BOLLETTINO DI GEOFISICA TEORICA ED APPLICATA VOL. XXXVI, N. 141-144 - MARCH-DECEMBER 1994

R. BARTOLE [1], G. BRANCOLINI [2], C. DE CILLIA [2] and T. MAMMO [3]

REPROCESSING OF DIGITAL SEISMIC DATA BY MEANS OF THE FX-DECON METHOD: EXAMPLE FROM TYRRHENIAN SEA

Abstract. The most significant results from a reprocessing of old multichannel seismic data are presented and discussed. The reprocessing procedure was applied to the Apenninic tracts of the profiles MS-5, MS-6 and MS-7, digitally recorded in the Tyrrhenian Sea in 1969. The procedure has effectively attenuated both seismic noise and reverberations, and has also evidenced many seismic horizons originally masked by noise. The reprocessed sections, of which parts are illustrated, supply much more geologic information than the 1969 versions. As a consequence, this test clearly demonstrates that proper reutilization of old seismic surveys will be an important step for future exploration activities, not only in the planning but also for integrating new and old data.

INTRODUCTION

In 1969 the Osservatorio Geofisico Sperimentale (O.G.S.) of Trieste began the first digital seismic reflection survey in the Tyrrhenian Sea under the auspices of the C.N.R. (Consiglio Nazionale delle Ricerche). During that year, 2950 km of 1200% coverage seismic profiles were recorded and the regional survey of the Tyrrhenian Sea was completed by 1982, giving 6450 km of profiles, recorded both in 1200% and 2400% coverage (Fig. 1).

This data set constitutes a fundamental contribution to our geologic knowledge of the Tyrrhenian Sea, and has served as the basis for several works aimed both at a description and interpretation of the geophysical features, and at a formulation of geologic hypotheses and geodynamic models (e.g. Finetti et al. 1970; Carrozzo et al., 1974; Finetti and Morelli, 1974; Bartole, 1981; Catalano et al., 1985; Finetti and Del Ben, 1986; Malinverno and Ryan, 1986).

The data used for these interpretations was processed in three different places: first at the O.G.S. Digicon Inc. Processing Center at the University of Bari; then at the Computing Center of the University of Padova; and finally, from 1978, at the O.G.S. Processing Center in Trieste.

From 1969 onwards, digital seismic data processing has undergone continuous up-dating aimed at improving quality. As a consequence, the reflection seismic survey of the Tyrrhenian Sea is presently formed from a rather inhomogeneous data set. Seismic sections, in fact, suffer from problems which may be divided into two types: the first involves quality, since the data have been processed at different times with different processing sequences; the second regards the variable graphic representation, both in terms of vertical and/or horizontal scale, and of final display.

Almost 20 years later, since the scientific community interest in the Tyrrhenian basin had

---

Manuscript received December 30, 1992; accepted August 1, 1994.

[1] Istituto di Geologia e Paleontologia, Università, Trieste, Italy.

[2] Osservatorio Geofisico Sperimentale, Trieste, Italy.

[3] Adiss Abeba Universiy, Somalia.

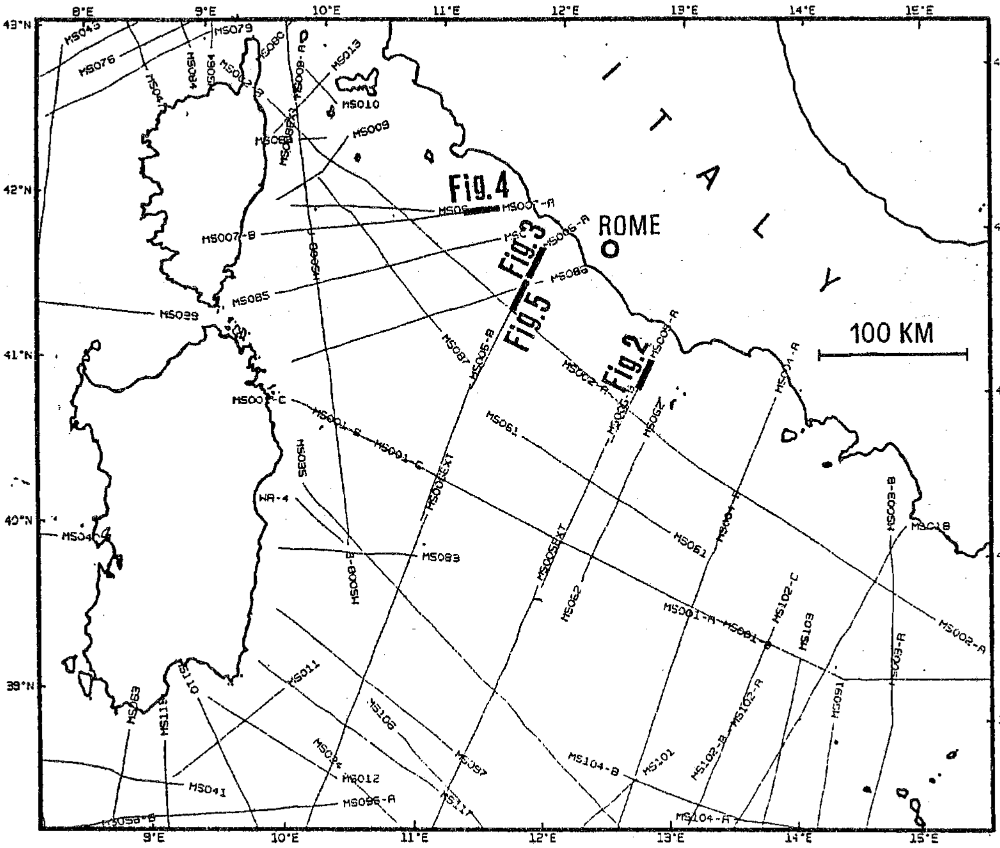

Fig. 1 - Position map of the O.G.S. seismic survey in the Tyrrhenian Sea. Thickened portions of the seismic lines along the Italian peninsular margin are illustrated in Figs. 2-5.

constantly increased, the possibility of using new and more effective processing techniques to extract further geologic information from seismic profiles, was seriously considered. Improving the quality of the oldest seismic lines, or generally speaking of those which originally were not characterized by an optimum signal-to-noise ratio, thus became the object of reprocessing.

The first approach to reprocessing the Tyrrhenian Sea seismic data was addressed to the Italian continental margin. Here, modern structural and seismo-stratigraphic knowledge (Bartole, 1984; Zitellini et al., 1984; Marani and Zitellini, 1986; Marani et al, 1986; Bartole, 1990; Bartole et al, 1991) allows a better appreciation and estimate of the new geologic information coming from the seismic reprocessing. Three initial segments of profiles MS-5, MS-6 and MS-7 (each approximately 35 km long) lying on the northeastern Tyrrhenian slope across the post-tectonic peri-Tyrrhenian basins (Fig. 1) were chosen for this first test. The reprocessing sequence, whose steps will be described in the next paragraph, made use of the FX-Decon method, which is a filtering process often applied to high-noise data. This gave a visible improvement in data quality, as may be seen in Figs. 2 through 5.

THE 1969 SEISMIC DATA ACQUISITION AND PROCESSING

- Aquisition

The seismic survey performed in 1969 by the M/V Ruth Ann of C.N.R. made use of the following aquisition parameters:

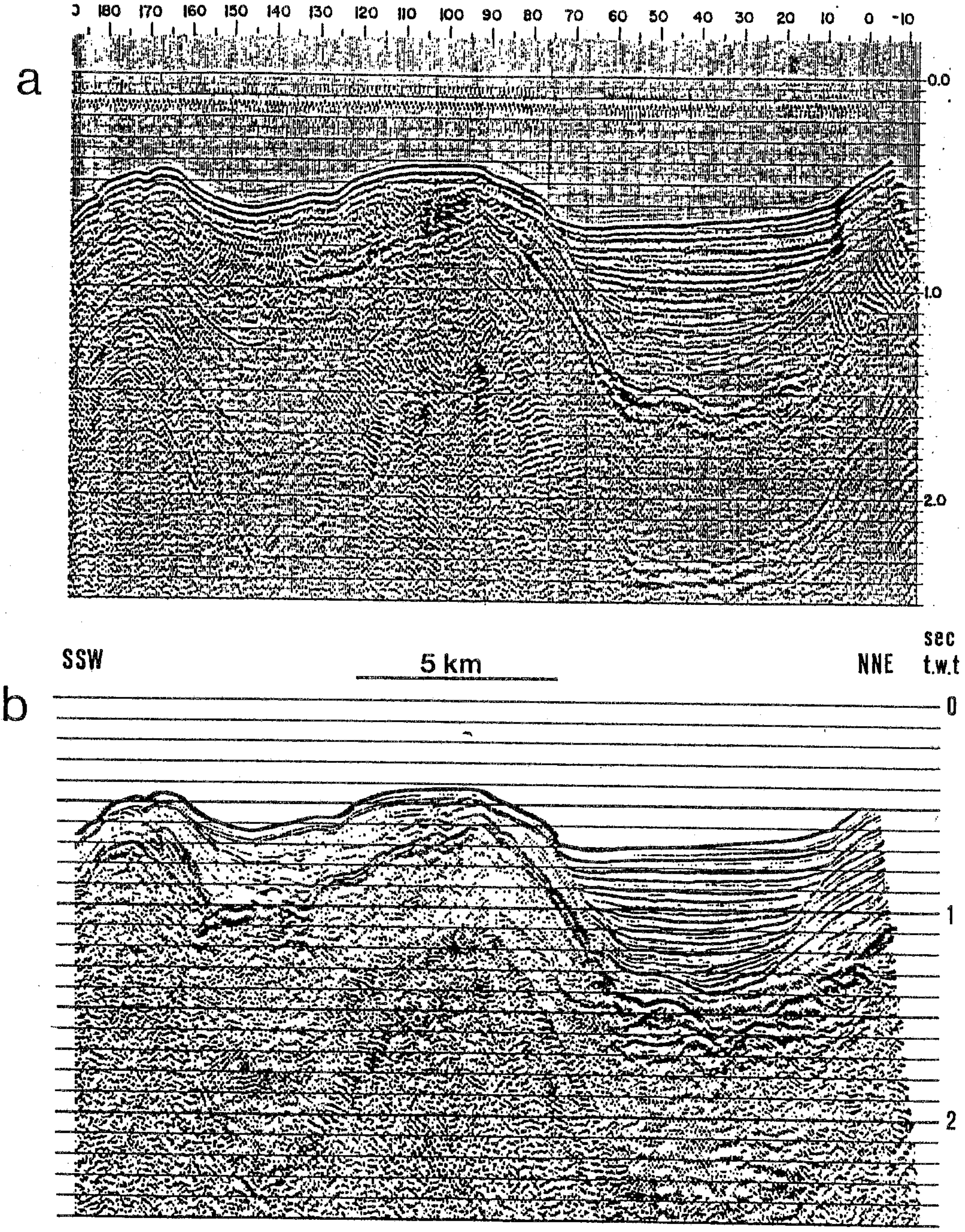

Fig. 2 - Section MS-5 between s.p. -10 and 180; (a): 1969 STACK-TVF version, (b): FX-decon version. Comments about reprocessing improvements are also reported in Fig. 6.

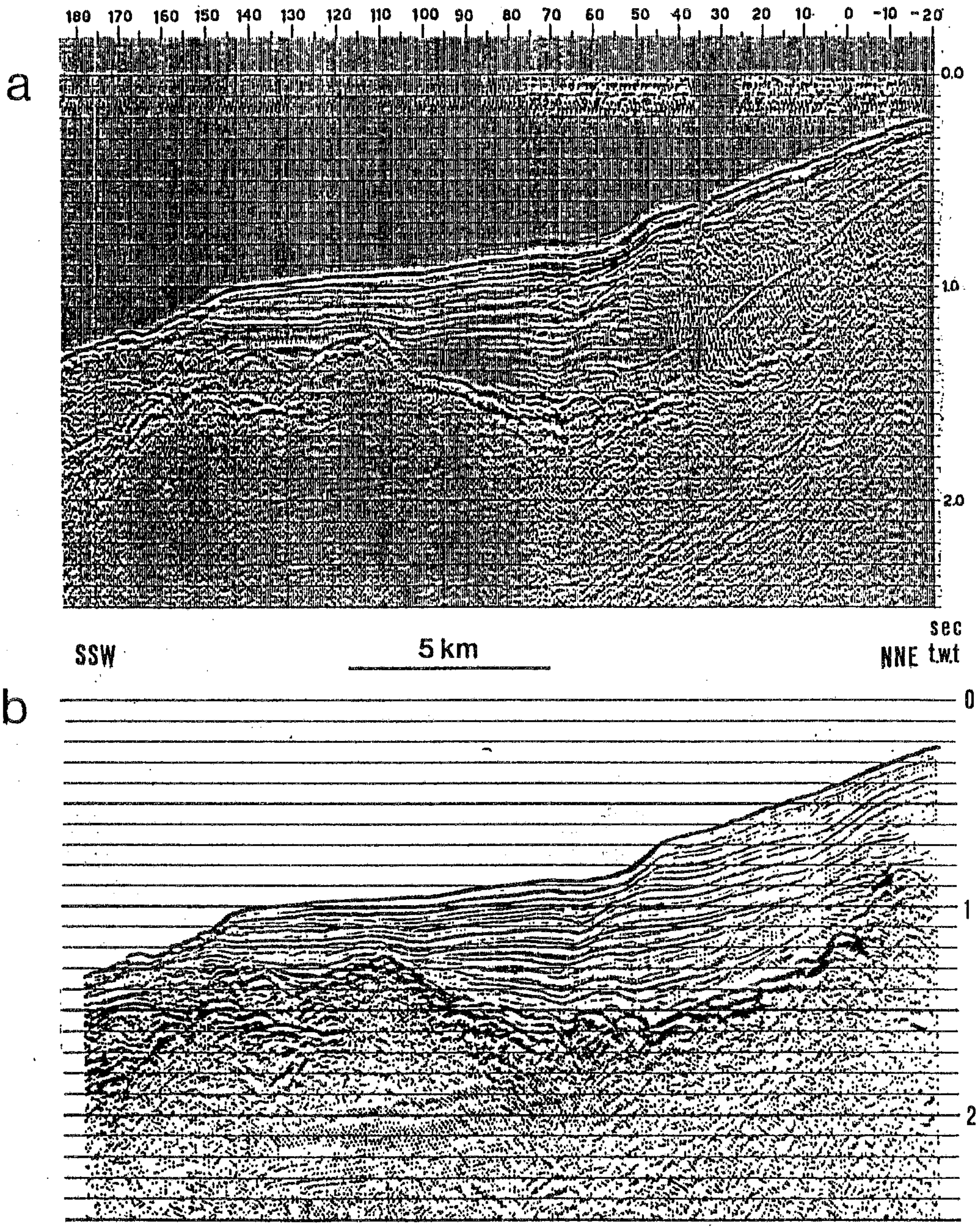

Fig. 3 - Section MS-6 between s.p. -20 and 180; (a): 1969 STACK-TVF version, (b): FX-decon version.

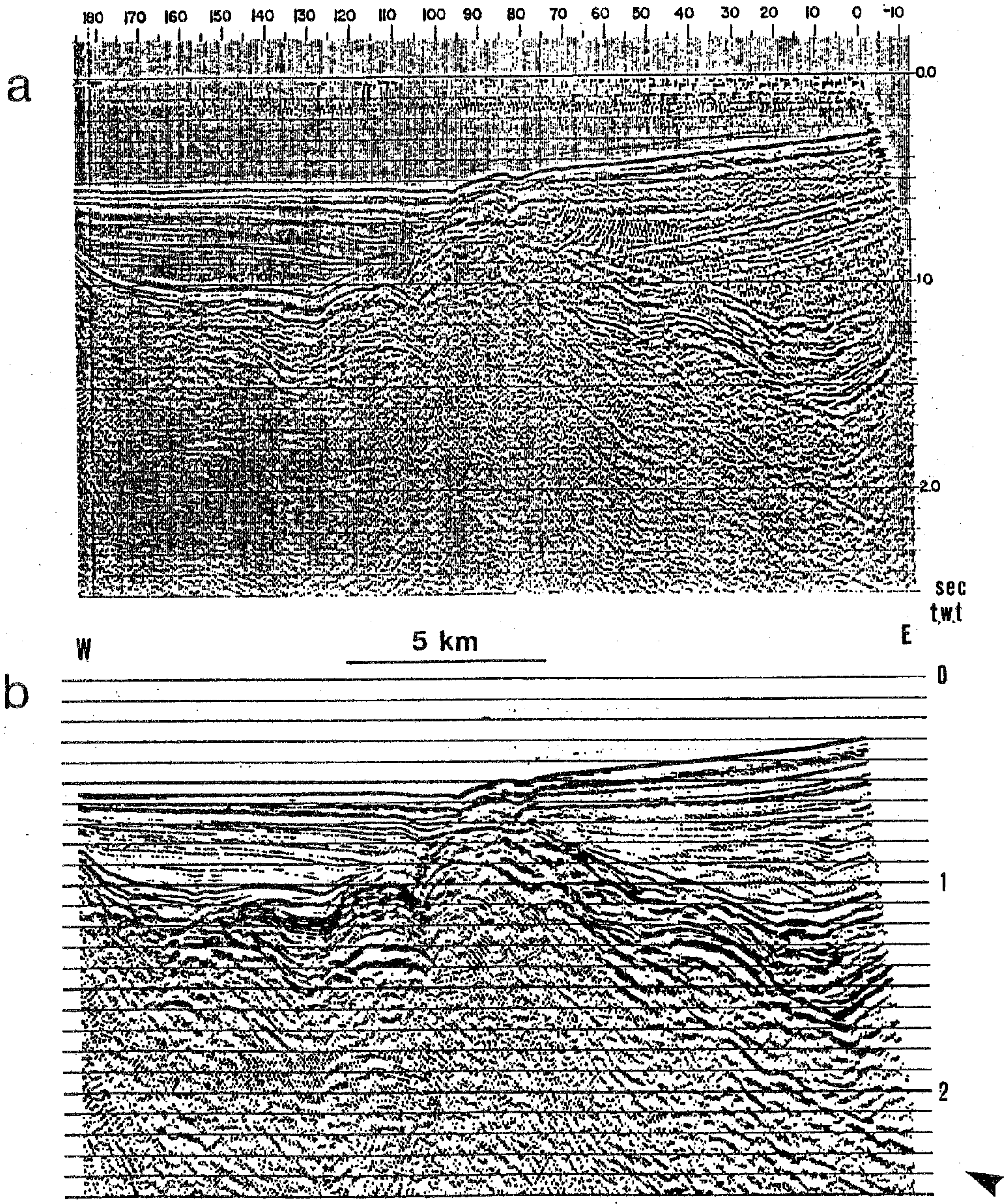

Fig. 4 - Section MS-7 between s.p. -10 and 180; (a): 1969 STACK-TVF version, (b): FX-decon version.

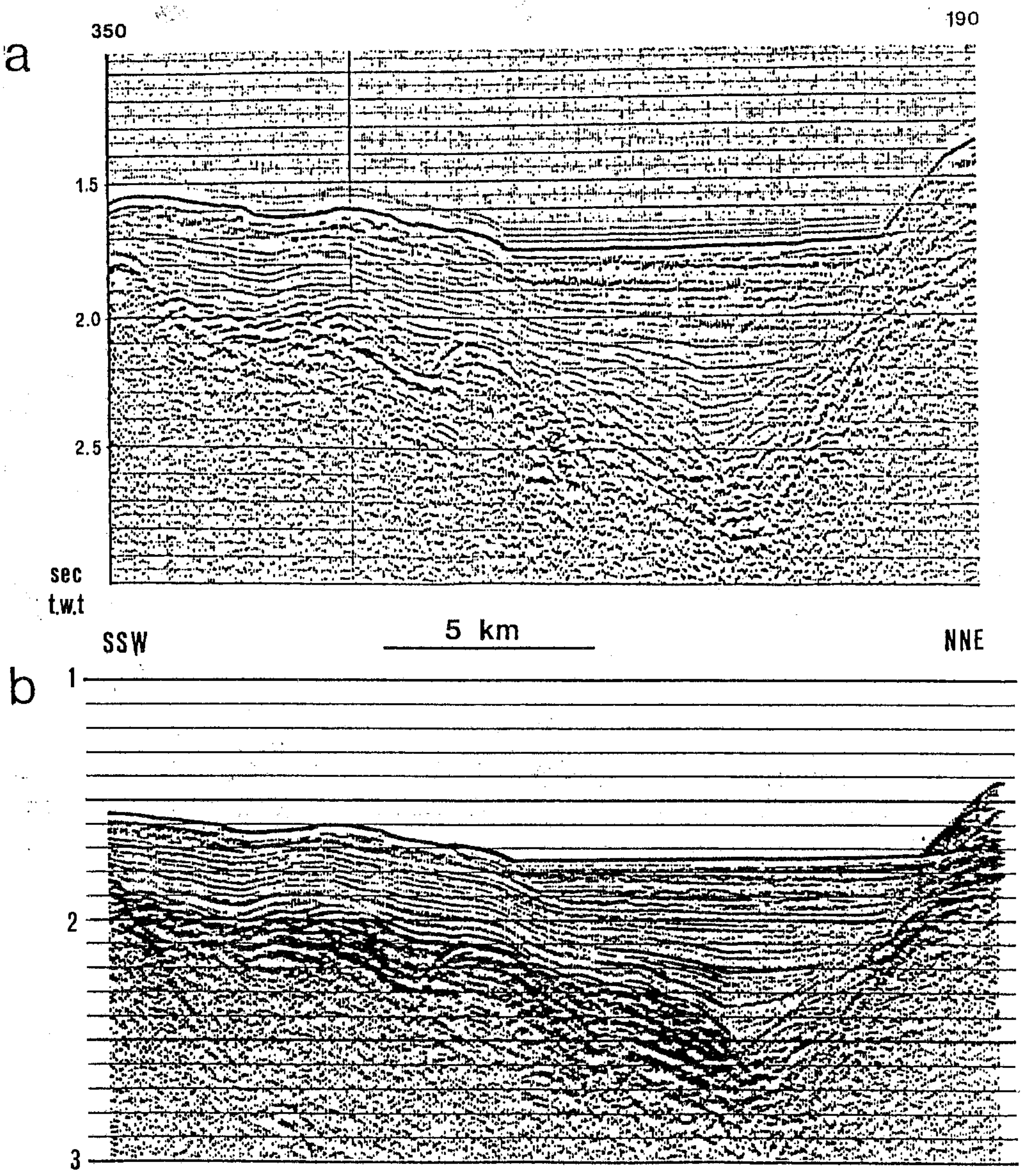

Fig. 5 - Section MS-6 between s.p. 190 and 350: (a) 1969 STACK-TVF version; (b): present-day STACK-TVF version.

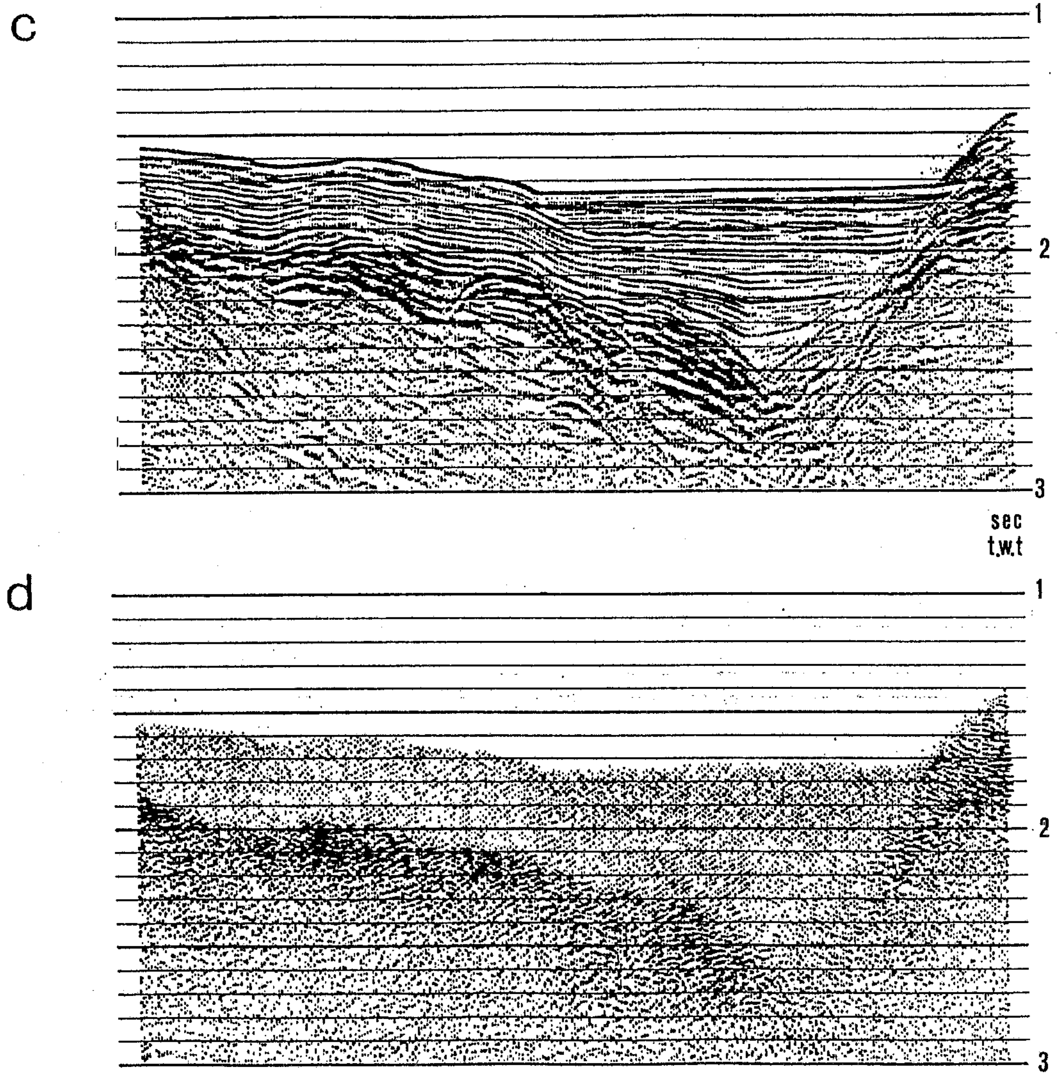

Fig. 5 continued - Section MS-6 between s.p. 190 and 350: (c) FX-decon version; (d) random noise.

source	Flexotir (3x50 gr per shot)
streamer length	2400 m
group interval	100 m
shot interval	100 m
offset	320 m
sample rate	4 ms
data length	10 s
coverage	1200 %
high-cut filter	70 Hz

Data were digitally recorded on a TI/10000 system. In addition, owing to the narrow dynamic range of the 16-bit fixed-point system, an automatic gain control (A.G.C.) was applied during acquisition.

- Processing

In 1969 the data were processed at the O.G.S. - Digicon Inc. Processing Center at the University of Bari. The flow chart of Fig. 6 shows the processing sequence. It should be noted that in the late sixties processing techniques were very primitive in comparison with today's. As a consequence the final sections plotted in 1970 were generally very noisy and full of reverberations.

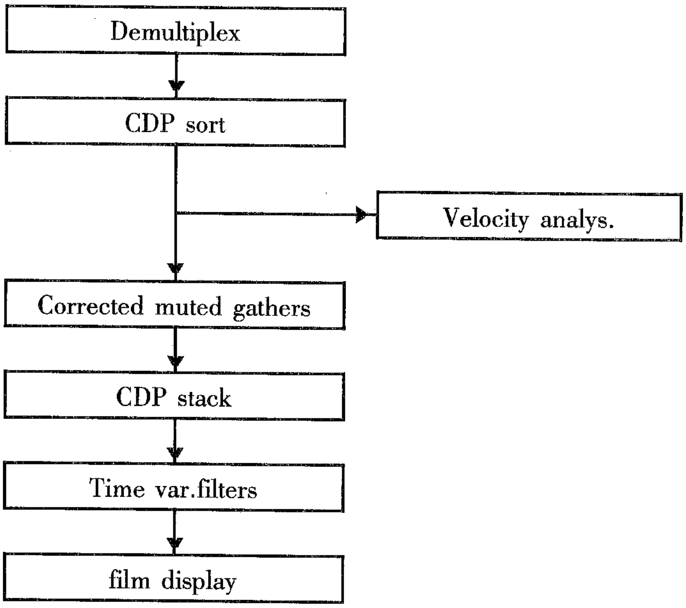

Fig. 6 - 1969 processing flow chart of the Tyrrhenian Sea reflection seismic data.

THE PRESENT DAY PROCESSING TECHNIQUE

Fig. 7 illustrates the present-day processing sequence, in which special care has been given to finding the most efficient procedures for noise and reverberation removal.

In order to illustrate the improvement in data quality after reprocessing, some selected parts of the three lines, both in the original and present-day versions, have been shown in Figs. 2 to 5. The improvement is fundamentally due to the application of more accurate velocity analysis, and of FX - deconvolution (FX-Decon) after stack in the frequency-space domain. The FX-Decon procedure is here discussed for line MS-6.

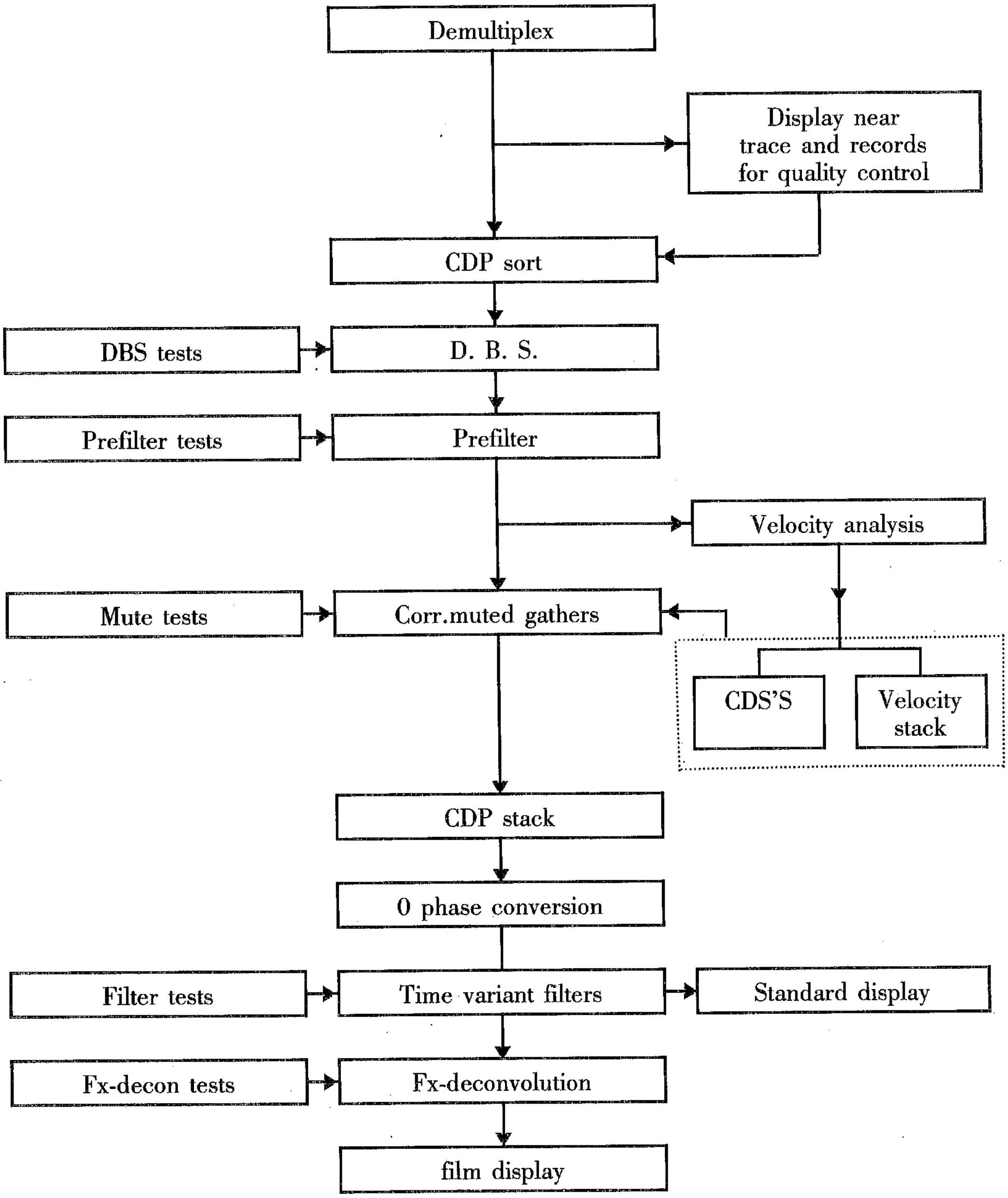

Fig. 7 - Reprocessing flow-chart of the seismic data. The sequence was applied on parts of Lines MS-5, MS-6 and MS-7.

Figs. 5a and 5b show respectively the 1969 and present-day T.V.F. versions of part of Line MS-6. There is still a high level of noise due to scattering of the signal on discontinuous horizons. Furthermore, the impossibility of removing the A.G.C. during demultiplexing means that a high noise level persists in the T.V.F. version: The A.G.C., since it was applied over short time-windows, gives the same mean output level both when signal prevails over noise or viceversa. Moreover the application of the T.V.F. proved unsuccessful in noise attenuation because of the overlapping of noise and signal frequency bands. It was thus decided, to use predictive deconvolution in the FX-domain, which is one of the most efficient procedures for random noise attenuation amongst those nowadays available in seismic processing.

FX-Decon

This is a spatially predictive deconvolution, as opposed to the usual time-domain predictive deconvolution widely used in seismic data processing. The technique is based on identification of spatial coherency, or predictability, in a data set of stacked traces (Canales, 1984). The data are deconvolved, frequency by frequency, to produce two output data sets:

- the predictable part (signal + organized noise (as shown in Fig. 5c)) and

- the unpredictable part (random noise) as in Fig. 5d. Mathematically, the input data D_i is the sum of the signal S_i and noise N_i :

$$D_i=S_i+N_i \, , \tag{1}$$

where i=1, 2,..., n samples.

The FX-Decon operates under the assumption that the seismic noise is:

a) spatially consistent, and

b) locally predictable.

It is important to note here that the FX-Decon does not distinguish between signal and coherent noise, since this also fulfils the above two requirements. FX-Decon is therefore only able to separate the unpredictable part (random noise) from the predictable part (signal + coherent noise).

We recall that seismic signals generally show a good spatial coherency, a property which is mathematically expressed by the predictability. On the contrary, random noise, since it is not spatially coherent, will not be predictable.

To implement the frequency-space deconvolution, the stacked data in the x-t (space-time) domain of each CDP are first transformed into the f-x (frequency-space) domain by means of the FFT (Fast Fourier Transform). At a given frequency f_i , the complex values belonging to different traces make up the f-x domain response in the x direction. This response is then fed into a one-step-ahead complex Wiener prediction filter (Treitel, 1974):

$$d_1, d_2 , ..., d_n \rightarrow F \rightarrow d_2 , ..., d_3 , ..., d_n+1.$$

This one-sample long complex filter predicts the value at the next sample point. The predictability can be illustrated by applying the prediction error operator

$(1, -f_1, -f_2,..., f_n)$ to the input data $(d_1, d_2, ..., d_n)$:

$(1, -f_1, -f_2, ..., f_n)*(d_1, d_2, ..., d_n)=(d_1, 0, 0, ...,0)$; or in terms of the Z-Transform:

$$[\, 1-Z \cdot F \,(z)] \cdot D\,(z)=D_1. \tag{2}$$

The prediction error operator has thus reduced the input to its first sample. The prediction filter F (z) can be obtained from eqn. (2):

$$F\,(z) \cdot D\,(z)=Z^{-1}\,[D\,(z)-D_1].$$

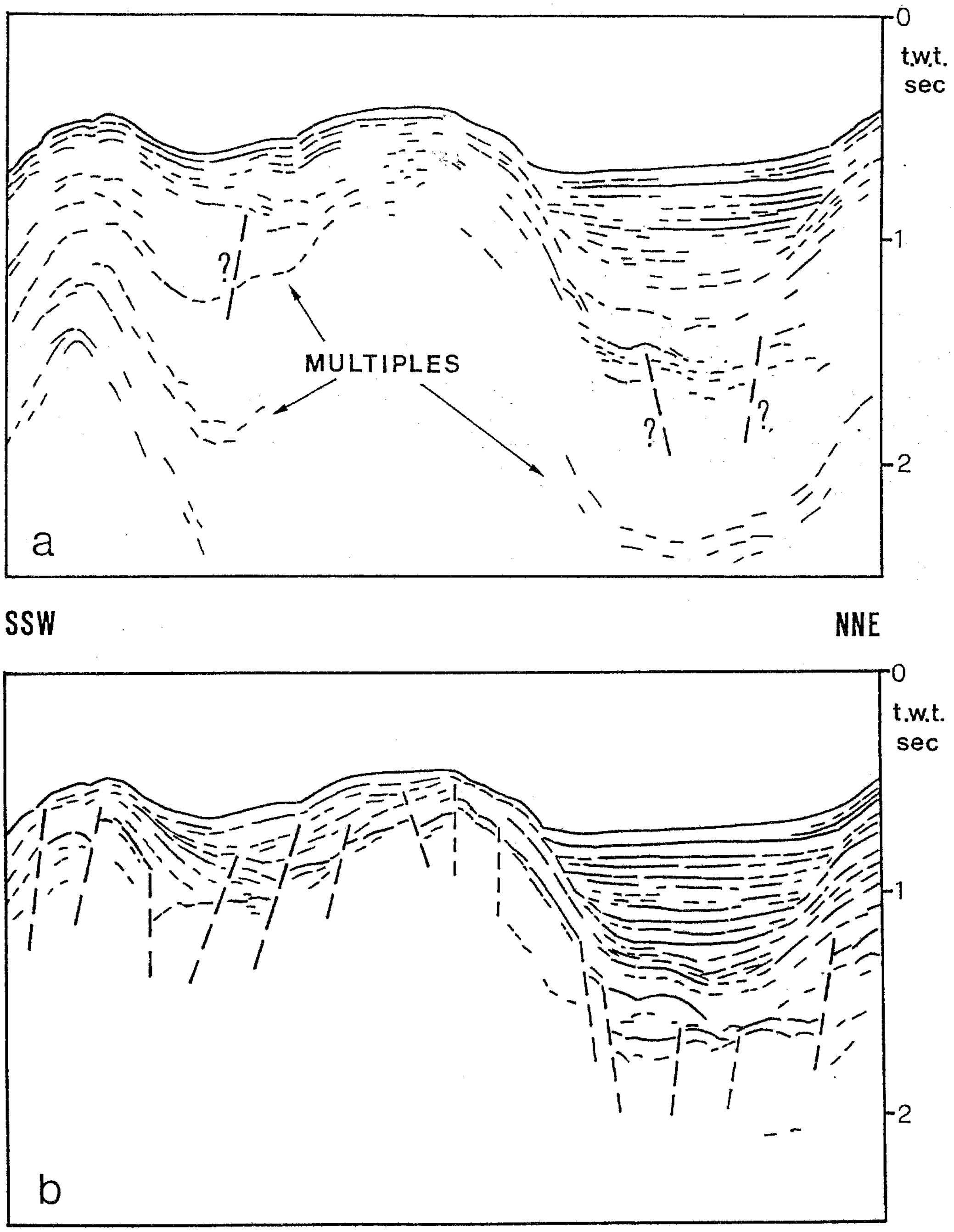

Fig. 8 - Line drawing and fault interpretation of Fig. 2: a) interpretation of the 1969 original section; b) interpretation of the reprocessed FX-decon version. Notice the remarkable difference in the stratigraphic resolution within the basin (right) and over the structural highs (left). The absence of multiples in the reprocessed version (b) and the good resolution of the basement reflectors permits a more reliable positioning of faults compared to the original line (a).

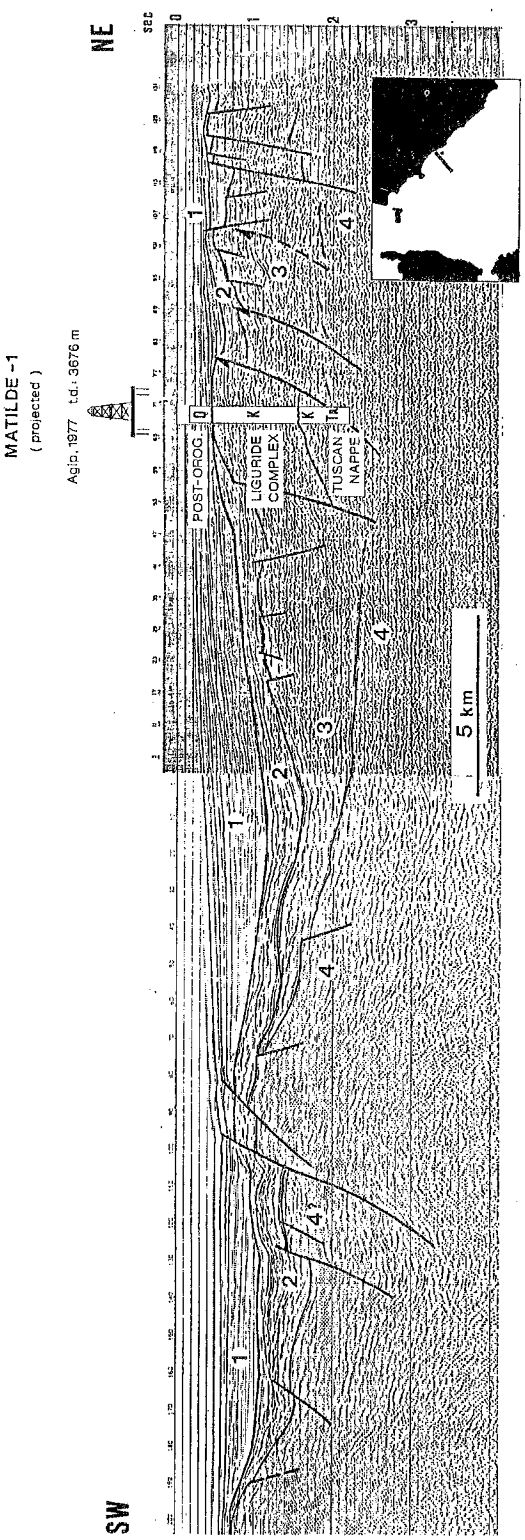

Fig. 9 - Compound seismic section across the Latium continental margin, obtained adding the reprocessed version of line MS-7 (see Fig. 4) to the line L-142 (right). The figure highlights the western limit and the base of a large body of the allochthonous unit (3) pierced at the well drilled on the shelf. Symbols: (1) - Plio-Quaternary sediments; (2) - Messinian to lower Pliocene sediments; (3) - Liguride unit; (4) - units of the Tuscan nappe.

Hence F (z) produces a one-sample advanced version of the input. The prediction filter F (z) can exactly predict both the amplitude and phase of the signal in absence of noise. In the presence of noise, however, only the spatially coherent part is predicted. Subsequent subtraction of the predicted part (Fig. 5c) from the input data (Fig. 5b) gives the unpredictable part, which is the random noise component (Fig. 5d).

By analyzing the random noise component (Fig. 5d) we can check whether the separation of the unpredicted (random noise) part from the predicted one (Fig. 5c) has been correct or not. In fact, only if the "noise" section (Fig. 5d) does not show any similitarity to the input section (Fig. 5b), or in other words, if the "noise" section has no significant alignments along the main primary reflectors, can the results of the FX- Deconvolution (Fig. 5c) be accepted. Should any similitarity be observed, the FX-deconvolution must be repeated modifying parameters such as the operator, or the length of the time-windows.

INTERPRETATION IMPROVEMENT

The selected profiles are illustrated in Figs. 2 to 5 in both their original and reprocessed versions. The profiles show some peri-Tyrrhenian post-orogenic basins, formed in a number of tectonic depressions along the inner (Tyrrhenian) side of the Apennine chain after the Oligo-Miocene collision between the Corsica-Sardinia block and the Adriatic microplate (Boccaletti et al., 1980). The basins are infilled by a sedimentary sequence of uppermost Miocene to Pleistocene age, which has been involved in extension tectonics characterized by normal faults, gentle folds and flexures. This sequence lies over pre-Tortonian Apennine units strongly deformed by compression and nappe tectonics. A high-amplitude seismic signal, composed of a few cycles often broken by normal faults, marks the limit between the post-orogenic strongly-reflective sequence and the underlying poorly-reflective Apennine units which represent the acoustic basement in the area.

Improvements in data quality giving a better resolution of the seismic horizons may be noticed along the entire seismic section: both at the shallow levels that represent the undeformed sedimentary infilling of the basins, and at deeper levels, such as near the base of the basins, or down at those levels pertaining to the strongly deformed Apennine units.

A careful comparison of the old and modern versions of the examples shown in Figs. 2 to 5 shows the improvements obtained by the FX-Decon program, expecially to the right of the sections (i.e., their eastern edges) where the original sections of 1969 are dominated by noise.

Seismic horizons defining the base of the basins are also better evidenced, since they are improved with respect to the 1969 versions in terms of continuity and of their geometric relationships. Good examples of the improvement are also shown in the structural highs, where the reprocessing sequence clarified the acoustic basement and the attitude of the recent sediments (see for instance Fig. 2 left side; Fig. 4 centre; and Fig. 5c left side).

To visually summarize the improvements brought about by the FX- Decon method, a comparison is shown in Fig. 8 between a line-drawing of an original profile and that of its reprocessed version. The two interpretations illustrate how the much better definition gained in the sedimentary cover and at the top of the acoustic basement improves detail in the structural pattern of the features.

Finally, Fig. 9 provides a clear example of the usefulness of seismic reprocessing for improving geologic knowledge of an area. The figure is a combination of the reprocessed version of Line MS-7, shown in Fig. 4, and Line L-142 shot on the continental shelf for hydrocarbon prospecting. Reprocessing of MS-7 in Fig. 4b have shown the existence of a deep east-dipping horizon (marked by the arrow) which was not appearent in the original version (Fig. 4a). This enabled us to define the thickness and western limits of a wide nappe in the Liguride complex which had been detected by a well drilled on the shelf.

CONCLUSIONS

Two main steps in the above described reprocessing sequence are at the basis of the quality improvement of the 1969 Tyrrhenian Sea seismic data tested in the present work:

a - more efficient velocity analysis procedures than those available in 1969;

b - FX-deconvolution used for random noise attenuation.

The reprocessing has demonstrated how old seismic records may still furnish stratigraphic and structural information whose quality does not differ much from that of modern data acquisition. Thus, re-utilization of old digital multichannel surveys should become an important step in future research activities.

Acknowledgments. This work has been supported with CNR research funds 85.00929.05, 86.00660.05 and 87.00848.05. The authors are indebted to A. Vesnaver (O.G.S.), A. Carlini (AGIP) and three anonymous referees for their constructive criticism.

REFERENCES

Bartole R.; 1981: *Seismic evidence of an earlier Pliocene erosional surface in the deep part of the Tyrrhenian Sea.* In: Wezel F.C. (ed), Sedimentary basins of Medierranean margins, Tecnoprint, Bologna, pp. 127-145.

Bartole R.; 1984: *Tectonic structure of the Latian-Campanian shelf (Tyrrhenian Sea).* Boll. Ocean. Teor. Appl., **2**, 197-230.

Bartole R.; 1990: *Caratteri sismostratigrafici, strutturali e paleogeografici della piattaforma continentale tosco-laziale; suoi rapporti con l'Appennino settentrionale.* Boll. Soc. Geol. It., **109**, 599-622.

Bartole R., Torelli L., Mattei G., Peis D. e Brancolini G.; 1991: *Assetto stratigrafico-strutturale del Tirreno Settentrionale: stato dell'arte.* Studi Geologici Camerti, Vol. Spec. 1991/91, 115-140.

Boccaletti M., Coli M., Decandia F.A., Giannini E. e Lazzarotto A.; 1980: *Evoluzione dell'Appennino settentrionale secondo un nuovo modello strutturale.* Mem. Soc. Geol. It., **21**, 359-373.

Canales L.; 1984: *Random noise reduction.* Expanded abstracts. p. 525, 54th SEG Annual International Meeting, Atlanta.

Carrozzo M.T., Giorgetti F. and Nicolich R.; 1974: *An example of comparative analysis of geophysical data.* Boll. Geof. Teor. Appl., **16**, 100-124.

Catalano R., D'Argenio N., Montanari L., Morlotti E. and Torelli L.; 1985: *Marine geology of the NW Sicily offshore (Sardinia Channel) and its relationships with mainland structures.* Boll. Soc. Geol. It., **27**, 207-215.

Finetti I., Morelli C. and Zarudzki E.; 1970: *Reflection seismic study of the Tyrrhenian Sea.* Boll. Geof. Teor. Appl., **12**: 311-346.

Finetti I. e Morelli C.; 1974: *Esplorazione geofisica dell'area mediterranea circostante il Blocco Sardo-Corso.* In: Paleogeografia del Terziario sardo nell'ambito del Mediterraneo occidentale, Suppl. ai Rend. del Sem. della Fac. Sci. Univ. Cagliari, pp. 213-236.

Finetti I. and Del Ben A.; 1986: *Geophysical study of the Tyrrhenian opening.* Boll. Geof. Teor. Appl., **28**, 110: 75-155.

Malinverno A. and Ryan W.B.F.; 1986: *Extension in the Tyrrhenian Sea and shortening in the Apennines as results of Arc migration driven by sinking of the litosphere.* Tectonics, **5**, 227-245.

Marani M. and Zitellini N.; 1986: *Rift structures and wrench tectonics along the continental slope between Civitavecchia and C. Circeo.* Mem. Soc. Geol. It., **35**, 453-457.

Marani M., Taviani M., Trincardi F., Argnani A., Borsetti A.M. and Zitellini N.; 1986: *Pleistocene progradation and post-glacial events of the NE Tyrrhenian continental shelf between the Tiber River delta and Capo Circeo.* Mem. Soc. Geol. It., **36**, 67-89.

Treitel S.; 1974: *The Complex Wiener Filter.* Geophysics, **39**, 169-173.

Zitellini N., Marani M. and Borsetti A.M.; 1984: *Post-orogenic tectonic evolution of Palmarola and Ventotene basins (Pontine Archipelago).* Mem. Soc. Geol. It., **27**, 121-131.