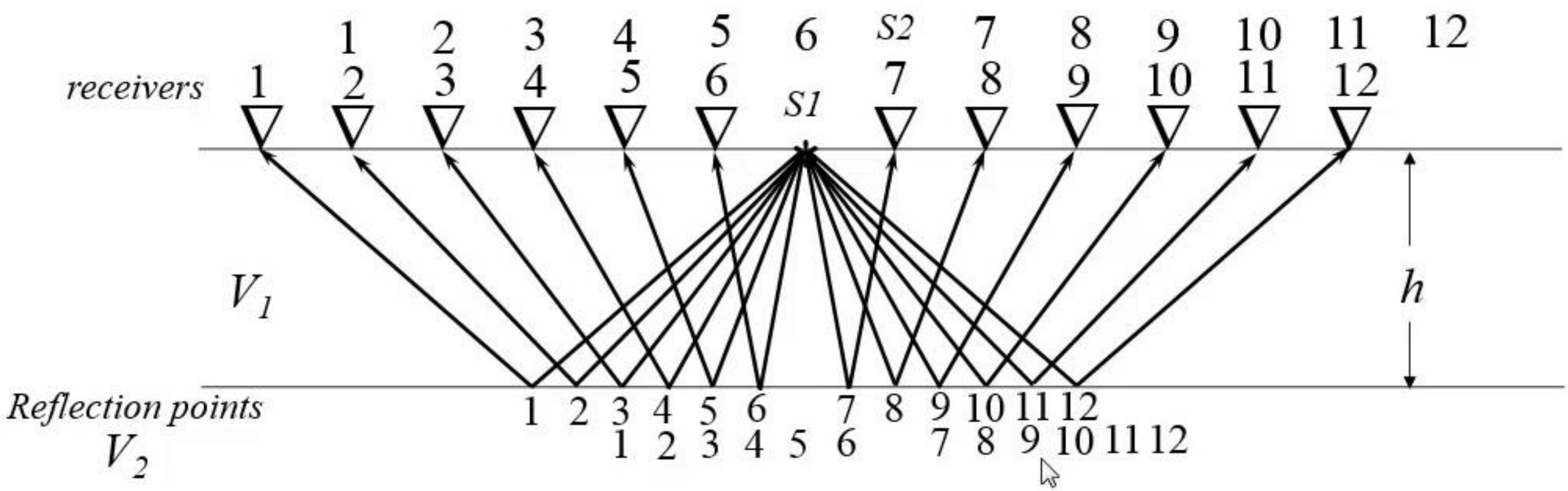
Reflection Seismics - Application

End-shot traversing



Reflection Seismics - Application

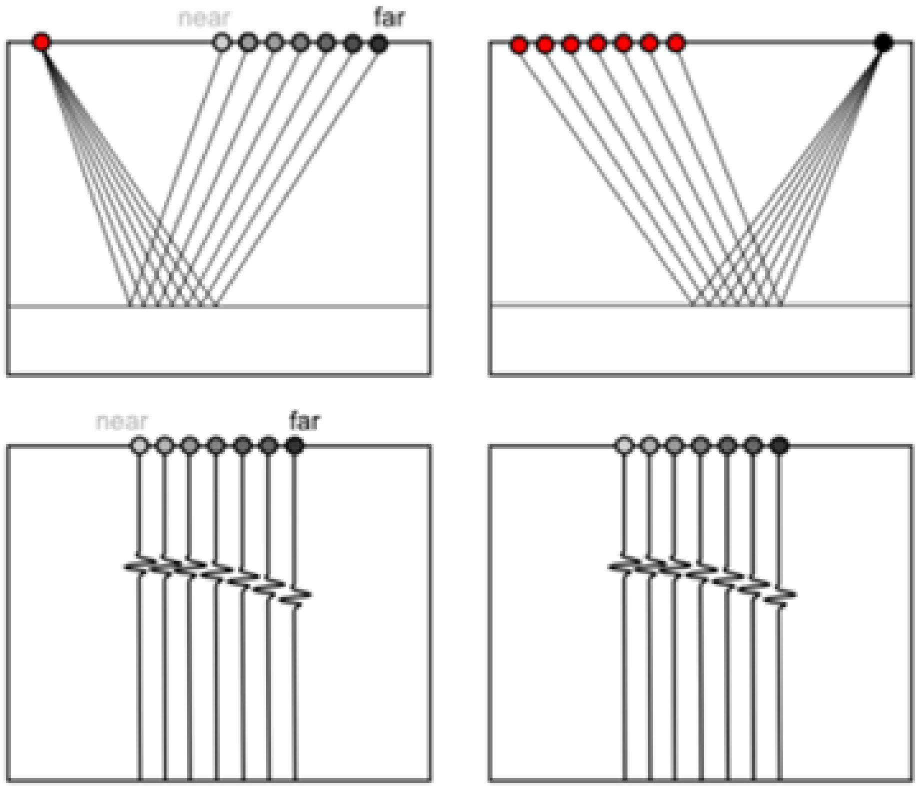
Split spread and midpoint source receiver combinations



Reflection Seismics - Application

Common shot or receiver gather

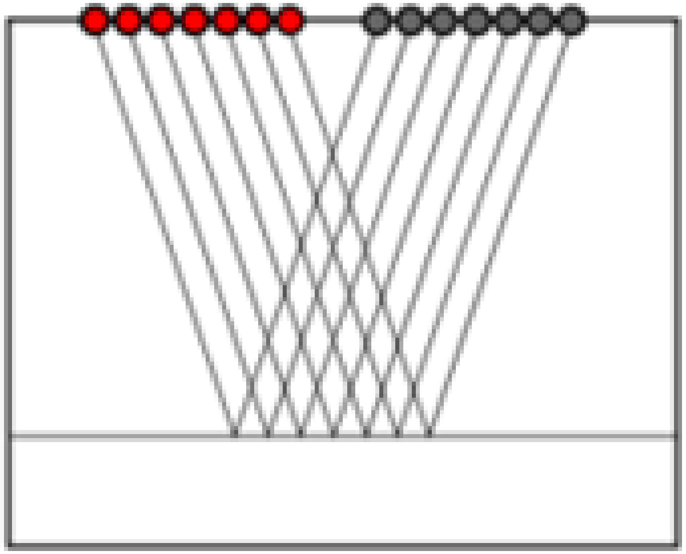
- easy to inspect traces in these displays for bad receivers or bad shots
- Typical for basic quality assessment in field acquisition (e.g. marine seismics)

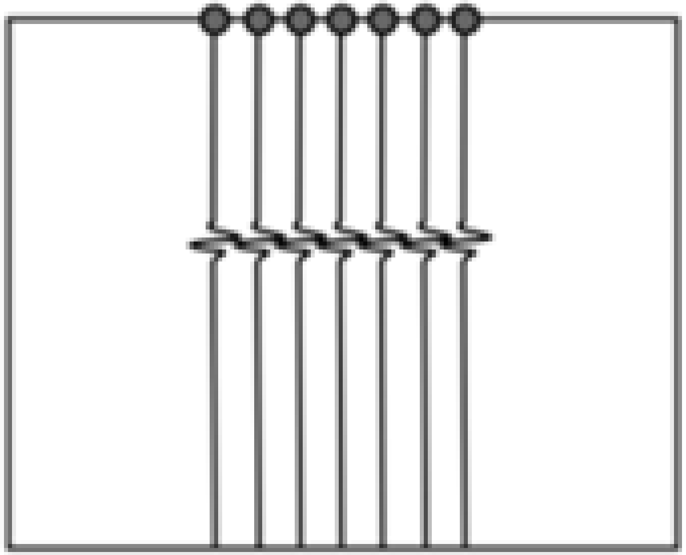


Reflection Seismics - Application

Common offset gather, COFF

- Represents approximates a structural section
- Water table mapping
- No NMO required
- Used in amplitude variation analysis
- Near offset trace → brute stack



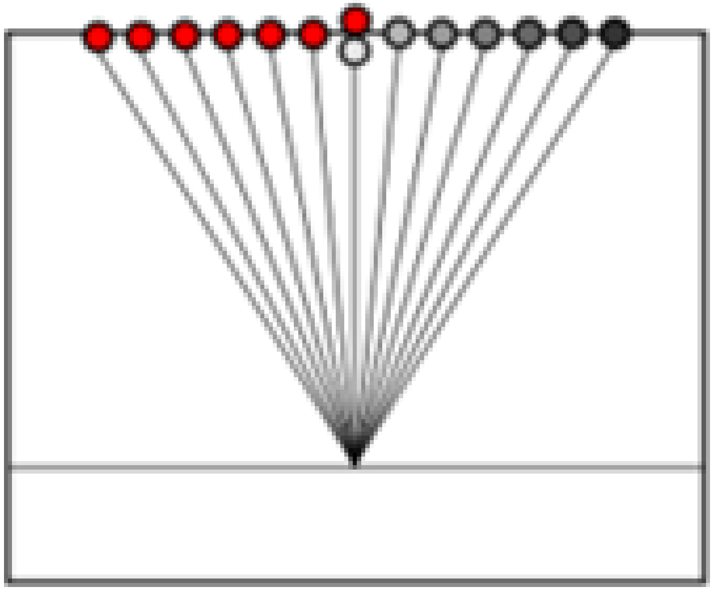


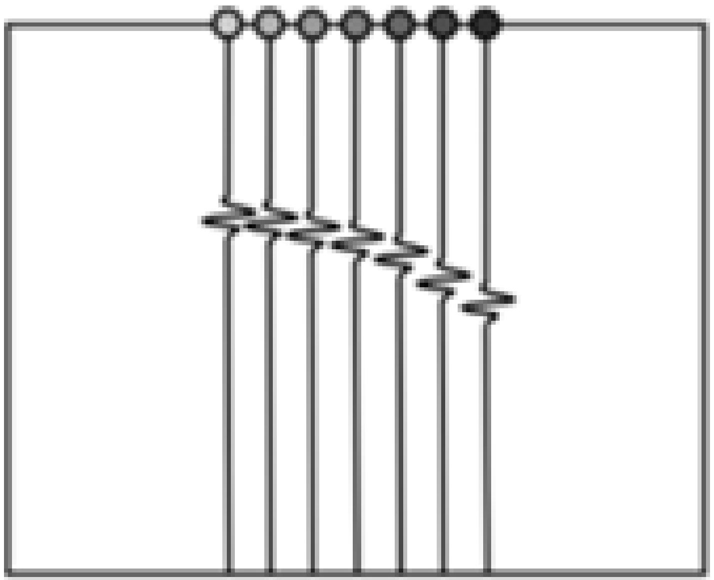
Reflection Seismics - Application

Common midpoint gather, CMP

- For horizontal reflectors, the reflection point is halfway between shot and receiver (at the “midpoint”)
- The basic objective is to sample each subsurface point more than once
- The number of traces in a CMP gather is known as the “fold” of the surv
- The essence of CMP processing is:

1. Resorting into CMP gathers
2. Correction for moveout
3. Summation, or “stacking”





Reflection Seismics - Application

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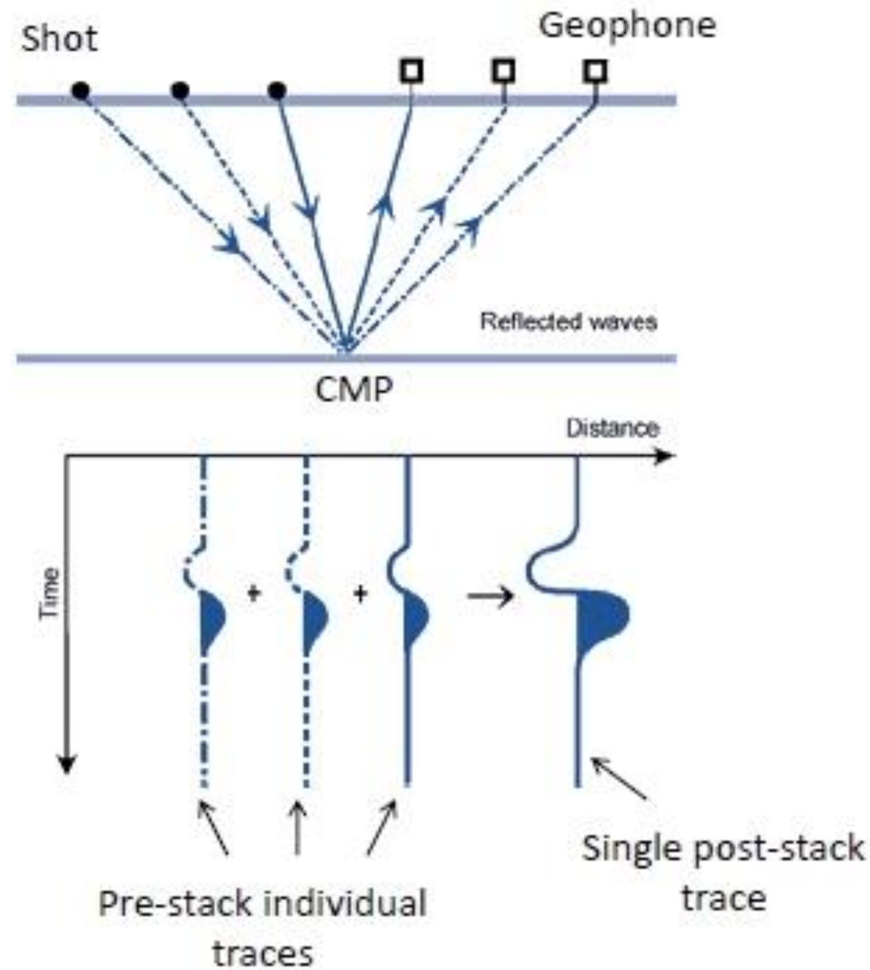
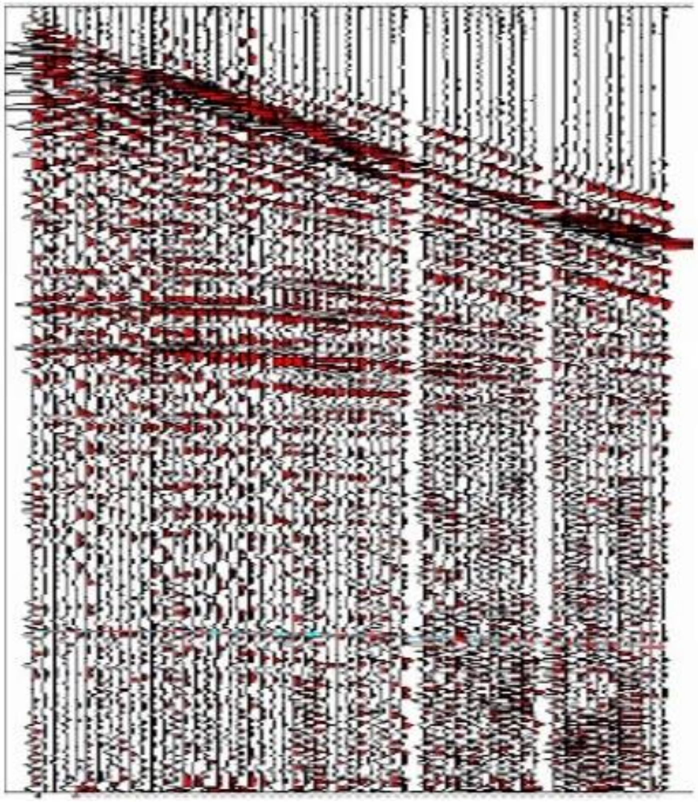
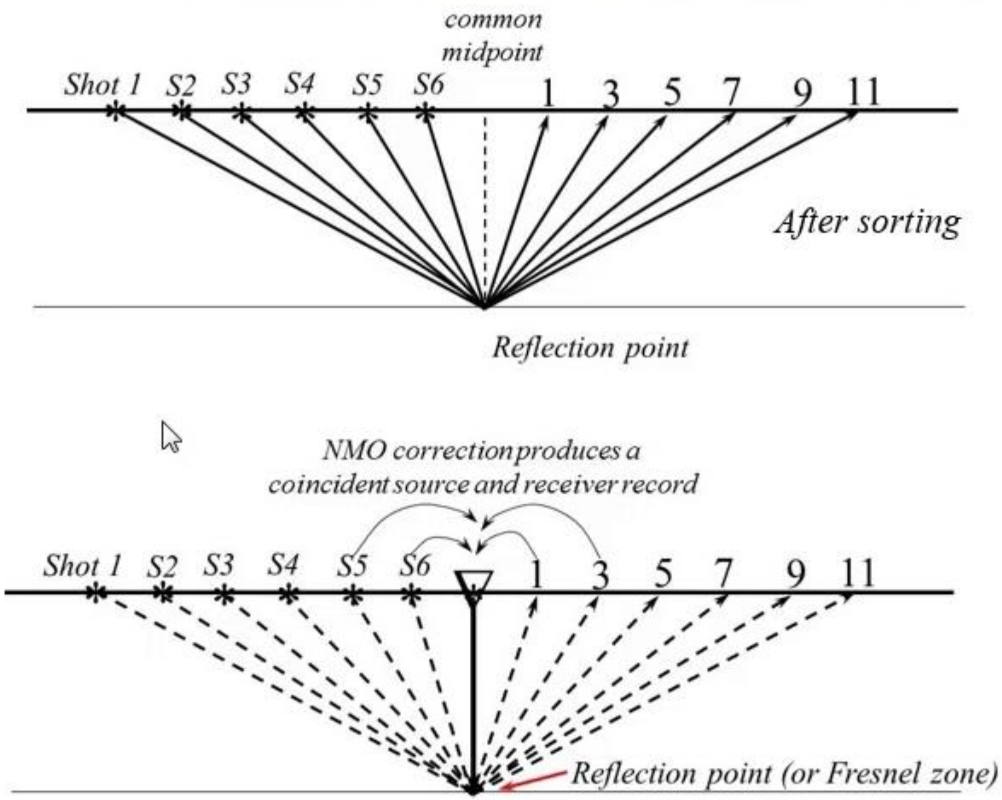


Reflection Seismics - Application

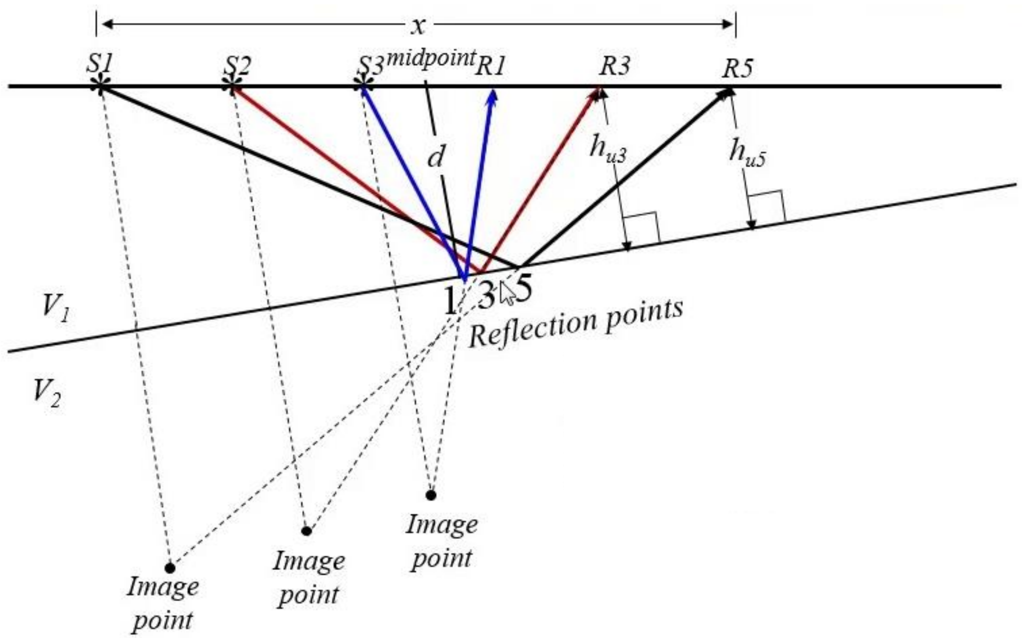
Common midpoint gather, CMP





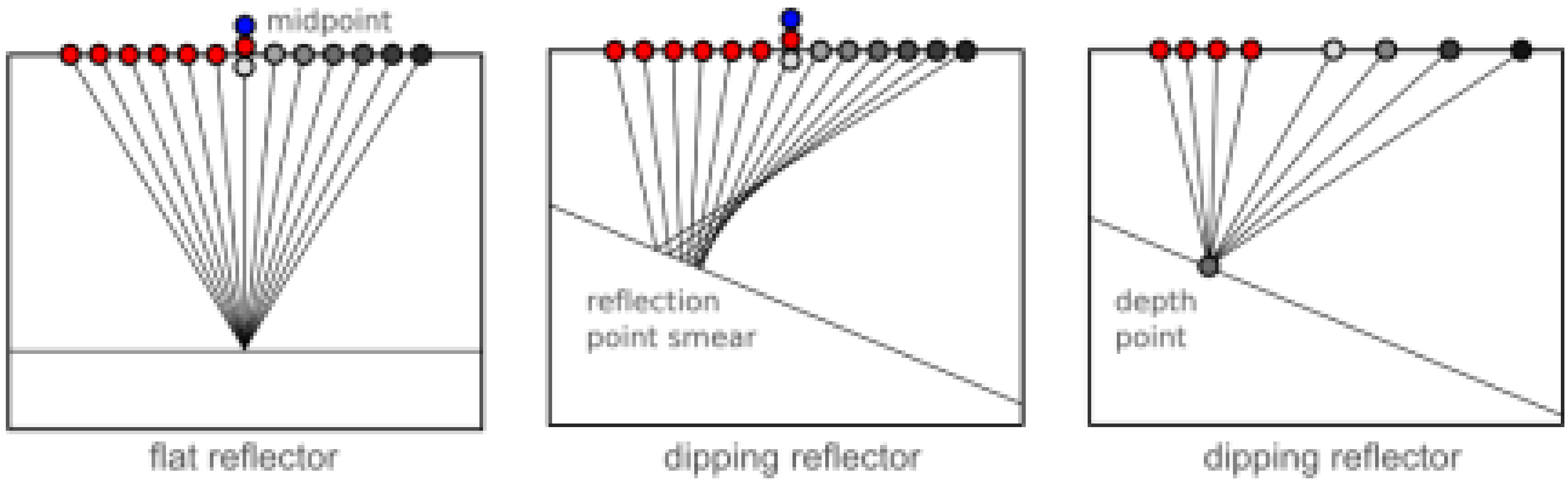
Reflection Seismics - Application

Common midpoint gather, CMP



Reflection Seismics - Application

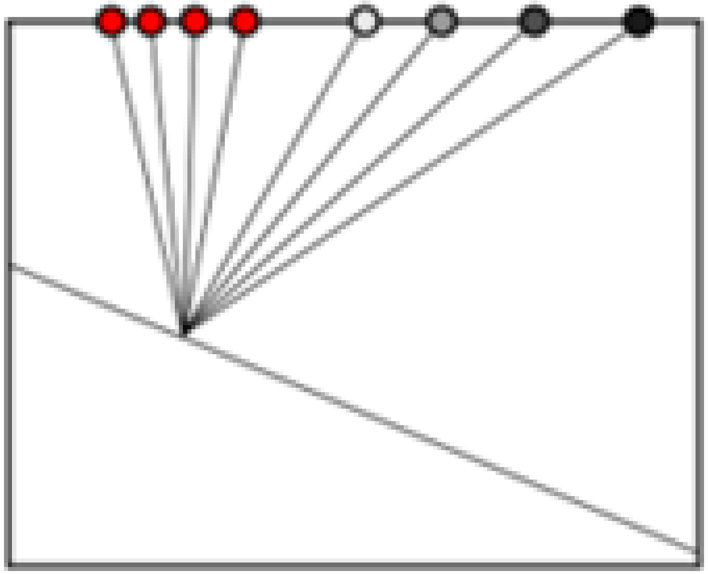
Common midpoint gather, CMP – gone wrong

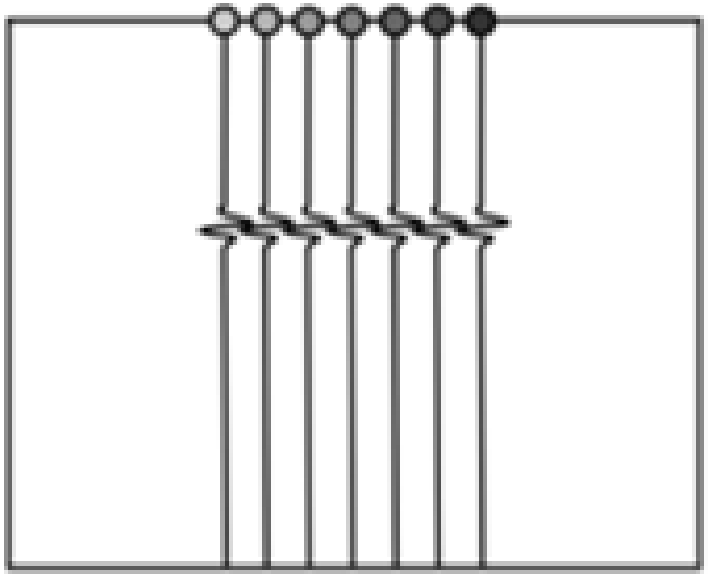


Reflection Seismics - Application

Common depth point gather, CDP

- With known velocities possible computation of the common depth point.
- Also used in amplitude variation analysis





Reflection Seismics - Application

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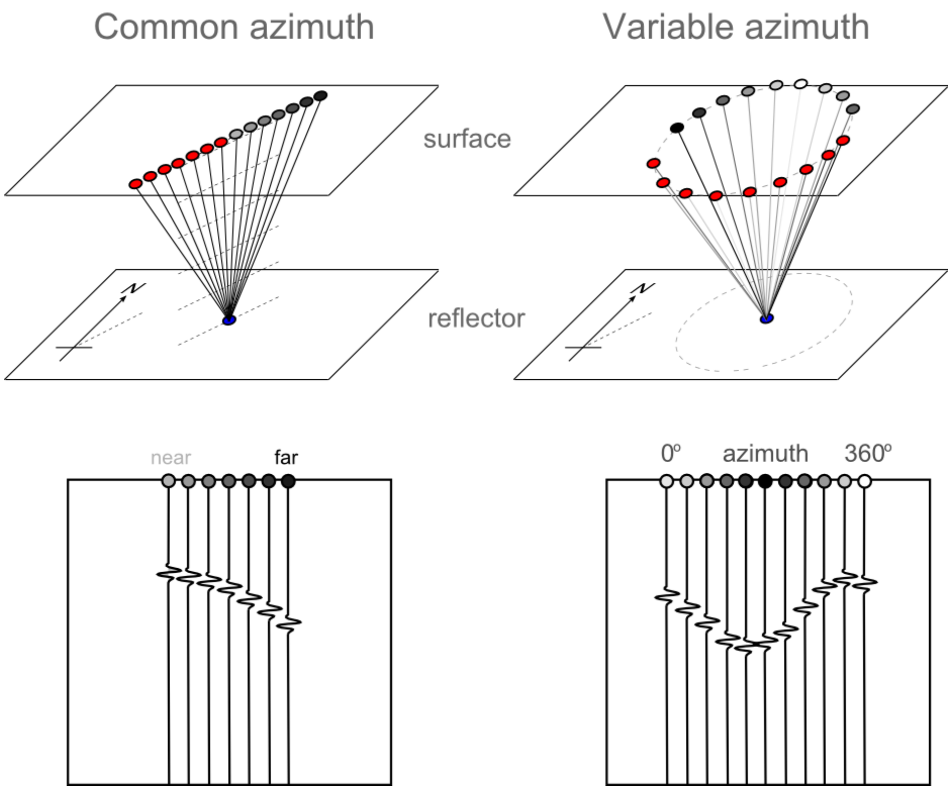
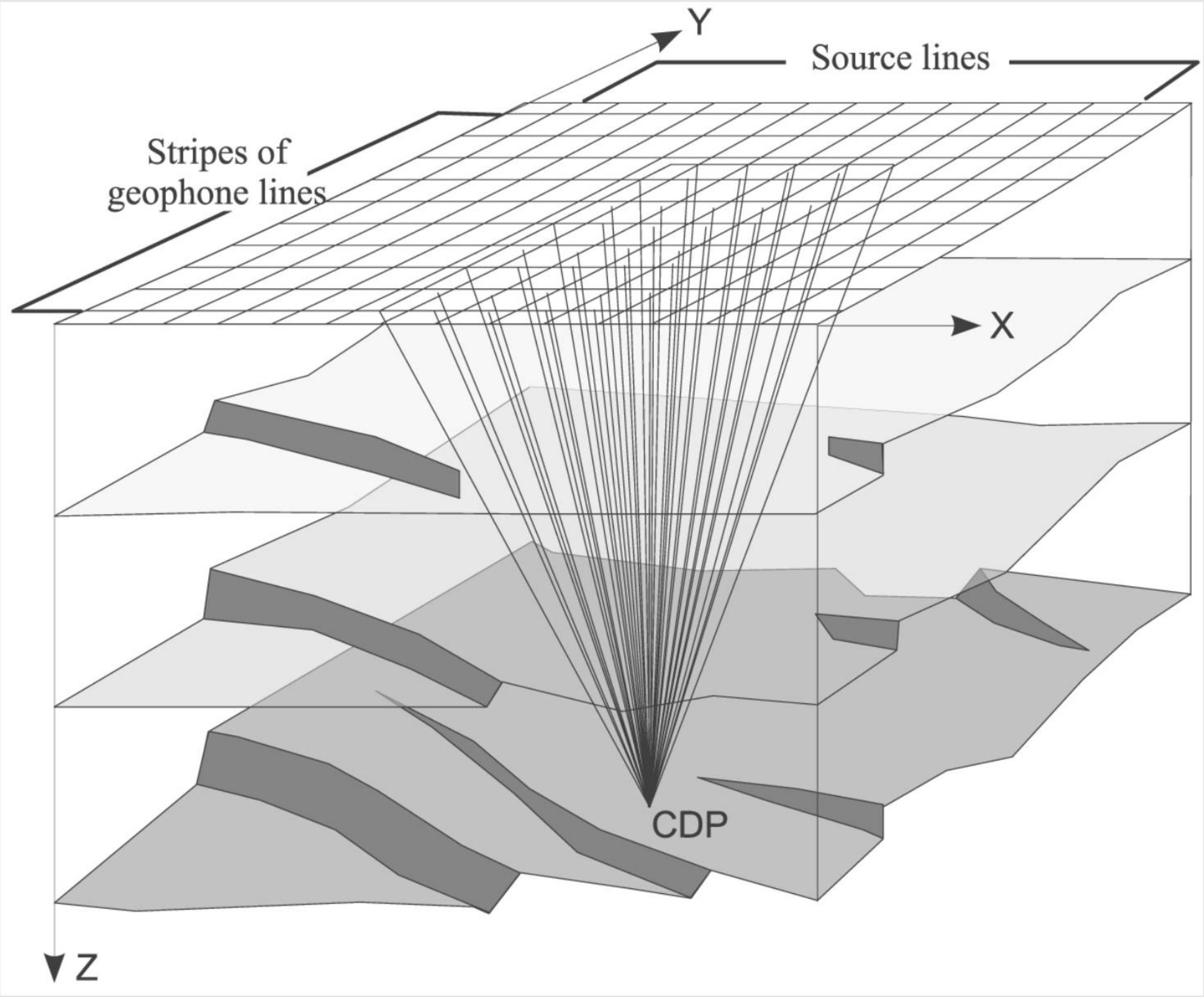
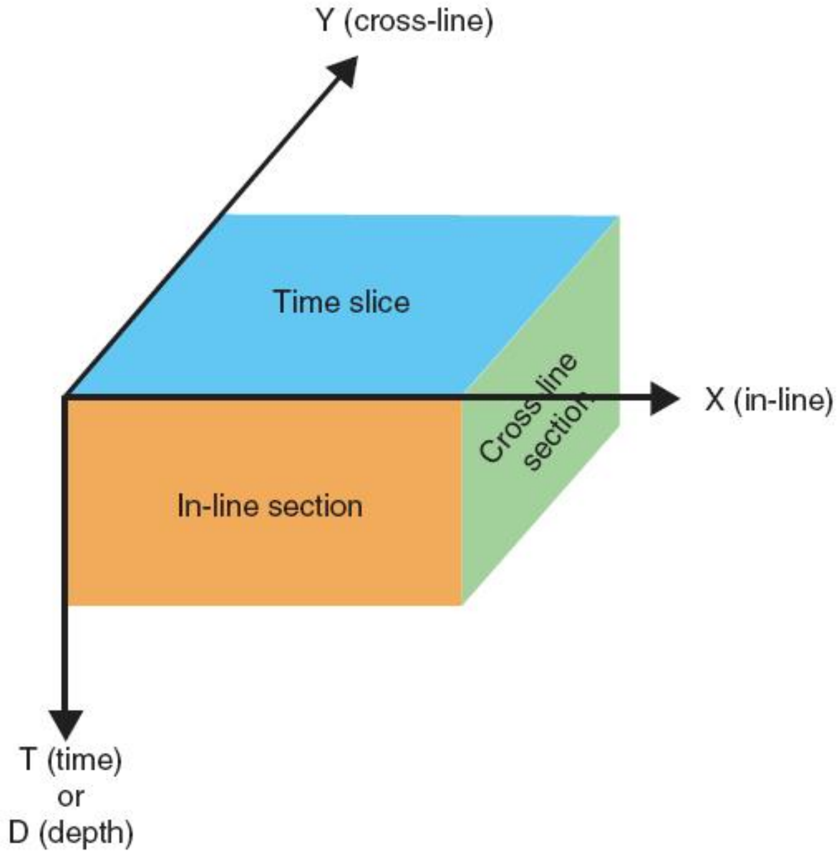


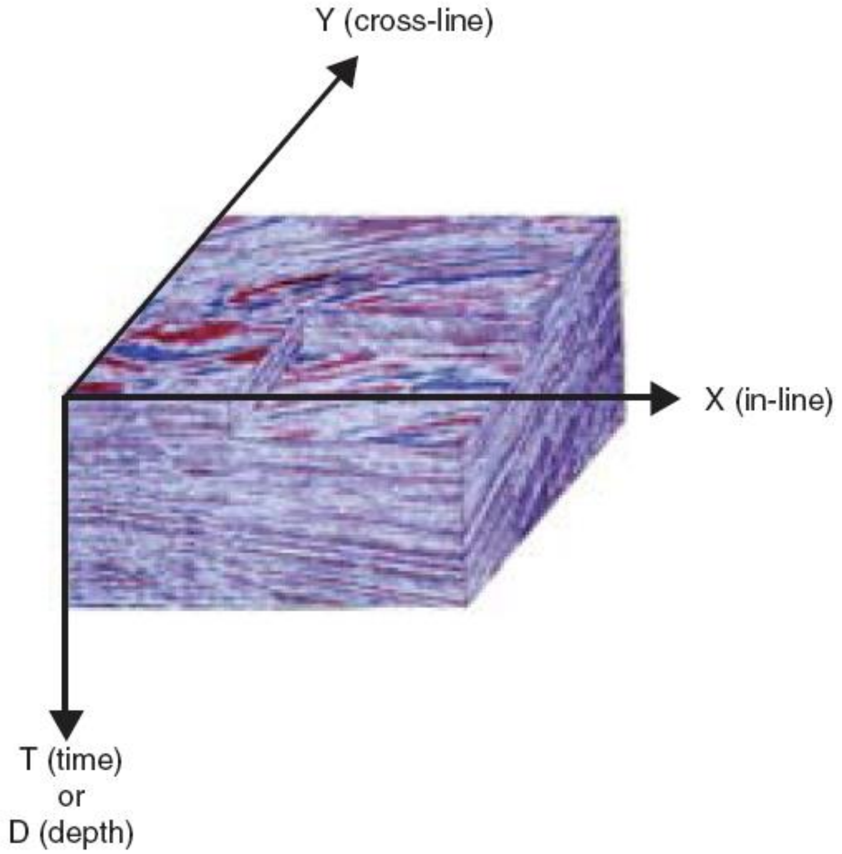
Reflection Seismics - Application

Common depth point gather, CDP



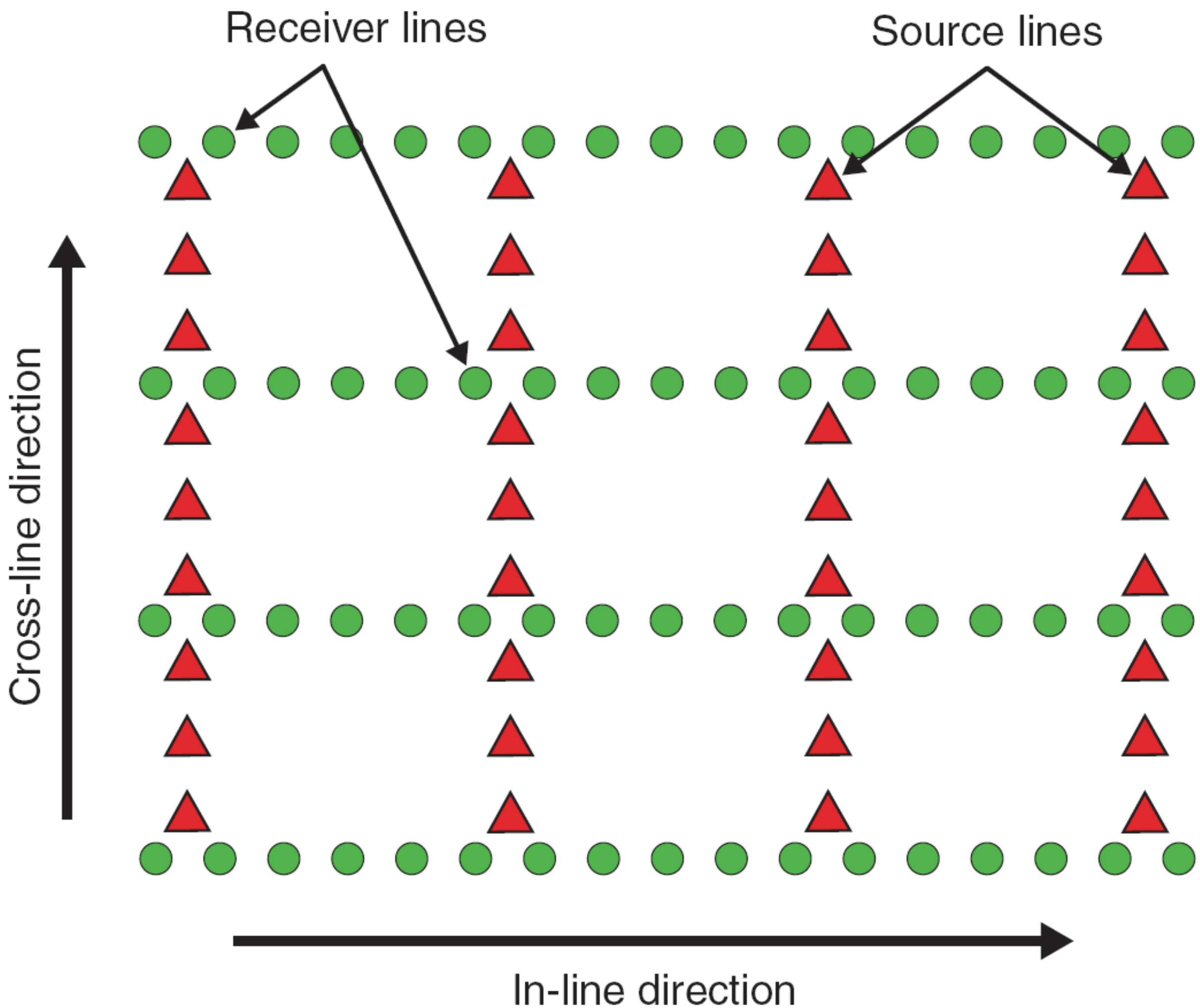
Reflection Seismics - Application





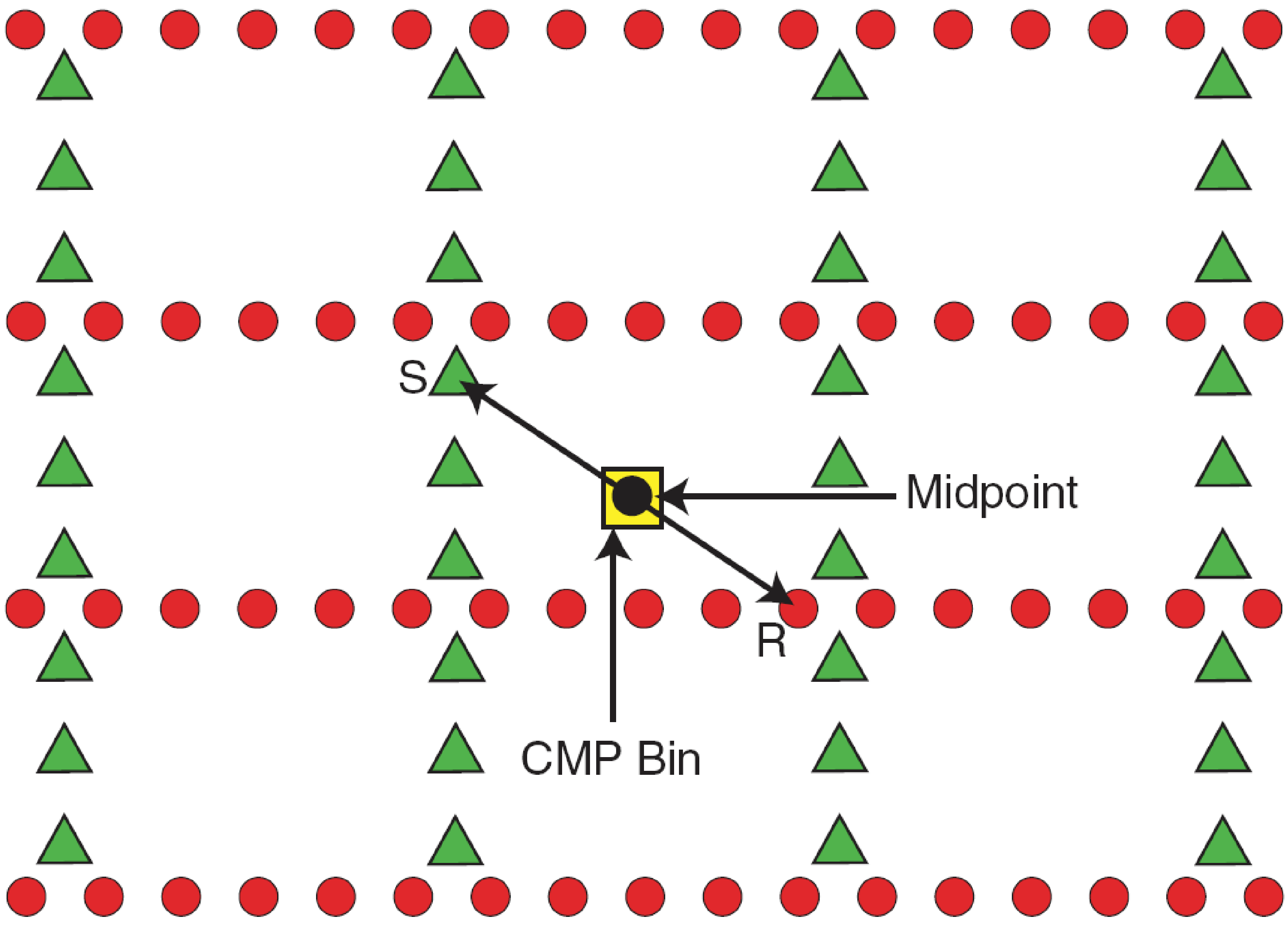
Reflection Seismics - Application

3D fold coverage



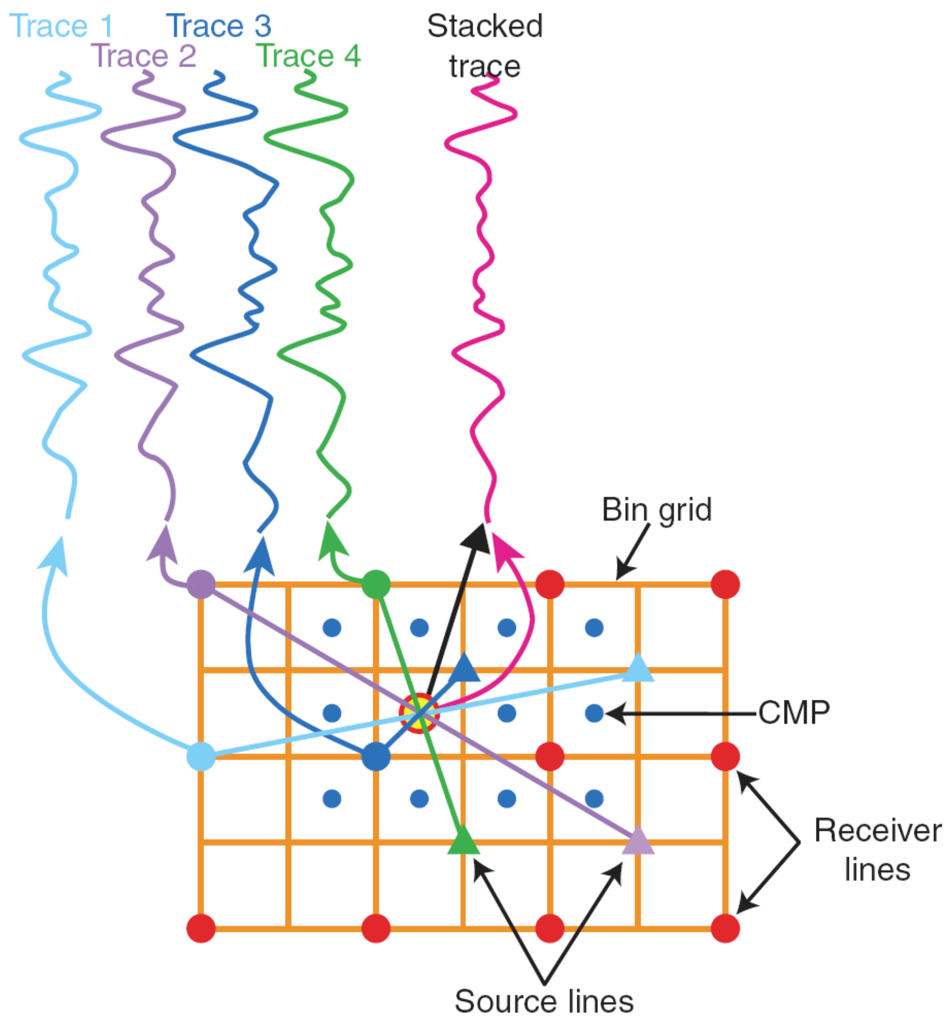
Reflection Seismics - Application

3D fold coverage



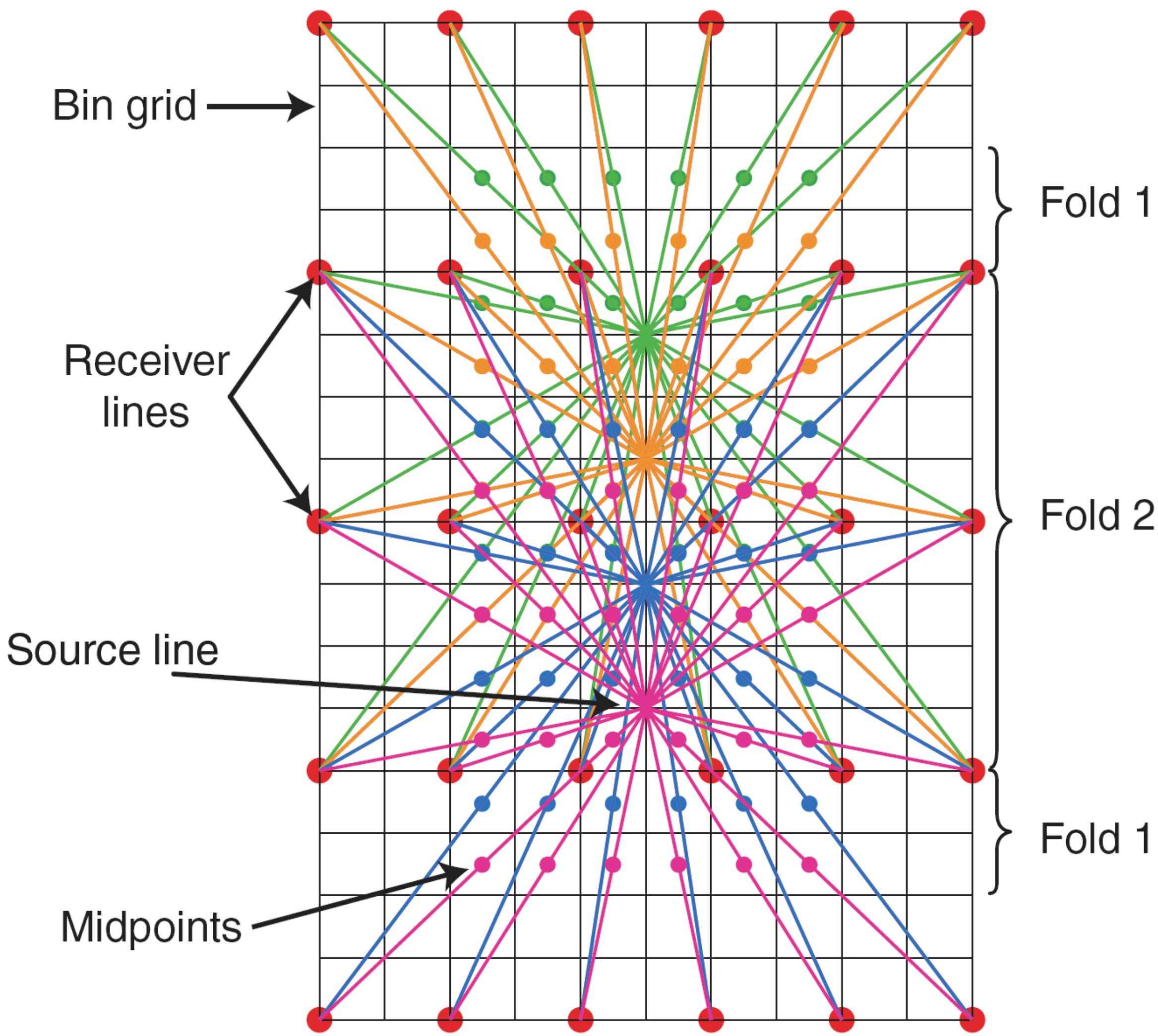
Reflection Seismics - Application

3D fold coverage



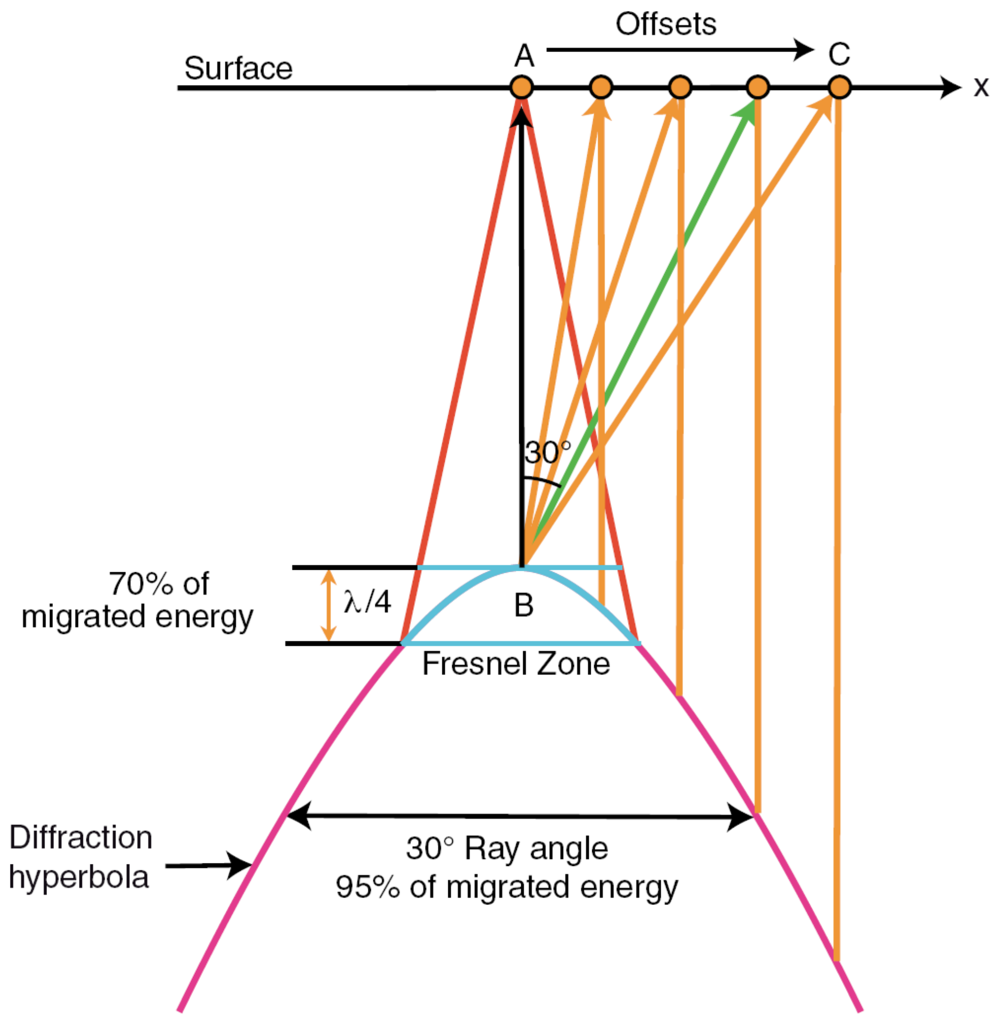
Reflection Seismics - Application

3D fold coverage

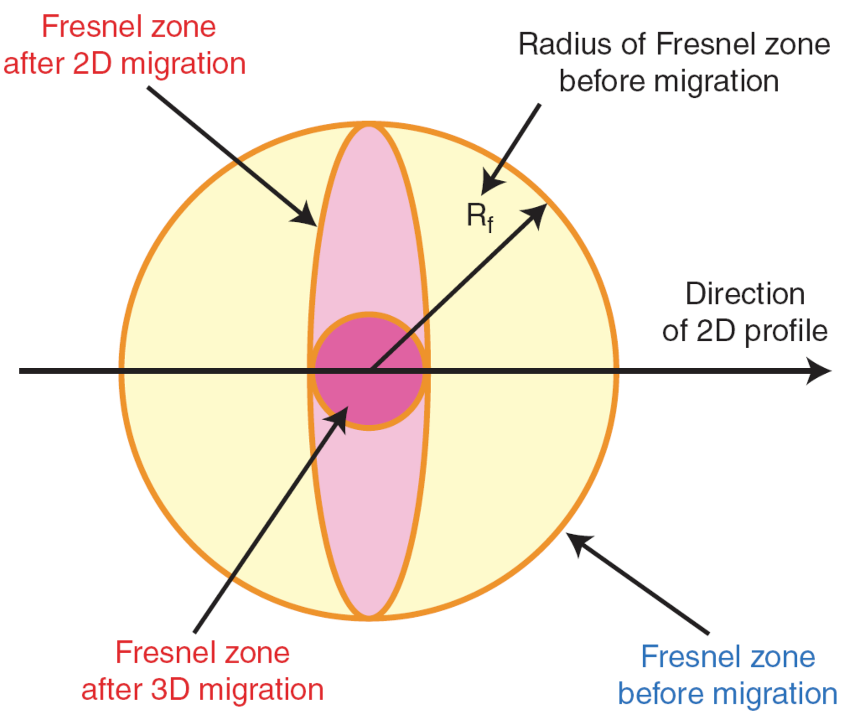


Reflection Seismics - Application

Fresnel zone



Fresnel zone



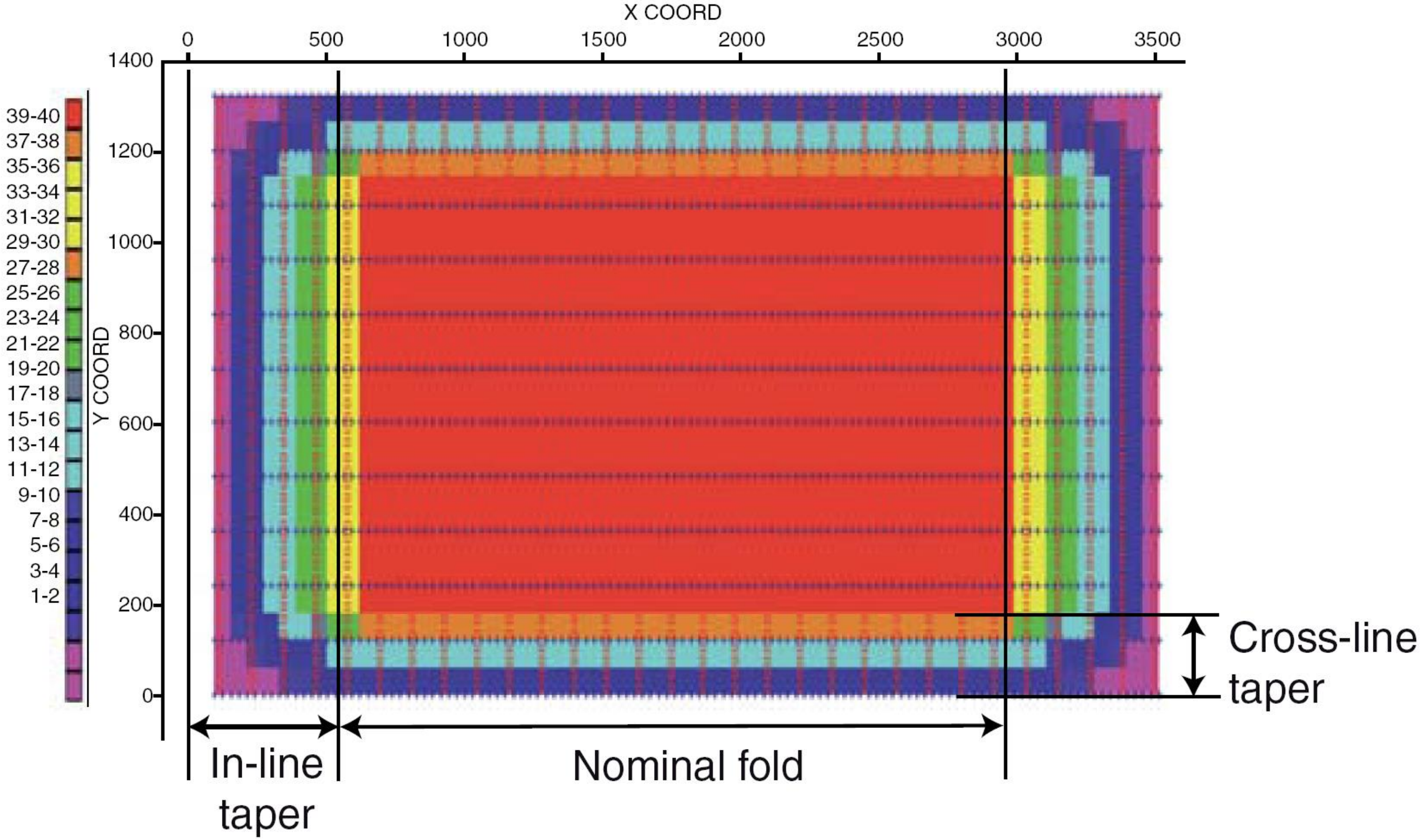
$R_f=(V/2)(t_0/f_{dom})^{1/2}$ (Radius of Fresnel Zone R, before migration)

$R_f=\lambda/2=V/2f_{dom}$ (Radius of Fresnel Zone R, after migration)

	s	m/s	Hz	m	m
Depth ↓	Two way travel time (t0)	Rms Velocity increases with depth	Frequency decreases with depth	Radius of Fresnel Zone R, before migration	Radius of Fresnel Zone R, after migration
	1.0	2000	55	134	18
	1.5	2500	50	216	25
	2.0	3000	40	335	38
	2.5	3500	35	468	50
	3.0	4000	30	632	67
	3.5	4500	25	842	90
	4.0	5000	20	1118	125

Reflection Seismics - Application

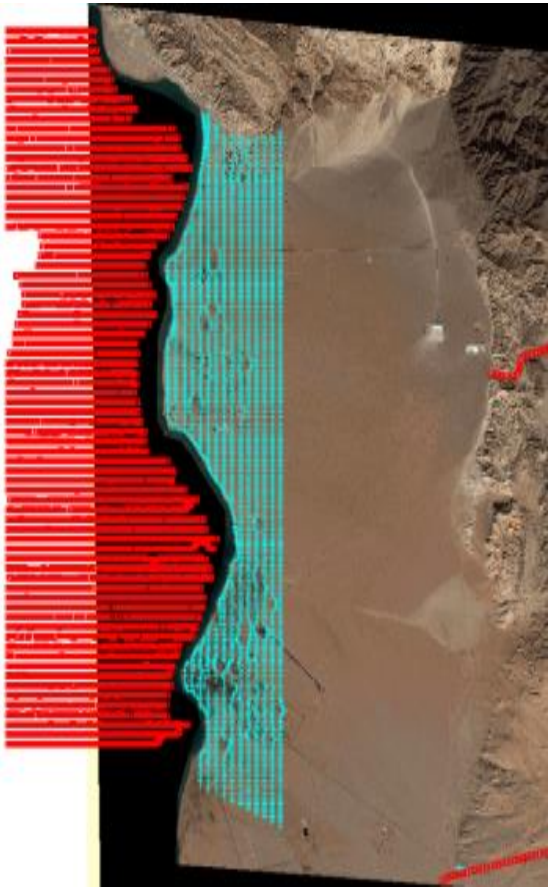
3D fold coverage



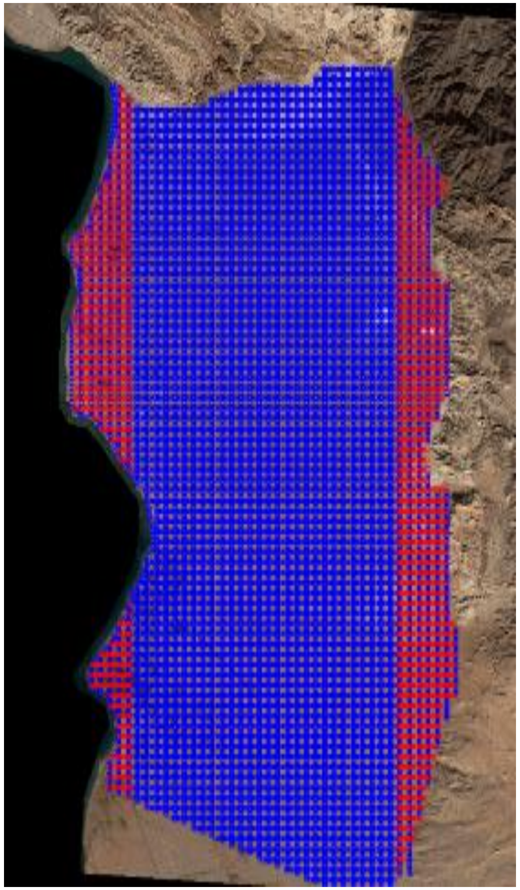
Reflection Seismics - Application

3D fold coverage

Field Area



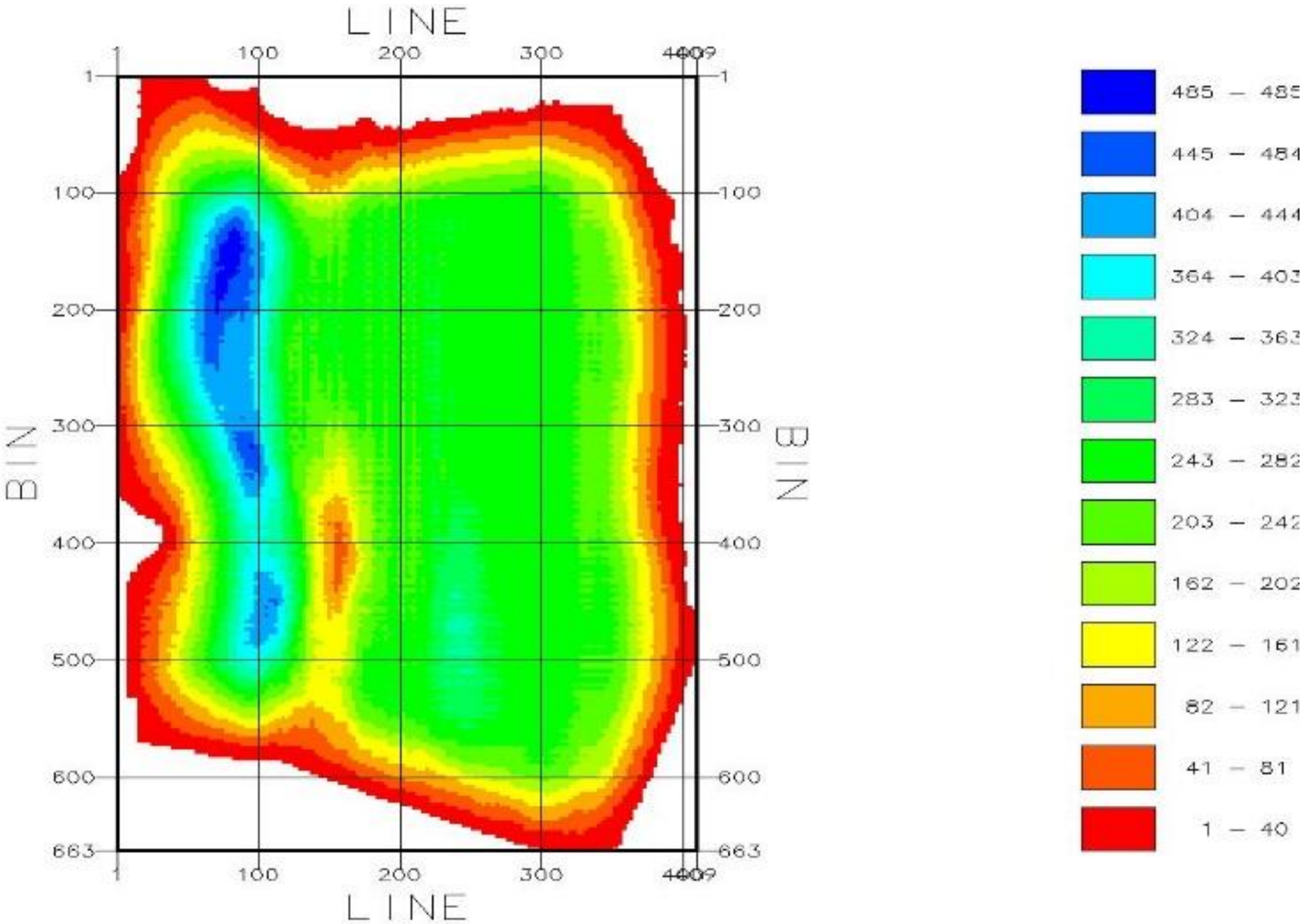
OffShore survey



OnShore survey

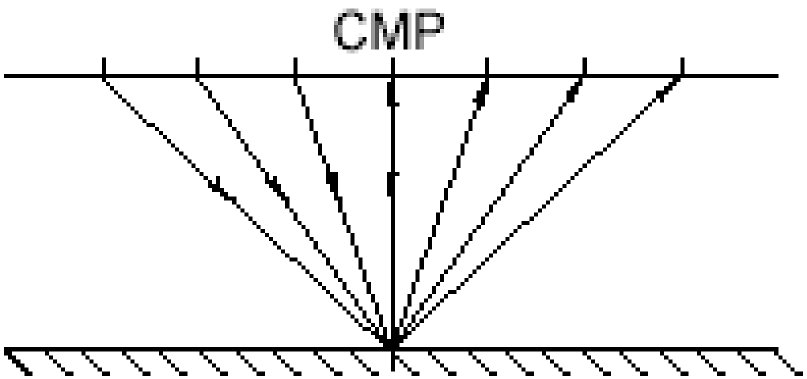
Reflection Seismics - Application

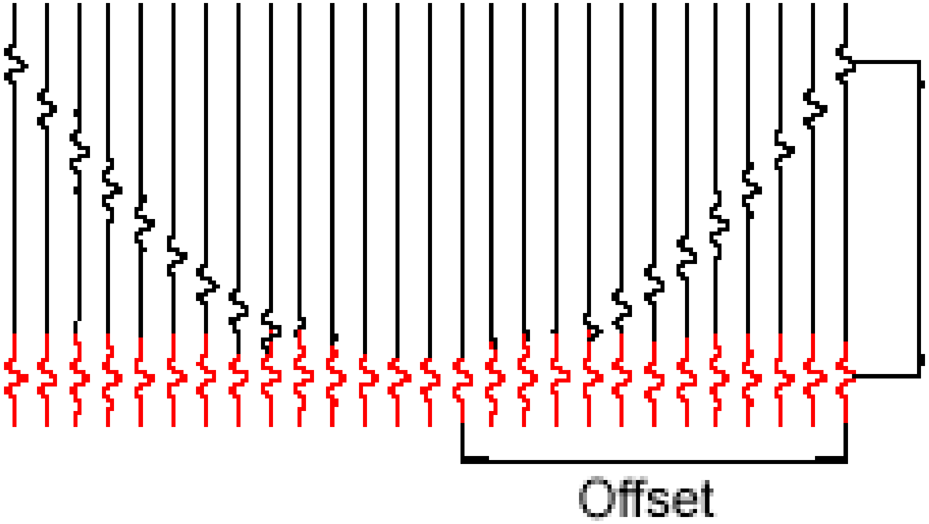
3D fold coverage



Reflection Seismics - Application

Common-Midpoint(CMP) and Normal Move Out





Reflection Seismics - Application

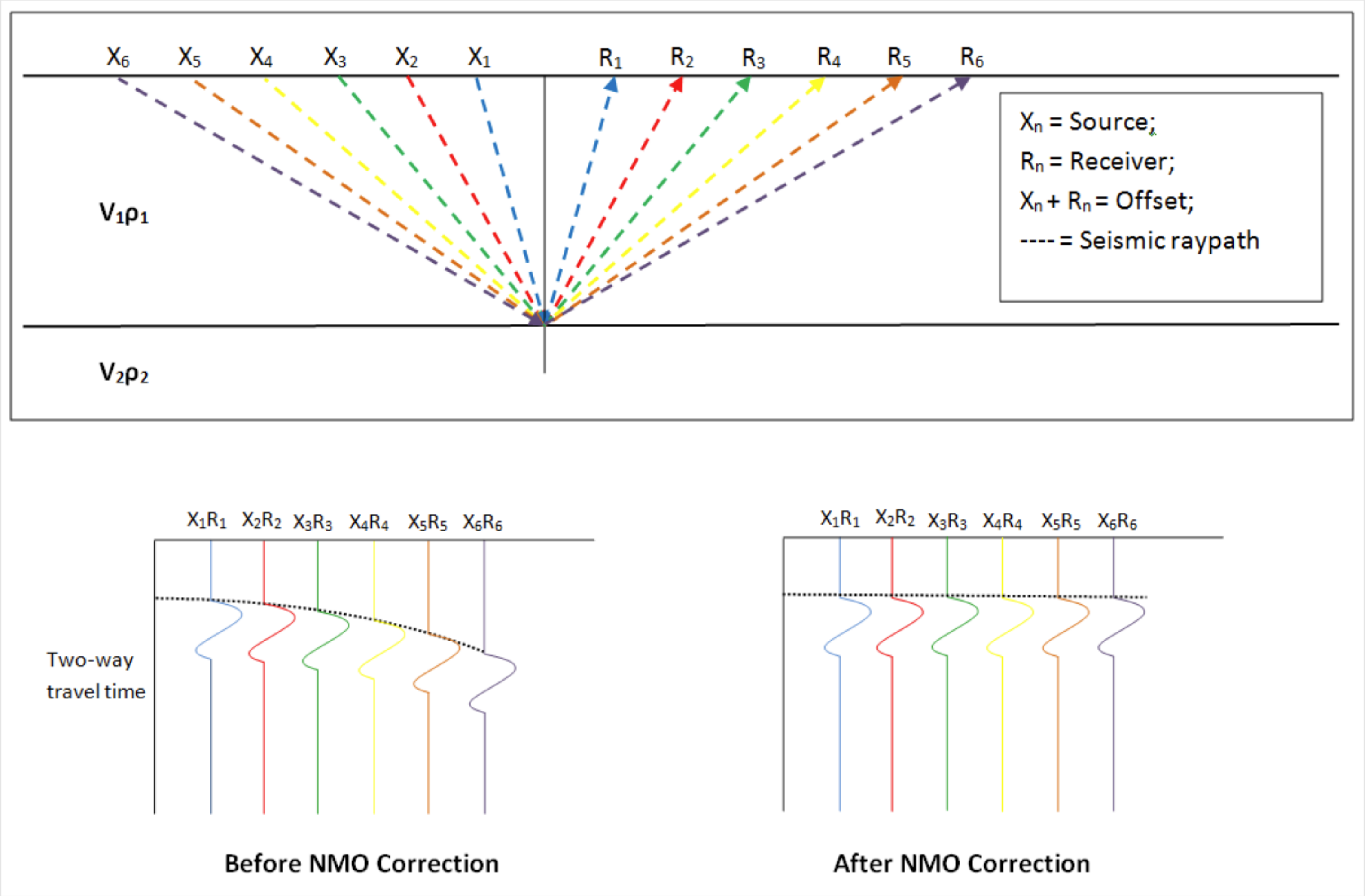
Normal Moveout Correction

The increase of the travel time with the offset of called Normal Moveout (NMO).

The correction to zero offset is called NMO correction or Common Midpoint (CMP) method. It is applied before stacking the seismic signals radiated by several sources or recorded by several geophones in order to improve the quality of the signal.

Reflection Seismics - Application

Normal Moveout Correction

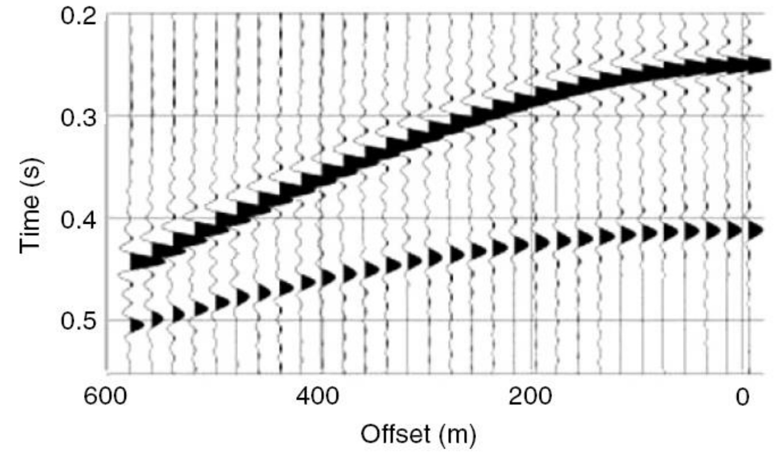


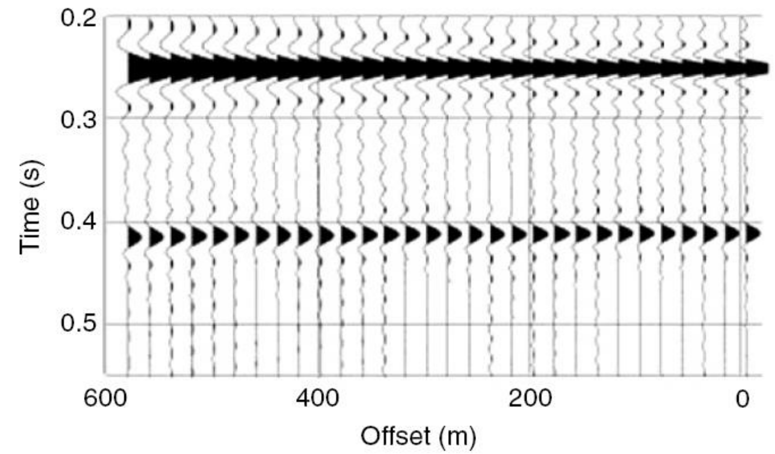
Source: Wikipedia

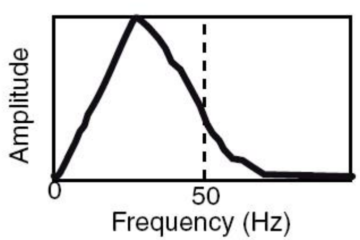
Reflection Seismics - Application

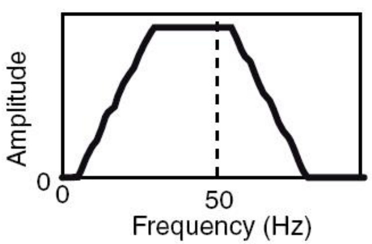
Normal Move Out Correction

- Increase signal-to-noise
- If traces are summed together, the stack trace is referred to as its fold
- For common shot or receiver gathers, frequencies of long offsets will be “smeared”









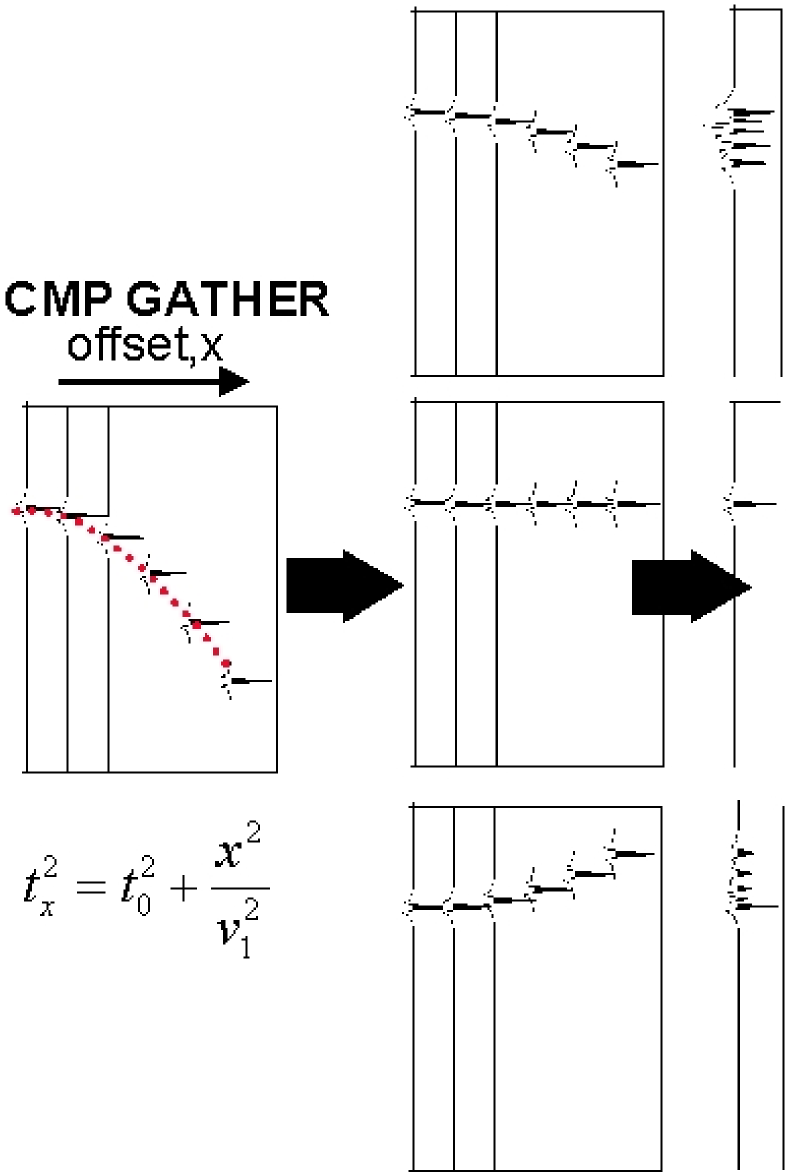
Reflection Seismics - Application

NMO pit falls

1. Undercorrected poor stack response
   NMO V = 2 km/s

2. Good stack response
   NMO V = 1.7 km/s

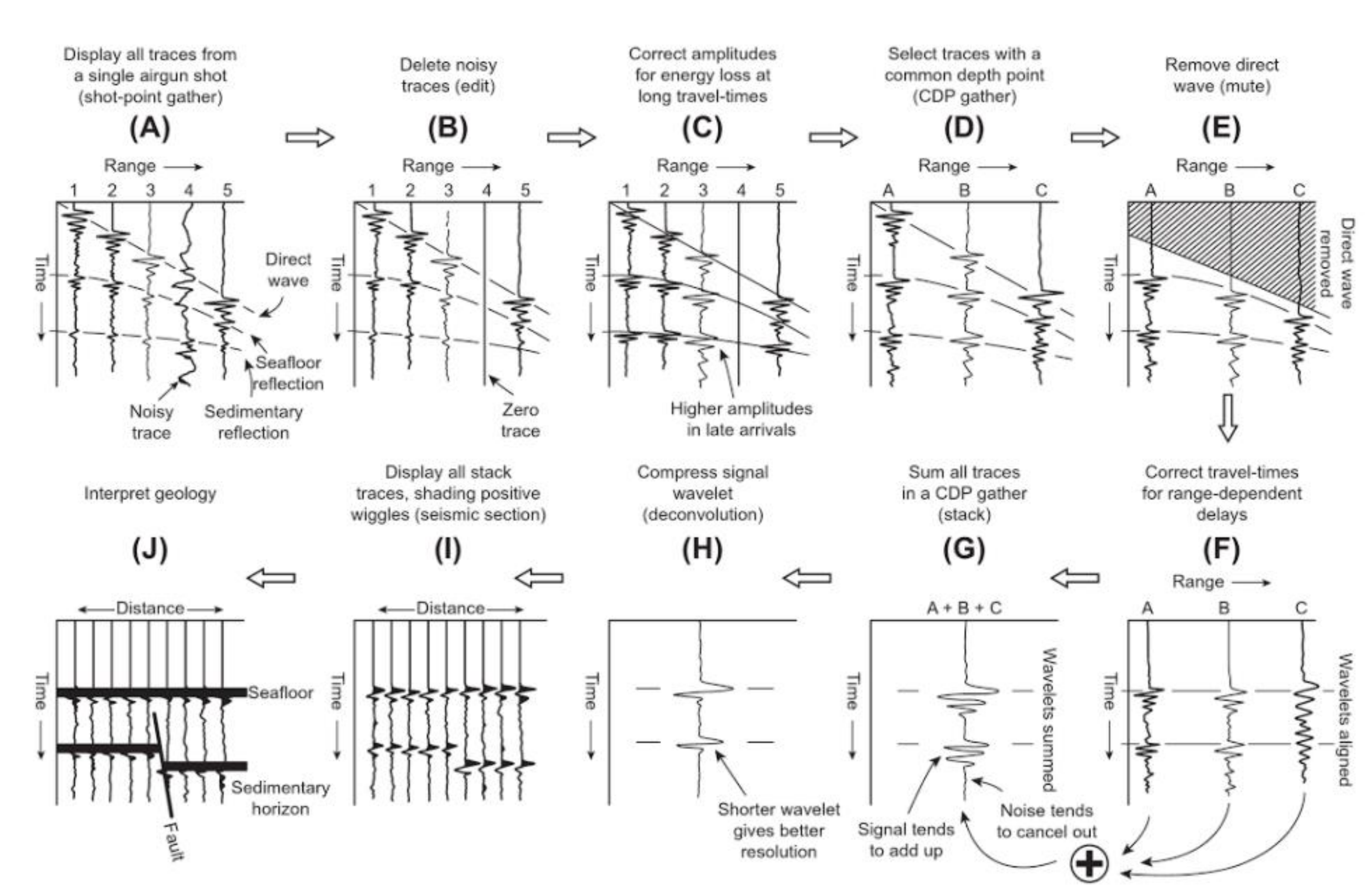
3. Overcorrected poor stack response
   NMO V = 1.5 km/s



$$t_x^2 = t_0^2 + \frac{x^2}{v_1^2}$$

Reflection Seismics - Application

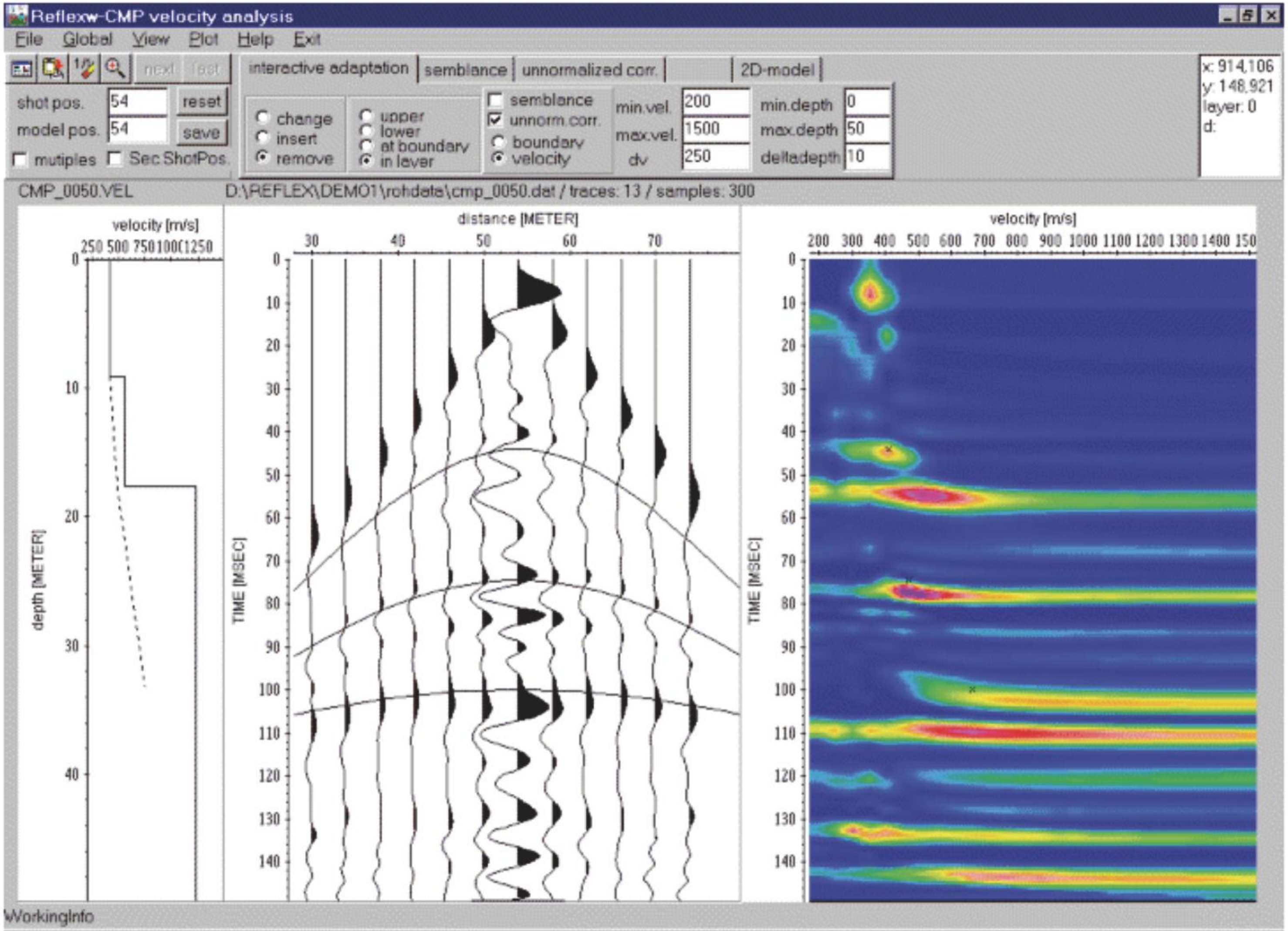
Editing sequences



(source: Selley and Sonnenberg,1985)

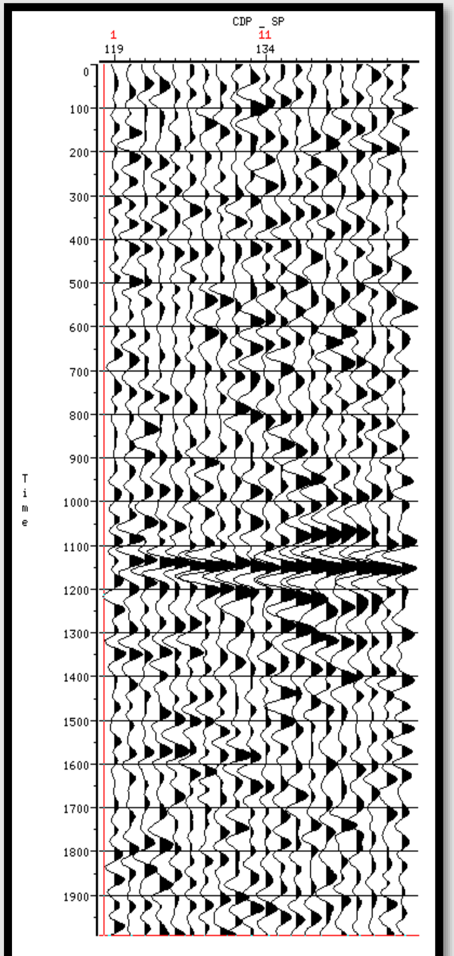
Reflection Seismics - Application

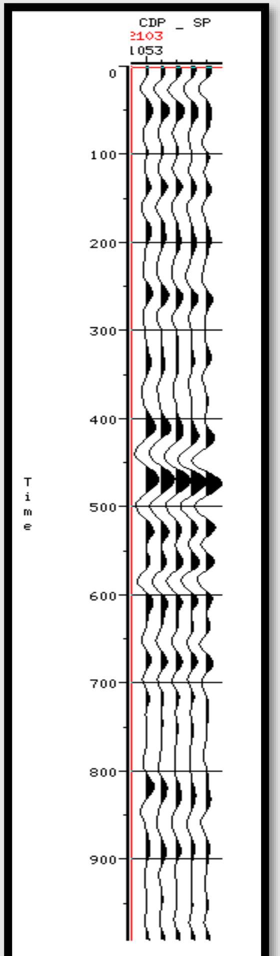
Synthetic Seismogram and Depth Inversion



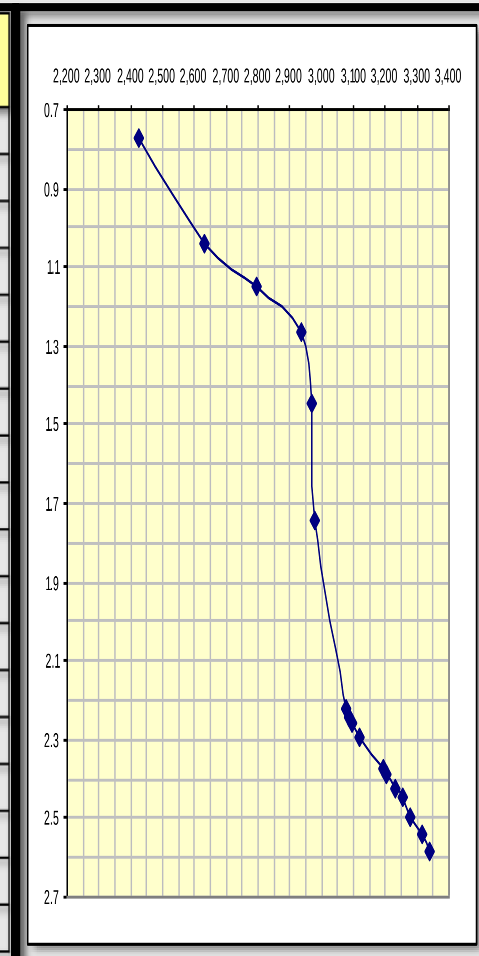
Reflection Seismics - Application

Depth migration



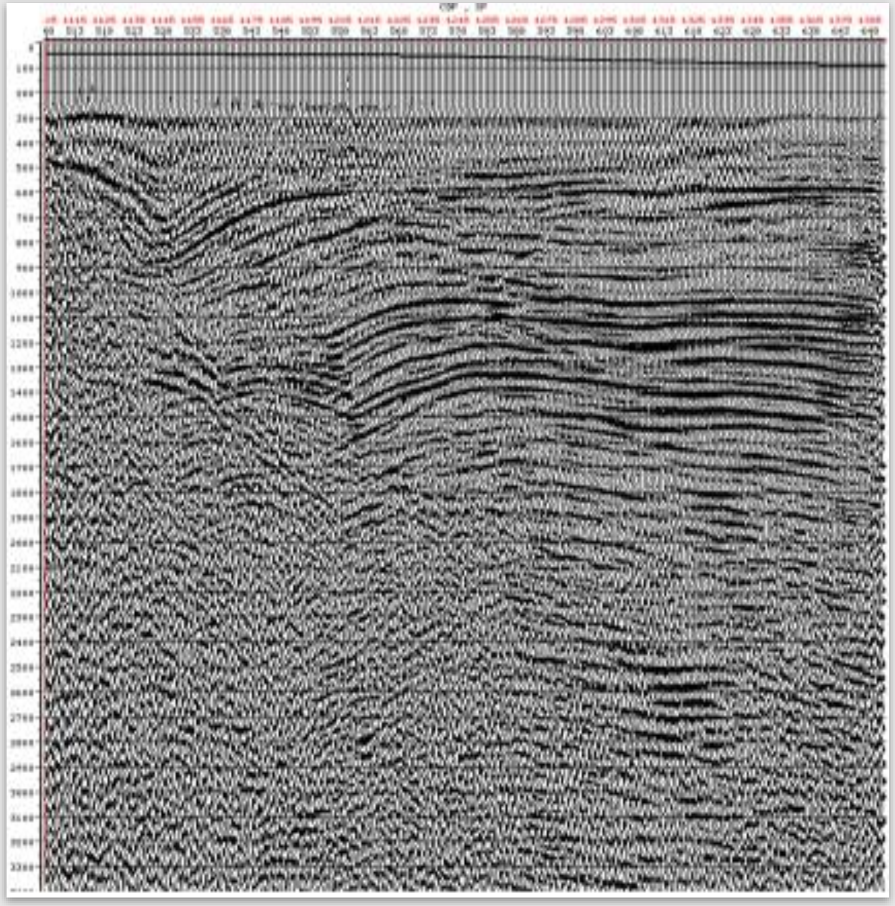


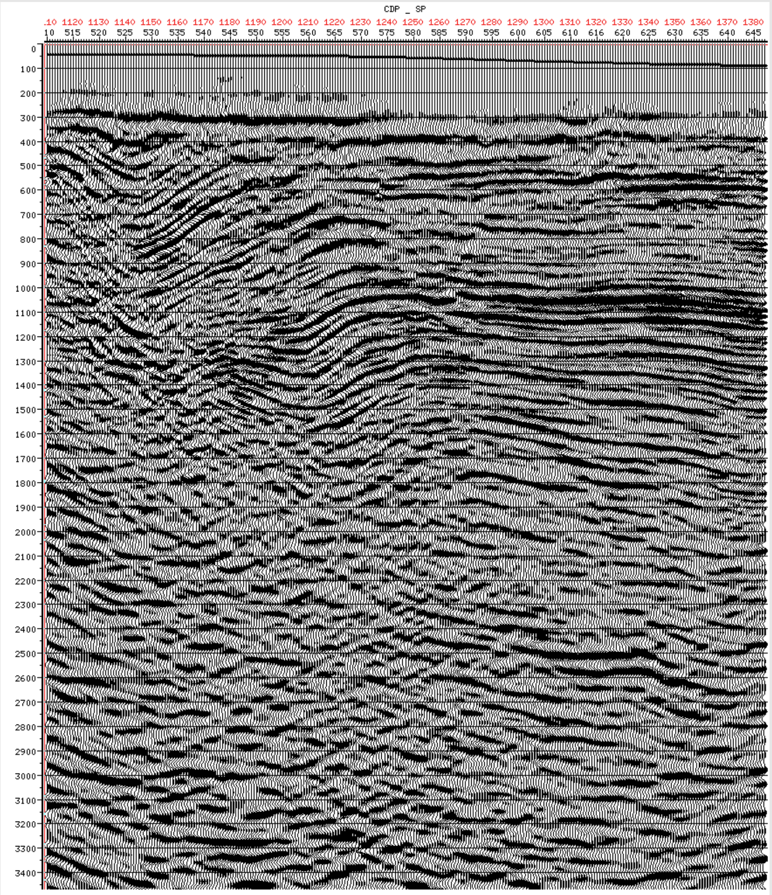
FORMATION	Depth (m) BMSL	TWT (ms) BMSL	Average Velocity (m/s)
ZEIT	935	771	2,427
SOUTH_GHARIB	1,374	1,044	2,632
BELAYIM	1,610	1,151	2,797
KAREEM	1,861	1,268	2,936
UPPER RUDEIS	2,150	1,449	2,968
LOWER RUDEIS	2,601	1,747	2,978
NUKHUL	3,420	2,224	3,076
EOCENE	3,464	2,244	3,087
INTRUSION	3,491	2,256	3,095
THEBES (EOCENE)	3,573	2,291	3,119
ESNA (PALEOCENE)	3,794	2,375	3,195
SUDR (U.SENONIAN)	3,830	2,391	3,204
LACOSTINA (BRWN LSTONE)	3,915	2,422	3,233
MATULLA (L. SENONIAN)	3,983	2,448	3,254
WATA (TURONIAN)	4,088	2,495	3,277
RAHA (CENOMANIAN)	4,210	2,539	3,316
NUBIA	4,310	2,583	3,337
TD	4,381		



Reflection Seismics - Application

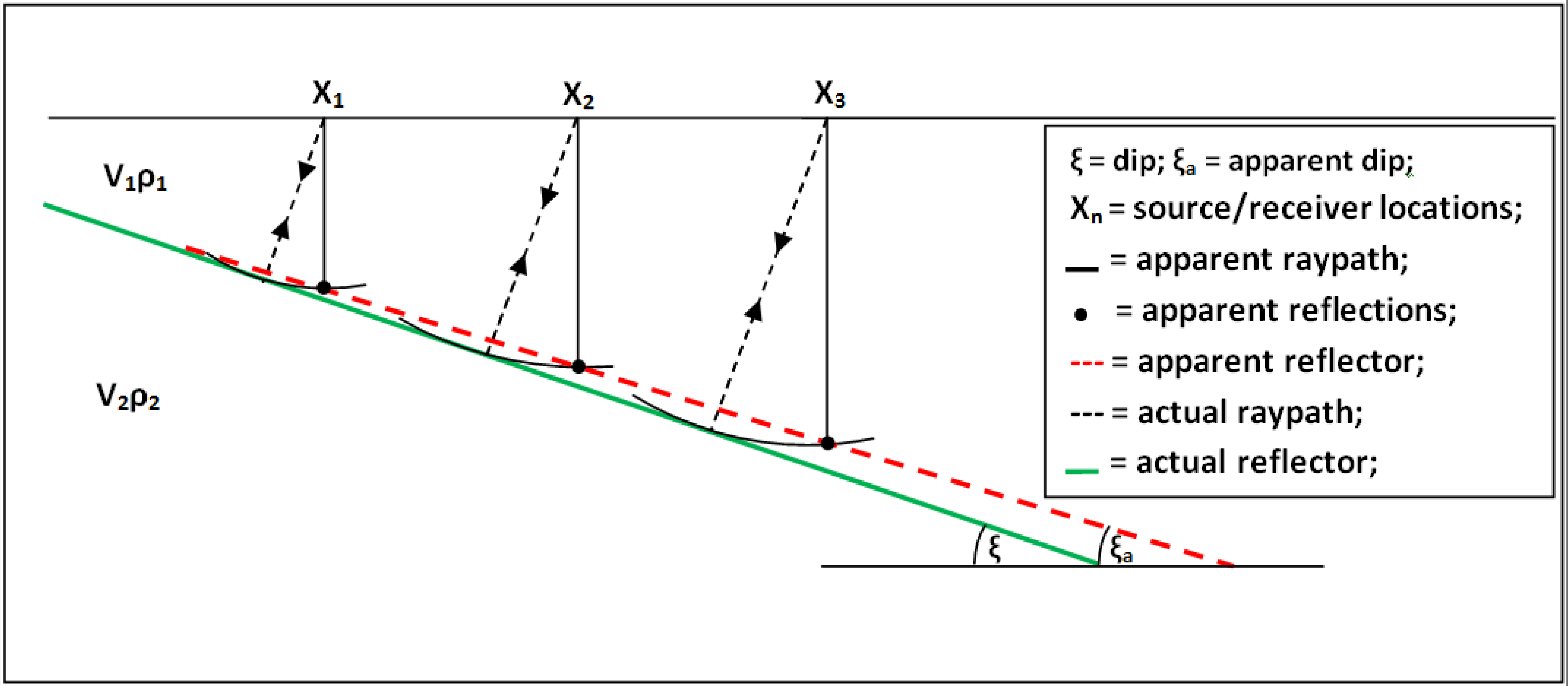
Depth migration





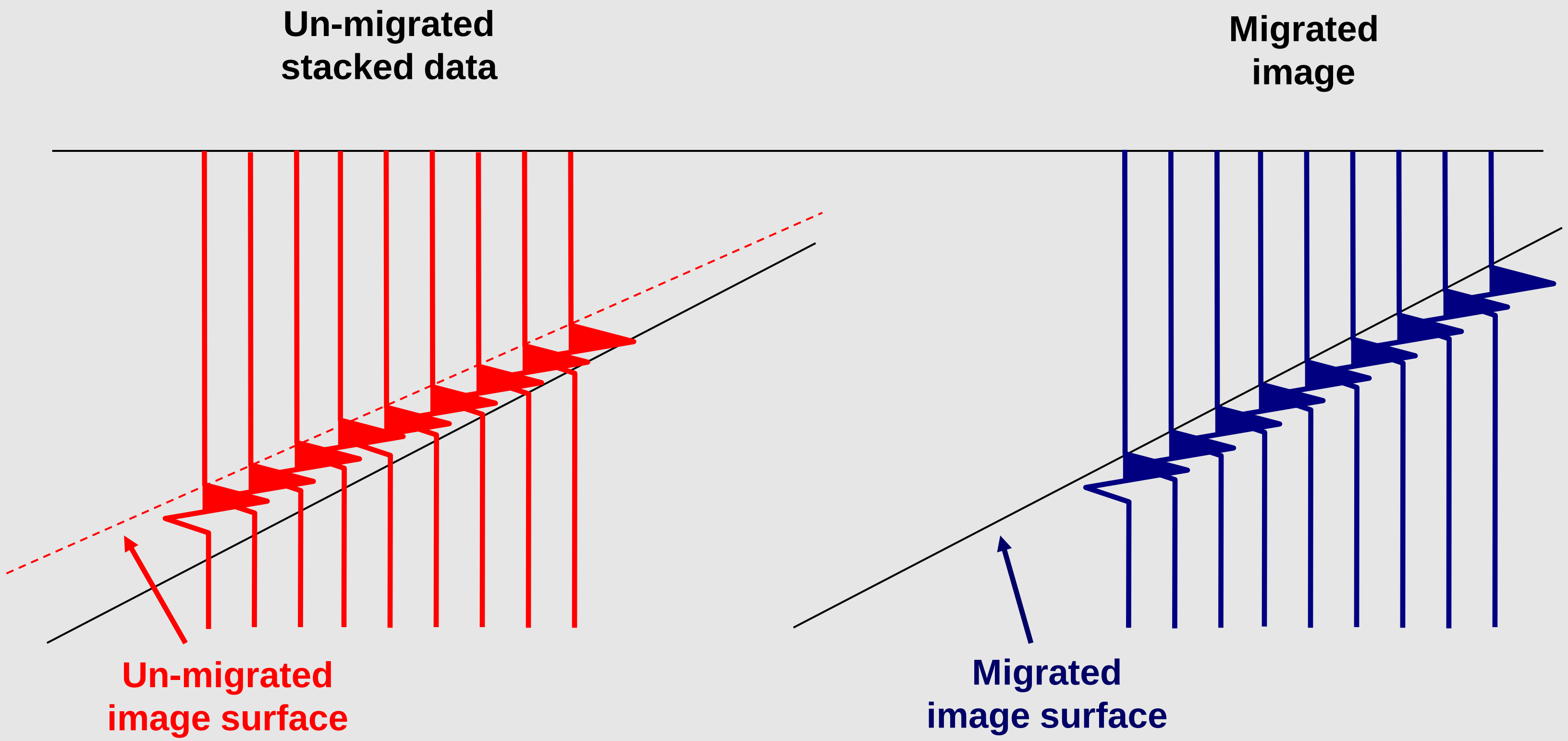
Reflection Seismics - Application

Migration



Reflection Seismics - Application

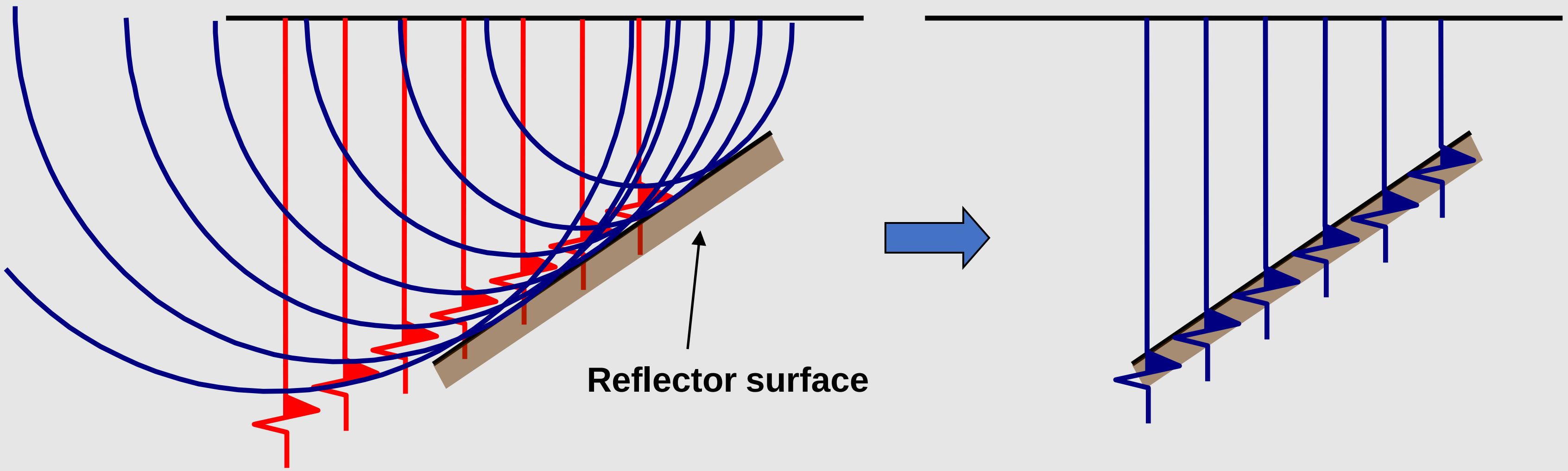
Migration



Migrating the seismic image on to the plane of the reflector

Reflection Seismics - Application

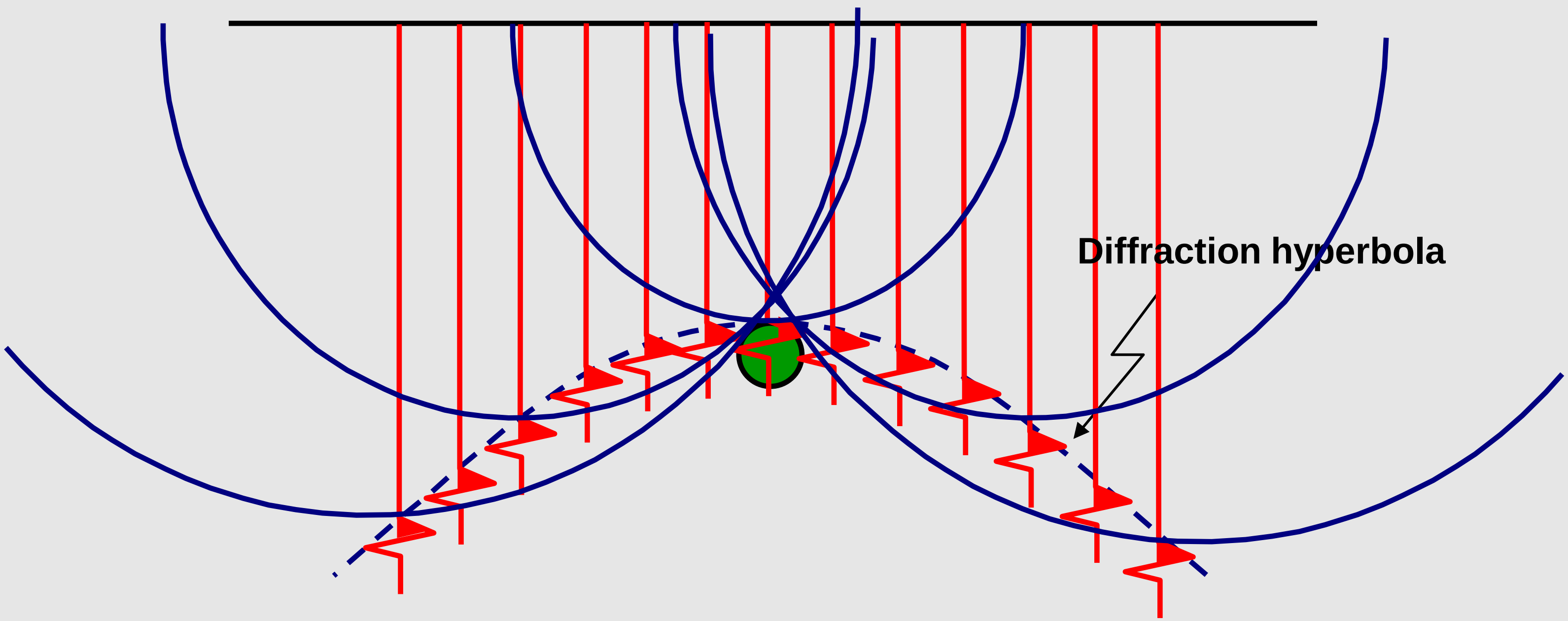
Migration



Migration of stacked (ZSR) trace
by Kirchhoff summation

Reflection Seismics - Application

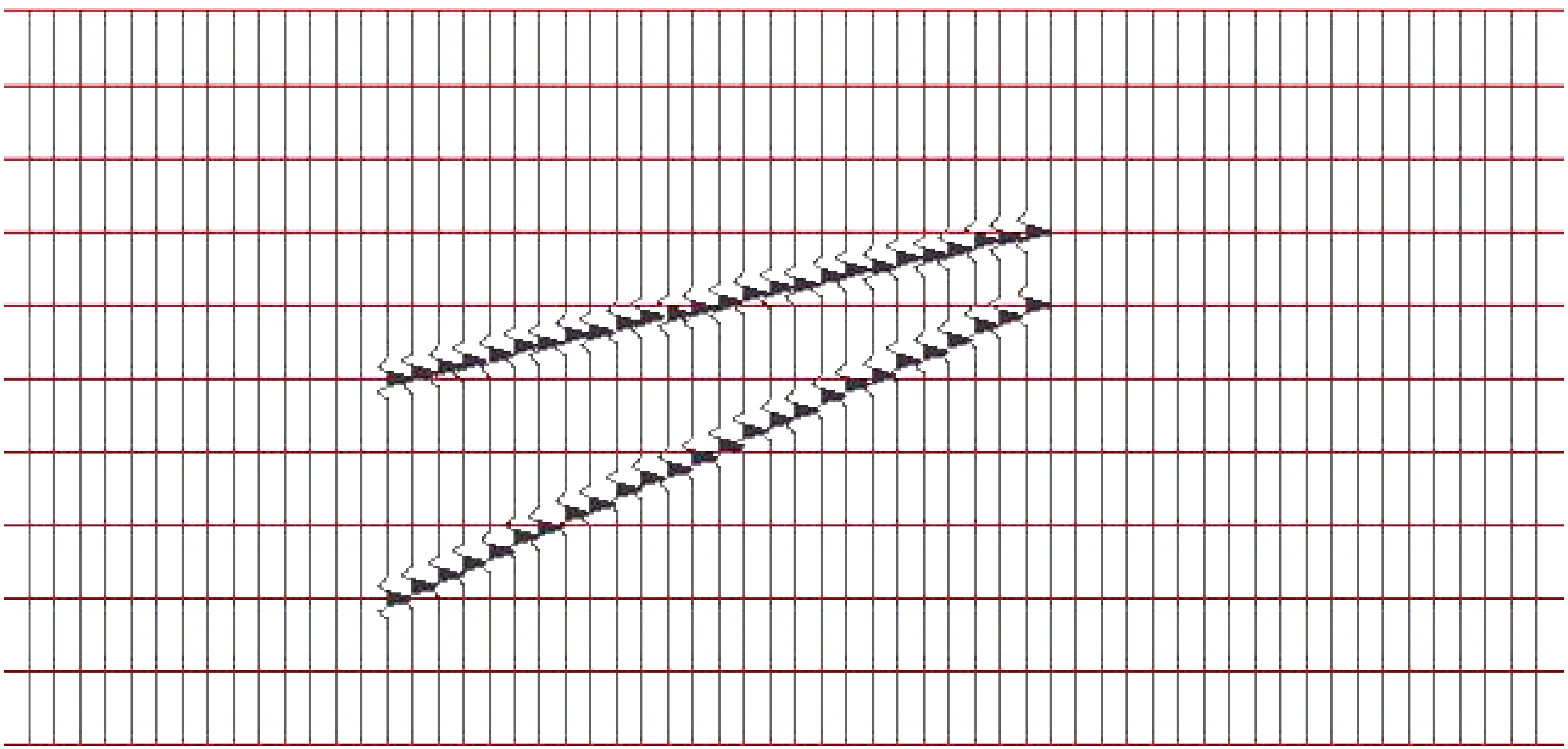
Migration



Migration of a diffraction by Kirchhoff summation

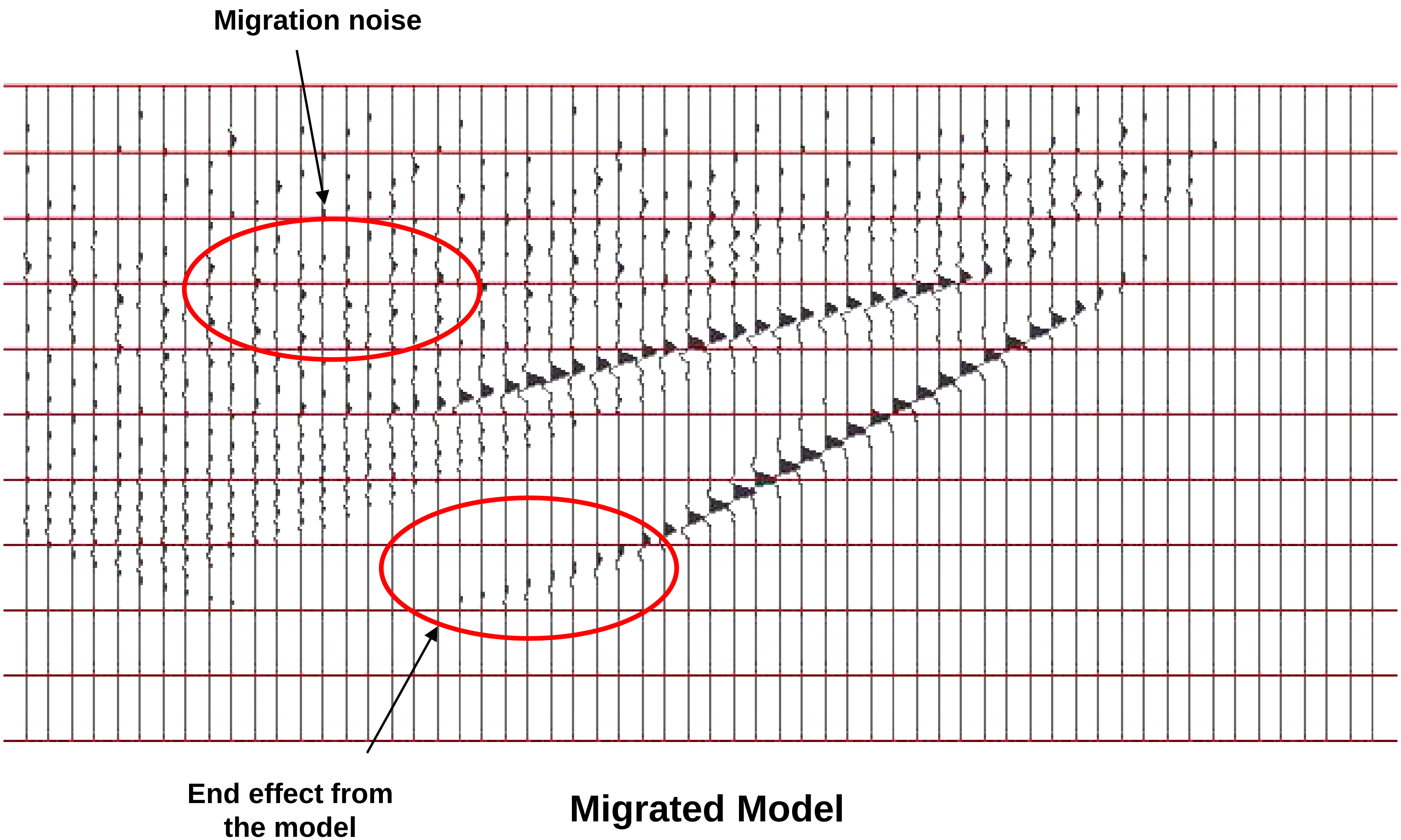
Reflection Seismics - Application

Migration



Un-migrated Model

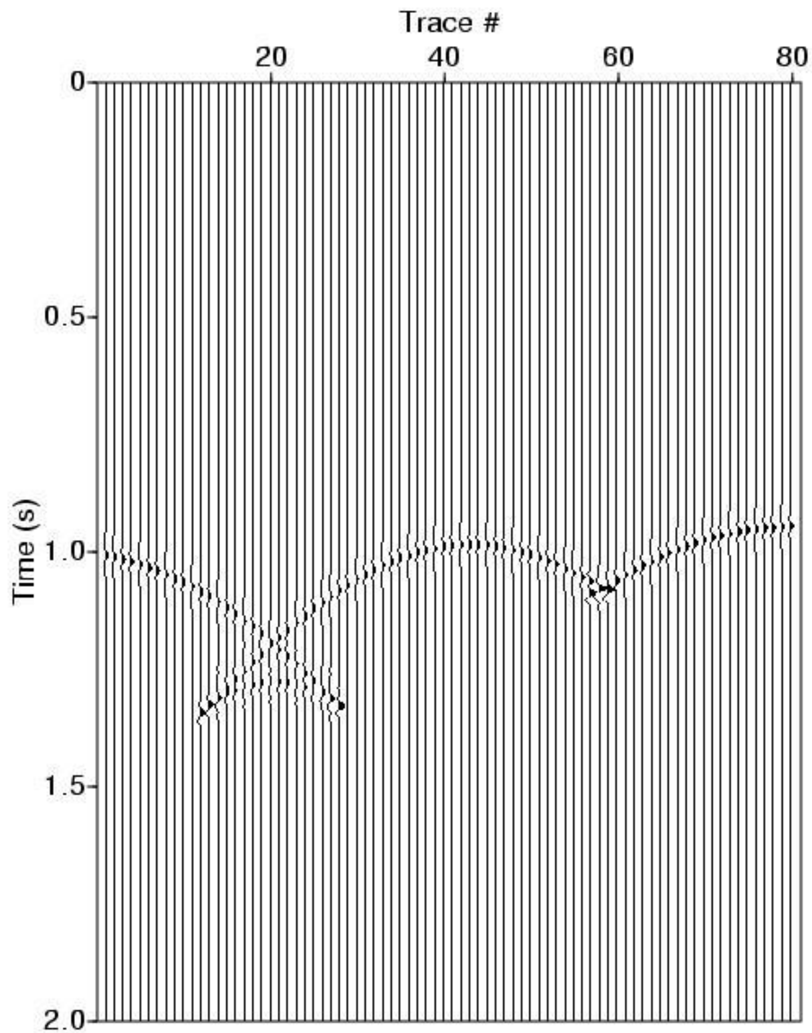
Migration



Migrated Model

Reflection Seismics - Application

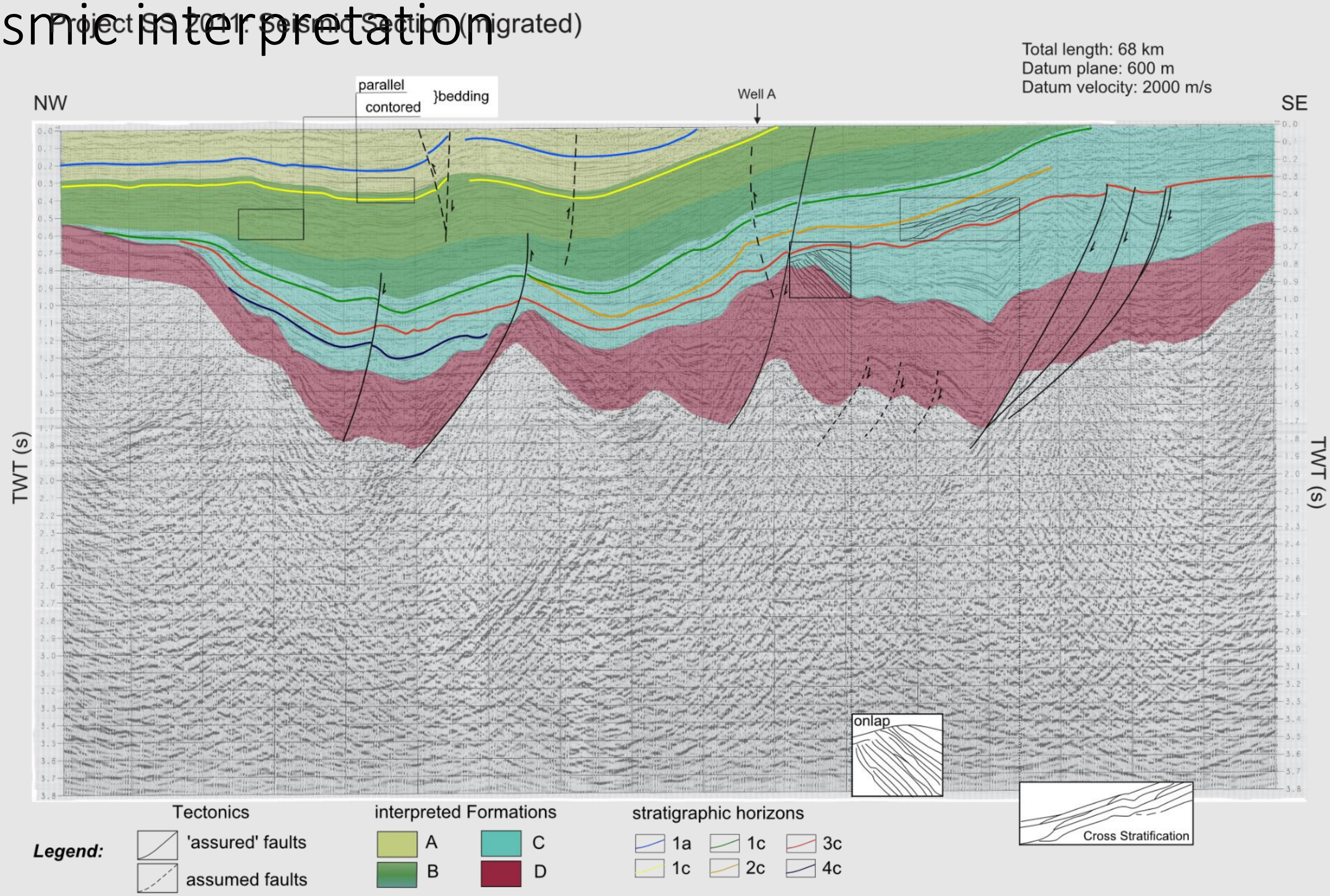
Migration



Simple Dataset

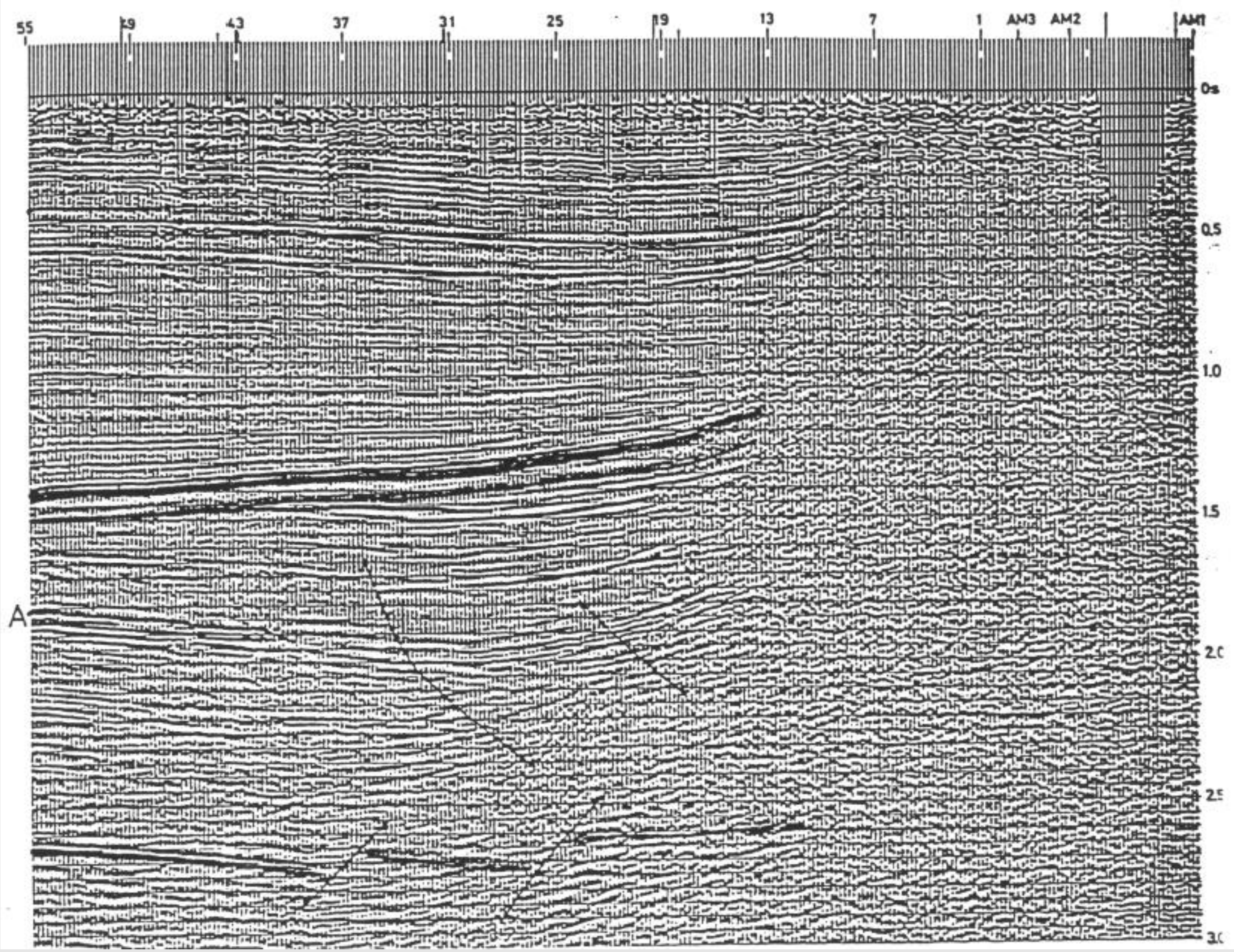
Reflection Seismics - Application

- Seismic interpretation



Reflection Seismics - Application

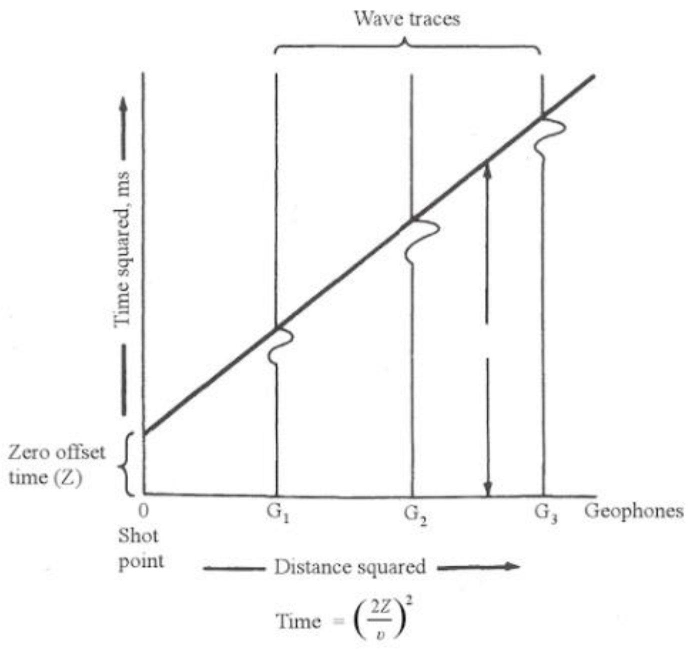
Seismic interpretation



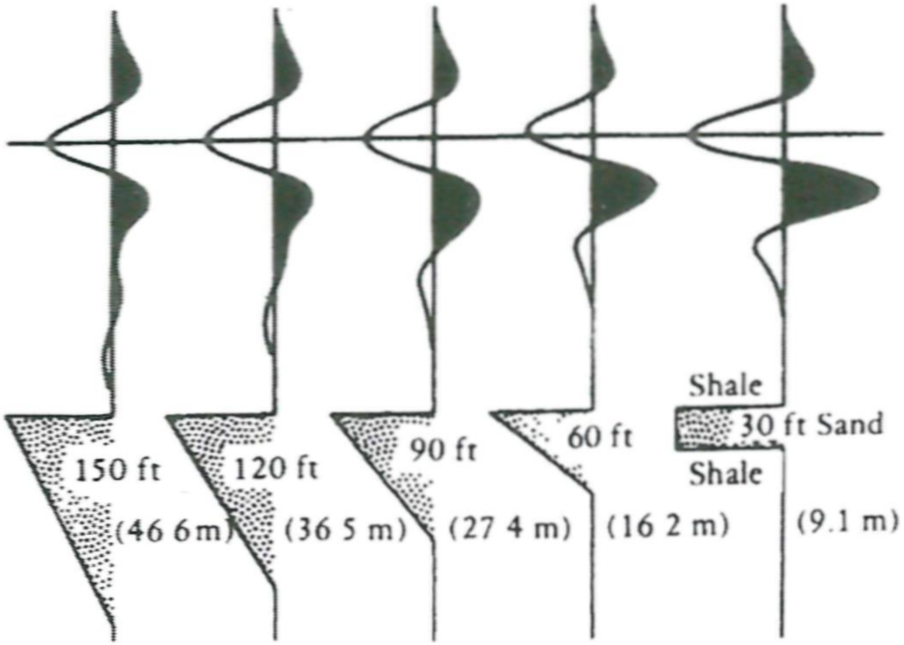
Reflection Seismics - Application

Signal form

Travel-time:



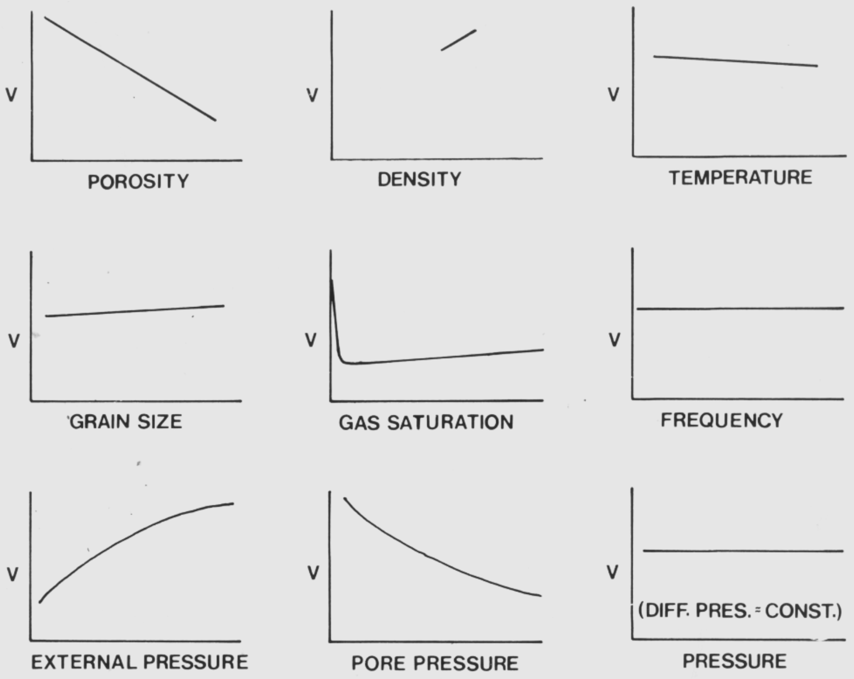
Impedanz contrast:



(source: Selley and Sonnenberg,1985)

Reflection Seismics - Application

Impedance contrasts



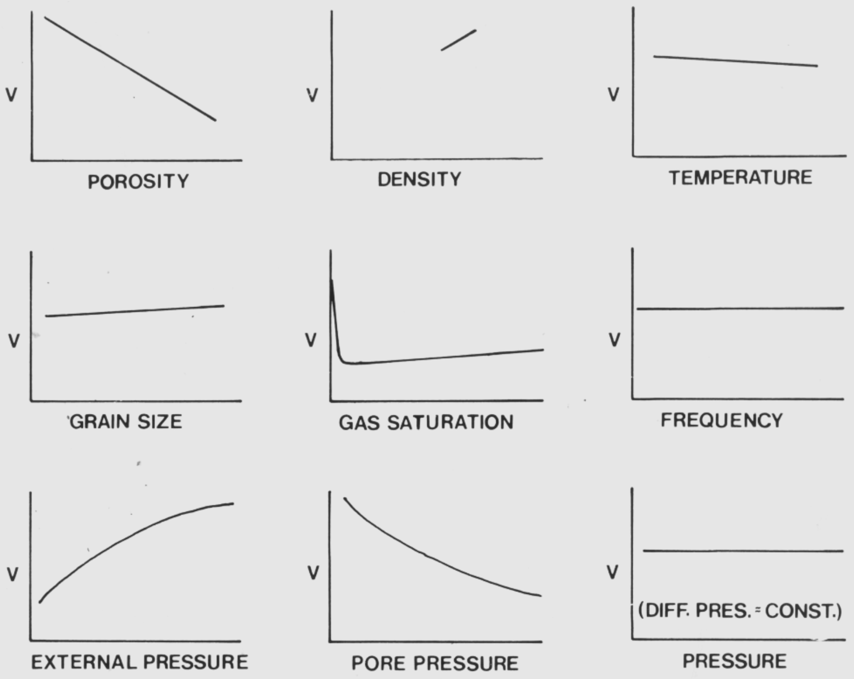
(source: Selley and Sonnenberg,1985)

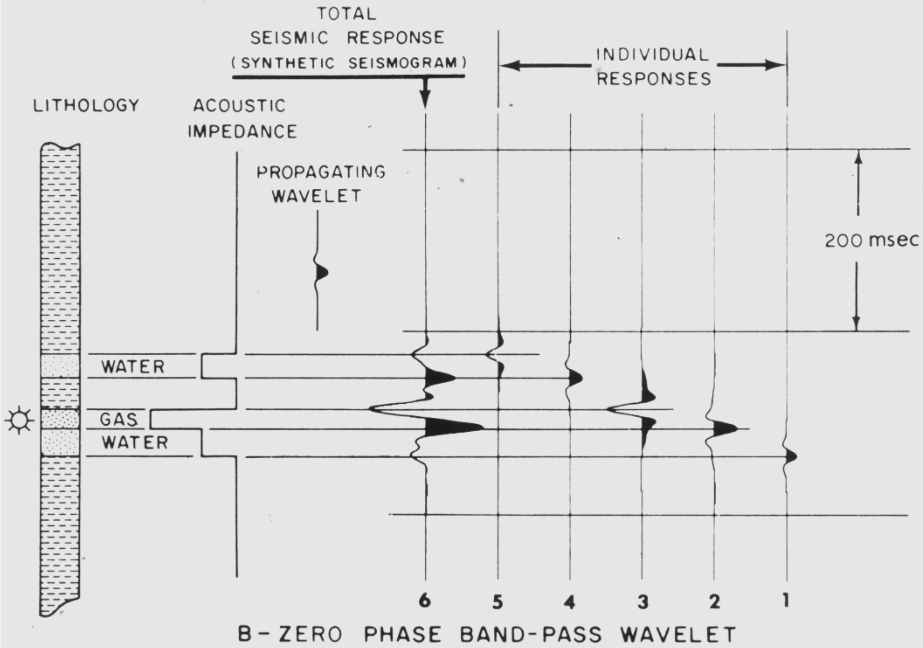
Table 2

Shale	v = 2 300 m/s
Gas-saturated sand	v = 1 900 m/ s
Oil-saturated sand	v = 3 000 m/s
Water-saturated sand	v = 3 200 m/s

Reflection Seismics - Application

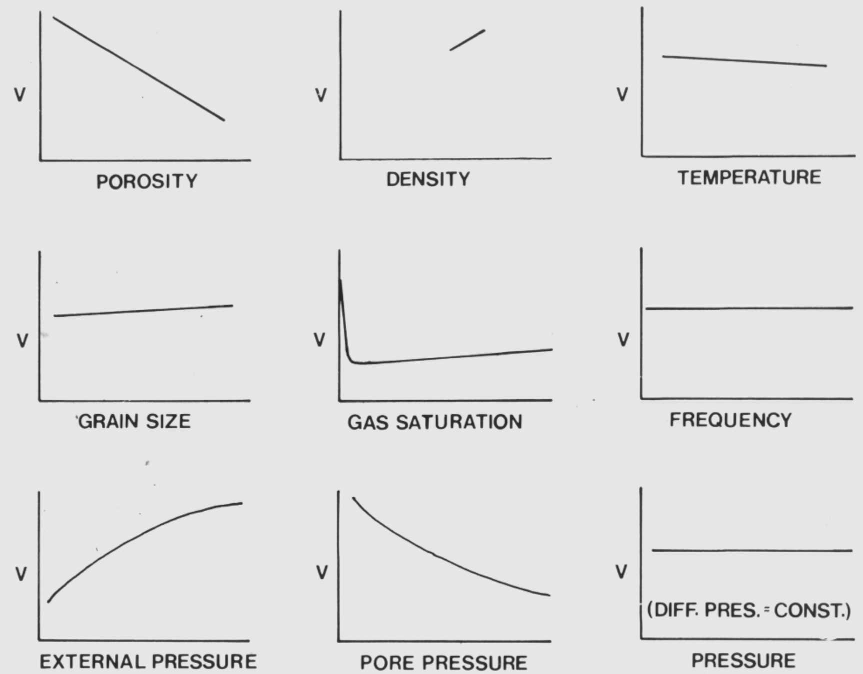
Interpreting subsurface properties

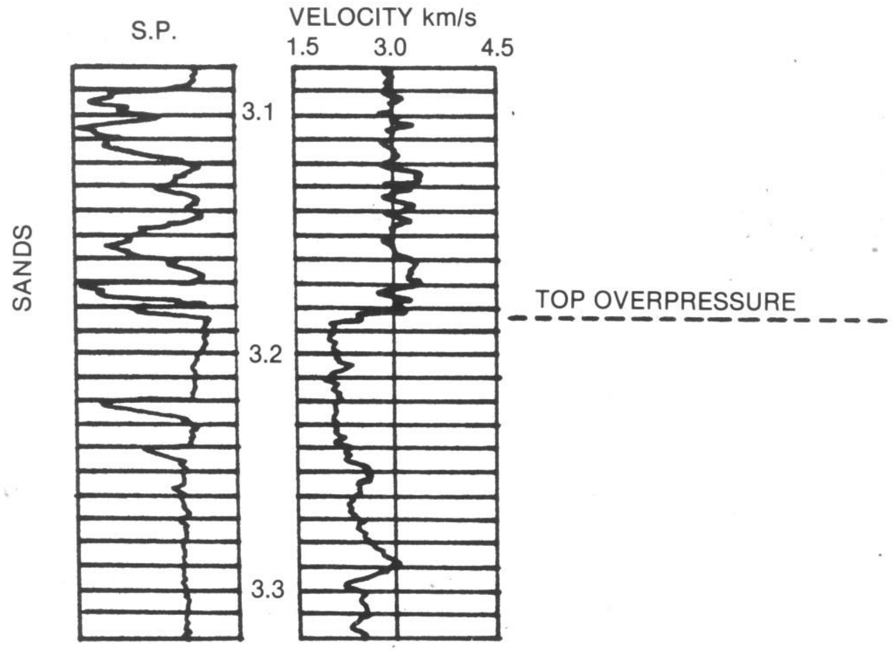




Reflection Seismics - Application

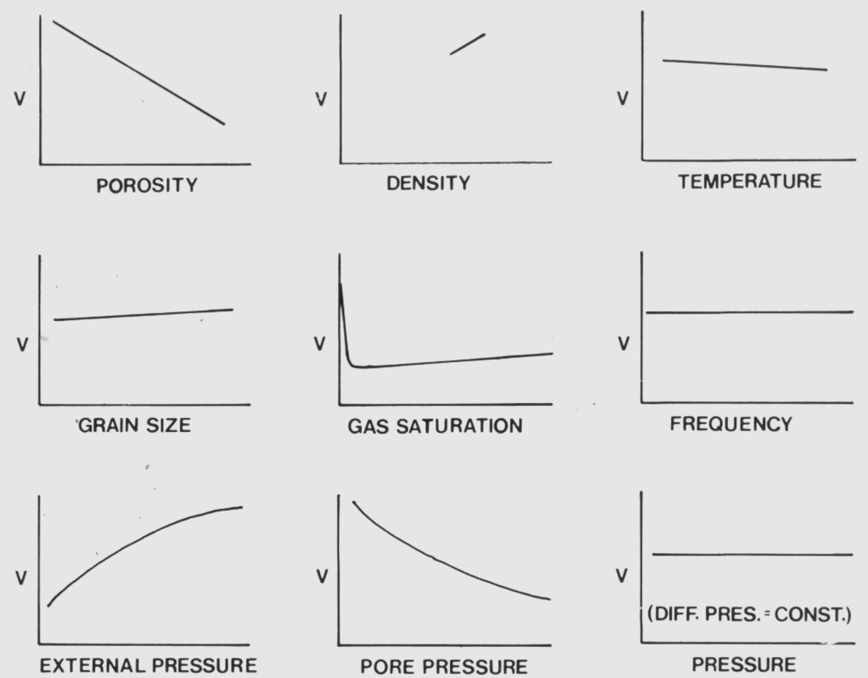
Interpreting subsurface properties



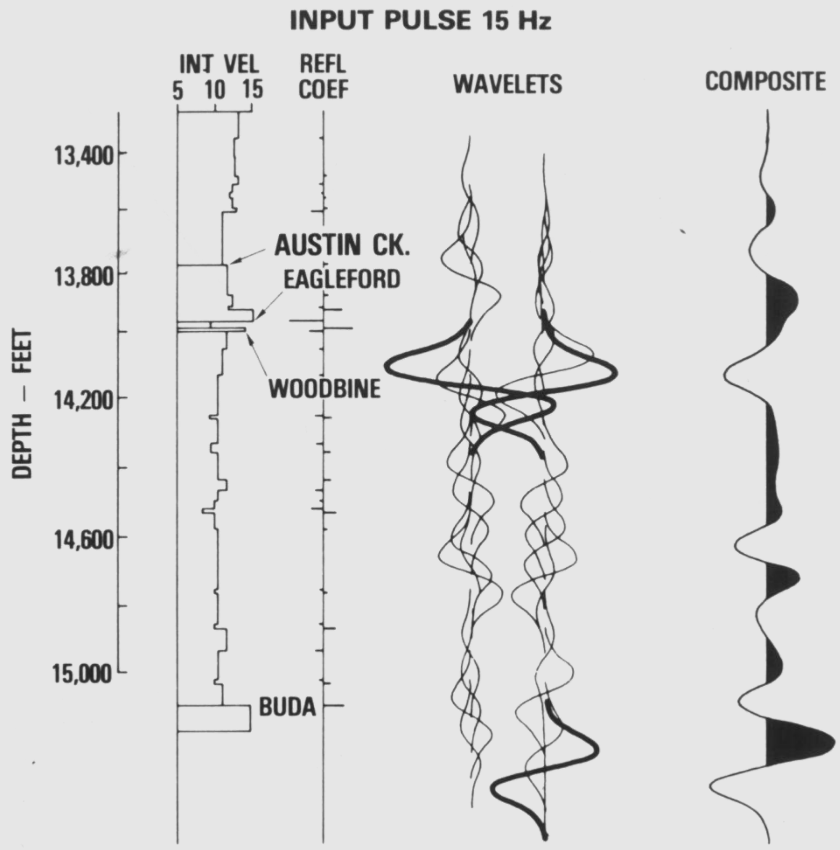


Reflection Seismics - Application

Subsurface properties ...

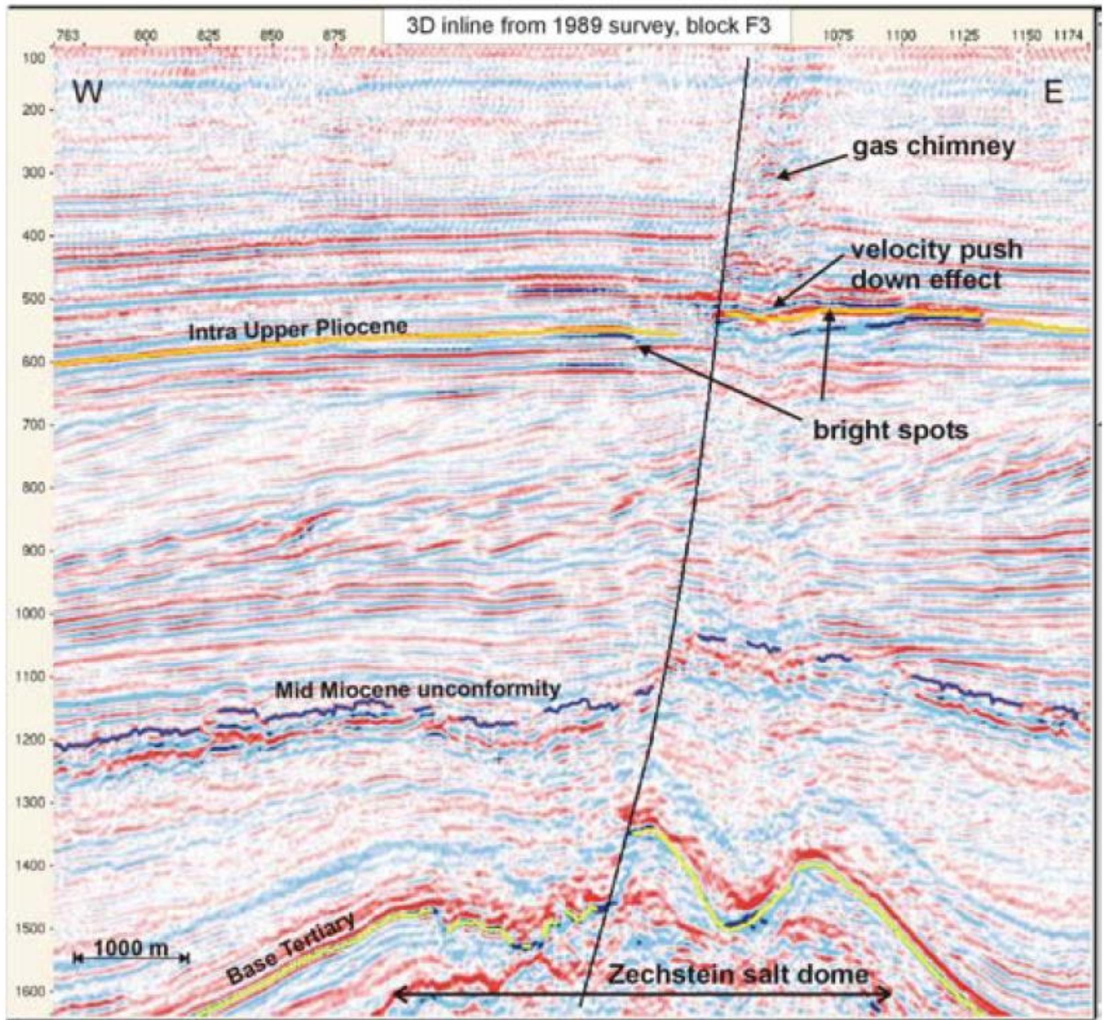


and wavelet analysis



Reflection Seismics - Application

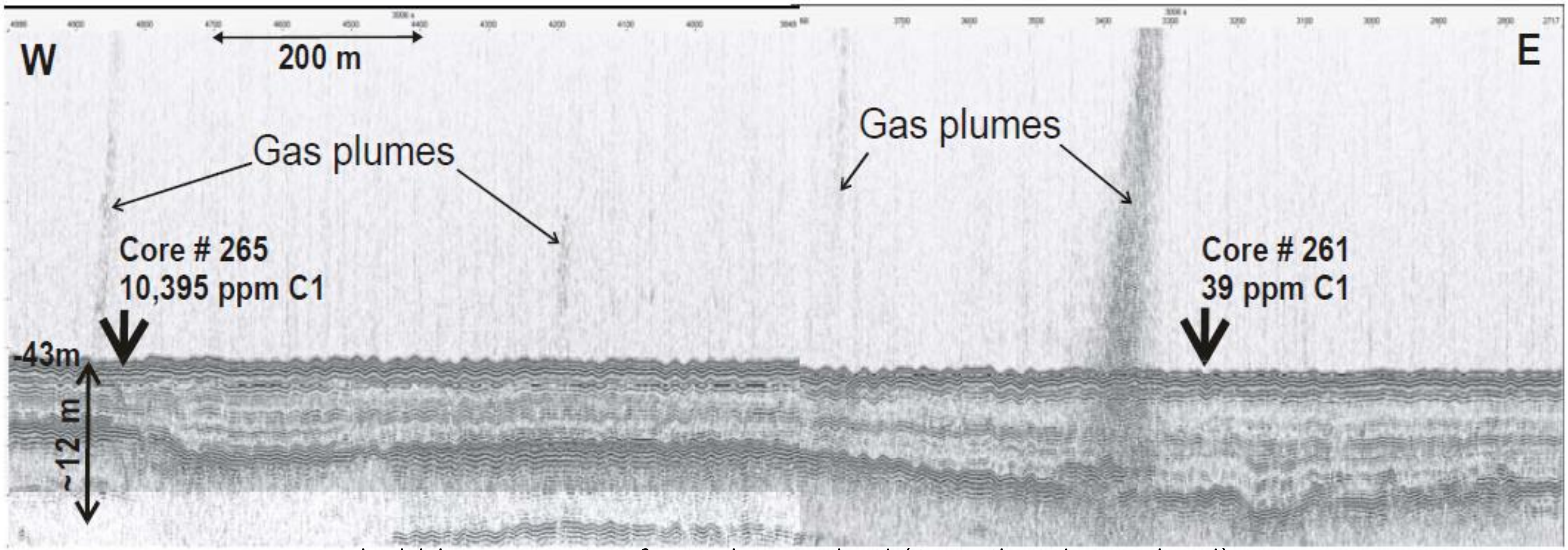
Interpreting subsurface properties



North sea seismic profile (Schroot and Schuttenhelm 2003)

Reflection Seismics - Application

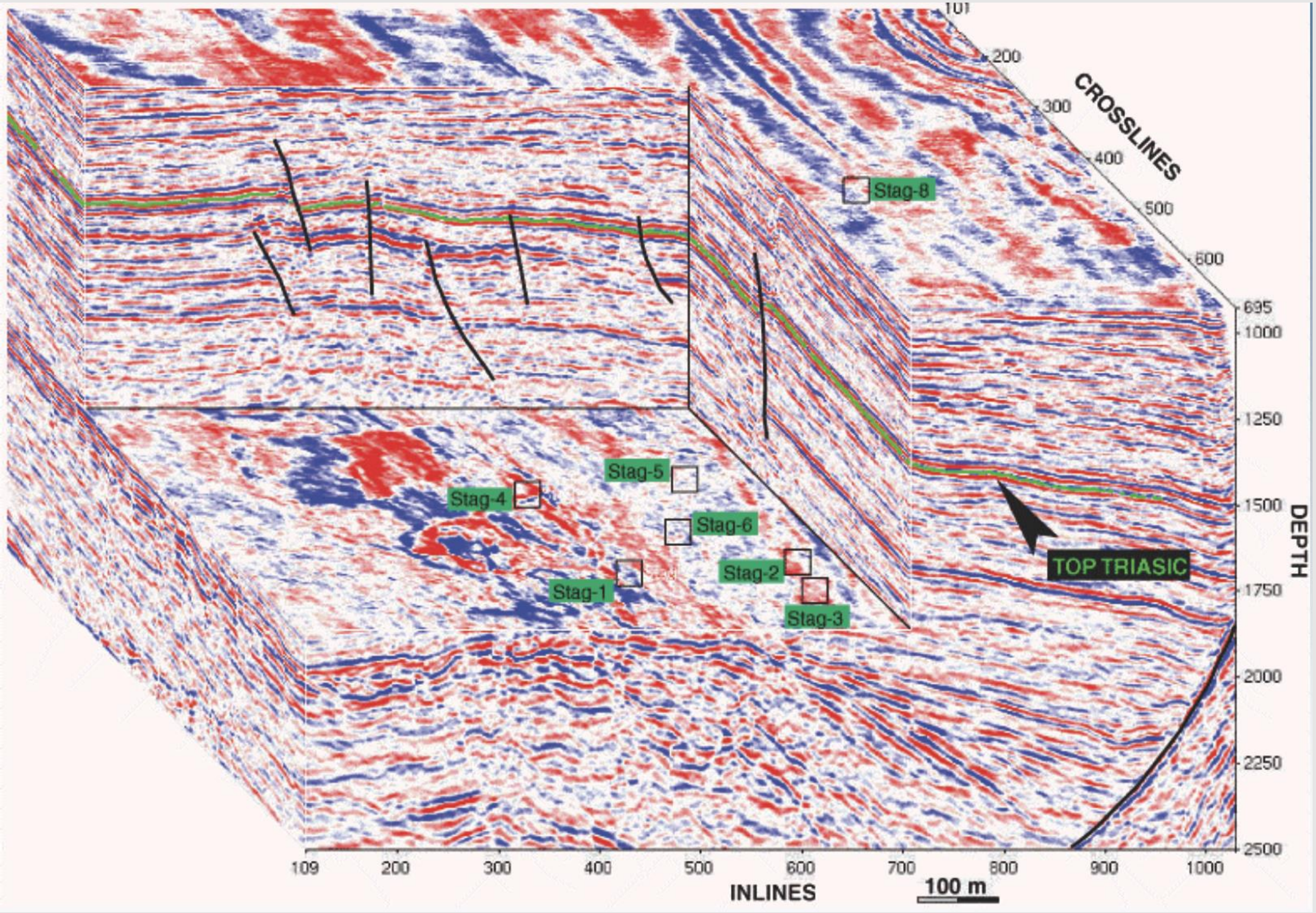
Interpreting subsurface properties



Gas bubbles emerging from the sea bed (Statoil and Heggland)

Reflection Seismics - Application

Seismic interpretation



Refraction Seismics vs. Reflection Seismics

Advantages of Reflection Seismics

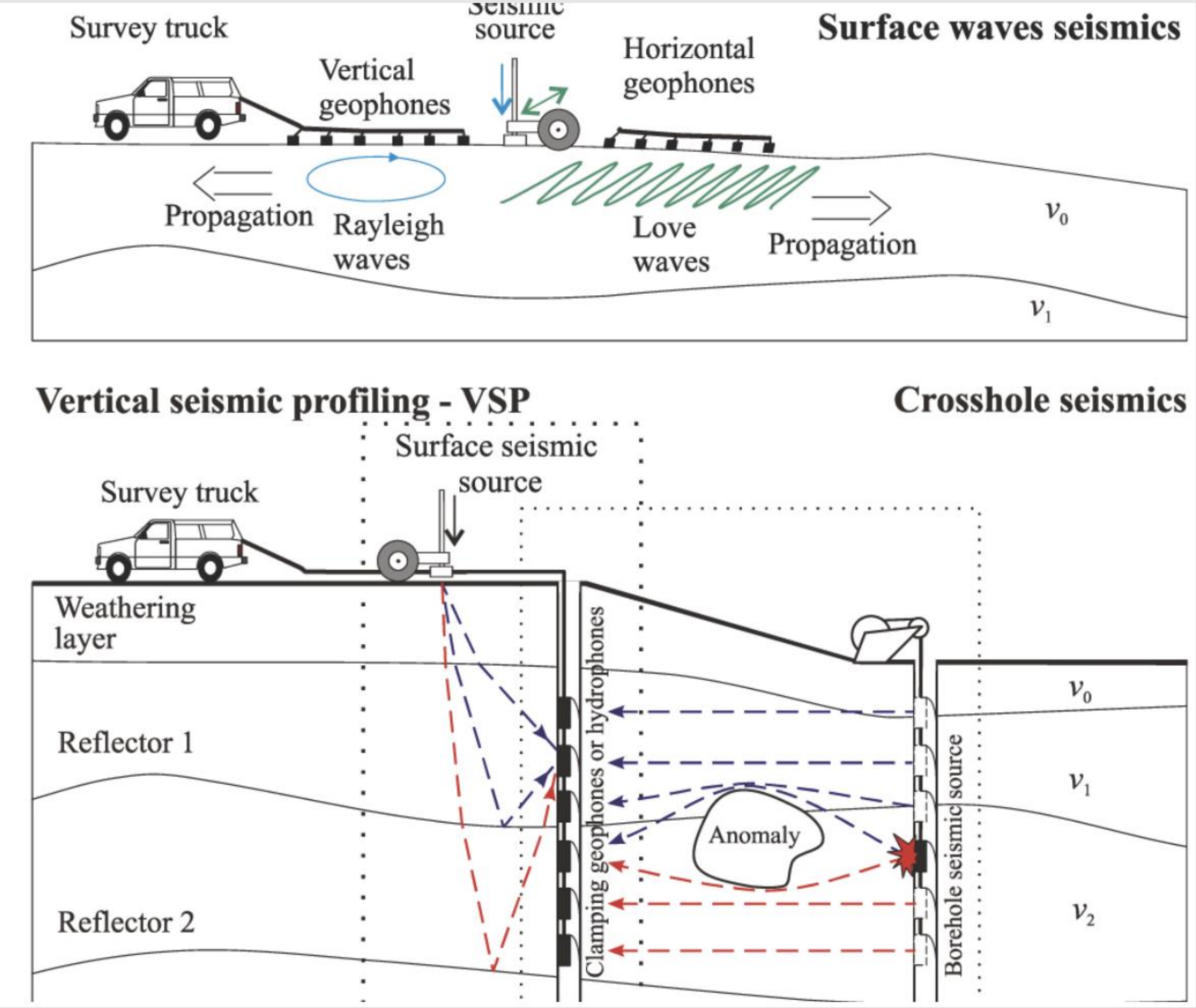
- High spatial resolution
- Complex geological structures (non-planar interfaces) can in principle be resolved.
- Layers with lower velocities can also be detected.

Advantages of Refraction Seismics

- Relatively simple evaluation.
- Moderate requirements on seismic energy.

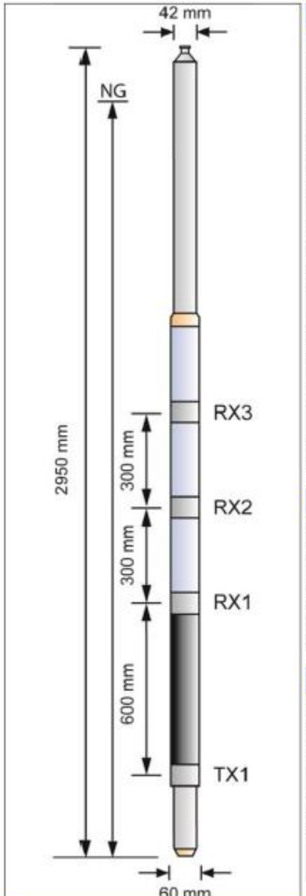
Reflection Seismics - Application

Borehole logging



Reflection Seismics - Application

FWS Probe



Overview

Principle
The probe uses a single-transmitter and triple-receiver array to provide high-quality formation acoustic-velocity data. A piezoelectric transmitter is stimulated by a high-voltage puls and radiates a high-frequency sonic wave via the borehole fluid and formation to the receivers. The probe records the full sonic wave-train at all receivers simultaneously and also the velocity of the first arrival.

Results
Full sonic wave-train and velocity of first arrival. Amplitude and arrival time of first casing arrival for CBL.

Applications
Geotechnical, groundwater prospection, cement bond log (CBL), detection of deep fracture system, determination of seismic velocities and calibration of seismic tomographies.

Options
Natural gamma detector

Borehole Conditions

Borehole Fluid:	✔ water	✔ mud	✘ dry
Casing:	✔ PVC	✔ steel	✔ none
Drill:	✔ core	✔ destructive	
Max depth:	2000 m (dep. on fluid dens.)		
Diameter:	> 70 mm		
Temperature:	< 70°C		
Max pressure:	200 bar		

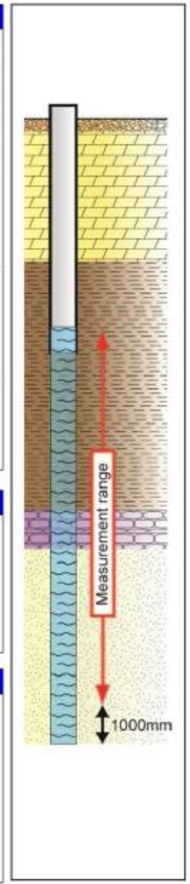
Technical spezification

Dimensions

Length:	2950 mm
Diameter:	42/60 mm
Weight:	20 kg

Sensors

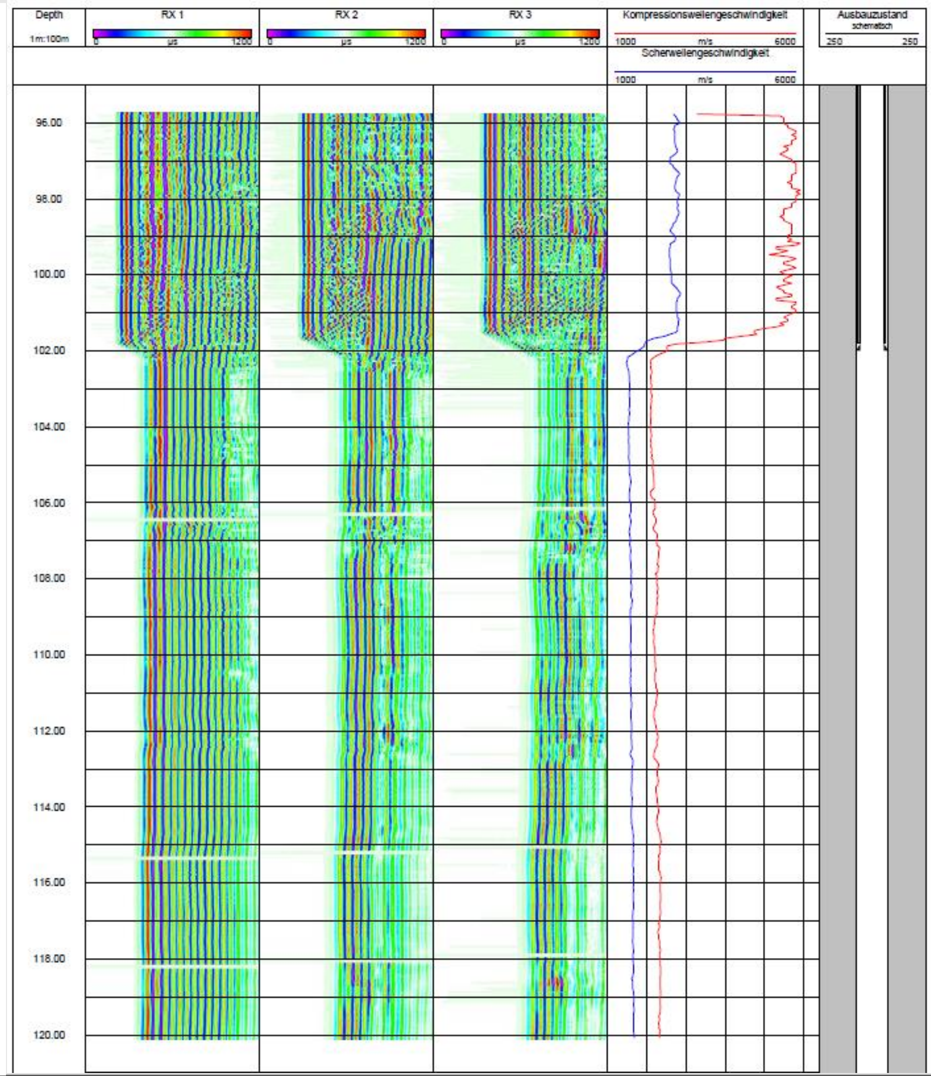
1 Transmitter	TX1
3 Receivers	RX1-3



Measurement – Image – Orientation

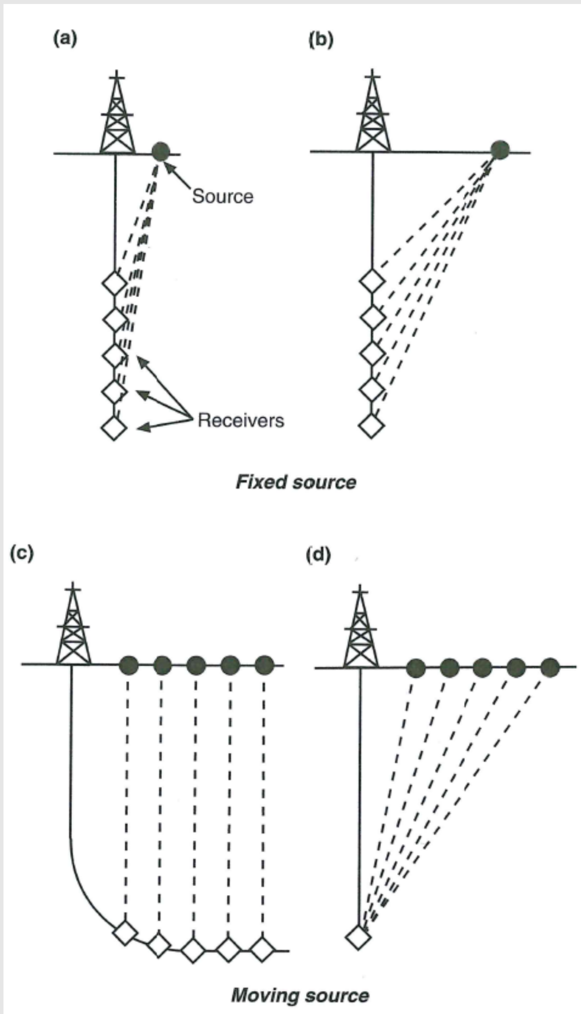
Measurement
Probe: ✔ centered ✔ excentric
Measurement: ✔ downward ✔ upward
Logging speed: 5 m/min

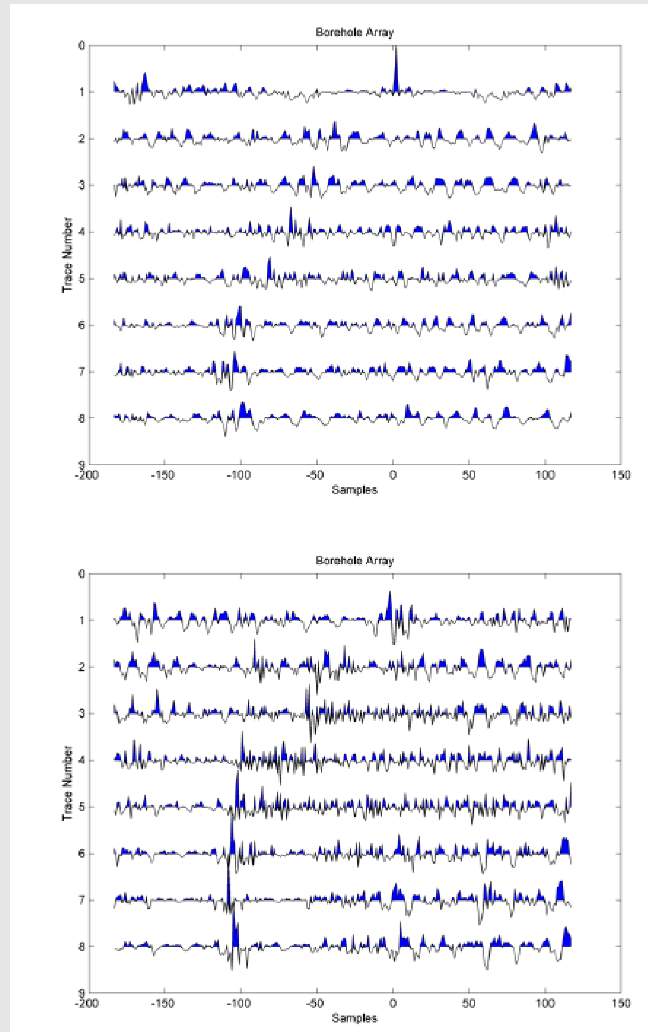
Sensors
TX1 – RX spacing: 60 cm, 90 cm, 120 cm
Transmitter type: 18 kHz piezoelectric
Sampling interval: 4µs or 8µs
Depth sampling interval: 2, 5 or 10 cm



Reflection Seismics - Application

Sonic Log - Vertical Seismic Profiling (VSP)



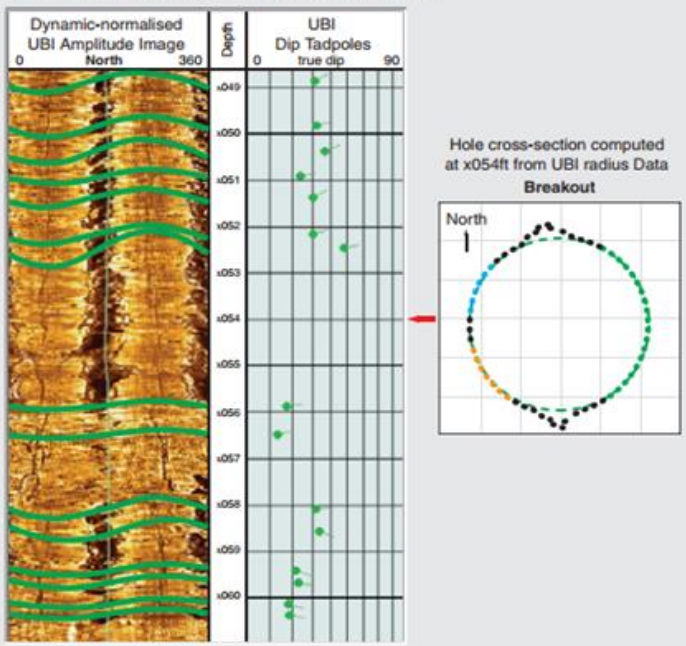


Reflection Seismics - Application

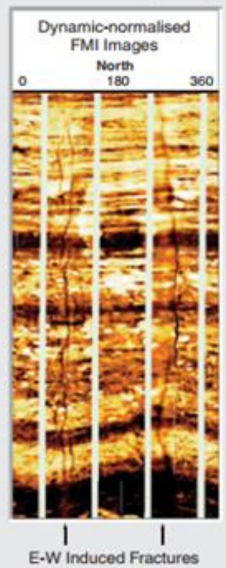
Sonic Log - acoustic imaging methods and FMI/FMS

- accurate characterisation of borehole breakouts and induced fractures (geometry, locations and orientation)
- improve wellbore stability modelling and well planning
- aid Frac-job design
- establish sealing potential of natural fractures

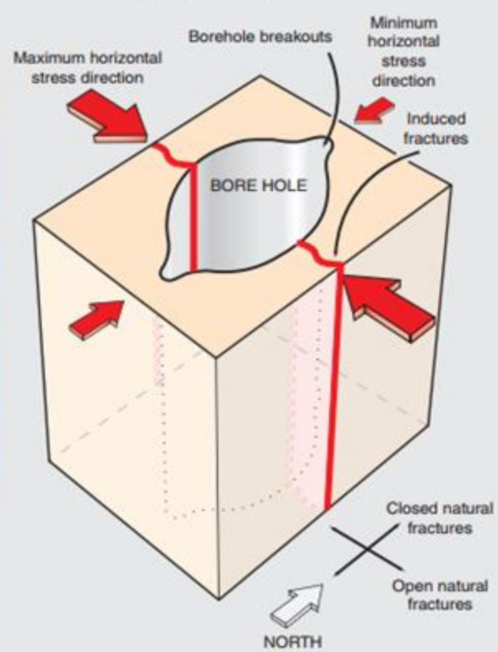
Borehole Breakouts in Acoustic Image



Drilling-induced Fractures in Resistivity Image



***In-situ* Stress Directions**



Quelle: Schlumberger 2017

Reflection Seismics - Application

Scale of a wavelet