Rend. Fis. Acc. Lincei
s. 9, v. 11:41-58 (2000)

Geologia. — *Quaternary structural evolution of Terracina and Gaeta basins* (*Eastern Tyrrhenian margin, Italy*). Nota di Gemma Aiello, Ennio Marsella e Marco Sacchi, presentata (*) dal Socio B. D'Argenio.

Abstract. — In the Terracina and Gaeta basins Quaternary sediments are displaced by normal faults, which affect also the Meso-Cenozoic tectonic units of the acoustic basement. The extensional tectonics is characterized by normal faults systems trending NE-SW and E-W. In the Terracina basin, roughly N-S oriented, half-graben structures are downthrown seaward through normal faults; the Gaeta extensional basin, E-W oriented, has two main depocenters and is bounded to the north and to the south by E-W trending normal faults and to the east by a NW-SE trending normal fault.

Key words: Extensional tectonics; Seismic stratigraphy; Terracina and Gaeta basins; Eastern Tyrrhenian margin.

Riassunto. — *Evoluzione tettonica quaternaria dei bacini di Terracina e di Gaeta* (*margine tirrenico orientale, Italia*). I bacini di Terracina e Gaeta mostrano un significativo controllo tettonico sulla sedimentazione quaternaria, causato dalla presenza di faglie normali: esse dislocano le unità tettoniche meso-cenozoiche che rappresentano il basamento acustico. Sistemi di faglie normali ad andamento NE-SW e E-W determinano nel bacino di Terracina una struttura di tipo semi-graben orientata N-S e ribassata verso mare da faglie dirette. Il bacino di Gaeta rappresenta un bacino estensionale ad andamento E-W, articolato in due principali depocentri e delimitato verso nord e verso sud da faglie normali ad andamento E-W e verso est da una faglia diretta ad andamento NW-SE.

Introduction

The Tyrrhenian sea, a young extensional domain with restricted areas of oceanic-type crust, encloses in its margins a number of basins («peri-tyrrhenian»; Fabbri *et al.*, 1981; Malinverno and Ryan, 1986; Trincardi and Zitellini, 1987; Oldow *et al.*, 1993) that show marked differences in size, thickness and internal architecture of the filling sequence.

The Terracina and Gaeta basins (fig. 1), located within the Eastern Tyrrhenian offshore of Latium offer good opportunities to investigate the relationships between tectonics and sedimentation in a marine area strongly deformed during Neogene times. The present study is mostly based on the interpretation of about 1000 km of multichannel seismic profiles (fig. 1) provided by the Italian Ministry of Industry («Zone E»), recorded by the Western Geophysical for the AGIP Oil Company, tied to the lithostratigraphic data of deep offshore wells (Michela 1 and Mara 1, Agip; fig. 1) and onshore boreholes (Ippolito *et al.*, 1973; Agip, 1977; Ortolani and Torre, 1981; fig. 1).

The Terracina and the Gaeta basins, covering an offshore area of about 750 km^2, extend in the continental shelf of the southern Latium region, since they are located in

(*) Nella seduta del 14 gennaio 2000.

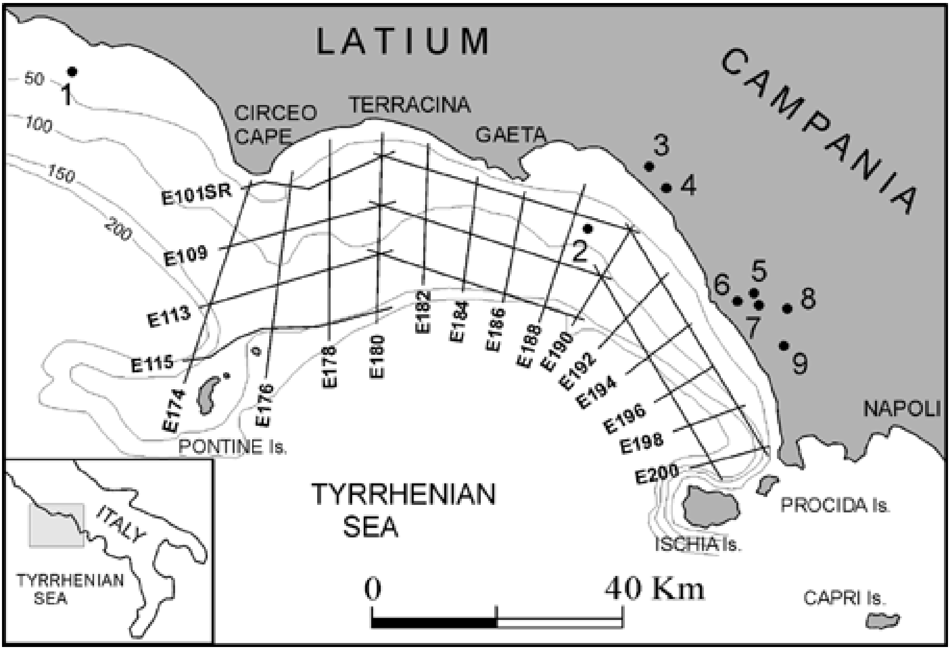

Fig. 1. – Sketch map showing the study area and the location of seismic profiles and exploratory wells analyzed in this paper. Offshore wells 1: Michela 1 well; 2: Mara 1 well. Onshore wells 3: Cellole Aurunci 1 well; Mondragone 1 well; 5: Castelvolturno 3 well; 6: Castelvolturno 1 well; 7: Castelvolturno 2 well; 8: Grazzanise 1 well; 9: Villa Literno 1 well.

waters down to the - 150 m isobath. The shelf break is at a water depth of about - 200 m and the continental slope is characterized by the occurrence of two important slope basins in the Pontine Archipelago (Palmarola and the Ventotene basins; Zitellini *et al.*, 1984).

Off the Latium and Campania coasts the peri-tyrrhenian basins often form the seaward prolongation of the coastal plains producted by Plio-Quaternary extensional tectonics (Mariani and Prato, 1988; Brancaccio *et al.*, 1991). The tectono-sedimentary evolution of Terracina and Gaeta basins is connected with the Neogene evolution of the Apenninic chain (Royden *et al.*, 1987; Patacca and Scandone, 1989). As suggested also by previous studies (Bartole, 1984; Argnani and Trincardi, 1990; Agate *et al.*, 1993; Sacchi *et al.*, 1994), the deformational history of the peri-tyrrhenian basins is characterized by alternating compressional and extensional tectonic phases during Plio-Quaternary times. In order to clarify the role of the different tectonic regimes in the Terracina and Gaeta basin evolution, it is necessary to discriminate between the eustatic and tectonic controls in the stratigraphic architecture of these basins.

According to the literature, the Tyrrhenian sea may be considered as an extensional back-arc basin associated with subduction of lithosphere of the African plate beneath the European plate during the Neogene and Quaternary (Boccaletti and Guazzone, 1974; Maliverno and Ryan, 1986; Royden *et al.*, 1987; Kastens *et al.*, 1986, 1988; Doglioni, 1990). Extension within the Tyrrhenian basin was accompained by the development of complex phases of contraction, strike-slip faulting and extension, coupled with large scale counterclockwise rotation of nappes in the Apennines (Channell *et al.*, 1990; Oldow *et al.*, 1993).

Moreover, in the last years it has become more and more clear that extension in the Tyrrhenian domain and development of accretionary prisms in the Apennines were synchronous in Late Miocene-Quaternary times and, possibly, genetically linked.

Aim of present paper is to contribute to the knowledge of the deformational history of selected sedimentary domains located along the Eastern Tyrrhenian margin.

Geologic setting

Neogene evolution of south-eastern «peri-tyrrhenian basins».

Large-scale extensional tectonics responsible for the thinning of the western sectors of Southern Apenninic chain dates back to Late Miocene. Thinning due to extension was not homogeneously distributed along the overthrust belt, but rather localized in discrete hyper-extension domain (Ferranti *et al.*, 1996), where the thrust pile was locally reduced to about one half of its original thickness.

Seismic profiles offshore Central-Southern Apennines (Latmiral *et al.*, 1974; Bartole, 1984; Mariani and Prato, 1988) show that the architecture of the peri-tyrrhenian basins, south of the 41° parallel line, is controlled by extension parallel to the strike of the fold and thrust belt.

More recently Oldow *et al.* (1993), Sacchi *et al.* (1994), Ferranti *et al.* (1996), have shown that, during latest Miocene-Pliocene the western margin of the Southern Apennines has undergone a severe extension more or less parallel to the axis of the orogenic belt, which was accomodated by low-angle detachment faults (such as the Sele-Salerno basin).

Modes of extension along the south-eastern peri-tyrrhenian basins are often characterized by listric normal faults and associated anthitetic faults, which generate SW-NE trending half-graben systems along the Tyrrhenian basin-Southern Apennines «hinge zone». Most of these peri-tyrrhenian basins extend landward to the E-NE. This causes a typical coastal landscape made of alternating transversal mountain ridges and intervening coastal planes (fig. 2).

Outcrop distribution and facies evolution of late Miocene marine deposits exposed on land (Ortolani and Aprile, 1978) indicate that large areas of the early Tyrrhenian basin were characterized by a complex coastal landscape with shallow-water environments. Large continental shelf areas individuated along the south-eastern Tyrrhenian margin, while delta systems were fed by early Apenninic rivers (*i.e.* protoTiber).

Seismic and well-log interpretation offshore Central-Southern Apennines also showed that, starting from the Messinian, shallow water sediments onlapped onto downfaulted blocks and accomodation space was rapidly created throughout the Lower-Middle Pliocene along the whole south-eastern peri-tyrrhenian margin. Later extensional tectonics

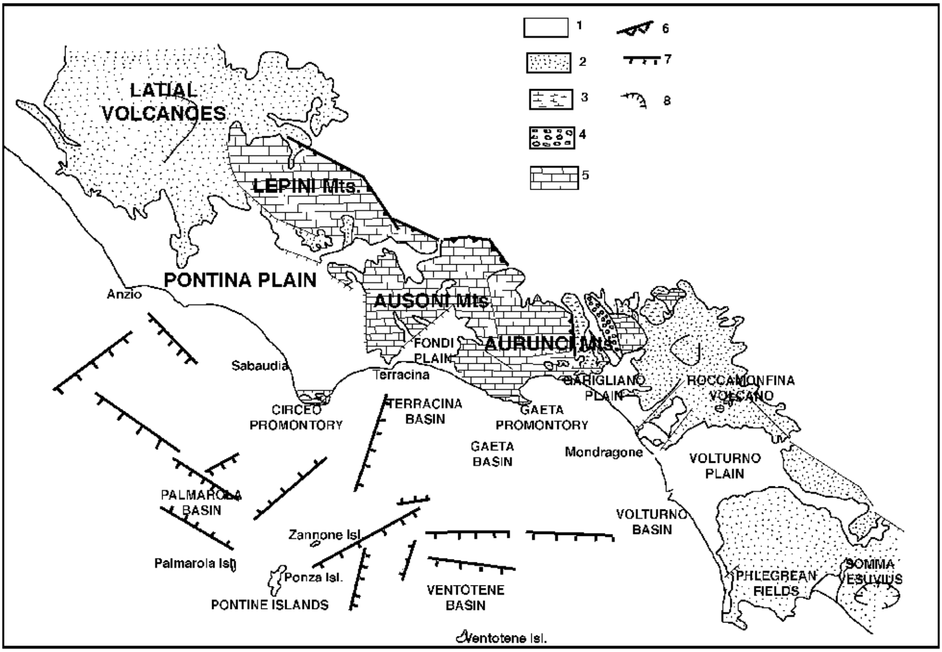

Fig. 2. – Map showing the main geologic features of the Campania-Latium region including the offshore, with reference to the Quaternary sedimentary basins located in this area (Terracina basin, Gaeta basin, Ventotene basin, Volturno basin). 1: Continental and marine deposits (Holocene - Late Pleistocene); 2: Volcanic deposits of the Campania-Latium region (Quaternary); 3: Arenaceous-clayey turbidites (Flysch di Frosinone; Tortonian-Messinian); 4: Shallow water organogenic limestones («Calcari a Briozoi e Litotamni»; Langhian-Serravallian); 5: Shallow and deep water limestones («Lazio-Abruzzi Unit»; Jurassic-Cretaceous); 6: Thrust fronts; 7: Normal faults; 8: Caldera rims.

caused a generalized uplift of the mountain belt and the renewed subsidence at basin centers and uplift at basin flanks controlled local structural evolution of coastal half-graben systems, where maximum throw attained up to 3 km (Mariani and Prato, 1988; Sacchi *et al.*, 1994).

However, a «uniform» post-Tortonian extension along the Tyrrhenian-Southern Apennines continental margin does not satisfactorily account for the late deformational evolution of this region, since late-stage contractional structures also developed during the same time span. In addition, a number of evidences exists along the peri-tyrrhenian basins, of minor contractional phases, often causing inversion structures, that interplayed with extension and lasted, far beyond the traditional beginning of the Tyrrhenian «post-rift» stage, possibly up to the Late Pleistocene. Seismic interpretation shows that local mechanisms for consuming contractional strain has been represented by folding, thrusting, transpression along WSW-ENE fault systems and reactivation of previous listric normal faults as reverse faults. NW-SE strike-slip systems are consequently regarded here as transfer systems both for contraction and extension when parallel to the axis of the Southern Apenninic orogenic belt (Sacchi *et al.*, 1994).

The Campania-Latium Tyrrhenian margin.

The Campania-Latium Tyrrhenian margin includes tectonic domains that can be recognized along the Central-Southern Tyrrhenian offshore between the Ostia-Anzio coast (Latium; fig. 2) and the Policastro Gulf (Campania). On the Campania-Latium margin, Quaternary basin fillings overlie submerged «internal» (western) tectonic structures of the Apenninic chain, resulting from the seaward extension of the tectonic units cropping out in the coastal belt of the Central and Southern Apennines (D'Argenio *et al.*, 1973; Parotto and Praturlon, 1975). These units usually form the acoustic basement of the coastal basins and are composed either of terrigenous-shaly basinal sequences («Unità Sicilidi», «Unità Liguridi», «Flysch di Frosinone», «Flysch del Cilento»; D'Argenio *et al.*, 1973; Parotto and Praturlon, 1975) or of thick platform and basinal carbonates: both sequences are widely exposed in the adjacent mainland (Bartole *et al.*, 1983; Bartole, 1984).

Extensional tectonics accompanying the uplift of the Southern Apennines begin in the Early Pliocene and continue up to the Middle-Late Pleistocene, playing a major role in controlling the present-day physiography of the Campania-Latium margin. Indeed Quaternary marine and continental sediments of the Campanian coastal plains, reach a thickness of up to 3000 m in the Volturno Plain and of 1500 m in the Sele Plain (Ortolani and Torre, 1981). NW-SE, NE-SW and E trending post-orogenic structures (mainly extensional faults) have been previously recognized in the Campania-Latium margin (Bartole *et al.*, 1983). While the apenninic (NW-SE trending) structures characterize the continental slope areas between the Pontine Islands and the Cilento Promontory, the anti-apenninic (NE-SW) ones often occur in the offshore between the Salerno Gulf and the Sorrento Peninsula, simulating a basin and ridge marine structure.

The volcanic activity played a major role in the Campania-Latium region during the Quaternary. It was responsible for the creation of both single large volcanoes (Roccamonfina and Somma-Vesuvius; Principe *et al.*, 1987) and volcanic complexes (Ischia, Procida and Campi Flegrei; Rosi and Sbrana, 1987). In the Phlegrean area a thermo-metamorphic basement about 1500 m deep has been inferred (Rosi and Sbrana, 1987), whereas in the Volturno Plain the «Villa Literno» 1 and «Parete» 1 wells drilled into thick basaltic and andesitic lavas (Ortolani and Aprile, 1978).

Results

The Terracina basin.

The Terracina basin represents the seaward extension of the Piana Pontina, bounded to NE and SE by the Ausoni and Aurunci carbonate massifs (fig. 2). The recent sedimentation of the Piana Pontina is characterized by Late Pleistocene-Holocene eolian and lacustrine deposits. The Gaeta basin instead represents the seaward prolongation of the alluvial plain of the Garigliano river, bounded to NE and SE by the Aurunci and Massico mountains and to NW by the Roccamonfina volcano (fig. 2).

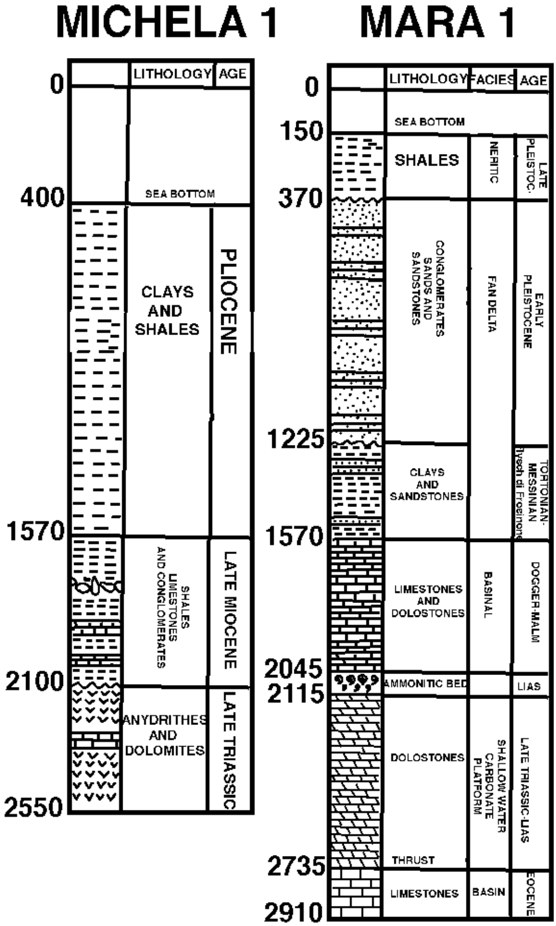

Fig. 3. – Schematic stratigraphy of exploratory offshore wells «Michela 1» and «Mara 1» (see figure 1 for location).

To the east of the Garigliano plain thick Mesozoic carbonates («Piattaforma Laziale-Abruzzese»; D'Argenio *et al.*, 1973) and related siliciclastic Upper Tertiary turbidites («Flysch di Frosinone», Parotto and Praturlon, 1975) extensively outcrop (fig. 2). The above units, recognized on seismics and drilled by onshore and offshore wells (fig. 3), form the acoustic basement of the Terracina basin, together with Meso-Cenozoic carbonates.

Plio-Pleistocene basin fill is characterized by siliciclastic deposits of marine, coastal and deltaic enviroments (conglomerates, sands and shales), sometimes with intercalations of volcanoclastic levels, as documented by offshore well stratigraphy (fig. 3). These deposits overlie an about 1000 m thick succession of alternating sands, shales and alluvial conglomerates at the offshore well «Mara 1» (fig. 3) and drilled also by some onshore wells (fig. 1). These conglomerates, Pliocene in age, correspond to a seismic facies characterized by prograding clinoforms, erosionally truncated at their top and correlate to a similar succession cropping out in the adjacent mainland near Scauri and Minturno (Latium; fig. 2).

The interpretation of seismic profiles suggests that the Terracina basin is bounded to the W by normal faults, NNE-SSW trending, which involve mainly the acoustic basement and only locally the basin fill and bound the southern flank of the Circeo structural high (fig. 4). The same basin is limited eastward by a structural high, located immediately offshore the Gaeta area («Gaeta Promontory»), which marks the transition to the Gaeta basin (fig. 5).

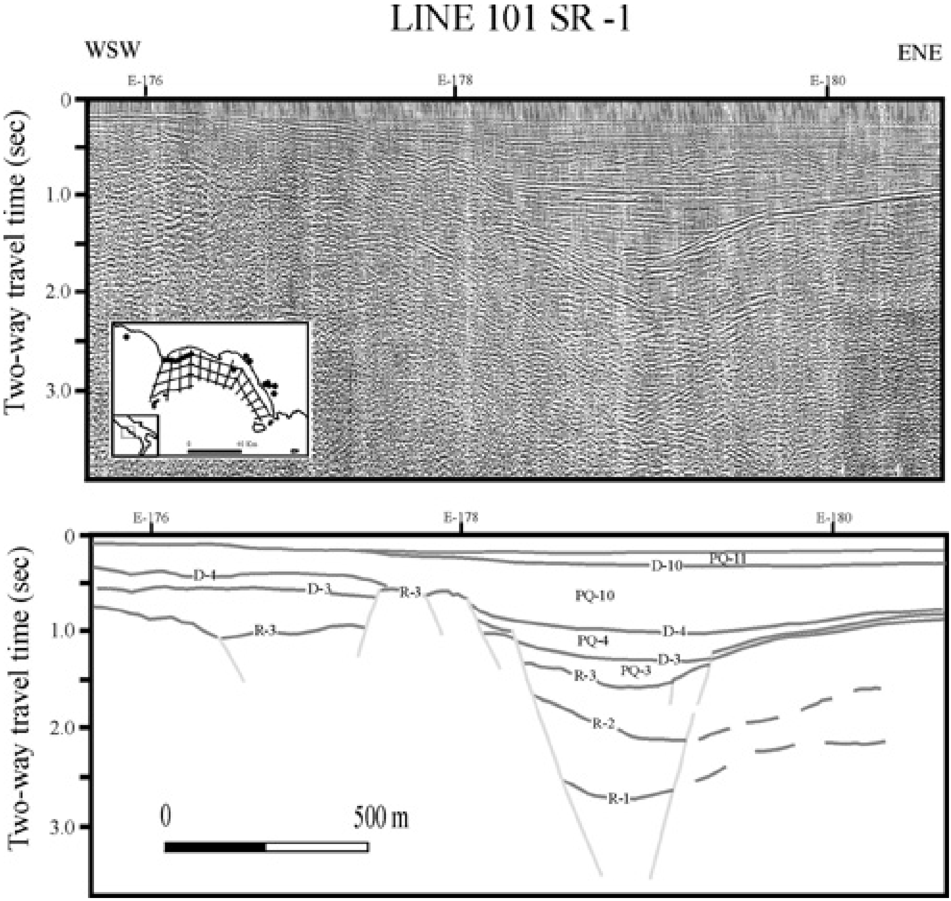

Fig. 4. – Seismic profile E101SR -1, showing the north-western margin of the Terracina basin bounded to the W by normal faults, NNE-SSW trending, which involve mainly the acoustic basement. The basin fill appears not so involved by extensional deformation. On the left of the profile it is possible to see the southern flank of the Circeo structural high, forming the seaward extension of the Circeo Promontory high (see also figs. 2, 10). The processing sequence, which is the same for all seismic profiles, is the following: 1) deconvolution before stack, 2) normal move out, 3) stack 1200%, 4) time variant filter, 5) playback unfiltered.

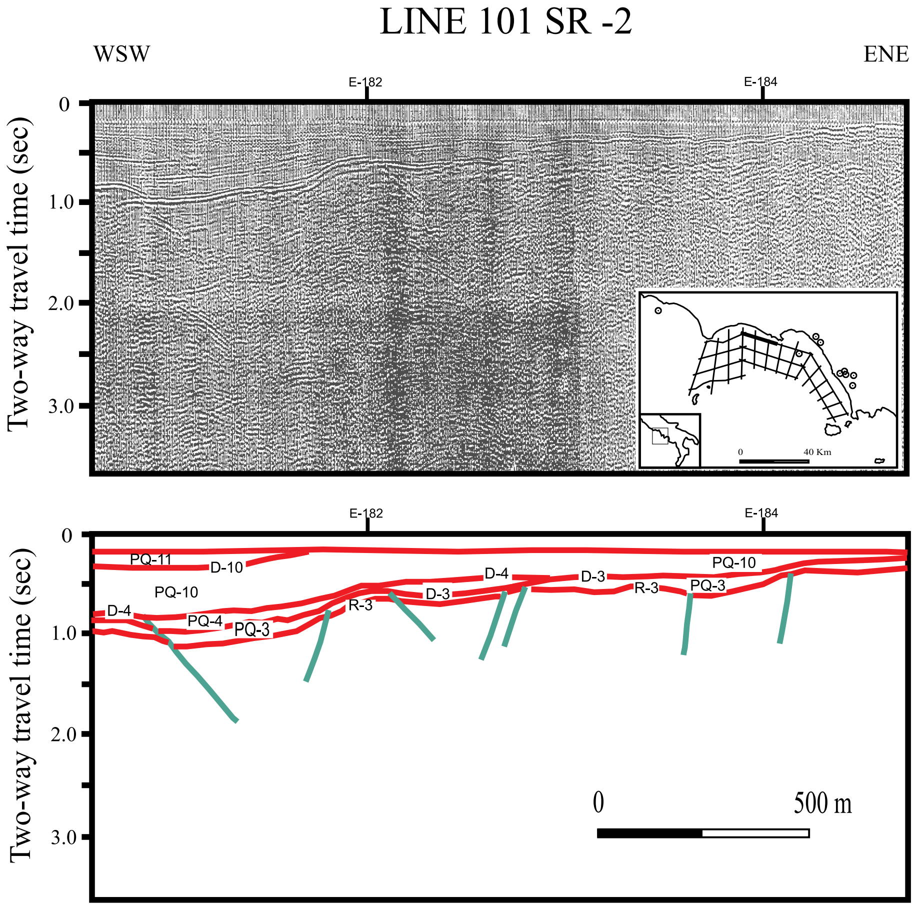

Fig. 5. – Seismic profile E101SR -2, showing the south-eastern margin of the Terracina basin limited eastward by a wide area of structural high located immediately offshore Gaeta («Gaeta Promontory»), which marks the passage to the Gaeta basin.

An isochrone two-way time map relative to the base of the Plio-Quaternary basin fill has been produced in order to evaluate the thickness of the basin fill and to reconstruct a regional tectonic framework of the Terracina basin (fig. 6). The basin fill shows a maximum thickness of about 2600 m and is supposedly formed by alternating sands and shales, with intercalations of conglomeratic levels («Michela 1» well; fig. 3). The whole tectonic framework of the basin seems to suggest an half-graben structure, roughly N-S trending, following extensional tectonics acting along systems of normal faults. A master fault, roughly NNE-SSW oriented, bounds the western margin of the basin (fig. 7); the acoustic basement forming the Circeo ridge is strongly downthrown by this fault, showing a throw of about 1 sec and presumably controlling the formation of the half-graben structure. The extensional deformation was probably active up to the early

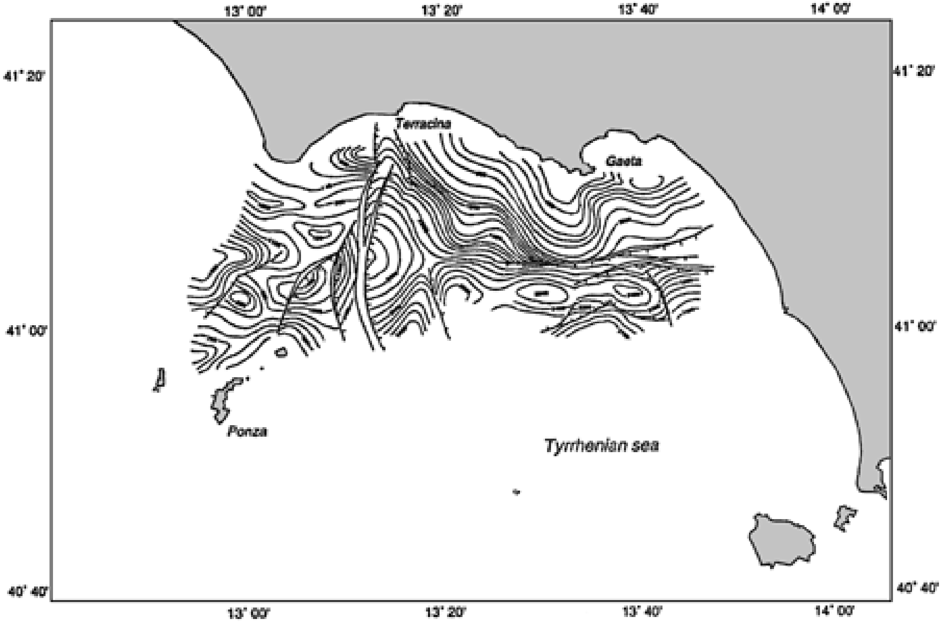

Fig. 6. – Isochrone two-way times map relative to the base of the Quaternary fill of the Terracina and Gaeta basins, showing the tectonic framework of the area and the depocenters of the basins. Both the basins seem to represent half-graben structures, respectively N-S (Terracina basin) and E-W (Gaeta basin) trending, developed as a consequence of extensional tectonics acting along systems of normal faults.

stages of the basin filling, as testified by wedging and growth processes locally involving the basal seismic sequences.

The stratigraphic architecture of the Terracina basin fill is characterized by 10 seismic sequences bounded by significant seismic horizons, corresponding to regional onlap and/or downlap surfaces, and, in the upper part of the fill, to erosional truncations, which separate different progradational stacking patterns. The lower group of seismic sequences (PQ1-PQ4; fig. 8) shows seismic facies with parallel reflectors onlapping the top of the acoustic basement and appears affected by normal faulting.

The reflector D4 (fig. 8) represents an important tectonically-enhanced unconformity, associated to a surface of regional downlap, probably Early Pleistocene in age, which fossilizes the lower seismic sequences and indicates a main variation of the depositional geometries. It marks the beginning of the progradation in the basin fill, as indicated by the occurrence of 5 prograding seismic sequences (PQ5-PQ10), formed by sandy and shaly sediments and not involved in significant deformation.

In the Terracina basin the depositional geometries recognized in the group of seismic sequences overlying the tectonically-enhanced unconformity (reflector PQ4) and characterized by the occurrence of prograding clinoforms can be interpreted as deltaic features. On seismic profiles (figs. 8, 9), parallel to the direction of deposition (progradation), it is possible to recognize reflection facies patterns typical for a prograding, deltaic environment. From the lowest part of the sequence upwards, bottomset, as well as foreset

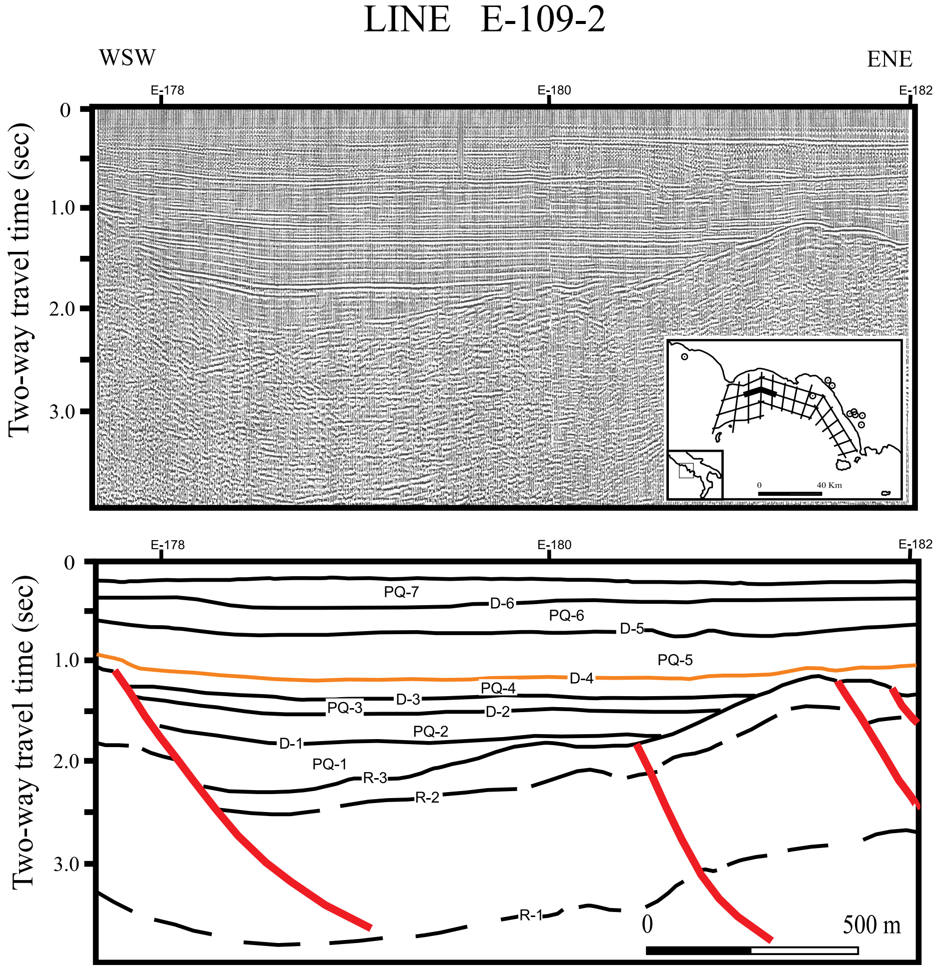

Fig. 7. – Seismic profile E-109-2, showing the master fault, roughly NNE-SSW oriented, bounding the north-western margin of the Terracina basin (see also fig. 6). The acoustic basement of the basin is strongly downthrown through this fault and shows a throw of about 1 sec presumably controlling the formation of the half-graben structure. The extensional deformation was probably active up to the early stages of the basin filling, as evidenced by wedging and growth processes locally involving the basal seismic sequences (PQ1-PQ3).

and topset beds of a deltaic system have been identified (fig. 8). The bottomset beds are represented by the sequence PQ5. The foreset beds in the middle of the sequence (sequences PQ6-PQ7) represent the bulk of the sediments in the system. The foreset stratal reflections, with sigmoid and oblique clinoforms are the most characteristic features of an outbuilding delta (Berg, 1982). Near the top of the foreset zone, sedimentary bypass and minor erosional truncations can be seen, which separate different phases of progradation, while low-angle downlap events are seen deeper at the lower boundary of the foreset zone. In the topset beds upwards into the delta plain (sequences

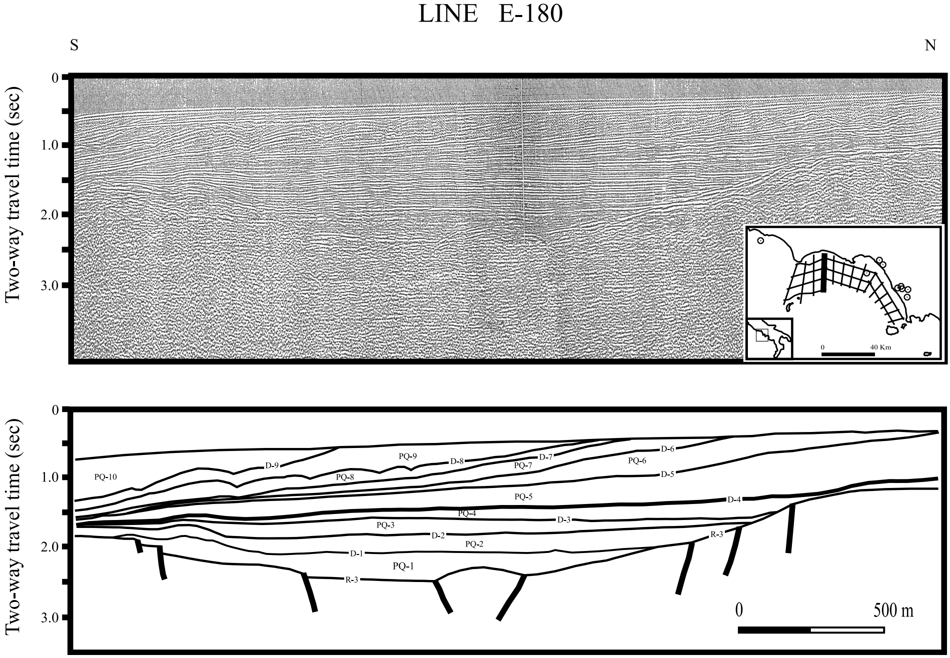

Fig. 8. – Seismic profile E-180, showing the stratigraphic architecture of the Terracina basin, characterized by 10 seismic sequences bounded by significant seismic horizons, corresponding to regional onlap and/or downlap surfaces, and, in the upper part of the fill, to erosional truncations. The lower group of seismic sequences (PQ1-PQ4) shows a seismic facies with parallel reflectors onlapping the top of the acoustic basement and appears locally involved by significative normal faulting, testifying a synsedimentary nature of these strata The reflector D4 represents an important tectonically-enhanced unconformity, which marks the beginning of the progradation in the basin fill, evidenced by 5 prograding seismic sequences (PQ5-PQ10).

PQ8-PQ10) infilled distributary channels occur. The deltaic system has been probably supplied during the Pleistocene by the adjacent alluvial plains of the southern Latium (Plain of Fondi and Pontina Plain), since a main direction of progradation from NW towards SE has been observed based on the interpretation of «dip» seismic lines.

In the foreset deltaic sequence of the Terracina basin offlap breaks (depositional shelf edges) of the prograding reflectors, which generally relate to the fairweather wavebase at an average depth of 8-15 meters (Bowman *et al.*, 1991) have been recognized. A progressive migration basinwards of the offlap breaks seems to suggest a regressive trending of coastal and marine facies during the Late Pleistocene, probably controlled not only by eustatic sea level changes, but also by high rates of the siliciclastic supply.

The Gaeta basin.

The continental platform offshore of Campania between Gaeta and the Ischia island constitutes the seaward extension of the alluvial plains of the Garigliano and Volturno rivers (fig. 2). The continental shelf decreases from NW to SE from the -200 m isobath, since it extends about 20 km in correspondance of the mouth of the Garigliano river and less than 10 km southward of the mouth of the Volturno river, where it connects

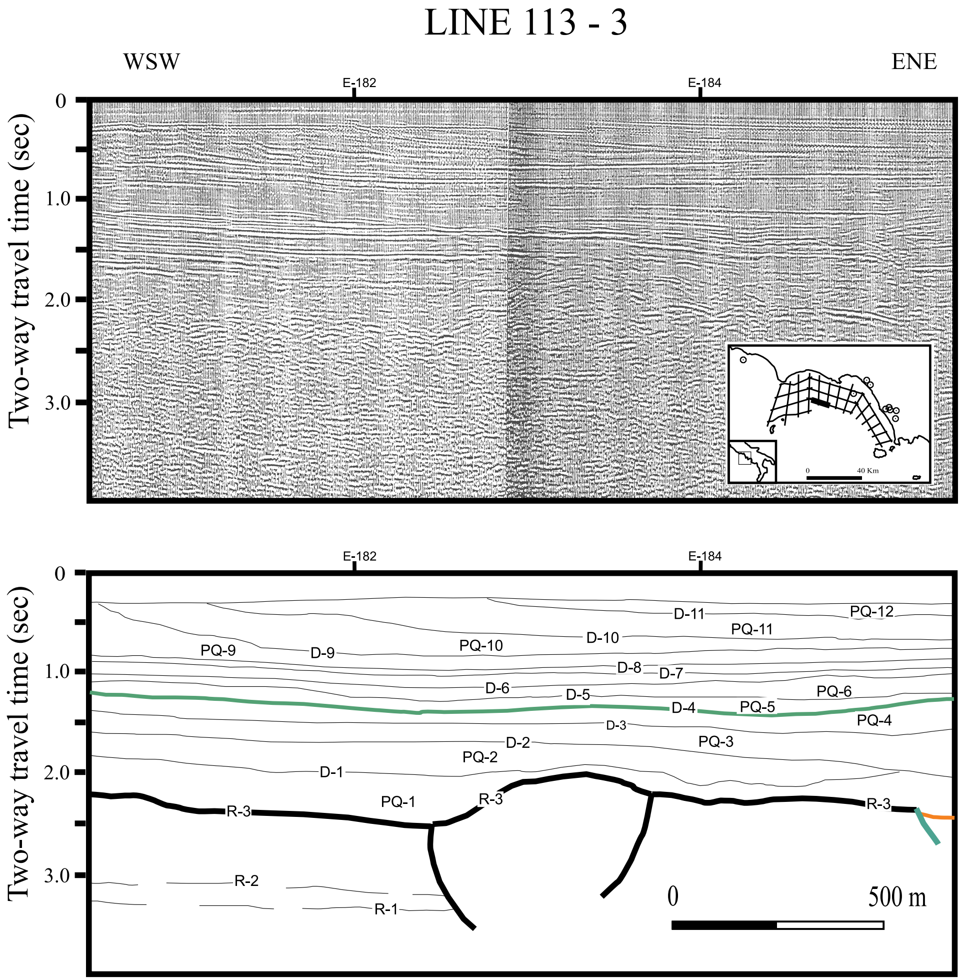

Fig. 9. – Seismic profile E-113-3, showing progradational geometries in the Terracina basin. The thick prograding system has been supplied during the Pleistocene by the Pontina Plain (see fig. 2 for location), as evidenced by the direction of progradation. Note the occurrence of a «pop-up structure» in the acoustic basement, suggesting local processes of basin inversion.

with the Ventotene basin (Zitellini *et al.*, 1984). As pointed out previously this part of the Campania-Latium offshore has undergone subsidence at a regional scale during the Plio-Quaternary, like whole Eastern Tyrrhenian (Ippolito *et al.*, 1973).

The subsurface stratigraphy of the Volturno Plain is partly known, since the area has been intensively explored (for oil, gas and geothermal fluids) mainly by Agip (Agip, 1977). The well data show a Plio-Quaternary sedimentary succession, formed by alluvial deposits (sands and conglomerates) and by marine and transitional sediments, with intercalations of lavas and volcanoclastic deposits (Ortolani and Aprile, 1978; Mariani and Prato, 1988; Brancaccio *et al.*, 1991). The depocenter of the Quaternary fill is located at the mouth of the Volturno river, where the thickness of the basin fill reaches

2500 msec and where the Mesozoic carbonate basement is downthrown through Late Tertiary-Pleistocene listric faults, originating wedging geometries during the Pleistocene (fig. 9; Mariani and Prato, 1988).

The exploratory well «Mara 1» (fig. 3), located in the Gulf of Gaeta, has penetrated a 300 m thick marine shaly sequence, probably Miocene in age, overlain by about 1000 m of continental conglomerates, probably Pliocene in age and then by about 300 m of Pleistocene marine deposits.

The formation of the Gaeta basin appears related to extensional tectonics, along systems of normal faults, mainly E-W trending and bounding the basin margins. In particular, a system of normal faults, E-W oriented and reaching a throw of 1 sec has been recognized at the northern margin of the Gaeta basin (fig. 6). The acoustic basement, ranging in depth between 300 msec and 1 sec in correspondance of the structural high offshore of the Gulf of Gaeta, is strongly downthrown along these faults. A second E-W trending system of normal faults, antithetic to the first one, bounds the Gaeta basin at its southern margin. Between these systems two main depocenters have been recognized, where the basin fill reaches a thickness respectively of 2.5 sec and 2.3 sec. The easternmost depocenter is bounded towards E by a NW-SE trending normal fault, marking the transition to the Volturno basin. Also the acoustic basement of the Gaeta basin, formed by siliciclastic deposits («Frosinone Flysch») and by Jurassic-Cretaceous basinal carbonates («Mara 1» well; fig. 3) is strongly affected by extensional normal faulting.

The depositional geometries relative to the Plio-Quaternary basin fill are similar to those recognized in the Terracina basin and the seismic units have been laterally correlated through the seismic grid, also if the Gaeta basin appears relatively more deformed. The first group of seismic sequences (PQ1-PQ4) is characterized by parallel horizons strongly affected by wedging and growth, as a consequence of the contemporaneous normal faulting. Locally, basin inversion associated with «pop up structures» and involving both the basal group of Plio-Quaternary sequences and the acoustic basement have been observed (fig. 9); they are also suggested by gentle bending of the unconformity located at the base of the marine filling.

The tectonically-enhanced unconformity (reflector D4), already recognized in the Terracina basin fill, marks the beginning of the progradation, as evidenced by the occurrence of seismic sequences characterized by obliquous progradings (sequences 5-8) and then by sigmoidal progradings (sequences 9-11). The main variation from obliquous to sigmoidal progradation shows the occurrence of a more pronounced aggradational component in the late stages of sedimentation. The internal organization of the prograding marine succession is characterized by the occurrence of minor erosional truncations, separating the different progradational bodies. Offlap breaks identified in the prograding strata shift more and more seaward, testifying a regressive trend of the coastal and marine facies during the Late Pleistocene. The prograding sequences have been supplied by the alluvial coastal plain of the Garigliano river and controlled by eustatic sea level changes in the Quaternary and by sedimentary supply, also linked to the uplift of the adjacent mainland during Plio-Quaternary times.

Discussion and conclusions

The interpretation of multichannel seismic reflection profiles in the Campania-Latium margin, integrated with the analysis of the lithostratigraphic data of offshore and onshore boreholes has allowed to recognize the main seismostratigraphic units and fault systems which bound its Plio-Quaternary basinal sectors («peri-tyrrhenian basins») and adjacent structural highs.

Some of these basins and high features partly correspond to the morphostructures cropping out in the adjacent mainland between the Circeo Promontory and the Massico Mt. and have been identified on the base of seismic stratigraphy and by correlation with the mainland geology. The following 6 regional elements have been recognized on the base of the analyzed dataset offshore of southern Latium and northern Campania (figs. 2, 6):

a) *Circeo high*: a structural high trending NW-SE and representing the seaward extension of the Circeo Promontory (fig. 10);

b) *Terracina basin* (figs. 8, 9): represents a half-graben, roughly N-S trending, which becomes larger seaward and laterally merges into the Gaeta basin;

c) *Terracina-Gaeta high*: is a wide belt of structural highs located immediately offshore the Gaeta coastline: it represents the physiographic separation between the Terracina and Gaeta basins;

d) *Gaeta basin*: represents an extensional basin bounded by normal faults roughly trending E-W and narrowing seaward, joining laterally to the Terracina basin;

e) *Massico high*: a structural high NW-SE trending and representing the seaward elongation of the M.te Massico high;

f) *Volturno basin*, characterized by a depocenter located in correspondance of the Volturno river mouth, with a basin fill reaching a thickness of about 2500 msec (Mariani and Prato, 1988).

The thickness of the Plio-Quaternary sedimentary fill is significantly reduced in proximity of the structural highs, while it reaches more than 2000 m in the basins. The basin fill is characterized by a basal group of seismic sequences, probably Pliocene in age, characterized by parallel reflectors laterally onlapping the unconformities located at the top of the acoustic basement. The internal organization of these sequences is characterized by well developed downlap surfaces (lower boundaries) and erosional truncations (upper boundaries). While in the Terracina basin these sequences appear undeformed or only partly deformed by extensional faulting involving mainly the acoustic basement, in the Gaeta basin they are strongly affected by wedging and growth processes controlled both by Plio-Quaternary extensional tectonics phases and tectonic inversion; the latter result not only in the reactivation of pre-existing normal faults along reverse faults and «pop-up structures», but also in a gentle folding in the basal unconformity of the Plio-Quaternary marine sequence.

A tectonic unconformity (reflector D4), probably Early Pleistocene in age, overlies the above sequences and indicates a main variation of the depositional geometries; it could correspond, at a regional scale, to the end of the Tyrrhenian basin «syn-rift» stage

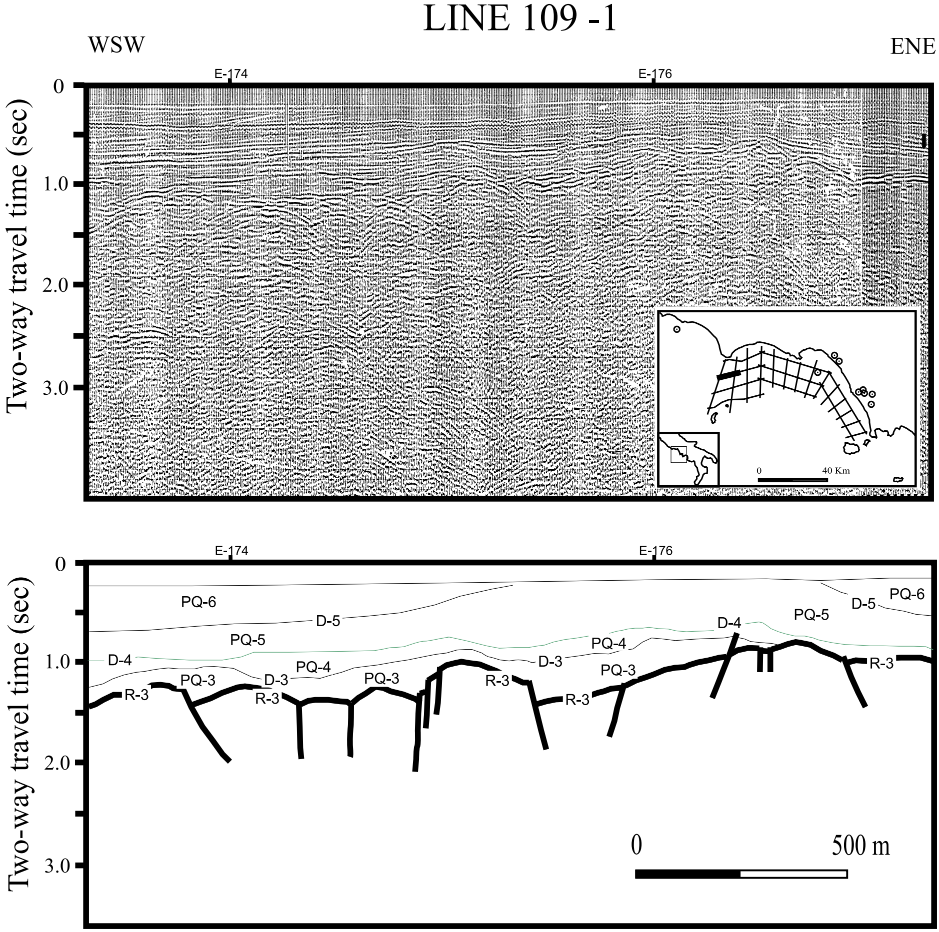

Fig. 10. – Seismic profile E-109-1, showing the structural high of the Circeo ridge, bounding the north-western margin of the Terracina basin.

and to the beginning of the «post-rift» (progradational) stage, as already shown for other parts of the Tyrrhenian margin (Trincardi and Zitellini, 1987).

The overlying Middle Pleistocene-Holocene prograding sequences, probably supplied by the Sisto river (in the Terracina basin) and Garigliano river (in the Gaeta basin) show an internal organization characterized by downlap surfaces and erosional truncations, which separate different phases of progradation. During this time interval a deltaic system developed in the present-day continental platform, as evidenced by the occurrence of deltaic features (bottomset, prograding foreset and topset with incised valleys). In both basins progressive shifting seaward of the offlap breaks, recognized in the foreset seismic reflectors, together with the occurrence of oblique (more than sigmoidal) offlaps (Bowman *et al.*, 1991) suggest low sea-levels and high sedimentary supply from the adjacent mainland during the Late Pleistocene. The formation of the deltaic system presumably is not controlled by tectonics, since the sequences are undeformed, and linked to the rivers crossing the adjacent coastal belt and forming the alluvial plains of the Latium (Pontina Plain, Fondi Plain) and Campania (Garigliano Plain, Volturno Plain; Brancaccio *et al.*, 1991).

The Terracina and Gaeta basins document a significant extensional tectonic control on the Plio-Quaternary sedimentation along normal faults, which involve the Meso-Cenozoic tectonic units of the acoustic basement. The structural control appears evident both at basin margins and in the basin interior, where it is stronger in the early phases of basin filling, as shown by synsedimentary tectonics, affecting mainly the basal seismic sequences.

The extensional tectonics is also shown by the occurrence of systems of normal faults, NE-SW and E-W trending and controlling the formation of a roughly N-S oriented half-graben structure downthrown seaward through normal faults, particularly in the Terracina basin. The Gaeta basin is a E-W oriented extensional basin, characterized by two main depocenters and bounded to the north and to the south by E-W trending listric normal faults, while NW-SE trending normal faults are limiting it towards the east.

Two main direction of extension have been recognized in this area (Oldow *et al.*, 1993; Ferranti *et al.*, 1996). The older extensional phase (mainly Pliocene in age), which acts through «Apenninic» (NW-SE) trending low-angle normal faults, is responsible of the «basin and ridge»-type structure of the investigated area, characterized by the alternance of basins and structural highs with «anti-apenninic» (NE-SW) trending in correspondance of the Tyrrhenian coastal belt (Mariani and Prato, 1988; Sacchi *et al.*, 1994). Lastly to the most recent Pleistocene extensional phase (which has acted through high-angle normal faults with anti-apenninic trends) are due the most recent deformations and the general downthrowing of the western Apenninic margin toward the central Tyrrhenian.

Acknowledgements

This work has been carried out at the Istituto di Ricerca «Geomare Sud», National Research Council, Naples, Italy. It was part of the research program of a post-doctoral fellowship carried ou by dr. Gemma Aiello during 1996-1997 in cooperation between the National Research Council and the University of Naples «Federico II».

Prof. Bruno D'Argenio is gratefully acknowledged for a review of the manuscript and Giovanni Alteriis for helpful discussion.

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Pervenuta il 12 novembre 1999,
in forma definitiva il 13 gennaio 2000.

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