High Resolution Seismic Reflection Practical basis

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Preface

This text is intended to the geologists or any people interested by the **seismic reflection practical aspects**. One will find it therefore a minimum of formulas, abundantly developed in many other text books, but more practical indications less often explained in the literature and simple processing examples using free or inexpensive software.

These paper result of the experience acquired to the recording and the processing of several hundred kilometers of HR seismic lines in many geological contexts, with several types of energy source, (explosives, vibrator) and geometry.

Some processing example will use the popular SEISMIC UNIX modules recompiled for Windows PC using the **Visual_SUNT graphical interface**.

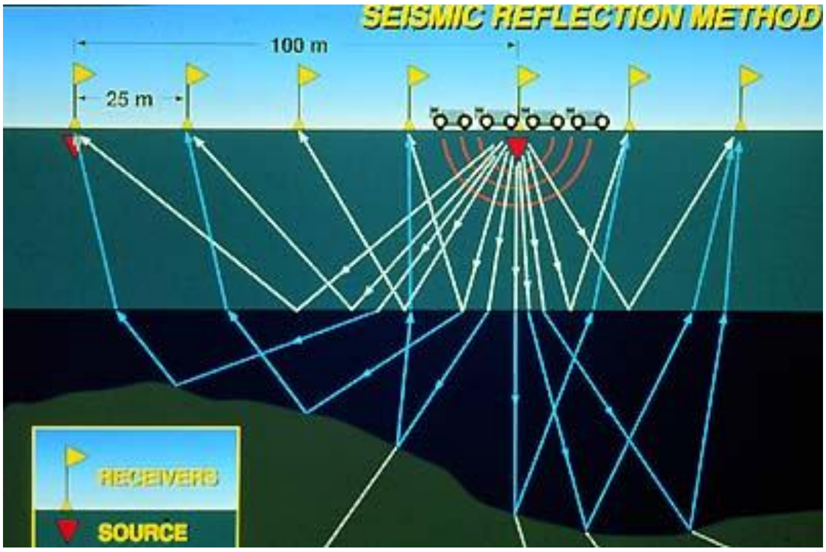


Figure 1 Reflection principle

INTRODUCTION

Historic

Reserved during the last decades to large specialized company working essentially for the oil prospecting, the use of the seismic reflection is extensively spread since the 1980's to smaller firms.

It is essentially the arrival on the market of powerful and affordable multi-channels digital recorders, coinciding with the phenomenal increase power of the personal computers, which permitted this evolution. Free or inexpensive PC based software's are now available, permitting all usual processing steps. Currently, this method is perfectly considering, as well technically that financially, for civil engineering studies, in shallow to deepwater research or for environmental and geo-technical problems.

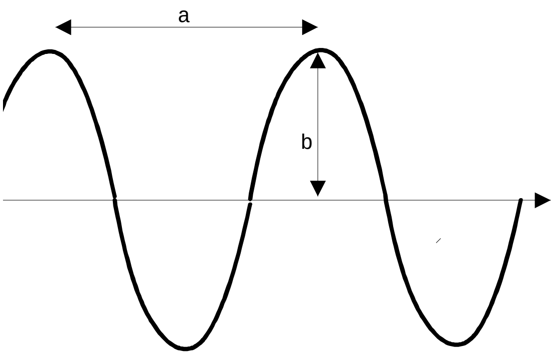


Figure 2 Nomenclature of the waves

Generalities on the waves

b = amplitude
a = length of wave,
v= Velocity of propagation
λ = Wave length
f= frequency (hertz)
k= number of waves/ km
T = period = time for one cycle
K = wave number
T = 1 / frequency = wavelength / velocity
Wave length = velocity / frequency
Velocity = frequency * wavelength
Wave number = 1 / Wavelength

Frequency = 1/ period
f/ k = apparent velocity
T = period = length of a cycle
The seismic waves are elastic distortion waves, which propagate some various velocities into the rocks or along some layers limits.

The reflection coefficient depends of the acoustic impedance. The acoustic impedance is the product of the acoustic velocity wave by the density of the layer (ρ).

$$r = v * \rho$$

The reflection coefficient per one ray arriving perpendicularly on a limit of layer is given by the formula:

$$R_{1-2} = \frac{v_2 * \rho_2 - v_1 * \rho_1}{v_2 * \rho_2 + v_1 * \rho_1}$$

Type of waves

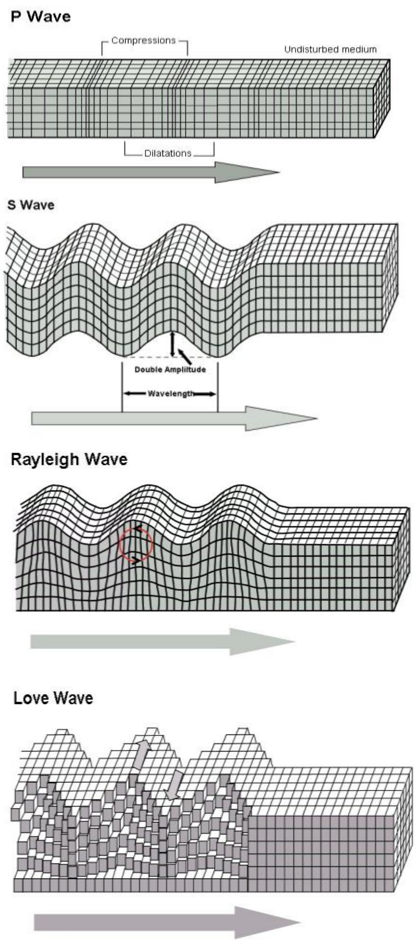


Figure 3 Types of waves

The seismic waves distribute in three main types, which differentiate by the orientation of the vibrations:

- The first corresponds to a parallel vibration to the direction of the wave propagation, by dilatations and successive compressions. It is the longitudinal waves so-called compression waves; they arrive the first during a seismic recording and are named **P waves;**

- The second group corresponds to a perpendicular vibration to the direction of propagation. One the so-called transverse or shears waves. They are **the S waves** (second arrivals); their velocity is below to the previous (P connection / S= 1.6 to 2) and they propagates only in the solid surroundings. Their amplitude is greatly bigger that the P. waves

- A third group of wave progress of more complex way, no into but to the surface of globe, unlike the previous. They are waves of great amplitude and great period (**Lowe waves** and of **Rayleigh** velocity 90 % of the S waves). The waves of Stoneley develop to the interface liquid - solid.

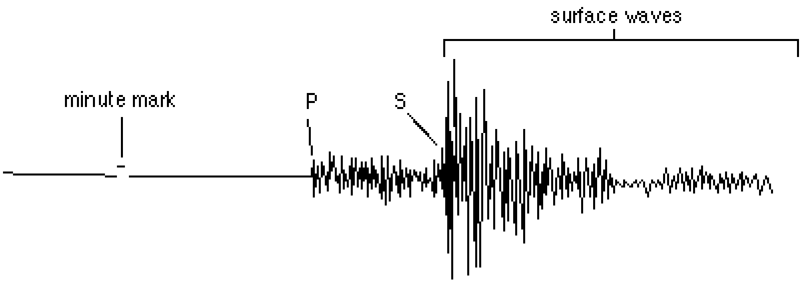
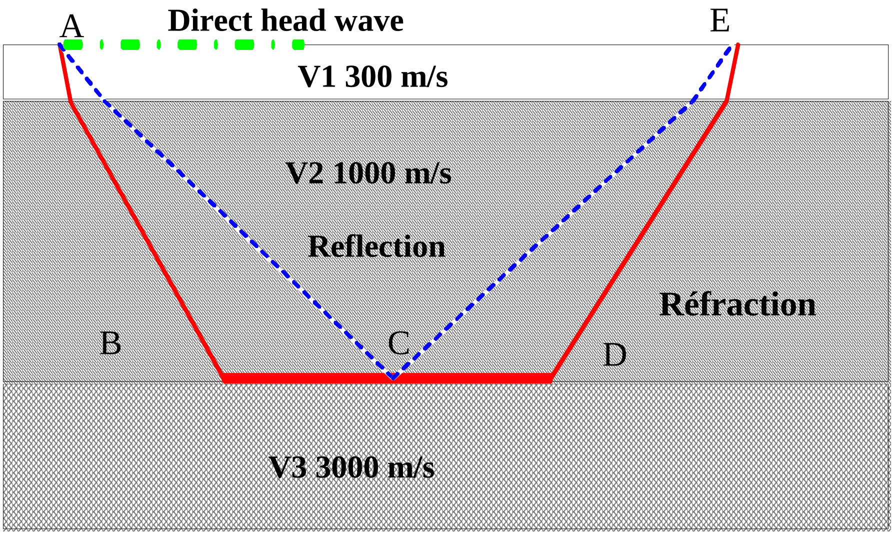


Figure 4 Diagram of a wave

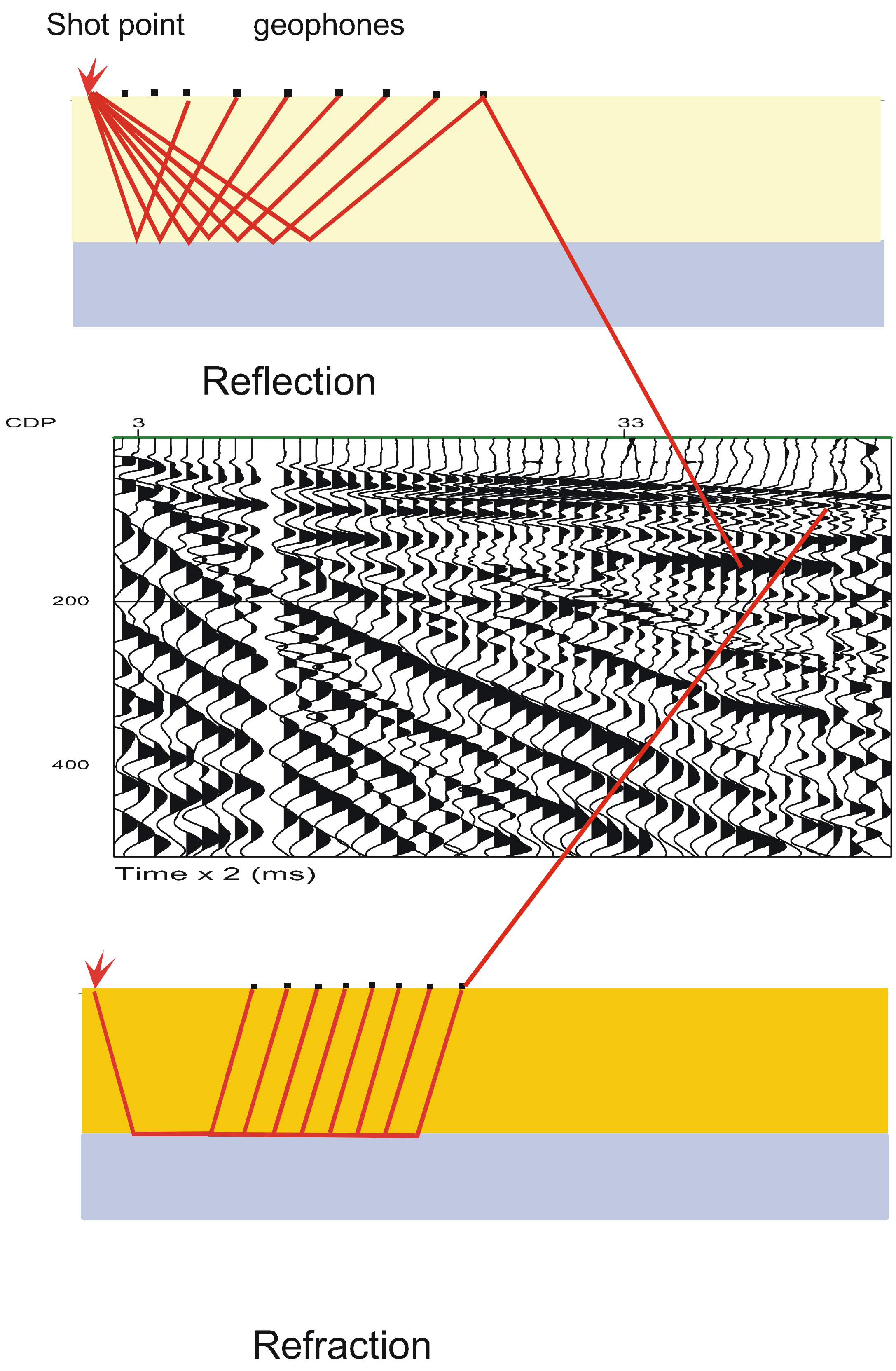
Order of arriving some waves seismic P

The P waves reach the first to the geophones. The direct waves reach the first the nearest geophones of the source, otherwise they are the refracted waves which arrive the first. The reflective waves arrive always after the refracted waves. The aerial noise, the waves of Raleigh and Lowe follows then.



The quickest way between A and E is through ABCDE

Figure 5 Travel of the seismic waves


Shot point
geophones
Reflection
CDP
3
33
200
400
Time x 2 (ms)
Refraction

Fourier demonstrated in 1807 that any sinusoidal always resulted of the sum of regular sinusoidal. This property is extensively used in seismic reflection (Fast Fourrier Transform)

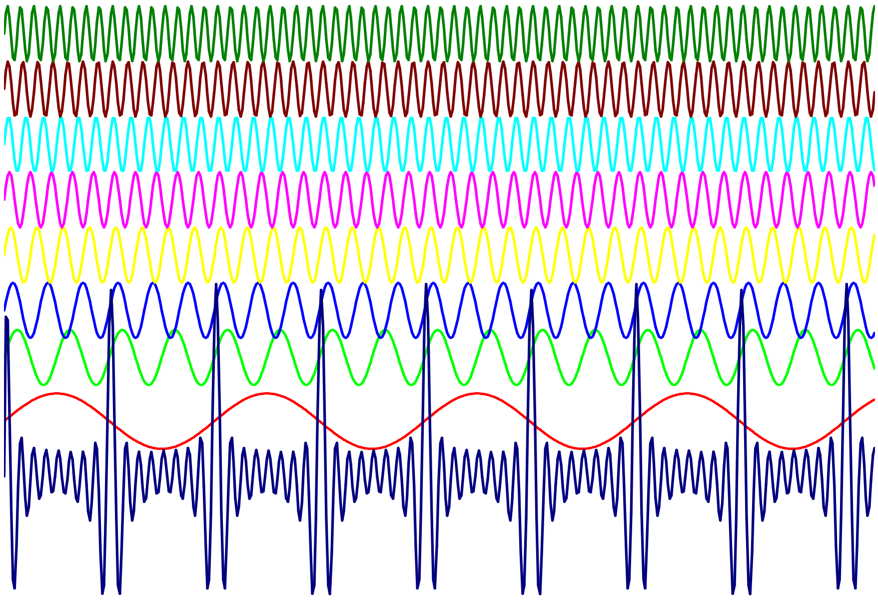


Figure 6 Sinusoidal and their sum (in bottom)

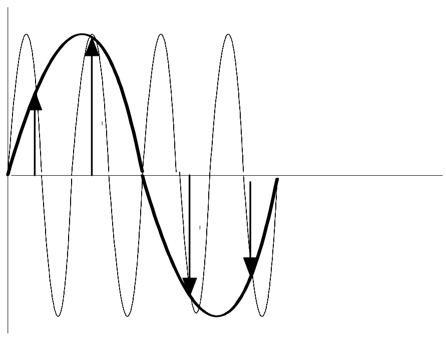
Sampling frequency

The seismograph samples regularly the signal received from the geophones in order to digitalise it. If the sampling frequency is insufficient, one could observe aliasing, that is a loss of the elevated frequencies, which appears then like lower frequencies.

In the diagram below, the frequencies in ***dash*** are not put in evidence, and some lower frequencies are created. The arrows represent the sampling rate.

The Nyquist law determines the most elevated frequency in function of sampling rate (Nyquist Frequency = 1/ 2 * sampling rate). With a sampling rate of 0,500 ms, one can theoretically distinguish some frequencies until 1000 hertz without aliasing.

In seismic high resolution, in working less than 500 meters of depth, one can to expect frequencies between 100 and 150 Hz, to 2 - 3 km, the frequencies lower less than 40 Hz. It acted therefore of sampling at least 1 ms, in order to apply a high-cut filter of 250 Hz, being the quarter of sampling.

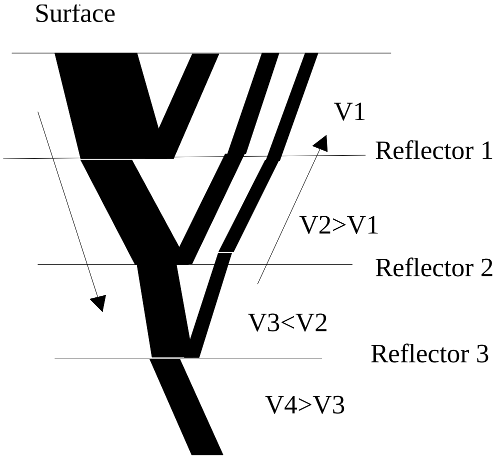


$$Nyquist\_frequency = \frac{1}{2 * \tau}$$

τ= = Sampling

Figure 7 **Sampling and aliasing**

Amplitude



Crossing a layer, the wave amplitude decreases, the figure opposite illustrates this phenomenon. Passing to a fast layer to a slow layer, one gets a coefficient of negative reflection (cf 1.2).

Figure 8 **Attenuation of the amplitude**

Vertical and lateral resolution

Vertical resolution

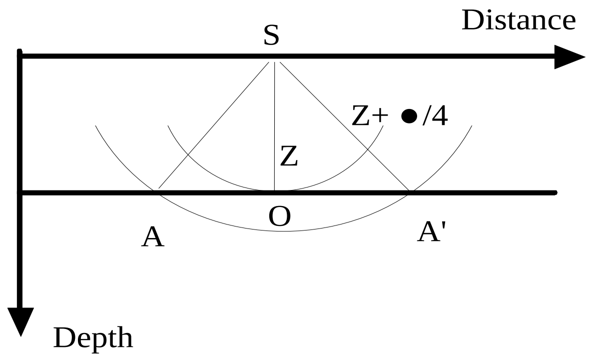
Vitesse (m/s)	f (Herz)	VR (m)
1000	150	2
1200	140	2
1400	130	3
1600	120	3
1800	110	4
2000	100	5
2200	90	6
2400	80	8
2600	70	9
2800	60	12
3000	50	15

For two reflections coming from the top and the basis of a layer, it exists distance limits below which, the distinction of this layer is no more possible. This limit (x or λ / 4) is function of the frequency (f) and the velocity (v) (λ= wave length)

$$x(m) = \frac{v}{4 * f}$$

Figure 9 Vertical resolution

$$AA' = \sqrt{\left(\left(z + \frac{\lambda}{4}\right)^2 - z^2\right)}$$



To A-A'= Fresnel zone = lateral resolution
(/ 4= Vertical resolution

Lateral resolution

Prof (m)	vitesse (m)	f (Hz)	r(m)
100	1100	140	20
200	1200	130	30
300	1300	120	40
400	1400	110	50
500	1500	100	61
600	1600	90	73
700	1700	80	86
800	1800	70	101
900	1900	60	119
1000	2000	50	141

In the same way it exists a minimal spacing in order to distinguish two reflectors. The reflections don't proceed of a precise point but of a zone. This lateral resolution (r) is linked, like in optic, to the zone of Fresnel in the formula (V = velocity, f = frequency, t = time in sec).
Lateral resolution depends of:

- wavelength,
- velocity and
- source-interface distance.

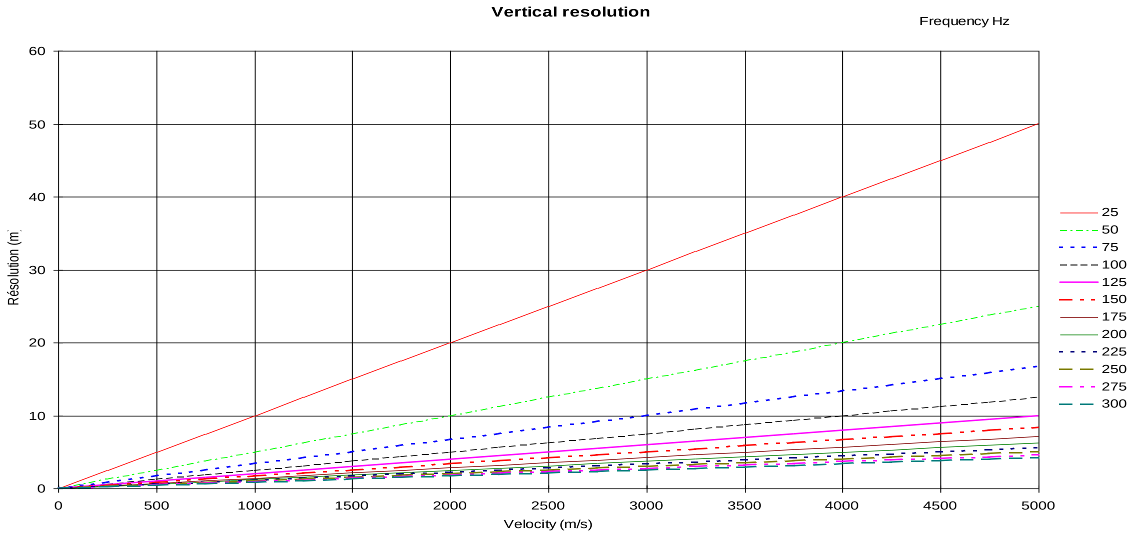


Figure 10 Diagram showing the vertical resolution

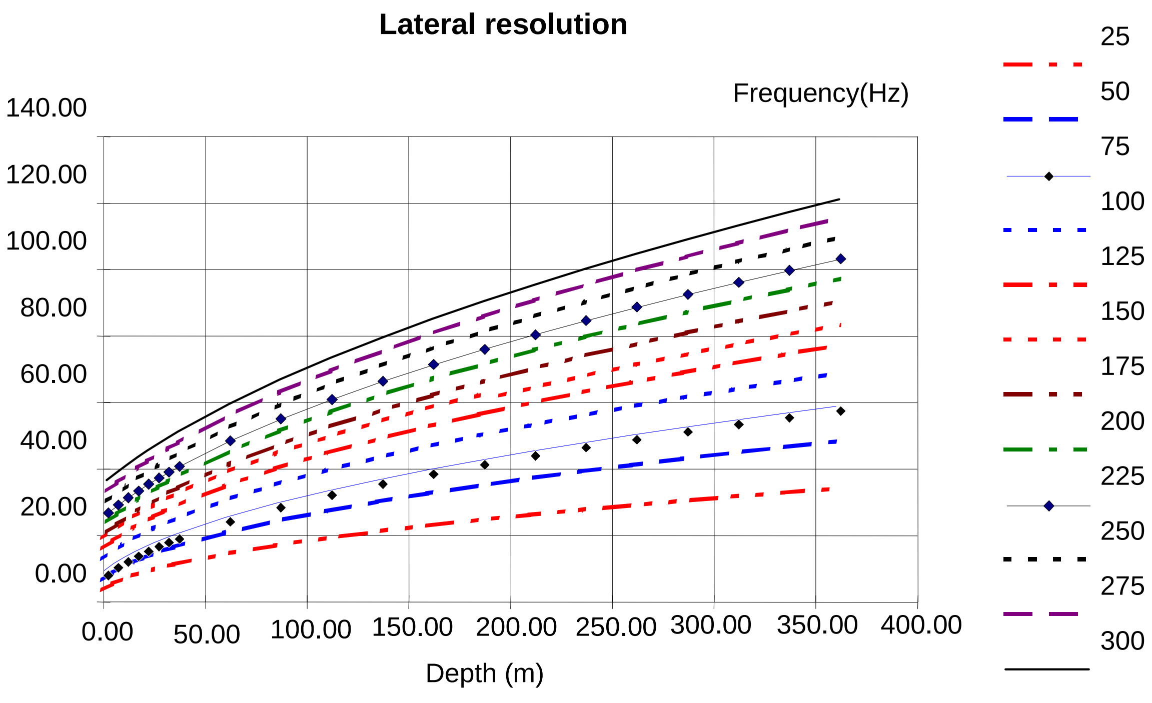


Figure 11 Diagram showing the horizontal resolution

The velocities in seismic reflection

We can distinguish several types of velocities in seismic reflection:

- Instantaneous velocity
- Summation velocity of stack
- Average velocity to a given depth
- Velocities means quadratic VRMS or Velocity Root Mean Square
- Interval velocity
- Apparent velocity, velocity of displacement of a wave front along a line of geophones, inverse of the slope in seismic refraction, given velocity by the indicatory curvature of the reflection hyperbole.

The **instantaneous velocity** is the V velocity to a given depth P

$$V = \frac{\Delta P}{\Delta t}$$

The **average velocity** to a given depth = $\dfrac{\text{m (Depth of a horizon)}}{\text{S (Time simple to this horizon)}}$

The **average quadratic** velocity VRMS or Velocity Root Mean Square, this velocity brings together of the summation velocity. $V_{RMS} = \sqrt{\dfrac{\sum V_i^{\,2} * t_i}{\sum t_i}}$

The **Interval velocity.**

$$V_{tranche} = \frac{\Delta P}{\Delta T}$$

The DIX formula links the interval velocity and the RMS velocity

$$V_{tranche} = \left[\frac{V^2{}_{RMS}n * t_n - V^2{}_{RMS}n - 1 * t_{n-1}}{t_n - t_{n-1}}\right]^{1/2}$$

The **apparent velocity** corresponds to the velocity of displacement of a wave front along a line of geophones; it is the reverse of the slope in seismic refraction and the given velocity by the indicators curvature of the reflection hyperbole.

In homogeneous middle:

Instantaneous V< VRMS< V apparent
Gap 3- 6% 0,5 - 1%

Example of velocity calculation

$$V_{RMS} = \sqrt{\frac{2000^2 * 300 + 3000^2 * 133}{433}} = 2353\, m/s$$

$$V_M = \frac{1000m}{433ms} = 2309\ m/s$$

Difference 1.9%

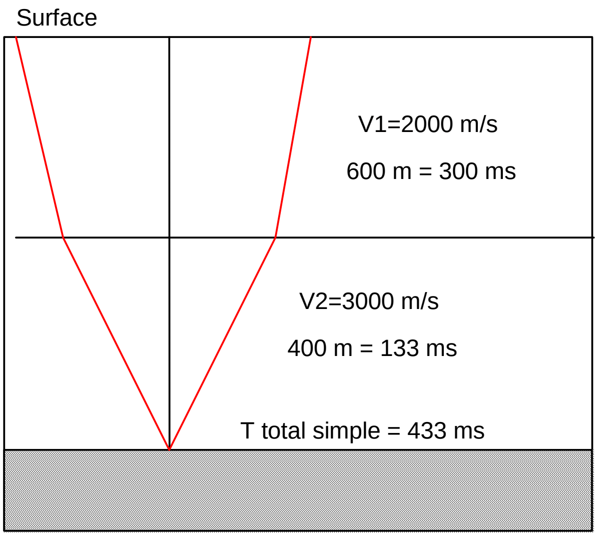


Figure 12 Seismic velocities

DATA ACQUISITION

Spread geometry

Recording in CDP

The most common recording type consists to send seismic waves from one shot point and to record reflected waves with many (48, 96 or more) geophones regularly disposed on the ground along a seismic cable. The CDP (*common depth point*) is the reflection point in depth, then CMP (*common mid point*) is the midpoint on the ground between shot and a geophone. With a switch (rollalong switch), the observer can "displaces" the recording geophones along the line with a constant number of actives geophones (24, 48 or more). The aim of this process is to add the travels having a reflective common point, in order to improve the signal / noise ratio. With 48 active geophones, there are 24 travels adding on a common reflector (Fold 24).

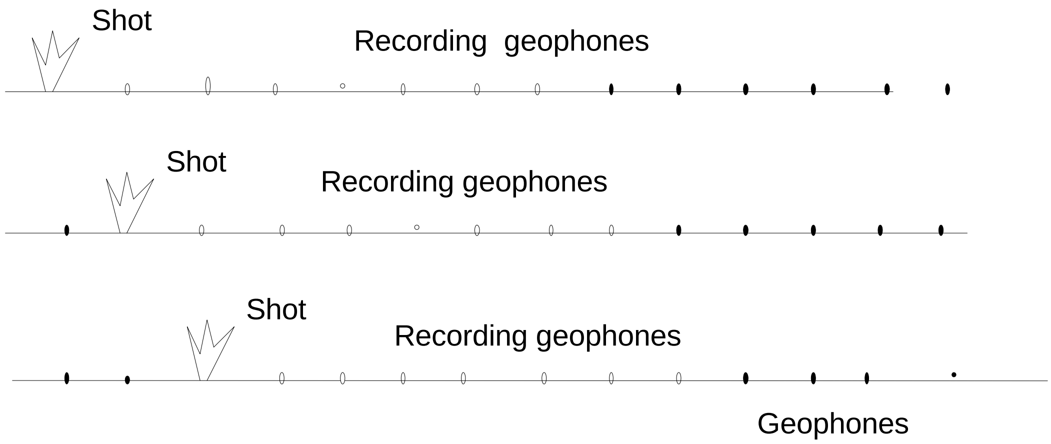


Figure 13 Diagram of position of the shootings

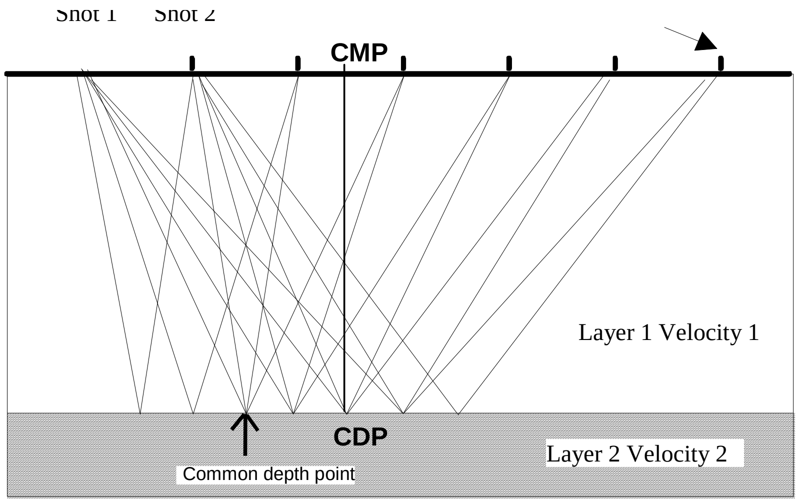


Figure 14 Diagram of the CDP acquisition

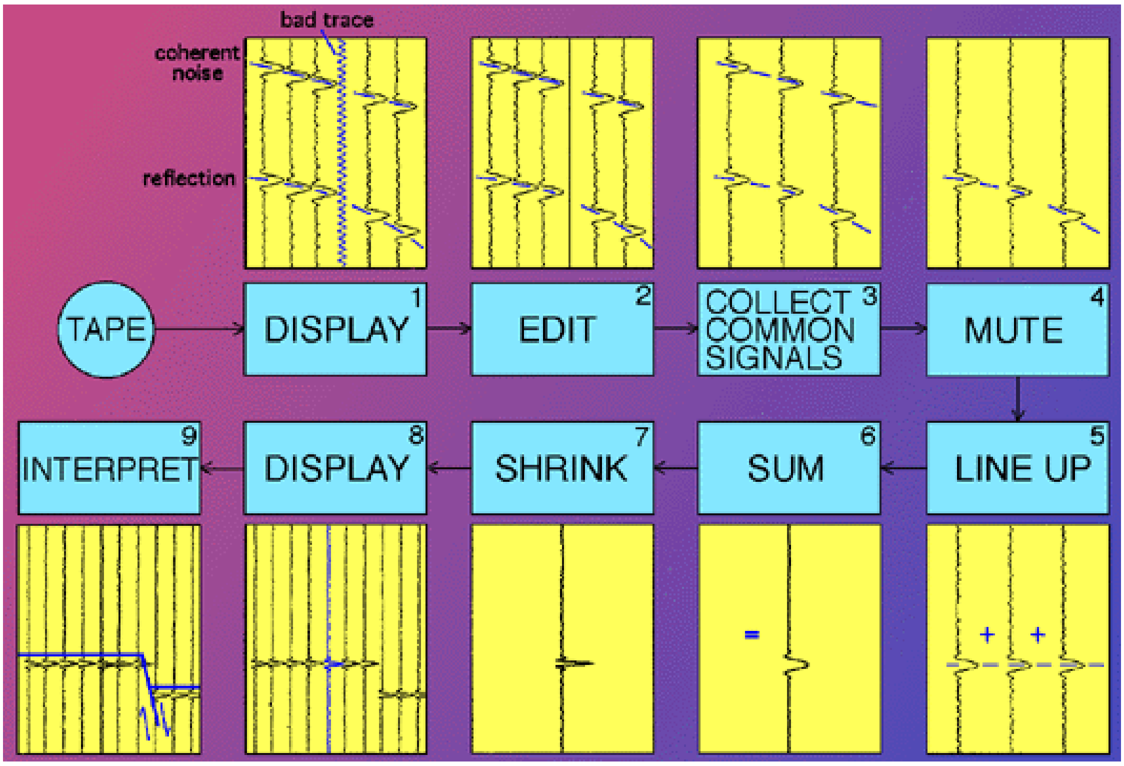


Figure 15 Summary of acquisition and processing of seismic reflection

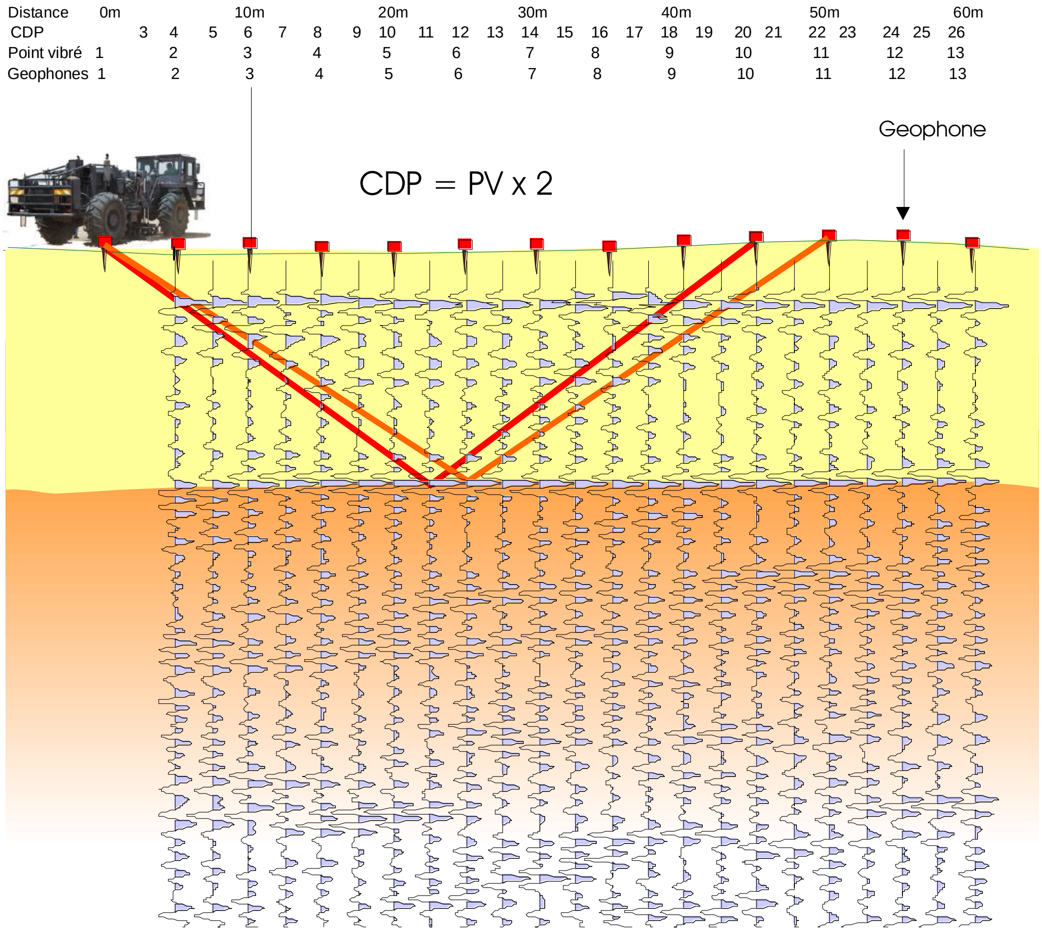


Figure 16 CDP, PV and traces

Shootings position and optimal window (optimum window)

The shot or the vibration point can be situated:

- At the extremity of the active geophones (End shot)
- At the center of the geophones. (Split spread shot)
- At a certain distance (offset) of first geophone

The last geometry allows to have a long distance of offset, the second is more adapted if the reflectors are tilted.

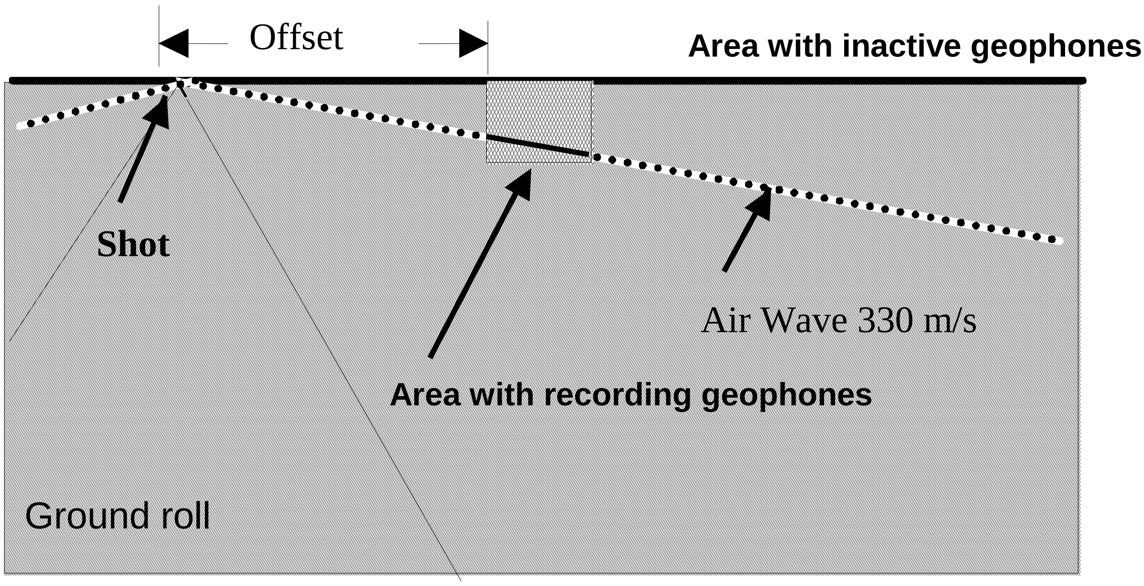
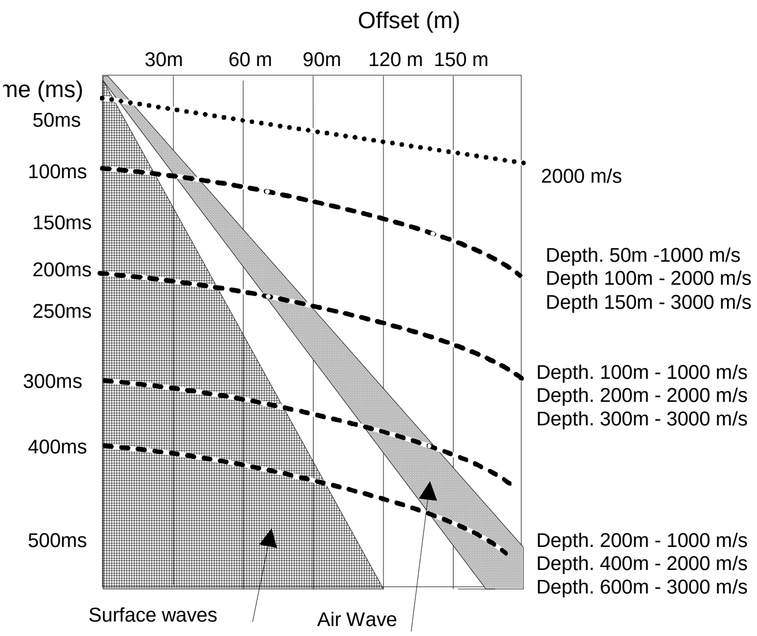


Figure 17 Diagram of the optimum window



The shooting position regarding to the first active geophone is very important. This distance, called *offset*, is chosen in function of the investigating depths, velocities of the layers and of the total length of profile recording. An important offset is used for some deep prospecting, no offset is used for shallow seismic prospecting. With 48 active geophones every 5 meters, the maximum offset is 240 meters from the shot point to the last geophone, 480 meters with a intertrace of 10. This permits of avoiding using an offset and having some near reflections of the surface and deep (500 ms, in accordance with the ground velocity). The aim of the offset is avoiding the noises (ground roll, airwave) superimpose to the reflections on the field recordings.

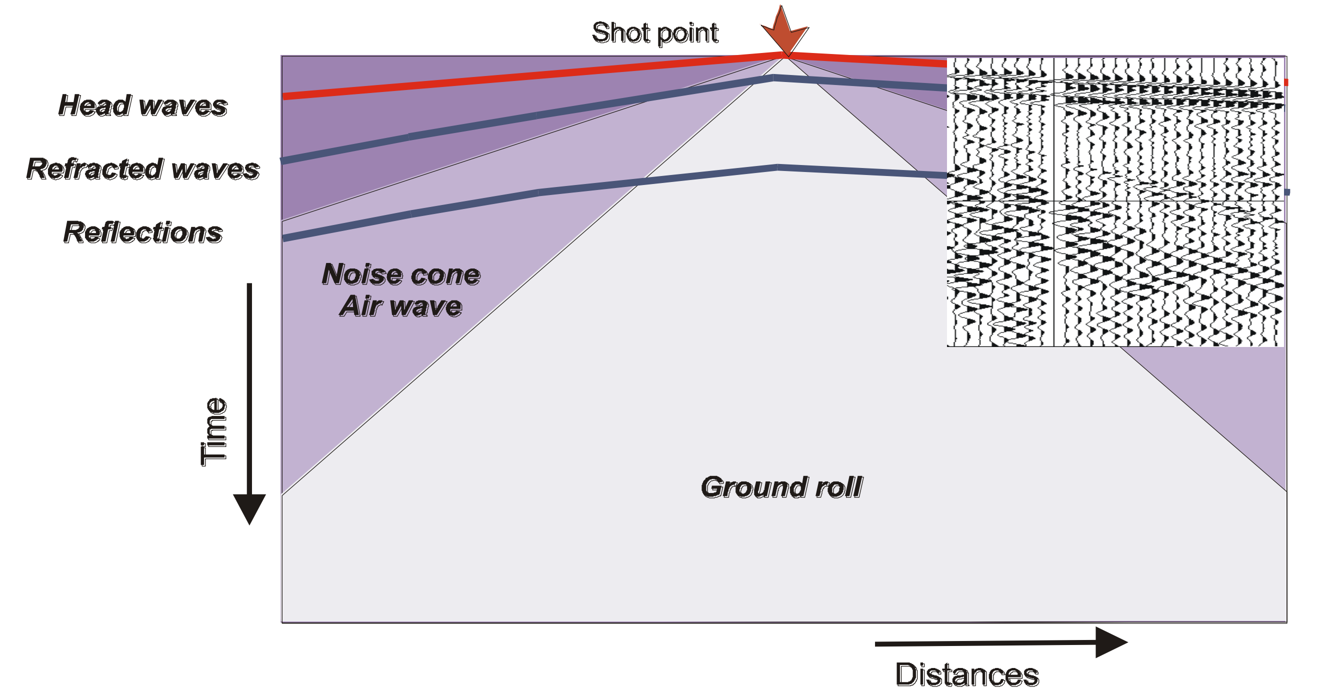
Receiver spacing must also be adapted to the depth of investigation. The following values are only indicative and can vary according to local geological conditions, mainly velocities:

Distance between geophones	**Minimum depth**	**Maximu m depth**	**Typical sample rate**	**Typical type of prospecting**
50 m	250 m	5000 m	2 ms	Usual distance for oil prospecting
10 m	100 m	3000 m	1 ms	HR seismic for deep water prospecting
5 m	50 m	1000 m	0.5 ms	Typical HR seismic
2 m	20 m	500 m	0.2 ms	Very HR seismic for very shallow prospecting
1 m	10 m	100 m	0.2 ms	Very HR seismic for very shallow prospecting

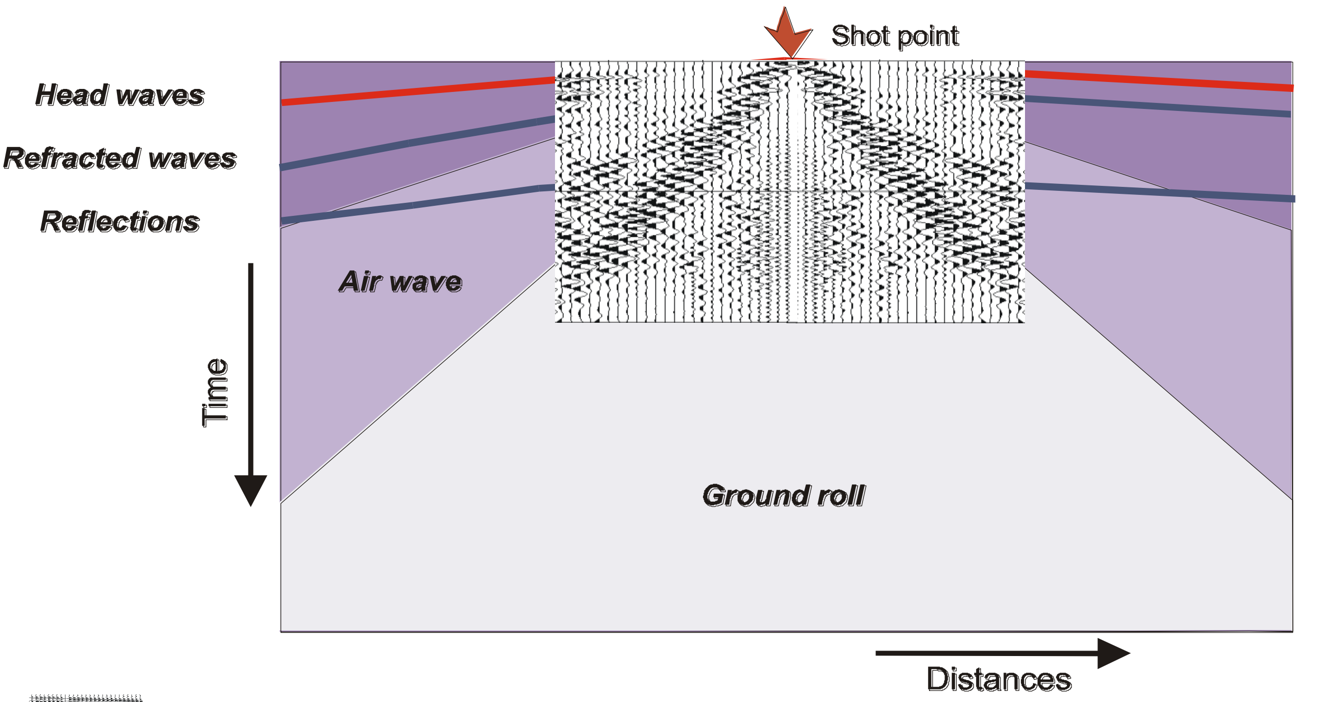
With 10 and 50 m receivers spacing, geophone group array are common, single geophone or grouped geophone nest are used with smaller trace spacing.

Seismic recording showing the different types of waves

Shot with offset



Shot split-spread



Geometry pattern of the strings of geophones

In deep seismic, with 30 m spacing between traces or more, it is classic to use strings of geophones instead of one sensor by trace. This technique used in seismic HR to medium depth allows to improve appreciably the signal, qualitatively and quantitatively. It permits in particular of attenuating the linear coherent signals of surface in arranging the geophones on a distance corresponding to a half-length of wave. A surface wave will shake the first geophone toward the high nullifies the effect on the last geophone having an inverse signal. On the contrary, the reflected waves coming from the depth reach all the geophones of a string almost synchronous.

In practice it is necessary to determine on a noise shooting, registered with the geophones grouped, the velocity and the frequency of the linear waves that one wants to eliminate.

- Velocity: 1500 m / s
- Frequency: 50 Hertz
- Length of waves: 1500 / 50 = 30 meters

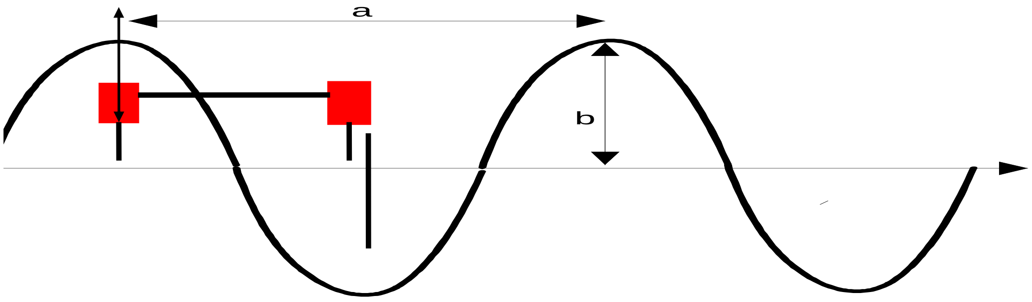


Figure 18 Attenuation principle of the linear noises by a string of geophones

The figures 16 and 17 show the result of the implantation of nine grouped geophones then spaced of 6.5 meters on a 45° diagonal with regard to the line. This geometry attenuates considerably the guided waves disperses that the filtering doesn't allow to eliminate. Note the apparition of an excellent reflection at 1300 ms visible equally in the cone of noise.

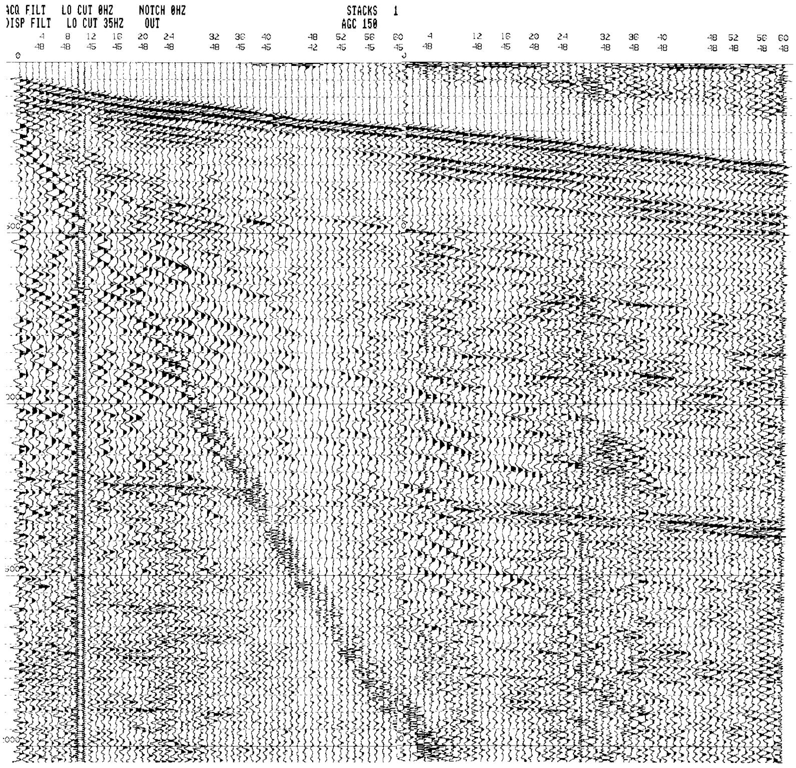


Figure 19 Recording with a geophone pattern

9 geophones in line per take out, 6.5m between geophones

Source: 1 kg explosive

Geology: sedimentary Palaeozoic and eruptive Precambrian (Morocco)

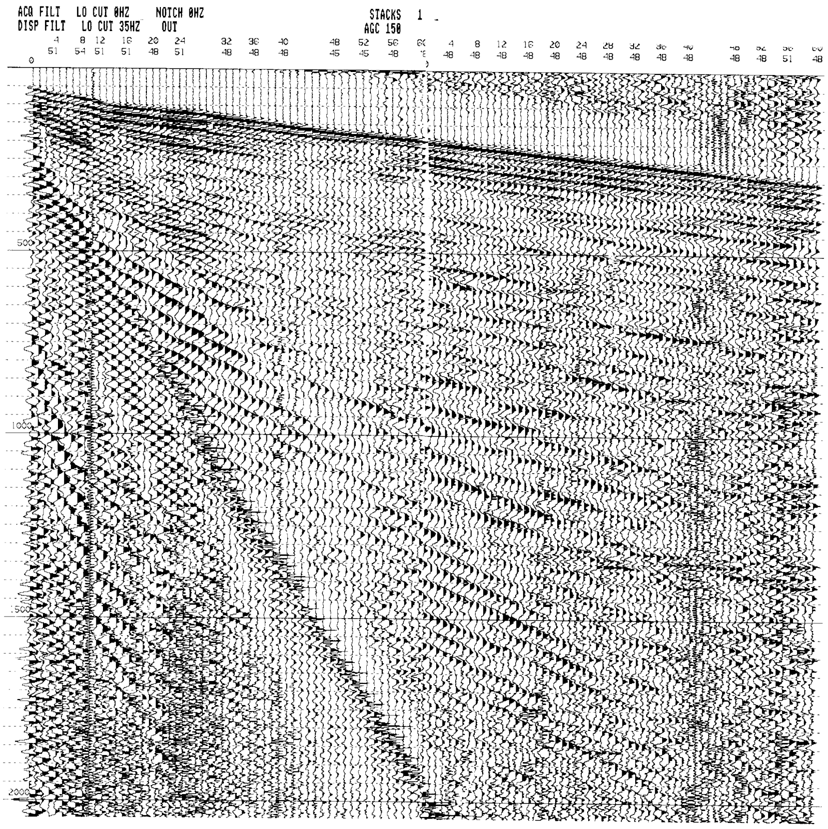
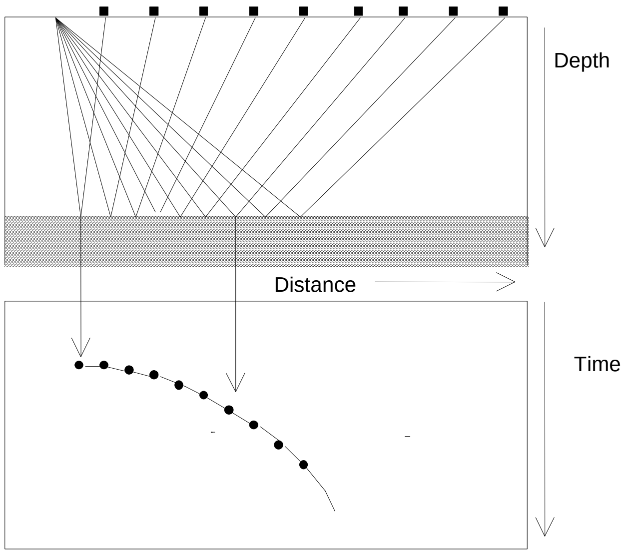


Figure 20 Recording with grouped geophones

Geometry of the reflections

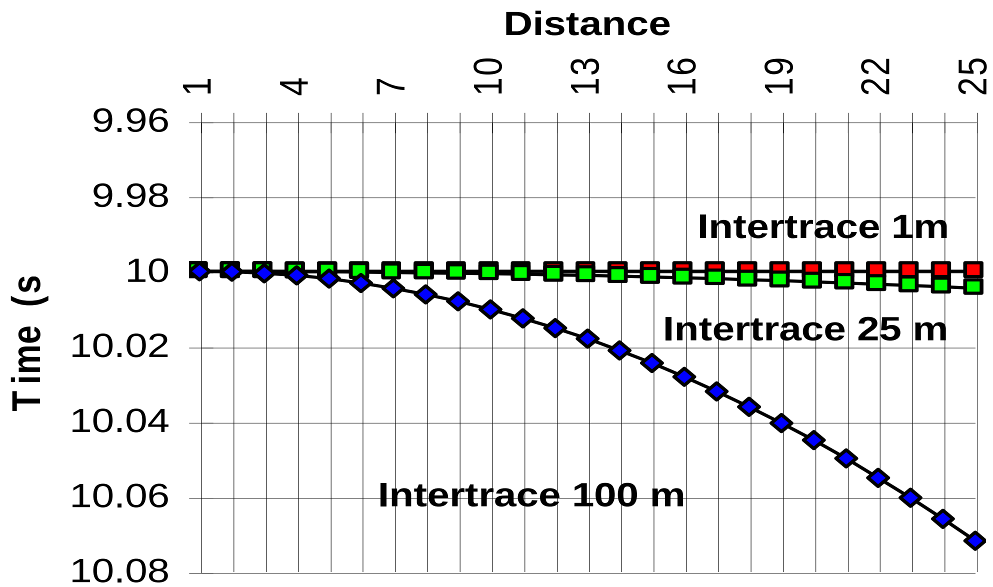
The reflective plans appear like hyperbole shape and not of rights on the seismic recordings, because the increase of time is not linear but follows this function.



$$\mathbf{T^2_{(x)} = t^2_{(0)} + x^2/v^2}$$

X = distance receiver - source
t (x) = travel-time source / receiver
t (0) = double time to the CDP
V = field velocity

Figure 21 Demonstration of the hyperbolic shape of the reflections



In seismic high resolution, the geophones spacing is small; of that fact the curvature of the hyperbole will be also little marked. The evaluation of the precise NMO velocities will be difficult to estimate, the Constant velocity scan seams to be the best solution in order to determine NMO velocities.

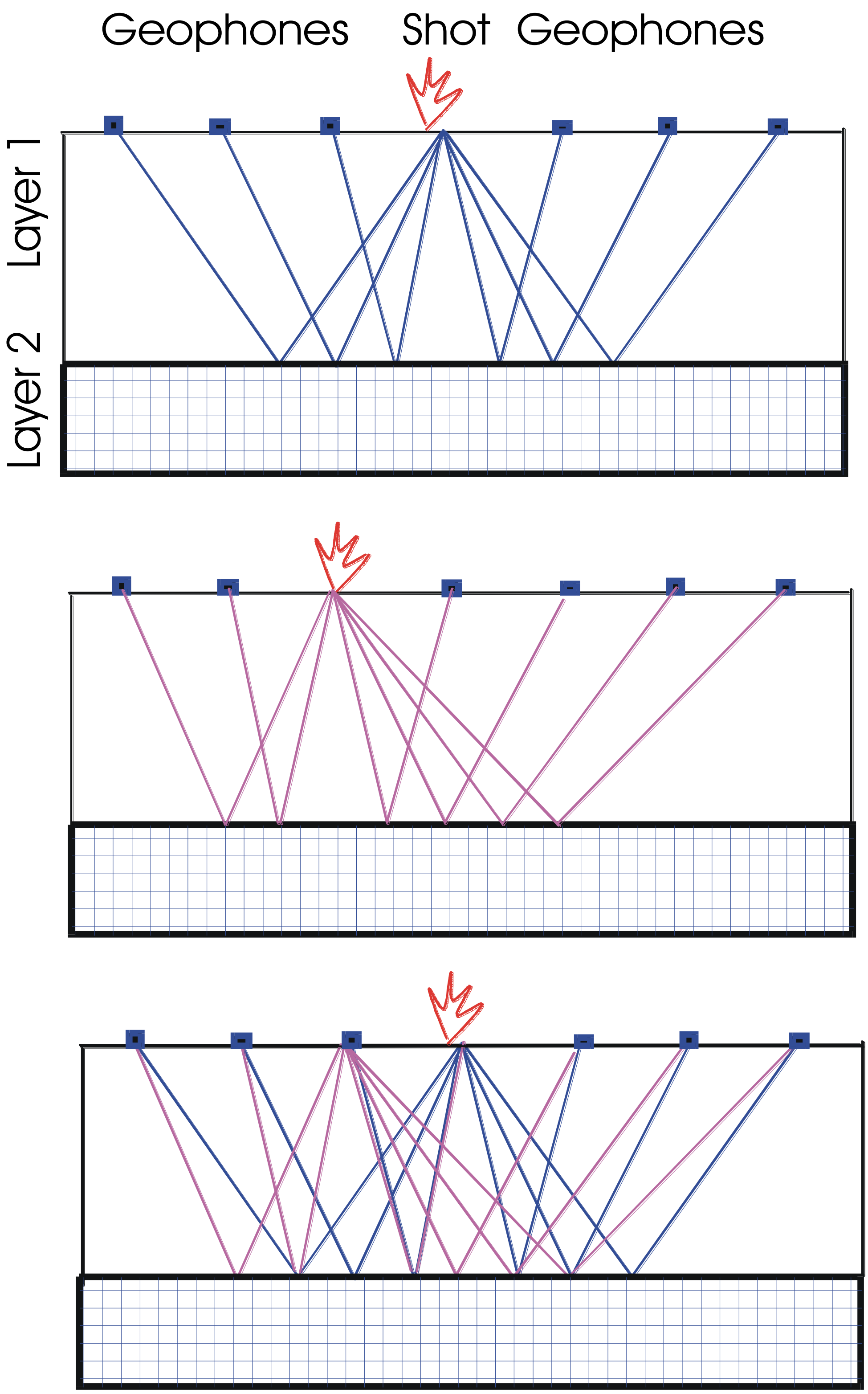


Figure 22 **Seismic ray line in CDP acquisition**

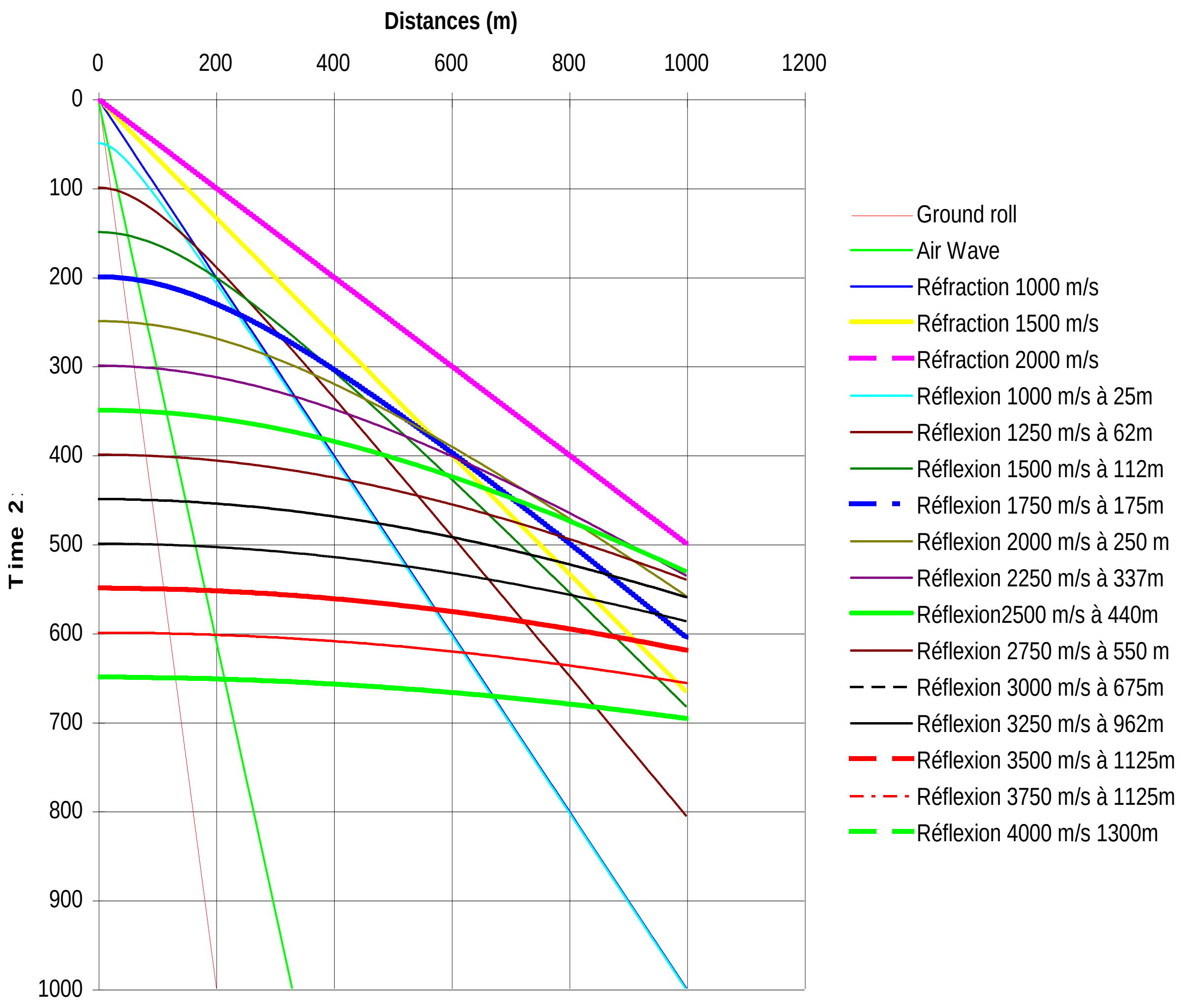
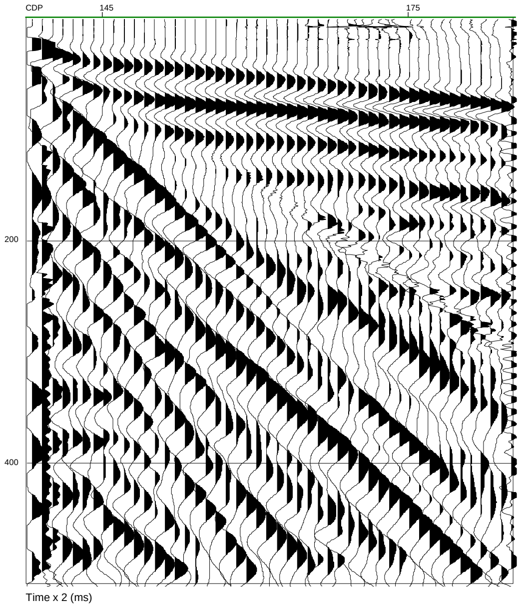
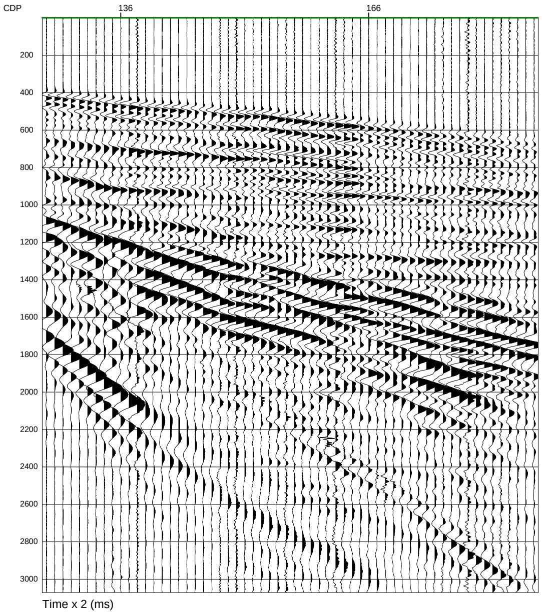


Figure 23 Example of visible events on a seismic recording

Figure 24 Examples of seismic records



Record 1



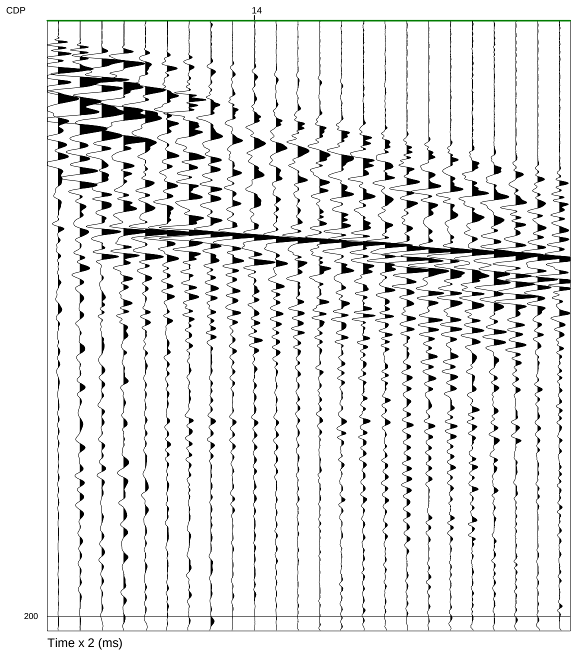
Record 2

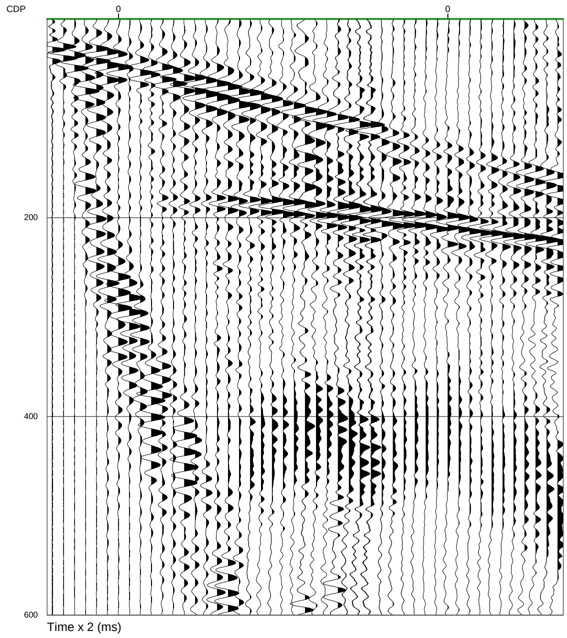
Record 1
Vetroz, Switzerland Type of geophone 50 Hz
Sampling 0,500 ms, Source: Buffalo gun
Recording time 500 ms, Interval between geophones 2 meters
No acquisition filter, display filter LC 50 Hz- HC 500 Hz
Type of geometry, shooting end of line Offset line 2 m
Active channels 48, Recorder Geometrics STRATAVIEW

Observations: Good reflective marks toward 100 ms, the airwave arrives to 300 ms, beneath reigns the ground roll.

Record 2
Jraïfia, Morocco Type of geophone 15 Hz
Sampling 1 ms Source: 1 kg explosive
Recording time 1000 ms Interval between geophone 10 meters
No acquisition filter, display filter LC 10 Hz
Type of geometry Offset line 300 m
Active channels 60 Recorder Geometrics STRATAVIEW

Observations: Good reflective appears between 700 ms and 1500 ms, after processing the guided waves were eliminated. The ground roll has very low frequencies.





Record 3 **Record 4**

Record 3

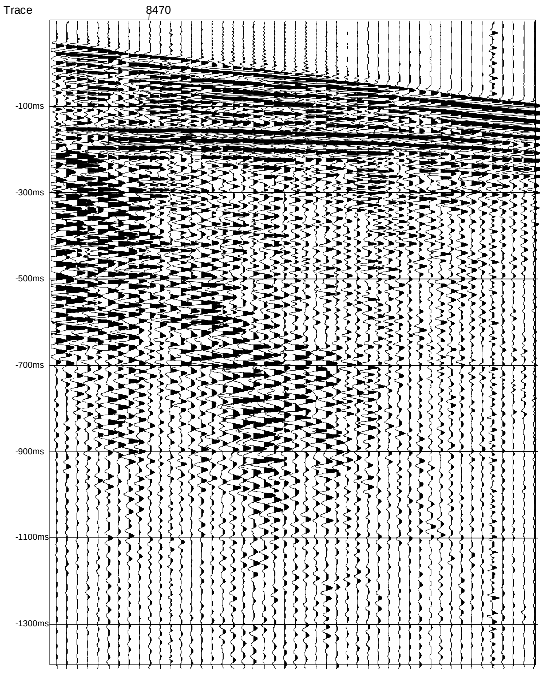
Geneva Switzerland Type of geophone 15 Hz
Sampling 0,200 ms Source: Hammer 4 strokes
Recording time 200 ms Interval between geophones 2.50 meters
Filter to the HC acquisition 500 Hz display filter LC 200 Hz
Type of geometry Shooting end of line Offset line 10 m
Active channels 48, Recorder Geometrics STRATAVIEW

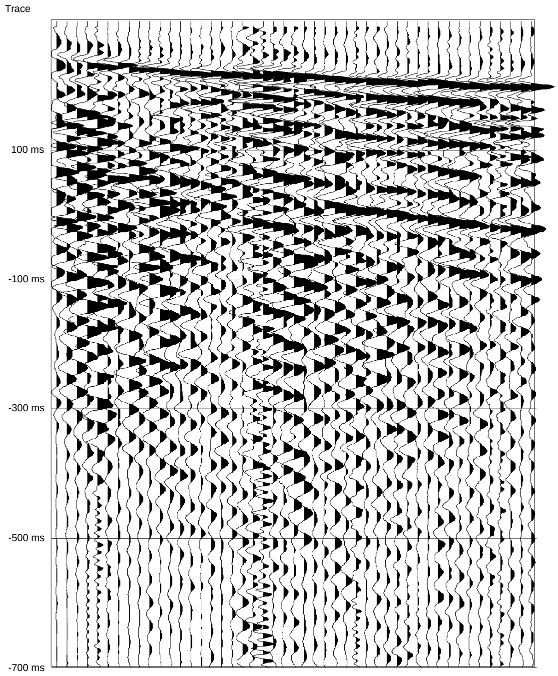
Observations: This record shows very good reflectors appearing toward 60 ms. The ground roll and the air wave are practically not visible.

Record 4

Yverdon, Switzerland Type of geophone 15 Hz
Sampling 0,500 ms Source: Mini Vibrator
Recording time 1500 ms Interval between geophone 5 meters
No acquisition filter, display filter LC 50 Hz
Type of geometry shooting end of line Offset line 20 m
Active channels 48 Recorder Geometrics STRATAVIEW

Observations: This recording, achieved with a mini-vibrator in urban perimeter, shows several very beautiful reflectors in particular the one at 250 ms. After filtering, this record produced a section of very good quality.





Record 5 **Record 6**

Record 5

France, Bordeaux Type of geophone 15 Hz
Sampling 1 ms Source: Vibrator Mertz M22/601
Sweep 12-72 Hz, 12 seconds
Recording time 1024 ms Interval between geophones 5 meters
Type of geometry shooting end of line Offset line 100 m
Active channels 48, Recorder Geometrics STRATAVIEW

Observations: This record shows very good reflectors appearing toward 160 ms. The ground roll and the air wave are very weak, refracted waves are strong,

Record 6

France, Aix-les-Bains Type of geophone 15 Hz
Sampling 1 ms Source: Vibrator Mertz M22/601
Sweep 20-100 Hz, 12 seconds
Recording time 2048 ms Interval between geophones 5 meters
Type of geometry shooting end of line Offset line 50 m
Active channels 48, Recorder Geometrics STRATAVIEW

Observations: Ground roll and air wave are practically not visible, refracted waves are very strong, reflectors appears before 100ms, strong 150 ms events are probably guided waves..

Sources of energy

Introduction

Sometimes you can have nice reflections at a depth more the 400 meters only with a small blank cartridge, other times you must use half a kilogram of explosive to record bedrock reflections below 100 meters of loose landslides. If the water level is near the ground surface, usually energy will propagates easily with high frequencies, in loose rocks, the loss of energy will be important and frequencies very low (30-50 Hz)

Hammer

A 5kg sledgehammer constitutes yet an effective and inexpensive seismic source. An accurate piezoelectric sensor trigger linked by cable to the recorder is set on the hammer, hits are generally made on an aluminium base plate. This economical and fast method is interesting for the subsurface prospecting. On soft ground, like some fields, the penetration of the waves is very weak (10 - 20 meters), striking directly on the asphalt of a road, produce often results astonishingly good (> 200 meters on some saturated soils).

This source constitutes in many cases the best energy source for shallow seismic, with a large frequency spectrum and a good energy, but the environment must not be too noisy.

Explosives

The blast of 100 to 200 grams of explosives produces a very strong energy, generally sufficient for some depths from 500 to 1000 meters. With 500 to 1000 grams, the depth of investigating passes 1000 m. In placing the explosives to the bottom of a hole from 1.20 to 2 meters, one avoids a great part of aerial noise (airwave) and the energy is better distributed. Besides, it avoids some dangerous projections in the air. In order to make the holes, a hammer perforator is usable or an auger in clay soils. In the sand, a simple metallic tube hardback to a compressor is very efficient.

During a fieldwork, the drilling of the holes is often the slowest field operation and govern all the acquisition work.

In some desert regions, where the drilling is impossible, explosives can be suspended and exploded in the air about 1.5 m from the ground (*Poulter Method*). This method, very noisy but with very few air projections, has given sometimes very satisfactory results.

Buffalo-gun (Pipegun)

Shooting a blank cartridge in a hole of some decimetres deep constitutes an interesting alternative to the explosive. The strength of the gunpowder corresponds roughly an equal weight of explosive and it is possible to add (stack) several shootings. One finds some "rifles" in the commerce, but many users make them manufacturing by craftsmen, because the technology is rudimentary. It was about a tube with an explosion chamber, in which one introduces a cartridge with a strike. The interest of this method is its strength, the possibility of shooting under the upper soft layer and of avoiding the administrative problems linked to the use of explosives. Cartridge of calibre 12, 10 and sometimes 8 are found at the gunsmith’s shop, the smaller values are the stronger.

Special cartridges with an electric ignition (BETSY, SISSY) containing powerful explosive are found on the market.

Figure 26 Sophisticated “buffalo gun” with breech for calibre 8 cartridge

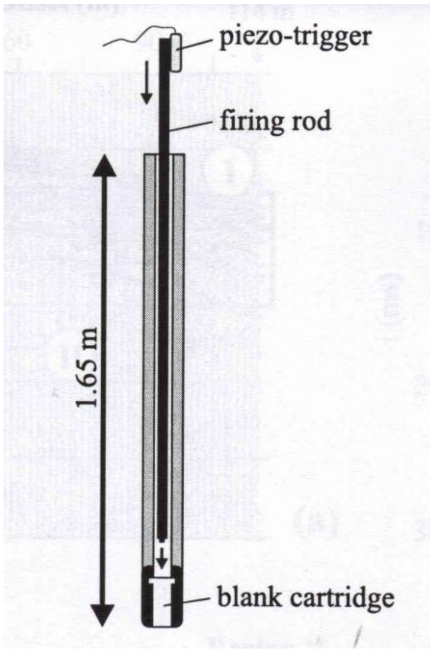


Figure 25 Pipe gun diagram

Vibratory sources

The most usual technique in "great seismic," vibroseismic becomes to the reach of the seismic high resolution thanks to the apparition of adapted recorders and of “small” vibrator. The seismograph records during several seconds (4-10 s) and then his software start the auto-correlation of the signal. After that, the observer can see on the recorder LCD display the correlated “shot”. The vibrating source must have a elevated frequency vibration (several hundred of hertz) and of a variable length (sweep). An important advantage of the vibroseismic is its possible use in urban zone and in a "noisy" environment.

OYO Center of Applied Geoscience in the Netherland has developed a “portable” 65 kg vibrator that generates a maximum peak force of 500 N with a frequency range between 25 and 1500 Hz.

Figure 27 Towed vibrator IVI of 3500 kg, depth of investigating of several hundred of meters

Figure 28 LRS Vibrator 309 of 22'000 pounds. Depth of investigating x 1000 meters

Weightdrop systems

Figure 29 Fall of weight

Weight drop systems are often employed in shallow seismic surveys. They generally include truck-mounted mechanisms that accelerate a large mass toward the ground. The interest of this method is yet limited by the fact that this process can be applied only along the roads if this tool is towed behind a vehicle and the power is not very important (until 7500 joules).

What can we see on a field record?

Introduction

Unfortunately for the geophysicists, the seismograph records not only reflections but many other waves and other noises which "parasite" the data. There are many tools to removes unwanted events, but it is not always possible to do it without to affect reflections. **Careful field recording testing** can help to produce data with a minimum of “bad” event using a good shooting geometry and receiver spacing or geophone pattern.

- Direct and refracted waves
- Surface waves
- Reflections
- S waves
- Noise
- Interference on the connectors of the geophones, especially by humid time.
- Roll along electrical parasites
- Air wave
- The multiple
- Guided waves

Direct and refracted waves

Head waves are always the first events seen on a record. They are linear and often very visible and strong. Sometimes they can disappear with large offset. Many geophysicists try to remove head wave using surgical mute, FK filtering or adapted NMO stretch mute value, but in some case, uppermost reflection and refraction can be very close and difficult to distinguish.

Surface waves

Surface waves (Raleigh, Lowe) are low velocity, low frequency signal seen below shots. They can be reduced using frequency filtering or FK filtering. Useful reflections are often very difficult to extract from surface wave for upper 500 ms below shots**.**

For this reason, acquisition using the optimum window is fundamental in shallow reflection seismic.

Noise

Unfortunately, many uncoherent noises are also recorded.

- Natural noises like the wind, appreciable especially if there is near some trees, rain with the impact of the water drops on the geophones.
- Human noises: cars, trucks, animals, trains and especially the planes.
- Electric noises (50 or 60 Hz, with harmonics, apply a reject notch filter).
- Internal noises to the seismograph.

Interference on the connectors of the geophones

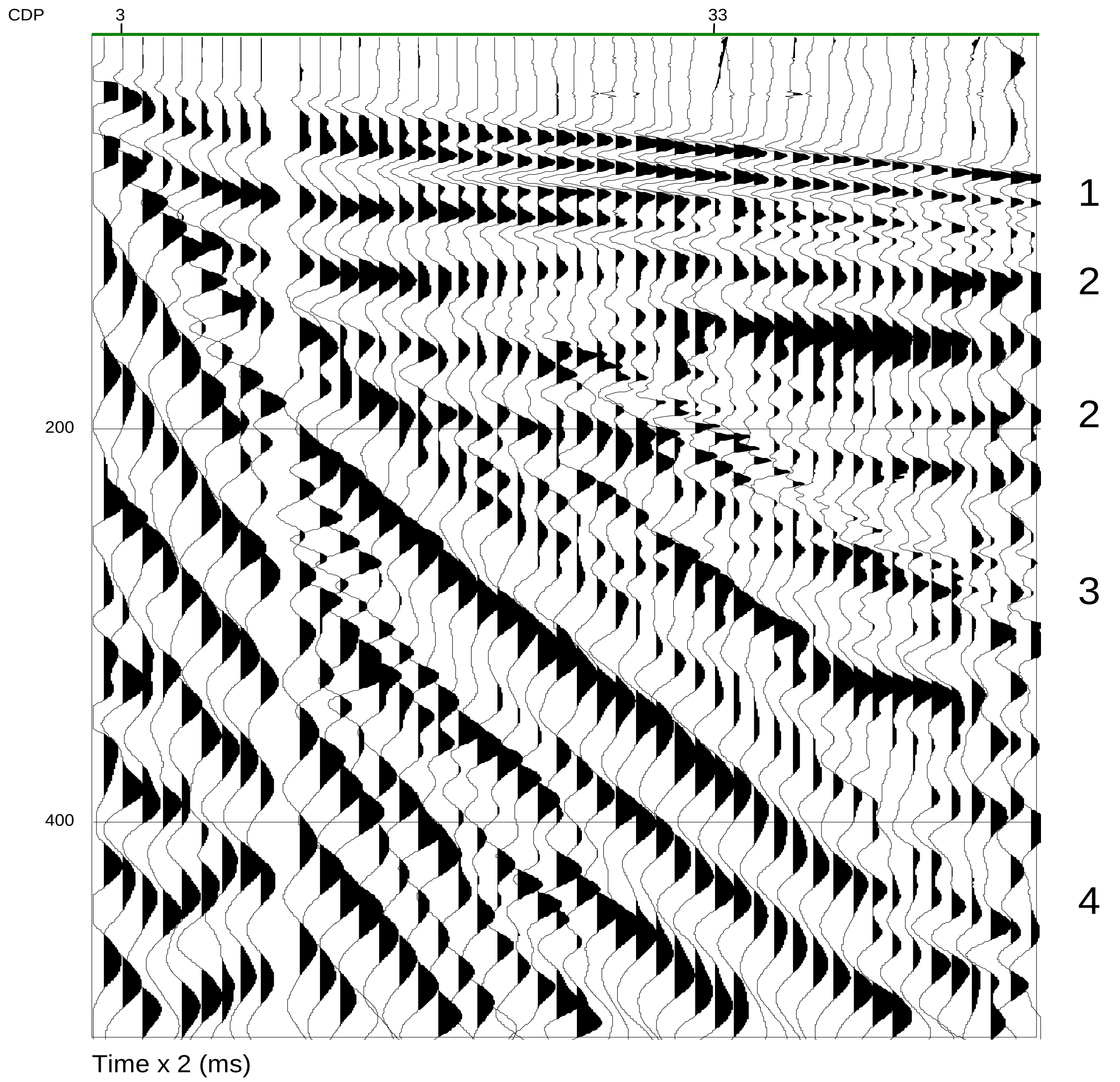
If the equipment is wet, you must use waterproof connectors to avoid electrical parasites. The roll along can produce many electrical noises. This item must be cleaned regularly and carefully checked.

Air wave

Airwave signal is often easy to determine with the 330 m/s velocity and high frequency. It can be remove using filtering or surgical mute. If you put explosive in deep hole, airwave will be strongly reduced.

Guided waves

On some records, strong, low frequency, curved waves are seen. They are called **guided waves** by some authors. Guided waves can cover all useful reflected signal on the main part of the record and they are very difficult to eliminate using any type of filtering. A good geophone pattern can reduce such “bad” waves (see upper).



Example of field record (2m trace spacing)
1= Refraction 2= Reflection 3=Air wave
4=Ground roll

The multiple

The reflections don't produce only with the "descendant" ray but could affect the reflective "amount" ray (primary reflection) toward the surface when these meet a velocity discontinuity. On the records the geophysicists distinguish them because, in flat field, these reflections show a double time.

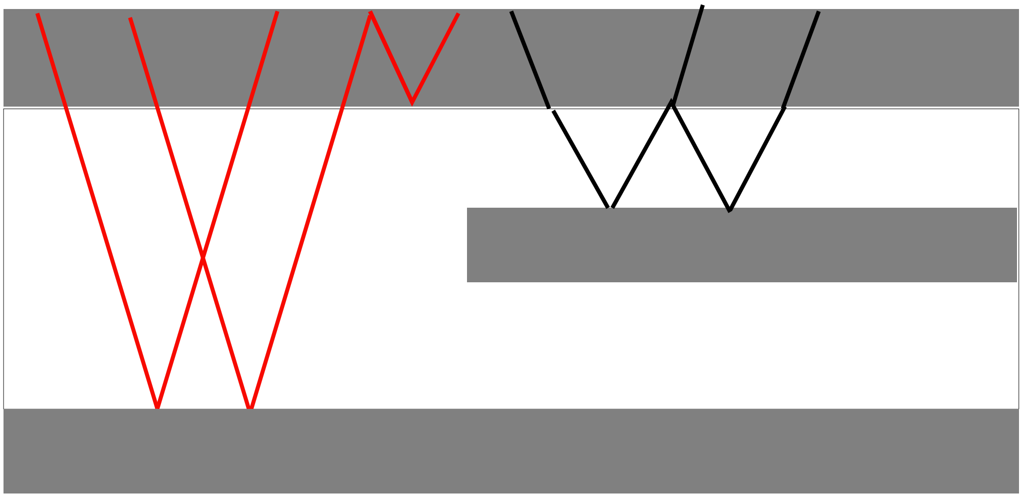
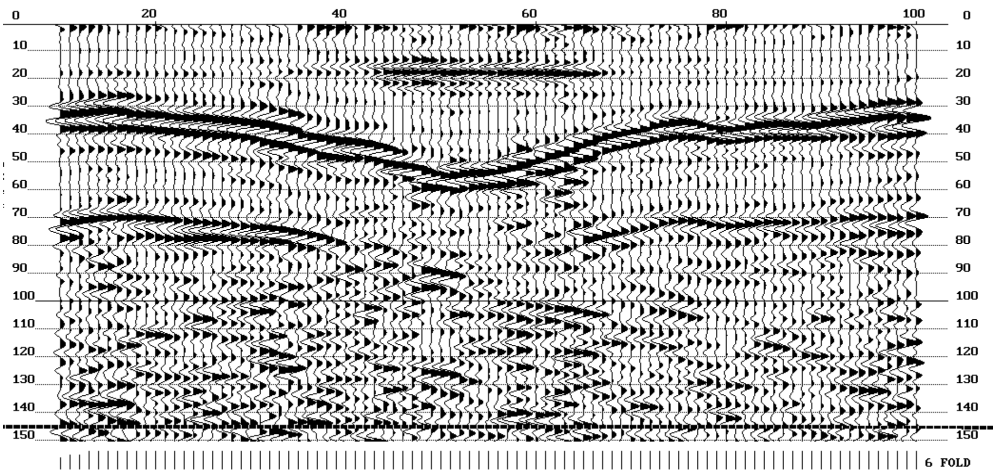


Figure 30 Generation of the multiple reflections and example

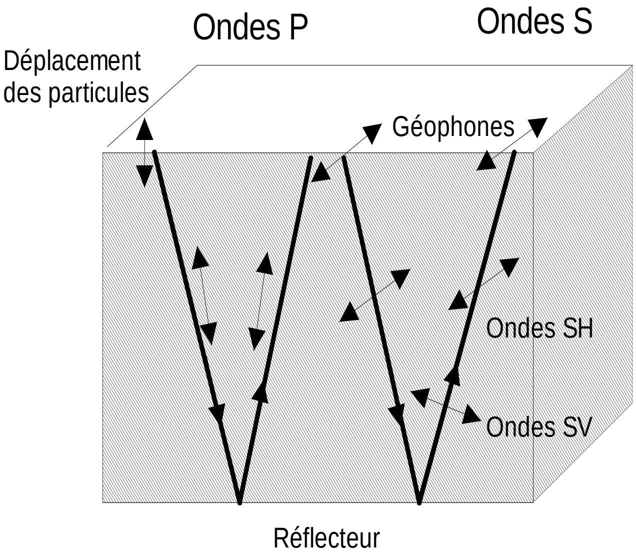
S waves

The seismic reflection takes an interest essentially to the P compression waves, in the setting of seismic studies for the geo-technical; the recording of the S waves can to prove out to be useful for the shearing modules calculation.

If the creation of P waves doesn't a problem, it is different in order to create some S waves, or waves of shearing. It is necessary to provoke a shearing shock, to the aide of an impact, with a horizontal vibrator. For the S waves, the displacement of the particles decomposes between the S waves (horizontal displacement in the perpendicular plan to the ray) and SV (vertical displacement in the perpendicular plan to the ray) In knowing the velocity of the P waves and S, it is possible of



calculating the Poisson's ratio:



$$\sigma = \frac{1}{2}\frac{\left[\left(\frac{Vp}{Vs}\right)^2 - 2\right]}{\left[\left(\frac{Vp}{Vs}\right)^2 - 1\right]}$$

Figure 31 Diagram of propagation of the P waves and S waves (according to WATERS, 1987)

For the investigating with S waves to low and middle depth, one finds described in the literature several methods, the more used are:

- Hit on the sides on a beam of wood set to the soil.
- Hit lateral on a metallic tube driven in the soil.
- The vibroseismic with a vertically axis of vibration

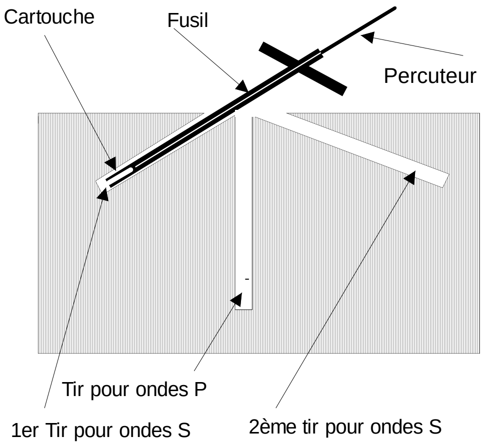


Figure 32 Creation of S waves

In order to create stronger S waves, it is possible of using a method less classic but very efficient. One shoots with a "Buffalo gun" 2 blank cartridges of calibre 12 to the bottom of one meter length hole and from 0.40 to 0.60 m of depth, dug to the aide of a motor-drilling.

It is necessary to do two shootings inclined to 60° with regard to the vertical, perpendicularly to the axis of profile, in the two directions. On the field, one records, with a positive polarity, the first shooting downstream, then one records the second shooting in inverted polarity, then, the two shootings are added. In so doing, one must observe the almost disappearance of the first arrivals in P waves, and an accentuation of signal of the shearing waves. The use of horizontal geophones is very important in order to improve the signal

Comparison of the sources of energy

The table below present the energy and the average frequency of different seismic sources (Values found in the literature or the descriptive advertising).

Type	**Masse 7 kg**	**Cartouche Betsy**	**Explosif**	**Chute de poids**	**Chute poids DynaSource**	**Vibro MiniVib**	**Mini Sosie**	**Sparker**
Quantité	1 coup	500 grains	100 gr	30 kg/3m	1 chute		10 sec	
Poids total					540			
Poids sol					40	1023	141	
Energie (J)	100	105000	345000	900			6700	10000
Energie relative	3.00E+08	1.80E+09	8.00E+10		3.00E+09			3.70E+08
Hertz max		130			500	190		
Hertz min.		50			10	10		
Emission					10-500 Hz			

Material of recording

Many digital portable recorder, containing from 12 to 120 channels are available on the market. Some contain a real computer who manages the acquisition. Scrolling menus on the screen of control facilitate the recording operations. The data are sampled digitally on 18 bits for the StrataView Geometrics figurative opposite. If it one disposes of 48 channels, in shooting close to each geophone, one will have a cover (fold) of 24 that is to say that will add 24 travel receiving source.

Figure 33 Strataview of Geometrics

Lines and geophones

Figure 34 Geophones with Mueller clip

Geophones and seismic lines constitute an important part of material. The used geophones could have some various frequencies 15. 50 or 100 hertz. The frequency of "work" some geophones go of their own frequency to 10 - 15 times this frequency. In seismic high resolution one could use geophones of 20 - 50 Hz, in seismic oil one uses usually some geophones 14 Hz. In "small" seismic, the geophones are often unique to every point of measurement, whereas the use of "string" of several geophones is usual in "oil great seismic". It exists vertical geophones in order to record the P waves, and horizontal geophones for the S. waves

The seismic lines (or spread cables) vary according to:

- the distance between the takeout
- The number of traces by spread cable (3,12, 24 or more)
- The presence of conductors in the spread cable, allowing to connect some spread cable without outside extension pieces.

It is necessary to assure a good contact of the geophones on the spread cable, avoid the humidity, in order to minimize the parasitic signals, the use of waterproof plugs becomes widespread. The use of a "notch" to filter the frequency of electric current (50 Hz, USA 60 Hz) or of its harmonic is sometimes necessary.

Precautions to take on the field

The recording of good data, with the good acquisition parameters is primordial. No processing won't allow to get a good seismic profile with bad field data.

It is necessary to make some tests before begin recordings in order to determine:

- The most adapted geometry, distance between traces and offset.
- The situation of seismic profiles which must be the easiest possible and avoid the obstacles in surface and underground in case of explosive shootings.
- The best seismic source (number of strokes of mass, quantity of explosive, sweep length and frequency)
- The acquisition filters and notch will make the object of very attentive tests, it is necessary to make attention to don't eliminate some interesting frequencies, in case of doubt, it will be always be possible to filter data during the processing. With a 24 bits seismograph, field filtering is no more necessary.
- The recording time must be always sufficient, because some artefact could appear after filtering below traces or again the objective can to deepen in end of profile.
- The frequency of sampling must be sufficient (cf. Nyquist); it will always be possible to resample the data, but never the opposite.
- A complete list of field data will be carefully filled with a maximum of information (Name of file, missed shootings, weather report, position of shooting, slope and azimuth of the line). The use of GPS simplifies the raised topographic.

GEO2X Sarl Geophysics&Geology

Area: ------------------------- Seismic line n° --------------- Source type:-----------------------------
Date: ------------------------- Observer: ---------------------- Trace spacing: -------------------------
Vibrator sweep:------------- Geophone type:----------Hz Shot spacing:---------------------------
Filter/notch:------------------- Recording time:-------------- Sample rate:----------------------------

Number	Record	Shot point	1st receiver	Offset	Rollalong switch	Remarks

Figure 35 Example of field data sheet

Field data processing

Generalities

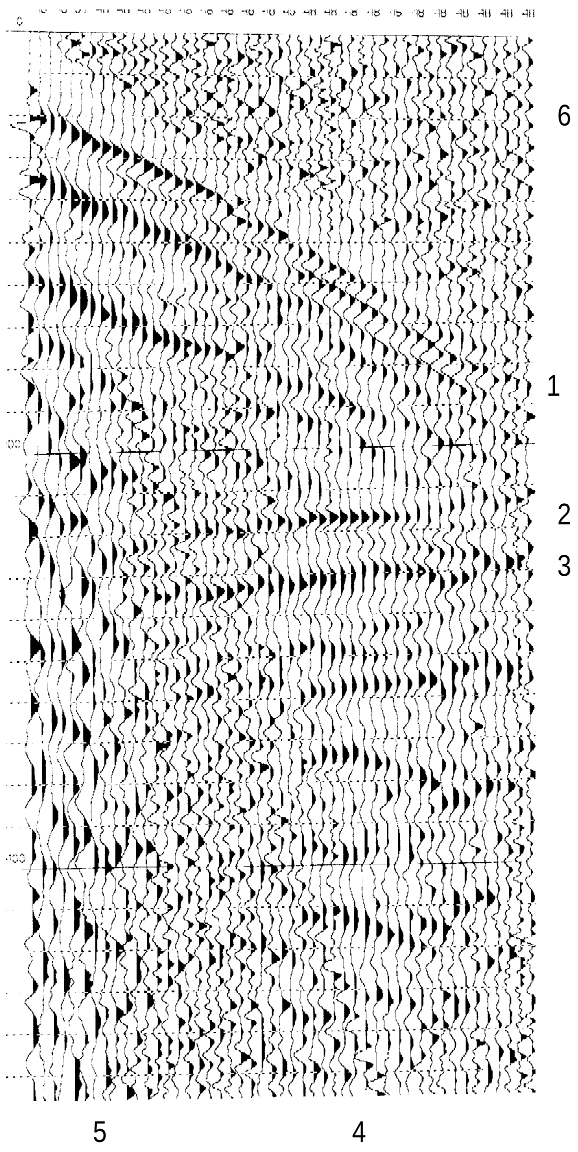


Figure 36 Example of record

1. Refracted waves
2. Primary reflection
3. Multiple some reflections
4. Aerial noises (air wave)
5. Waves of surface
6. Parasitic noises

On the field files one notes the presence of several types of waves which can superimpose.

1. refracted Waves, of which the picks linearly aligned
2. primary Reflection (very tilted substratum)
3. Multiple some reflections
4. aerial Noises (air wave)
5. Waves of surface (ground roll)
6. Disruption to the receptor
7. Parasitic noises

The field files processing has for object of improving the primary reflections and of eliminating as much as possible the other.

Of general manner, one must distinguish some reflections on the field record, after AGC and filtering eventually. In the contrary case, it will be necessary seriously think if the acquisition parameters are correct, the energy sufficient, the offset adapted etc…

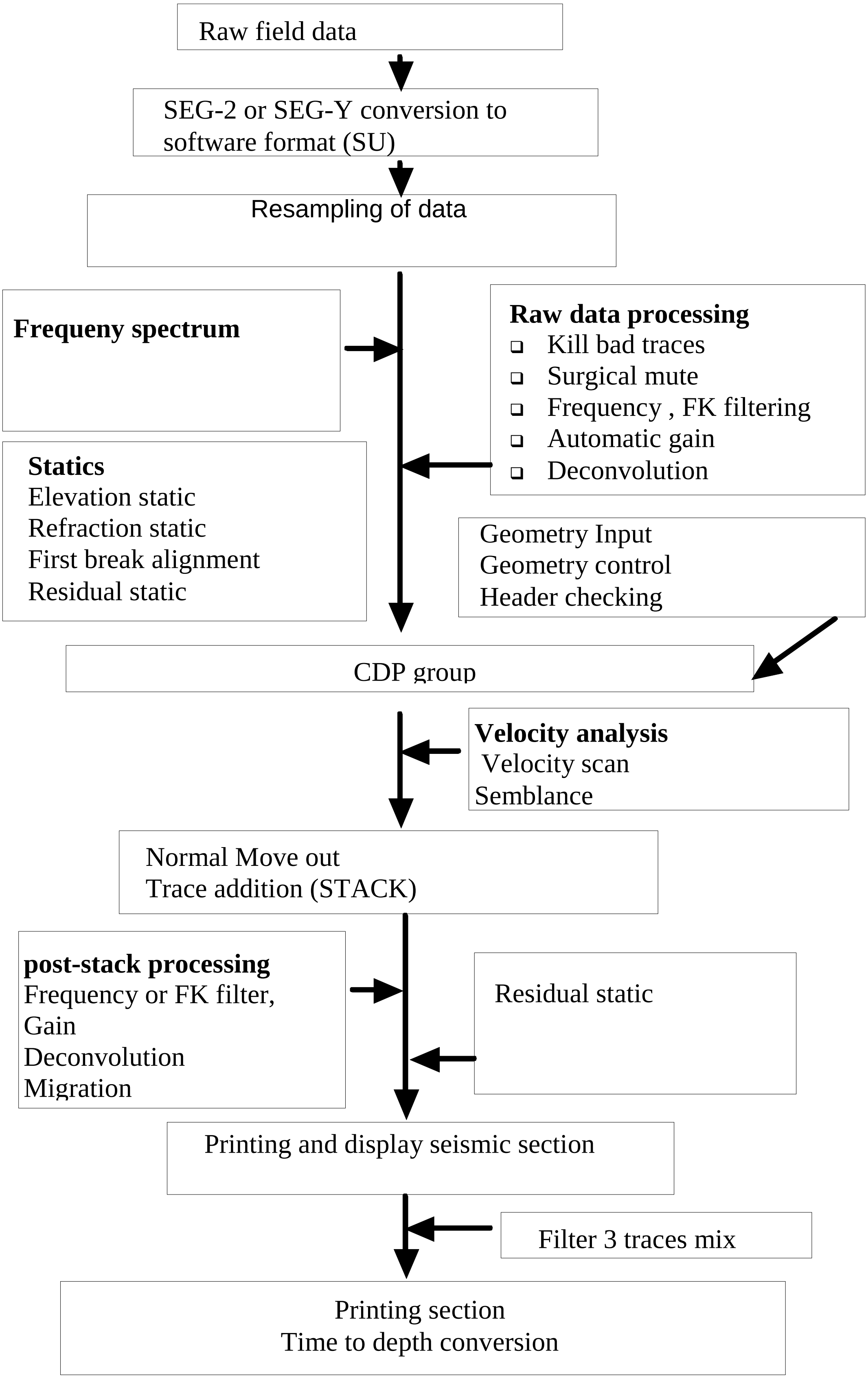


Figure 37 Processing flow chart

The data acquired on the field must be process by data processing. The unwinding of processing could vary considerably, yet the organization chart opposite constitutes the most common chain. The seismic processing software don't always permit all the presented options. Of general manner:

- The data of seismograph is converted in an acceptable format by the software.
- The different files are then grouped.
- One must introduce the geometry of field profile.
- The raw data are filtered, the refraction and the aerial eliminated noises.
- The traces are grouped in CDP and added (stack) according to a pattern of optimal velocity.
- The profile" stacked" is processed (filter, deconvolution, migration).

After the recording of the field data, a long set of operations is necessary before get a seismic section, "geological profile" but in the domain distance - time.
A typical sequence of processing is the following:

Example of processing sequence

1. *Data import from seismograph*
2. *Record conversion SEG2 or SEG-Y to processing format*
3. *Surgical mute*
4. *CDP, geometry input*
5. *Automatic gain*
6. *Frequency or/and FK filtering*
7. *Deconvolution*
8. *Static dynamic*
9. *Static by refraction and residual static*
10. *Analysis of velocities and Normal Move Out*
11. *Stack*
12. *Automatic gain*
13. *Migration*
14. *Filter, FK, 3 traces mix*
15. *Time to depth conversion*

The processing time can considerably vary, in accordance with the quality of the data, the volume of data and the complexity of the geology. He could take some hours to several days per one-kilometer profile.

On the market, geophysicist finds about ten of seismic processing reflection software currently working on some PC or Macintosh. Their price varies between few hundreds dollars (Visual_SUNT, Eavesdropper, WinSeis) to 100 times more expensive. The more "professional" software are implanted on UNIX work stations. A very fast computer with a big capacity hard disk is indispensable in order to process some long profiles of very satisfactory manner. The CD-ROMs are the ideal solution to record safely and at low cost a huge volume of data.

Among the most usual PC software:

- *Eavesdropper* (Developed by the Kansas Geological Survey, little convivial and incomplete but efficient and economical
- *WinSeis* software under WINDOWS of Kansas Geological Survey
- *Vista for Windows* (Powerful, very complete, expensive), Windows and DOS version, manages the seismic 3D.
- *Reflex* for PC under Windows
- SPW for Windows and Macintosh of Parallel GeoScience Corporation
- *Seistrix* of Interpex (Convivial, complete, middle price, version DOS only, difficult to use under Windows, slow impression)
- *Geoscope* (Powerful, fairly convivial, modulable, under DOS and now Windows)
- SU Seismic Unix very complete and fast freeware under Linux / Unix downloaded on Internet, few convivial
- *SUNT* Compilation for NT of the modules Seismic Unix with interfacing graphic and many new modules *Visual_SUNT* of *W_GeoSoft*, powerful, convivial and inexpensive.
- *SIOSEIS* American freeware under Unix
- GLOBE Claritas PC under Unix, powerful, expensive, manages the seismic 3D.

Data conversion

The seismographs record the data in format SEG-2, SEG-Y or in specific format to a device. The software uses the most often their own format that brings together more or less some precedents. The all - first operation consists in to convert the field data format to the software format.

This operation can cause a great problem if the standard have not been respected, SEG-Y data have often such difficulties.

Old seismograph file conversion can be also difficult.

Format of the seismic files

Most of the seismic formats present thus:

1. Header of file (optional)
2. Header of trace
3. Values of sampling

The header preceding every trace contains some "words" indicating the parameters of recording, geometry, topography, values of transfers, dead trace etc.

SEG-Y and SU format

SEG-Y Header words are found in annex. The header of file SEG-Y has 3600 bytes.

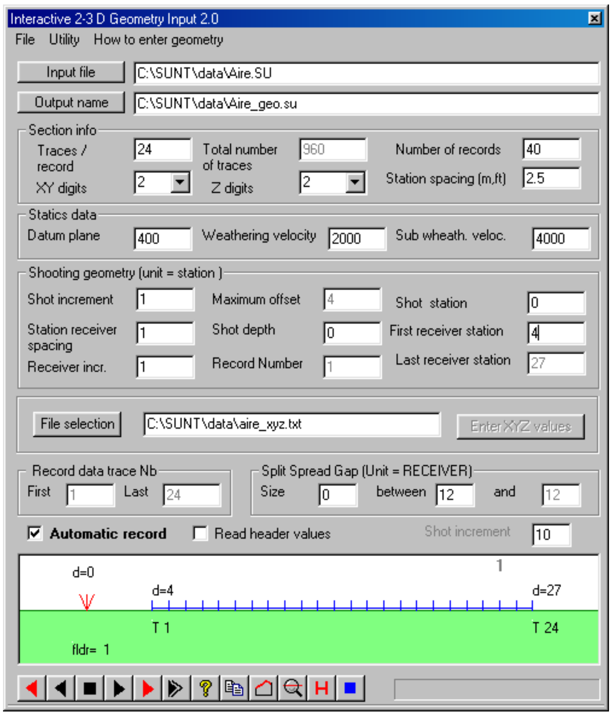
Type	EBCDIC header	Binary header	Trace1 header	Trace 1 values	Trace 2 header	Trace 2 values
Bytes	3200	400	240	4 x nb samples per trace	240	4 x nb samples per trace

The 240 bytes header SEG-Y counts 80 of2 or 4 bits word length. The data consist of a list of binary values (often in floating points values of 4 bytes). Records have often 1024 samples or a multiple. If the data are converted in short integer (2 bytes) the size of file is divided by 2, but one loses of the information.

SU format is very similar to SEG-Y, only the record header (3600 bytes) are missing. Be careful with bytes swapping, IBM and large computer seismic files and “small” PC computers are different.

Eavesdropper KGS format is very similar to SEG-Y, the record header (3600 bytes) is also missing and trace header has only 2 bytes words.

Introduction of the geometry



It is necessary to describe perfectly the recording geometry of seismic profile. It is an important operation, Some mistakes in the introduction of the geometry are a very common source of problems in seismic reflection, especially with some irregular geometry. Location units can be stations number or geographic XYZ coordinates, eventually from GPS.

Generally, it is necessary to locate at least.

- the shooting or vibrating point,
- the first active geophone,
- the last active geophone.

The geometry may be recorded in an external file or registered in the header (SEG-Y, SU). This last solution is more interesting.

Figure 38 Interactive geometry input module (*Visual_SUNT example*)

Convivial software produce a **stacking chart** showing all station with shot and all receiver location. The geophysicist can verify all the common travel to a CMP and the validity of the geometry. A graphic representation permits a much more easily control of the geometry.

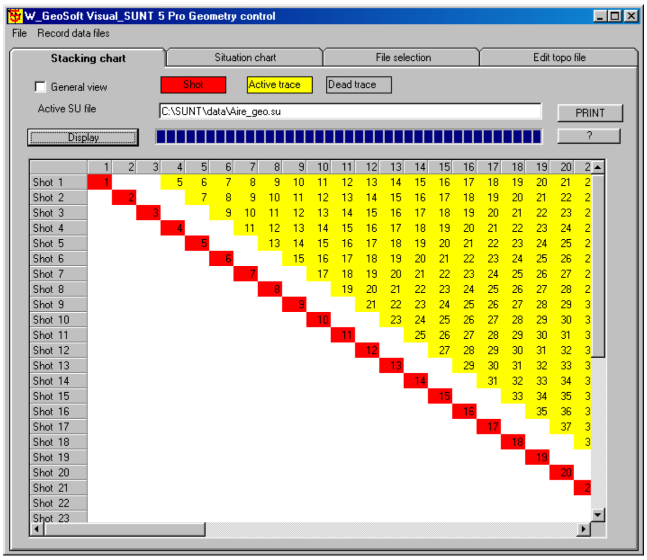


Figure 39 Stacking chart (Visual_SUNT)

Filtering

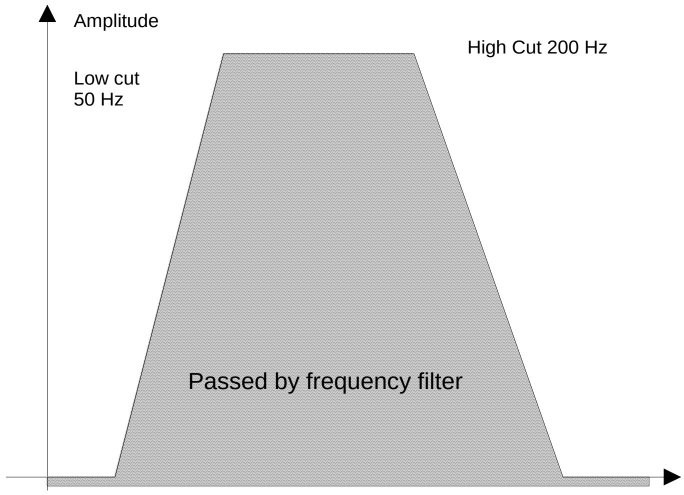


Figure 40 Diagram of a filter

A frequencies spectrum of a trace data file allows to distinguish the lengths of waves of ground roll, some aerial noises (air wave) and some searched signals. In applying an adapted filter then, it is sometimes possible of eliminating, partly at least, the signals no wanted. Attention, the filters could create some parasitic phenomena's, in particular to the extremities of the traces. (*Seismic Unix instruction: SUFILTER, SUBFILT*).

The filtering slope is often describe in dB = 10 x Log10 (frequency ratio)

In deep seismic reflection "oil", frequencies often have less 50 hertz, in shallower seismic high resolution; the frequencies of the reflectors are located between 50 and 400 hertz. These frequencies depend of multiple factors: type of source, field, depth of the reflectors etc. In seismic aquatic, the frequencies are always very elevated.

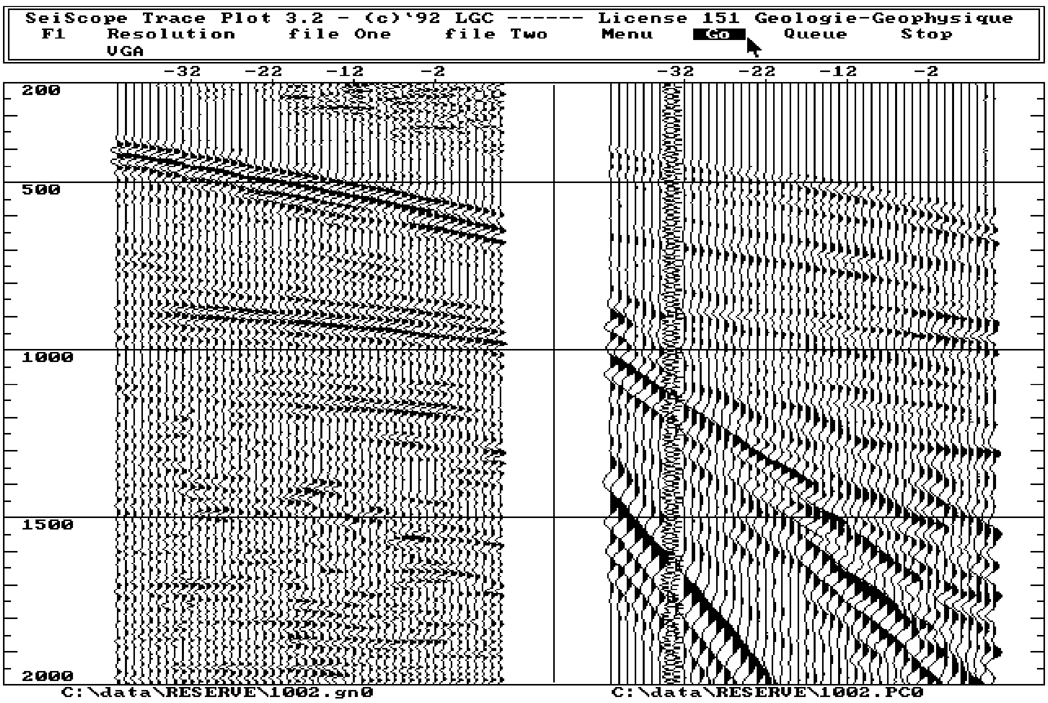
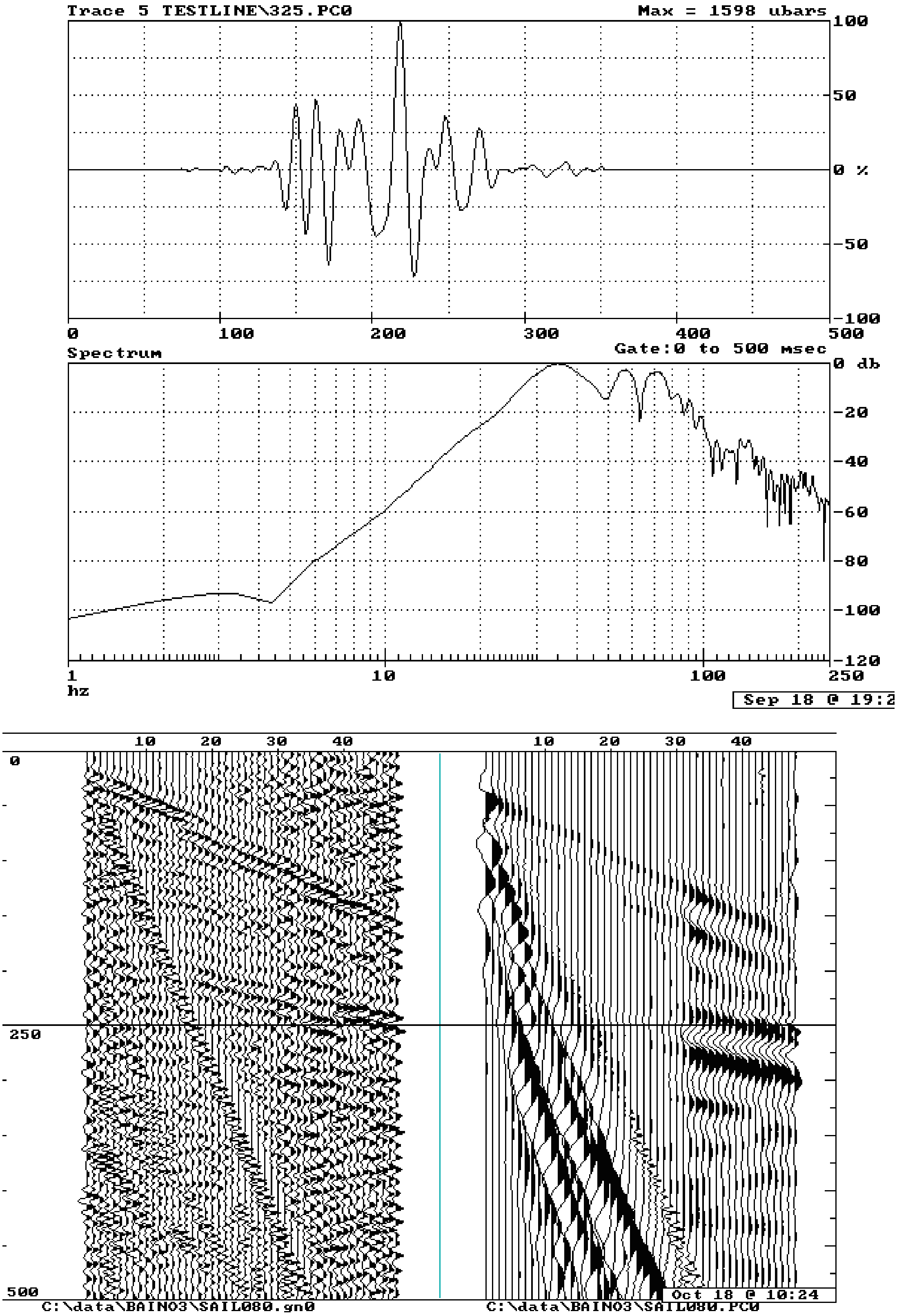
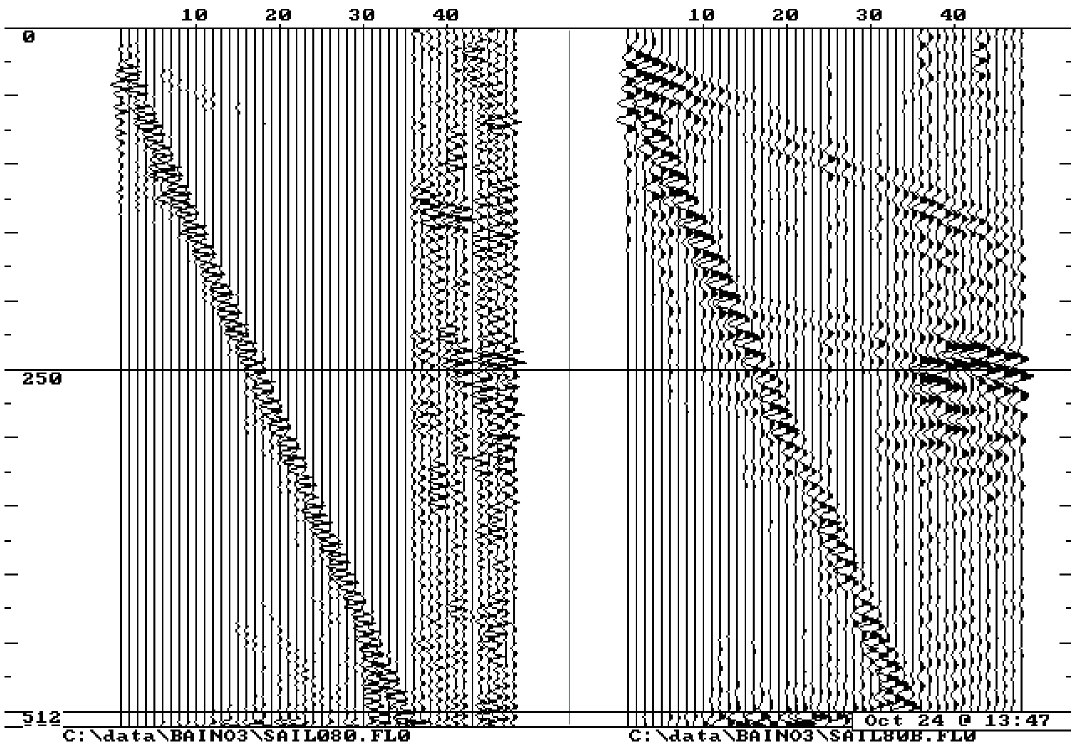


Figure 41 Example of raw file and after filtering



Low Cut 60- High Cut 200 Hz **Raw data unfiltered**

Figure 42 Frequency spectrum and records



Filter Lc 100- Hc 200 Hertz **Filter Lc 50 - Hc 120 Hertz**

Figure 43 Example of filtered records (Geoscope)

The filter Lc100 Hc200 eliminated all reflections, the filter Lc50 Hc120 allows to suppress the waves of surface (ground roll), the aerial noise subsists, but a filter Lc60 Hc200 appears more adapted.

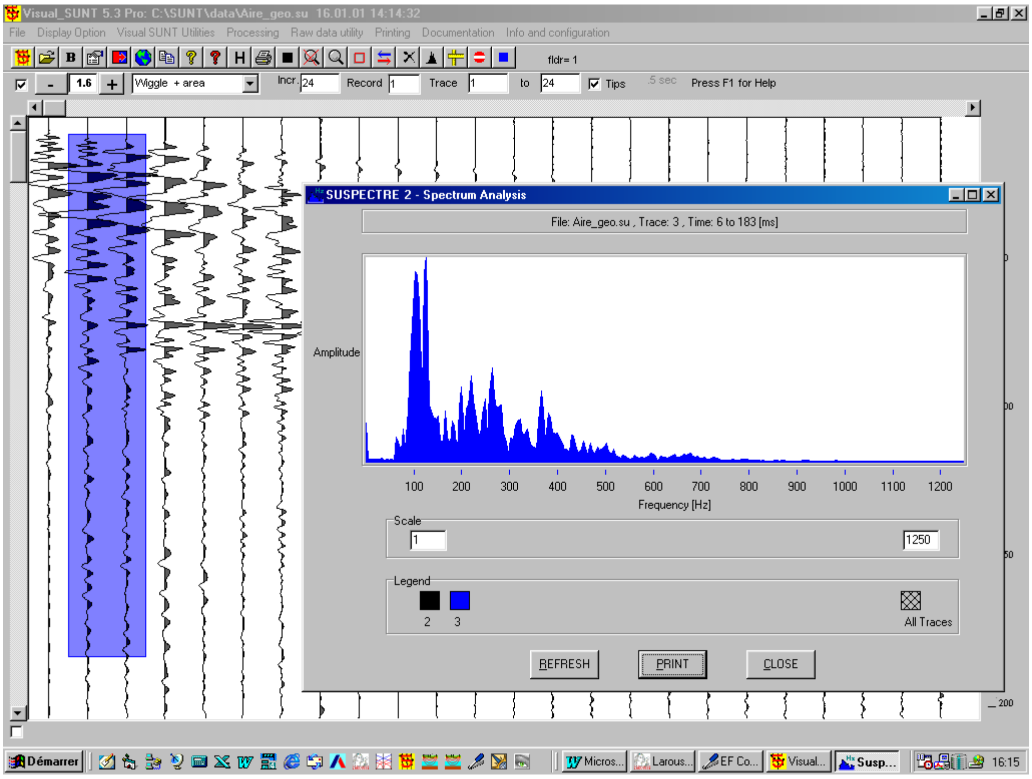


Figure 44 Seismic record and frequency spectrum (Visual_SUNT)

The choice of a good filter is primordial, many tests are sometimes necessary, and the realization of frequency spectrum for some noisy traces on one hand, and a good seismic signal on the other hand will solve the choice of the parameters.

Filter FK (or bi dimensional)

It is possible of converting a field recording (time/ distance) in a FK diagram, frequency (number of cycles/ seconds) with regard to the number of cycles by unit of distance (K). On this type of diagram, one could determine the zones correspondent to some events of a given velocity and of frequency known data. That, it was about to determine a sector of diagram to eliminate or preserve in rejecting the remainder. This type of filter, delicate to use, is very powerful and allows eliminating the linear events of record (aerial noise, ground roll, refracted waves). (*Seismic Unix instruction: SUDIPFILT or better with Visual_SUNT SUFKFILTER*)

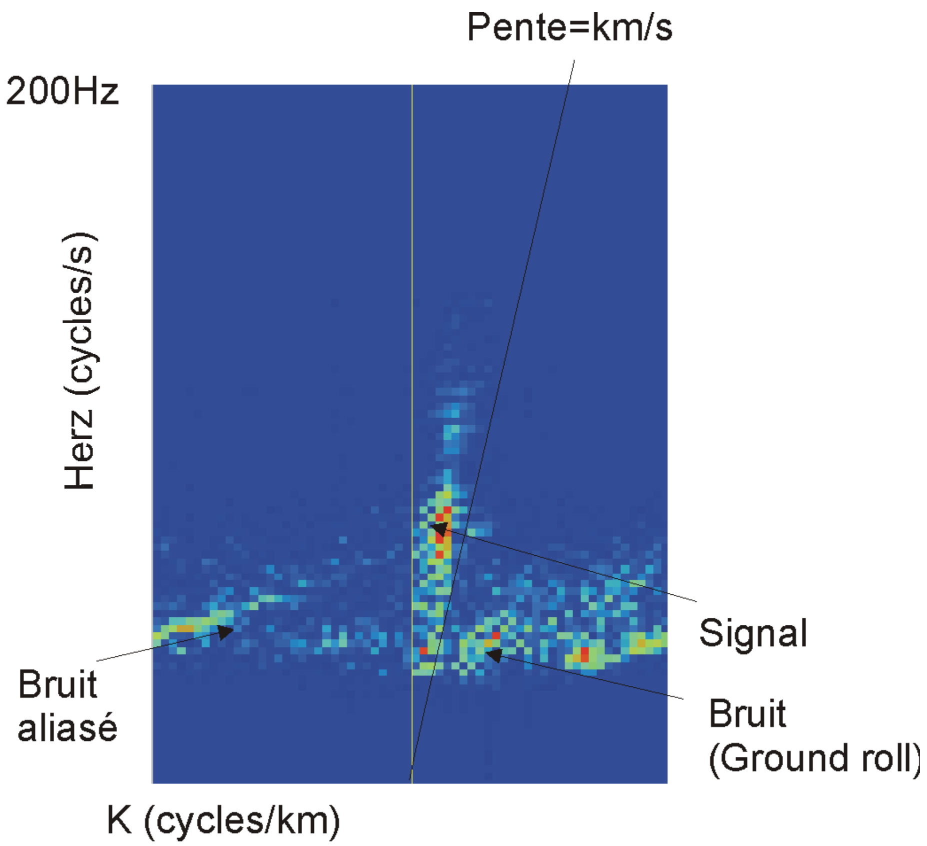


Figure 45 FK Diagram (Visual_SUNT module)

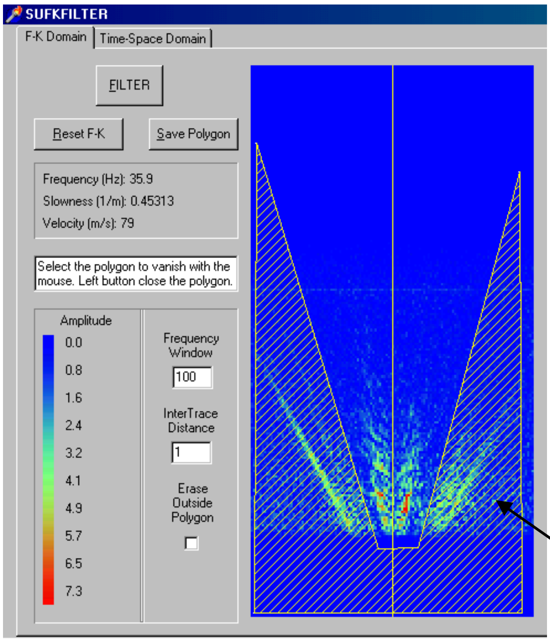
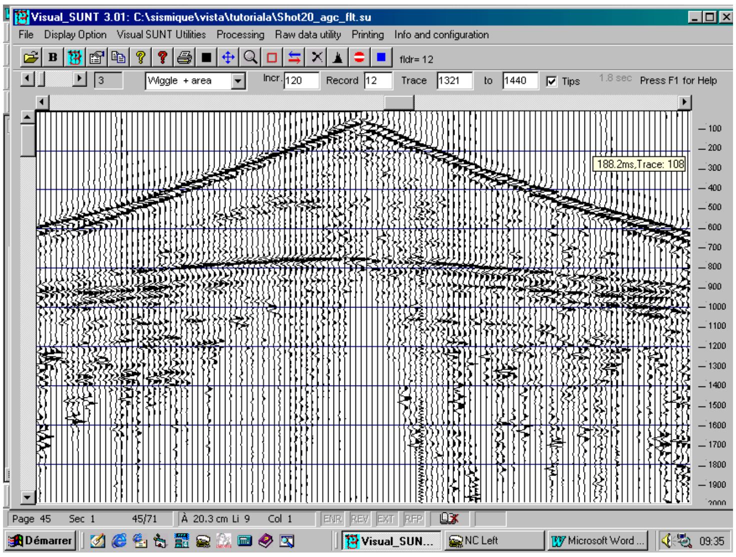
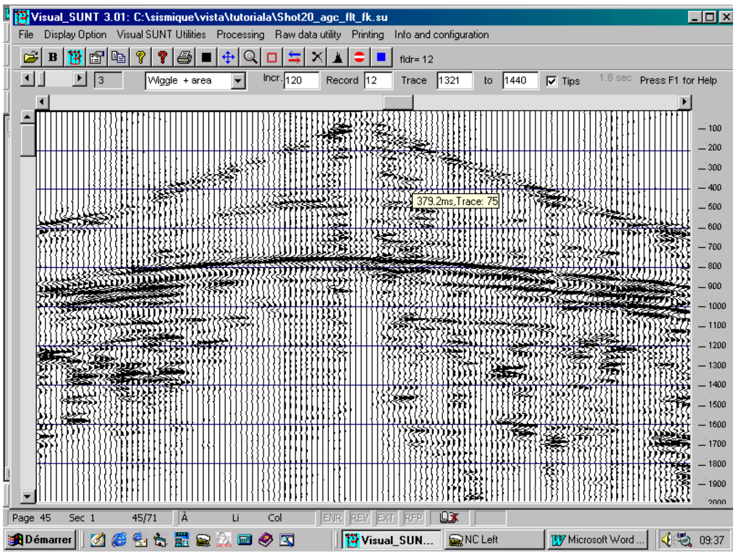


Figure 46 Diagrams F/K and selected zone, file before and after FK filtering

Rejected data



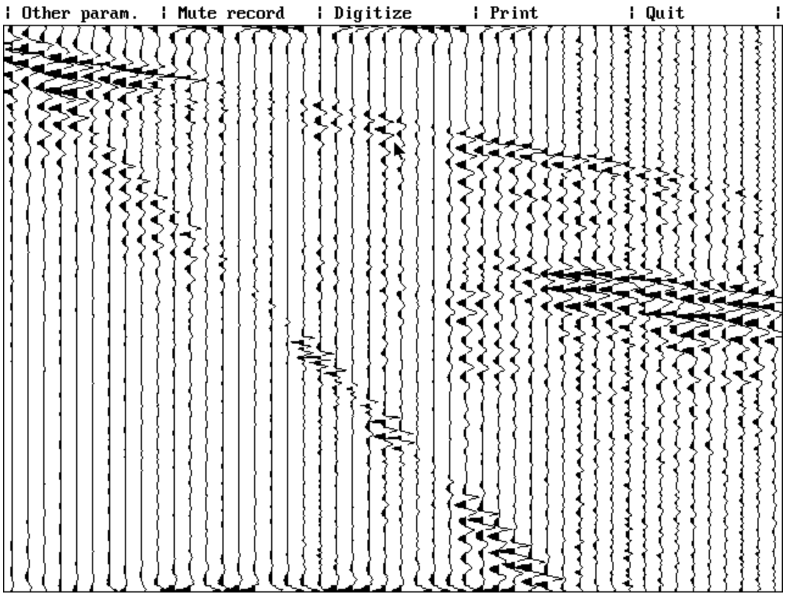
Before filtering



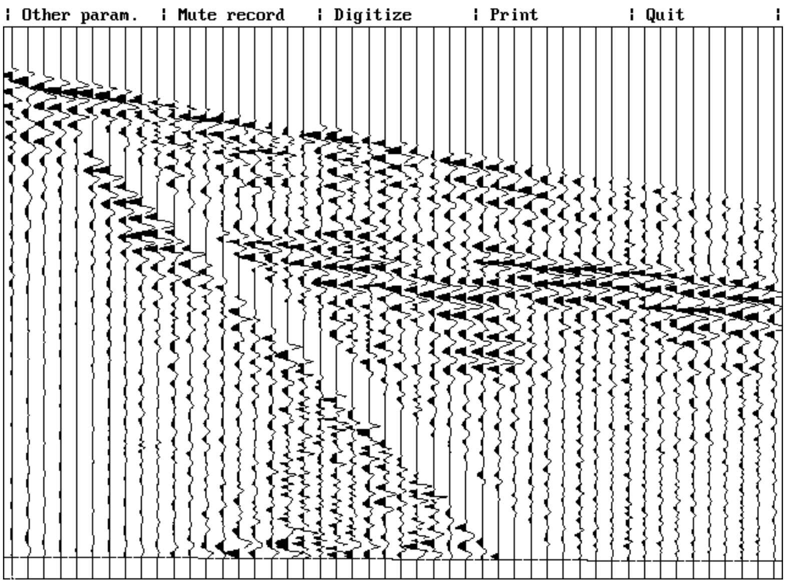
The FK filter perfectly removed the first arrivals

"Surgical" Mute

The "linear" waves on the field data (aerial noise, ground roll, refracted waves) must be eliminated in order to come out again the reflections hyperbolic. If they could not be filtered, one could erase them (surgical transfers) on the digital field data. Some software permit an automatic transfer of all the files, it is necessary to indicate the time of beginning and of end the zone to "transfer", this for the first and the last trace. On the example below, transfers it is applied, recording after recording. It is necessary also suppress the noisy or dead traces carefully. This part of work is long and sometimes boring, but of a great importance for the final result. (Seismic Unix instruction: SUMUTE)

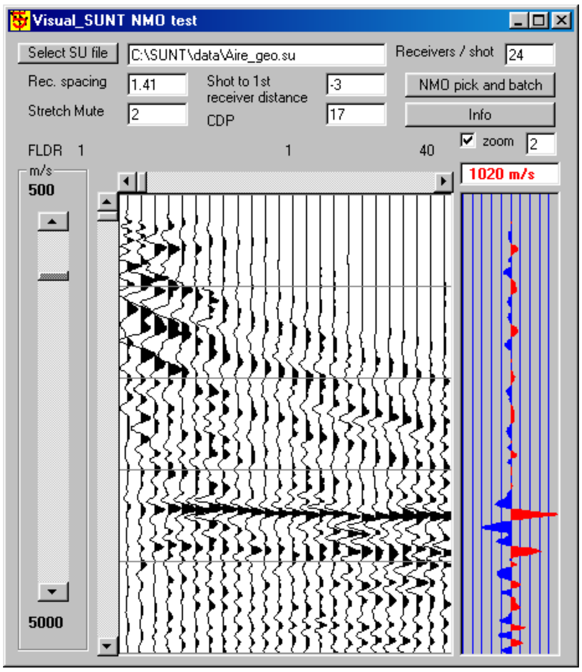


Original file



Record with air wave mute

Stretch mute



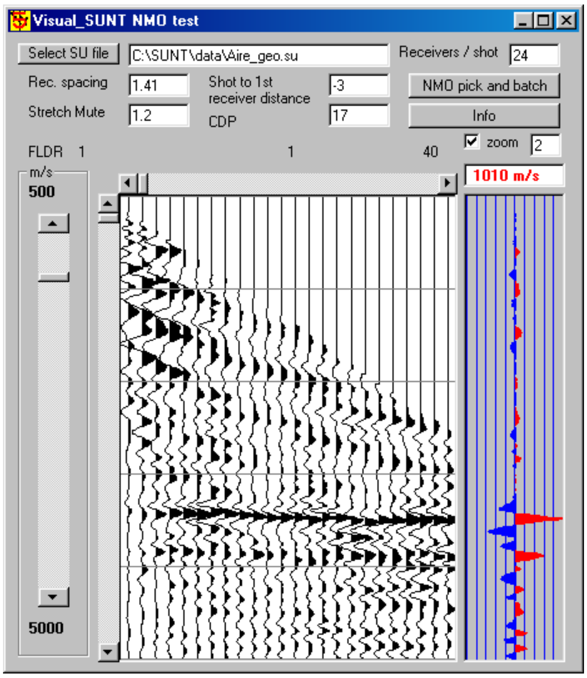
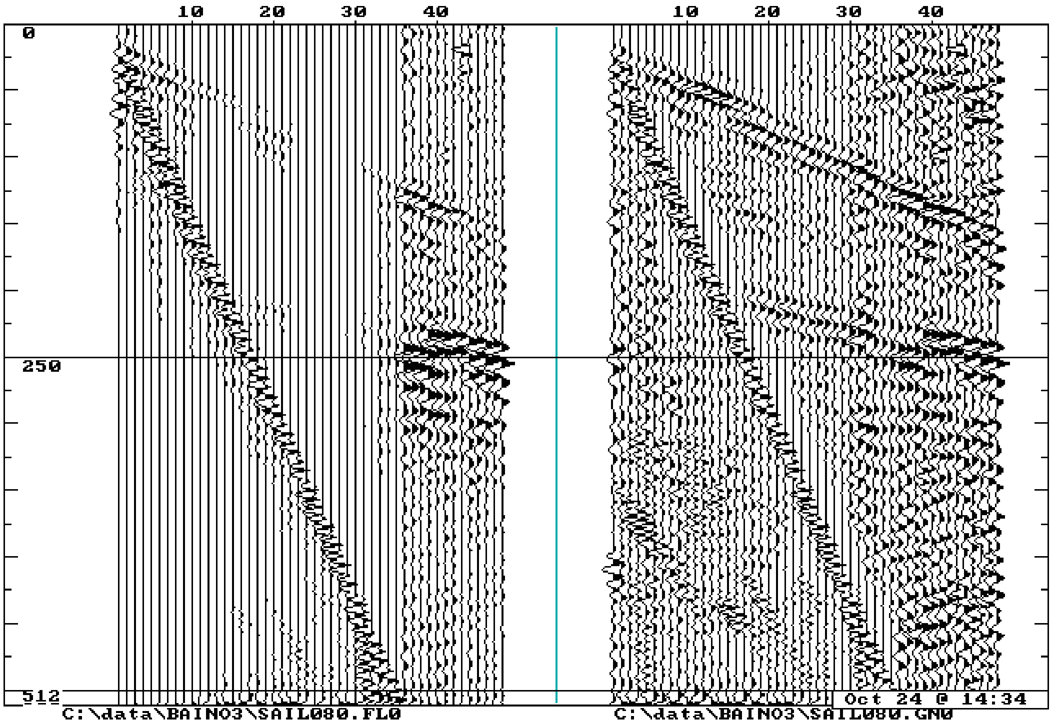


Figure 47 Stretch mute (left value=2 right value=1.2)

“Normal Move Out” procedure usually requires a stretch mute factor. This mute value avoids frequency distortion in large offset and shallow times.

Gain

A useful function consists in amplify the signals which are weaker at the end of recording. This operation is commonly called AGC "Automatic Control Gain", it is necessary to indicate the program the size of the window of amplification (in time). A small window homogenizes the traces, a bigger window allows to preserve the relative amplitudes. (Seismic Unix instruction: SUGAIN)



Original record **Record with an 100 ms window AGC**

Figure 48 Original and 100 ms AGC record

Time variant filter

This type of filter allows compensating the absorption of the high frequencies to the deep layers (cf 1.4). It was about a LC filter/ variable HC in the time, the filter rejecting in beginning of trace of the low frequencies, which will be kept in end of recording. (Seismic Unix instruction: SUTVBAND)

Deconvolution

The deconvolution is an important operation that allows suppressing or attenuating the multiple some reflections. This operation is performed on the records before stack, or on the sections seismic final. It exists several methods of deconvolution, the predictive deconvolution is particularly efficient, it is necessary to indicate to the program wavelet interval time. *(Seismic Unix instruction: SUPEF or better SUDECON with Visual_SUNT*)

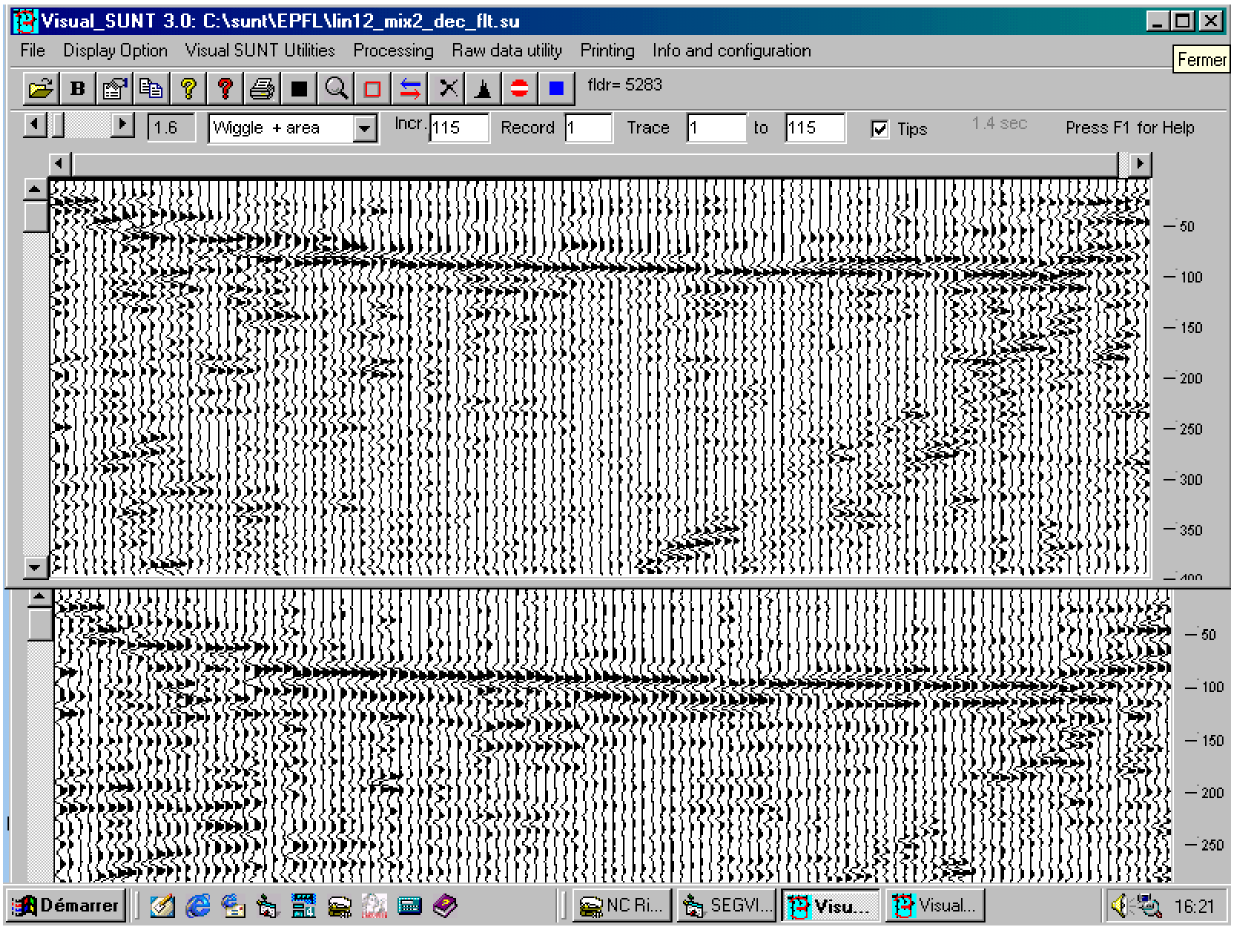


Figure 49 Original file (below) and after a predictive deconvolution (above)

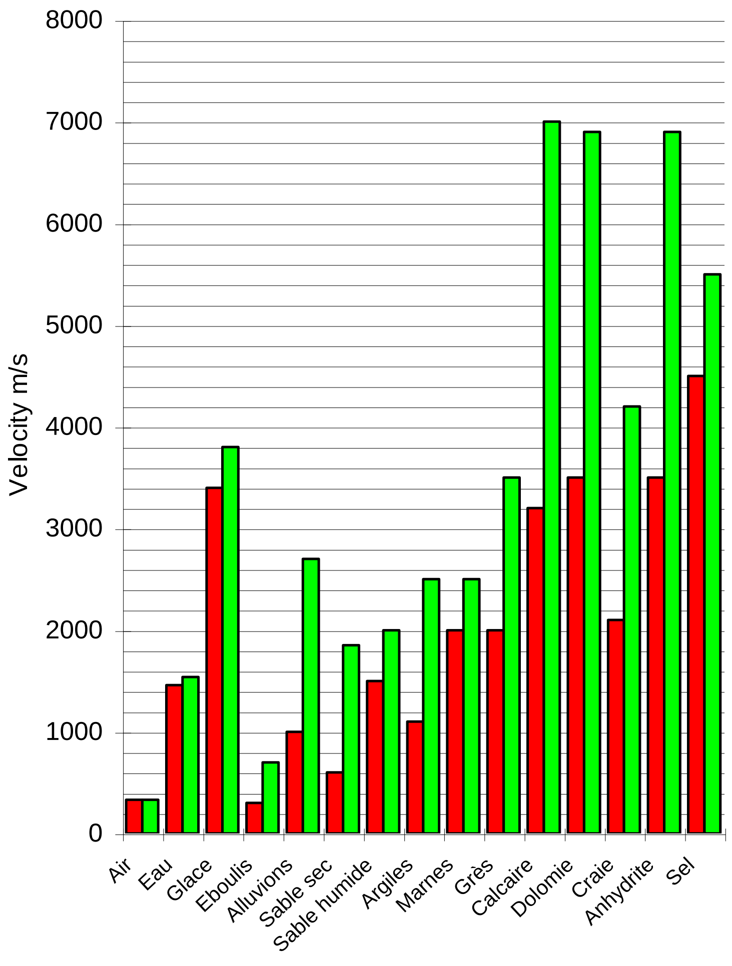
Determination of the velocities

The velocities of the layers always constitute the biggest uncertainty in seismic. It exists several methods of determination:

- The velocities of the superficial layers can to determine by seismic refraction.
- In trying to add some CDP with different velocities, the geophysicist determines the different velocities in observing the amplitude of the reflections appearing successively (*Constant velocity scan*)
- Analysis of the amplitude for different velocities on a group of trace of same CDP (*Semblance analysis*)
- The indicatory curvature of a reflection depends of the geometry and of the velocity of the layers, it can therefore used to calculate the velocities.
- One could know the velocity of the deep layers from a sonic diagraphy in a forage deep neighbor.
- The velocities could be determined in forage thanks to some shootings or some sensors in the well and vice versa.

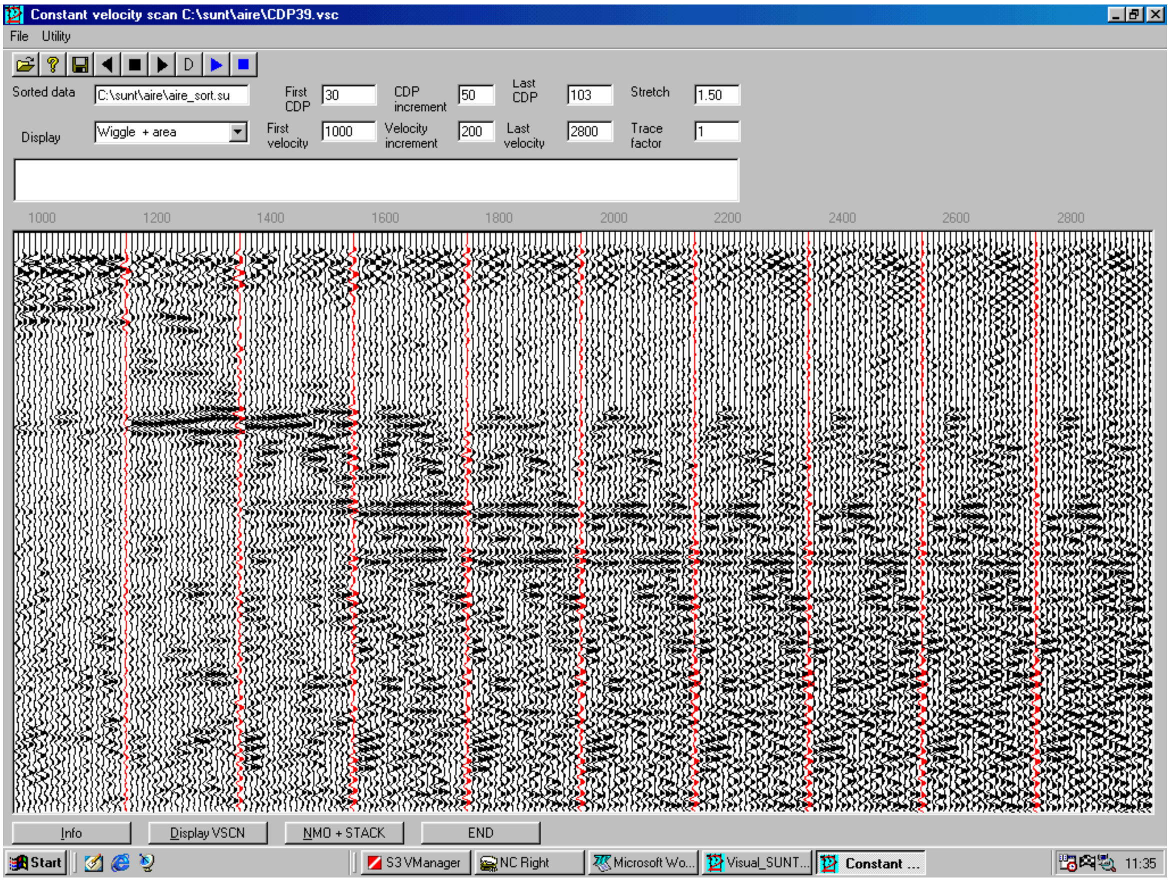
P seismic velocities

In green maximal velocities,
In red medium velocities



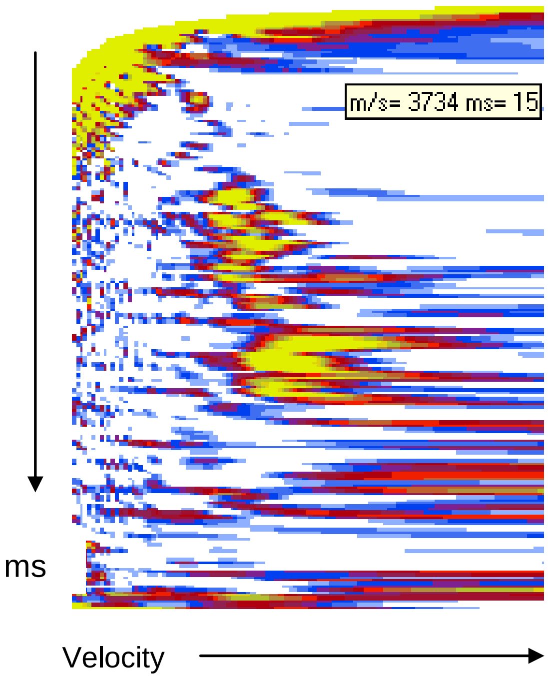
Constant velocity scan

A very efficient method in order to determine the velocities in seismic reflection consists trying to add a certain number of traces with a set of constant velocities (CVS). The reflectors appear for some velocities and to a given time. It is these velocities, called NMO velocities, that geophysicist will use for the summations.



Constant velocity scan (Processing with Visual_SUNT)

Analysis of velocity by "semblance"

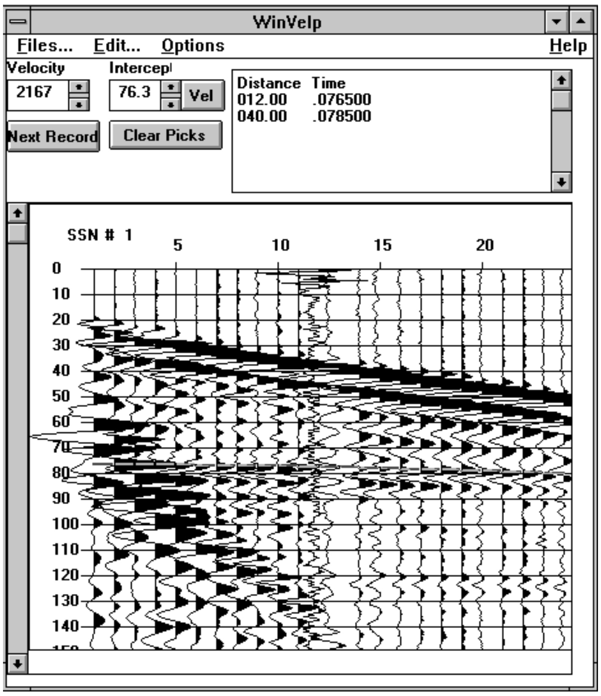


All the traces proceeding of a same CDP are added successively for different velocities. The yellow colors correspond to the maximal amplitudes after addition.

From this diagram one could establish a pattern of velocity for the NMO easily.

(Seismic Unix instruction: SUVELAN)

Determination of the velocities by the indicatory curvature

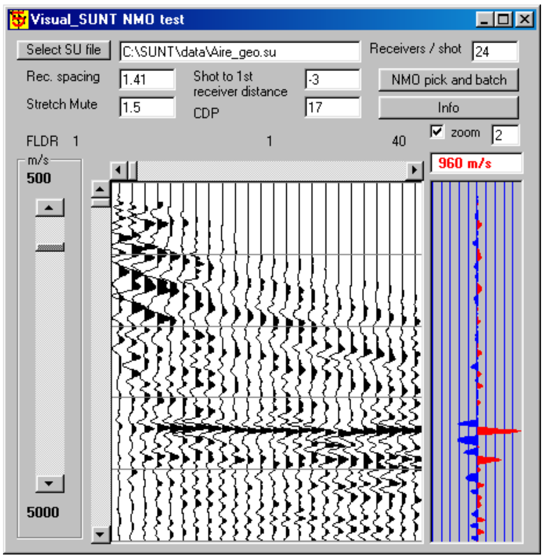


Knowing the distance between the geophones (traces), the shape of the hyperbole allows to calculate the velocity of reflector.

In "pointing" two points on the hyperbole, the interpretation software calculates the corresponding velocity.

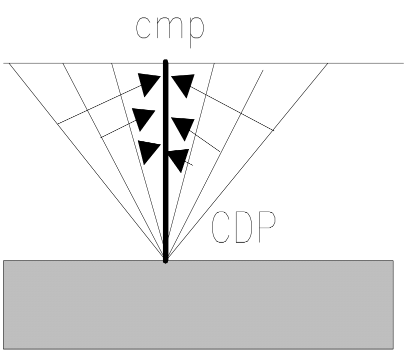
Processing with WinSeis

Interactive NMO



Another method to determine NMO velocities consist to perform a NMO with different velocities and to see the result.

Grouping by CDP

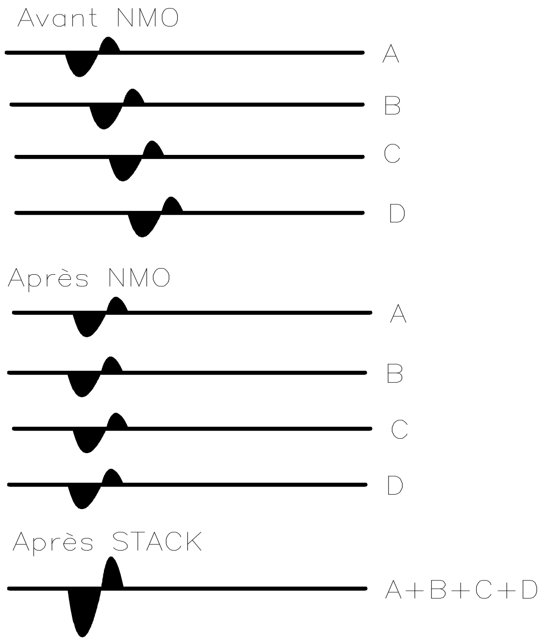


All the traces having a point common mirror is first of all grouped (*Seismic Unix instruction: SUSORT*) to the center of a seismic spread of 48 geophones, there will be 24 grouped traces, in beginning and at the end of seismic line, the cover increases and decreases progressively in order to reach the half of number of geophones.

The interest of an important cover is of reducing the noises and of improving the quality of the reflections as well as of attenuating the multiple.

In second step, the geophysicist applies a dynamic correction in order to bring back all the traces to one trace to the aplomb of shooting. For it one uses the pattern of velocity previously determined. (*Seismic Unix instruction: SUSORT*)

Addition of the traces



In order to improve the signal / noise ratio, the present method in seismic reflection consists in to add (stack) the traces which have a reflective common point, after have brought back all the traces to one trace to the aplomb of shooting (dynamic correction*). (Seismic Unix instruction: SUSTACK*)

The improvement is equal to the root of number of geophones, is 7 per 48 geophones.

If the dynamic corrections improve the amplitude of signal, they could bring some modifications of frequencies for some distant traces and for the weak depths. The signal will have some lower frequencies. It will be necessary therefore avoid bringing back some traces too faraway (open angles) and limit the NMO (in % of contraction).

POST SUMMATION PROCESSING

Filtering

After addition of the traces, it could be necessary of (re) filter the final profiles in order to eliminate the low frequencies that appear then. (Seismic Unix instruction: SUFILTER)

Gains

The application of an AGC gain allows increasing the signal of the deep reflectors. A great window of AGC respects the amplitudes; a small window tends to standardize the amplitude of the reflectors. (Seismic Unix instruction: SUGAIN)

"3 traces mix"

To the means of this filter, one adds the signal of three traces contiguous then one makes a mean. So, the noise has a tendency to lower and the signal increases. (Seismic Unix instruction: SUMIX)

File original File after 3 trace mix

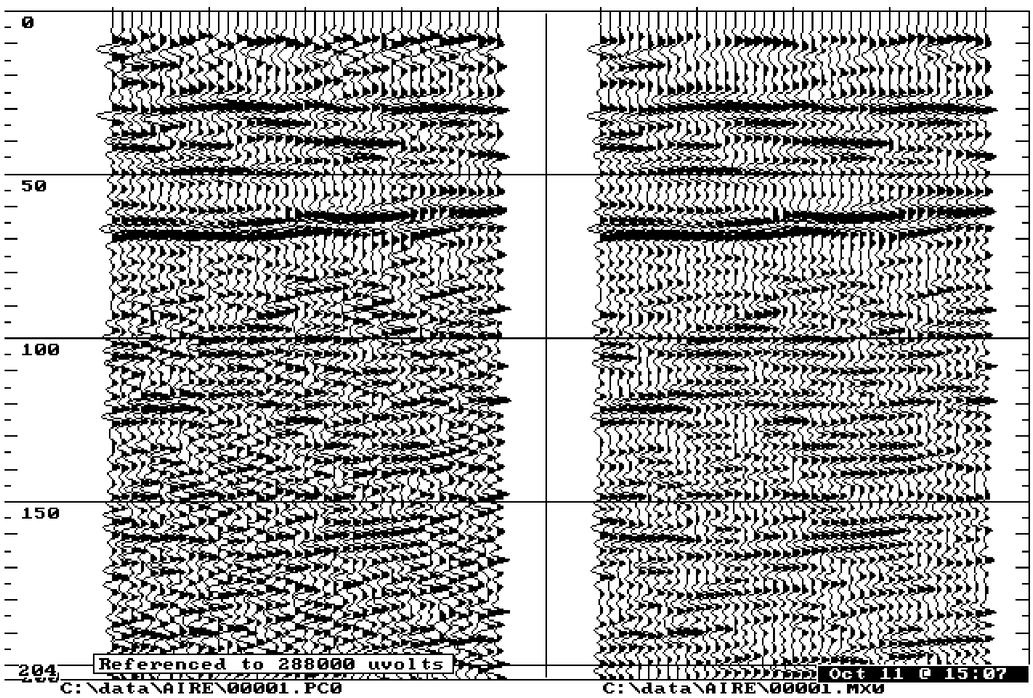


Figure 50 Trace mixing Processing with GeoScope

FK filters

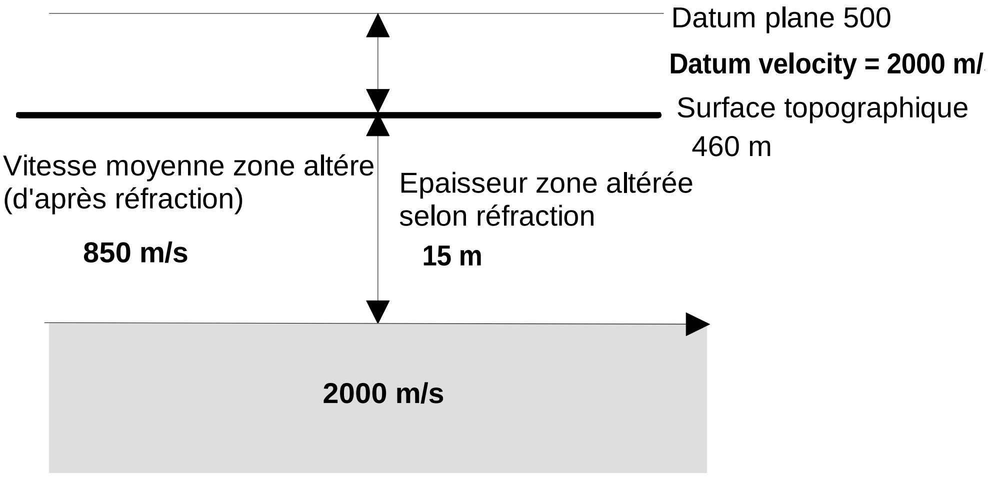
The FK filters allow eliminating some linear events that would have appeared to the course of processing. Generally, the parameter of necessary processing is the velocity (or slope) of phenomenon to eliminate as well as the acceptable tolerance.

It is important of verifying that the alignment that one wants to eliminate is an artefact and no a reflector, this type of filter remains of a delicate use. *(Seismic Unix instruction: SUDIPFILTER, SUFKFILTER or SUMEDIAN*)

Static

The static corrections have for object of eliminating the effects to the variations of altitudes, of velocity or of thickness of the altered zone (weathering zone). Generally, all the traces are brought back to a surface of reference (Datum plane) chosen under the topographic surface or, like it is more often the case in seismic high resolution, above of the surface of lot. (Seismic Unix instruction: SUSTAT)

Field static =(500-460)/Datum velocity*1000



$$Td = \frac{2\,(\text{Elev. datum - Elev. topo + Epais. altérée})}{\text{Vitesse bed-rock}} - \frac{\text{2 x Epais altérée}}{\text{Vitesse Z. altérée}}$$

Correction statique totale

Td = 2* (500 - 460 + 15) /2000 - (2*15 / 850) = 55 - 35 =20 ms

Topographic corrections

First phases of the data processing consist in introducing the geometry of seismic profile. Generally, it is necessary to indicate the X coordinates, There, Z of all the shootings and receiving. This has for object of determining what is the common travel and correcting the effects of the differences of altitude for profiles in uneven field.

Seismic Applications Editor - Survey Format

Station	X-value	Y-value	Z-value
1	0	0	467
2	0	5	467
3	0	10	467
4	0	15	467
5	0	20	467
6	0	25	467
7	0	30	467
8	0	35	467
9	0	40	467
10	0	45	467
11	0	50	467
12	0	55	468
13	0	60	468
14	0	65	468
15	0	70	468
16	0	75	468
17	0	80	468
18	0	85	468
19	0	90	468
20	0	95	468
21	0	100	468
22	0	105	468
23	0	110	468
24	0	115	468
25	0	120	468
26	0	125	468
27	0	130	469
28	0	135	469
29	0	140	469
30	0	145	469

```
Enter a number for a cell.       Arrow Keys select cell.
ROW  Commands:  (C)opy (D)elete (E)xtrapolate (F)ill (N)ew (Z)ero
COL  Commands:  (I)nterpolate   (K)ill  (L)ow_row=1    (H)i_row=10
File Commands:  (END) & save.   (ESC) & do not save.
Input File: BAIN3.SRV           Output File: BAIN3.SRV
15          INSERT to set lines /  page.
```

Static by refraction

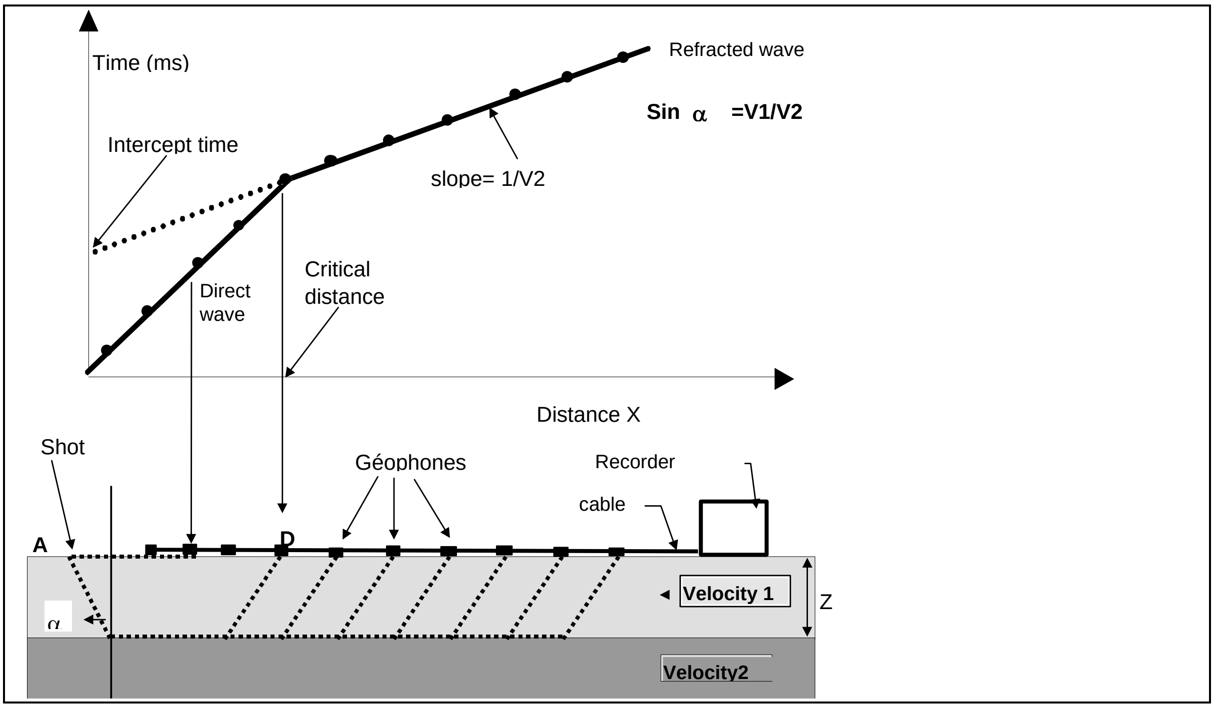


Figure 51 Diagram of propagation of the refracted waves and of the corresponding dromochronique

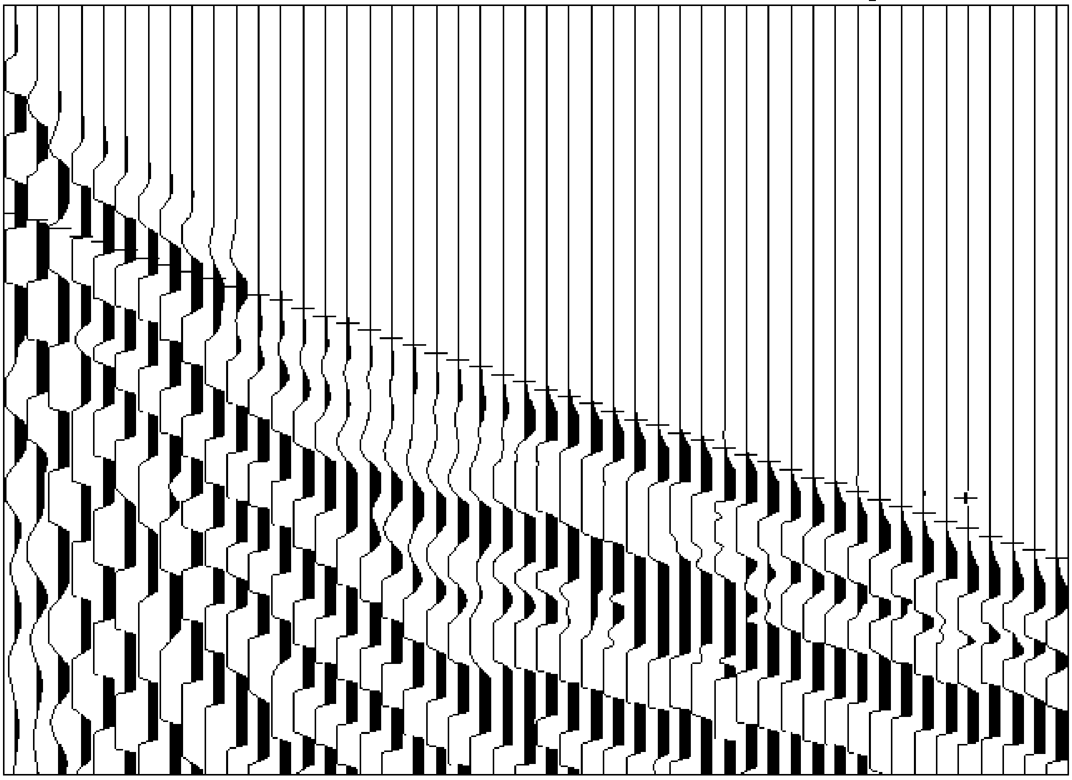
In using the shootings done for the survey of seismic reflection or achieved shootings especially for the refraction, to the means of pointing the first arrivals, it is possible of determining the velocity and the thickness of the first layer. These data are usable directly by most of the software in order to nullify the effect of the heterogeneity of the superficial layer.

The method of the seismic refraction is based on the detection of the first arrived waves (P waves or waves of compression). Using a distance / time diagram of the first arrivals, said dromochronique or travel time, the geophysicist determine the velocity of the different layers correspondent graphically on the inverse slope of the travel time.

The laws of the optics govern the propagation of the waves in the basement; the angles of refraction depend of the velocity of the layers. These known, one could calculate their travel, and in particular the thickness of the different slices of layers (Z1) of distinct velocity (Cf REDPATH, 1973) if he one knows the time of intercept (T1) and the velocity of the lots (V1 and V2).

$$Z_1 = \frac{T_i * V_1}{2 * Cos\left(Sin^{-1} \frac{v_1}{v_2}\right)}$$

First arrivals alignment



A method of correction of the local irregularities of the first arrivals under the geophones (residual very static) consist to align the first arrivals on straight lines of which the slope corresponds on the inverse velocity of first layers.

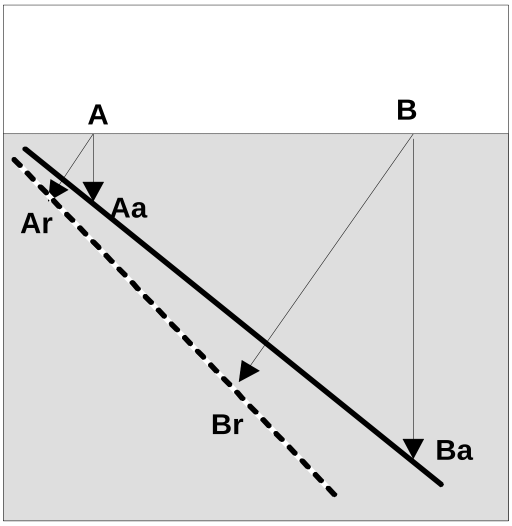
In the figure above, the features correspond to a velocity of 2100 m / s, the trace 44, among some other, present a "delay" that it one could fill in it entrenching some millisecondes. These corrections allow correcting the curvatures of reflection also and thus of improving the quality of the reflectors.

This method requires the pointing of all the traces of all the shootings, it is therefore long to achieve, but often efficient.

Residual static

Like the previous method, this processing aims to eliminate the small irregularities of the hyperbole to the variations under the geophones after the topographic corrections and the static refraction. Contrarily to the described method above, the pointing is automatic, from trace pilots. One correlate for example the best draws of an added section and one determines the shift that replaces every draw in alignment with the other with a view to the final addition.

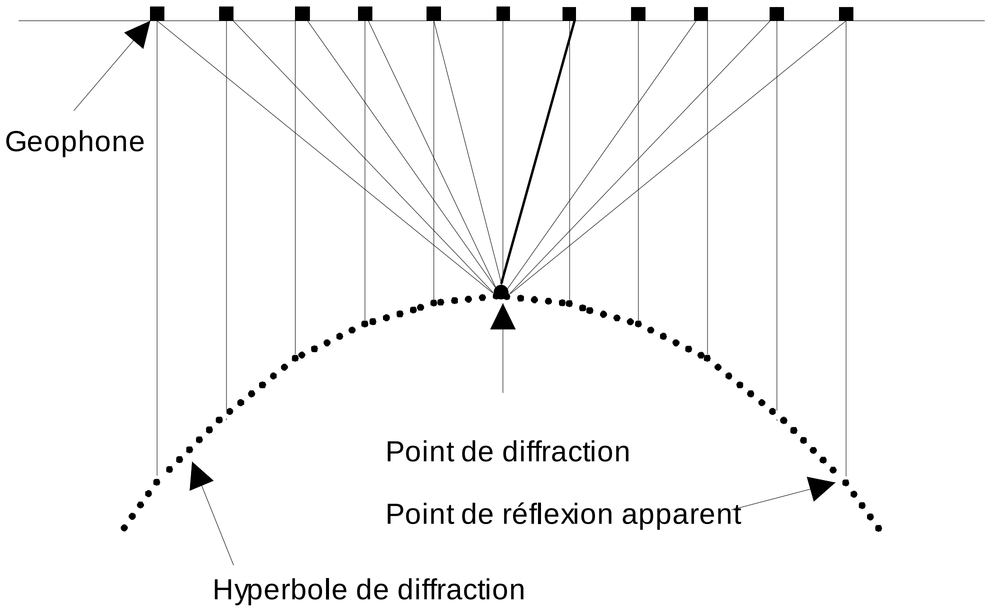
Migration



In seismic, the reflection doesn't come from the aplomb of geophone (A-Aa or B B-Ba), but produces on the nearest point, in all the directions (A-Ar B B-Br).

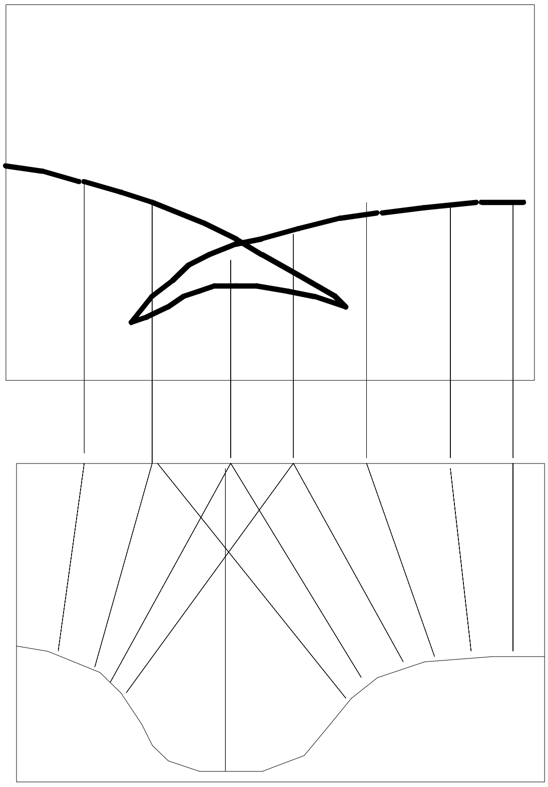
A very reflective point will produce a hyperbolic curve on a stacked section, so-called hyperbole of diffraction.

This phenomenon implies that the position and the dip of the tilted layers are corrected. This correction does to the means of the migration. The parameter used for this operation is the velocity of migration. This one must be chosen carefully for an optimal migration.



At the time of the migration, the hyperbole of diffraction disappear, the lips of the faults are correctly positioned.

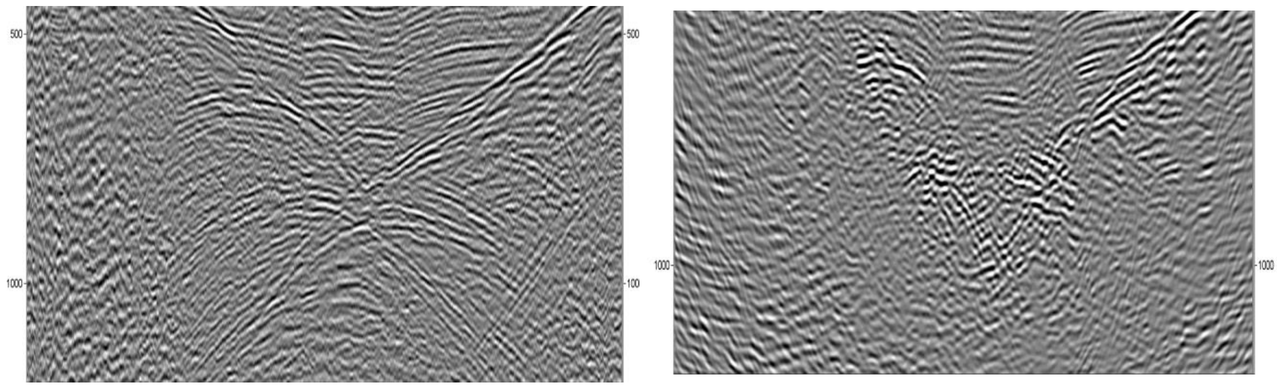
Coupe distance / temps doubles



Coupe géologique

Figure 52 Example of a buried valley

A synclinal or a buried valley produces a very particular reflection in "node of tie." A correct migration will replace the reflectors to their place of origin.



Vallée alpine avant (haut) et après migration (Kirchof)

Section unmigrated

It is necessary to note on the cut opposite, the interruption of main reflector and the presence of hyperbole of diffraction forming a" node of tie."

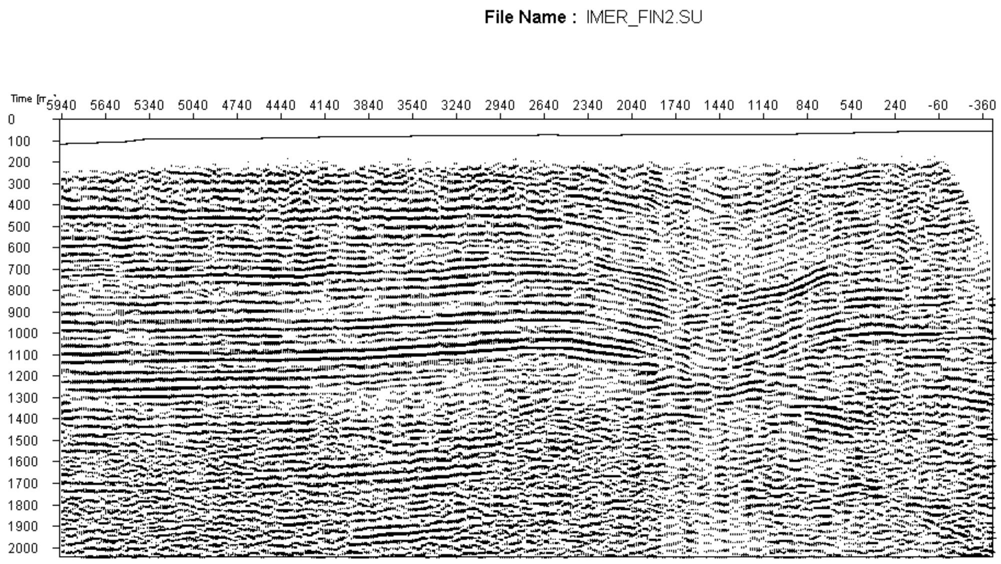
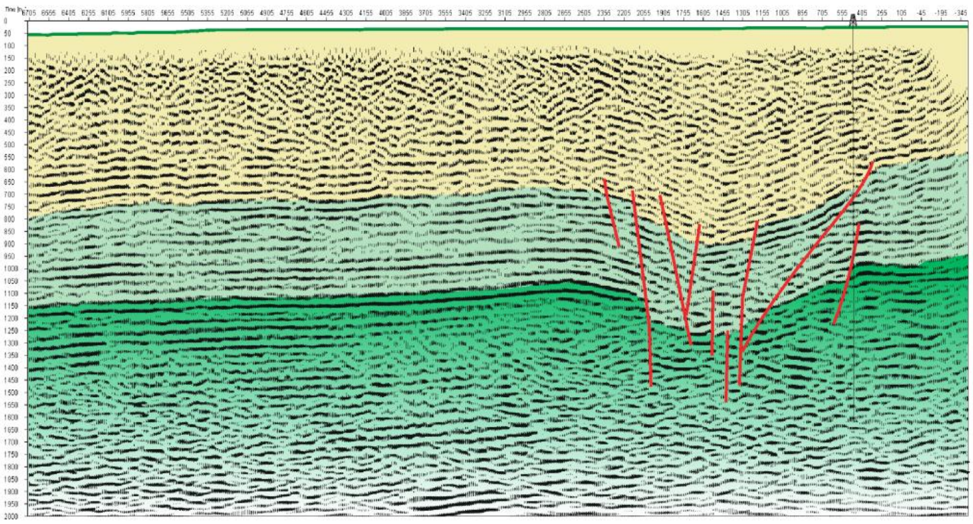
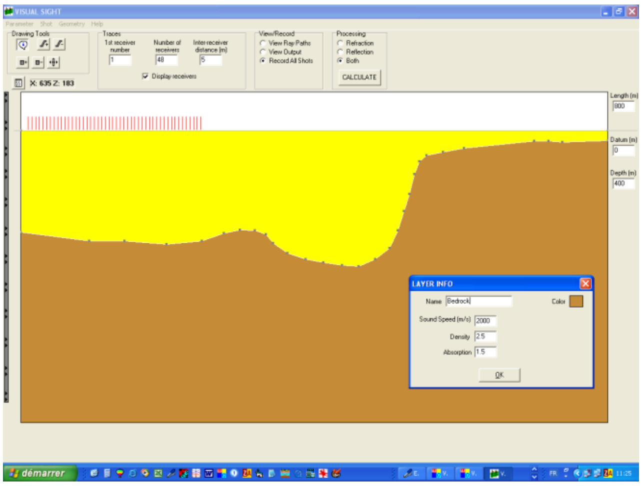


Figure 53 Example of seismic section unmigrated and migrated

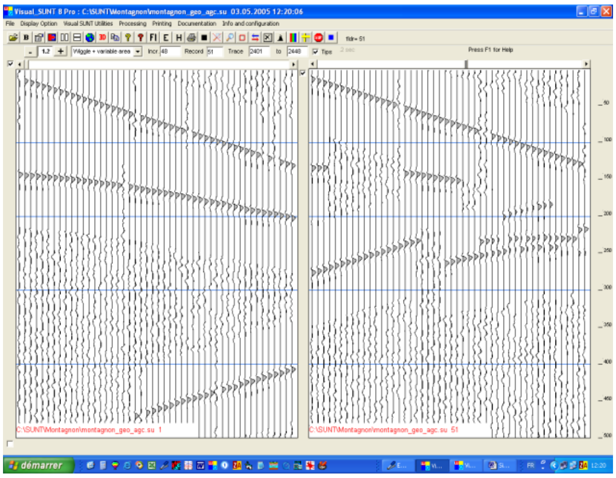


Section migrated

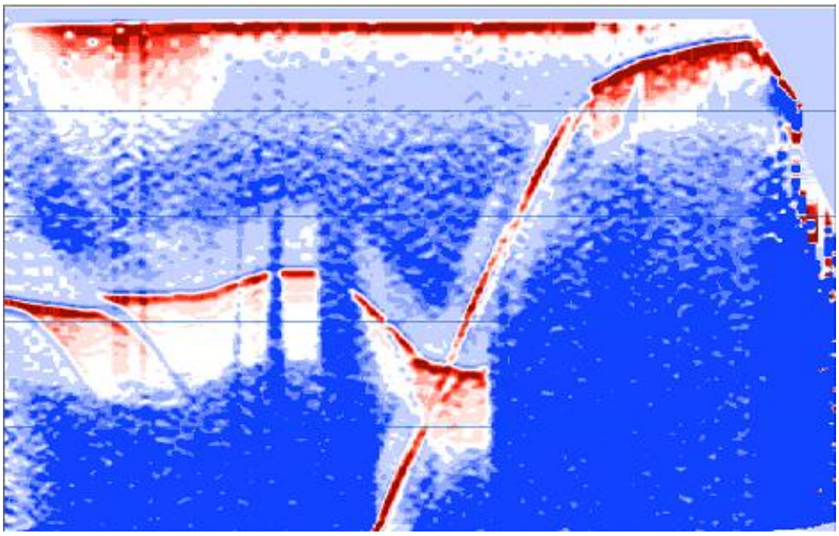
The "node of tie" disappeared and marks well a channel to the same place.



1

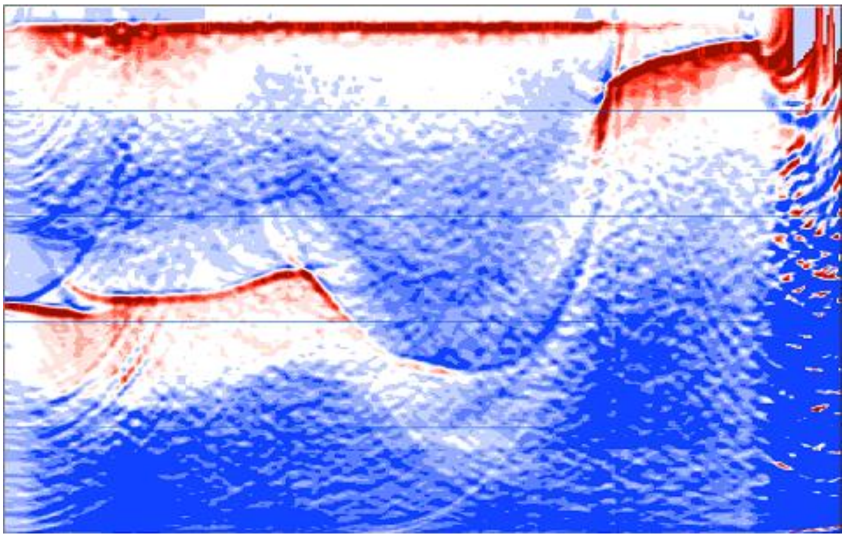


2



3

1. Synthetic profile
2. Synthetic field records
3. Time section before migration
4. Time section after phase shift migration



4

INTERPRETATION

Seismic original profile (section distance / double time)

The aim of seismic studies is of determining the position of the layers and some faults in depth and no in time. It is necessary therefore convert the time/distances sections (cf above) in distance/depth sections, The parameter of calculation is the seismic interval velocity. In order to convert the times in depth, the DIX formula is used to compute the interval velocities from NMO velocities. Another method consists to digitalize the reflectors on the screen or on a table before do the calculation.

Some software allows transforming the profiles seismic directly distance / time sections of it distance / depth. It is necessary evident to know the velocities of slice of the different layers, the software repositions the different reflective. Some upper levels are contracted, some deeper are dilated. The low frequencies that one observes in the deep layers are again amplified by reason of the velocities raised of these.

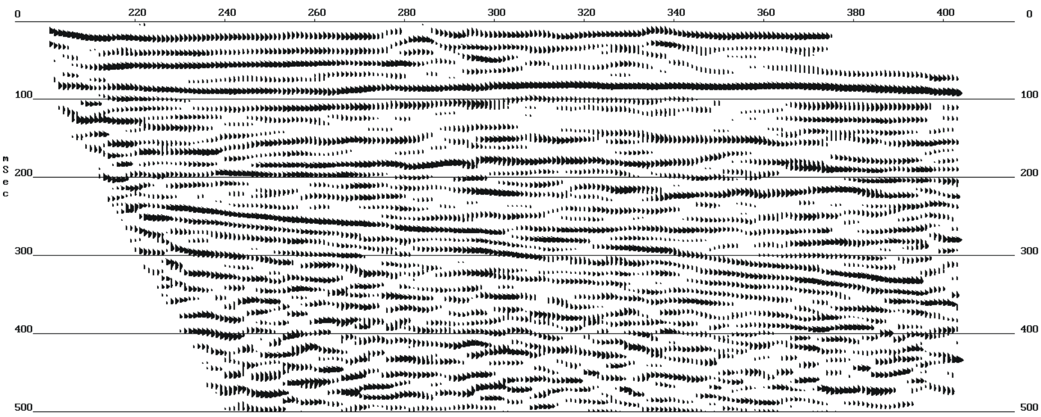


Figure 54 Section distance / time (2x)

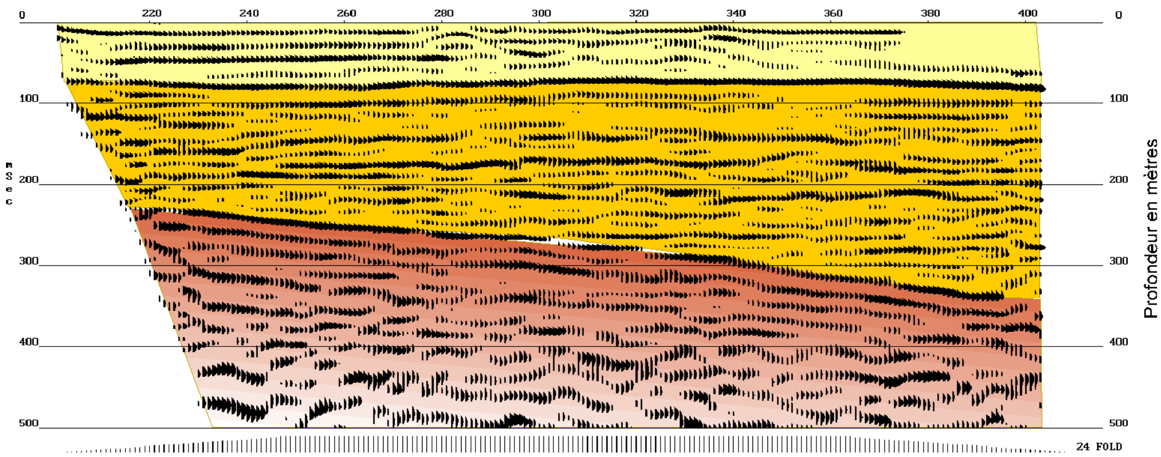


Figure 55 Section distance / depth

In order to calculate a thickness, it is necessary to divide the half of the difference of double time between the basis and the top of the layer by the velocity of interval of this layer.

$$Epaisseur\ \ X = \left(\frac{T\sup - Tbase}{2} \right) / \, Vitesse\ Couche$$

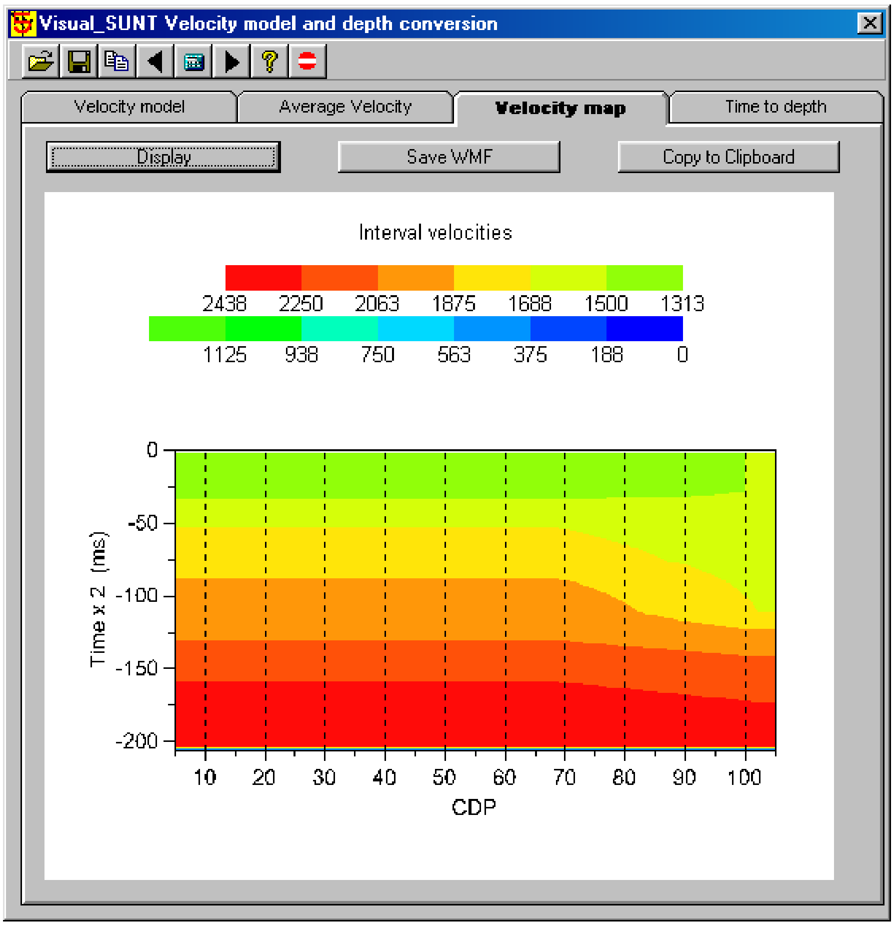


Figure 56 Distribution of the velocities for the pattern

Seismic stratigraphy

The survey of the reflectors gives some precious indications on the lithology and the sedimentology of the deep layers.

- The continuous mirrors and of strong amplitudes often corresponds to some interfacings marl - limestone in quiet middle.
- Some continuous mirrors but of variable amplitude could translate some levels of erosion, especially if it is associate to oblique mirrors.
- Some mirrors discontinuous and of variable amplitude makes to think of some deposits detritic, fluviatil for example.
- This seismic section shows some chalky deposits regaining a set detritic.

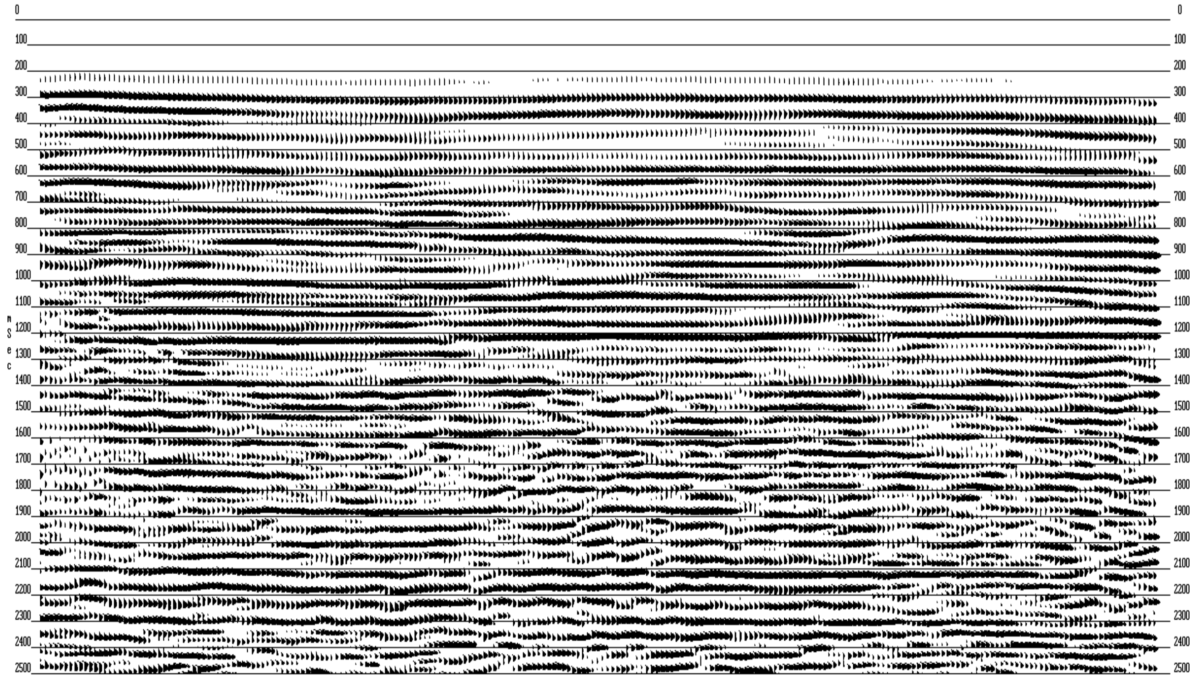
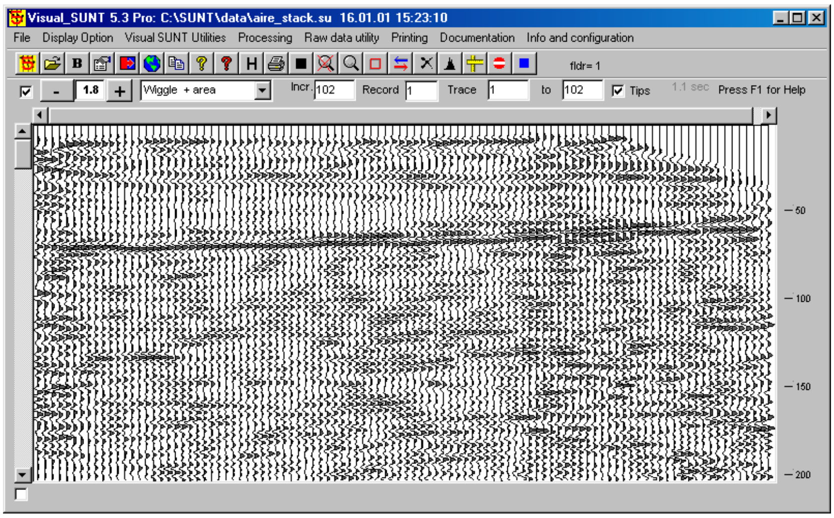


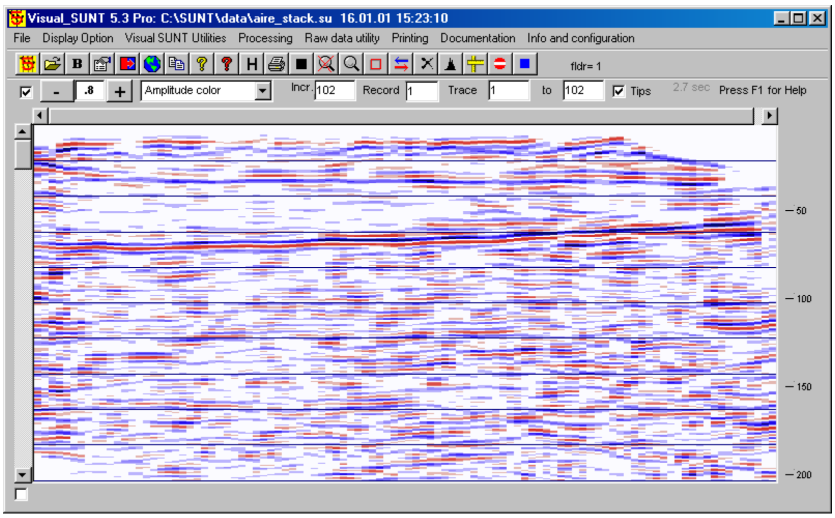
Figure 57 Example of seismic section with limestones overlying sandstones

FINAL SEISMIC SECTION

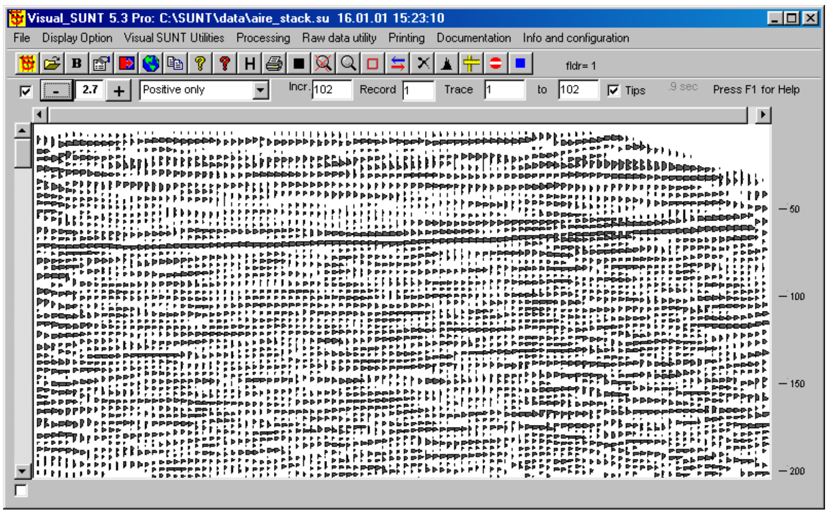
Seismic traces are displayed using different representation and scale, the geophysicist must find the type which will produce the best display to see the geological structures.



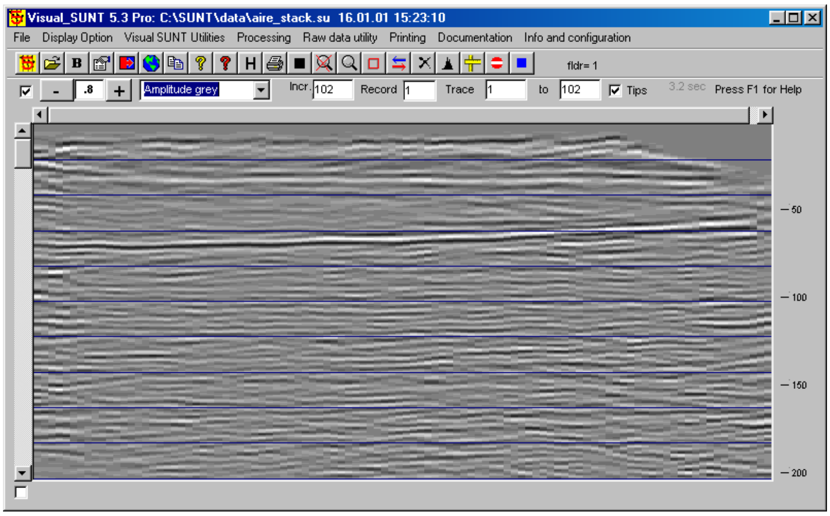
Wiggle and variable area



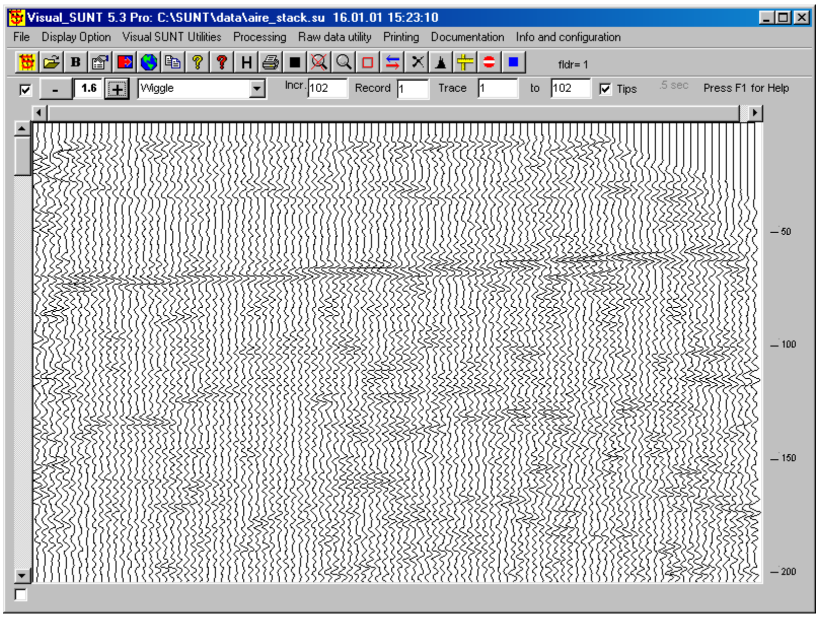
Color amplitude



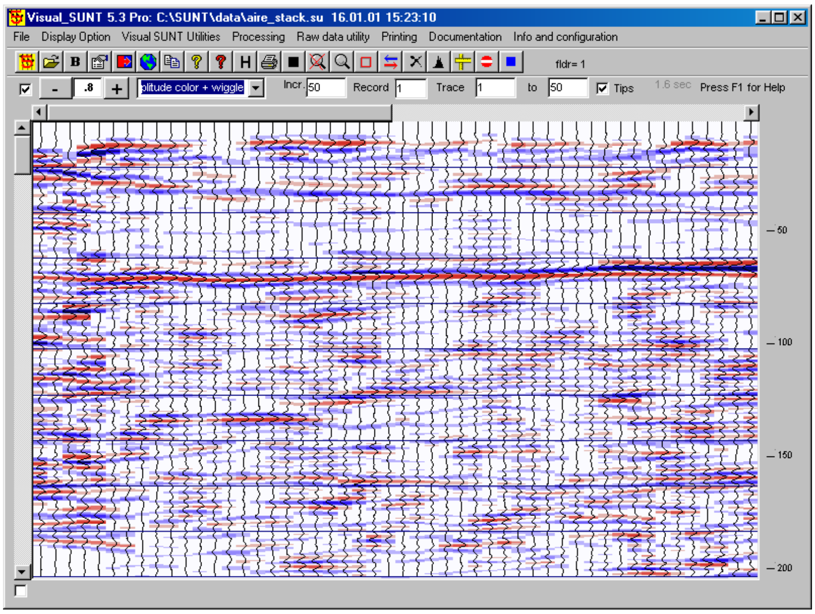
Variable area



Grey scale amplitude



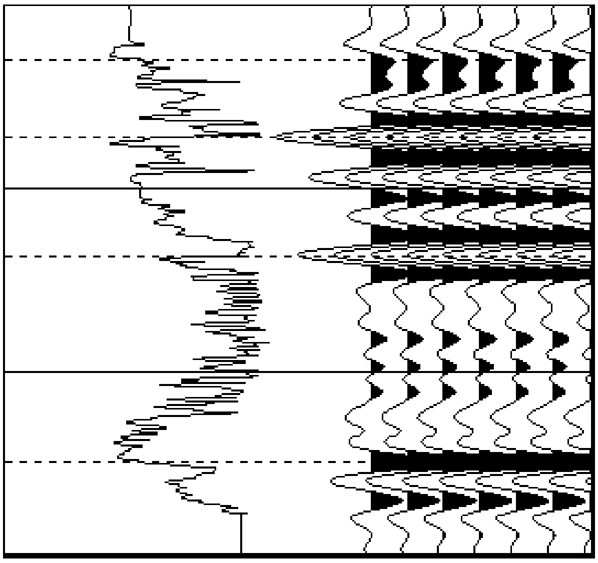
Wiggle only



Wiggles and
color amplitude

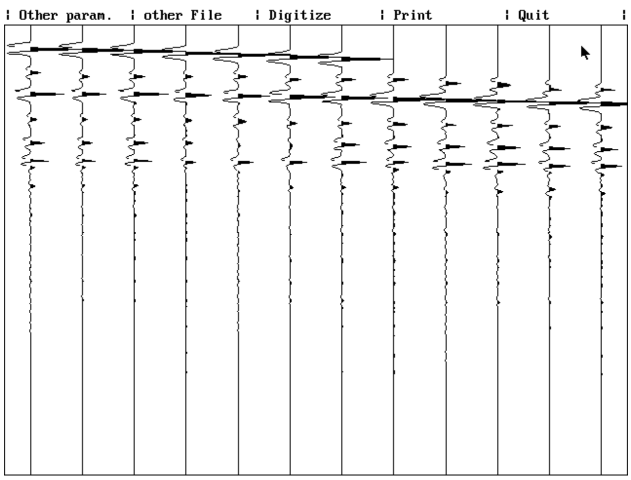
CONCLUSIONS

Synthetic



In order to prepare a seismic reflection campaign or verify a hypothesis, it is possible of achieving a synthetic seismogram. At this end, it is necessary to know the thickness of the layers, their seismic velocity and their density, to the means some well logging of forage for example.

Modellisation



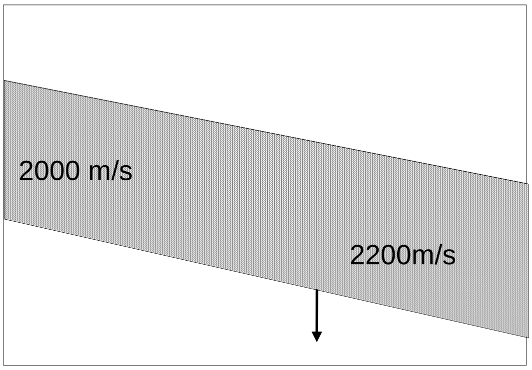
Some software's permit also models a complete profile, this that is particularly useful in order to verify an interpretation or prepare campaign. Like for the previous tool, it is necessary to know in addition of the geometry of the layers, the thickness of the layers, their seismic velocity and their density. The programs prepare either some synthetic records, as well a seismic profile.

Seismic reflection pitfalls

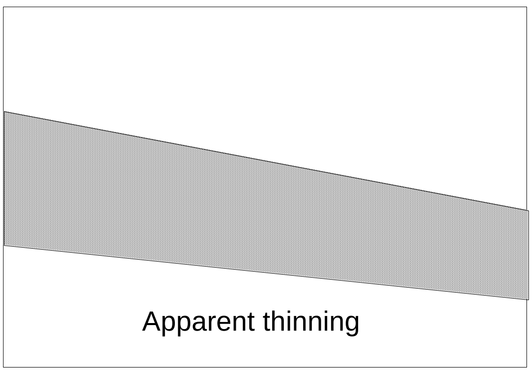
The traps are numerous and various during a seismic reflection interpretation.

- the seismic sections are distances / time sections.
- Seismic sections are 2D documents whereas the reflections proceed of a space tri dimensional.
- All visible phenomenon's on the seismic sections are not geological facts, but could result of data processing.

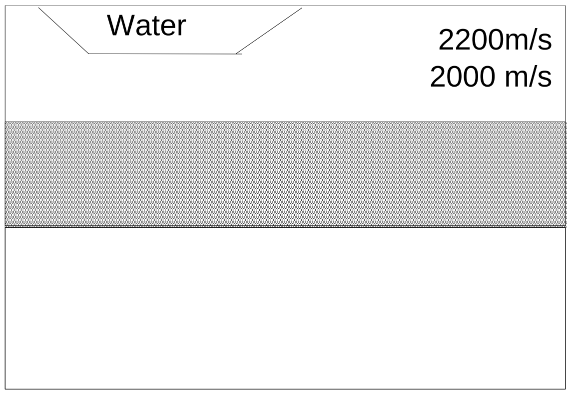
The figures above show two possible mistakes at the time of the interpretation of the seismic, mistakes to some lateral variations of velocities. A depth section with some true velocities should solve the problem.



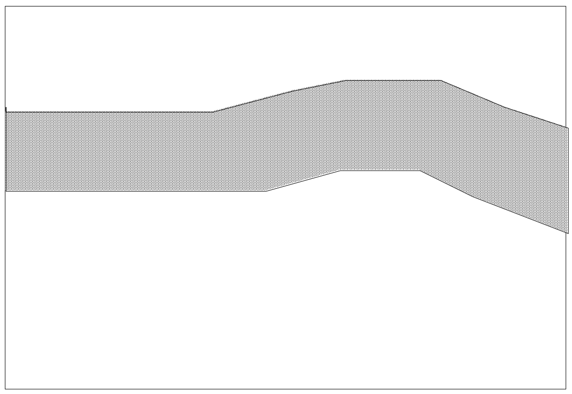
Geological model



Seismic section



Geological model



Seismic section

Utility of the seismic reflection

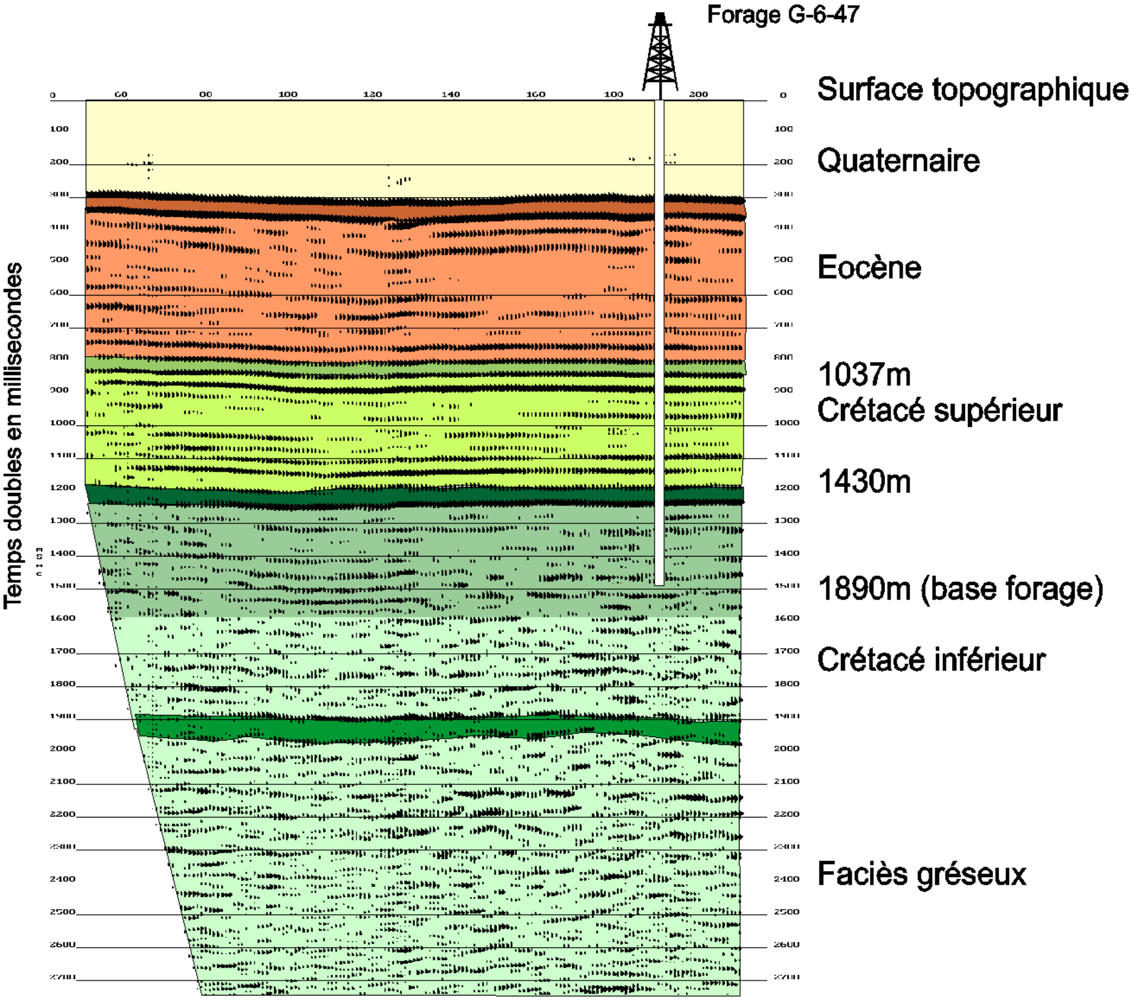
Currently, the seismic reflection high resolution represents a very efficient method in order to know the constitution of substratum between ten and hundred meters of depth. The studies of applied geology (tunnel, dam), of research of deep water or of environment (survey of garbage dump) there makes call besides in addition regularly.

It exists some limitations to its use nevertheless:

- It is necessary to dispose of enough space in order to put the lines.
- The source of energy must be compatible with the investigation depth and the location of the survey (problem of the explosive in urban middle).
- The underlying layers must have some of velocities and / or densities contrasts.
- It is necessary to never forget that the reflections proceed of a tri-dimensional environment, the seismic reflection and refraction puts some problems of geometry sometimes insoluble.
- Some dry and coarse ground (mass of fallen rocks) in surface filters the waves and lets to pass very little energy, only low frequency will be kept.
- The studies in noisy environment (cities, factories) are to avoid, otherwise it will be necessary to record during some quieter periods.

Example of studies

Excerpt of a seismic profile of 20 km achieved in the Moroccan Sahara, 10 m between traces, 1 kg of explosive by point of shooting, strings of 6 geophones:



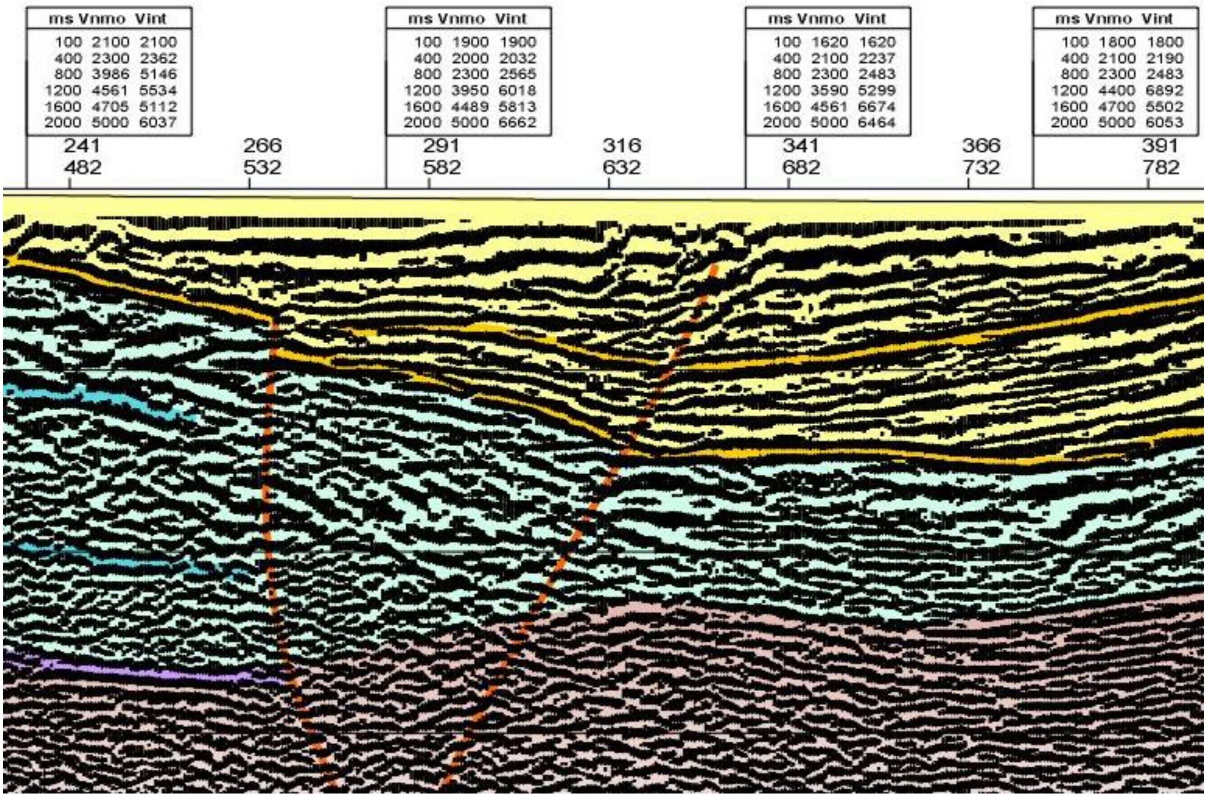
Geo2X project
Partnership with
GEOATLAS

High resolution vibroseismic for deep water survey

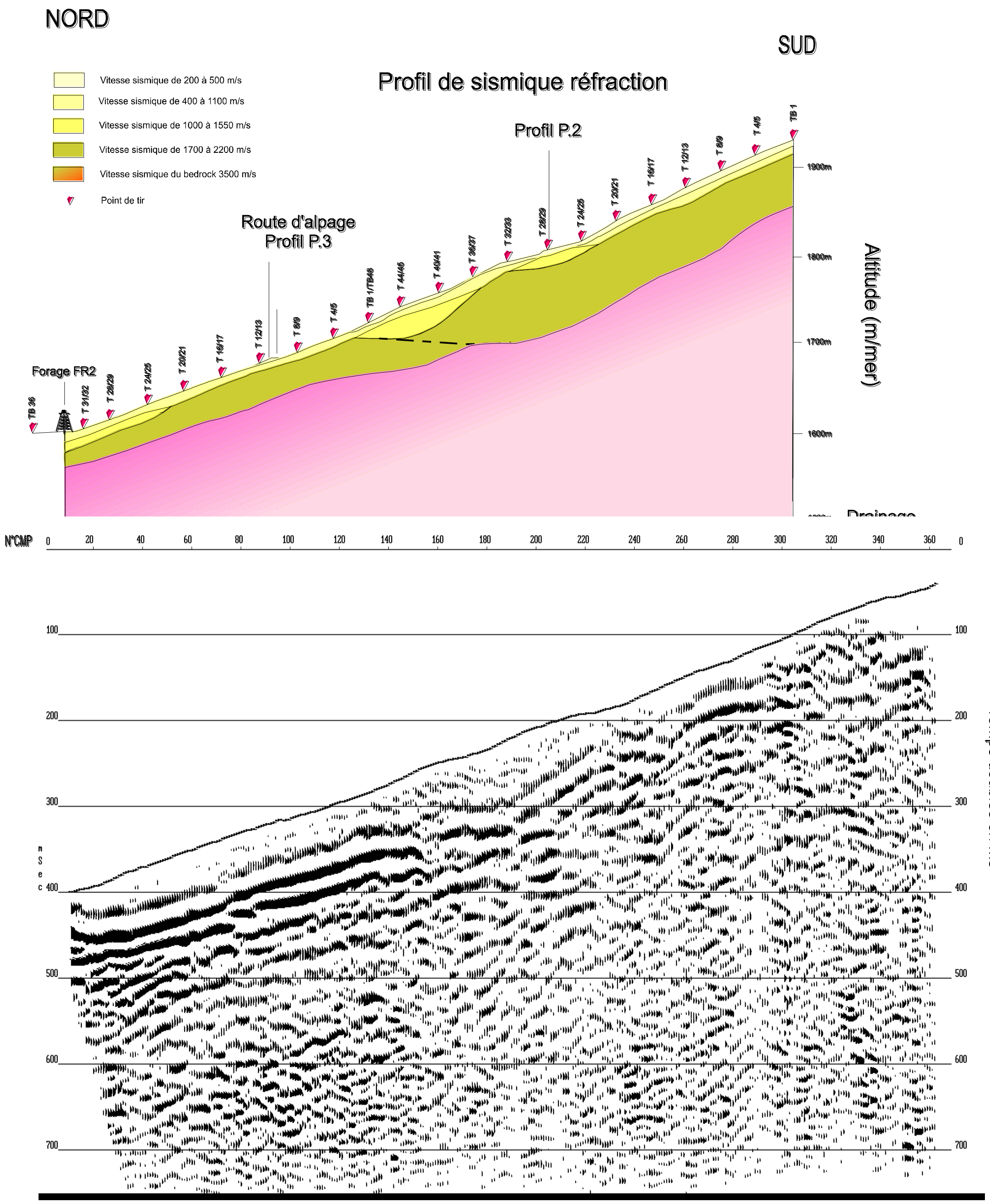
Deep water prospecting requires expensive investment, particularly for drilling works. Seismic reflection survey helps to locate accurately the drilling location.

In urban area or alluvial plains, no outcrops reveal the geology, only geophysics can be used t locate faults, folds and limestone layer in depth.

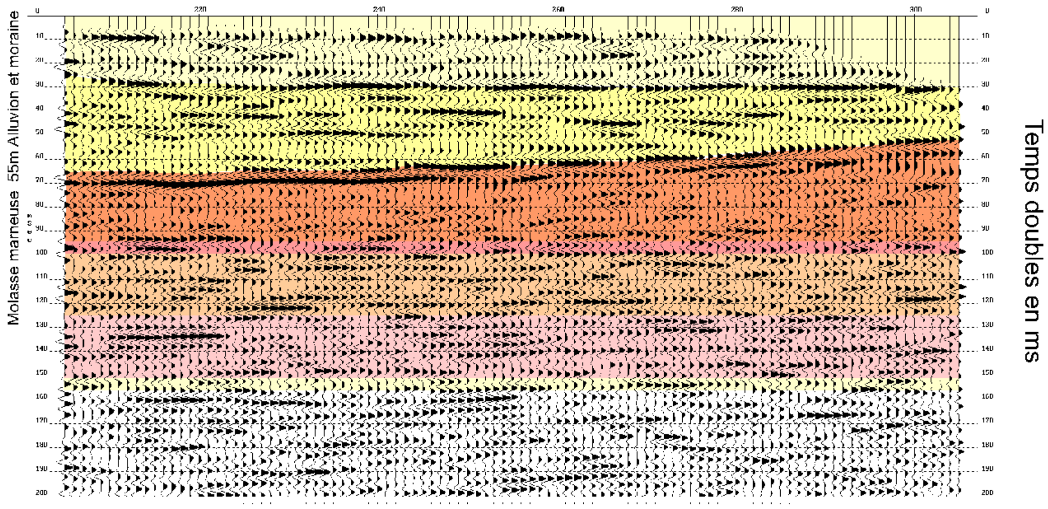
In Berkane area (NE Morocco), 75 kilometres of seismic lines have been recorded. 5 vibrators with 25 meters station spacing have been applied. The target was the Lower Jurassic limestone, from 0 to 2500 m deep.

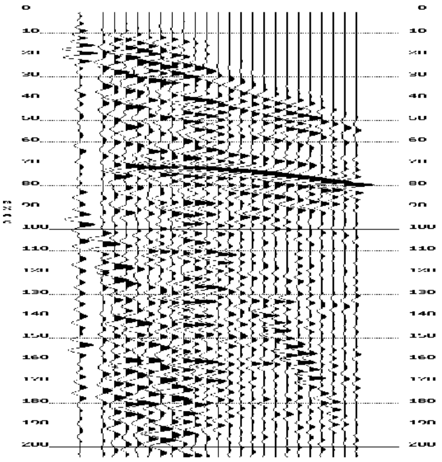


Glissement des Peillettes
(région de Nax, Valais)



Nax_mst.cdr





Enregistreur ES-2401 Géophones 24
Source d'énergie: marteau
Distance entre géophones et tirs: 2 m
Distance entre CDP 1m Fold 12

Traitement: logiciel Eavesdropper et GeoScope
Séquence de traitement: mise en collection, corrections statiques et dynamiques
Filtres LC et HC, filtre FK, Normal Move Out, sommation CDP, filtre antialiasing, AGC

Exemple d'enregistrement

Figure 58 Field pictures

Vibrator in the city
Explosive seismic survey

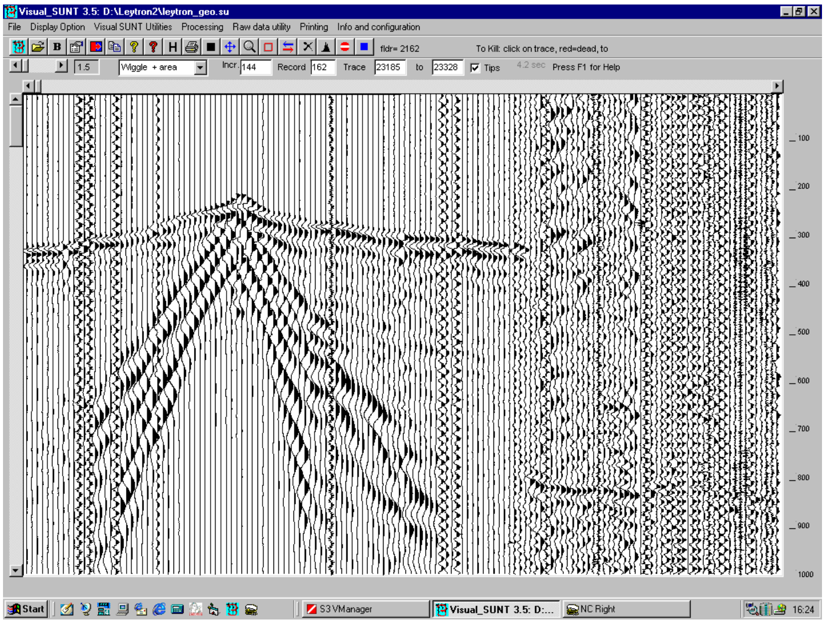
Drilling holes for explosives

Vibrators LRS-309 in Southern Morocco

Strataview R48 and rollalong IO-RLS1200

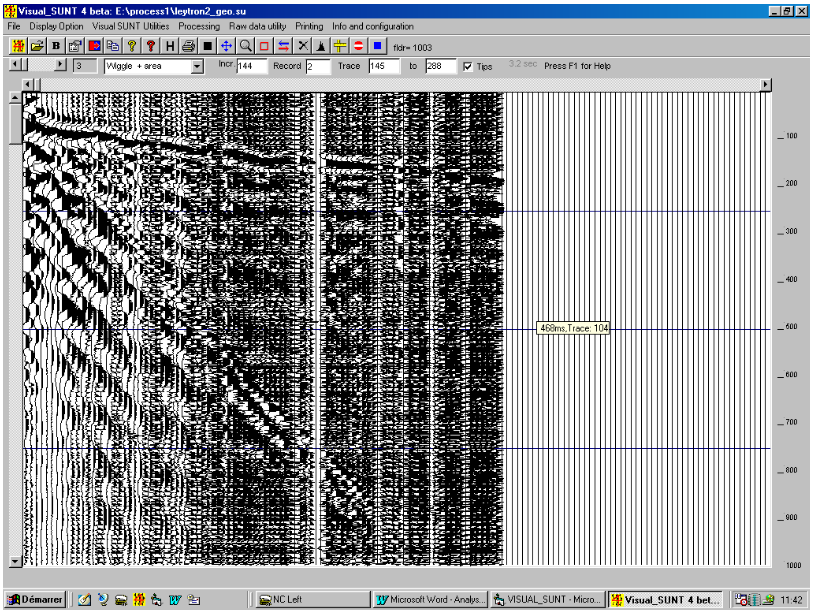
Example of problems at the time of the acquisition of the data

Triggering problem



The position of cone of noise shows that the recording started 300 ms before the time zero!

very unfavorable ratio signal/noise

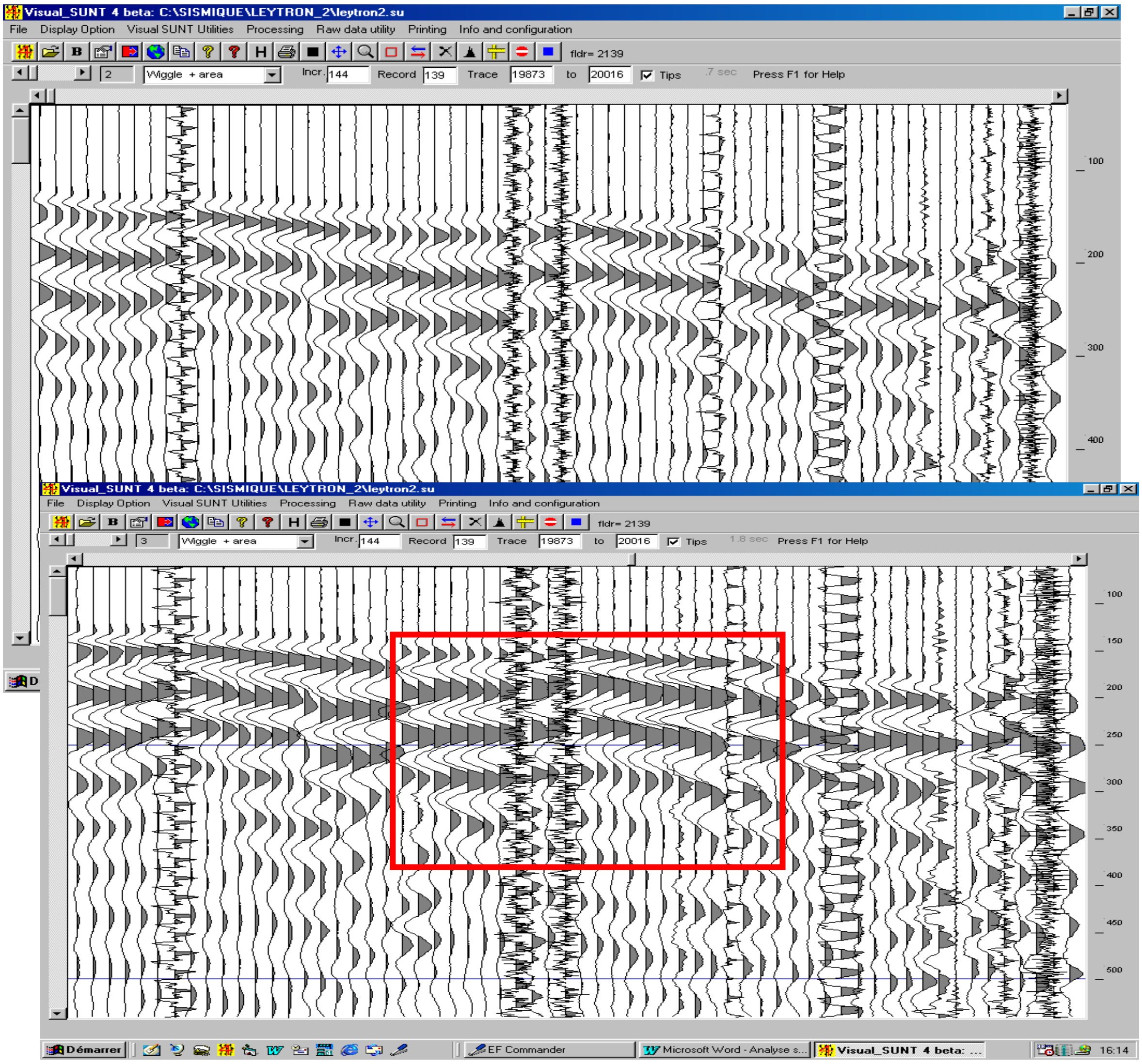


shooting particularly noisy done in end of line

Spread cable plugged

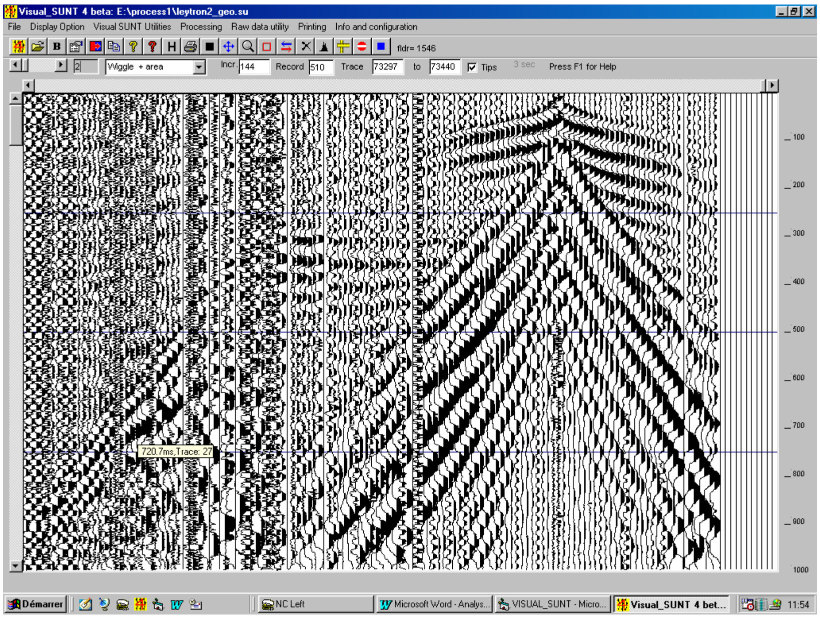
Along profile 2, the polarity of a group of 24 traces is inverted. This can be explain by a mistake of branching of the seismic cables. This evidently nullifies the signal at the time of the addition of the traces completely.

The polarity of the traces 96 to 120 (framed zone in red) is inverted, after correction, the positive picks align (original and corrected Recording).



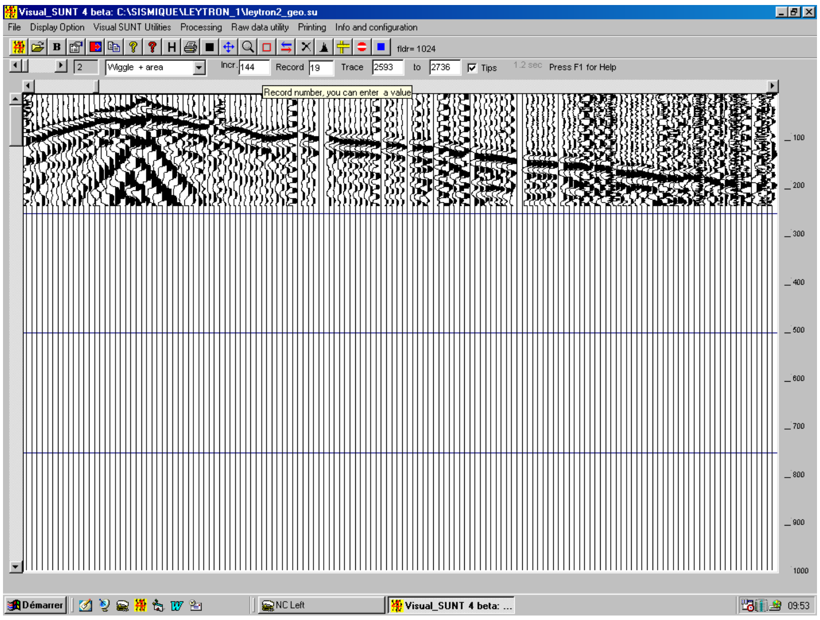
Mistake of connecting of the spread cable

The cone of noise of the first 24 traces of the recording doesn't link up with the cone descended noise of shooting!

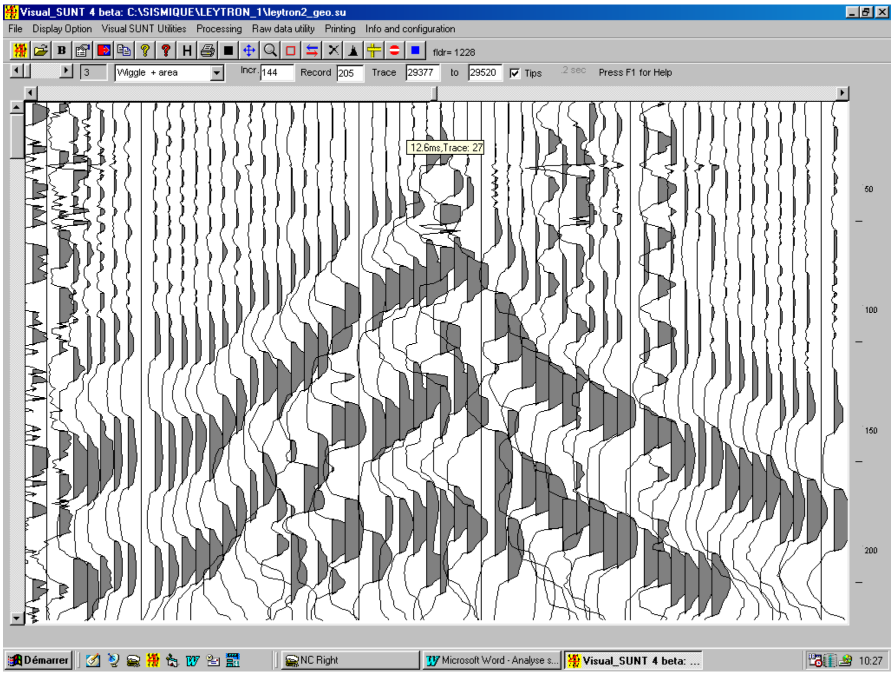


Partial recording

The recording is decree after 234 ms!



Problem of zero time



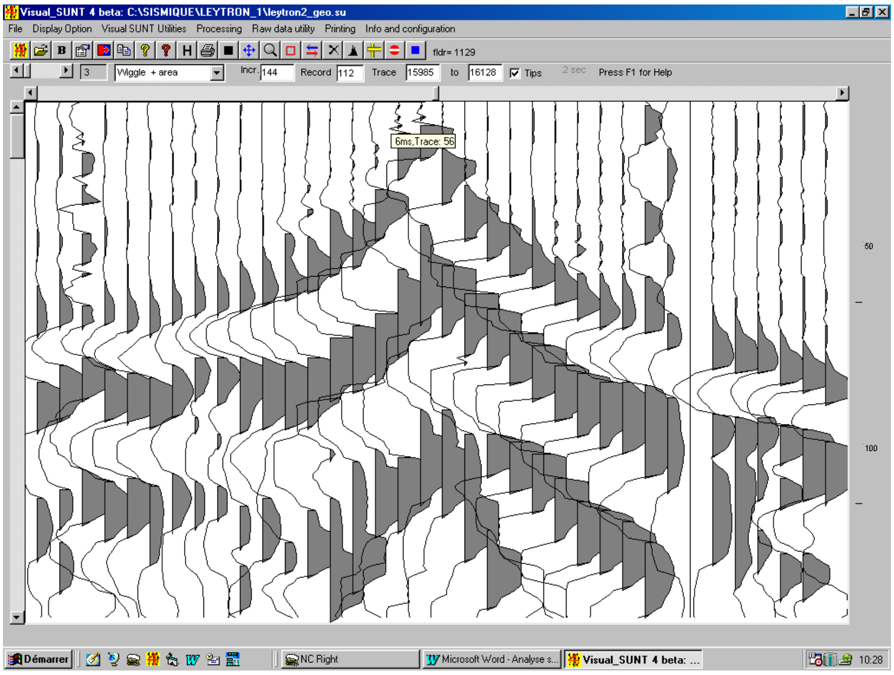


Figure 10 Consecutive records with some very different zero times

On some consecutive shootings, the time of arriving some direct waves vary between 6 ms and 14 ms. The shooting being placed to 2.5 m of the nearest geophones, a time of the order 7 ms is plausible if the velocity of the superficial layer is of 300 m / s. A superior time can to explain (with difficulty) by the presence of very slow layer or by a delay of activating the recorder.

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Some interesting WEB sites

GEPH212 Seismic Prospecting Course outline Seismic prospecting techniques are widely used for determining shallow and deep geological structures in the search for minerals and hydrocarbons
http://www.es.lancs.ac.uk/es/people/teach/br/geph212 /

High Resolution 3-D Seismic Reflection Survey
NFESC Environmental Department Technology Description: High Resolution 3-D Seismic Reflection Survey Background. Seismic reflection surveys have been performed in oil exploration to delineate the subsurface structure since the 1930's http://enviro.nfesc.navy.mil/ps/3d/srsatt1.htm

GEPH212 Seismic Prospecting Course outline Seismic prospecting techniques
are widely used for determining shallow and deep geological structures in he search for minerals and hydrocarbons,
http://www.es.lancs.ac.uk/es/people/teach/br/geph212/default.htm

Identification and Suppression of Multiple Reflections in Seismic
Prospecting Contents: Preface Introduction CHAPTER 1. SUPPRESSION OFMULTIPLES AS A PARTIAL PROBLEM OF SEISMIC INVERSION Transformation
http://www.vsppub.com/books/earth/cbk-IdeSupMulRefSeiPro.html

Geophysics Course Resources on the Internet Course University Course
Geophysics Acadia University Exploration and Environmental Geophysics
Arizona State University Advanced Field Geophysics California State @
Long Beach Geophysics California State
http://www.uh.edu/~jbutler/anon/anoncoursegeoph.html

Geological Sciences 434 Reflection Seismology Cornell University, Spring
1998 Larry D. Brown brown@geology.cornell.edu 3124 Snee, 5-7357 Ground Rules
http://www.geo.cornell.edu/geology/classes/gs434/gs434home.html

Geophysics at Monash University - Jim Cull
Geophysics can be used for direct detection of mineral deposits and other rtefacts of immediate commercial interest. However it is more common to use geophysical data in combination with other independant observations (in particular geological data)
http://www.earth.monash.edu.au/Department/jim_cull.html

XGI Services Page
Methods : Select an item from the left column Ground Penetrating Radar GPR) Seismic Reflection Seismic Refraction Forward Looking Seismic Gravity / Microgravity Electromagnetics (E/M) Magnetics Electrical
http://www.xenongeosci.com/services.htm

BUTSURI-TANKO Contents (vol. 24, no. 4) GEOPHYSICAL EXPLORATION. 1.
Technical Papers. An Approximate Solution for the Seismic Reflection
http://segjsvc.geosys.t.u-tokyo.ac.jp/segj/journal/vol_e/v24n4.html

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Geophysical Prospecting, 47, 6-99, pp. 1105-1119.
http://iapetus.unice.fr/~hustedt/publications.html

Inversion of seismic reflection data AVO inversion of seismic reflection data Seismic traveltime tomography with constraints Anisotropic traveltime tomography
http://tansa1.kumst.kyoto-u.ac.jp/tansa/topics_e.html

Applied geophysics (60 hours) Jiri Skopec (Faculty of Sciences, Charles University) Introduction Principles of applied geophysics, interrelation between applied geophysics and geophysics, geology and some industrial ranches. http://seis.karlov.mff.cuni.cz/lectures/f097.htm

Geophysical Methods in Archaeology
HOW GEOPHYSICAL METHODS CAN HELP THE ARCHAEOLOGIST by Lambert Dolphin
http://www.best.com/~dolphin/Geoarch.html

UU: Reflection and Refraction Seismology
Uppsala University | Department of Earth Sciences | Geophysics Reflection
and Refraction seismic group The reflection and refraction seismic group t the Section for Solid Earth Physics carries out field acquisition, Processing and interpretation
http://www.geofys.uu.se/seismic

Robert Laws's publications in the public domain
The physics of marine seismic source http://www.cam.net.uk/~aaa314/papers.html

Seismic investigation - exploration, mining and civil engineering
SHALLOW SEISMIC SURVEY FOR GEOLOGICAL, MINING and CIVIL ENGINEERING PROJECTS NORTH AMERICA | SOUTH AMERICA | AFRICA | ASIA | AUSTRALIA | EUROPE Alluvial Placers gold diamonds Alluvial
http://www.minelinks.com/seismic/index.html

High Resolution 3D Seismic Reflection Surveys for Characterization of Environmental Technology Proceedings: Third Tri-Service Environmental Technology Workshop contents: Agenda Attendees Introducing USACE's New In- situ Air Sparging Manual Barometrically Driven Bioventin
http://aec.army.mil/prod/usaec/et/etw/17.htm

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Technical Papers. Field Experimental Study on the Applicability of Anisotropy.
http://segjsvc.geosys.t.u-tokyo.ac.jp/segj/journal/vol_e/v48n2.html

Milo Backus
Massachusetts Institute of Technology, 1956 Exploration Geophysics. Selected Recent Publications Zeng, H., Backus, M. M., Barrow, K. T., and Tyler, N., 1996,
http://www.cc.utexas.edu/cons/geo/people/names/backus.html

GEPH316 Seismic Data Processing Course outline This course covers the techniques of seismic data processing and various seismic reflection
http://www.es.lancs.ac.uk/es/people/teach/br/geph316/default.htm

Seismic Waves that propagate through the earth as elastic waves are referred to as seismic waves . There are two broad categories of seismic waves: body waves and surface waves.
http://www.mines.edu/fs_home/tboyd/GP311/MODULES/SEIS/NOTES/swaves.html

Department of Earth Sciences
M.TECH COURSES (Geoexploration) Core Courses (Two in I Semester) Course Name. L. . . T. . P. C. GS 651 Exploration Geology and Mineral...
http://www.iitb.ernet.in/~geos/Mtechsyl.htm

NH6 Open session on mass movements .3 Geophysical investigation of landslides and unstable slopes
Convener: Wasowski, J. Co-Convener(s): Del Gaudio, V.; Lollino, G.
http://www.mpae.gwdg.de/EGS/egsga/denhaag99/nh6-3.txt

Lithoprobe Seismic Processing Facility: The LITHOPROBE Seismic Processing Facility (LSPF) is the national data archive centre for all deep crustal reflection and refraction seismic data acquired under the Canadian National Geoscience Projec http://www.litho.ucalgary.ca

Seismic Reflection Processing Illustrations The Stacking Chart and Normal Moveout Click on an image for a high-resolution Adobe Acrobat PDF version of the figure. http://www.seismo.unr.edu/ftp/pub/louie/class/hydro/nmo.html

Sandmeier Scientific Software
Ground-Penetrating-Radar (GPR) and reflection/refraction-seismic data processing software as well as solutions for various other near-surface geophysical applications like ultrasound and geoelectric.
http://www.ka.shuttle.de/software

Seismic processing system SIOSEIS
20 June 2000 SIOSEIS is a software package for enhancing and manipulating marine seismic reflection nd refraction data, sponsored by NSF (the National Science Foundation) and SIA (the Scripps Indu...
http://sioseis.ucsd.edu/

Seismic Deconvolution
GEOPHYSICS 5104 - Seismic Deconvolution Course Outline, Lecture and Laboratory Notes, Index No. 2685, Quarter equivalent: GEOL 5140 http://rglsun1.geol.vt.edu/gif/g5104.html

The Resource Geology Seismic Processing System
This is a description of a very limited, but workable seismic processing system. I originally developed it for my own use in Caltech's resource geology program, and have continued
http://www.seismo.unr.edu/ftp/pub/louie/rg/rg.html

intro Seismic monitoring of fluid flow I believe one of the next major breakthroughs in Geophysics will be seismic time-lapse monitoring of subsurface fluid flow .
http://sepwww.stanford.edu/public/docs/sep91/

Seismic Reflection Method, Seismic Reflection Software
http://www.wgeosoft.ch

Advantages and Disadvantages of the Refraction and Reflection Methods
http://www.mines.edu/fs_home/tboyd/GP311/MODULES/SEIS/NOTES/sadv2.html

Project funded by the Jet Propulsion Laboratory, California Institute of Technology Principal UNR Investigator: John N. Louie Seismological Laboratory, The University of Nevada, Reno
http://www.seismo.unr.edu/ftp/pub/louie/dome/

Geol 453/653 - Seismic Reflection Processing Lab
John Louie, February 14, 2000 Alternative Exercise You can complete either the exercise below, or the alternative exercise from Geol 492/692.
http://www.seismo.unr.edu/ftp/pub/louie/class/453/refl.html

What is Seismic Migration?
Seismic migration is a data-processing technique that creates an image of earth structure from the data recorded by a seismic reflection survey.
http://www.seismo.unr.edu/cemat/migration.html

GEOSPHERE INC: Seismic Reflection and Refraction Methods
Seismic Methods Introduction "Seeing" with sound is a familiar concept. Bats and submarines do it and so does a blind man with a cane. In total darkness we can sense whether we are in a closed or open space by the echoes from our footsteps.
http://www.geosphereinc.com/seismic.htm

CMST-CP September 1995 Progress Reports - 3D/3C Reflection Seismic /...
3D/3C Reflection Seismic for Site Characterization This task will investigate the near-surface earth in a three-dimensional manner through acquisition, Processing, and interpretation of 3D.
http://www.cmst.org/cmst/Cmst-Cp_reports/Sep95/AL941001.html

Stanford University Department of Geophysics SEISMIC REFLECTION ACQUISITION, PROCESSING AND INTERPRETATION Professor Simon Klemperer teaches this three-quarter sequence of classes for geophysicists
http://geo.stanford.edu/~sklemp/18234info.html

SEG Society of Exploration Geophysicists http://www.seg.org

Multichannel seismic reflection data, Ross Island. (CEOS IDN datasets)
CEOS-IDN Multichannel seismic reflection data, Ross Island. Contents - Quality - Summary - Reference - Contact Information - Temporal coverage
http://version0.neonet.nl/ceos-idn/datasets/ICAIR-001.html

Thomas Henyey's Home Page
Academic Background Geophysics, University of California, Berkeley
Geophysics, California Institute of Technology Professional Experience
http://www.usc.edu/dept/earth/people/henyey/index.html

True--amplitude processing techniques for marine crustal-reflection seismic data Title: True--amplitude processing techniques for marine
Hutchinson. Author: Lee, Myung W. Hutchinson, Deborah
http://dra.library.ubc.ca:4105/MARION/ACW-6303

UU: Reflection and Refraction Seismology
The reflection and refraction seismic group at the Section for Solid
Earth Physics carries out field acquisition, processing and interpretation of both normal incidence and wide-angle/refraction http://www.geofys.uu.se/seismic/index.html

The CWP/SU: Seismic Un*x Home Page CWP Sponsor web Site Sponsor Web Site
Picture of Jack K. Cohen and John Stockwell from 1994 SU Installs Sample NMO stack Send email to: john@dix.Mines.EDU Acknowledgement of Support
http://timna.mines.edu/cwpcodes

SeisNav - Seismic Software for UNIX and NT
SeisNav, Inc. specializes in seismic survey QC and pre-stack processing software tools with the SeisNav Resolve package and custom programming on UNIX and NT systems.
http://www.seisnav.com

Seismic Unix Jobs
http://www.geophysik.uni-kiel.de/itrinks/4D-GEORADAR/node46.html

Practical SeisX 2D 3D Seismic Interpretation
Practical SeisX: The Unofficial SeisX Web Site, A self help tutorial on how to start SeisX, import culture, wells, logs, generate base maps, load SEGY data, post stack processing, mistie analysis and correction, automatic grid balancing, 2D, 3D interpretation
http://www.vector-archives.com/keyser

Theory of Seismic Imaging by John Scales Notes for a graduate course in seismic imaging taught at the Colorado School of Mines. Numerous exercises based on the Center for Wave Phenomena's Seismic... http://samizdat.mines.edu/imaging

NHCGTTC: FALL 99 COURSE SCHEDULE
announces several NEW courses available this fall! Linux Introduction
UNIX Shell Scripting & Awk Seismic Geophysics for Geologists Introduction
to Seismic Surveying: PLACES http://www.seg.org/sections/gsh/gshgttcs.html

CREA Dynamic Analysis (Seismic, Blast, Vibration)
CREA Consultants. Home page for DynaTool. Managing Director Chris Rogers.
Dynamic analysis, ANSYS & Consequence and Safety Engineering, FE Consultants. USFOS Consultants. Seismic, http://www.cr-engineering.co.uk/Dynamic.html

Geophysical Freeware There is an increasing number of freeware applications which may be of interest to the practicing geophysicist and many of these are available via the Internet.
http://www.uh.edu/~jbutler/geophysics/freeware.html

Seismic Image Software Ltd. Products Page
OMNI is a modular 3D seismic survey design package. OMNI takes the user all the way from the original concept to actual field positioning and analysis. http://www.sisimage.com/Products.htm

Darstellung mit Seismic Unix-Programmen
http://www.uni-karlsruhe.de/~nf25/bericht3/node10.html

IGNS: Interactive Software for Processing Seismic Data, Globe Claritas Globe Claritas is a fullly interactive 2D/3D seismic processing package which offers a rich and wide range of processor modules, excellent refraction statics and velocity analysis applications,...
http://www.gns.cri.nz/help/services/petroleum/software.html

http://www-geo.phys.ualberta.ca/howto
Resources for HPC, Data Processing and Seismic Imaging In this page you will find a collection of resources for seismic data processing and High Performance Computing. Parallel Computing Seismic Unix SeismicLab Latex (by D. Gingrich at UofA) Unix http://www-geo.phys.ualberta.ca/howto

THE IGG SEISMIC NETWORK
The I.G.G. Seismic Network, managed by Seismological Group of the DipTeRis (Dipartimento per lo studio del Territorio e delle sue Risorse, Sezione Geofisica), in its current pattern represents a devel
http://www.dister.unige.it/geofisica/summary.html

Geodynamics Annual Report 1996
Extract from RSES annual Report 1996. GEODYNAMICS. The research of the Geodynamics Group can be categorized into three areas: (i) the modelling
http://rses.anu.edu.au/geodynamics/AnnRep/96/96ARgeod.html

Seismic Reservoir Characterization Laboratory http://verrucano.geol.vt.edu/srcl

Catalog of compilers: sub (seismic unix basic)
subscript is a bytecode-compiled scripting language that provides a convenient way of manipulating binary stream data. It is currently distributed embedded in a demo application (sub), which illustrates the processing of seismic data
http://www.idiom.com/free-compilers/TOOL/subscrip-1.html

SIA - system for advanced (seismic) data analysis SIA is a highly integrated software package used for many seismic processing tasks encountered in the wide range of seismic processing and data analysis. It is being developed since mid-1995
http://asuwlink.uwyo.edu/~seismic/sia

ORFEUS: software links
Observation and Research Facilities for EUropean Seismology (ORFEUS): Seismological Software Library; software links
http://orfeus.knmi.nl/other.services/software.links.html

Sam's Page
Education and K-12, Mac apps, Science, GeoScience and petroleum Geophysics and Geology from Calgary. http://www.cuug.ab.ca:8001/~johnstos/index.html

sci.geo.petroleum FAQ - Internet Resources. From: quinlivan@slb.com
(William F. Quinlivan) Newsgroups: sci.geo.petroleum,sci.answers, ews.
http://www.cis.ohio-state.edu/hypertext/faq/usenet/geology-faq/petroleum-resources/faq.html

SEG-Y et SU Header

Number	Type	Name	Description
1	int	**tracl**	trace sequence number within line
2	int	**tracr**	trace sequence number within reel
3	int	**fldr**	field record number
4	int	**tracf**	trace number within field record
5	int	**ep**	energy source point number
6	int	**cdp**	CDP ensemble number
7	int	**cdpt**	trace number within CDP ensemble
8	short	**trid**	trace identification code:1 = seismic data 2 = dead
9	short	**nvs**	number of vertically summed traces (see vscode in bhed structure)
10	short	**nhs**	number of horizontally summed traces (see vscode in bhed structure)
11	short	**duse**	data use:1 = production 2 = test
12	int	**offset**	distance from source point to receiver group (negative if opposite to direction
13	int	**gelev**	receiver group elevation from sea level
14	int	**selev**	source elevation from sea level
15	int	**sdepth**	source depth (positive)
16	int	**gdel**	datum elevation at receiver group
17	int	**sdel**	datum elevation at source
18	int	**swdep**	water depth at source
19	int	**gwdep**	water depth at receiver group
20	short	**scalel**	scale factor for previous 7 entries with value plus or minus 10 to the power 0,
21	short	**scalco**	scale factor for next 4 entries with value plus or minus 10
22	int	**sx**	X source coordinate
23	int	**sy**	Y source coordinate
24	int	**gx**	X group coordinate
25	int	**gy**	Y group coordinate
26	short	**counit**	coordinate units code: 1 = length (meters or feet) 2 = seconds of arc
27	short	**wevel**	weathering velocity
28	short	**swevel**	subweathering velocity
29	short	**sut**	uphole time at source
30	short	**gut**	uphole time at receiver group
31	short	**sstat**	source static correction
32	short	**gstat**	group static correction
33	short	**tstat**	total static applied
34	short	**laga**	lag time A, time in ms between end of 240- byte trace and time break,
35	short	**lagb**	lag time B, time in ms between the time break and the initiation
36	short	**delrt**	delay recording time,
37	short	**muts**	mute time--start
38	short	**mute**	mute time--end
39	unsigned short	**ns**	number of samples in this trace
40	unsigned short	**dt**	sample interval in micro-seconds
41	short	**gain**	gain type of field instruments code: 1 = fixed 2 = binary 3 = floating point
42	short	**igc**	instrument gain constant
43	short	**lgi**	instrument early or initial gain

44	short	**corr**	correlated: 1 = no 2 = yes
45	short	**sfs**	sweep frequency at start
46	short	**sfe**	sweep frequency at end
47	short	**slen**	sweep length in ms
48	short	**styp**	sweep type code: 1 = linear 2 = cos-squared 3 = other
49	short	**stas**	sweep trace length at start in ms
50	short	**stae**	sweep trace length at end in ms
51	short	**tatyp**	taper type: 1=linear, 2=cos^2, 3=other
52	short	**afilf**	alias filter frequency if used
53	short	**afils**	alias filter slope
54	short	**nofilf**	notch filter frequency if used
55	short	**nofils**	notch filter slope
56	short	**lcf**	low cut frequency if used
57	short	**hcf**	high cut frequncy if used
58	short	**lcs**	low cut slope
59	short	**hcs**	high cut slope
60	short	**year**	year data recorded
61	short	**day**	day of year
62	short	**hour**	hour of day (24 hour clock)
63	short	**minute**	minute of hour
64	short	**sec**	second of minute
65	short	**timbas**	time basis code: 1 = local 2 = GMT 3 = other
66	short	**trwf**	trace weighting factor, defined as 1/2^N volts for the least sigificant bit
67	short	**grnors**	geophone group number of roll switch position one
68	short	**grnofr**	geophone group number of trace one within original field record
69	short	**grnlof**	geophone group number of last trace within original field record
70	short	**gaps**	gap size (total number of groups dropped)
71	short	**otrav**	overtravel taper code: 1 = down (or behind) 2 = up (or ahead)
72	float	**d1**	sample spacing for non-seismic data
73	float	**f1**	first sample location for non-seismic data
74	float	**d2**	sample spacing between traces
75	float	**f2**	first trace location
76	float	**ungpow**	negative of power used for dynamic range compression
77	float	**unscale**	reciprocal of scaling factor to normalize range
78	int	**ntr**	number of traces
79	short	**mark**	mark selected traces
80	short	**unass[15]**	unassigned--NOTE: last entry causes