

Introduction to seismic method

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FuSe Tihany, 2026

Seismics (exploration)

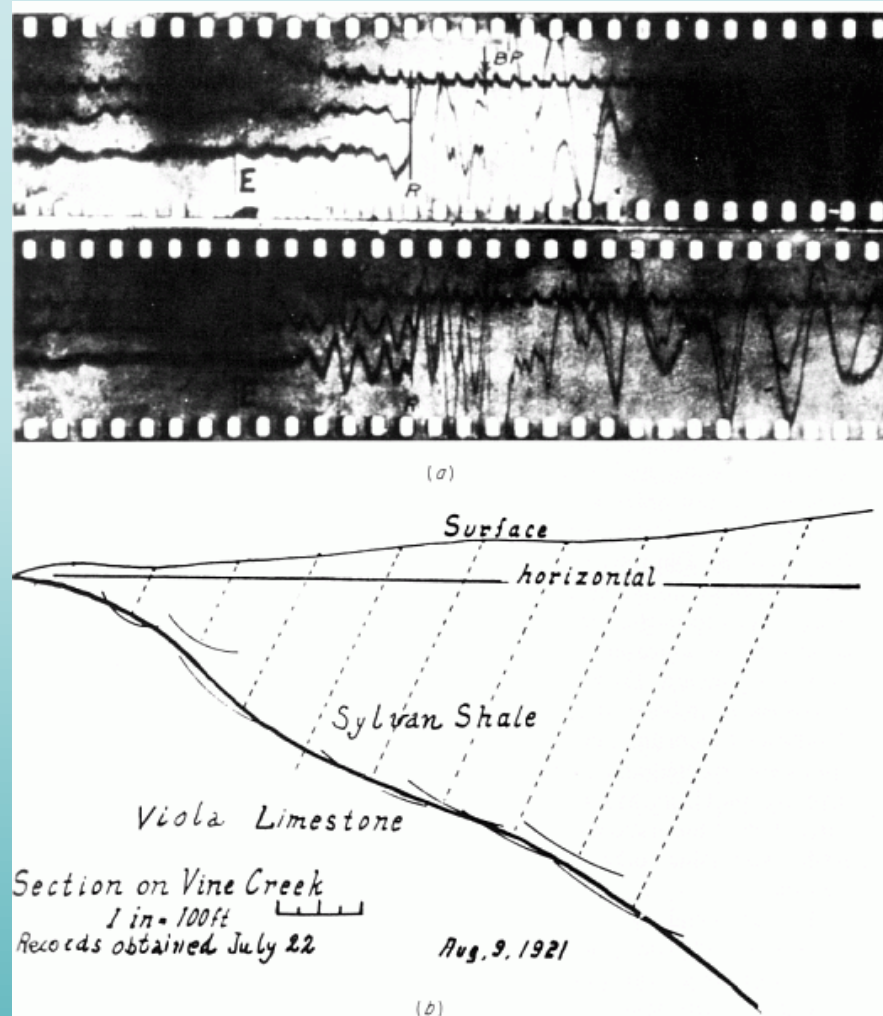
- Seismic method is probably the most important geophysical tool
- Main usage: hydrocarbon exploration
- This is the main source of our knowledge about the geology and structure of sedimentary basins
- Also useful tool for engineering geophysics

Connection to seismology

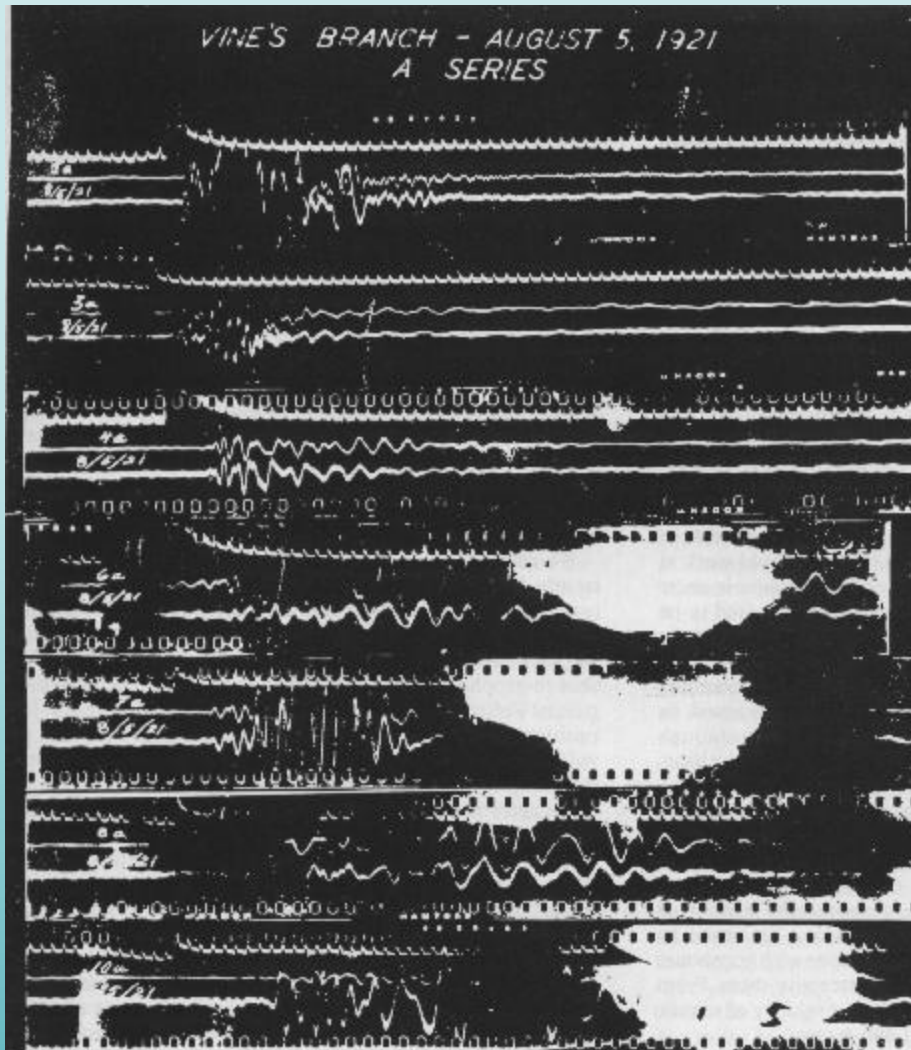
- Similarities:
 - Object of investigation (Earth)
 - Wave types
 - Detection methods
- Differences:
 - Source
 - Energy
 - Frequency range

As well as its practical applications, it is also ideally suited to basic research (structural geology) surveys and can therefore assist in the investigation of seismically active zones.

The beginnings...



The beginnings...



**Definition of seismic
„CHANNEL” :**

The waveform recorded over time by a seismograph that detects ground vibrations.

In case of more seismograph, we talk about „multichannel” measurement.

In this Oklahoma example there were three channels

Seismic instruments

- Geophone
 - industrial: 10-15Hz
 - Velocity measurement
 - 1,3 component (p,s)
 - Geophone group (5-20 pcs/point)
- Hydrophone (p wave only)
- Recording devices
 - Gain, filter, ADC
 - 24 (16) bit
 - 2-~10000 channels
- Triggering
 - Fast blasting cup (<1ms)
 - Trigger geophone
 - Accelerometer



Signal sources

- Sledgehammer
- Drop weight
- Blasting

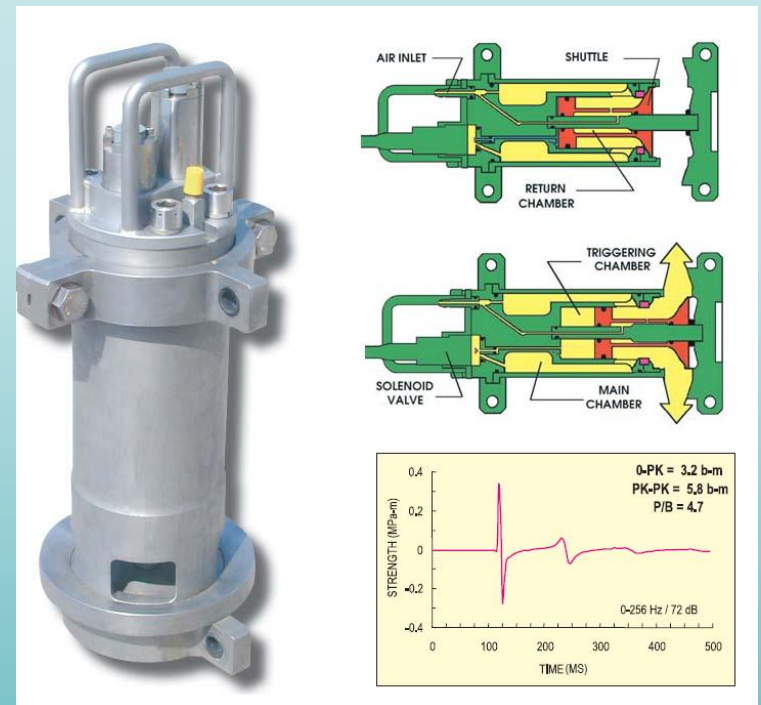
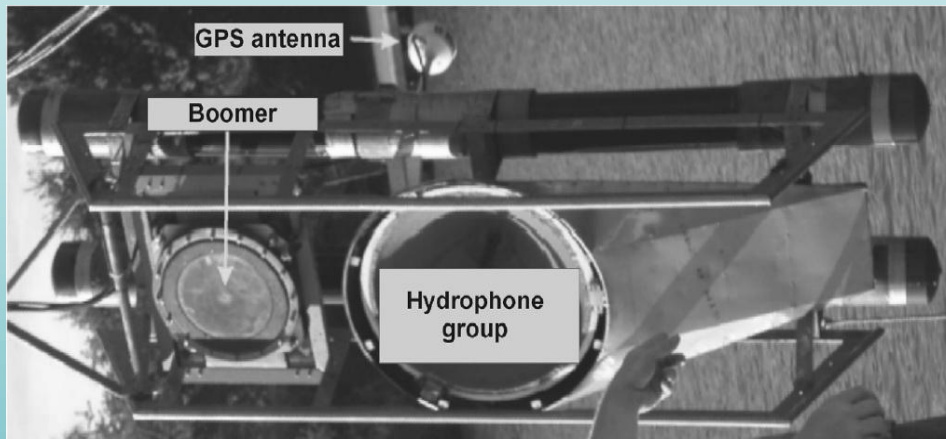


Vibroiseis



Water seismics

- Sparker
- Boomer
- Air gun



Seismic surveys

Planning

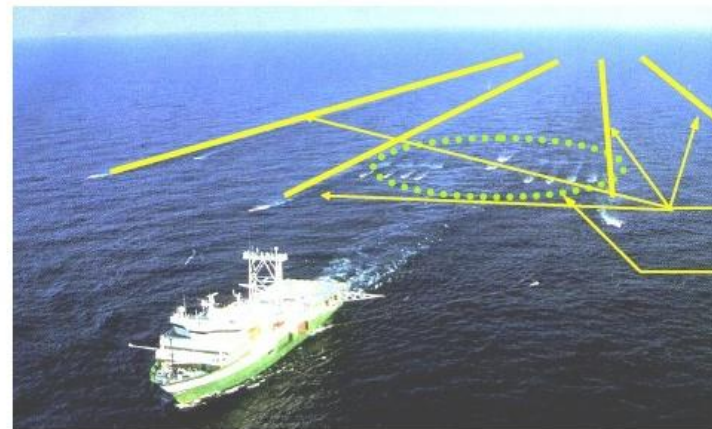
Geodesy

Logistics

Geophone planting

„Shooting”

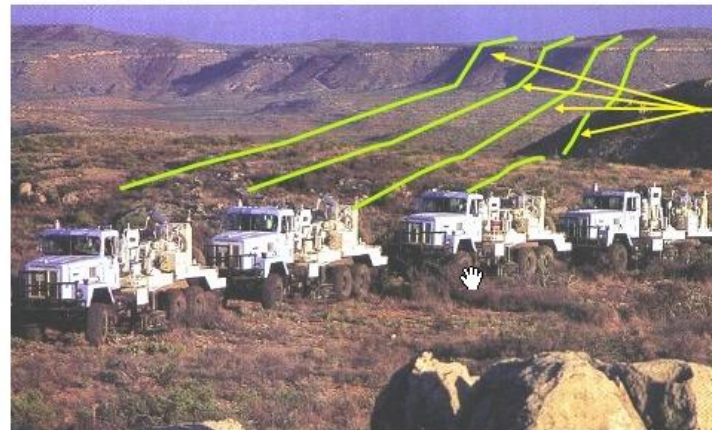
Damage recultivation



Receivers = cables of hydrophones

Source = Airgun array

(a) Typical marine seismic survey



Receivers = lines of geophones

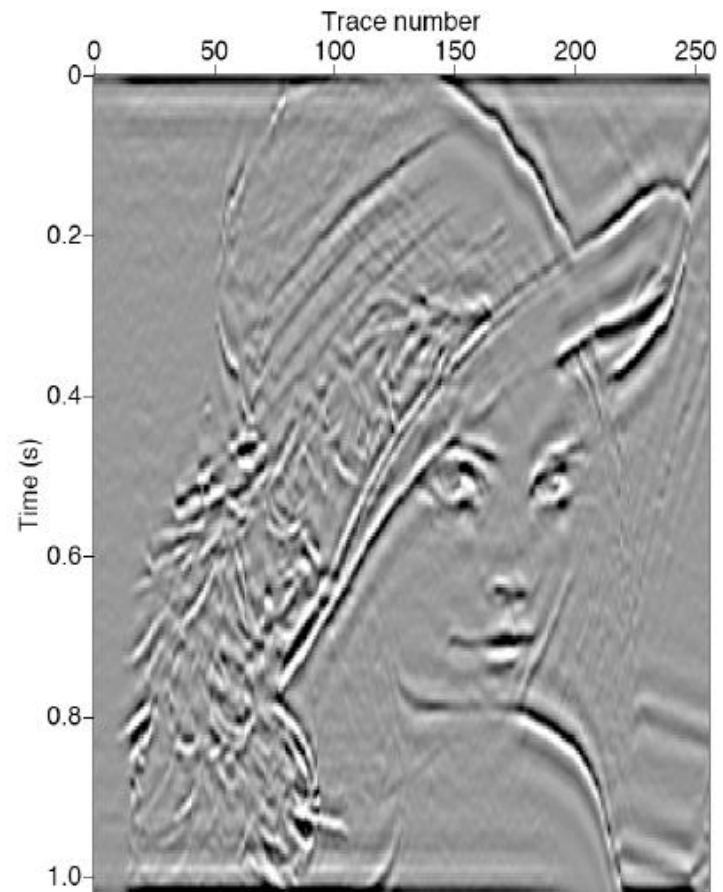
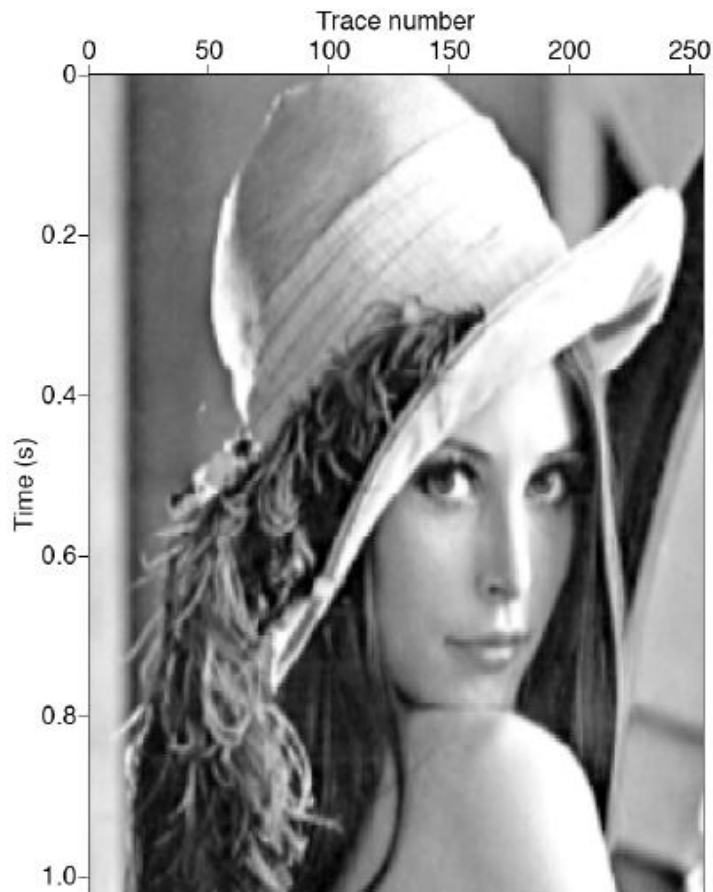
Source = Vibrator trucks, dynamite

(b) Typical land seismic survey

Figure 1.01: Typical seismic surveys. The elastic wave is produced by *sources*: air guns (marine), vibrator trucks or dynamite (land). The “echoes” or reflections are recorded by a series of hydrophone cables towed by the boat (marine data) or geophones planted in the ground (land data). Echoes or reflections are recorded digitally on tapes for further processing.

General Concepts

- Seismic data shows edges of geologic units
- Edge detection that responds to AI changes
- $AI = \text{acoustic impedance} = \text{velocity} \times \text{density}$



Wave types in the seismic exploration:

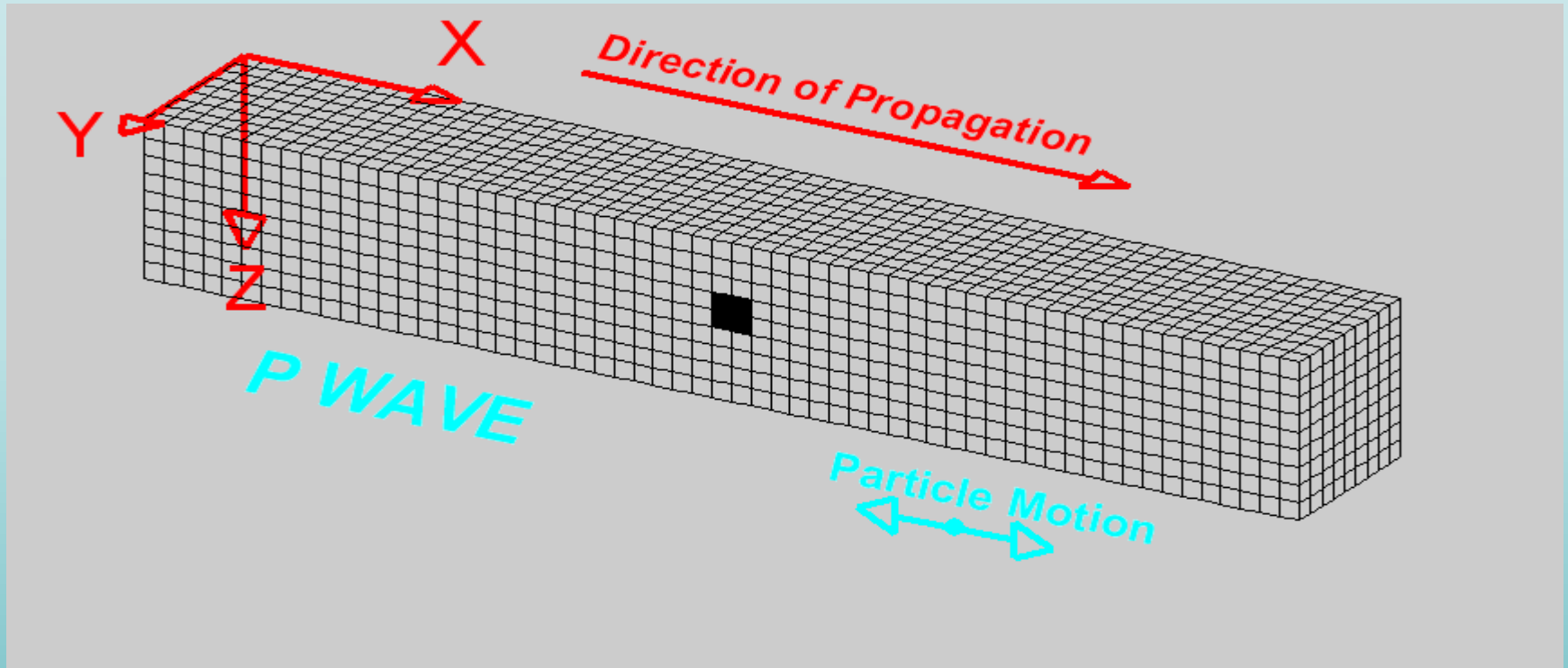
- P, S, surface waves, (sound wave)
- Velocity range: ~ 100 m/s - ~ 5000 m/s
- Useful frequency range: $\sim$ several Hz - 3-500 Hz, mostly 10-100 Hz
 $\Rightarrow$ sampling interval: usually 0.5;1;2;4 ms
- Wavelength: $\sim$ dm- ~ 100 m, in land survey mostly 10m-100m
(Higher frequency: better resolution (up to $\lambda/4$), but smaller penetration)

Velocities of P waves

Unconsolidated material:	Dry sand	0.2 - 1.0 km/s
	Wet sand	1.5 - 2.0 km/s
	Clay	1.0 - 2.5 km/s
Sedimentary rocks:	Tertiary Sandstone	2.0 - 2.5 km/s
	Carbonate Sandstone	4.0 - 4.5 km/s
	Chalk	2.0 - 2.5 km/s
	Limestone	3.4 - 7.0 km/s
	Salt (Evaporite)	4.5 - 5.0 km/s
Igneous/metamorphic rocks:	Granite	5.5 - 6.0 km/s
	Gabbro	6.5 - 7.0 km/s
	Gneiss	3.5 - 7.5 km/s

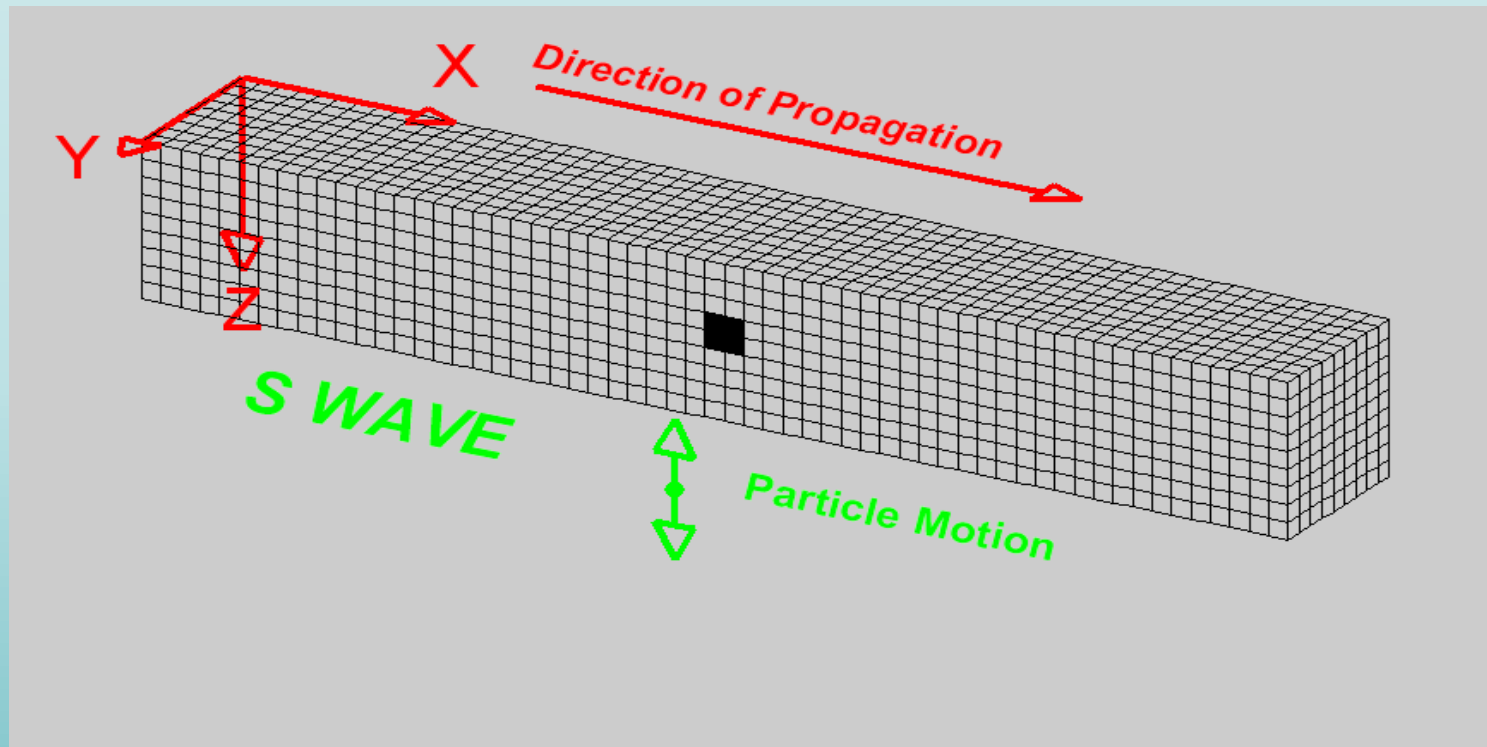
Air: 0.33 km/s; Water: 1.43-1.54 km/s; Petroleum: 1.3-1.4 km/s

P wave



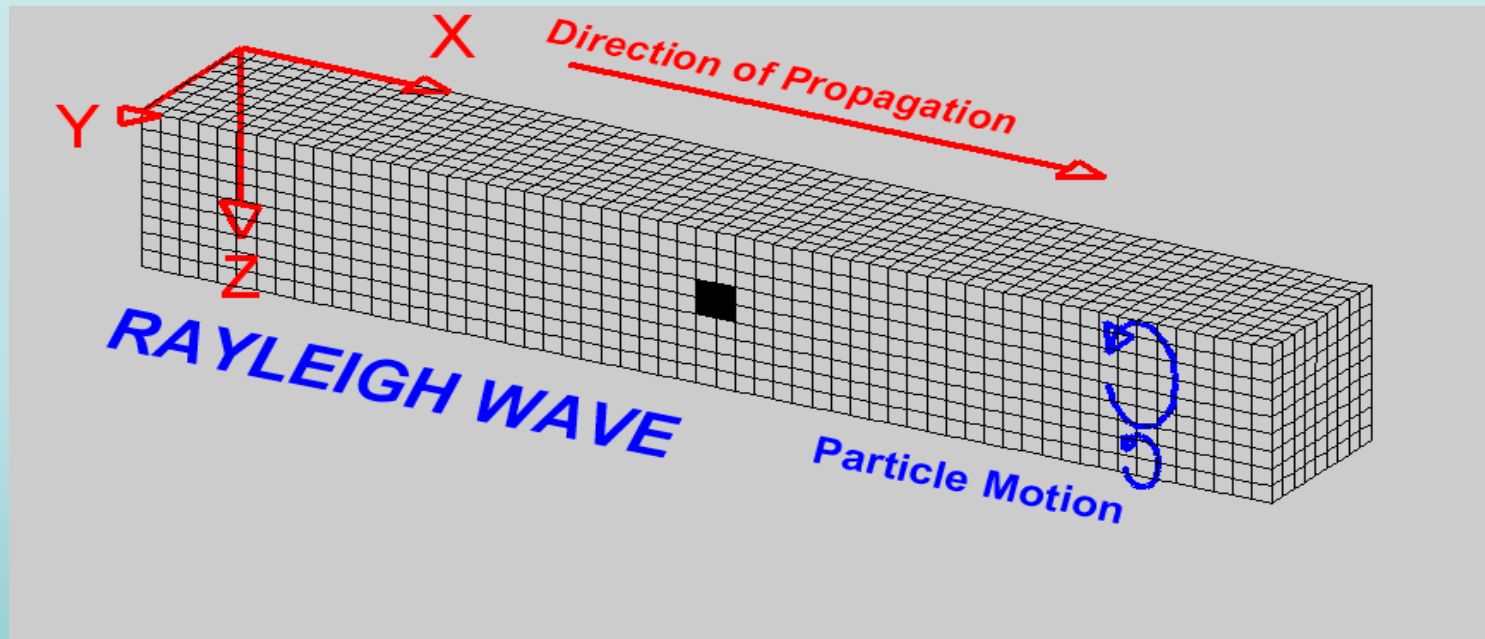
The longitudinal wave is the compression or primary (P) wave

S wave



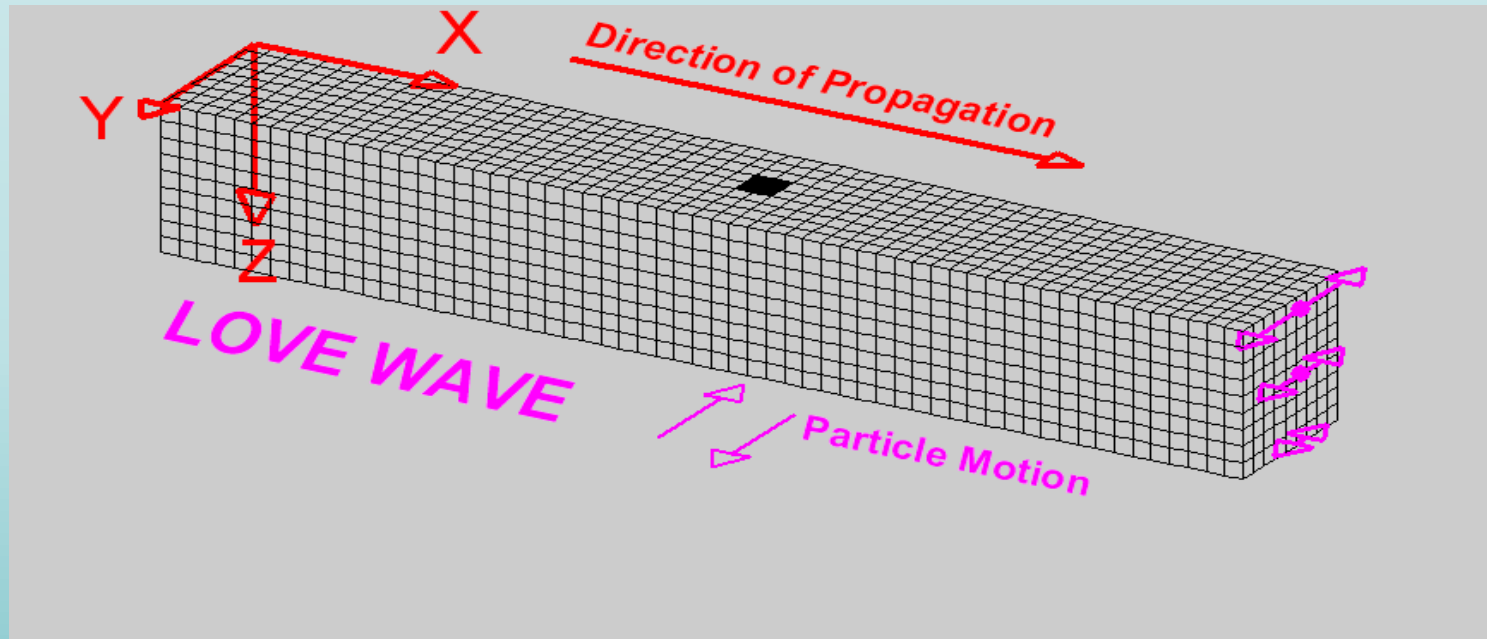
The transversal wave is the shear wave or secondary (S) wave

Surface waves: Rayleigh wave



- Circular motion of the particles.
- The movement has both longitudinal and transversal component.
- Can be generated on the surface of half-infinite space.

Surface waves: Love wave

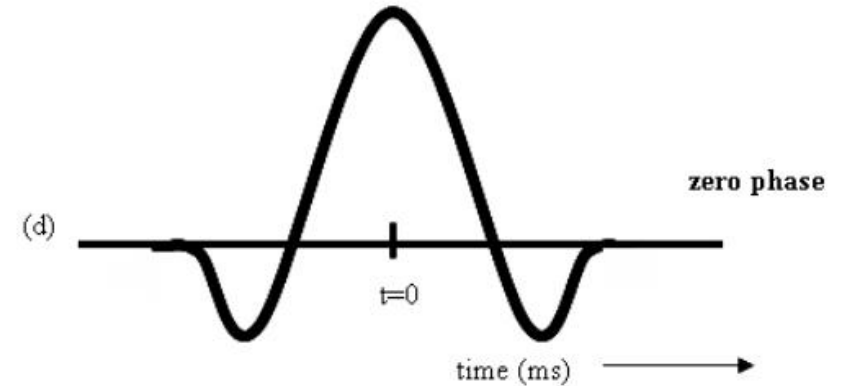
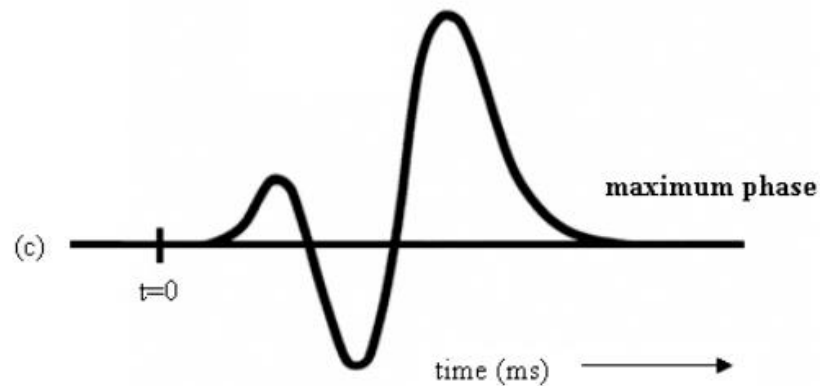
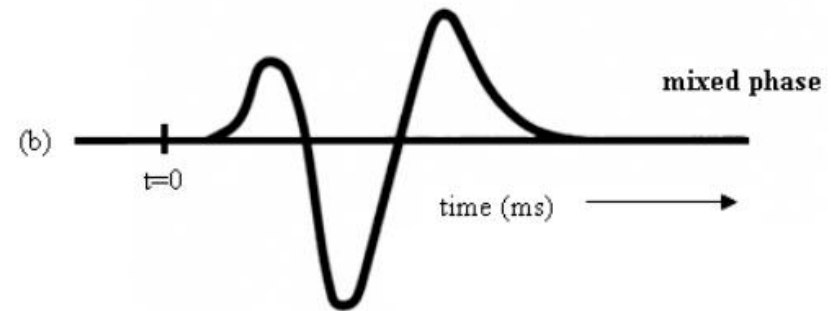
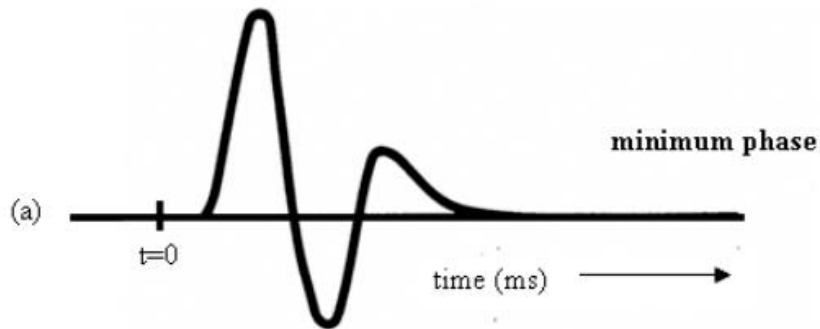


The particles move perpendicular to the propagation with highest amplitude at the surface.

Can't be generated on homogenous media, another layer with different elastic properties is needed in shallow depth.

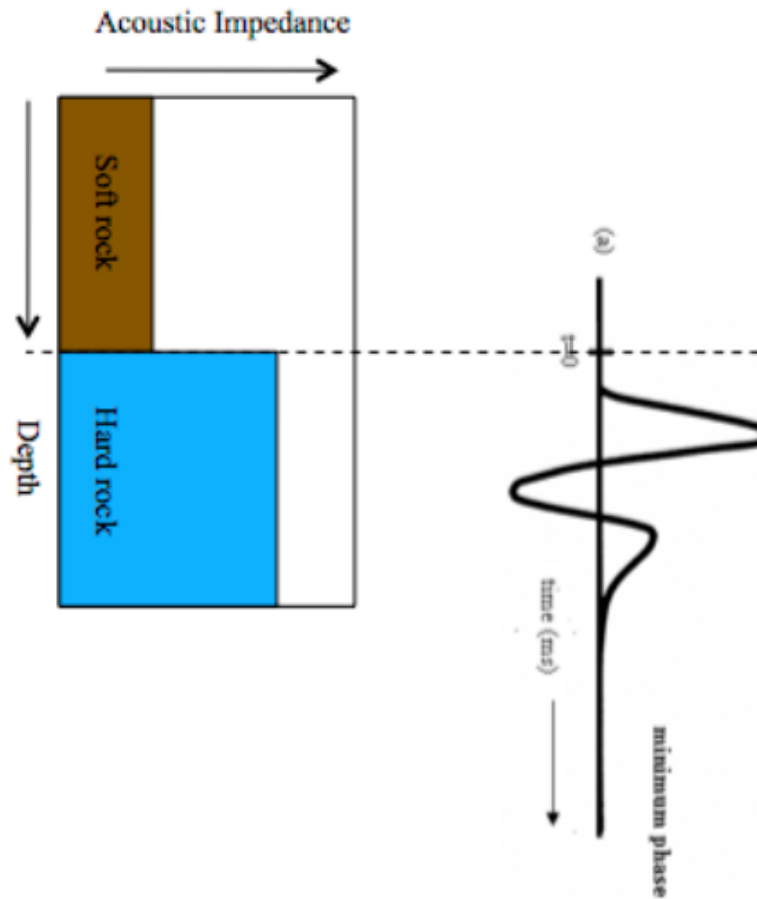
I. Properties of waves: 2. Waveforms

► Wavelets



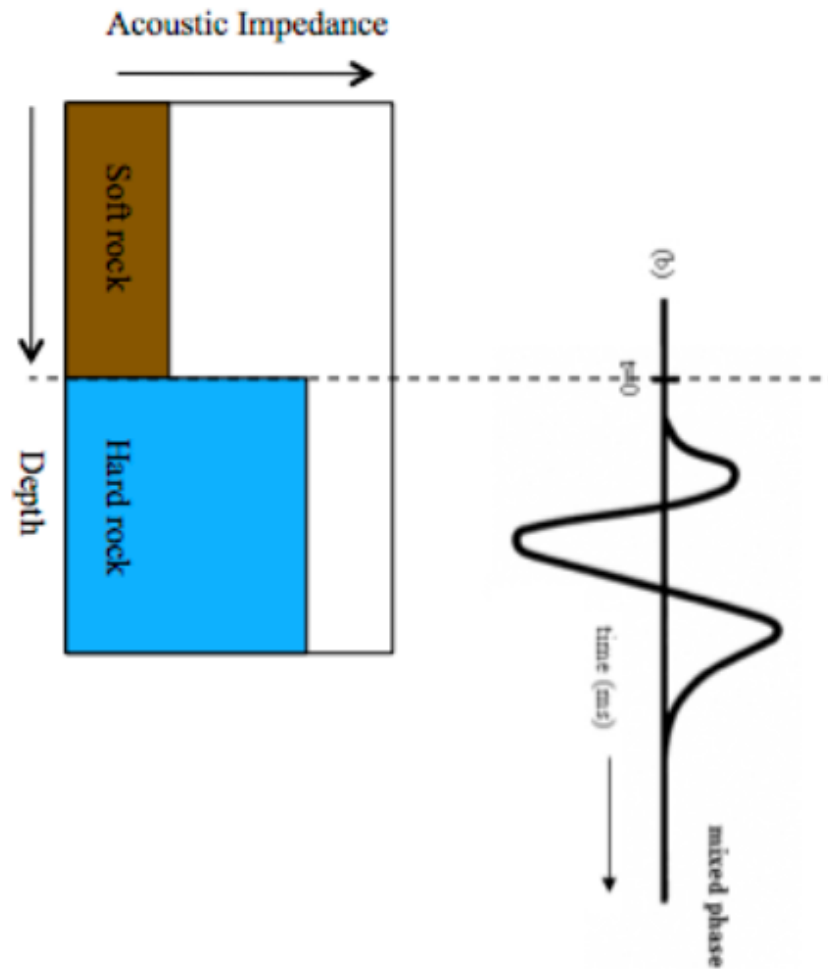
I. Properties of waves: 2. Waveforms

► Minimum phase



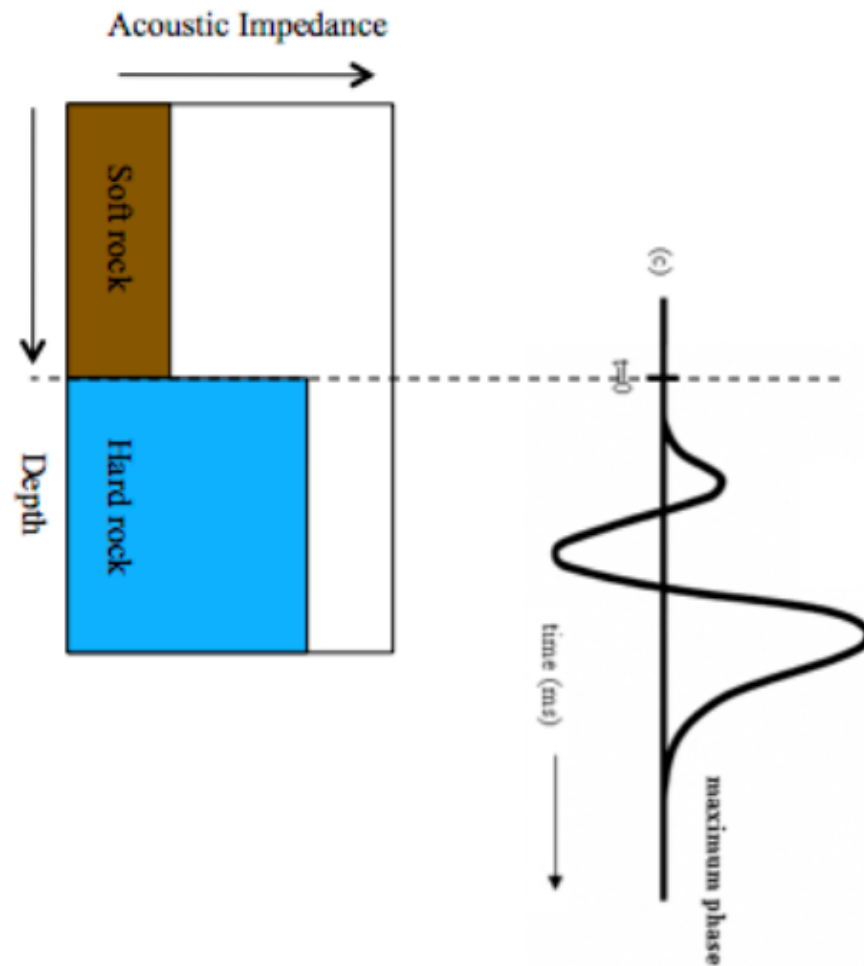
I. Properties of waves: 2. Waveforms

► Mixed phase



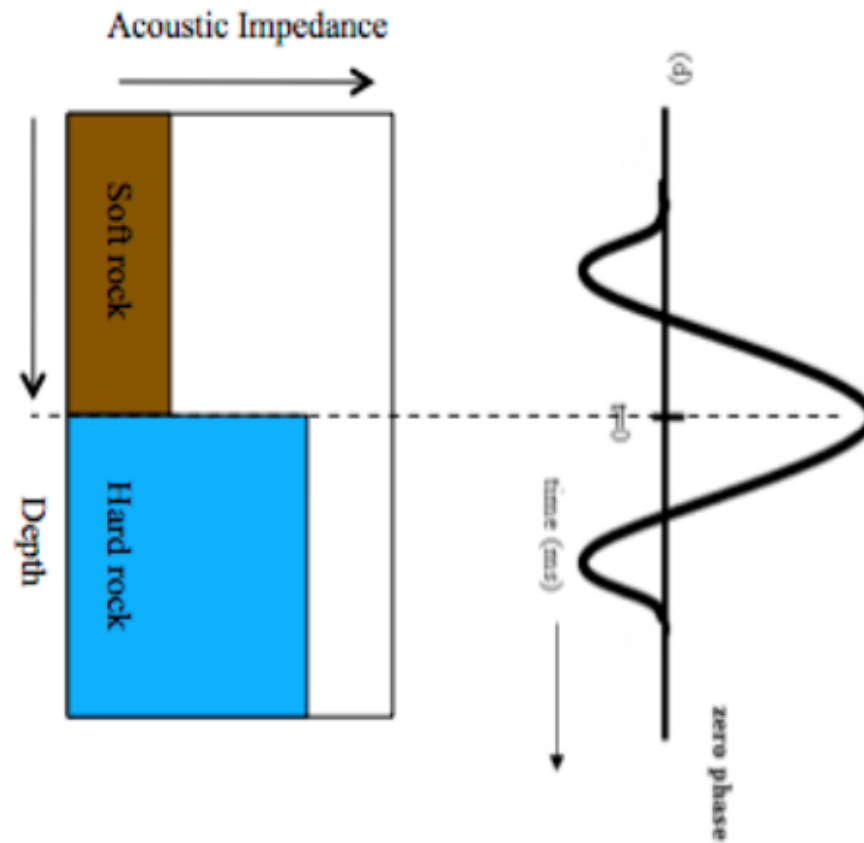
I. Properties of waves: 2. Waveforms

► Maximum phase

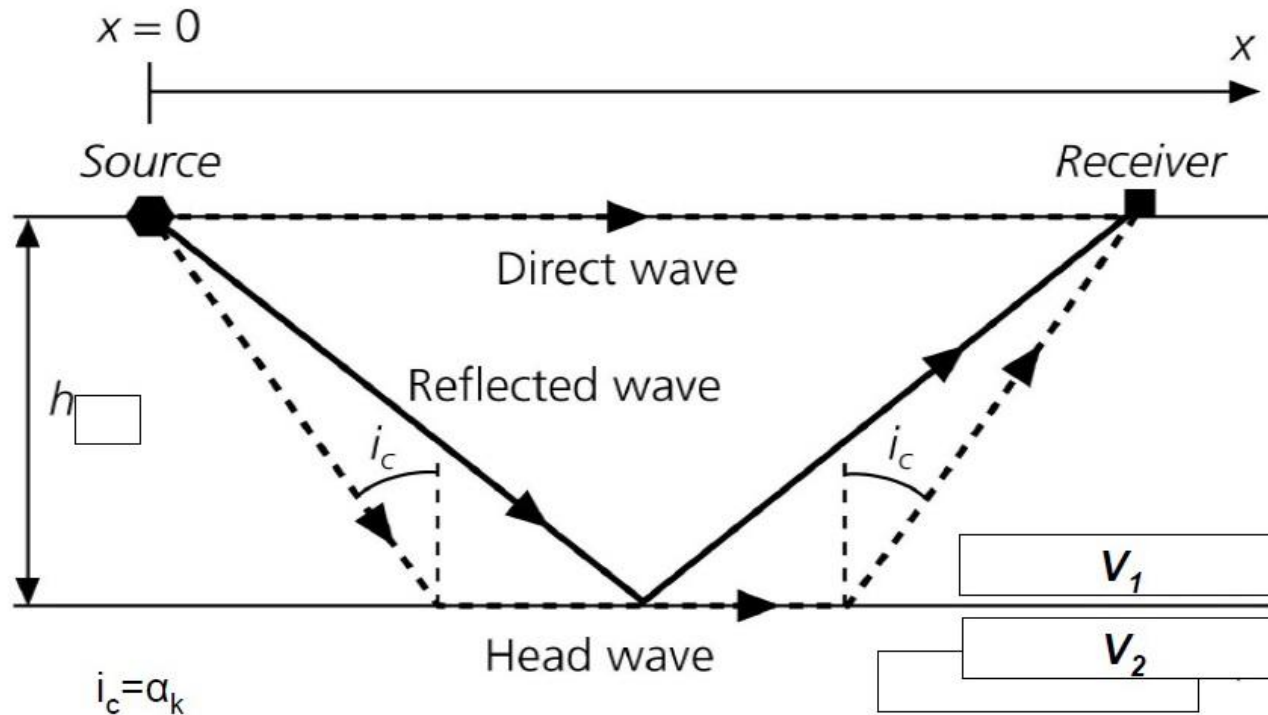


I. Properties of waves: 2. Waveforms

► Zero phase



Travel times in the function of source-receiver distance



Direkt hullám
(Direct wave):

$$t = x/V_1$$

straight

Reflektált hullám
(Reflected wave):

$$\frac{V_1^2 t^2}{4h^2} - \frac{x^2}{4h^2} = 1$$

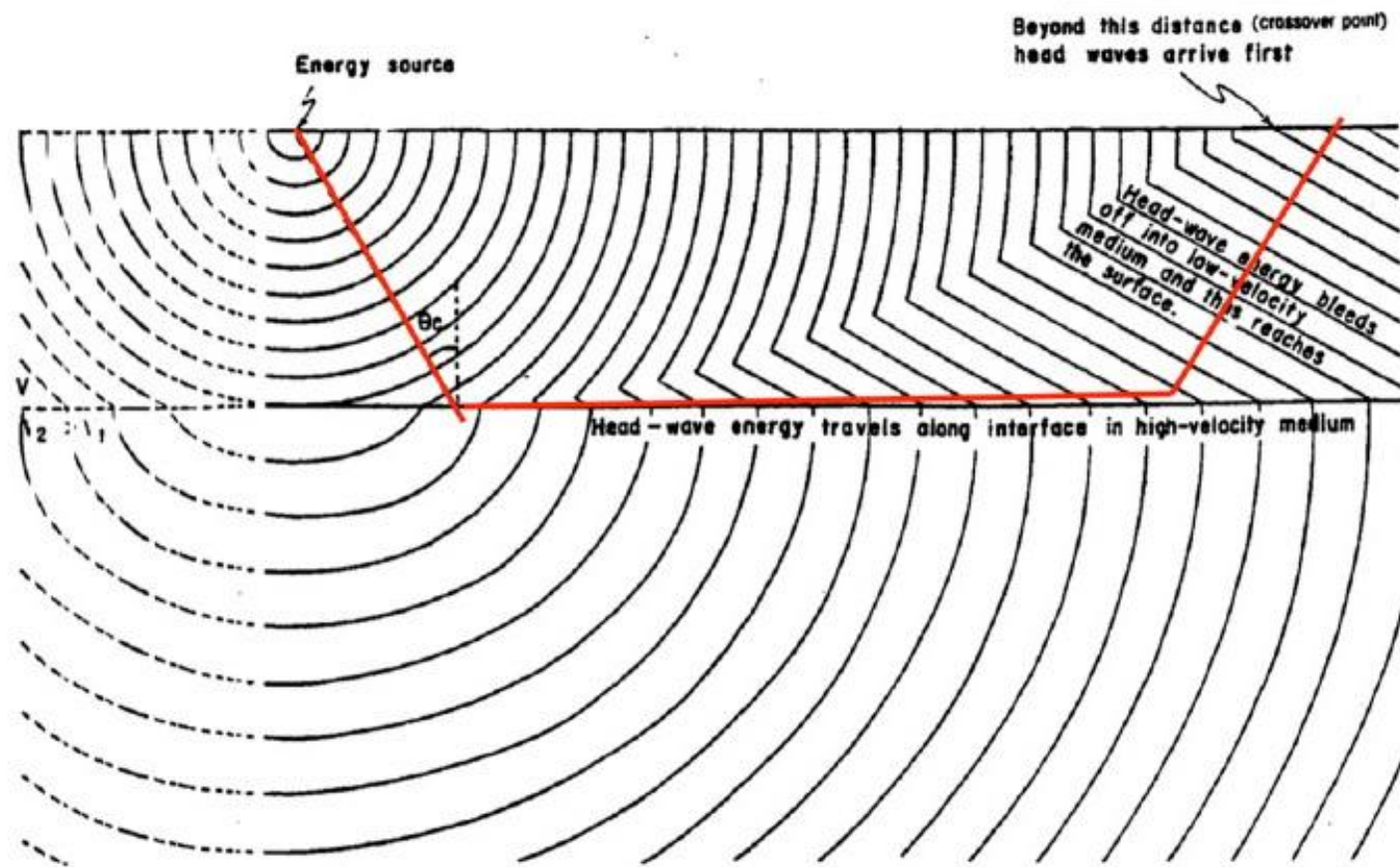
hyperbole

Refraktált hullám
(Head wave):

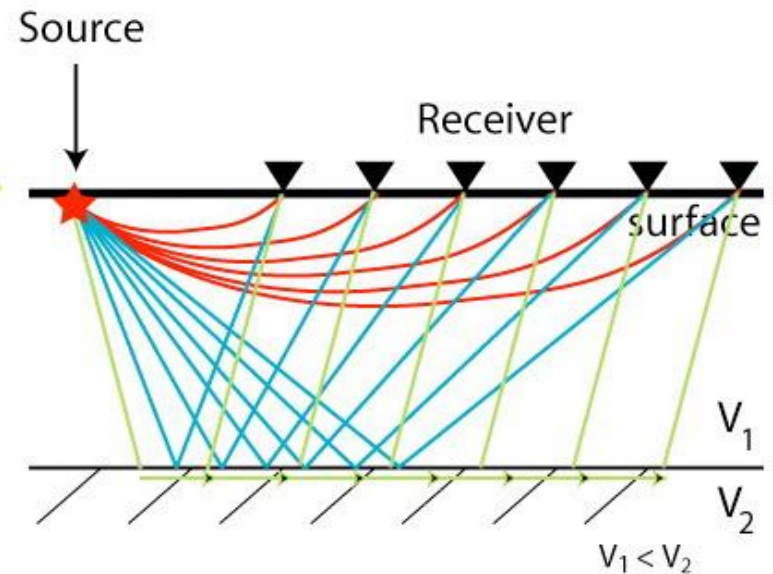
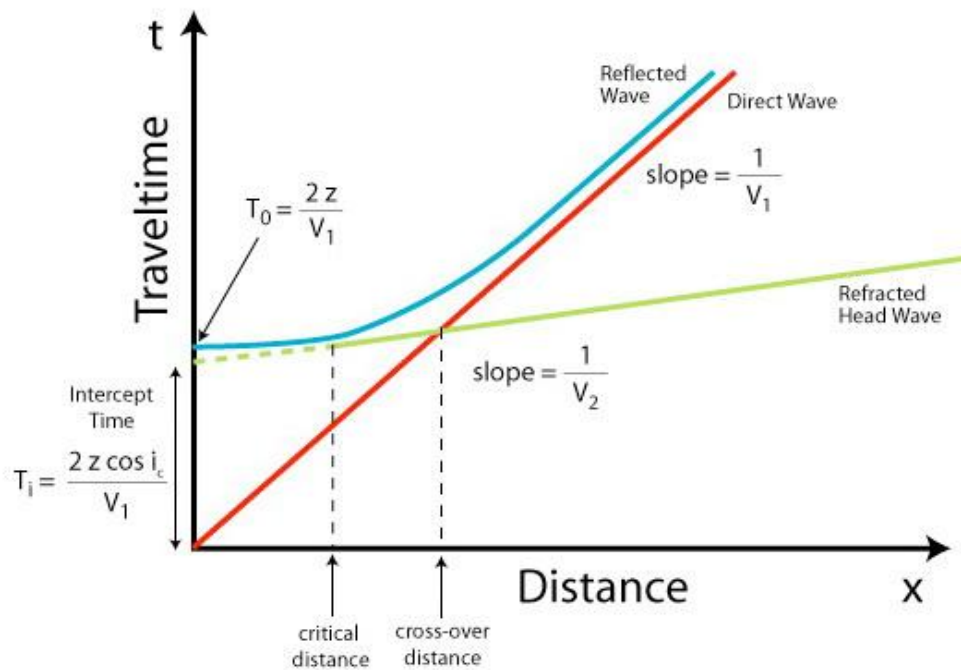
$$t = \frac{x}{V_2} + \frac{2h \cos \alpha_k}{V_1}$$

straight

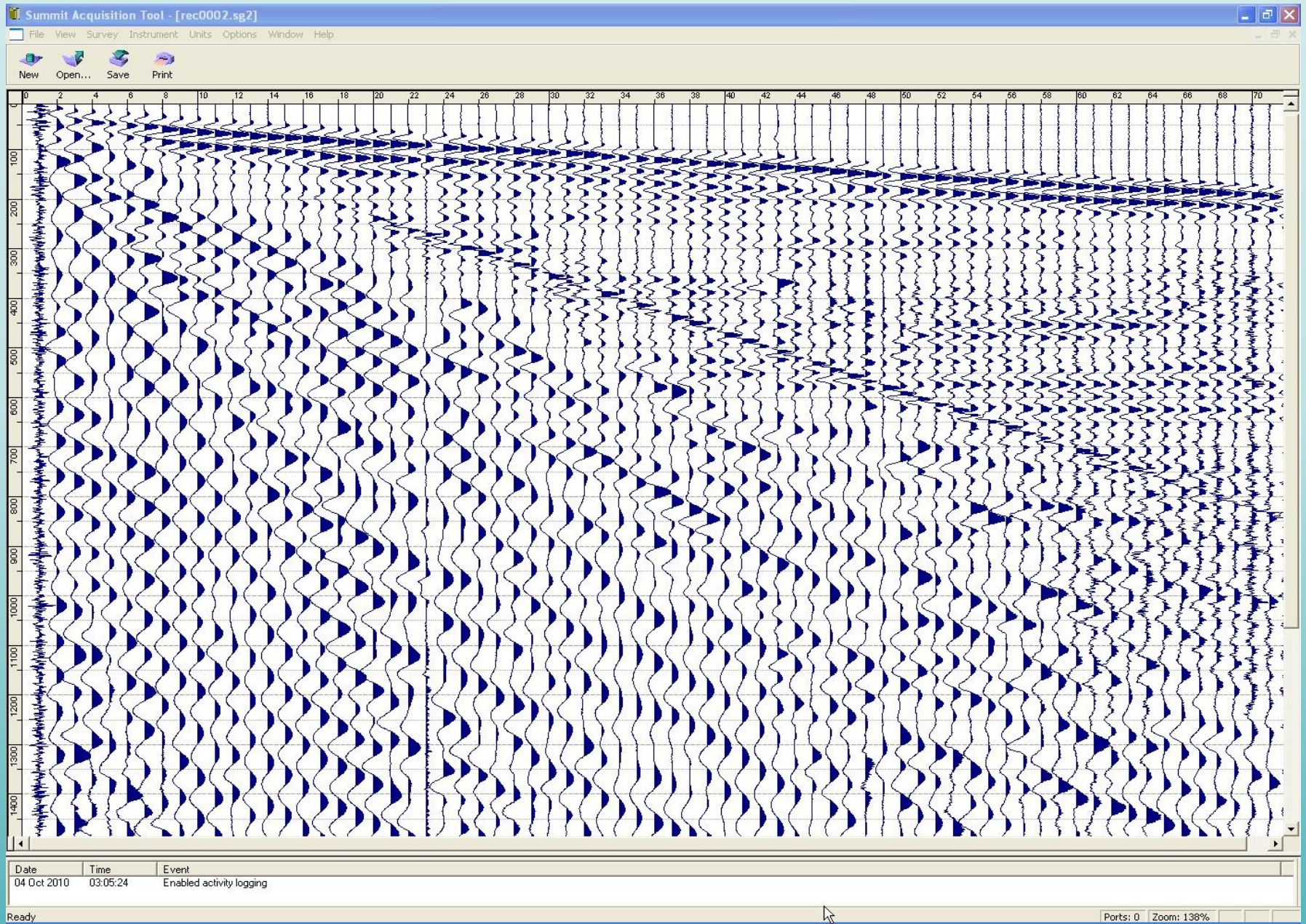
- ▶ Rays which enter or leave a high velocity medium at a critical angle are known as head waves or refracted waves



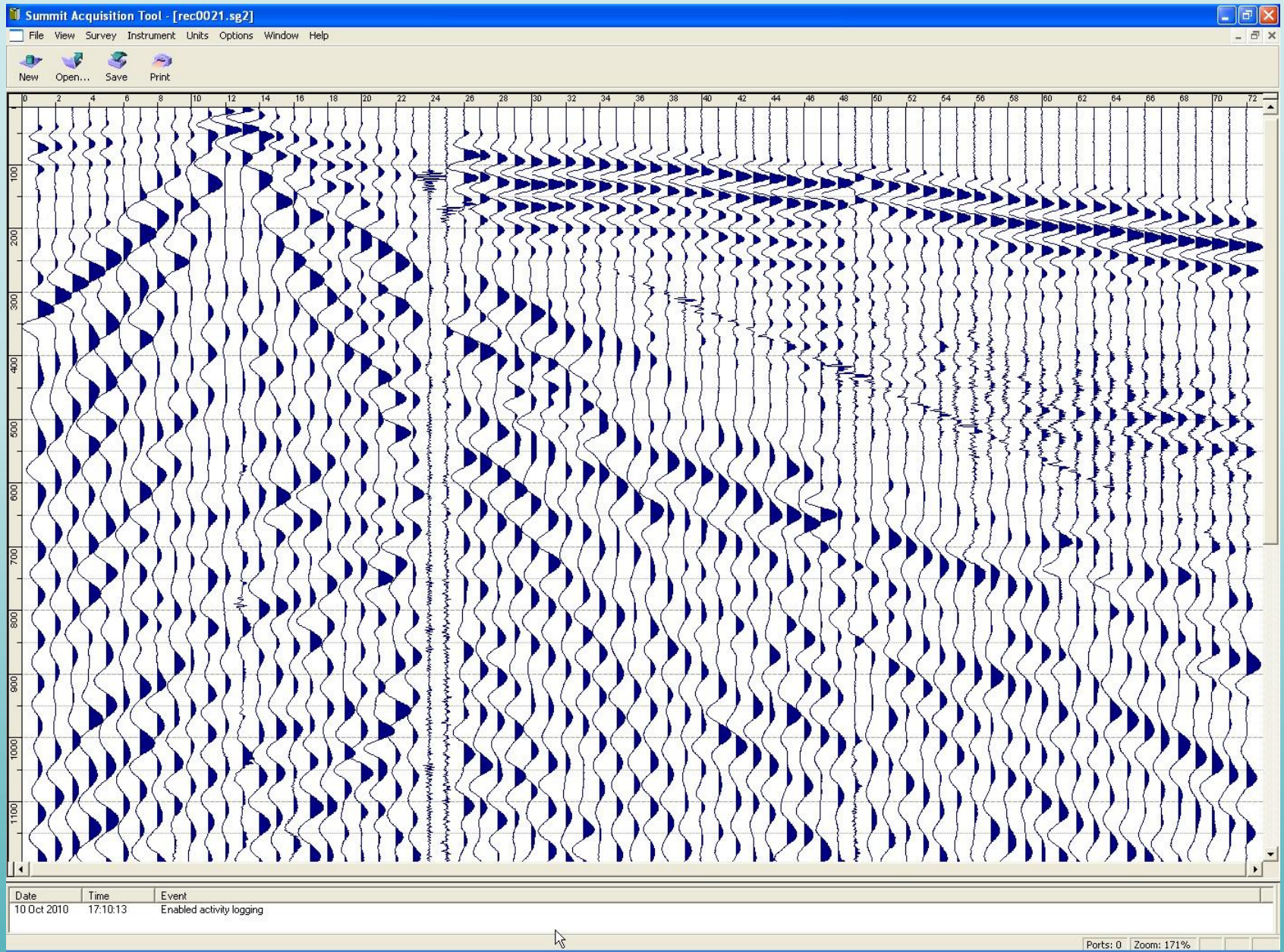
I. Travel times:



Seismic record



Offset dependence of the „useful” range

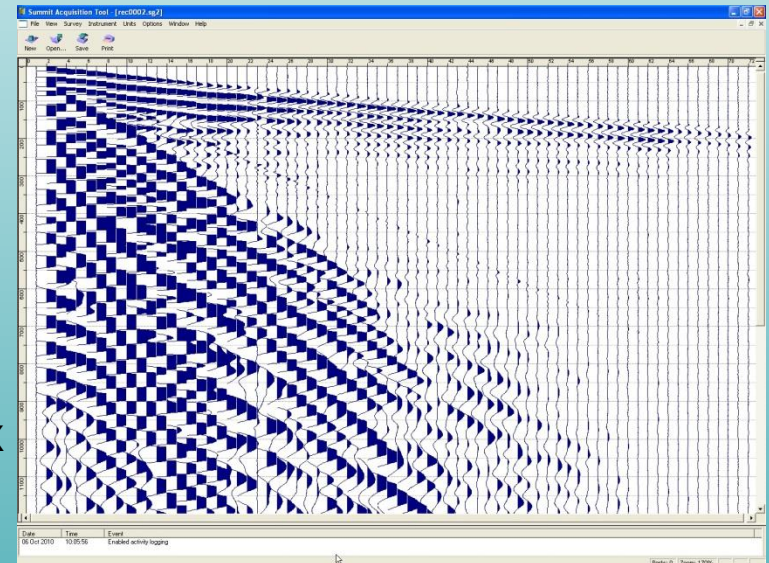
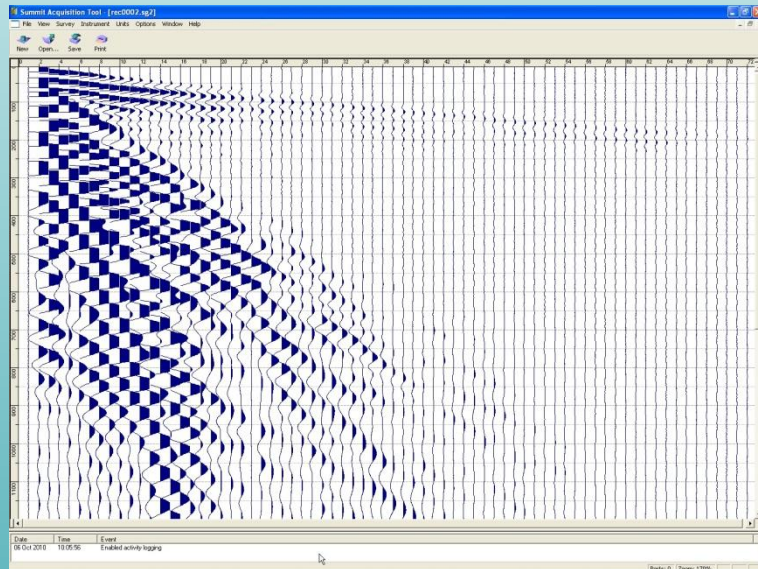
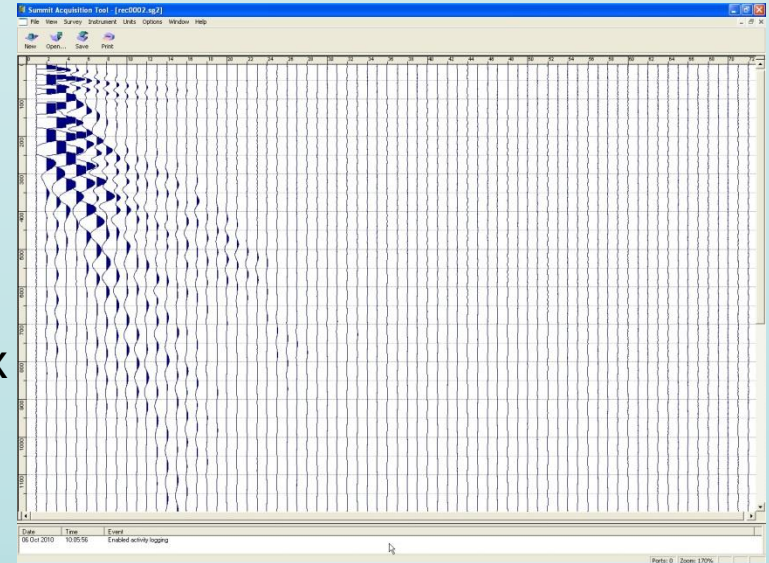
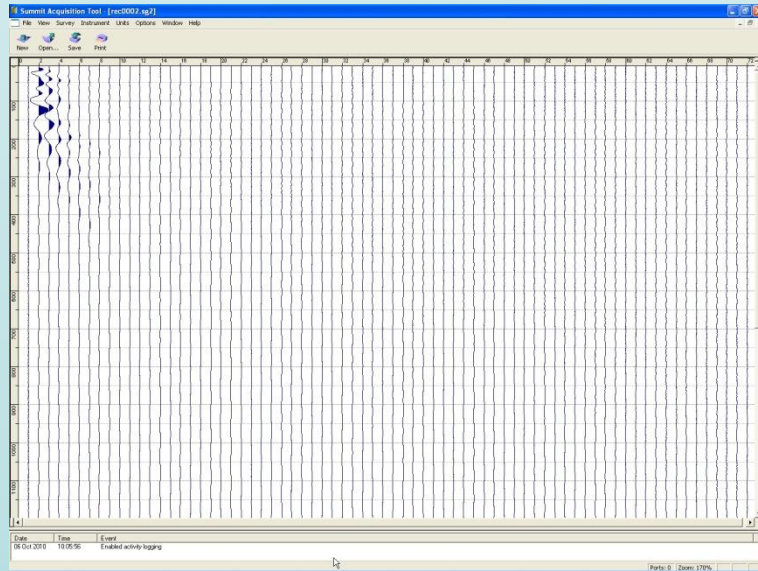


Amplitudes

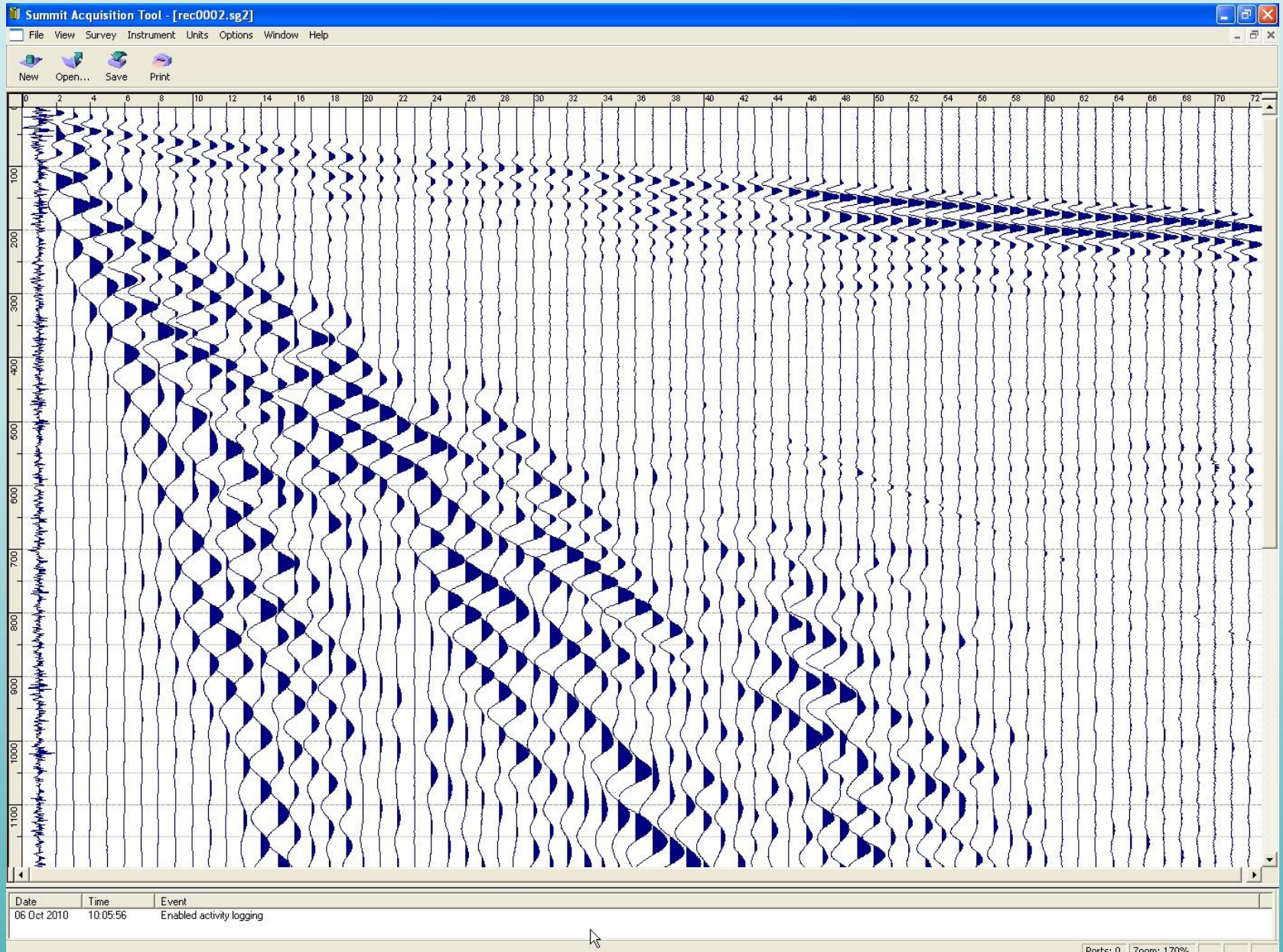
- Signal voltage range: $\sim 10\mu\text{V}$ - $\sim 1\text{V}$
Can be increased: source strength, geophone group, stacking
- Mechanical noise range: ~ 1 - $10\mu\text{V}$
Can be decreased: careful planning, good connection between the geophone and the ground, good timing (weather)
- Electronic noise range: $< 1\mu\text{V}$
Can't be decreased

Dynamic-range: 6-7 order of magnitude $\Rightarrow$ 24 bit is needed

„Uniform” or „entire” scaling



Individual scaling



Automatic Gain Control (AGC)

- RMS

$$g(t) = \frac{K}{\sqrt{\frac{1}{N} \sum_{i=1}^N A_i^2}}$$

K : desired gain

N : number of samples in the time gate

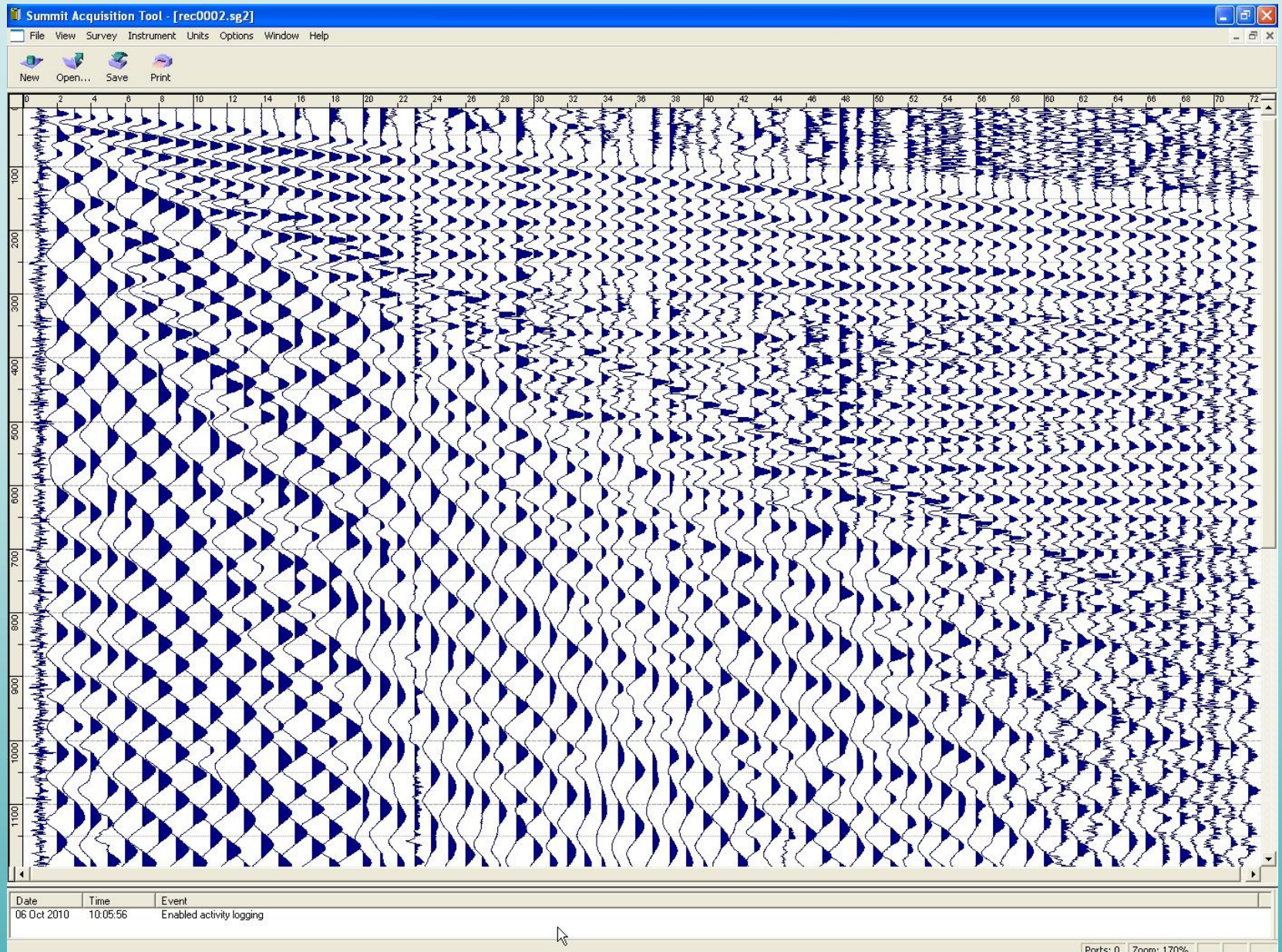
Fixed time gates: the gain is calculated for the middle sample, the other values are interpolated

- ABS

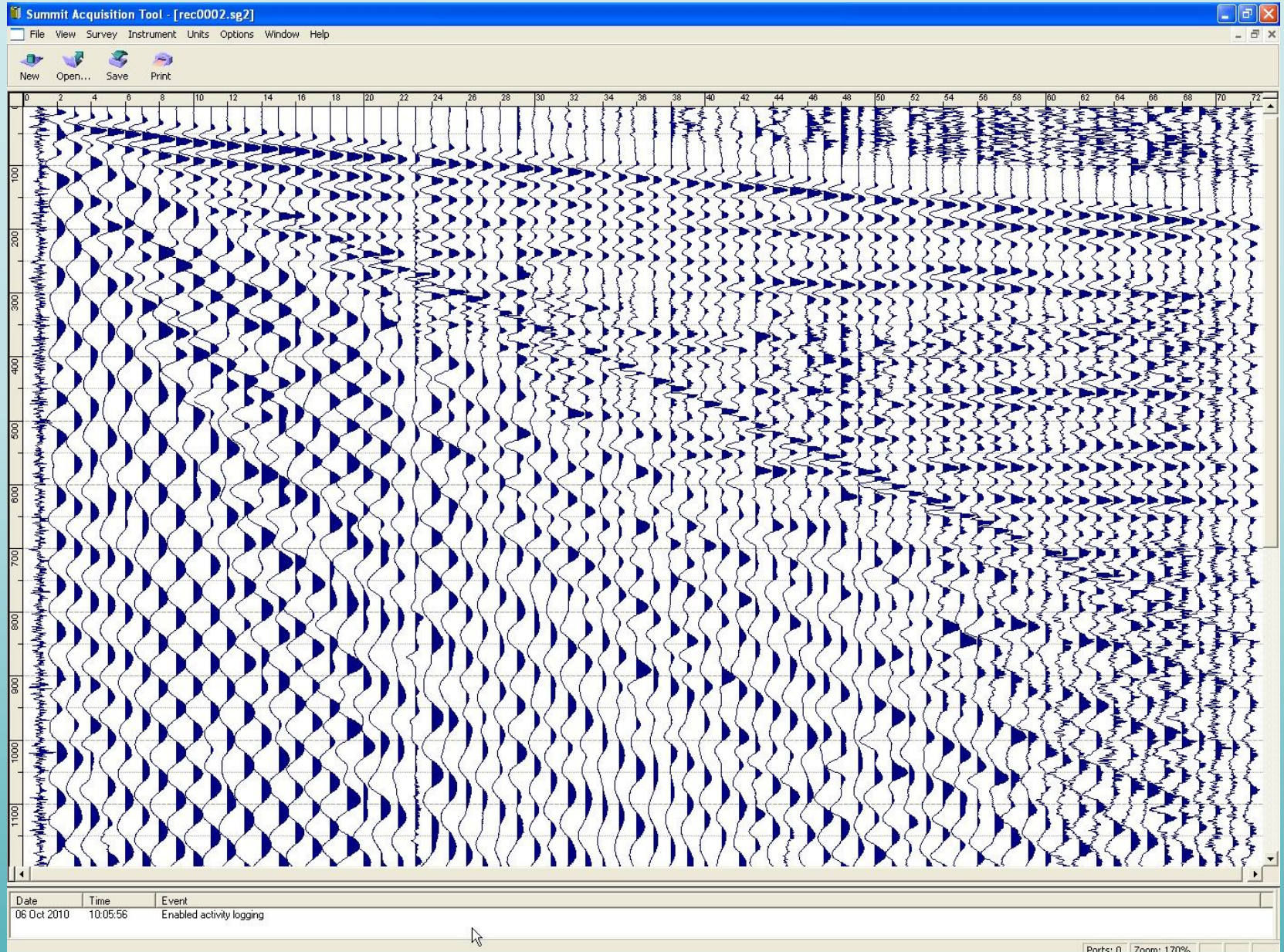
$$g(t) = \frac{K}{\frac{1}{N} \sum_{i=1}^N |A_i|}$$

Stepping time gate: the gain for all the samples is calculated

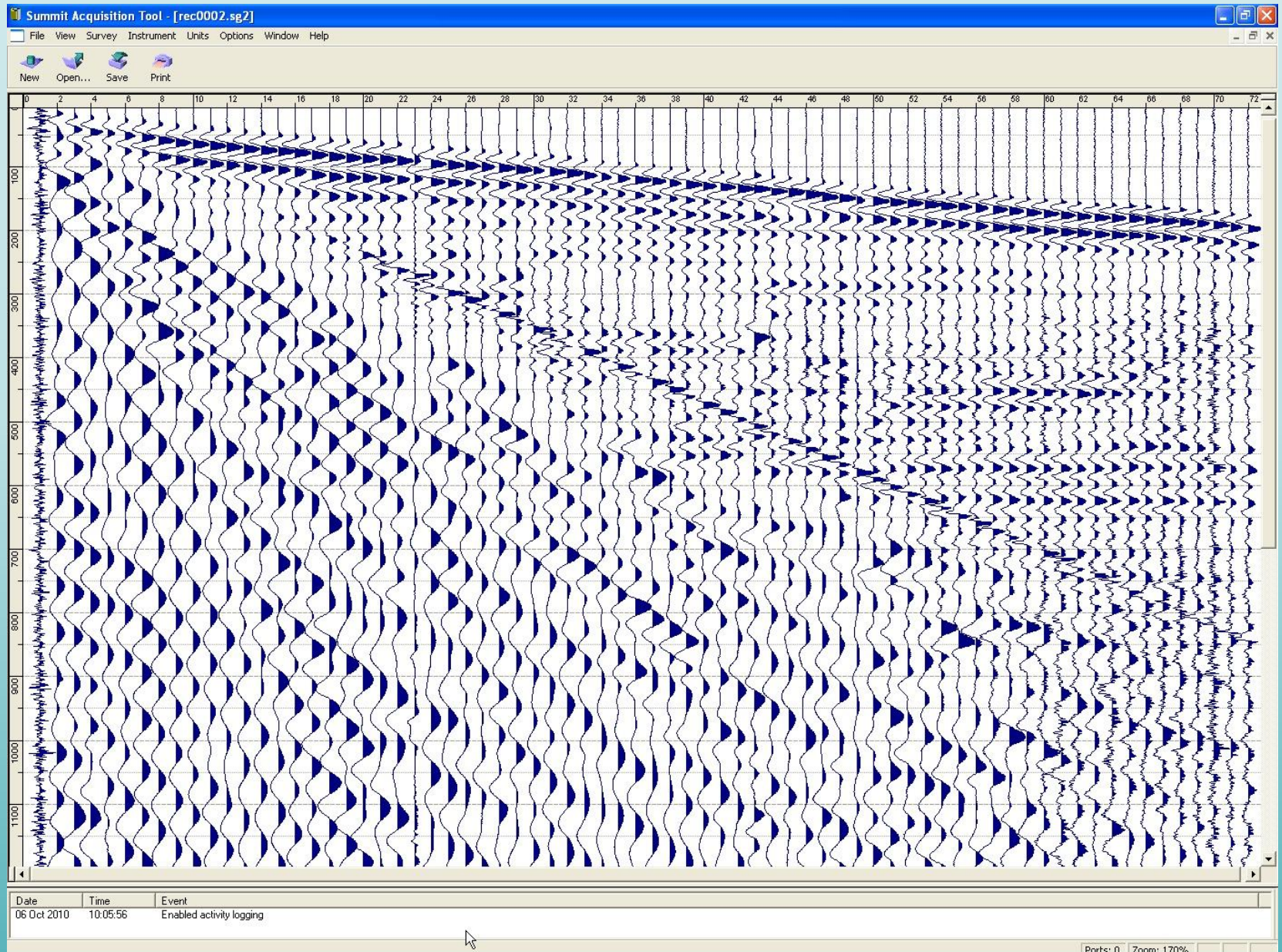
AGC 50ms



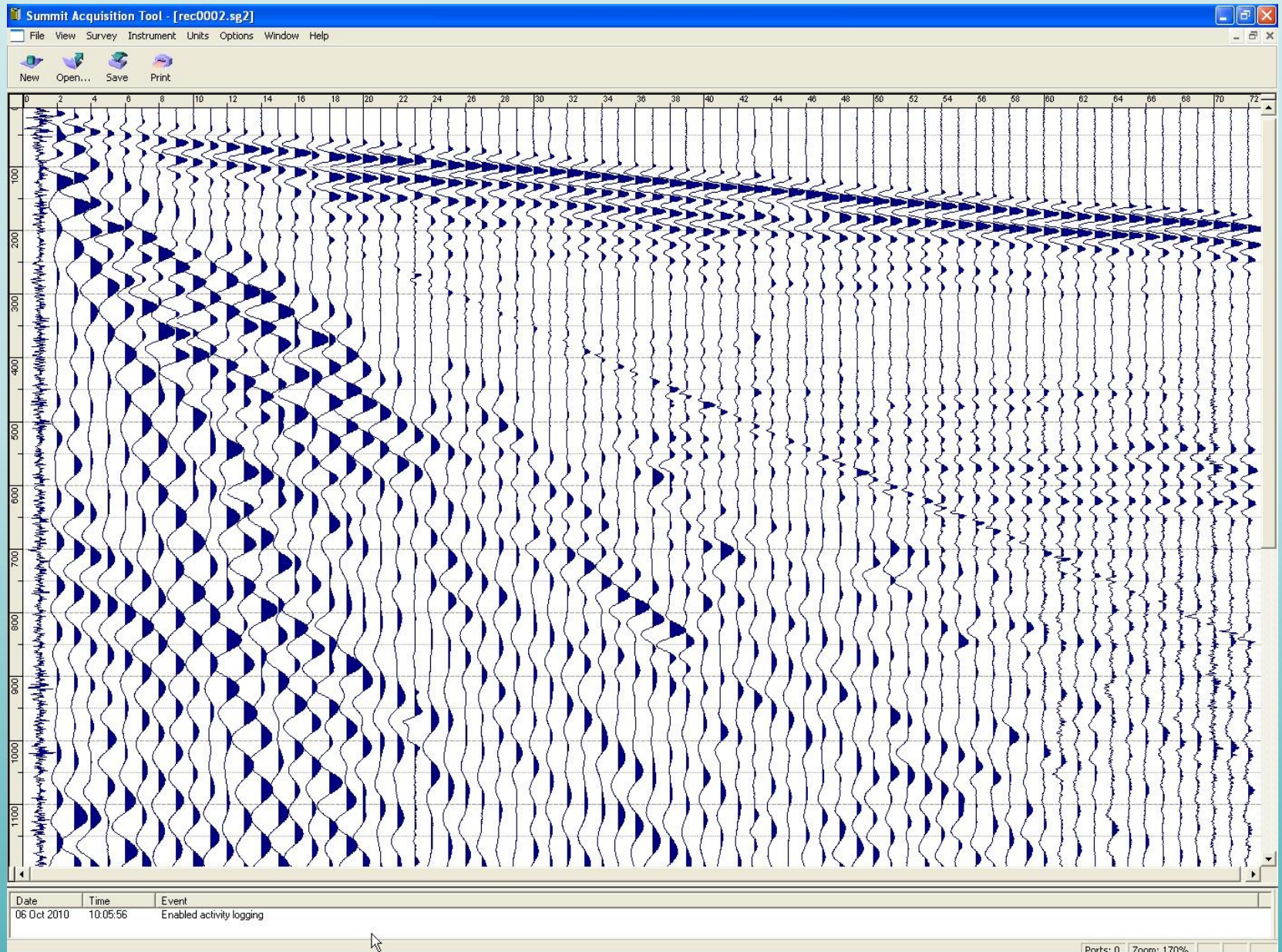
AGC 100ms



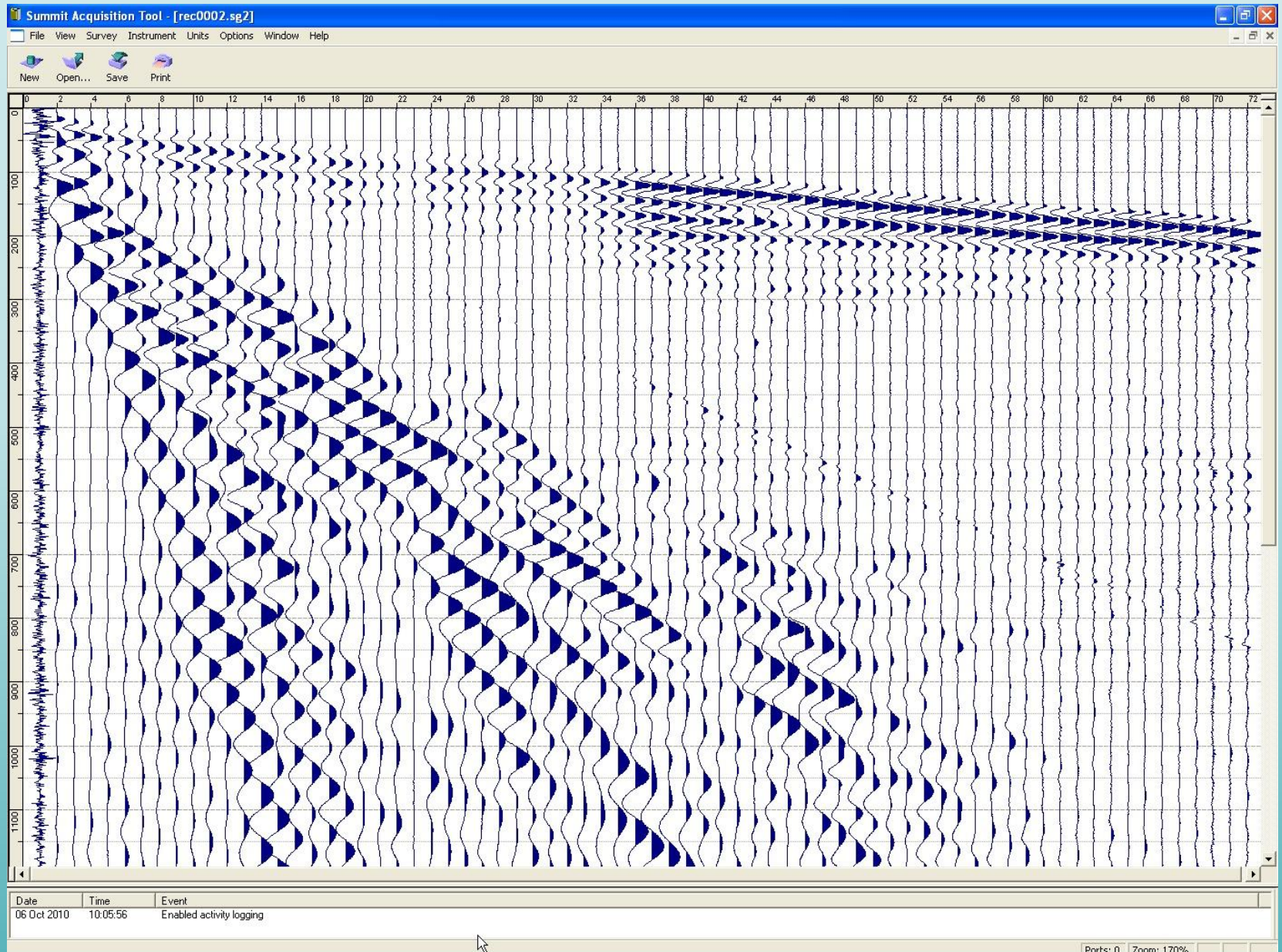
AGC 200ms



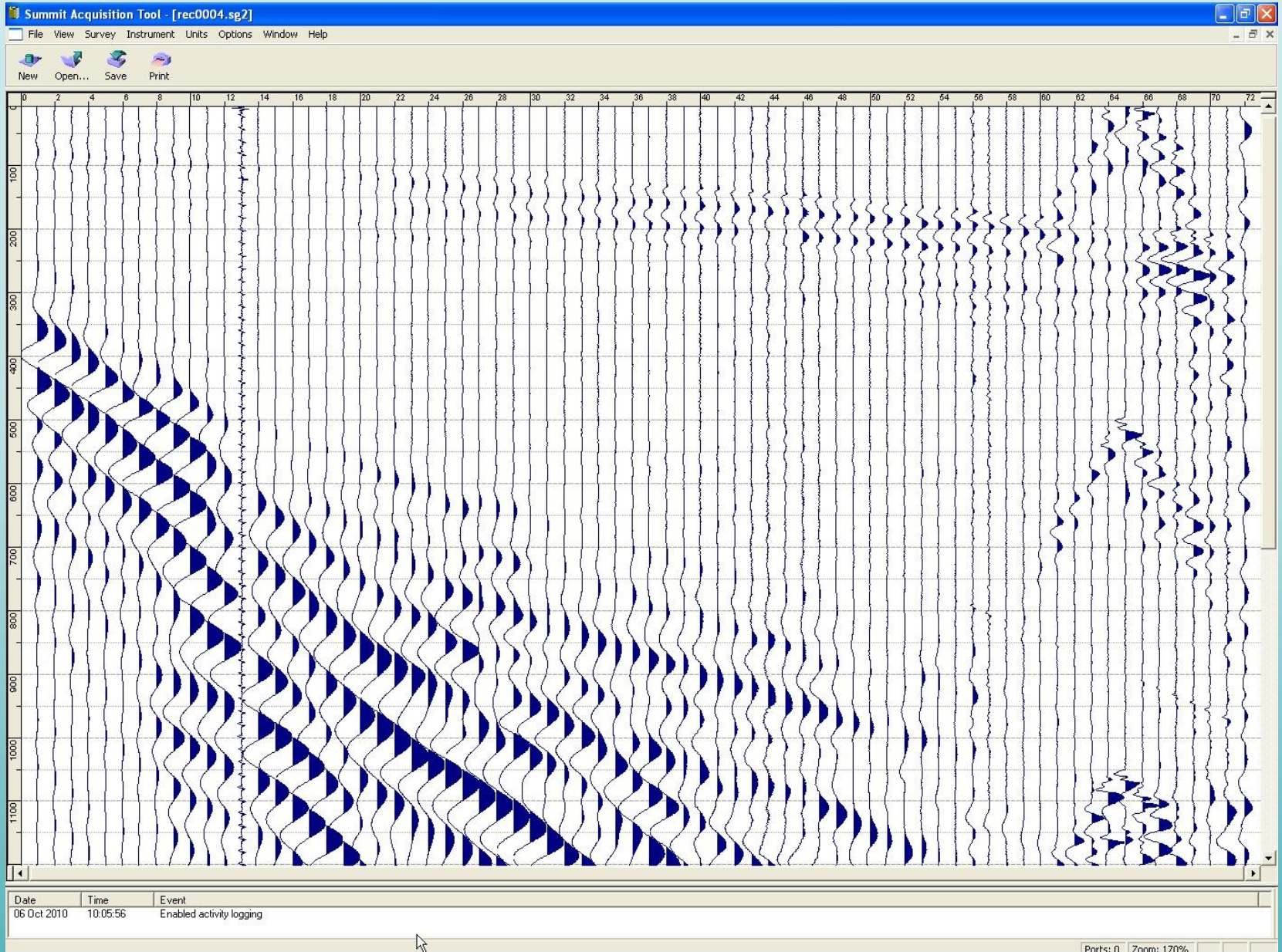
AGC 400ms



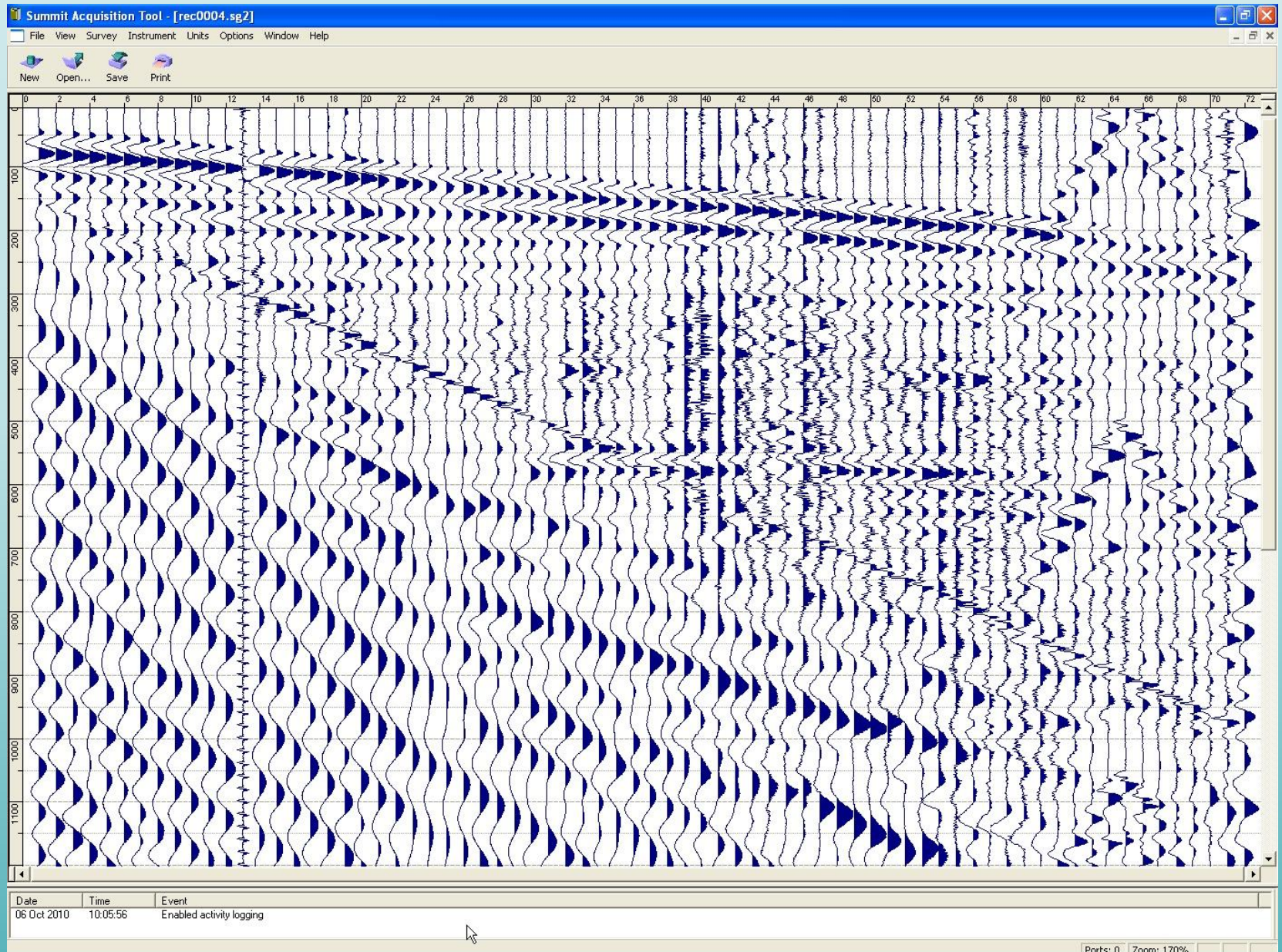
AGC 1000ms



„Step in” on individual scale

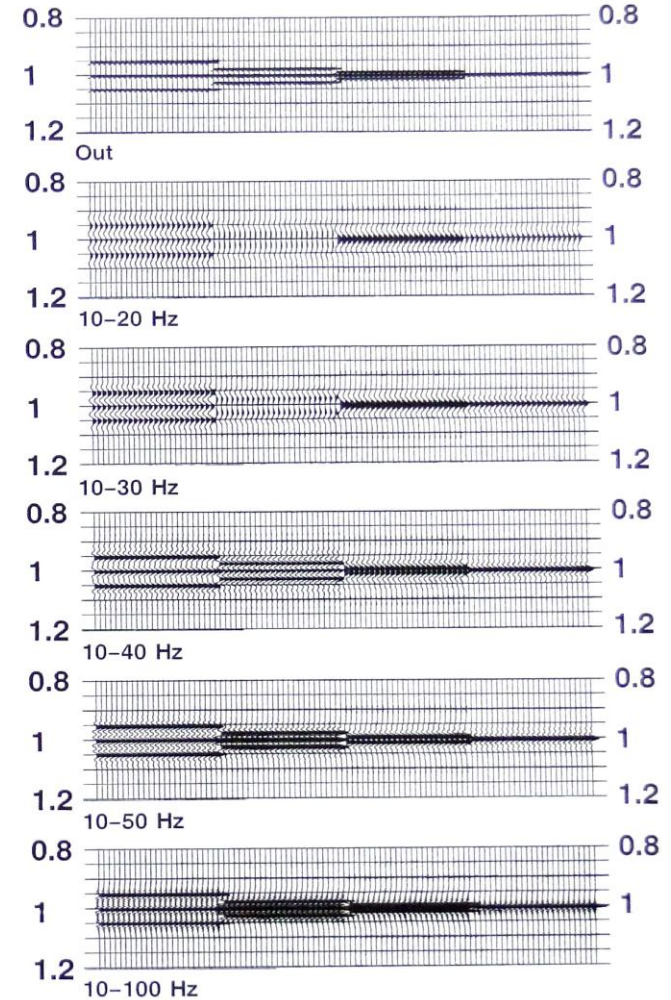
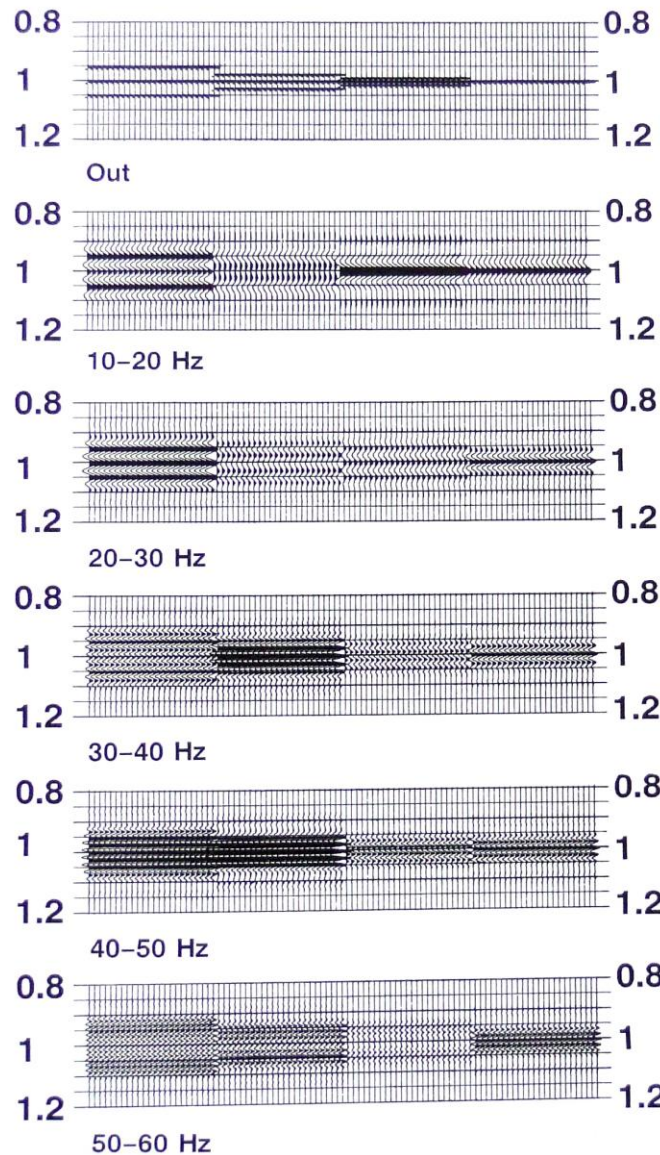


„Step in” with AGC

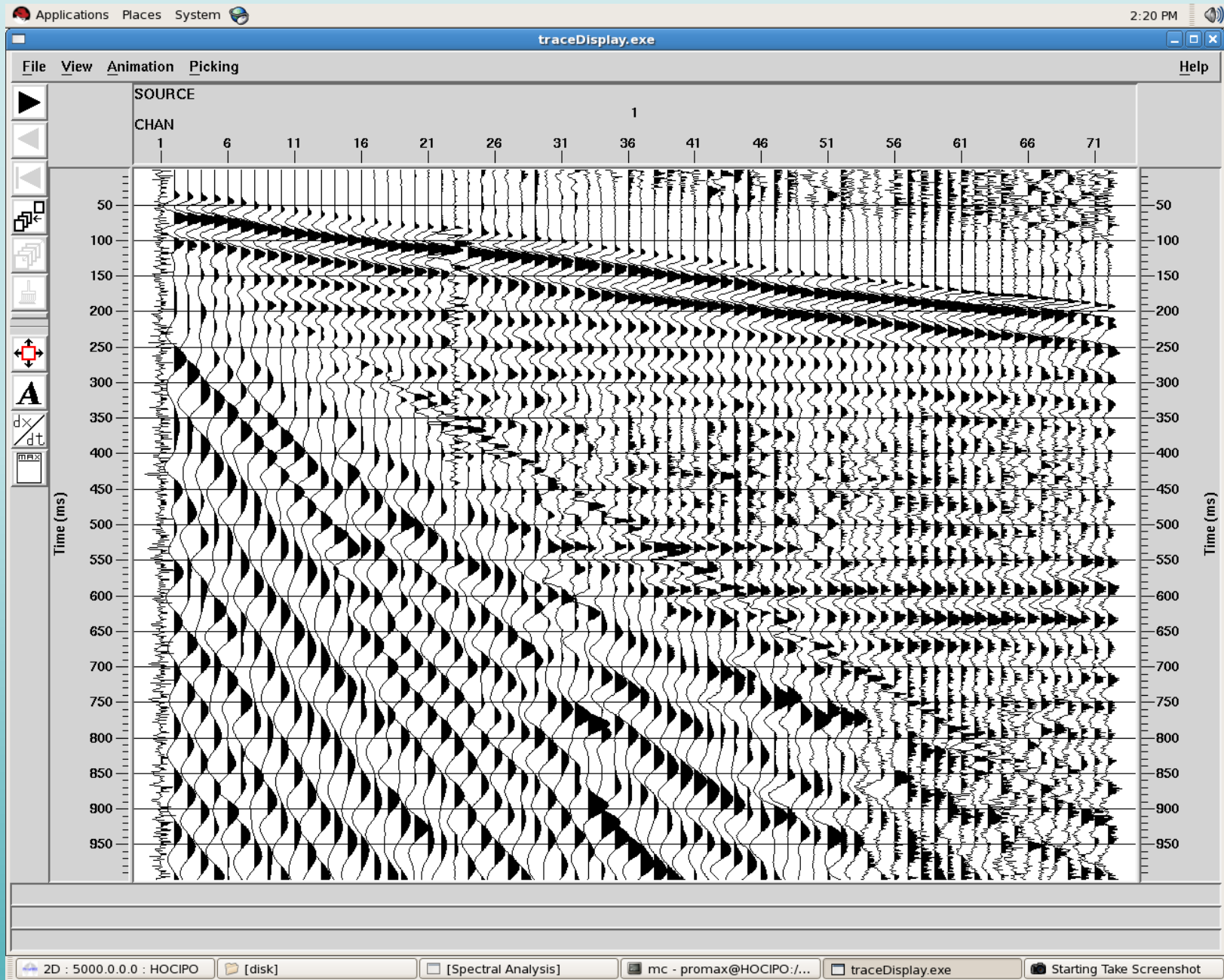


Band width and resolution

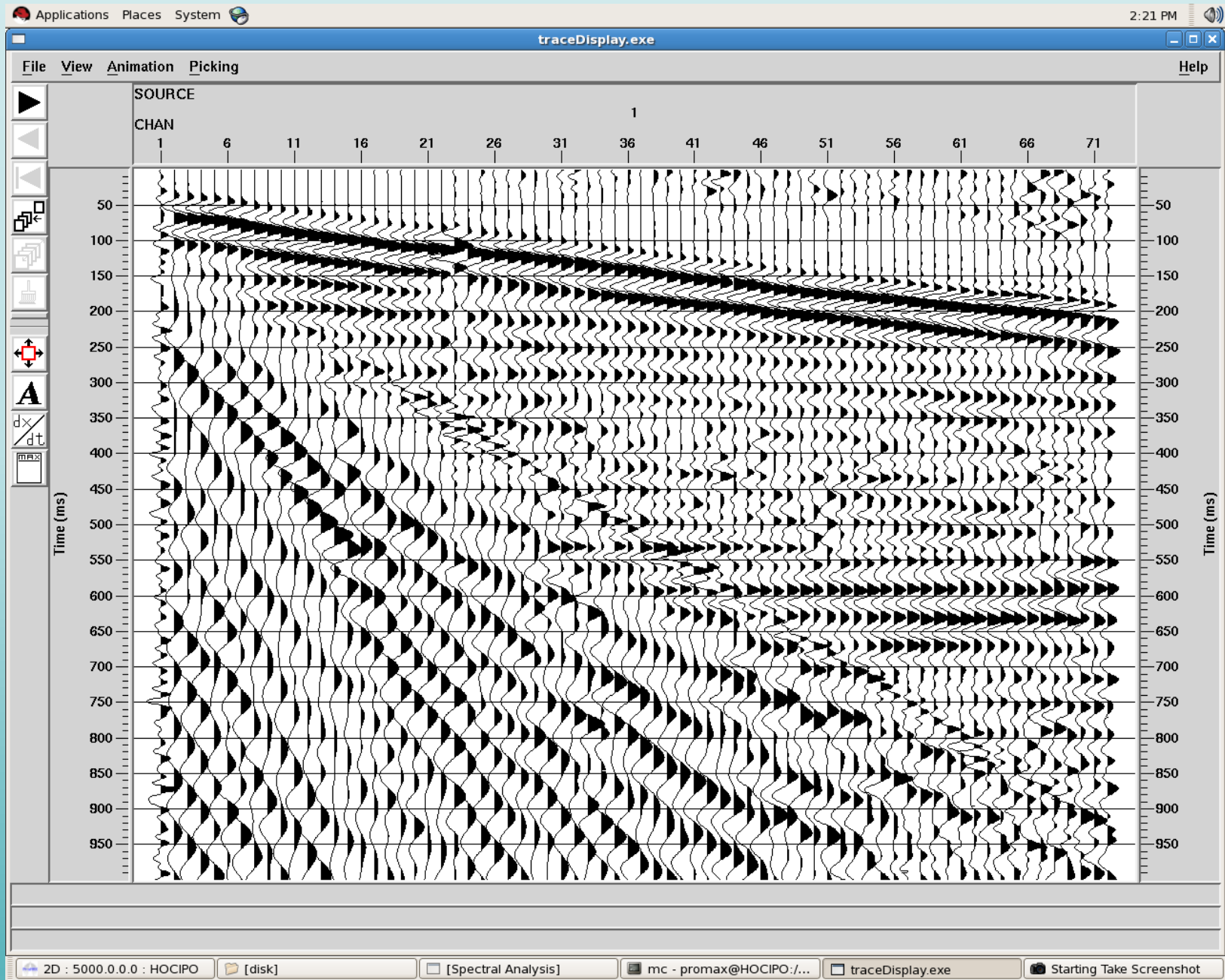
For good
resolution
BOTH the
lower and higher
frequencies are
needed



Raw record with AGC



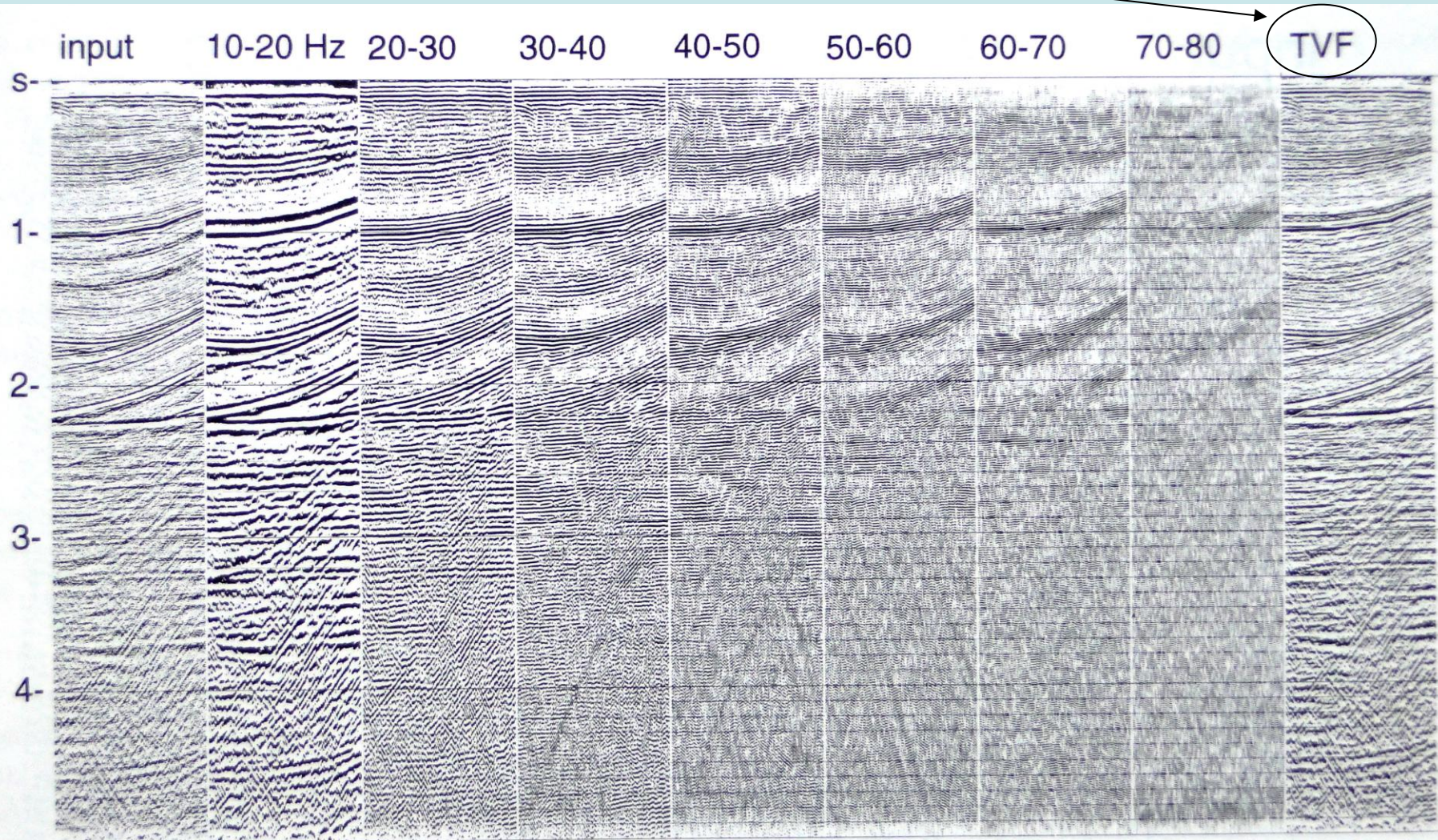
Filtered record (8-12-60-80) with AGC



Time variant bandwidth filtering

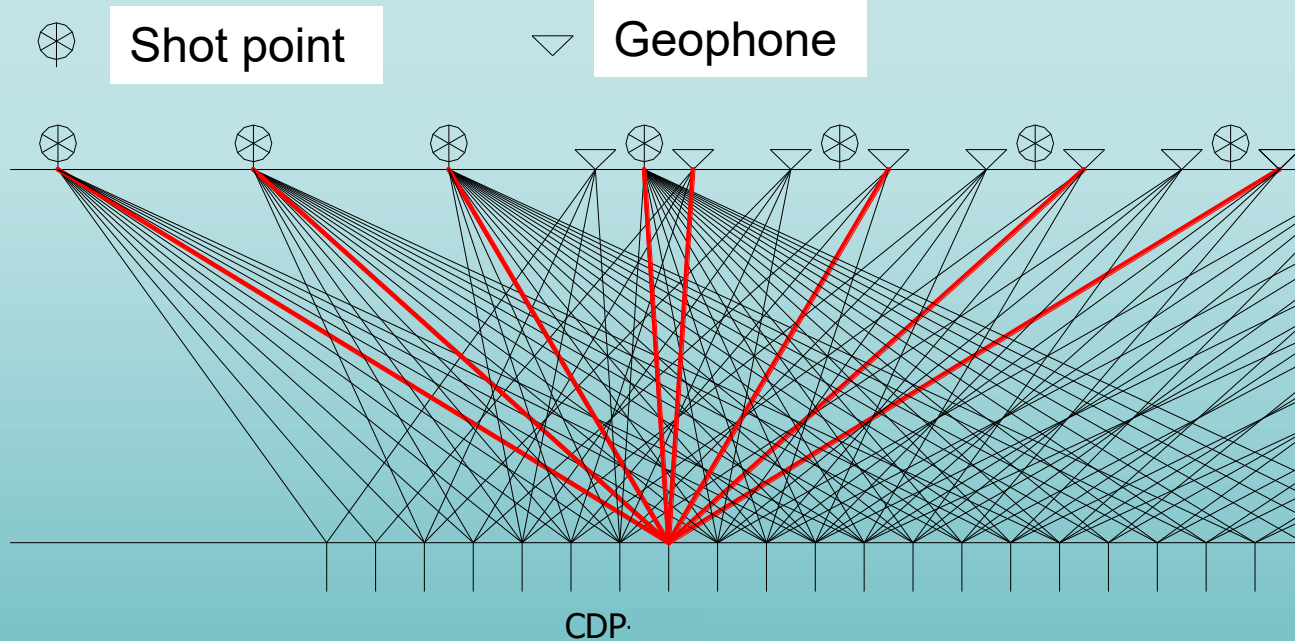
0s → 5s

5-10-70-80 Hz → 5-10-40-50 Hz



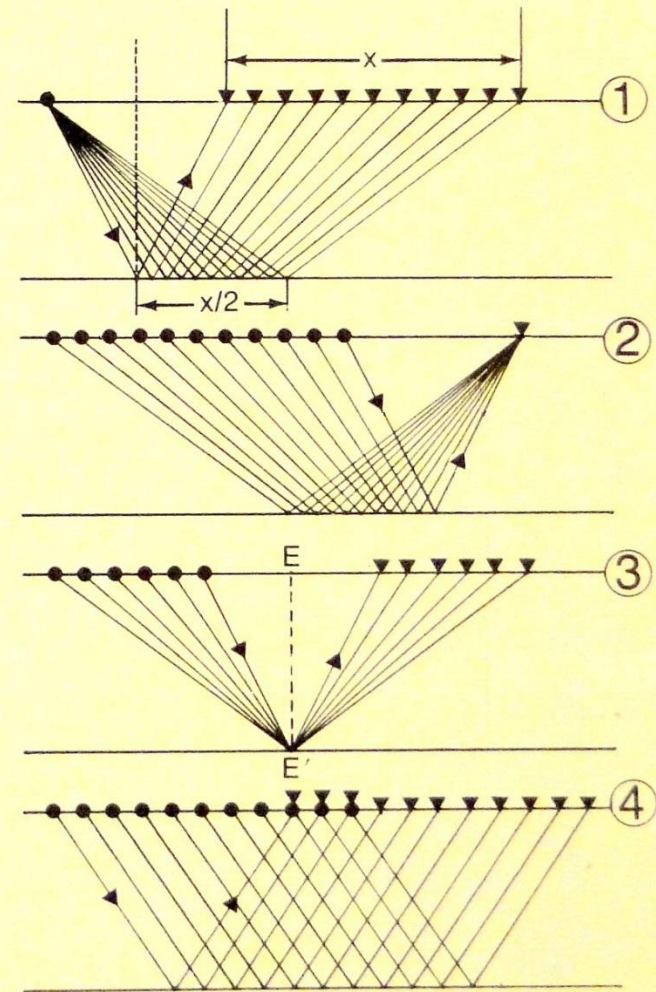
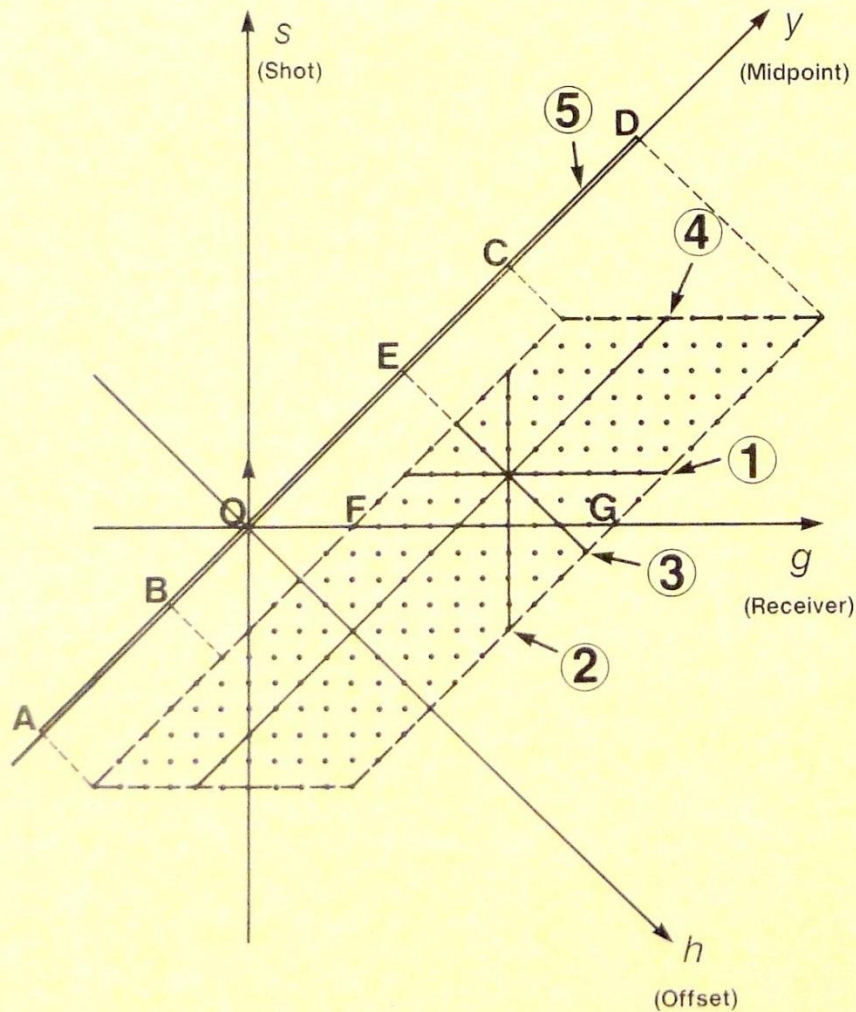
Shooting systems, CMP, CDP

Reflection seismic array with double shot point distance



Offset: source-receiver distance

Grouping of seismic channels



What is velocity?

„Local” velocity: v_{lok}

Layer velocity (interval-velocity),

$v_{int} \cdot v_{lok}$

Average velocity: v_{av}

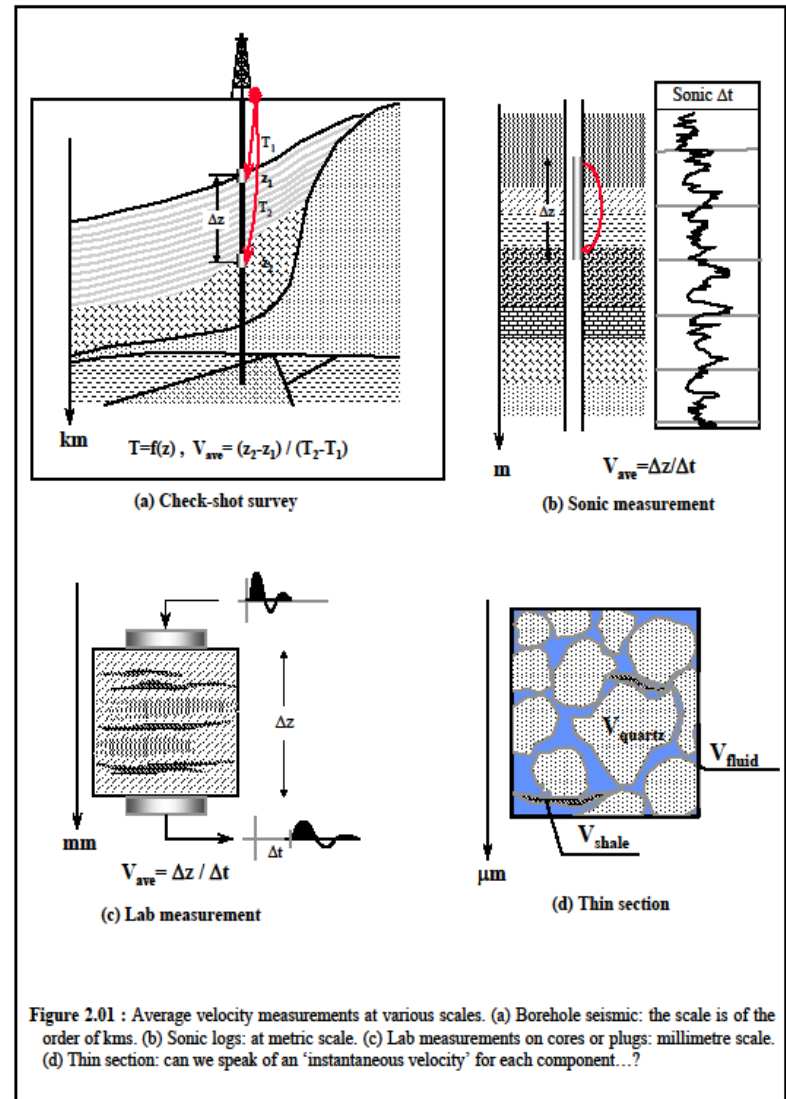
$$v_{av} = \frac{z_2 - z_1}{\int_{z_1}^{z_2} \frac{dz}{v_{lok}(z)}}$$

Root-mean-square velocity: v_{RMS} :

$$v_{rms}(T) = \sqrt{\frac{\int_0^T v_{lok}^2(t) dt}{T}} \quad v_{rms} \geq v_{av}$$

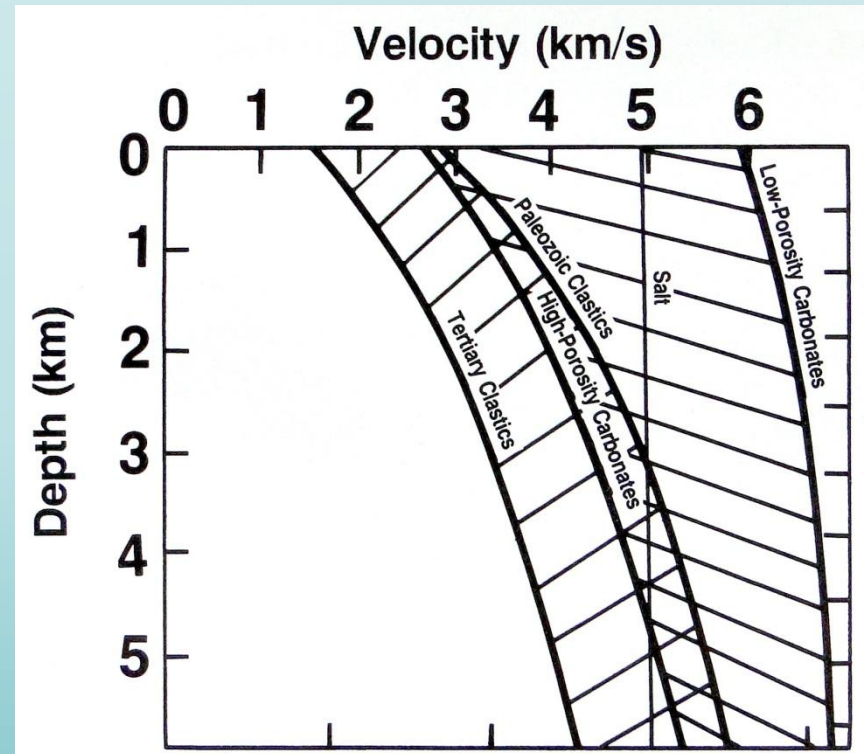
Interval velocity from rms velocity (Dix):

$$v_{int} = \sqrt{\frac{v_{RMS(n)}^2 t_n - v_{RMS(n-1)}^2 t_{n-1}}{t_n - t_{n-1}}}$$



How much is the velocity?

- Based on the type of the rock.
- Affected by:
 - porosity
 - shape of the pores,
 - saturation
 - temperature
- The velocity more rapidly increases with pressure (depth) at first; then later the changing is slower (closing of pores).
- P wave velocity is larger than S wave velocity for all type of rocks

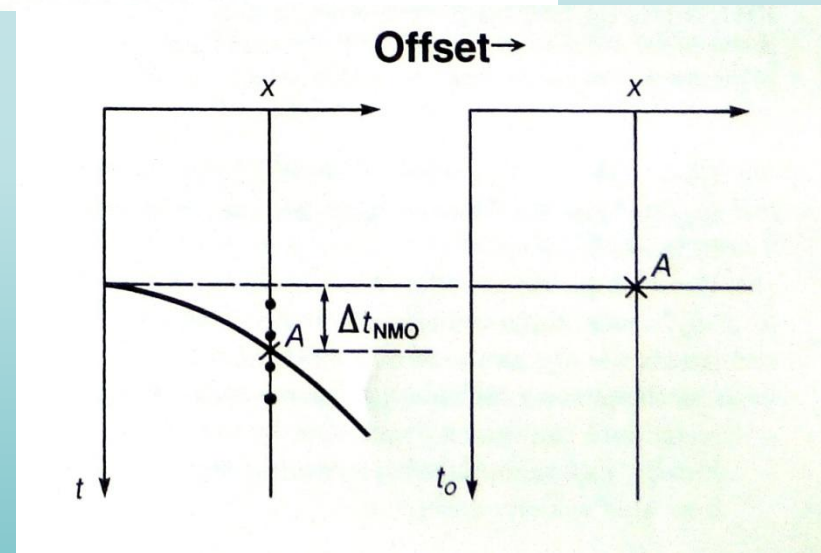
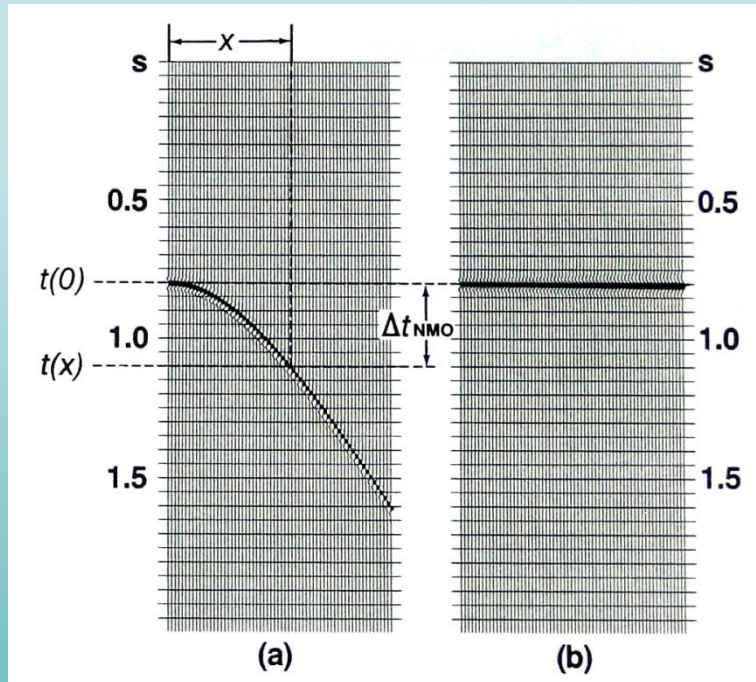
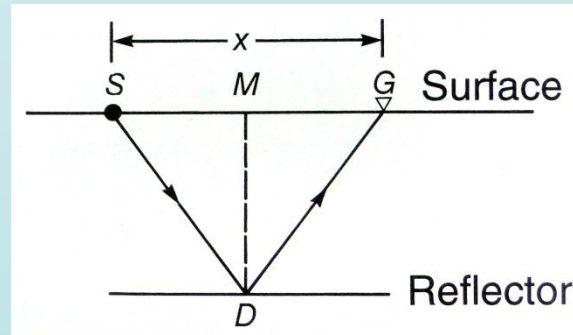


$$v_{lok} \approx 1500-6000 \text{ m/s}$$

Normal moveout (NMO)

Homogeneous layer,
plain reflector:

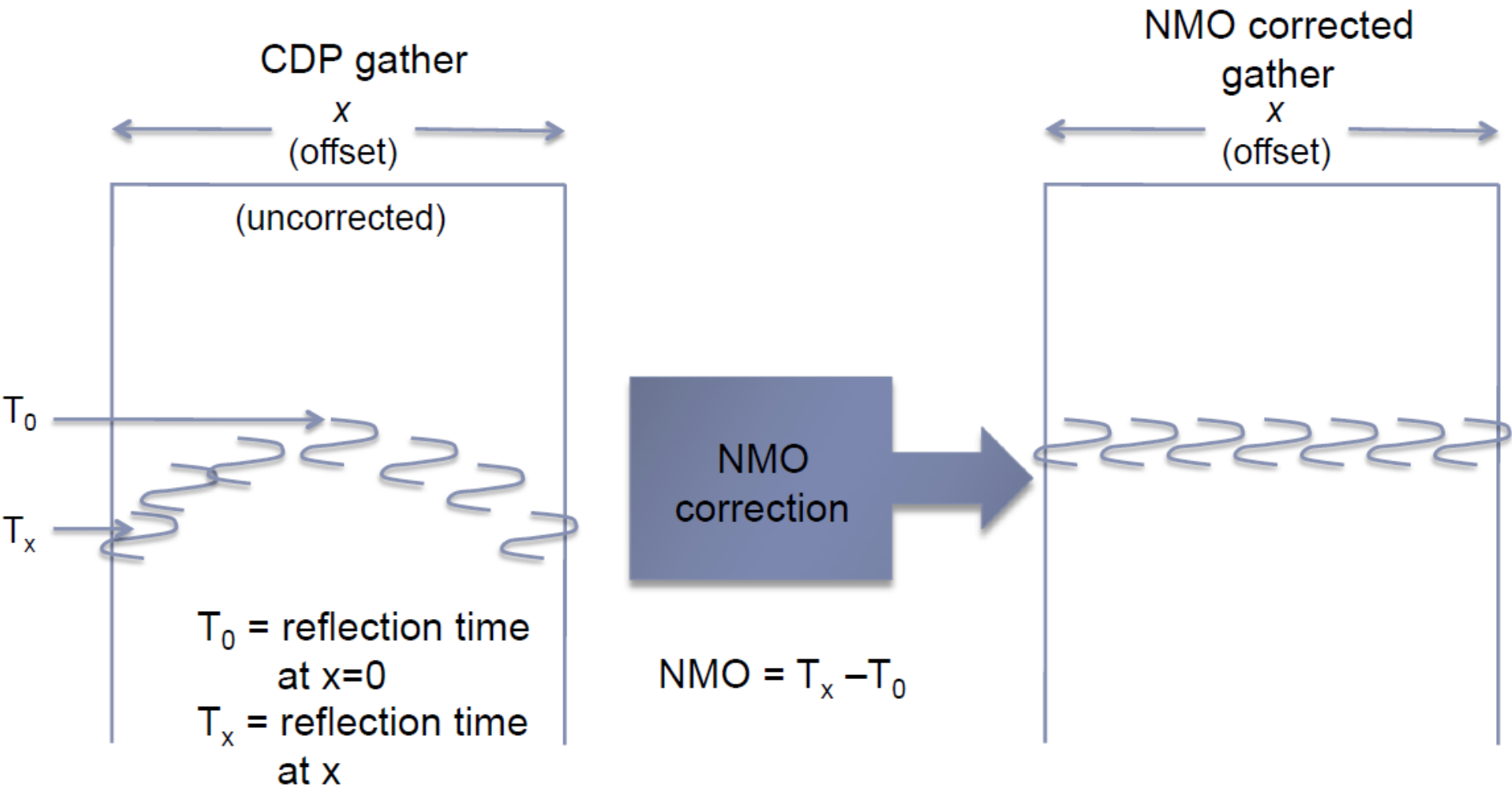
$$t^2 = t_0^2 + \frac{x^2}{v_{NMO}^2} = t_0^2 + \frac{x^2}{v_{int}^2}$$



Dynamic
correction:

$$\Delta t_{NMO} = t - t_0 = t_0 \left[\sqrt{1 + \left(\frac{x}{v_{NMO} t_0} \right)^2} - 1 \right]$$

I. Travel times: Why NMO corrections



I. Travel times: NMO correction example

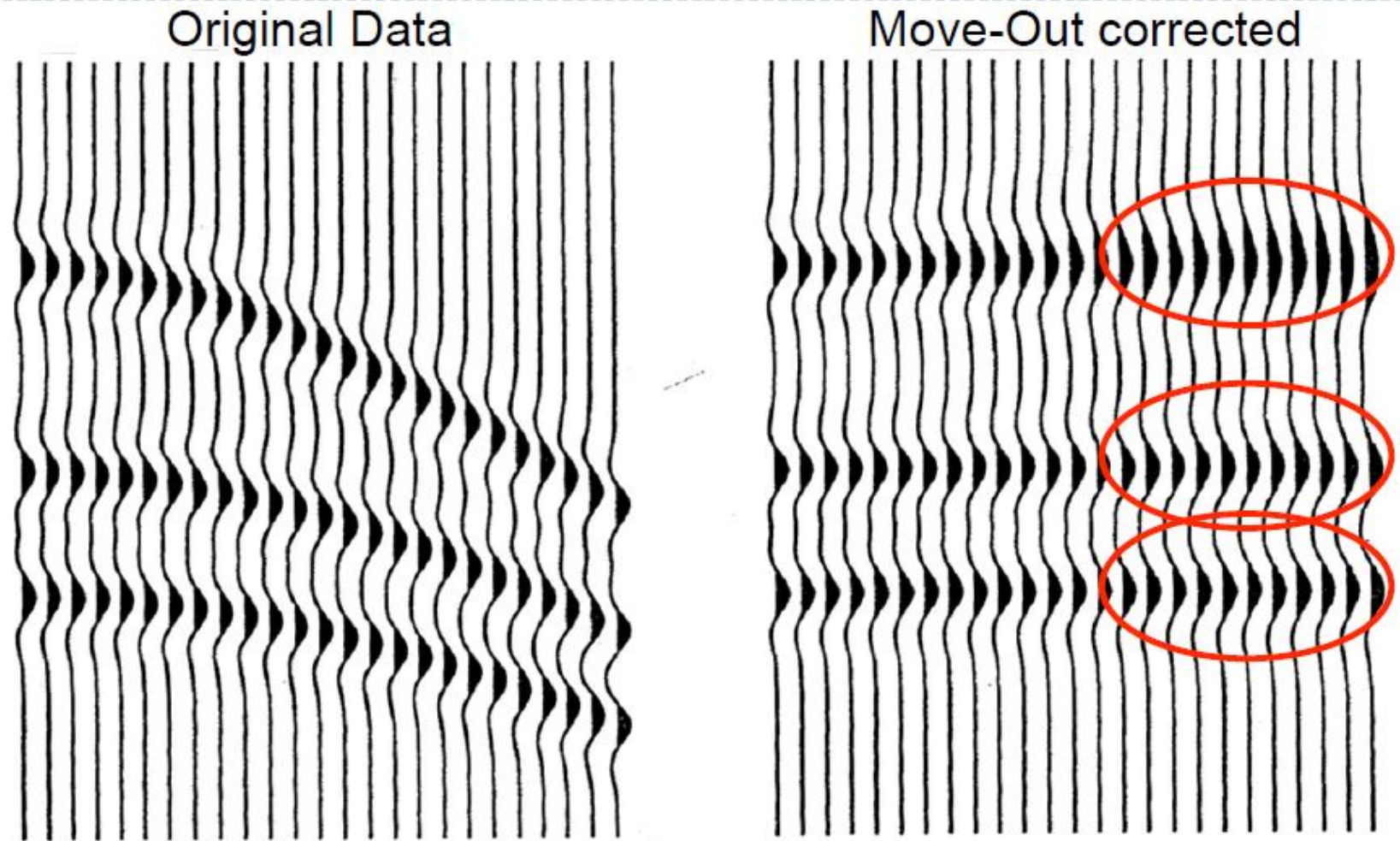


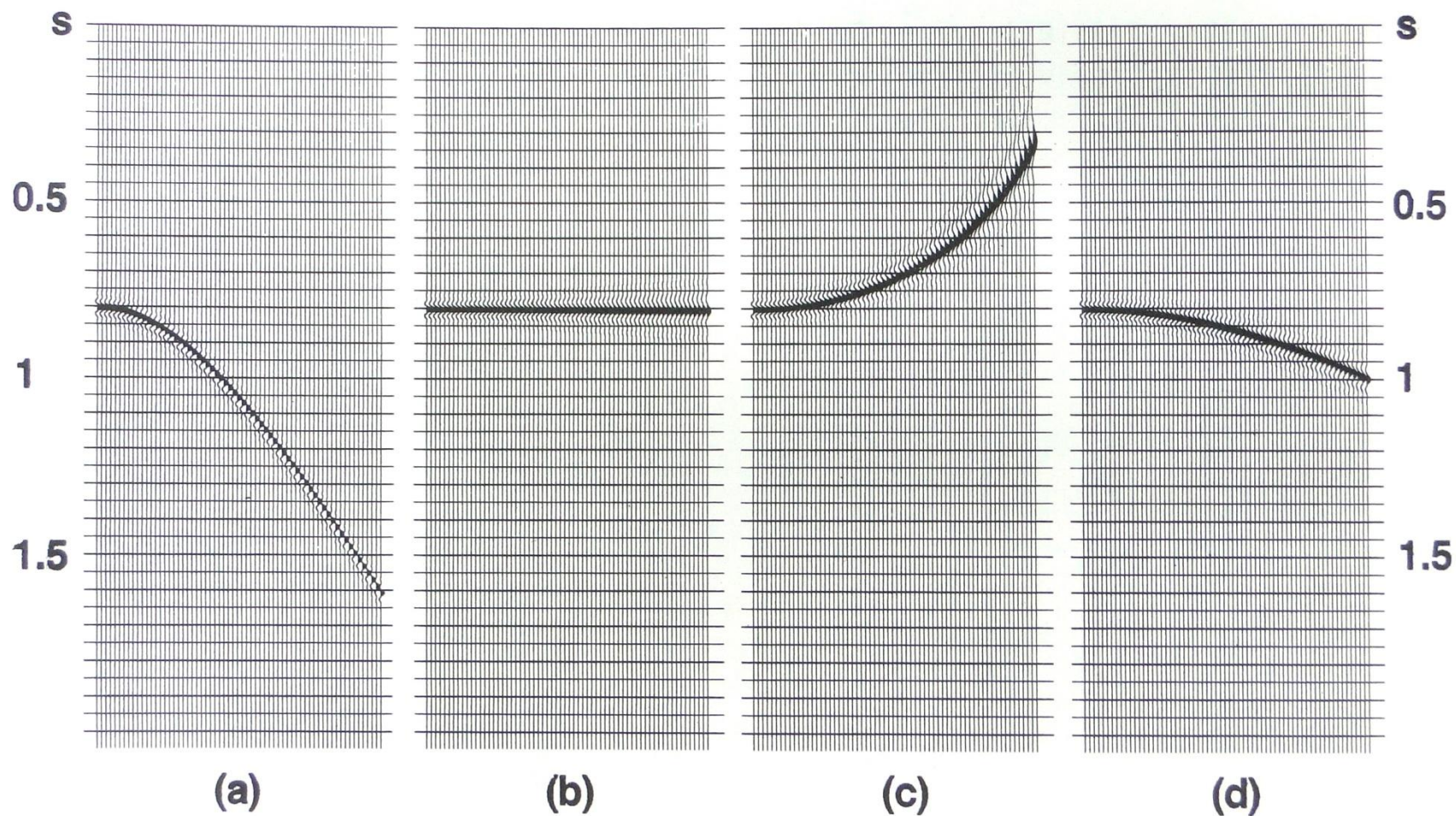
Fig. 7.5. The left plot shows reflection seismograms at increasing source-receiver distance. The right plot shows the same profile after applying a NMO correction to each time series. Note that this removes the range dependence in the arrival times. The NMO corrected records can then be stacked to produce a single composite zero-offset record.

Without NMO

Proper velocity

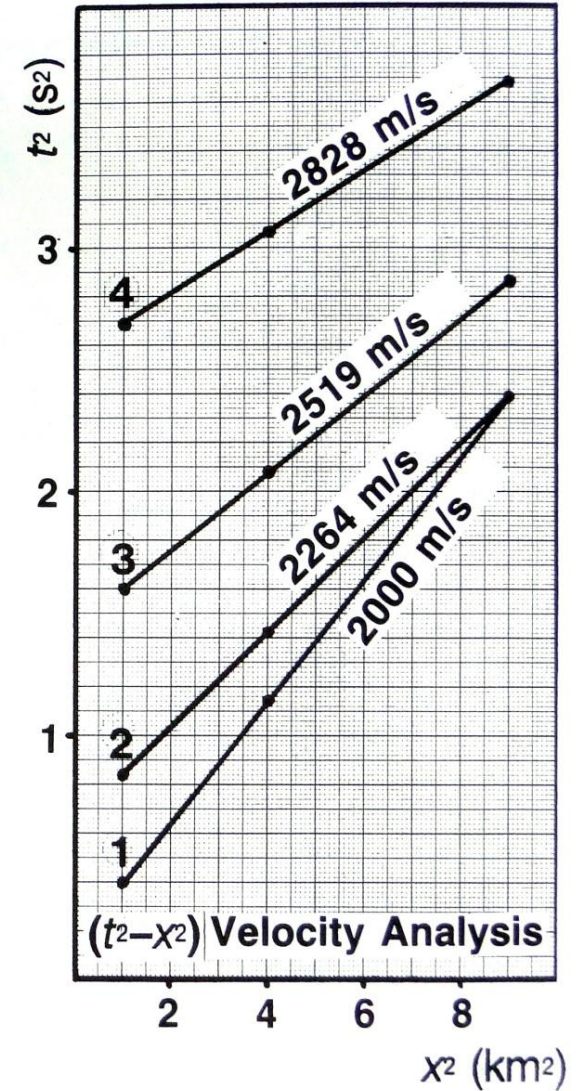
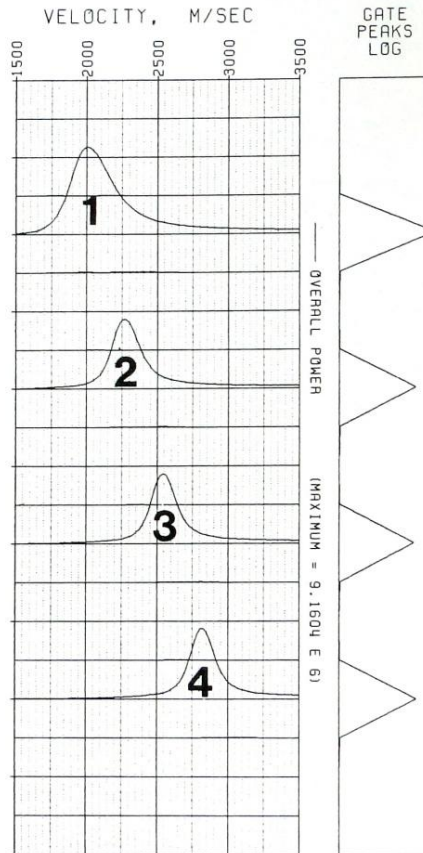
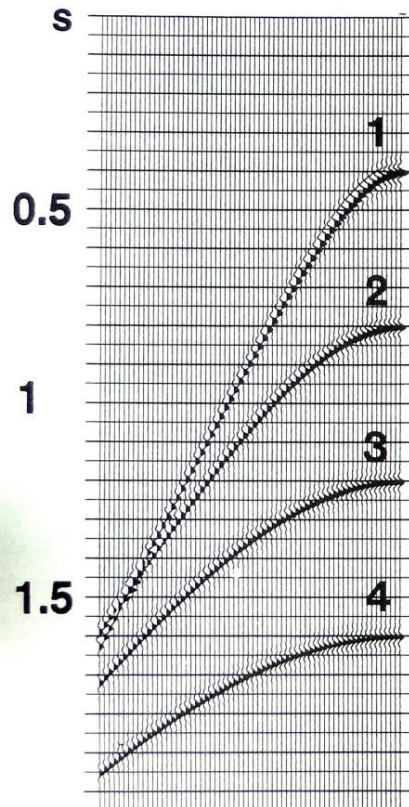
Too low velocity

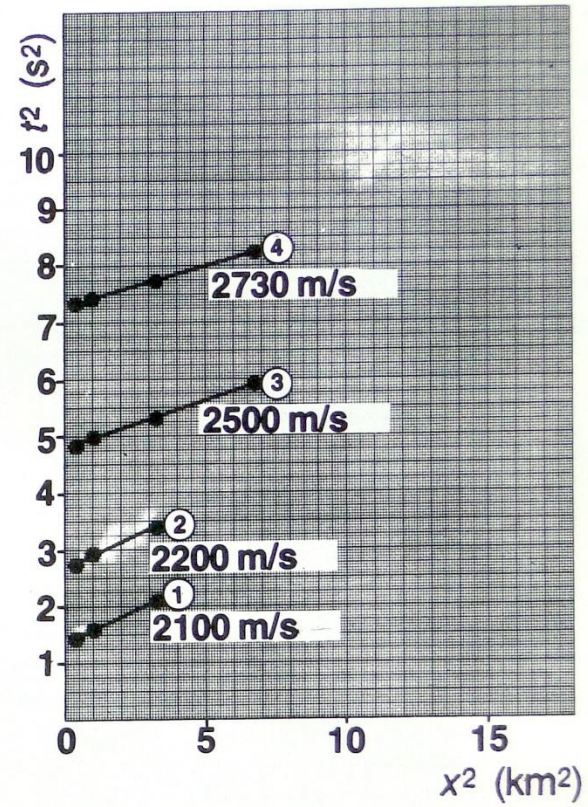
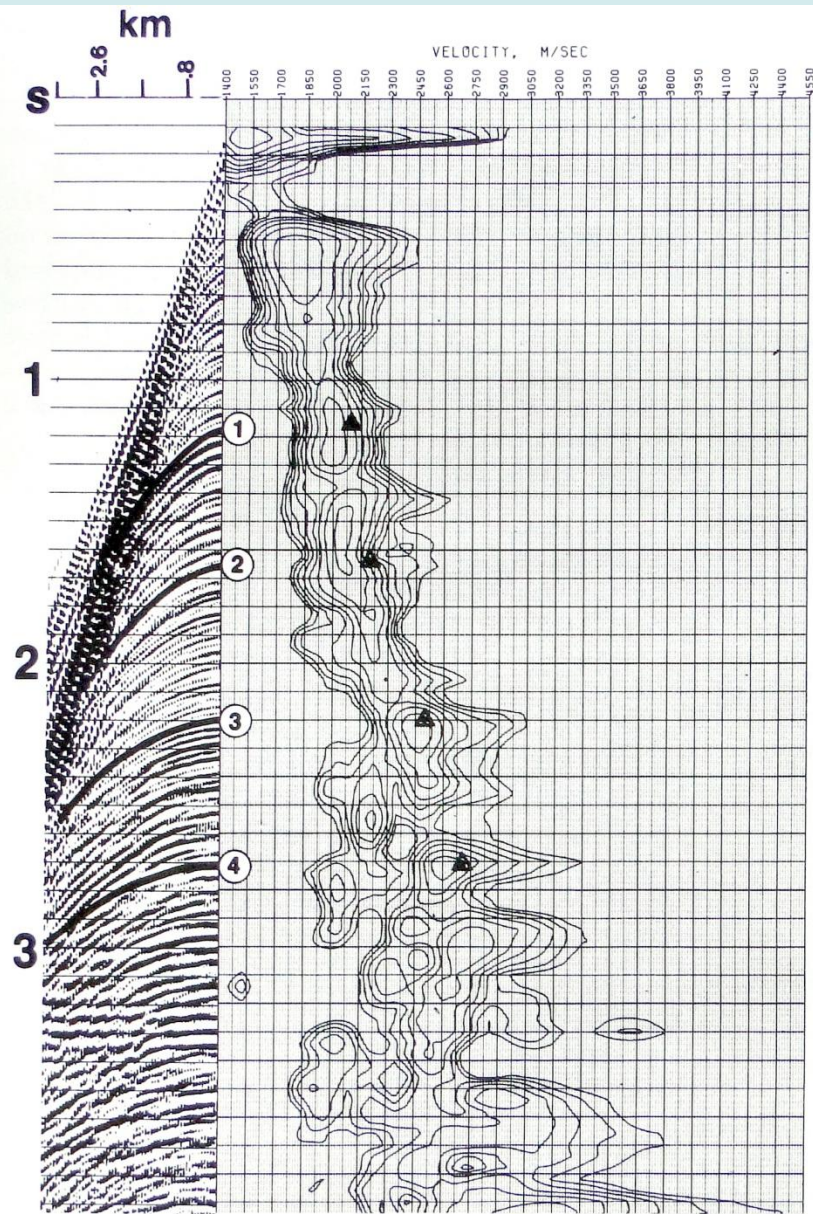
Too high velocity



Velocity analysis

$$t^2(x) = t^2(0) + \frac{x^2}{v_{NMO}^2}$$



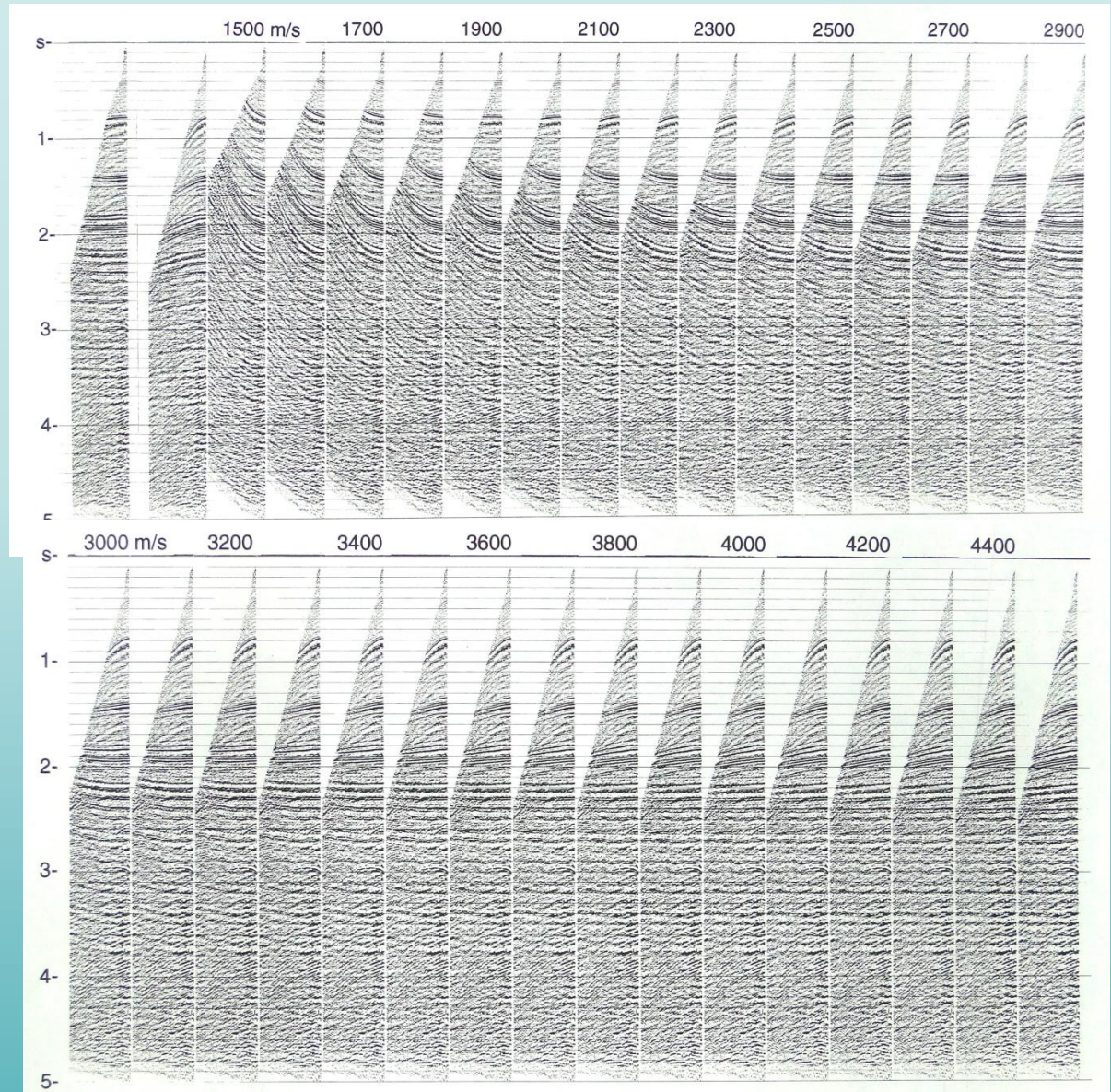


Velocity spectrum

Constant velocity scan

CDP gathers
corrected by
different
constant
velocities

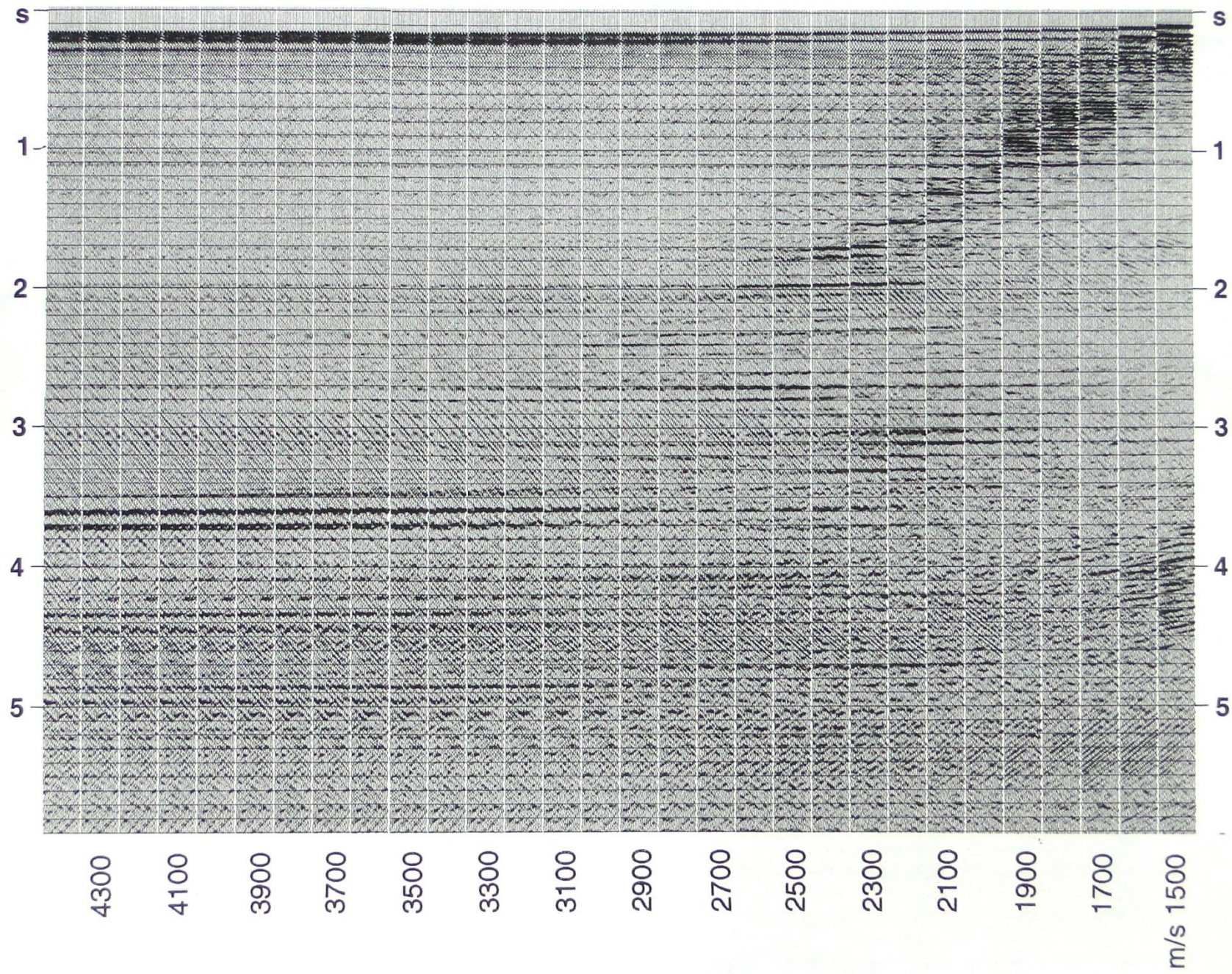
The proper
velocity is where
the reflection is
horizontal.



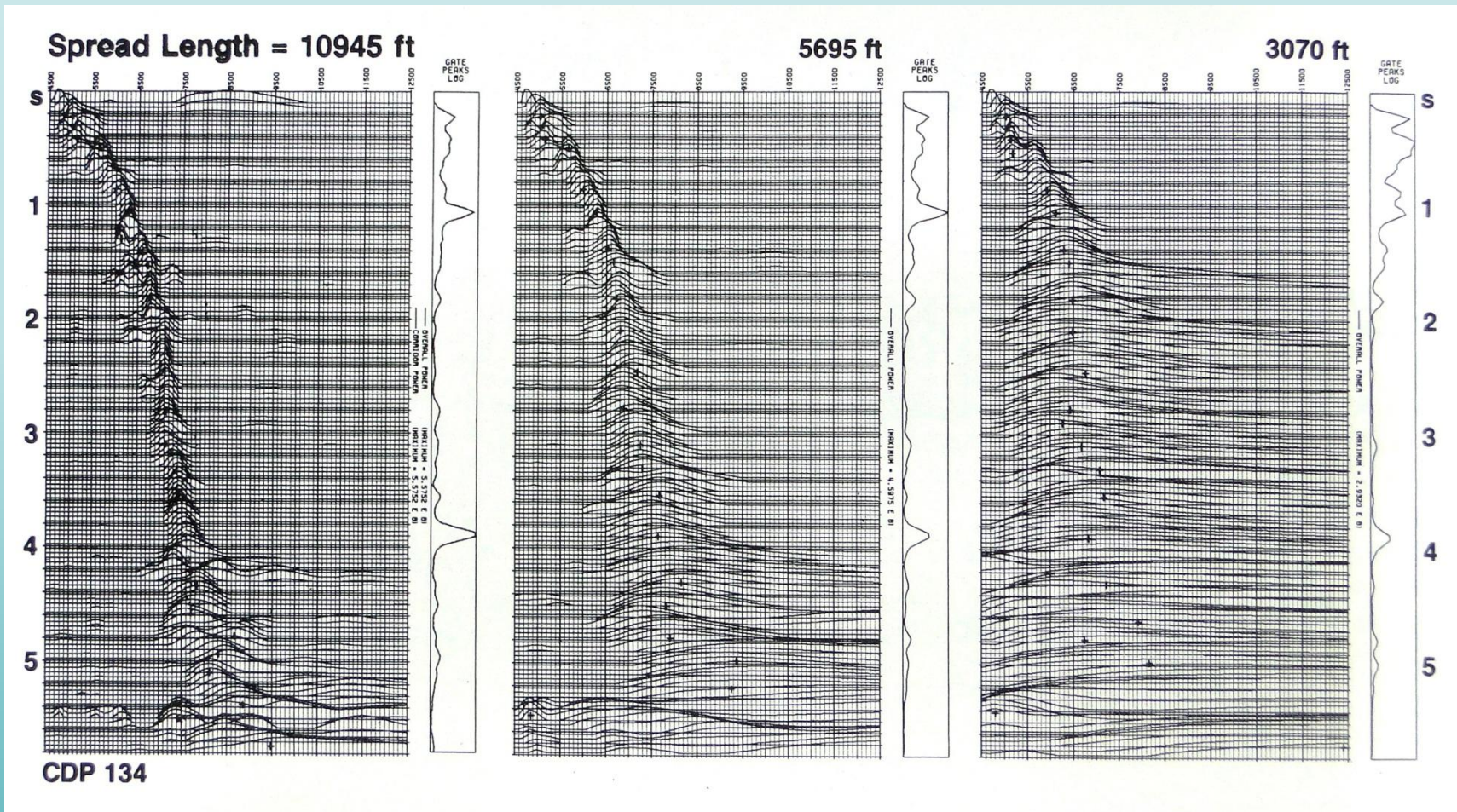
CVS (constant velocity stack)

The panel (velocity)
with the best
stack response is
chosen.

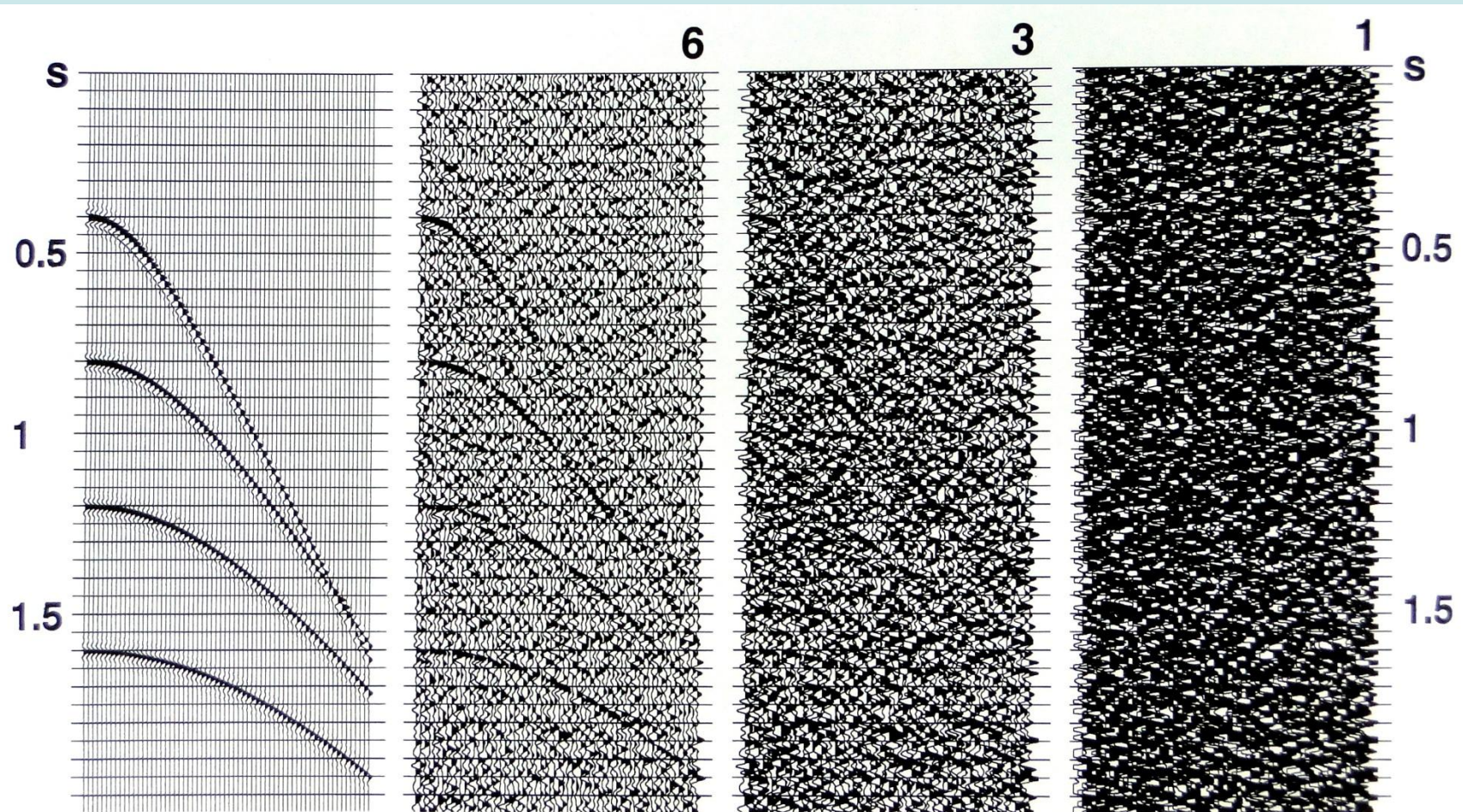




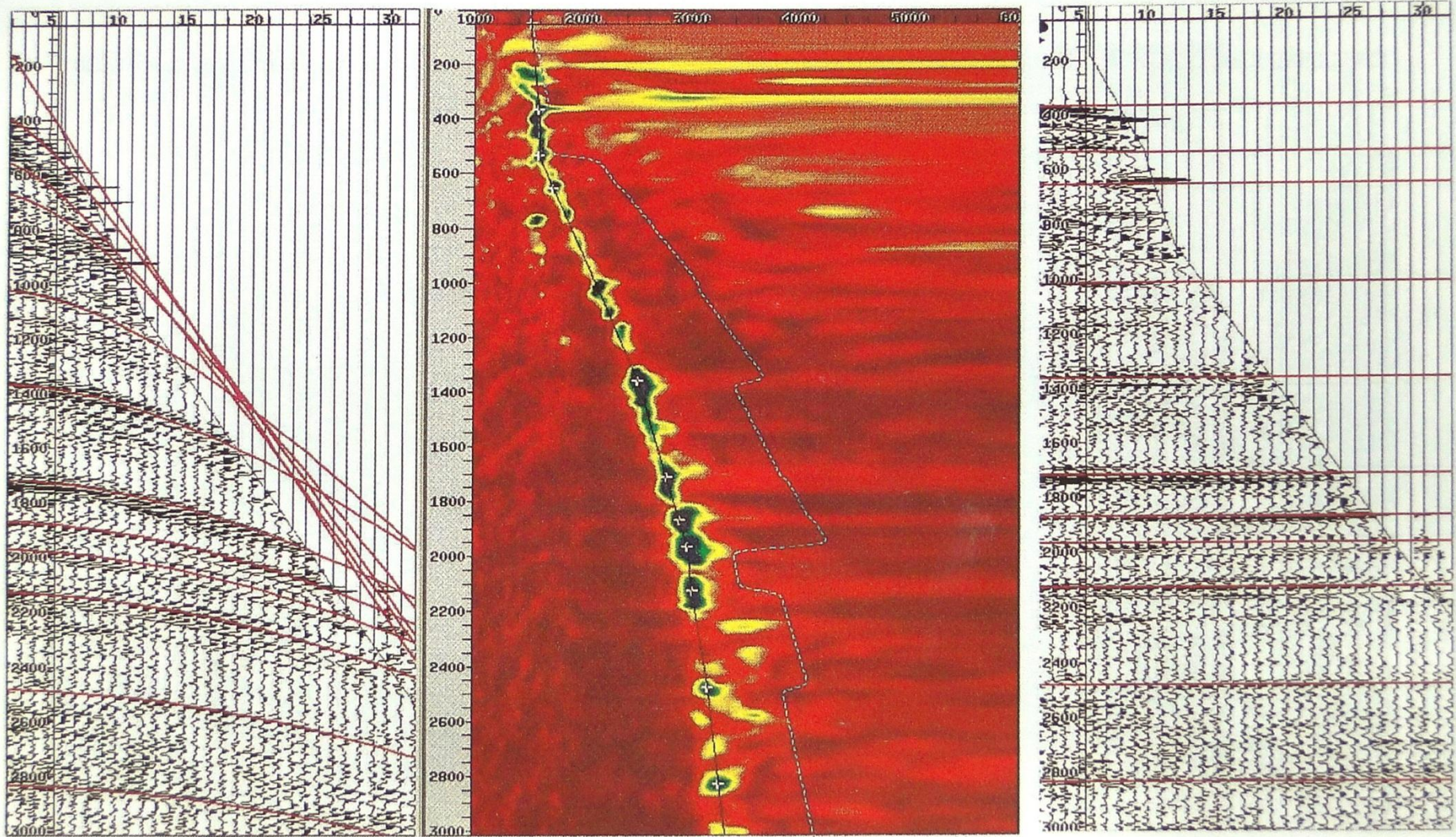
Spread length dependence of the velocity spectra



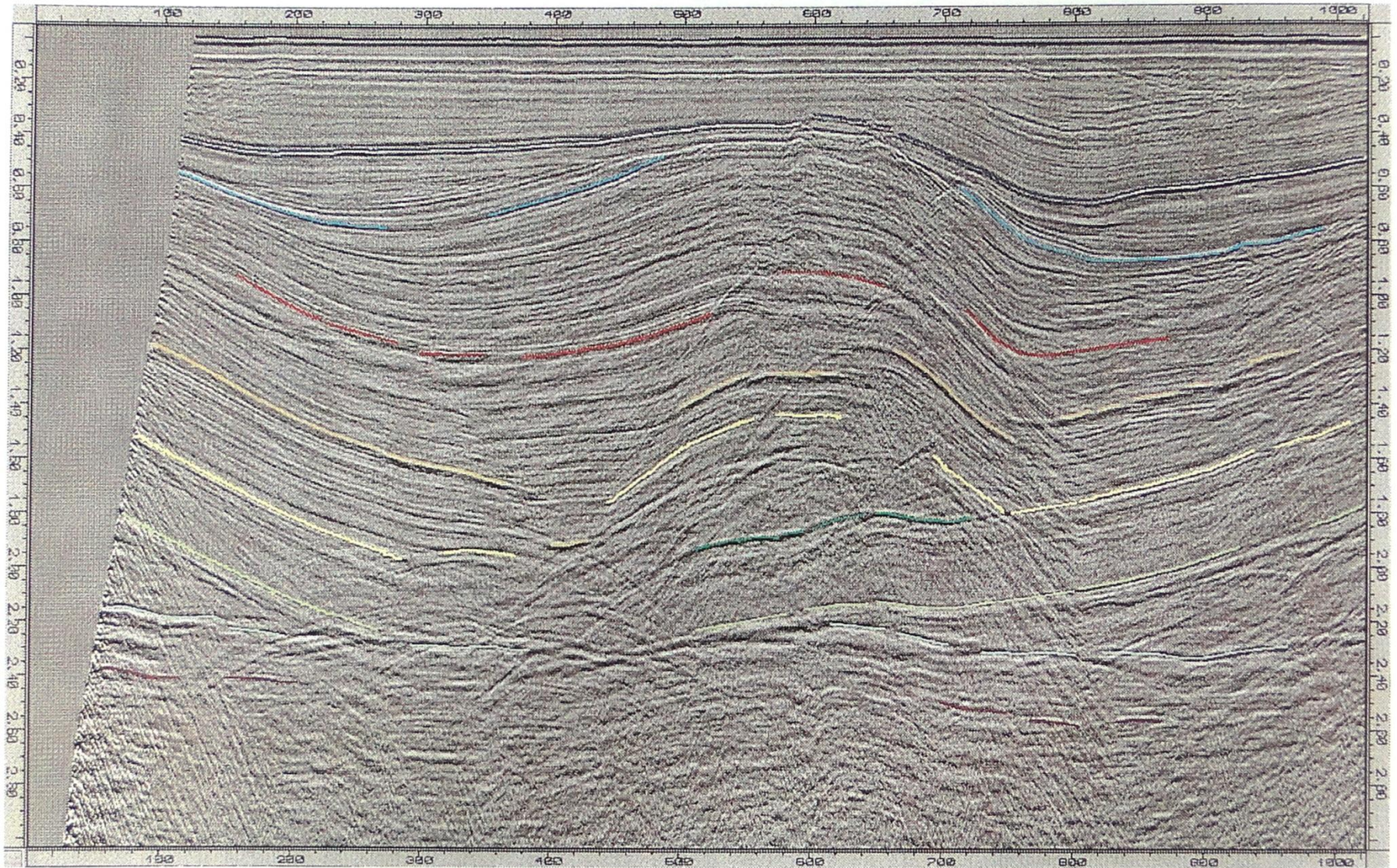
Signal to noise ratio



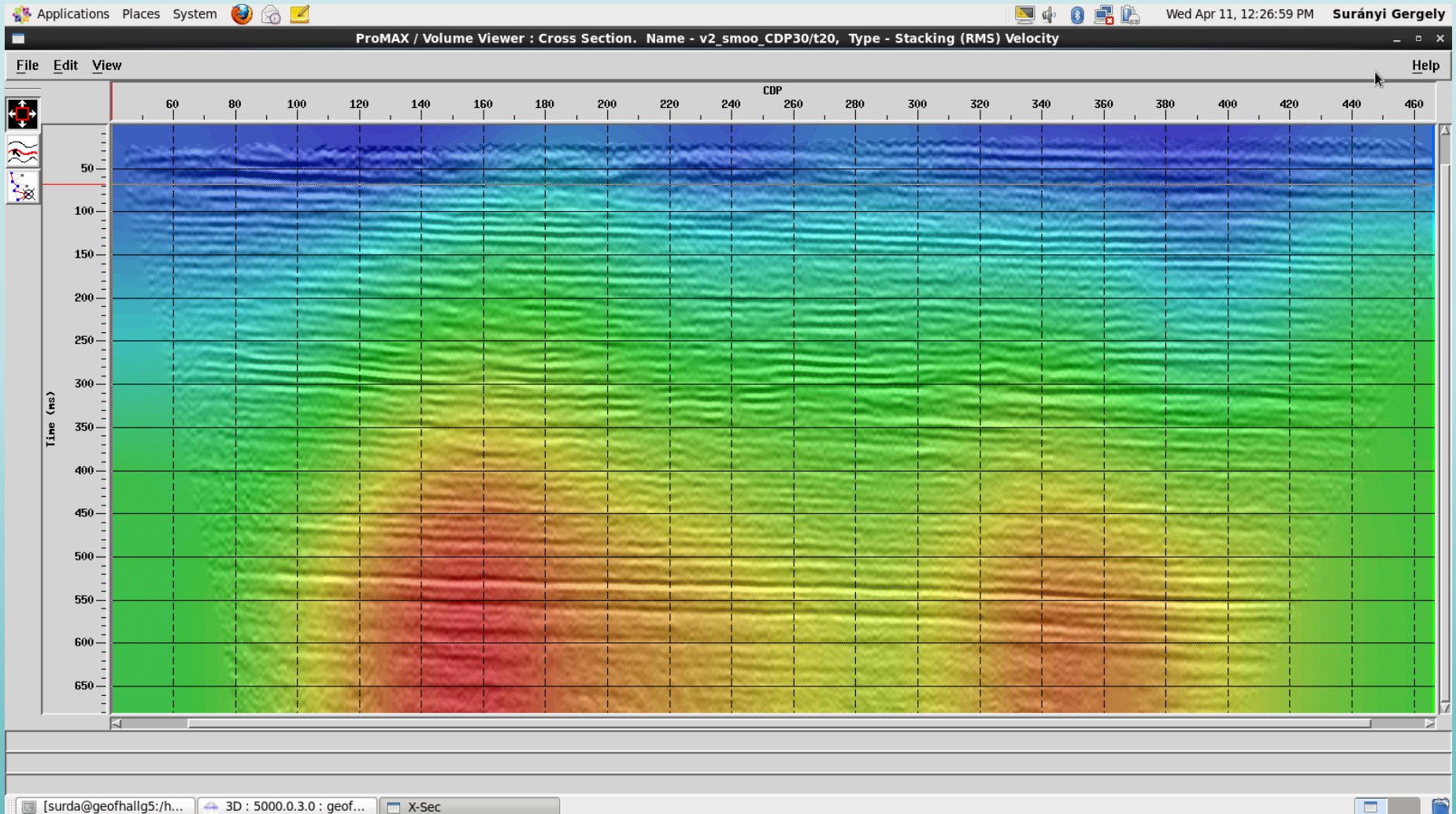
Interactive velocity analysis



The main result: the stack



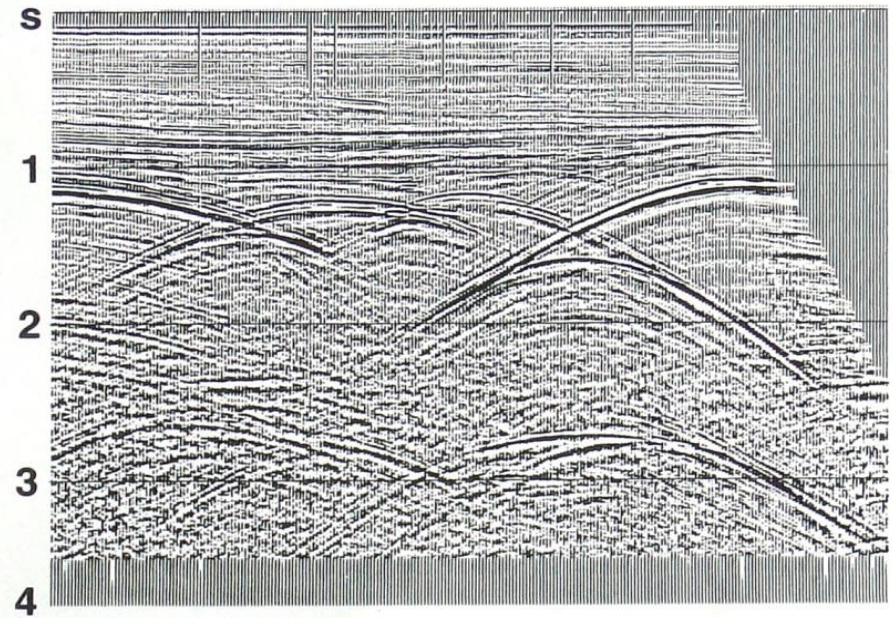
Velocity filed on a stack



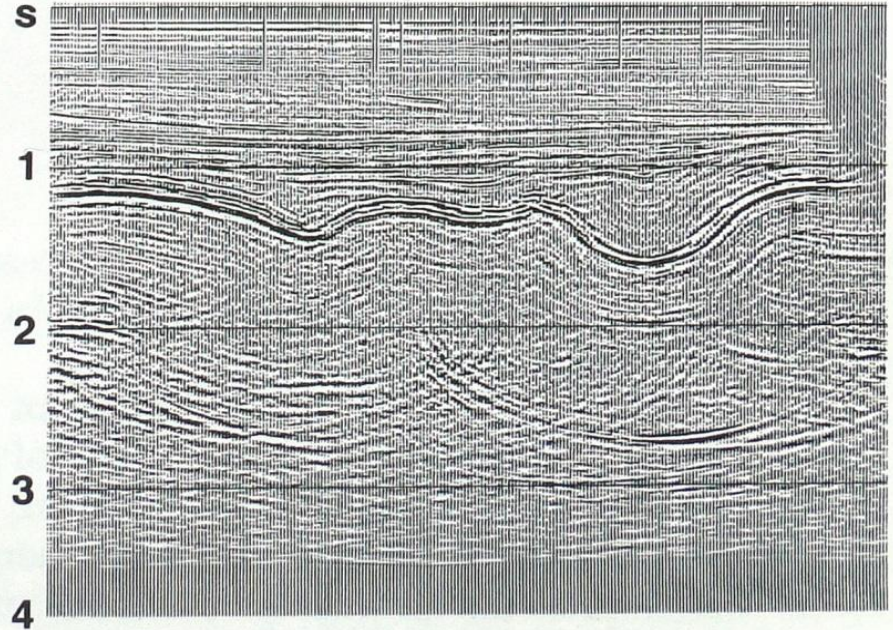
Migration

Goals:

- moving the reflections visible on the stack into their actual geometric positions.
- time-depth conversion



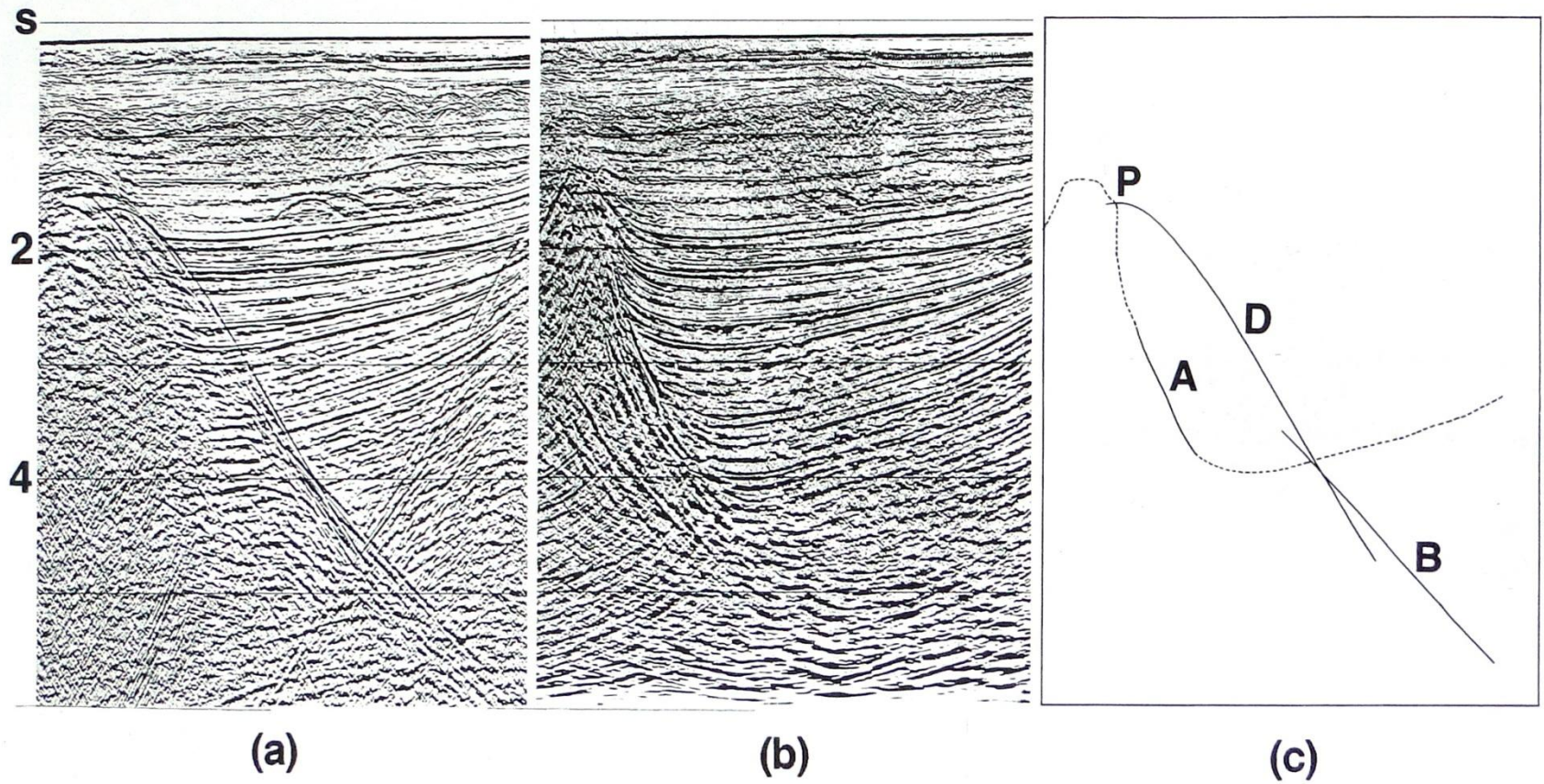
(a)



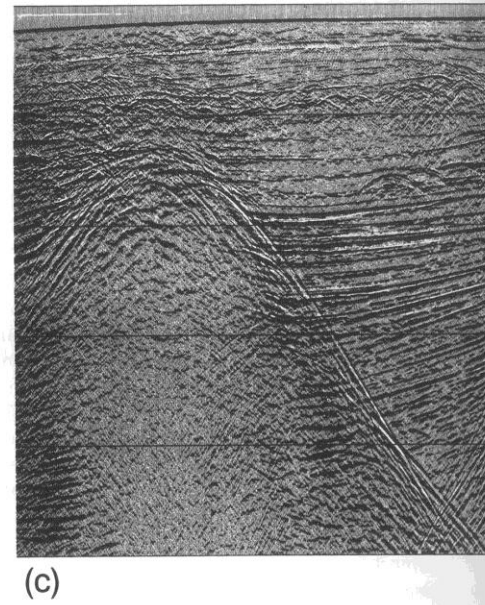
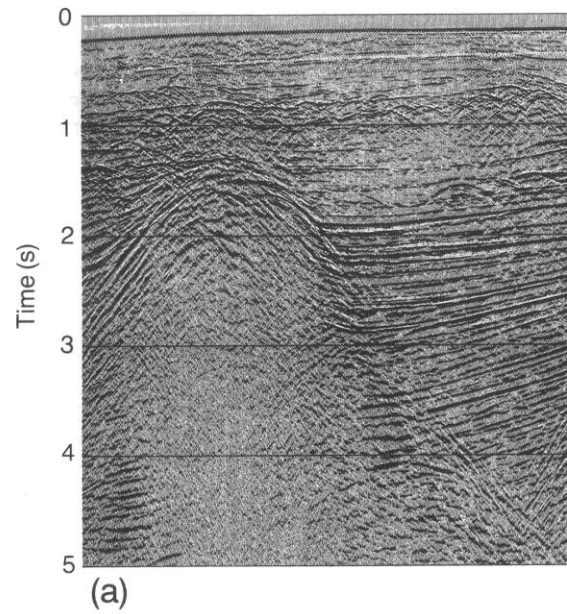
(b)

Two main tasks:

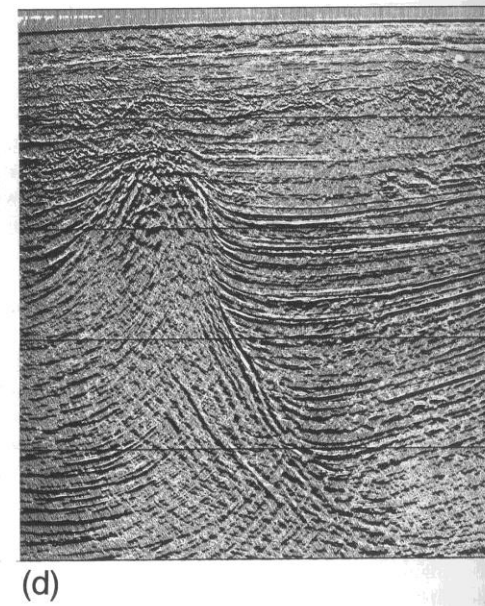
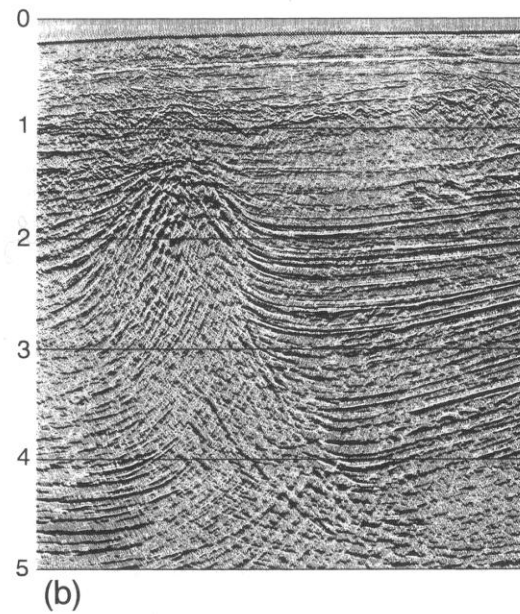
- determining of the real dips,
- „combining” diffractions



Stack



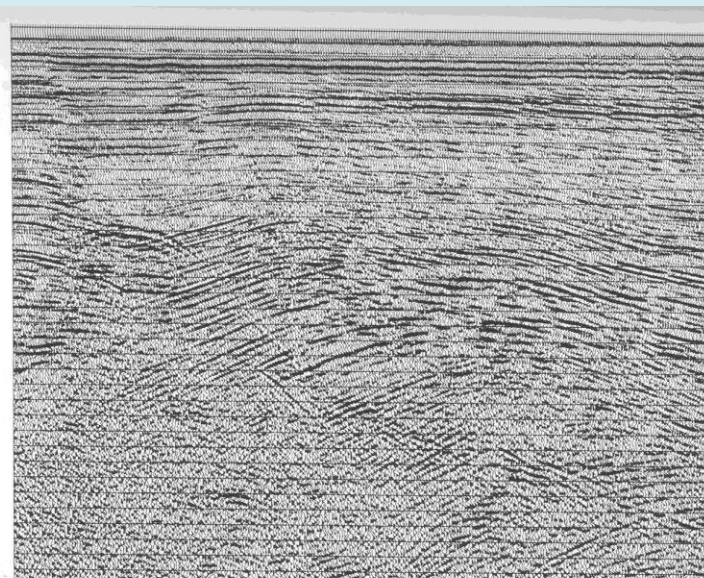
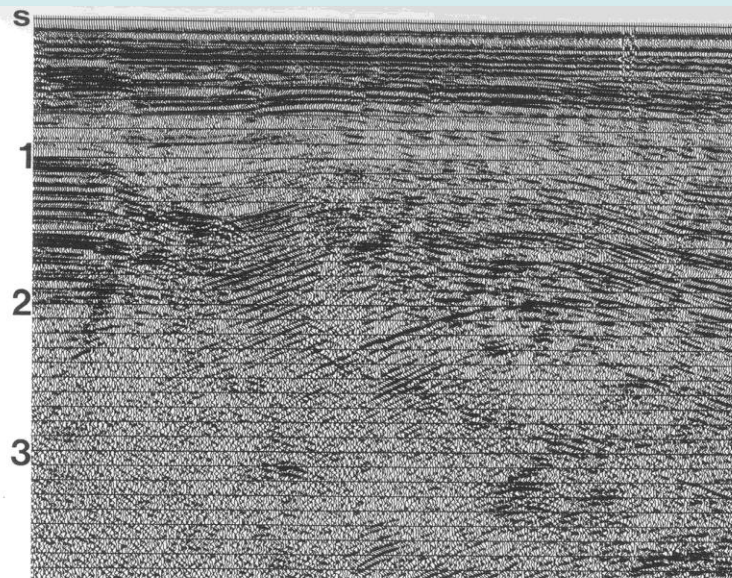
Migrated
section



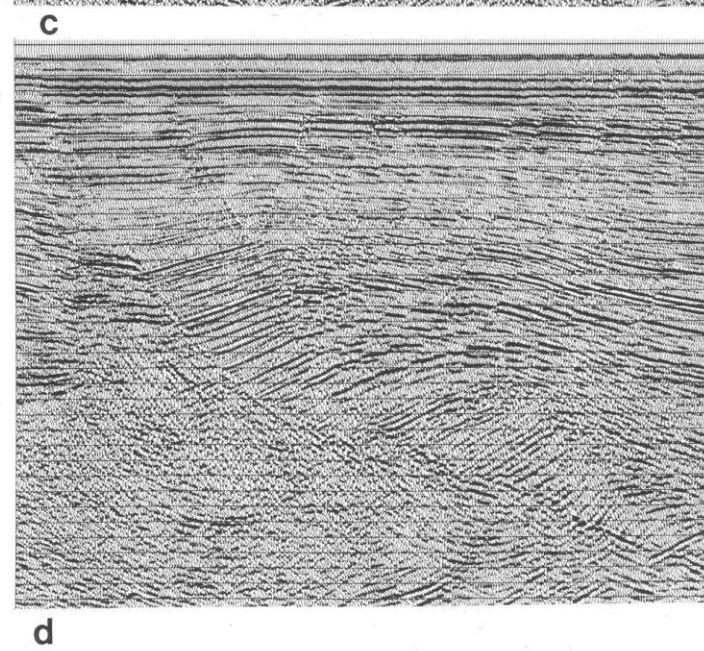
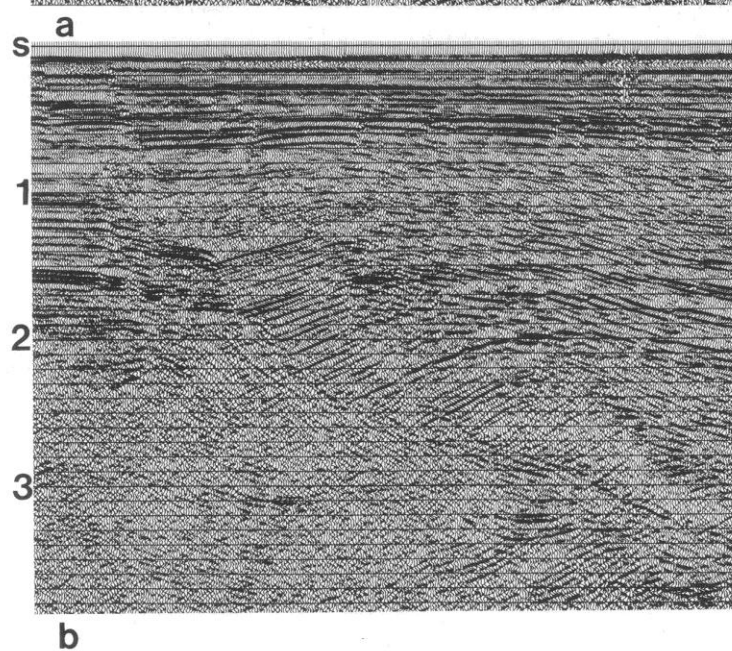
only NMO

NMO+DMO

stack



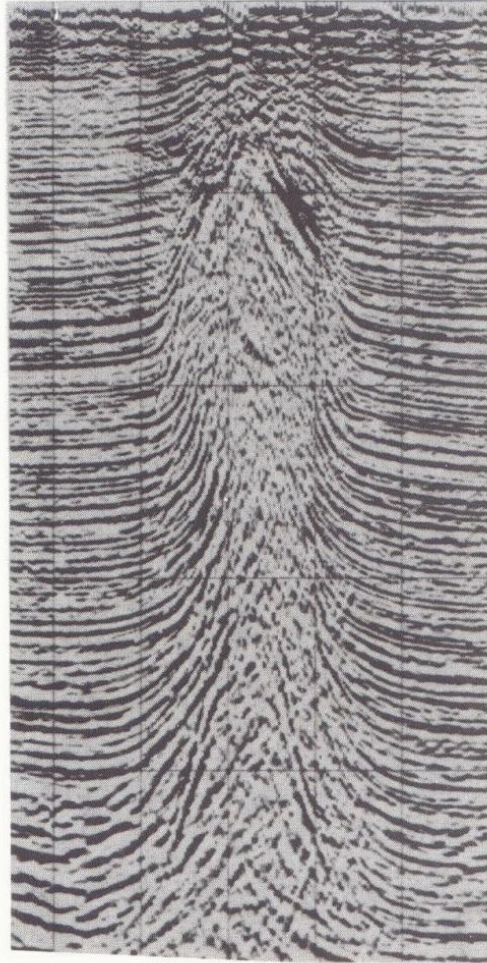
migr.



NMO

NMO+DMO

Turning-wave migration at a salt diaper

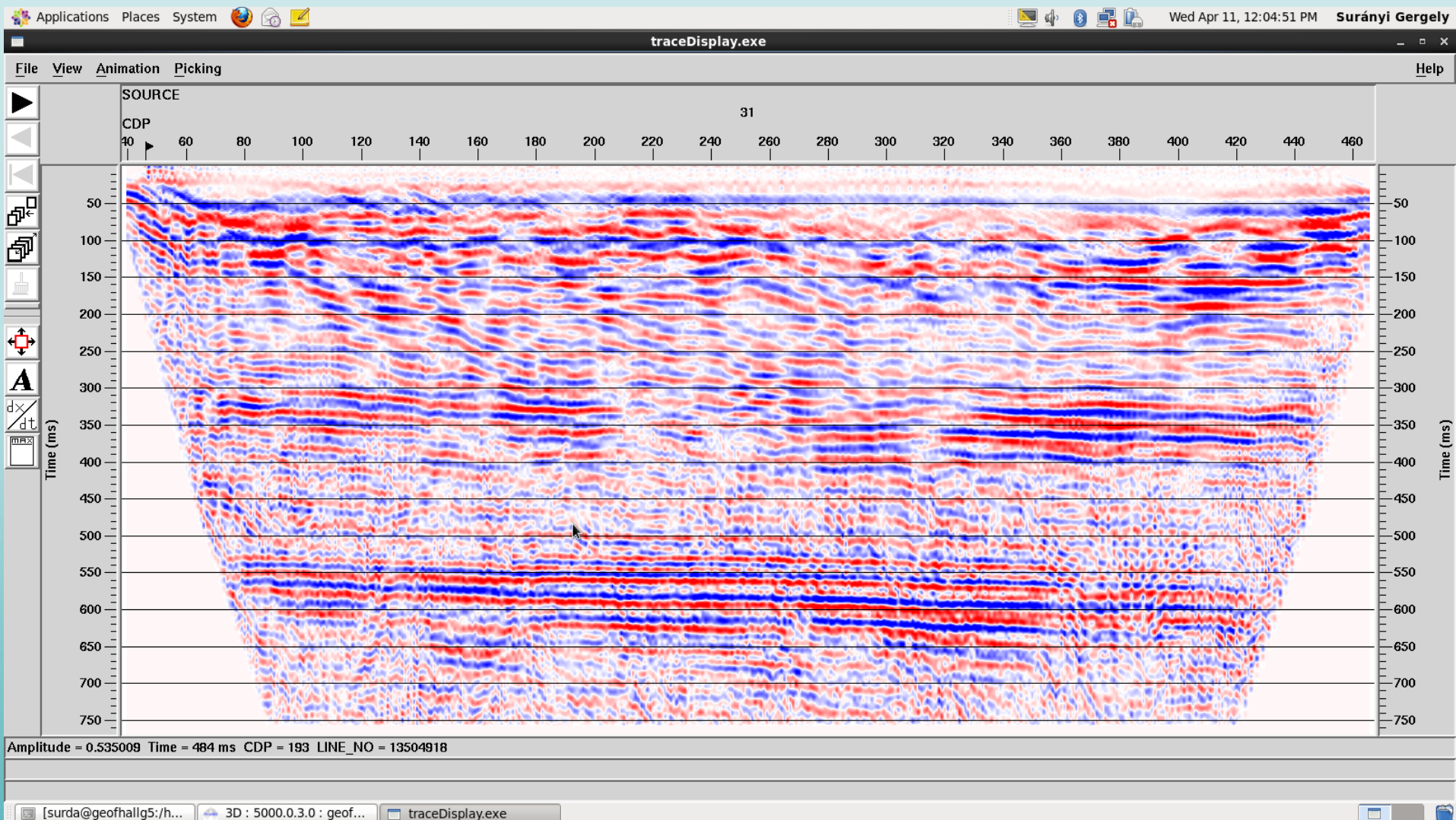


a

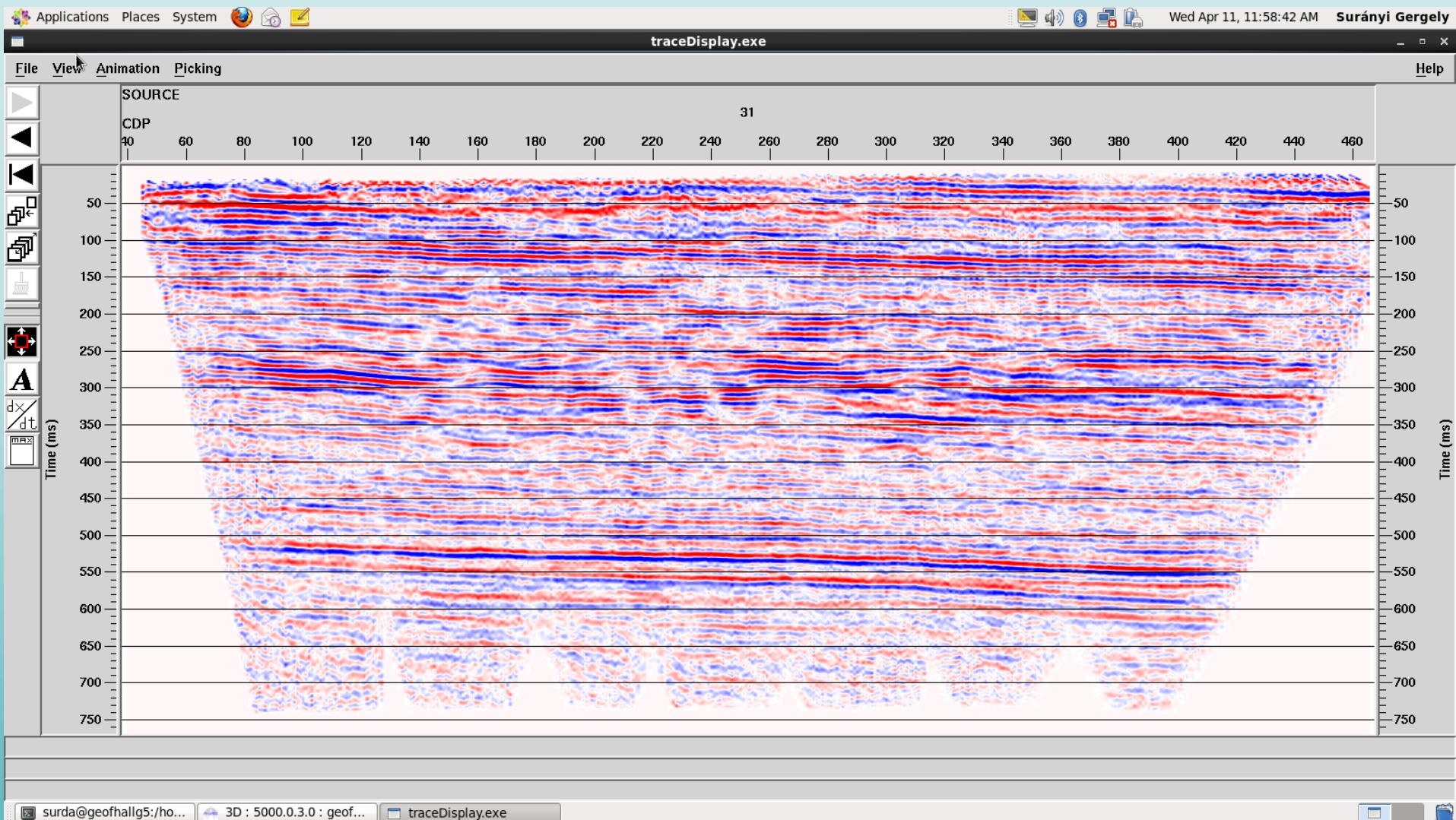


b

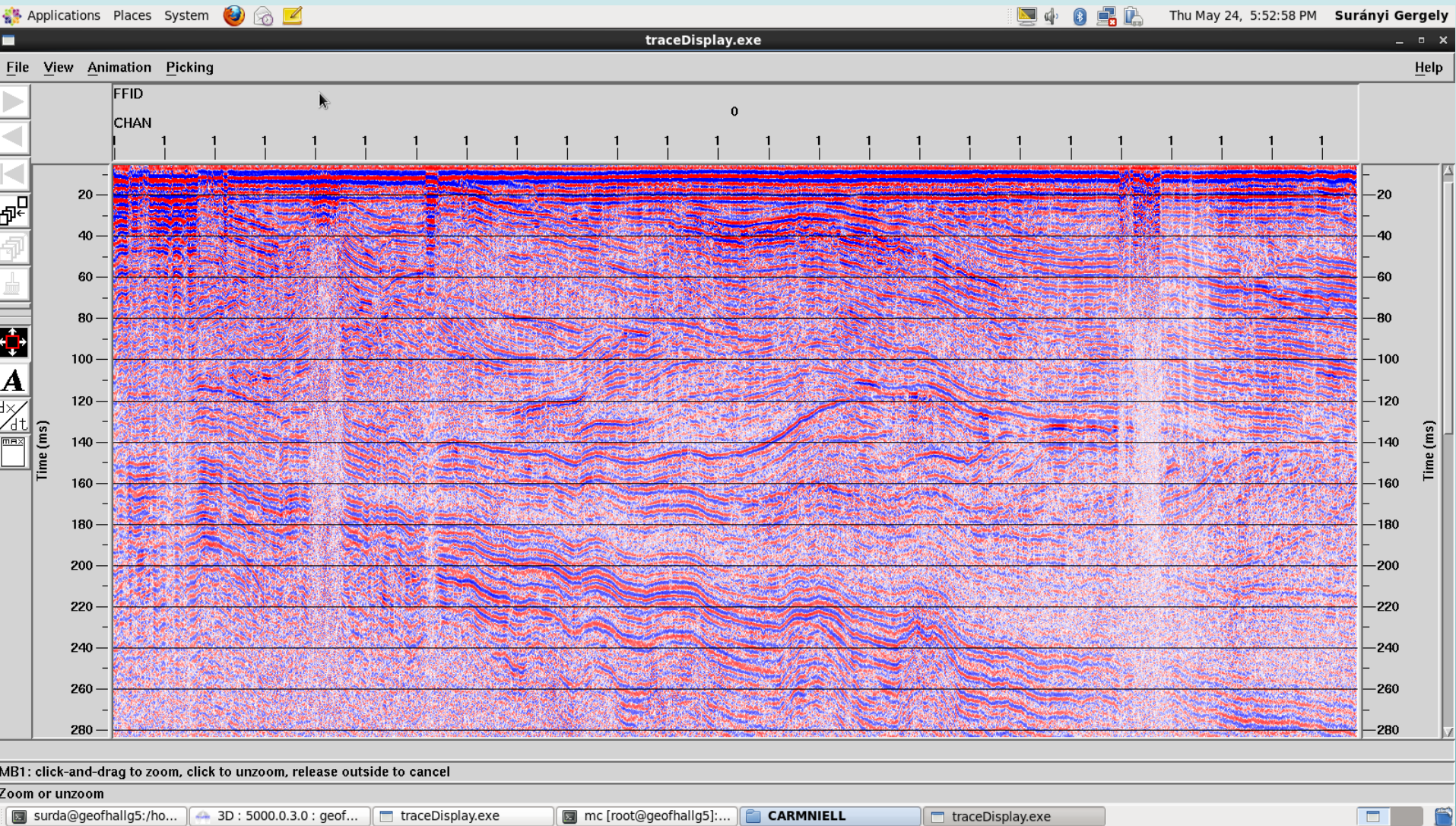
Brute stack: university filed practice near lake Balaton with sledgehammer source



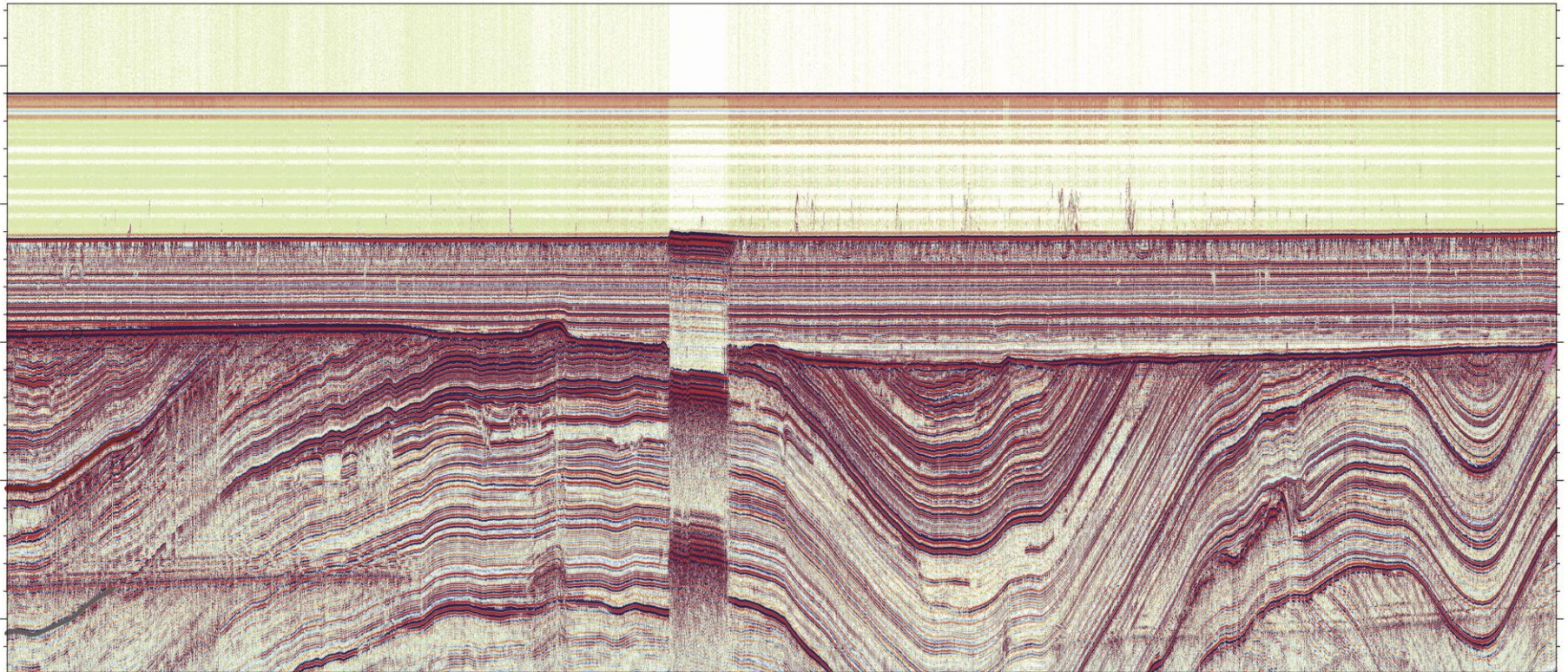
Processed stack: university filed practice near lake Balaton with sledgehammer source



Single channel water seismics on lake Balaton

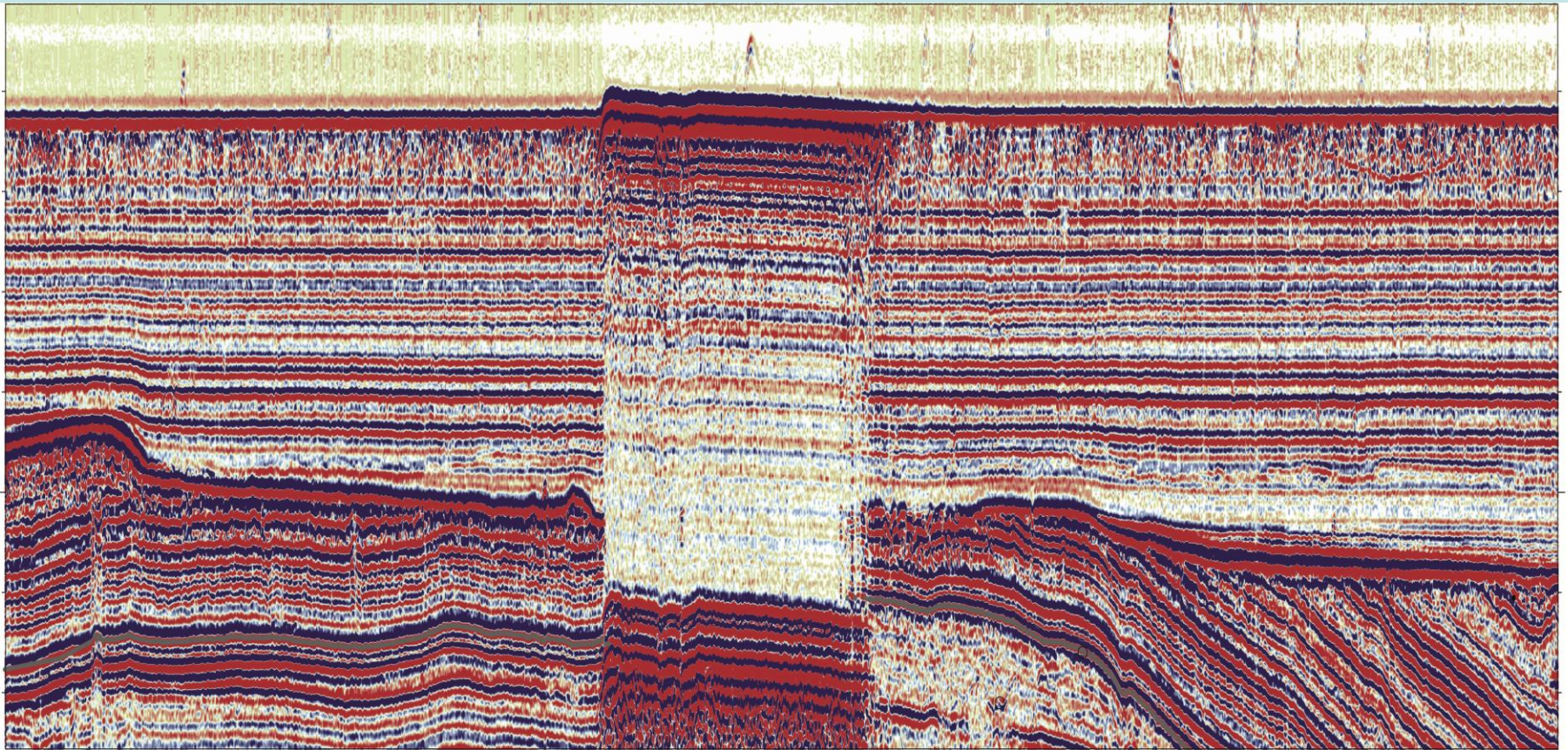


Single channel water seismics on lake Balaton



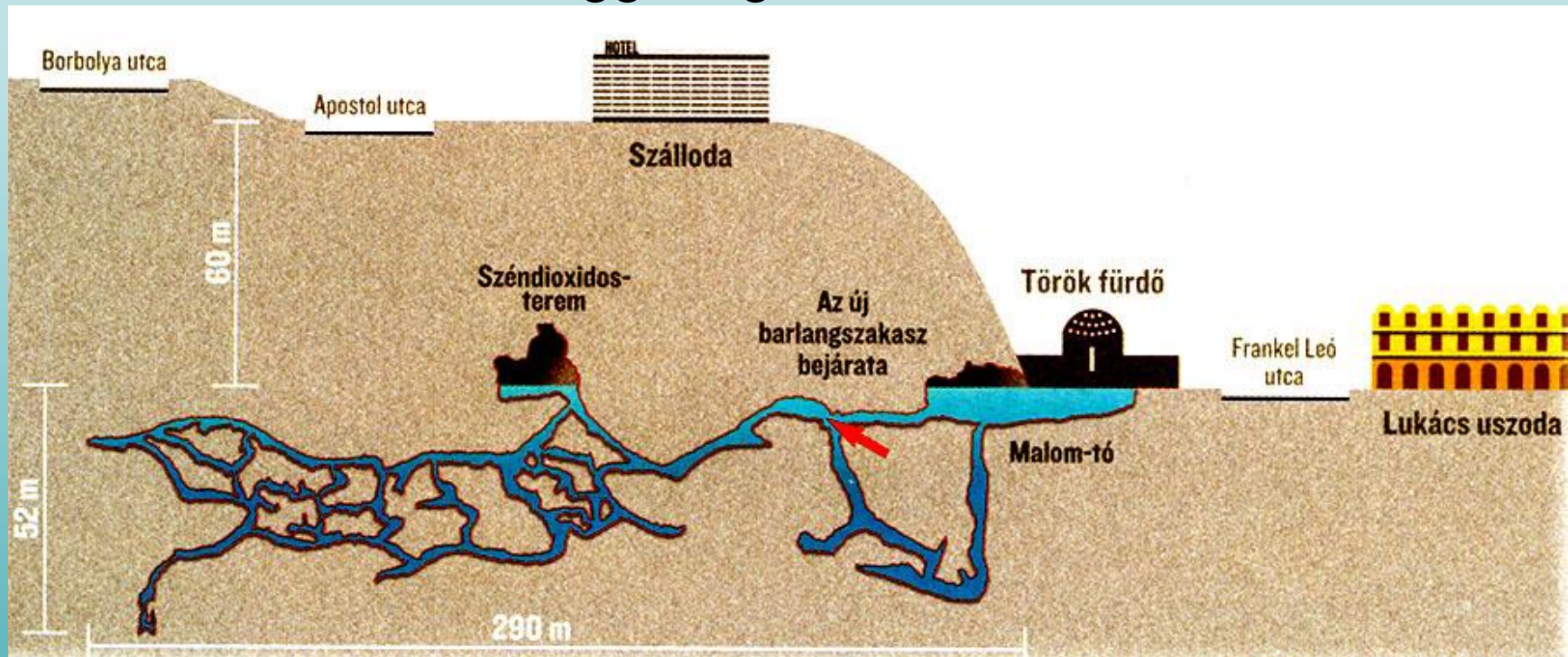
Single channel water seismics on lake Balaton

~300 m

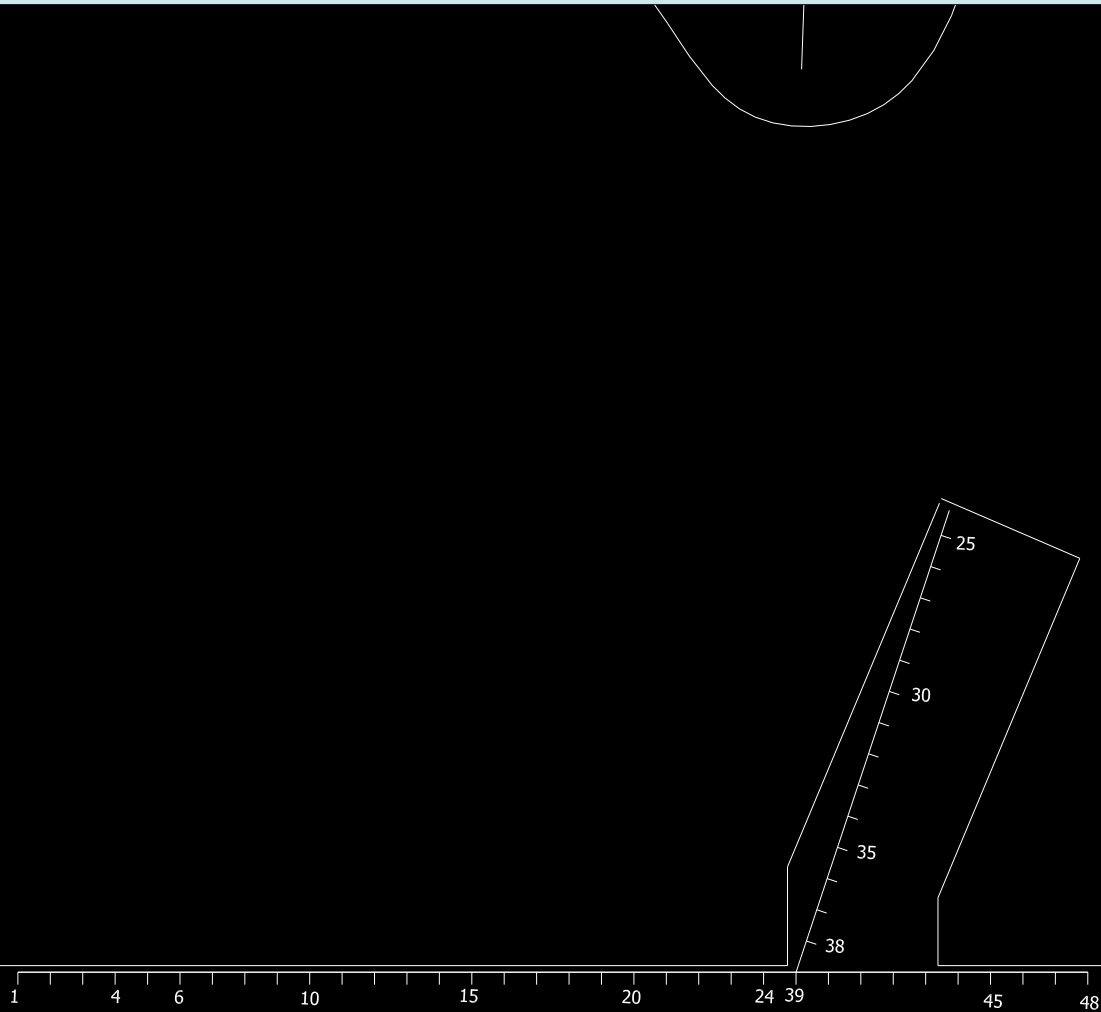


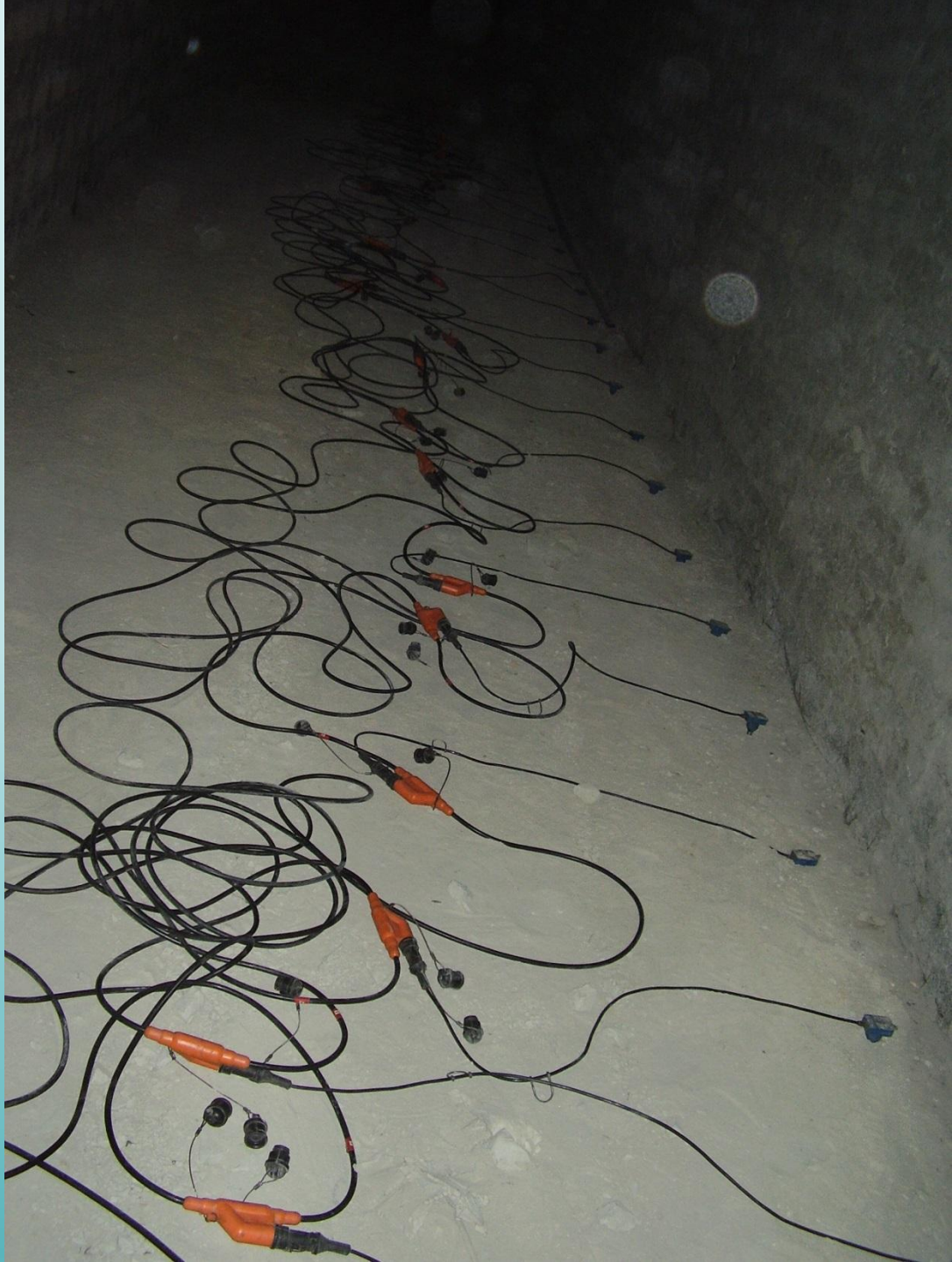
Seismics in Molnár János cave

- Goal: connecting the inner chamber to an existing tunnel
- Signal source: hammer
- Processing: first break picking
- Problem: lack of triggering



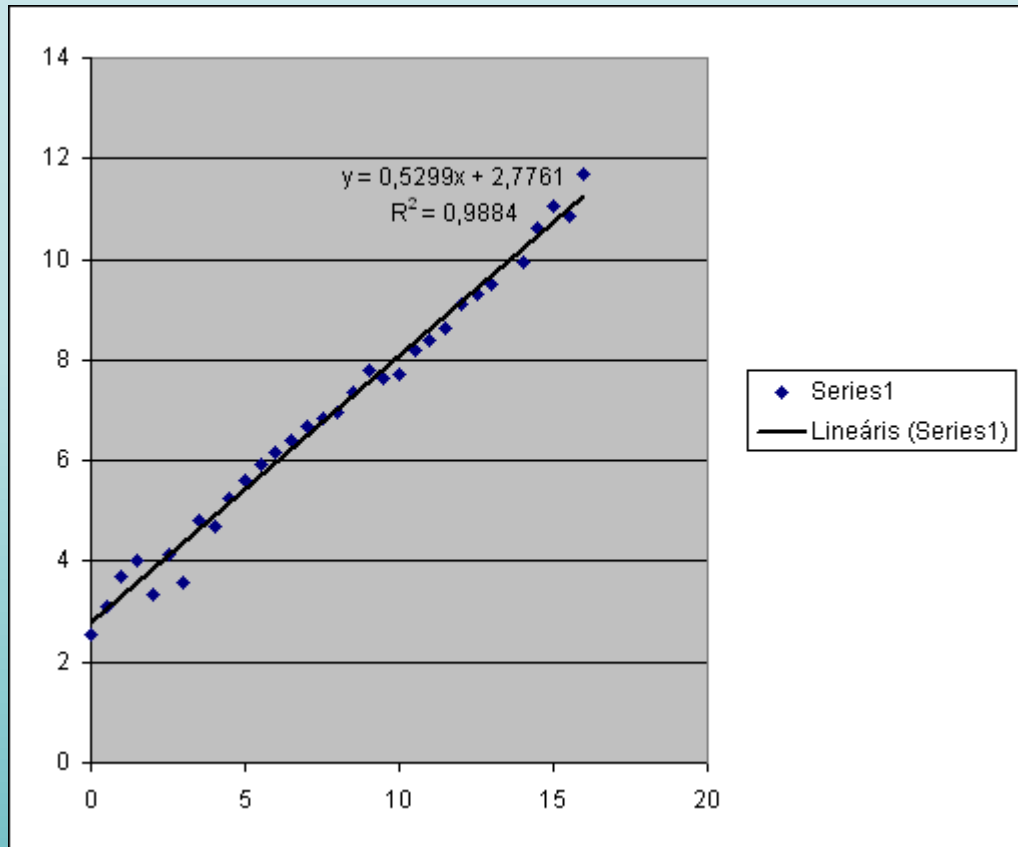
Geophone arrangement







First test: velocity determination

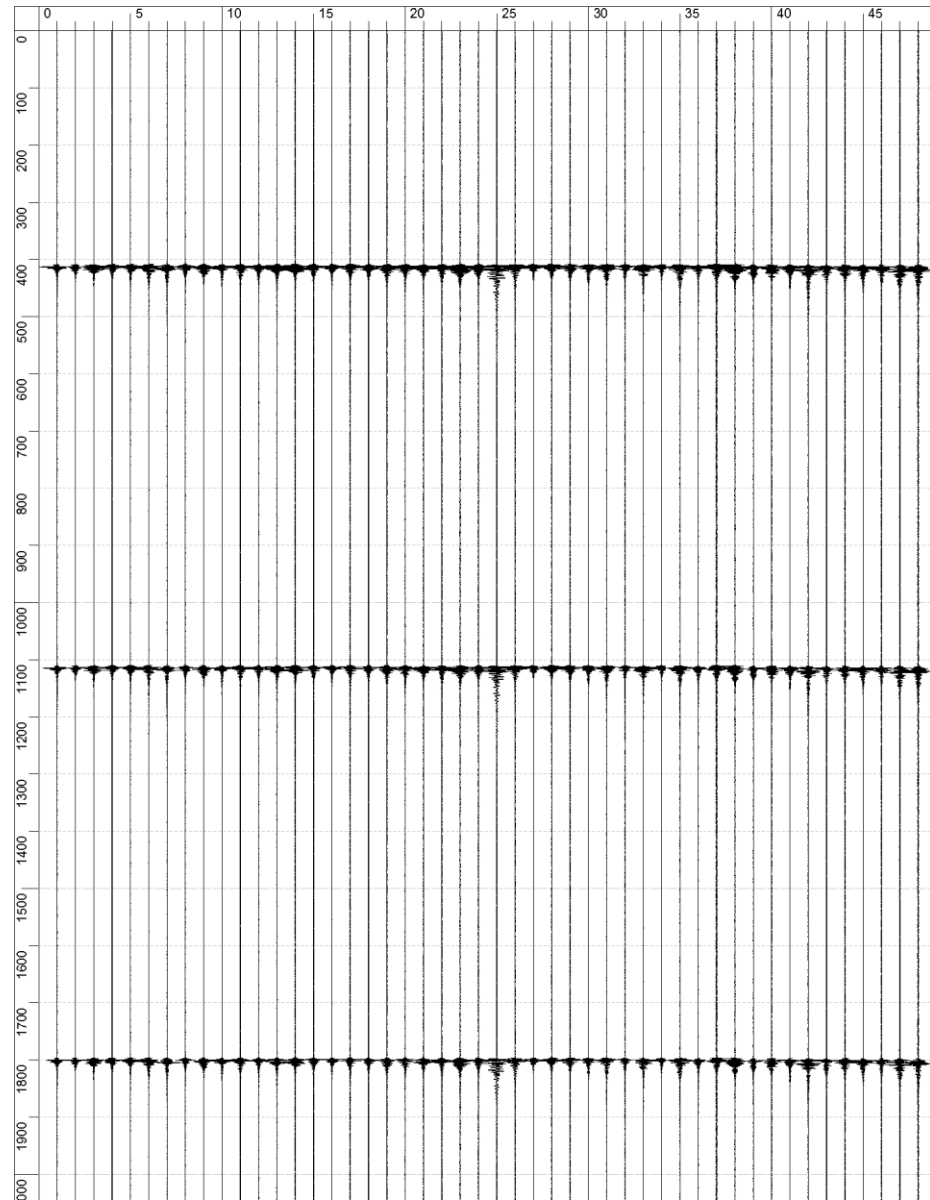


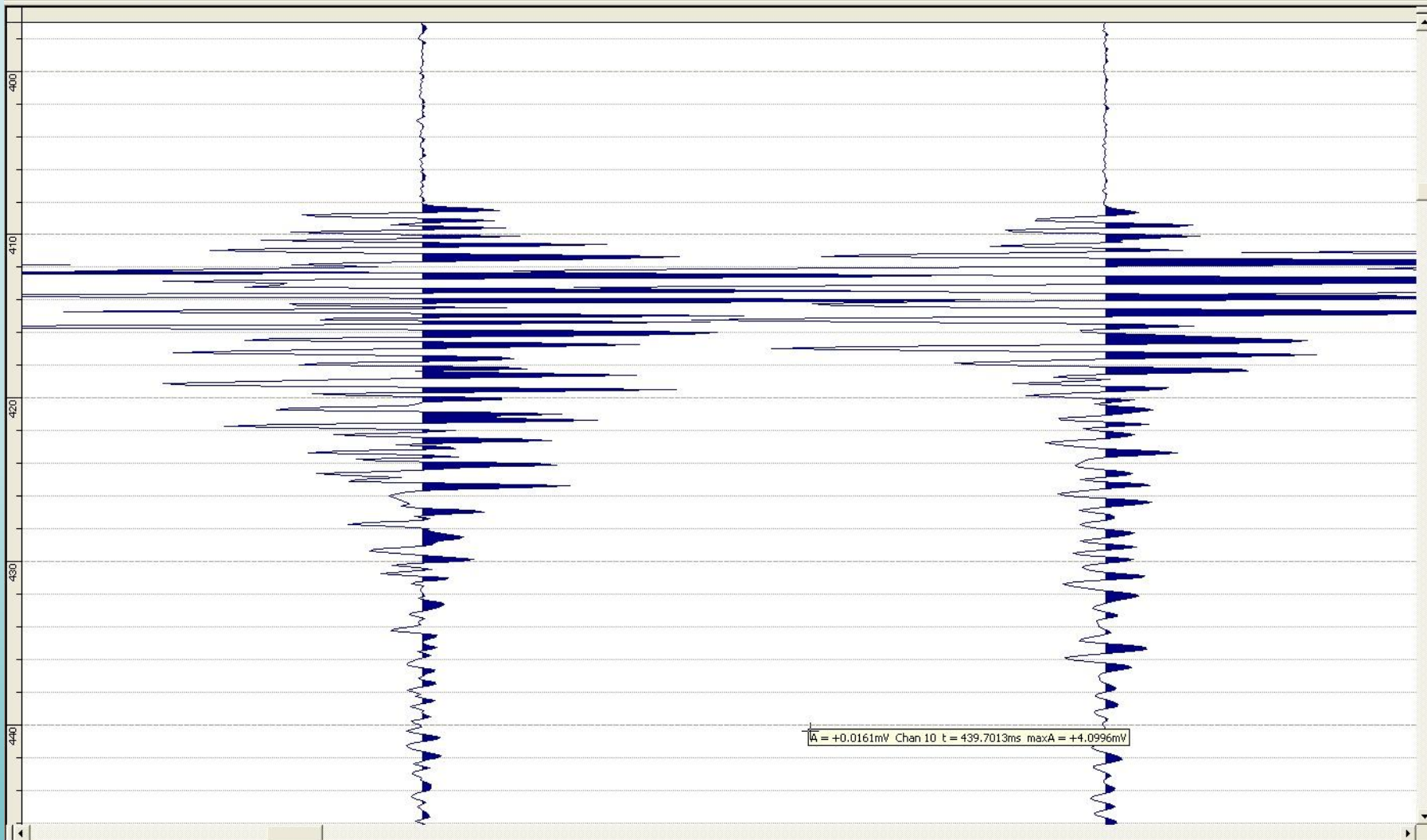
Average velocity:
1880 m/s

The
measurement:
hammering in
the chamber

Record
length: 2 sec.

Project: N/A Survey: N/A
Record: 9 Shot Line: 1 Shot Station: 9
Channel 1 is at Station: 1/1
Trace Length: 16384 Sample Interval: 0.1250000 ms Plot Length: 2047.8750000 ms
AGC: Off





Date	Time	Event
07 Nov 2008	00:02:38	Enabled activity logging

Result of first break picking: 48 travel times (t_i)

- Known: 48 geophone x, y, z coordinates, z_0 and t_i .
- Known to some extent: v velocity.
- To be determined : x_0, y_0, t_0
- Equation: $v=s/t$

here:
$$v = \frac{\sqrt{(x_i - x_0)^2 + (y_i - y_0)^2 + (z_i - z_0)^2}}{(t_i - t_0)}$$

- 48 equation, 3 unknown→minimizing

