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METHODOLOGIES AND TECHNIQUES OF PROCESSING OF DEEP MULTICHANNEL SEISMIC DATA IN THE GULF OF NAPLES (SOUTHERN ITALY)

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ABSTRACT

The techniques and methodologies of seismic data processing applied to deep multichannel seismic data recorded in the Gulf of Naples are herein shown and presented. The processing techniques used for the elaboration of the seismic profiles are up-to-date and some of them are based on complex mathematical models, which have allowed to carry out a good attenuation of multiples (especially the sea bottom multiples) and to perform good velocity analyses for the production of the stacked sections, on which the geological interpretation has been carried out. The procedures of treatment of the multichannel seismic data starting from the field data are reported in sketch diagrams of data elaboration applied to the different phases of the whole data processing. The used software are the Promax 2D (Landmark Ltd) and the Seismic Unix (Colorado School of Mines). The predictive deconvolution and the spiking deconvolution have been applied to three processed seismic profiles. The best results have been obtained through the application of the spiking deconvolution, allowing for a simple definition of the different seismic reflectors during the geologic interpretation of the processed lines.

Key words: Seismic data processing, multichannel data, flux of elaboration, predictive deconvolution, spiking deconvolution.

1. INTRODUCTION: THE SEISMIC REFLECTION METHOD

The techniques of seismic prospecting and especially the techniques of the reflection seismic data are strongly varied during the last years. The contribution to this variation is coming from the oil industry, which has invested many resources in the geophysical methods for the hydrocarbon searching. The basic techniques for the seismic exploration consist of the artificial generation of seismic waves in the ground (source) and in the measurement of the time requested from these waves to cover the way from the source to the receivers. The ray pathway may be reconstructed from the knowledge of the time of arrival of these waves to the different receivers and of the corresponding velocities. The reconstruction of the ray pathway may be performed through the refraction if we consider the times of the refracted phases or through the reflection if we consider the reflected phases. One of the main advantages of the seismic reflection method, if compared with the seismic refraction method is the not necessary condition of the increase of the velocity with the depth. An abrupt variation of velocity, both as an increase and as a decrease, is enough to determine a reflection of the seismic waves on the surface of discontinuity.

1.1 BASIC PRINCIPLES ON THE PROPAGATION AND PHASES OF THE SEISMIC WAVES

The propagation of the seismic waves may be described through the principle of Huygens-Fresnel of the geometric optics and through the Fermat-Snell principle. Accordingly to the principle of Huygens-Fresnel each point of the wave front may be considered as a secondary source, where the envelopment of the new wave fronts defines the location of the primary wave during next time, being the secondary waves active only the direction of propagation.

The wave movement happens in such a way that each point of the wave front proceeds in a direction perpendicular to the each one. Based on this assumption the wave rays may be defined as half straight lines perpendicular to the wave front. The Fermat principle, instead, describes the walk of the wave ray in the inner of the material. The walk followed by the wave is that one which makes minimum the travel time. Given a velocity distribution in a medium it is possible to geometrically define, by using this principle, the pathway of the wave ray. It can be demonstrated that the laws of the reflection and of the refraction derive from the principle of Fermat. From the linearity of the wave equation it follows the principle of superimposition. This principle states that the superimposition of a certain number of waves is equal to the sum of the effects of the single components. This principle is basilar to the next Fourier analysis.

The velocity and the direction of propagation of the different types of waves vary accordingly to the physical properties and to the dimensions of the crossed medium. The waves travel with constant velocities along rectilinear rays in an ideal infinite medium, homogeneous, isotropic and perfectly elastic. In a quasi-real situation the earth is supposed to be stratified, with layers of different thickness and variable physical characteristics (velocity, density) and not perfectly elastic neither isotropic. Perhaps, significant variations occur both in the direction and in the velocity of propagation, more than in the characteristics of amplitude and phase of the wave.

Accordingly to the rules of the geometric optics, when a wave ray meets a surface of separation between two media which are supposed to be homogeneous, but with different physical characteristics (in particular the velocity), a part of the energy is reflected and a part transmitted in the second medium. The phenomenon is defined as refraction if during the transmission a variation of direction is observed. The direction of the reflected ray is determined from the law of reflection.

1.2 P WAVES AND S WAVES

The seismic waves propagate in the inner of the earth with velocity, frequency and amplitude depending on the elastic properties of the rocks. In a medium crossed by a wave train, two types of waves of volume propagate: the longitudinal P waves, oscillating in the same direction of propagation and the transversal S waves, which have the vibration plan perpendicular to the propagation plan.

For the P waves the equation of motion is of the following type (Sheriff et al., 1995):

$^{1}/_{\alpha^{2.}}$ x $\partial^{2}\,{}^{\Delta}/_{\partial t^{2}} = \Delta^{2}\Delta$ (**equation 1**)

where the velocity α is given from:

$\alpha^{2} = \lambda + 2\mu/\rho$ (**equation 2**)

For the S waves the equation of motion is of the following type (Sheriff et al., 1995):

$^{1}/_{\beta^{2}}$ x $\partial^{2}x\partial^{x}/\partial t^{2} = \Delta\partial^{x}$……………….(**equation 3**)

where the velocity ß is given from:

$\beta^{2} = {}^{\mu}/_{\rho}$………………………………**(equation 4)**

1.3 RAYLEGH AND LOVE WAVES

The seismic waves propagate in a homogeneous medium in all the available volume. Nonetheless this, if the elastic medium shows a surface of separation it is possible to verify that a particular type of waves, i.e. the Raylegh waves, propagate on the considered surface. They are a linear combination of P and S waves with an amplitude rapidly decaying with the depth.

Fig. 1 shows the motion of the particles seen on a vertical plan, parallel to the direction of propagation of the wave. It can be observed that the elliptical orbit retrogrades. To whom concerns the velocity of propagation we have that:

VR = 0.92Vs……………………….(**equation 5**)

Where Vs is the velocity of the S waves in the same medium.

The ground roll, which may be seen in the seismic reflection recordings onshore is a Raylegh wave. This is a noise which may be suppressed through particular acquisition geometries or during the elaboration with numerical filters.

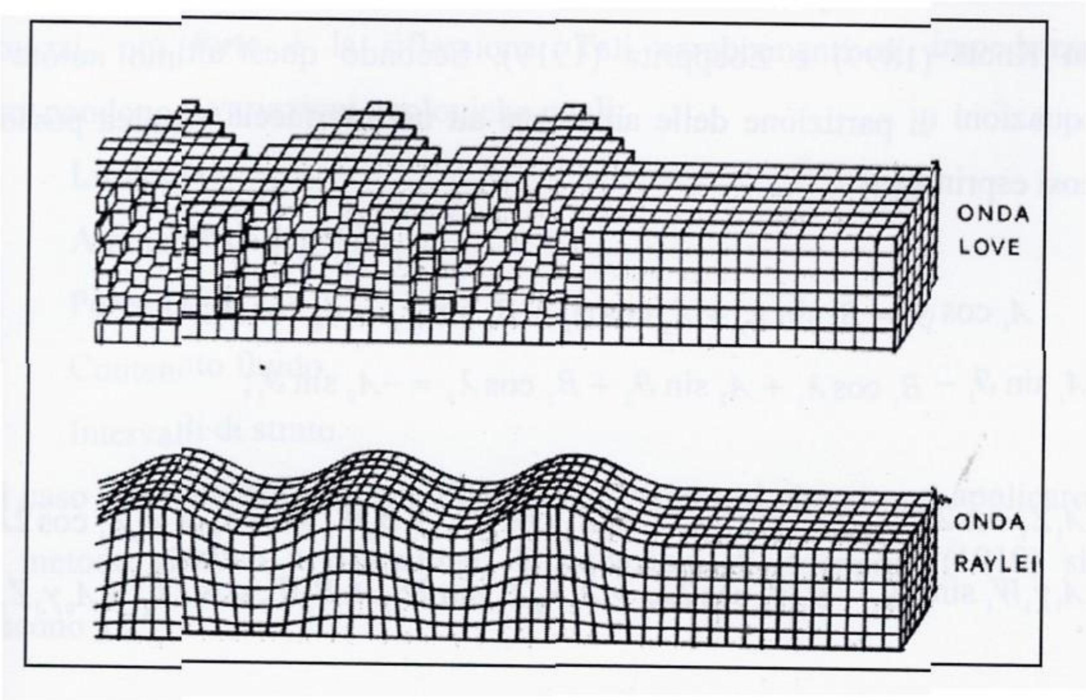

Fig. 1: Representation of the motion of the Raylegh and Love surficial waves (modified after Gasparini and Mantovani, 1984).

The Love waves exist at the condition that the medium is stratified with a shallow layer having a low velocity located on a substratum having a high velocity or a layer having a low velocity between two faster layers (Fig. 1). They have a propagation velocity depending on frequency and are undergone to the dispersal phenomenon. It can be demonstrated that when the velocity of propagation of the Love wave approximates to that one of the substratum having a high velocity, the wave length increases. Instead, when it tends to have the velocity which characterizes the low layer, the wave length decreases. This kind of waves is not surveyed from the geophones having a vertical component.

1.4 REFLECTION COEFFICIENT AND TRANSMISSION COEFFICIENT

The determination of the equations which put in relationships the coefficients of amplitude of the incident, reflected and refracted waves has been studied by Knott (1899) and by Zoeppritz (1919).

Accordingly to Zoeppritz (1919) the equation of partition of the amplitudes at a seismic interface may be expressed as it follows:

$A_1\cos\partial_1 - B_1\sin\lambda_1 + A_2\cos\partial_2 + B_2\sin\lambda_2 = A_0\cos\partial_1$ (**equation 6**)

$A_1\sin\partial_1 - B_1\cos\lambda_1 + \mathrm{A}_2\sin\partial_2 + B_2\cos\lambda_2 = A_0\sin\partial_1$ (**equation 7**)

$A_1 Z_1\cos 2\lambda_1 - B_1 W_1\sin 2\lambda_1 + \mathrm{A}_2 Z_2\cos 2\,\partial_2 + B_2 W_2\sin 2\lambda_2 = A_0 Z_1\cos 2\lambda_1$ (**equation 8**)

$A_1\gamma_1 W_1 sin2\partial_1 - B_1 W_1\cos 2\lambda_1 + \mathrm{A}_2\gamma_2 Z_2\sin 2\,\partial_2 + B_2 W_2\cos 2\lambda_2 = A_0\gamma_1 Z_1 \sin 2\theta_1$ (**equation 9)**

where A_0, A_1, A_2 respectively indicate the amplitudes of the P waves, incident, reflected and refracted;

∂_1 and ∂_2 indicate the angles of reflection and refraction of the waves

λ_1 and λ_2 indicate the angles of reflection and refraction of the waves.

B_1, B_2 amplitude of the S waves reflected and refracted.

$Z_1 = \rho_i . v_{pi}$ ***Acoustic impedances***

W_1 = ρii. v_{si}

In order to apply these equations to an interface we must know the density and the velocity of each medium in such a way to determine the parameters γ_1, Z_1 and W_1.

If we know A_0 and ∂_1 from the law of Snell we calculate ∂_2, λ_1 and λ_2, while the coefficients expressing the amplitudes A_1, A_2, B_1, B_2 need to be calculated. The reflection occurs each time that there is an abrupt change of the acoustic impedance. More greater is the contrast of acoustic impedance among the media, more stronger is the reflection. These changes of acoustic impedance correspond to geological variations, such as the lithology, the facies (depositional environment), the porosity, the content of fluids and the strata intervals.

In the case of a normal incidence of a P wave (a hypothesis which may be applied to the seismic reflection method) the equations of Zoeppritz (1919) may be reduced to two:

$A_1 + A_2 = A_0$ (**equation 10)**

$Z_1A_1 + Z_2A_2 = -Z_1A_0$ (**equation 11)**

The equations 7 and 9 will give as results $B_1 = B_2$ since the stresses and the tangential shifts in the examined case should be zero. Resolving the two equations with respect to A_1 and A_2 we obtain that:

$A_1 / A_0 = Z_2 - Z_1 / Z_2 + Z_1$ (**equation 12**)

$A_2 / A_0 = 2Z_1 / Z_2 + Z_1$ (**equation 13**)

The ratios A_1 /A_0 and A_2 /A_0 are respectively called the reflection coefficient and the transmission coefficient. The amplitude of the reflected wave increases with the increasing of the difference between the acoustic impedances. When the amplitude A_1 is negative a shift of 180° of the reflected wave with respect to the incident wave may be observed. The validity of the equations herein presented may be extended, in the case of a normal incidence, to angles of incidence up to 20°.

1.5 GEOMETRY OF THE SEISMIC EVENTS

The theory of the raw allows for the illustration in a simple way, accordingly to the criteria of the optics, the relationship between the times of arrival of the reflected and refracted waves and the location of the discontinuity bounding the geological strata. In the case of two-dimensional models with parallel strata (Fig. 2) we consider a layer having a thickness h on a homogeneous half-space and a distance x between the energizer source S and the receiver R. Now we see which are the times of running for the direct, reflected and refracted phases.

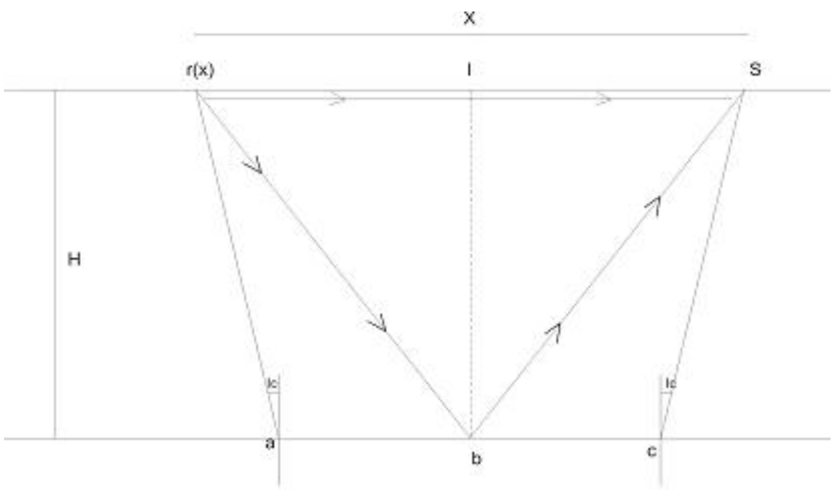

Fig. 2: Geometry of the raws related to the direct, refracted and reflected phases.

The direct wave will reach the receiver r (x) after a time expressed from the following equation:

$t_d = {}^{x}/_{v_1}$………………………………………………………..(**equation 14**)

which is the equation of a straight line passing through the origin.

The refracted phase covers the trajectory (racS) during the time:

t^2r = ${}^{x}/_{v^2}$ + ${}^{2H}/_{v_1}$ + ${}^{2H}/_{v_1}$cos (i_c) (**equation 15**)

which represents the equation of a straight line which does not cross the origin and having an angular coefficient $\frac{1}{v_2}$.

The reflected phase which will cross the trajectory (rbS) will reach the receiver after a time:

$t_{rifl}^2 = \frac{1}{v_1} (\frac{x}{2})^2 + \frac{H^2}{v_1}$; $t_{rifl} = \frac{1}{v_1} \sqrt{(\frac{x}{2})^2} + \sqrt{H^2}$………………………(**equation 16**)

which is the equation of a hyperbola, symmetrical with respect to the axes x and t and having as the asymptote of the straight lines passing for the origin with angular coefficients +/- $\frac{1}{v_1}$. The asymptote coincide with the direct wave.

The depth of the reflecting interface has been individuated by the time of arrival of the reflected wave in the source point (offset 0).

$t_0 = \frac{2H}{v1}$…………………………………………………….**equation 17**

If we consider a point on the reflection hyperbola corresponding to the time t_1 and taking

$t_i = t_0 + \Delta t\ (x)$ and applying the Pitagora's law to the triangle rbl (Fig. 5), we transform the times of running in the corresponding pathways and obtain the following equation:

$(\frac{v_1}{2}.t_0)^2 + (\frac{x}{2})^2 = \{\frac{v_1}{2}.[t_0 + \Delta t\ (x)]\}^2$………………………..**equation 18**

Solving the square we obtain the following equation:

$v_1^2 \, . \, t_0^2 + x^2 = v_1^2 \, (t_0^2 + \Delta T^2 + 2t_0 \Delta t)$ **equation 19**

If we neglect the term ΔT^2 it remains:

$\Delta T \, (x) = \frac{x^2}{2v_1^2} \, t_0$ **equation 20**

The term $\Delta T \, (x)$ is defined as the Normal Move Out (NMO). Fig. 3 shows an example of dynamic correction of the seismic traces (NMO).

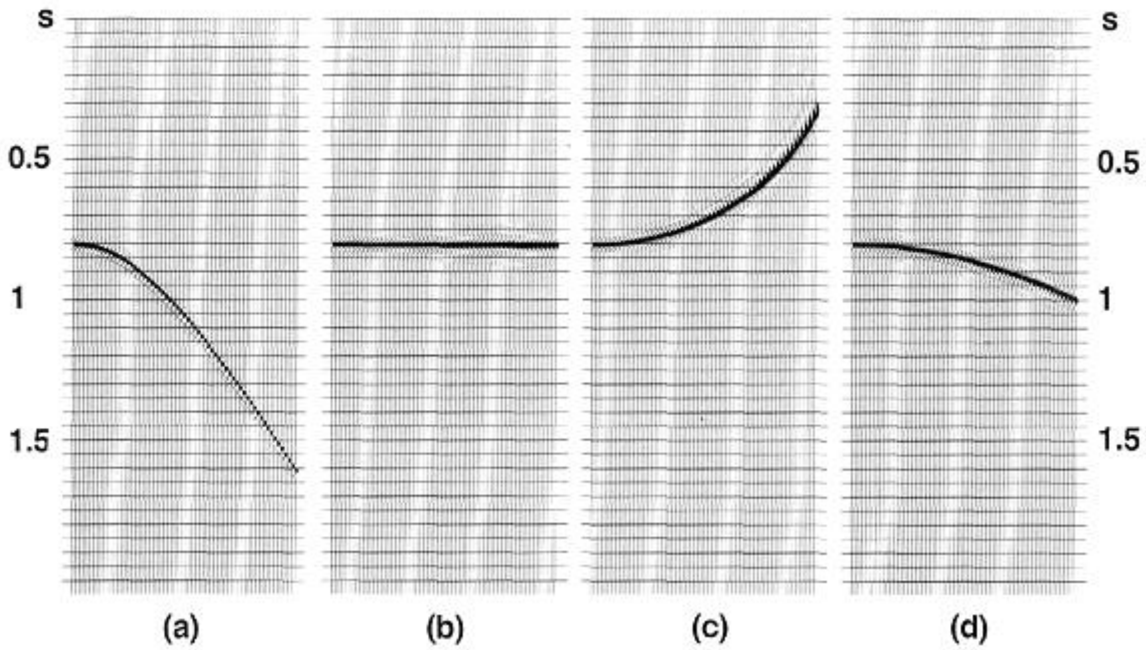

Fig. 3: (a) CDP panel (Common Depth Point) including a reflected event with a velocity of 2264 m/sec; (b) NMO correction using an exact velocity value; (c) correction with a too low velocity (overcorrection); (d) NMO correction with a too high velocity (undercorrection). Modified after Yilmaz (1987).

2. SEISMIC DATA ACQUISITION

A detailed oceanographic cruise of digital seismics has been carried out between the 4 and the 28 June 1999 (Sister99; Seismic Investigations in South Tyrrhenian Extensional Regions), aimed at surveying the area of the Southern Tyrrhenian sea, particularly referring to the Gulf of Naples. These researches have been carried out by the CNR of Naples coupled with the Free University of Amsterdam (The Netherlands). About 2400 kilometers of multichannel seismic lines have been recorded. The employed instruments and advanced techniques have allowed to obtain seismic data having a good quality also in areas where the occurrence of pyroclastic levels and volcanic bodies have produced a strong scattering of the energy of the elastic waves. The seismic acquisition has been carried out using two Airgun seismic sources, a 48-channels streamer and the acquisition system Geometrics Inc.

The Airgun is a seismic source employed in the marine environment, which instantaneously puts into the sea air at a high pressure, ranging between 150 and 400 atmospheres. The Airgun is constituted of two cylindrical chambers closed by two pistons (triggering piston and shot piston), rigidly connected to a cylinder provided of an axial orifice. Compressing air from the supply pipe into the control chamber through the orifice among the two pistons, the air reaches the shot chamber. The shot piston, taken closed since the pressure is reached, is instantaneously shifted from a solenoid releasing air through the lateral windows of the recipient and coming back into the starting location in 10 msec.

The instrument is ready to energize another time after a time depending on the air production in the related compressor. The parameters which modify the pulse and the spectrum of an Airgun are the volume of the discharge chamber, the pressure of exercise, the depth location into the sea and the number and the combination of the Airguns having different volumes in a single set. The capacity of the Airguns varies from 0.5 to 60 liters. The spectra more rich in frequency correspond with greater capacities. Sometimes batteries having up to 36 Airguns are used.

The processing of three seismic lines located in the Gulf of Naples is herein shown, for a total length of 150 kilometers. The acquisition parameters are shown in the Table 1.

Type of source	GI Gun SI/Sodera (210 c.i.)
Length of the seismogram	5 sec
Sample interval	1 msec
Distance among the sources	25 m
Distance among the hydrophones	12.5 m

Table 1: Acquisition parameters of the processed seismic lines.

3. SEISMIC DATA PROCESSING

3.1 INTRODUCTION

The processing techniques used for the elaboration of the seismic profiles are modern and some of them are based on complex mathematical models, which have allowed to carry out a good attenuation of the multiples (especially the multiples pertaining to the sea bottom) and to obtain good velocity analyses for the production of the stacked sections, on which the geological interpretation has been carried out. It should be mentioned that the increase of the number of processes in a flux of elaboration does not imply obtaining good results. In fact, it is known that at the base of a good success of a data elaboration a good acquisition of the recorded data must be performed. During a next step a particular process can show the event occurring in the data without adding seismic noise or further inexistent events.

Starting from the field data the procedures of seismic data processing are herein shown. Some sketched diagrams are reported, which can be applied to the phases of the whole processing. The used software for the seismic data processing are the Promax 2D (Landmark Ltd.) and the Seismic Unix (Colorado School of Mines).

The processing of the seismic lines has involved similar processes (Yilmaz, 1987). Perhaps, a single flux of elaboration has been constructed for all the seismic lines. Some advanced processes have been applied to a basic flux of elaboration in order to enhance the useful seismic signal occurring in the data.

The post-stack elaboration has involved the auto-vector filter, which has not further improved the stacked sections and consequently, the same filter has not been applied. The seismic data have been prepared in such a way to produce stacked sections, ready to be interpreted and eventually, migrated. Fig. 4 represents the whole flux of elaboration applied during the seismic data processing.

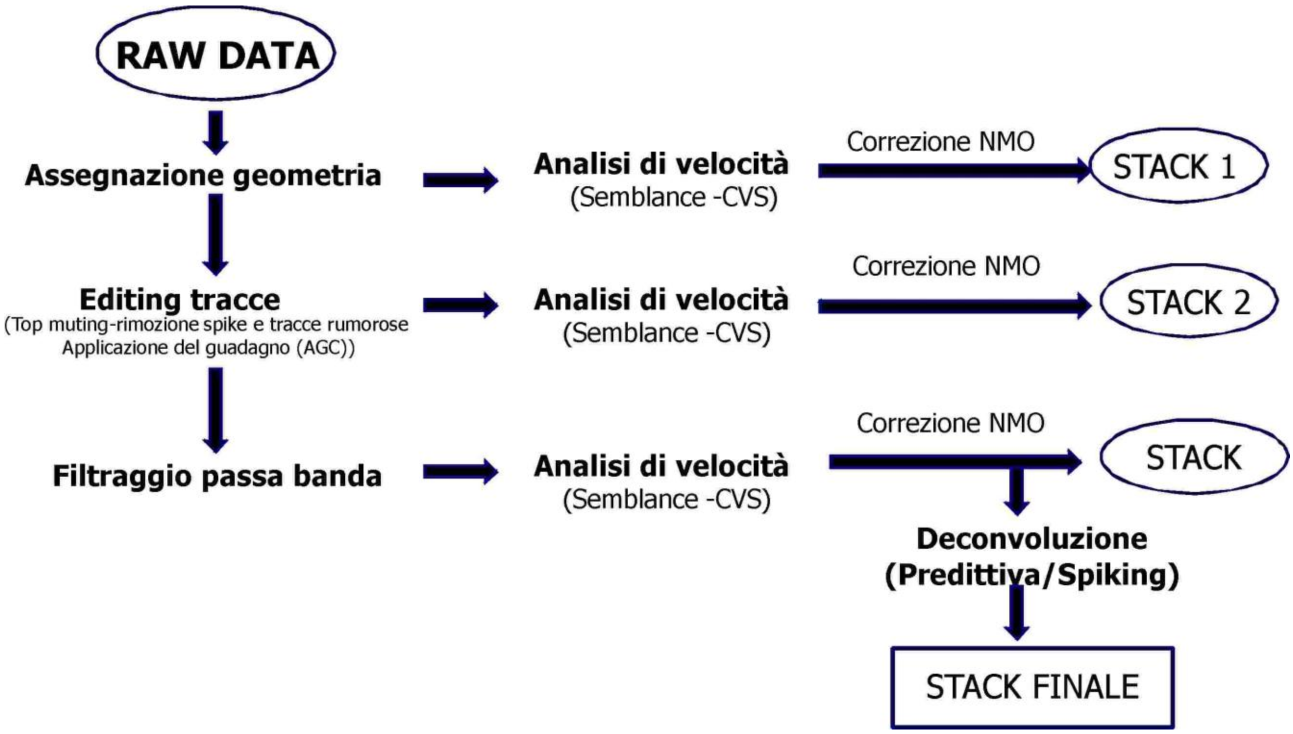

Fig. 4: Flux of elaboration of the multichannel seismic data of the Gulf of Naples.

3.2 SEISMIC PROCESSING

During the phase of pre-processing of the seismic traces the acquisition geometry has been assigned, using the acquisition parameters previously reported. During a next step all the seismic traces considered too noisy (trace kills) or which cannot be used have been eliminated from the seismic record.

The muting of the first arrivals is an operation through which all the seismic noise over the first arrivals and the undesired spikes occurring in the seismograms have been eliminated. In the case of the spikes, some areas of the seismograms on which the data extrapolation must be applied are given proximal to zero. This data extrapolation allows to have a continuity of amplitude in the seismograms and to avoid in that case possible mistakes, when the operations with the seismic traces are carried out.

The application of the gain is the compensation of the decay of the seismic signal due to the phenomena of absorption, scattering and decay of amplitude. It is necessary to restore a part of the lost seismic signal and to obtain similar levels of amplitude in all the seismic data.

The process which aims at this result is the Automatic Gain Control (AGC). This technique varies the gain of the traces as a function of the amplitude occurring in a time window, whose extension has been determined through a length operator defined during the processing phase.

The Automatic Gain Control shifts this time window downwards, sample by sample, by calculating a scaling factor for each position. This scaling factor may be equal to the reverse of the mean, of the statistical median and of the RMS of the amplitude of the signal enclosed in the window.

This scaling factor may be equal to the reverse of the mean, of the statistical median and of the RMS of the amplitude of the seismic signal included in the window. In the processed lines the chosen window for the application of the AGC was of 2000 msec. This value has been calculated after carrying out a set of tests on the seismic data.

3.2.1 SORTING

One of the fundamental steps which have brought the exploration seismics to be the reference methodology in the field of the geophysical methods having an industrial and scientific meaning, is the technique of acquisition of seismic data with a multiple coverage. This technique allows to obtain a redundancy of information for a same point surveyed at depth.

Accordingly with the simple laws of the reflection, the reflecting point is located on the vertical of the median point source-receiver. Using different scattered configurations it is possible to record a certain number of energizations, in such a way that the median point (representing the reflection point) is common to all the source-receiver configurations. In this way we obtain, with an adequate scattered configuration (with the technique of the increasing distances, for instance) a set of signals of seismic reflections, which are reflected by a single point at depths (**Common Depth Point** or CDP).

The method of the multichannel reflection seismics having a multiple coverage has been introduced as a routine in the acquisition surveys of the sixties (Mayne, 1962; 1967). Fig. 7 represents the acquisition geometry (on the left) and the geometry related to a CDP in coordinates (y, h) median point-offset (on the right). The transformation from a type of coordinates to another one has been identified in the procedure of sorting. Based on the model shown in Fig. 7 the coordinates in which the seismic processing is carried out, median point (medium) and offset (y, h) have been defined in terms of (s, g) as it follows:

$y = (g + s)/2$

$h = (g - s)/2$

The seismic traces may be ordered in groups having a various type and are the following:

- ***Common Shot Gather*** (field recording);
- ***Common Receiver Gather*** (groups of traces relative to the same channel of acquisition);

- ***Common Depth Point Gather*** (generally called CMP-gather);
- ***Common Offset Gather*** (re-ordering of the seismic traces based on the distance source-receiver);
- ***CMP Stacked Section*** (seismic section ready for the geologic interpretation).

3.2.2 VELOCITY ANALYSIS

Once that the seismic data have been ordered in CDP (*Common Depth Point*), on the same data the velocity analysis has been carried out aimed at producing the first stacked section. The same velocity analysis has been repeated after applying new processes of elaboration of the data, trying to understand if the same data produced or not improvements of the seismic signal.

The velocity analysis is a fundamental passage in order to apply the *Normal Move Out Correction*, which may be defined as it follows:

$$\Delta t_{NMO} = \sqrt{(t_0^2} + \sqrt{\frac{x^2}{v^2}} - t_0 \qquad \textbf{equation 21}$$

This correction is necessary in order to make horizontal the reflection hyperbola before carrying out the stacking of the seismic traces. Through the velocity analysis we obtain additional information on the velocity of the seismic reflectors occurring in the seismic section.

Different techniques exist in order to perform the velocity analysis. In the most part of the cases the Constant Velocity Stack (CVS) has been adopted (Fig. 7), which is compared with the semblance during a next step of elaboration. The CVS consists of the selection of a portion of data from a minimum of 5 CMP to a maximum of 25 CMP and of the generation of a set of stack panels.

By individuating on different panels, corrected for NMO and added, the zones which are better corrected, based on the indicative velocity of the panel, the function indicating the variation of the velocity with the depth has been reconstructed.

The examples of the velocity values obtained through this technique have been then revised by using the velocity spectra (semblance), in which a CMP gather is considered, so defining the semblance, representing the ratio between the energy in a given time interval Δt:

$S_t = \sum_{t=t}^{t+\Delta t}(\sum_1 x_{ti})^2$ **equation 22**

N$\sum_{t=t}^{t+\Delta t}\sum(x_{ti}^2$……………………………….. **equation 23**

where N is the number of traces, x_{ti} is the width of the single-channel I at the time t, $\sum_1 x_{ti}$ is the amplitude of the stack at the time t, while the square is the related energy. Consequently, so greater is the semblance, better will be the used stacking velocity.

3.3 NORMAL MOVE-OUT

When the velocity analysis has been completed, it is necessary to correct the reflection hyperbola. As a consequence, we should clarify geometrically the sense of the NMO correction. The simplest case is that one in which the seismic reflector is horizontal. In that case, if we report a Cartesian diagram x-t the times of arrival of the reflected wave for each receiver, we will obtain a hyperbola. The straight line OM is the graph of the times of arrival of the direct wave, whose runtime is S-R and is characterized by a velocity $t_d = x/V$.

In order to calculate the running way of the reflected diagram to reach the geophone R, it is necessary to project a point I below the reflector at a distance which is equal to the distance between S and the same reflector (h) and to join I with R. For the geometrical construction we will have that the space covered by the wave (SC+CR) is equal to that one obtained from our construction.

The constructed hyperbola with the times of arrival of the reflected is a consequence of the fact that the times for farthest geophones will be greater and the difference between the times of arrival of the waves at two different geophones is defined as the move-out Δt.

Then the move-out does not represent other that the delay accumulated from the wave front of the reflection in reaching the receivers, more and more farthest.

In the particular case of a receiver located at the source, we will have that:

$\Delta t_{NMO} = \sqrt{(t_0^2} + \sqrt{\frac{x^2}{v^2}} - t_0$……………………………………………. ……….**equation 24**

By examining this equation it is worth noting that the NMO increases with the offset x, which is the distance between the source and the receiver and is reversely proportional to the velocity. In practice, the curvature of the travel-time curve of the reflected waves rapidly increases by considering receivers more and more distant, but decreases with the increase of the time of recording.

The NMO correction is applied before carrying out the stack of the seismic traces in order to eliminate the curvature which prevents for correctly locating the seismic reflector. The correction is carried out by inserting a velocity value, calculated in the formula through the velocity analysis. If this value is exact, we will obtain that the traces will show a residual curvature (Fig. 8d). On the other side, if the inserted velocity is too low, the traces will show an opposed curvature (Fig. 8c).

3.5 STACKING

The stacked section generally represents the final product of the seismic data processing. It is composed of traces which represent the in-phase sum (stack) of the traces coming from the same CDP. The stacking allows for the increasing of the signal/noise ratio, by reducing the casual noise included in the data. During the stacking the coherent signal will increase, for the constructive interference, its amplitude of a factor equivalent to the data coverage, while the casual noise will add to other noise increasing a few its amplitude.

3.6 BANDPASS FILTERING

In many applications, as the analysis of the seismic signals and as a general rule, of the geophysical processes, given a seismic signal f (t) (we assume that t is a continuous variable) we are interested in its content of frequencies.

The Fourier continuous transform is defined as:

$$f(w) = \int_{+\infty}^{-\infty} f(t)\, e^{(-iwt)} dt \qquad \textbf{equation 25}$$

It furnishes a representation of the content of frequency of f (t).

Perhaps, a Fourier analysis is carried out in order to identify the contents of frequency (Bracewell, 1965) of the signal in the different seismograms and eventually to apply a bandpass filter, which allows to enhance the frequencies of interest.

The filtering consists of the modification of a temporal set through the application of another filtering temporal set, opportunely constructed. The application of a filter consists of the convolution of the filter itself with the seismogram. A generic bandpass filter has an answer in amplitude equal to the frequencies included between p and q; this interval is called band-passing. These values of frequencies are taken in correspondence to the points in which the amplitude A of the filter is of three decibel less than the bandpass filter.

The applied filter is obtained inserting of the values of frequencies which individuate the vertexes of a trapeze and a parameter which governs the slopes of the sides of the trapeze. This last parameter, expressed in decibel for octave is essential to know how much the frequencies have been reduced. These frequencies are outer to the bandpass, after the application of the filter. The choice of the filter has been done only after analyzing the content of frequencies of the data, in order to individuate the interval of frequencies in which the useful signal was concentrated. The chosen filter resulted to be quite conservative (0-20-50-70 Hz), allowing, in any case, to eliminate the high frequency noise occurring in the data. Fig. 9 reports a frequency spectrum before and after the bandpass filtering.

3.7 TECHNIQUES OF MULTIPLE REMOVAL

The reflection multiples verify when the signal is reflected more times from the inner discontinuities of the earth before arriving to the sensors. Since the amplitude of the signals is proportional to the coefficients of reflection of each seismic reflector, only the most marked contrasts of acoustic impedance generate seismic signals strong enough to be recognized as seismic events. Two classes of multiple reflections may be defined: short-period multiples and long-period multiples.

The reference event for this classification is the primary reflection. The effect of the short-term multiples translates in a deformation of the primary wave, since the two reflections are proximal one to each other and can be strongly individuated with precision without a direct analysis of the waveform of the source.

The long-period multiple can be individuated as a distinct event on the stacked sections. Many techniques of multiple suppression exist, whose knowledge is based on one of the listed characteristics of the multiple reflections:

- Moveout differences between primary and multiple reflections (discriminant of velocity).
- Differences of inclination between the primary events and the multiple ones in the CDP stacked sections;
- Differences of frequency content between the two types of signal;
- Periodicity of the multiple.

In the study case the procedure of attenuation of the multiples herein applied has been that one of the stacking and of the predictive deconvolution. It was possible to discriminate through the stacking the move-out between the primary reflections and the multiple reflections and to define a correct function of velocity of the primary reflections. In that case, the coherent noise under-corrected is attenuated during the sum not in-phase of the related events (Marr and Zagst, 1967).

The effectiveness of the stacking is improved with the increase of the coverage and of the maximum offset, increasing the number of traces to be added in the CMP-gather. The predictive deconvolution has been carried out on the seismic data aimed at eliminating or further reducing the multiple signal which has characterized the same sections, also if not always the same operation has produced significant improvements of the seismic data. In each case, the occurrence of multiples in the seismic signal has been useful during the phases of geological interpretation for a better definition of the main seismic reflectors and a comparison of the stratigraphic relationships between the same reflectors.

3.7.1 DECONVOLUTION

The deconvolution is a main step in the elaboration of the seismic signal, allowing to recover the high frequencies, to attenuate the multiples and to reconstruct the waveform. This process is an operation in the time domain, whose aim is to remove the effects of the convolution on the recorded data. The deconvolution simplifies the seismic wave of the source w (t) of the recorded traces in order to reconstruct the function of the earth's reflectivity e (t), with which the wave has been convoluted accordingly to the following equation:

$s(t) = e(t)*w(t)+n(t)$……………………………………………………**equation 26** and consequently, in order to increase the time resolution of the data. In practice, it consists of the convolution of the seismogram with a reverse filter (Wiener filter). The principle of the deconvolution is to remove the effects of a previous filter, the earth, which reduces the high frequencies. The main difficulty in order to carry out this operation consists of the reconstruction of the reverse filter, since the properties w (t) are unknown.

The deconvolution may be distinguished as:

- Spiking deconvolution, which aims at removing the effects of the wave of the source of the seismogram, controlling a widening and a flattening of the spectrum of the frequencies.
- Predictive deconvolution, which aims at predicting and eliminating the reverberations included in the seismic signal, as for instance the multiples.

The spiking deconvolution is theoretically defined starting from the convolution model, according with which the seismogram, if we exclude the noise n (t) will be given by the equation already listed as 26.

The earth's reflectivity e (t) may be calculated applying a Wiener filter f (t), which modifies the waveform by compressing it and approaching to the function of the Dirac delta:

$e(t) = f(t)*s(t)$ **equation 27**

where the function of the Dirac delta $\delta(t)$ may be defined as an impulsive function, which assumes the value of infinite for $t = 0$ and it is zero for each other point, which is:

$\delta(t) = \{\infty, t = 0; 0, t \neq 0$

From next calculations the filter f (t) may be calculated:

$f(t) = \delta(t) * 1/w(t)$……………………………………….**equation 28**

By resuming we have obtained, applying the filter to the seismogram, an impulsive function and the equation 28 establishes that the filter is the reverse of the seismogram.

To whom concerns the predictive deconvolution, if we consider our seismogram x (t), one aim of this deconvolution is to predict the value which has the function x (t) at the time $(t + \alpha)$ with α as a distance of prediction. The bases of the predictive deconvolution are the same of the spiking deconvolution. The main difference consists of the construction of the reverse filter and in particular, in the choice of the parameters.

The parameters to be known in order to construct the filter necessary to the deconvolution are the following:

- Window of application: the window of the datum on which the autocorrelation is applied.
- Distance of prediction or gap: a part of the wave which we will preserve. It represents the delay before the multiple reflection and before the reverberation to be eliminated.
- Operator length: it represents the length of the filter and is defined based on the number of reverberations which must be eliminated.

For all the three processed profiles both the types of deconvolution have been applied. Fig. 5 shows an example of application of the spiking deconvolution. It is worth noting (in the upper part of the figure) that the signal appears more spike (compressed) and consequently, it is more simple to define the different reflectors during the phase of the geologic interpretation.

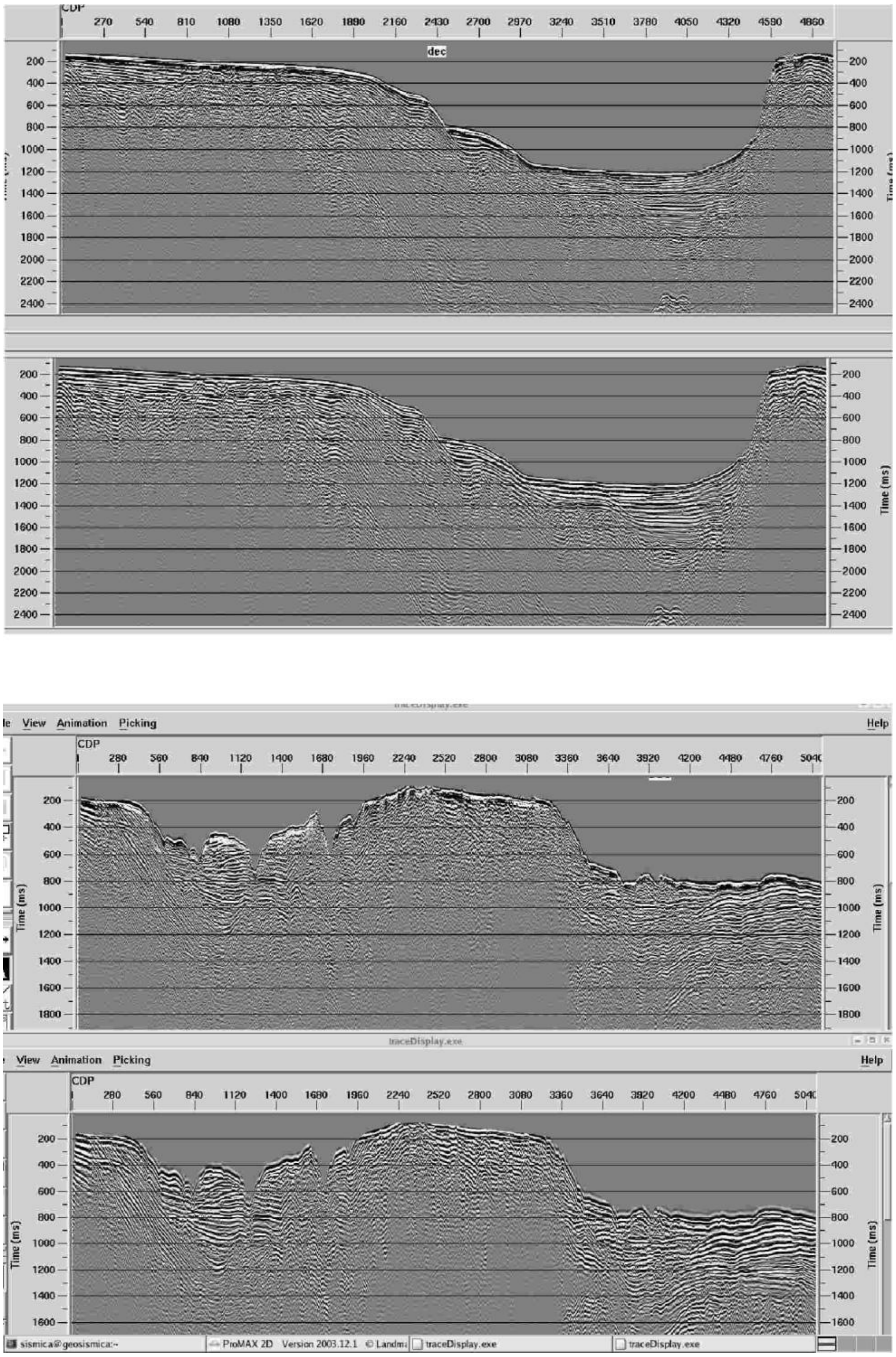

Fig. 5: Example of spiking deconvolution of the multichannel seismic data in the Gulf of Naples.

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