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Foreland deformational pattern in the Southern Adriatic Sea

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Abstract
Two major deformation belts occur in the portion of the Adriatic Sea offshore the Gargano Promontory. Although these two belts display similar characters on seismic profiles, they are different in other respects. The NE-SW–trending Tremiti Deformation Belt, located north of the Gargano Promontory, originated during the Plio-Quaternary, while the E-W–trending South Gargano Deformation Belt, located south of the Gargano Promontory, formed in a time span that goes from Eocene to early Pliocene. On the ground of structural and stratigrafic evidence these deformation belts are interpreted as originated by tectonic inversion of Mesozoic extensional faults. This inversion tectonics, of Tertiary age, can be related to the evolution of the fold-and-thrust belts that surround the Adriatic Sea.
A moderate seismic activity, recorded around the Tremiti Island, and historical seismological data suggest that the whole of study area is, at present, seismically active. Therefore, this portion of the Adriatic block still represents a preferental site of deformation.

1. Introduction

This study aims at contributing to the investigation of an area in the Southern Adriatic Sea where the presence of tectonic structures of possible regional significance has been reported and where seismic activity occurred in the last years. The area is located offshore the Gargano Promontory and rests within the so-called «Adria continental block» that is the foreland of the Apennines and Dinarides fold-and-thrust belts. Whether Adria belongs or not to the African plate is at present a matter of debate, and some Authors (Favali *et al.*, 1990; Westaway, 1990) favour, mainly on the ground of seismological data, a plate boundary running just across this part of the Adriatic Sea.

Using a data set consisting of exploration wells and seismic profiles, mostly commercial but some collected on purpose, we attempt to define geometries, trend and geologic evolution of the above-mentioned structures and to relate them to the observed seismicity. The results we obtain, although still preliminary, show a picture of complexity so far unreported that we believe may be relevant to interpret the kinematics of the region.

2. Geologic setting

The area we examine (fig. 1) lies within a portion of relatively undeformed continental crust (Adria) rimmed on three sides by thrust and folded units belonging to a previous passive margin succession. They are: to the west the east-verging Apennines, to the north the south-verging Southern Alps, and, to the east the west-verging Dinarides (Channell *et al.*, 1979). Adria represents the foreland area of these fold-and-thrust belts and, as such, it has been deflected in response to the load applied by the adjacent mountain belts (Moretti and Royden, 1988). All along the deformed belt surrounding Adria a marked seimicity is reported (McKenzie, 1972). This seismic activity defines the main plate boundary between Adria and Europe. The connec-

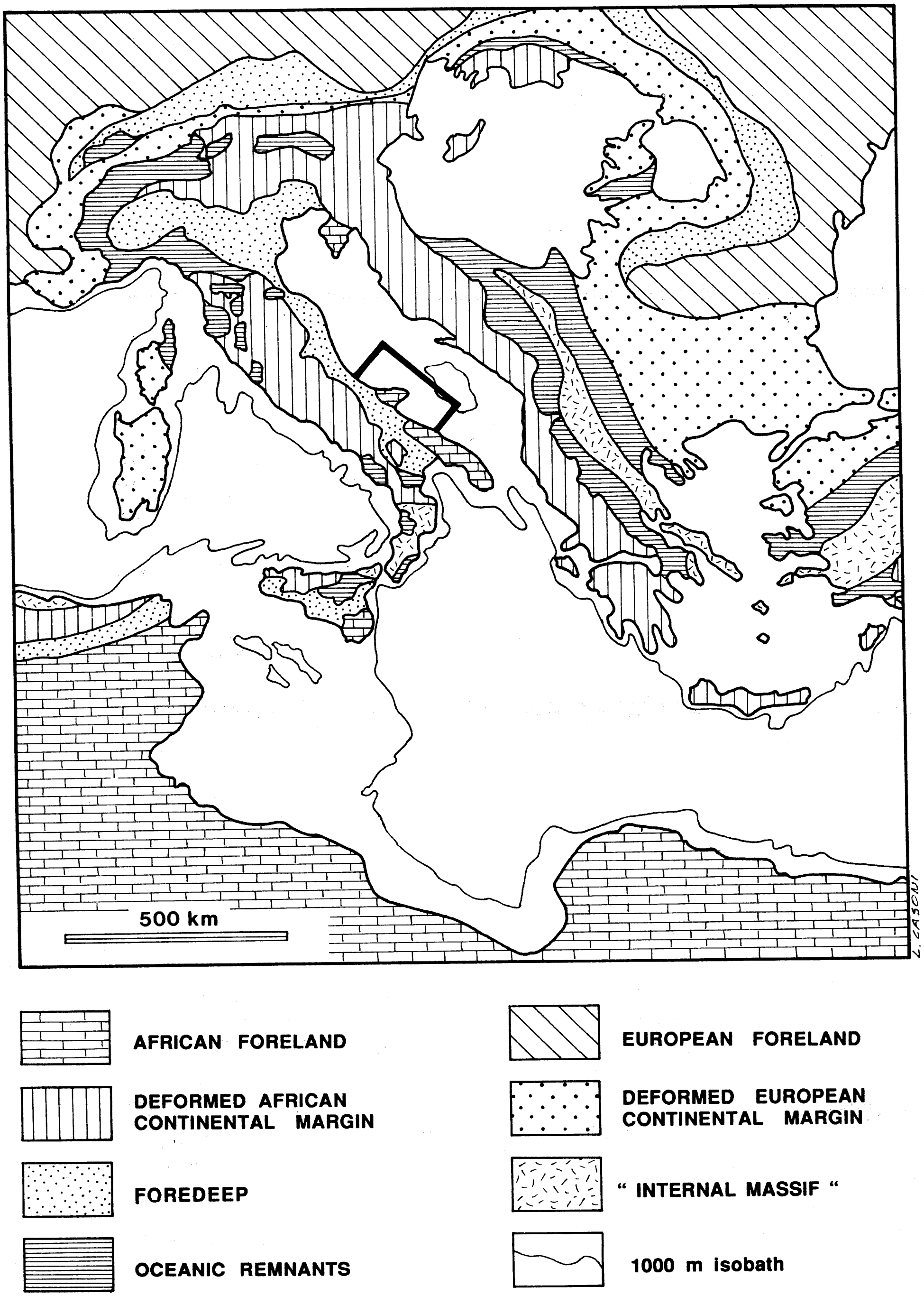


Fig. 1. Summary geological sketch of the central Mediterranean region. Bold outline represents the study area that surrounds the Gargano Promontory.

tion of Adria with the African plate is favoured by several Authors (Argand, 1924; McKenzie, 1972; Channell *et al.*, 1979; D'Argenio and Horvath, 1984; Dewey *et al.*, 1989), while Others (Vanderberg and Zijderveld, 1982; Morelli, 1984; Jongsma *et al.*, 1987; Anderson and Jackson, 1987; Favali *et al.*, 1990; Westaway, 1990) consider Adria, at present, as a separate microplate.

Lithospheric thickness in this region is in the order of ($100 \div 110$) km (Calcagnile *et al.*, 1982; Mueller and Panza, 1984) while the crust is 30 km thick on average (Morelli *et al.*, 1969; Geiss, 1987), although some thickness variations do occur. These geophysical data, therefore, indicate that we are dealing with a piece of truly continental lithosphere.

Moho depth underneath the Gargano Promontory is estimated to be less than 25 km. This is considerably shallower than the adjacent region where Moho depths are in the order of 35 km (Geiss, 1987).

Units belonging to the foreland sedimentary cover outcrop in the Gargano Promontory that is located just onshore the study area (Martinis and Pavan, 1967; Cremonini *et al.*, 1971). They are made up essentially by carbonate rocks ranging in age from Jurassic to middle Miocene with a thickness of over 4000 m. Exploration wells have found Triassic evaporites at depths of about 6000 m. The Gargano Promontory appears as a broad east-west–elongated anticline affected by faults trending NW-SE, E-W and, in minor extent, NE-SW. The nature of these fault systems and their cronology are not too well assessed. Apart from the Notes to the Geologic Map, only few papers have been devoted to the study of this Promontory and they differ significantly in their conclusions. Some Authors put more emphasis on sinistral strike-slip tectonics acting along the E-W–trending Mattinata fault system (Funiciello *et al.*, 1988), while Others favour N-S and NE-SW compressional phases (Ortolani and Pagliuca, 1987). They only agree on the fact that the last phase reactivated in extension many of the previous faults and that some component of strike-slip motion occurred along the E-W–trending fault system.

The Tremiti Islands, located north of the Gargano Promontory, consist of four small islands where a Tertiary succession about 500 m thick outcrops. Sediments range in age from Paleocene to Upper Pleistocene and bedding planes generally dip SE-ward defining a NE-SW–trending monocline. The tectonic evolution of these Islands, according to the Geologic Survey, is as follows (Cremonini *et al.*, 1971). Minor folds, trending NE-SW and WNW-ESE, affected only Paleocene and Eocene sediments while faults with little throw, mainly trending NW-SE but also E-W, cut across sediments older than Middle Pliocene. Plio-Pleistocene sediments record a progressive southeastward tilting of the monocline of about 5°-6°. A micro- and meso-structural study carried out in these islands (Montone and Funiciello, 1989) emphazises the role played by E-W strike-slip faults. In their interpretation the Tremiti Islands represent a pushed-up ridge within a E-W dextral strike-slip system, with the main faults being, however, in an unknown position offshore.

As far as the geology offshore Gargano is concerned, Finetti (1984) in his synthesis of the Adriatic Sea, suggested the presence of two major dextral strike-slip faults, the NE-SW–trending Tremiti fault and the E-W–trending Mattinata fault, located north and south of the Gargano Promontory, respectively. Unfortunately, the detail of these faults is not represented. The area south of Gargano has been further investigated (De'Dominicis and Mazzoldi, 1987; Colantoni *et al.*, 1990) and an E- W–trending structural high has been observed. The Authors interpret this structure either as a diapir anticline originated during Mesozoic salt tectonics and later reactivated by strike-slip faulting (De'Dominicis and Mazzoldi, 1987), or as a positive flower structure originated during dextral strike-slip movements active until the base of Pliocene (Colantoni *et al.*, 1990).

The E-W trend defined by the Gargano Promontory is also well expressed in the Bouguer gravity anomaly contours (fig. 2). The positive anomaly, that reaches 110 mGal over the Promontory, stretches offshore to a considerable extent following the same trend (Finetti and Morelli, 1973). The same applies to the magnetic basement that underneath the Gargano Promontory and its offshore is about 2 km higher than the surrounding regions where it is deeper than 10 km (Cassano *et al.*, 1986).

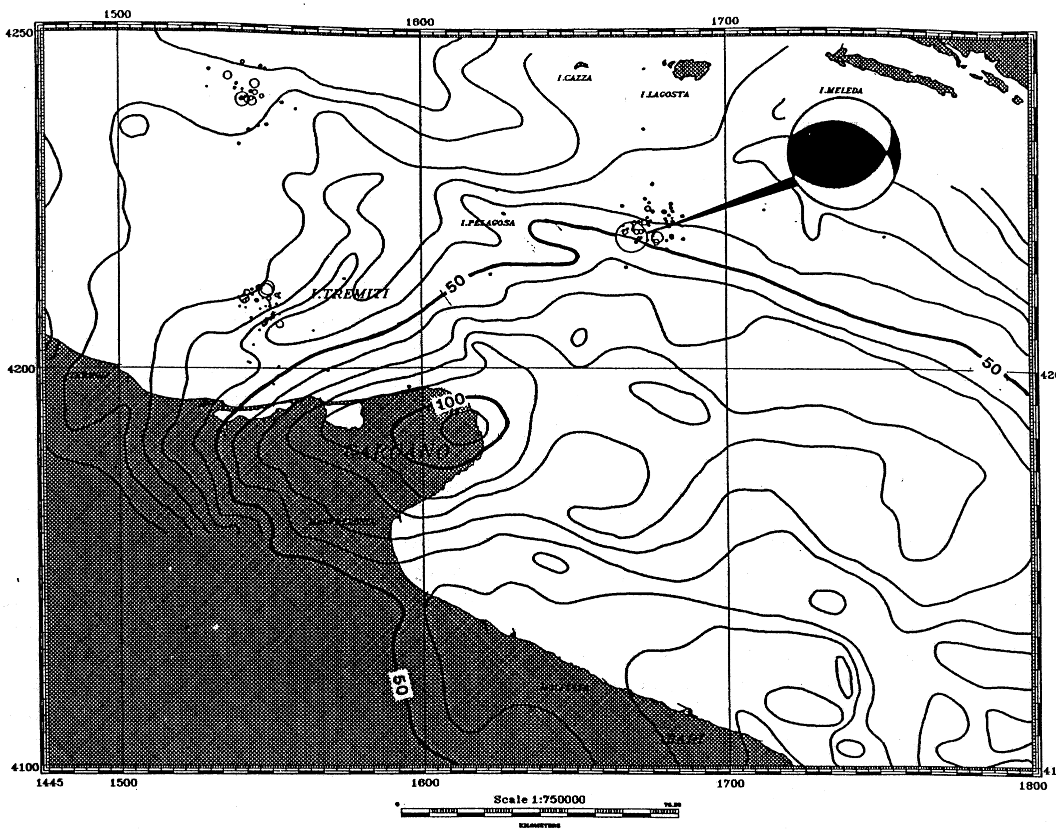


Fig. 2. Bouguer gravimetric anomaly field and earthquake epicentres of the Gargano Promontory and surrounding areas showing the + 100 mGal anomaly located on the promontory and the focal mechanism of the 5.3 magnitude earthquake that occurred in 1988 midway between the Italian and Yugoslavian coasts. Seismicity data from Console *et al.* (1992), gravity data from Finetti and Morelli (1973).

Paleomagnetic data collected in Upper Cretaceous sediments of the Gargano Promontory, show a CCW rotation of about 23° with respect to the Africa pole (Channell, 1977; Vandenberg, 1983). However, a rotation of 17° seems more appropriate taking into account conservative data evaluation (Lowrie, 1986). Gargano Promontory and Istria present the same amount of post Late Cretaceous rotation suggesting that this part of Adria behaved as a separate block with respect to Africa. Recent data (Tozzi *et al.*, 1989) show a CW rotation of 9° in Eocene limestones. This would imply an alternate CCW and CW rotation of the Gargano area that, according to the Authors, fits a model of E-W–trending strike-slip faults and block rotating about vertical axes. However, the limited amount of rotation and the slight worsening of the precision parametres of the Fisher statistics, after the tectonic correction, cast some doubts as to the age of magnetization that in fact has the same direction of the present Earth magnetic field before correction.

3. Seismicity

The Gargano Promontory and its neighbouring area are well known as a seismically active zone. Many earthquakes, such as the 1627, 1646 and 1731 events, reached destructive effects.

Moreover, these earthquakes were often followed by many aftershocks and in some cases the seismic sequences lasted over one year (Baratta, 1901). Nevertheless, the seismicity was often mislocated as it was based only on macroseismic information. In fact, macroseismic investigation associates the epicentral area of an earthquake to the most damaged localities, where the damage can be caused by local geological situations. In many cases it is possible to infer that the earthquakes took place offshore but caused damages and site effects inland. For example the 1627 earthquake is classified as XI MCS. Such an intensity was reached only in some small centres of Gargano (San Severo, Apricena, etc.) (Postpischl, 1985a), but historical chronicles about tsunami waves along the northern coast suggest an offshore hypocentral area. A detailed analysis of the Italian seismic catalogues (Postpischl, 1985b; ING, 1990) points out the occurrence of seismic activity offshore Gargano. This activity is located both north and south the Promontory although, on the basis of these data, it is quite impossible to localize it correctly.

On the other hand, the implementation of the Italian Telemetered Seismic Network, of which the Istituto Nazionale di Geofisica is in charge, has allowed a better localization of the lower-magnitude earthquakes occurring in Italy and surroundings. During the last years (1986-1990) three interesting seismic sequences occurred in the Southern Adriatic Sea and, when properly localized (Console *et al.*, 1989; 1992) (fig. 2), they appear associated with the Tremiti fault zone (as defined in Finetti, 1982 and Finetti *et al.*, 1987) and demostrate that this structure is seismically active (Console *et al.*, 1992). Only the main shock of the 1988 sequence (m_b = 5.3) allowed one to compute a reliable focal mechanism. This mechanism was obtained using a «double couple» model (using only teleseismic data) and was also supported by the Centroid-Moment Tensor (CMT) method (Dziewonski *et al.*, 1981). Both solutions show strike-slip component, more evident in the «double-couple», and thrust component, more evident in the CMT. Tha actual fault plane was interpreted as striking ENE-WSW with a sinistral strike-slip movement (Console *et al.*, 1992).

4. Data set

This study is based on a data set consisting of several exploration wells and of a rather dense grid of seismic profiles. Most of these profiles are commercial but some were collected on purpose during a cruise carried out in 1991 (fig. 3). About 1000 km of multichannel seismic reflection profiles were collected offshore the Gargano Promontory onboard of the R/V Bannoch of CNR. The details of acquisition and processing are given in tables I and II, respectively. Not all of the profiles were processed to the final slip; for some of them only the stacking was performed.

Seismic profiles have been interpreted defining first the unfaulted panels and then, within such panels, identifying reflection terminations and geometric arrangements of reflection packages.

A set of about 15 exploration wells has been used to work out the stratigraphy of the area and, whenever possible, well data have been tied to seismic profiles in order to put stratigraphic constraints to seismic interpretation.

Nine stratigraphic logs are shown in fig. 4 and 9 where they are arranged in two transects cross-

Table I. Acquisition parameters.

Source	Sodera G.I. Gun
Gun mode	True G.I.
Capacity	Generator 45 ci; Injector 105 ci
Pressure	2000 psi
Depth	3.5 m
Shot interval	25 m
Streamer	Teledyne
Length	600 m
Depth	12 m
Groups	24
Hydrophones per group	20
Group interval	25 m
Seismograph	Geometrics 2420
Sampling rate	1 ms
Record length	5000 ms
Antialiasing filter	180 Hz
Tape format	SEG-D / 6250 bpi
Coverage	1200%

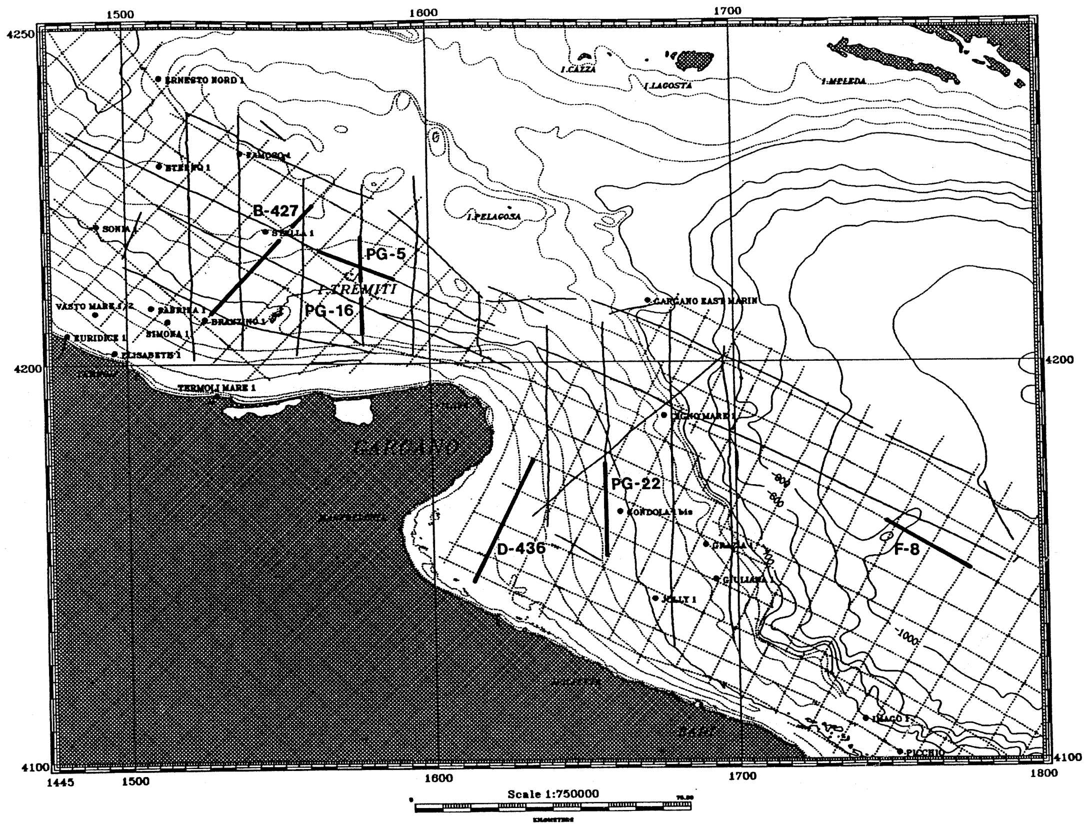


Fig. 3. Grid of seismic lines utilised in the present study (dotted: commercial; continuous: PG91 cruise) and location of public domain exploration wells. Bold lines indicate seismic sections illustrated in fig. 5 and 10. Bathymetry from IBCM dataset.

ing the northern and southern parts, respectively, of study area.

For the wells where the stratigraphic record is more complete, water-loaded subsidence curves have been computed using a modified version of the Program BASTA (Friedinger, 1988) that follows Steckler and Watts's (1978) equations. Thickness of dated stratigraphic intervals, porosity-depth relationships for different lithologies and paleowater depths are needed to calculate the water-loaded subsidence. The first piece of data derives directly from well logs, while porosity-depth functions were taken from Sclater and Christie (1980) and Schmoker and Halley (1982).

Paleowater depths are more critical to determine and, for this reason, a depth range has been used so as to take uncertainties into account. Paleowater depth estimates are taken from Wood (1982). Airy isostasy has been assumed to describe the lithospheric response to loading. This assumption may be valid for the Mesozoic rifting subsidence but is likely to be not so good an approximation for the successive evolution of the area where some flexural rigidity has been shown to exist (Royden, 1988).

Sea-level variations have not been taken into account because the several sea-level curves presented differ significantly both in time and magnitude of fluctuations, and no one has gained general acceptance.

Table II. Processing sequence.

Resample:	to 2 ms
Edit	
True amplitude recovery	
Spherical divergence compensation	
Air gun delay:	25 ms
Mutes	
Predictive deconvolution	
Operator length:	255 ms
Predictive lag:	24 ms
Windows:	0(*)-2000(*) ms
	2000(*)-5000 ms
Trace equalization	
Time variant filter	
CDP sorting	
Velocity analysis	
NMO correction	
Stack:	1200%
Spike deconvolution	
Time variant filter-windows:	0(*)-0(**) 12/65 Hz
	0(**)-1500(**) 10/50 Hz
	1500(**)-5000 8/33 Hz
Trace equalization	
Finite difference time migration	
AGC-gate length:	500 ms

(*) Time from zero water bottom.
(**) Time from base Plio-Quaternary.

5. Interpretation

In a describing and interpreting the data, the study area has been subdivided into two parts separated by the Gargano Promontory. The reason for this is not just purely geographic because, as will be shown below, these two parts appear to have undergone a different geologic evolution, at least from the Tertiary onward. After the two zones are described, a general interpretation where they evolutions are compared and contrasted in a unified picture will be presented.

5.1. *Zone North of Gargano*

The major feature in this part is a NE-SW–trending structure that is well expressed in the bathymetry (fig. 3). The Tremiti Islands belong to this structure that is hereafter referred to as Tremiti Deformation Belt (TDB).

Wells are unevenly distributed in this part (fig. 3) and none of them is located on top of the above mentioned structure. A transect from coast to offshore (fig. 4), constructed using three wells, illustrates the gross stratigraphy of this zone. The drowing of a carbonate platform system is well documented in the two offshore wells, while it never occurred in the near coast one.

The variation in thickness of the Mesozoic pelagic sediments likely reflects deposition in half-grabens as shown by the seismics (fig. 5, line B-427). It is noteworthy that above a depocentre of Mesozoic pelagics (well Famoso) the Paleogene section is incomplete and mostly of shallow water, while in an area of reduced Mesozoic pelagics (well Stella) the same section is com-

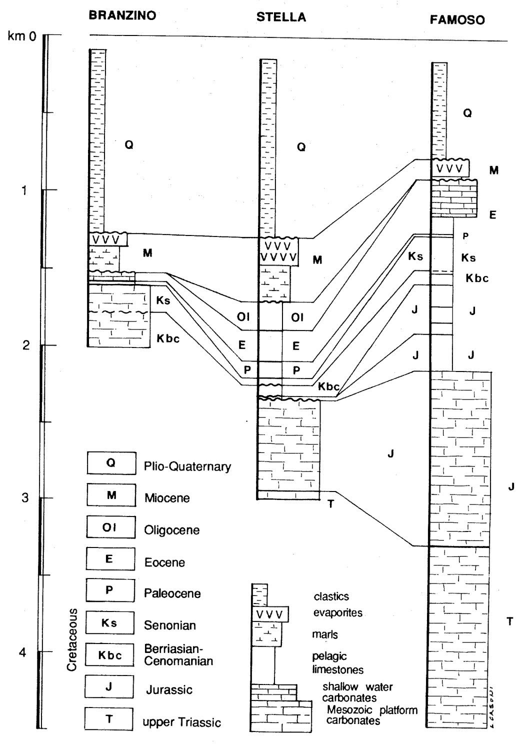


Fig. 4. Summary stratigraphy from coast to offshore north of the Gargano Promontory. Note the expansion of the Mesozoic section and the reduction of the Paleogene section that occurs passing from Stella to Famoso. For further discussion, see text.

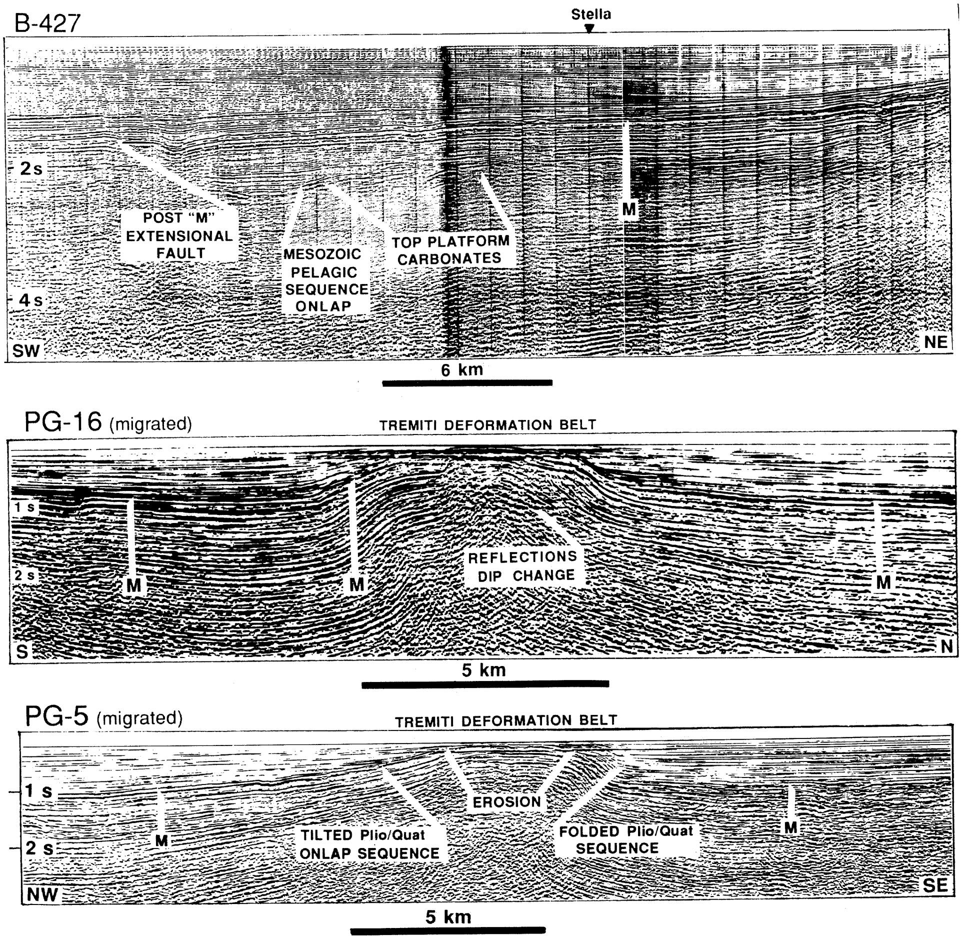
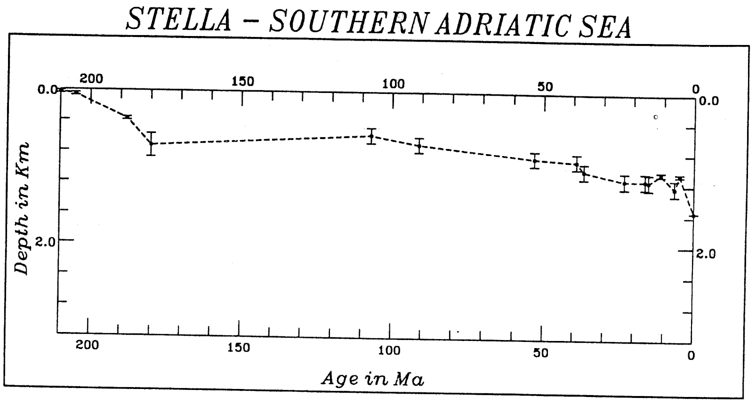
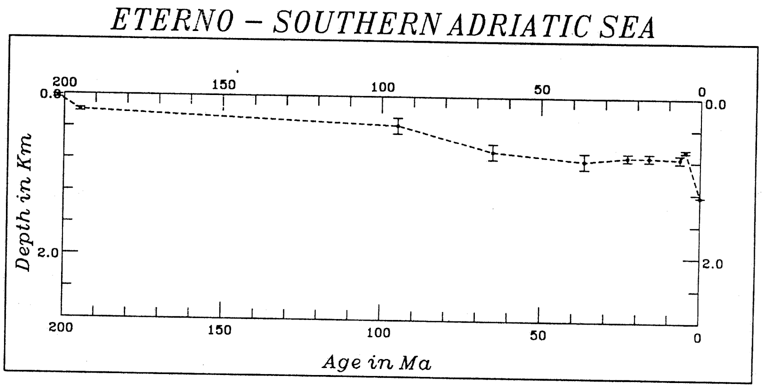


Fig. 5. Selection of seismic lines north of the Gargano Promontory showing the general stratigraphic features of the area (Line B-427) and the geometry of the main structural feature of this zone, the TDB (Lines PG-16 and PG-5). For discussion, see text.

plete, more expanded and made up by deeper-water sediments. Following the Messinian evaporites are the fine-grained clastic sediments of the Apennine foredeep that thin northeastward. The tectonic subsidence curves (fig. 6a)) show a typical passive margin trend from 220 to 50 Ma. On the contrary of what commonly reported in the literature (Bernoulli and Jenkyns, 1974; Winterer and Bosellini, 1981) the main rifting episode is observed in Late Triassic, before the carbonate platform drowning occurred. A comparable early-to mid-Triassic stretching episode results from a study carried out along the Tethyan passive margins (Wooler *et al.*, 1992). From 50 to 30 Ma minor pulses of uplift and subsidence are observed while at about 5 Ma the onset of the Apennine foredeep is clearly marked.

Three seismic lines have been selected to illustrate the principal aspects of this zone (fig. 5). The dating of horizons and seismic units have been assessed by means of well ties whenever possible. The westernmost line (B-427) is far away from the TDB and shows, at a depth of about 3 s Two Way Traveltime (TWT), a package of reflections onlapping onto a tilted horizon. From well ties the onlapping package is at-





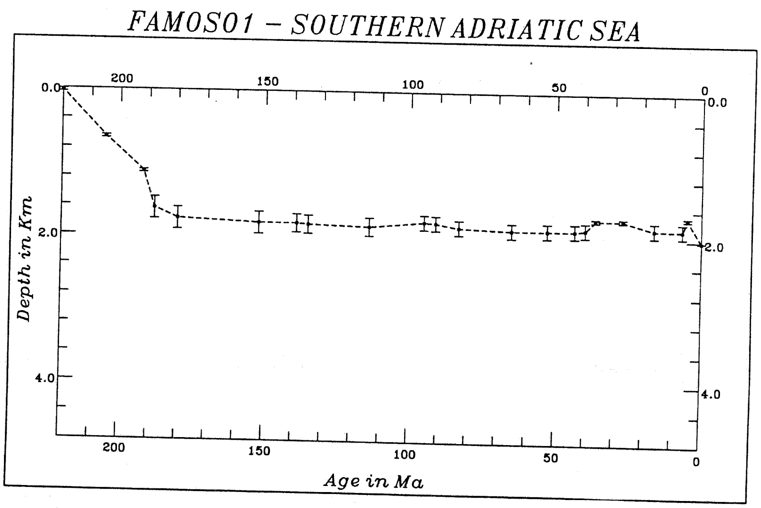


Fig. 6a). Observed water-loaded tectonic subsidence curves based on well data from the area north of the Gargano Promontory.

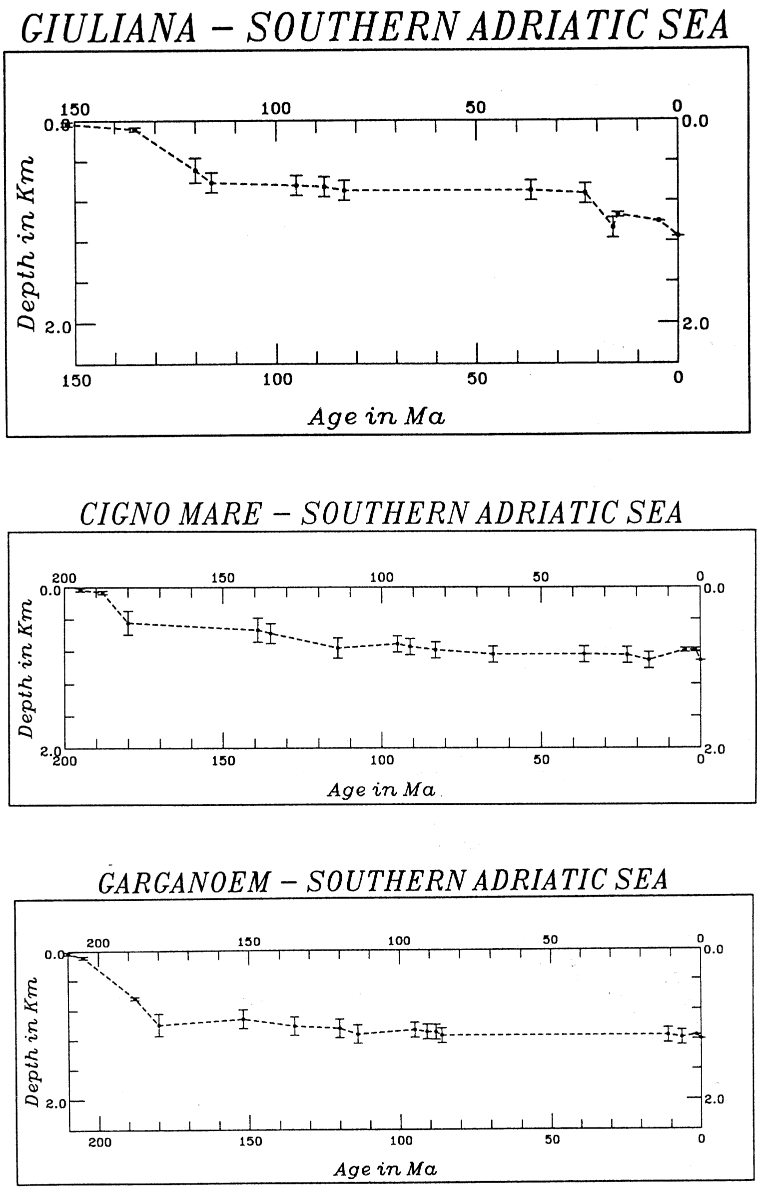


Fig. 6b). Observed water-loaded tectonic subsidence curves based on well data from the area south of the Gargano Promontory.

tributed to Mesozoic pelagic sediments while the underlying horizon represents the top of platform carbonates tilted by extensional block faulting. Above the southwestward tilted unconformity «M», that marks the base of the Plio-Quaternary, foredeep sediments display an onlapping unit, at the base, followed by a thick packet of north-eastward prograding clinoforms. Line PG-16 and PG-5 cross each other on top of the TDB and illustrate its general folded appearance. The TDB trends NE-SW and is slightly asymmetric, as best seen on line PG-5, with a steeper southern flank. The most remarkable feature is that Plio-Quaternary sediments have folded very recent as can also be noted in the base Plio-Quaternary isochron map (fig. 7) where the TDB is well characterised. The upward decrease in amplitude of the fold indicates that the sediments deposited during deformation. On the other hand, below the «M» unconformity no significant thickness change is observed, suggesting that folding is mainly of Plio-Quaternary age. Seismic resolution and penetration are not good enough to allow the unravelling of the structural complexity of this folded feature. A tenuous hint appears on Line PG-16 where a convergence of reflection can be seen in the core of the fold.

To sum up, the main characters of this part located north of Gargano Promontary are the following. This zone was affected by rifting in late Triassic. The breakdown of carbonate platforms brought to deposition of pelagic sediments with half-grabens over most of the area, although in some places carbonate platforms remain for the whole Mesozoic. Hiatuses, lateral facies changes and thickness variations within Paleogene sediments, together with pulses of subsidence and uplift, suggest that tectonic activity occurred during this period. However, this activity did not originate any major structure. The main activity occurred after the Messinian: to the north the onset of the Apennine foredeep; and, close to the Gargano Promontory, the growth of the TDB that lasted for almost the whole Plio-Quaternary.

5.2. *Zone South of Gargano*

This zone is mainly characterised by a roughly E-W–trending structure, the South Gargano De-

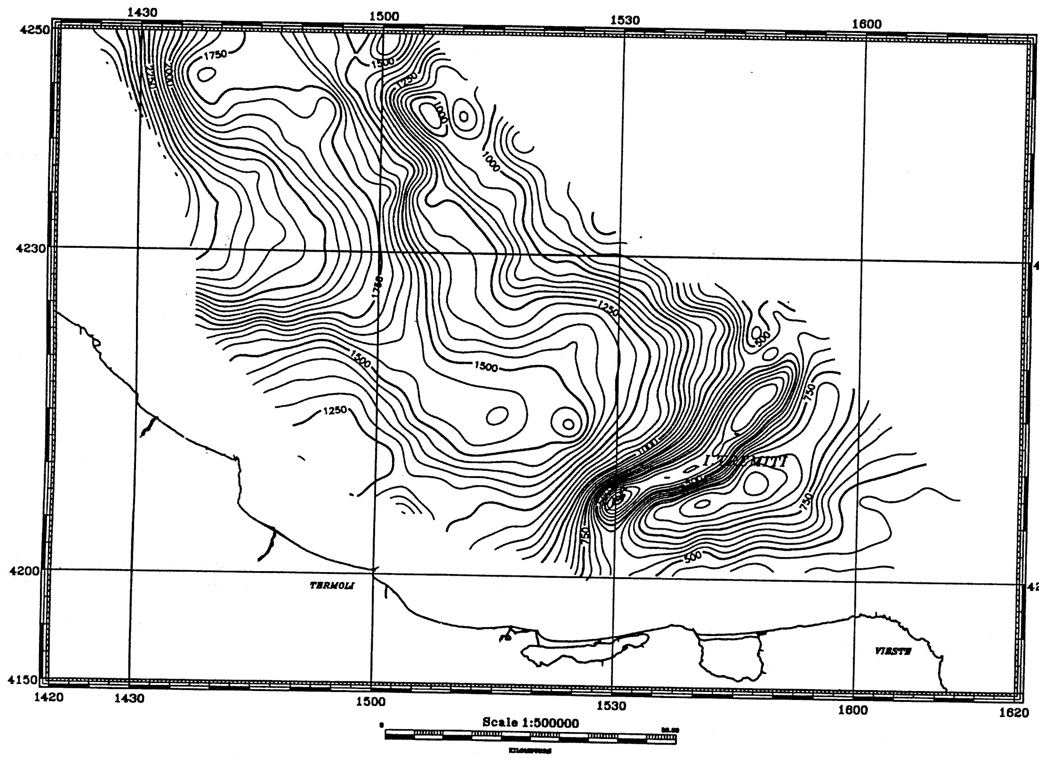


Fig. 7. Base Pliocene isochron map of the northern sector of the study area. The TDB is observable as well as the deepening trend to the west of the Apennine foredeep.

formation Belt (SGDB). On the contrary of what happens for the TDB, the SGDB has no bathymetric expression but does result as a relative high in the base Plio-Quaternary isochron map (fig. 8). As discussed below, the SGDB displays no substantial activity during the Plio-Quaternary.

Wells are located on either side of the structure as well as on its top. A N-S transect, perpendicularly crossing the structure is shown in fig. 9. As seen in the area north of Gargano, the Mesozoic is characterised by the presence of Triassic and early Jurassic platform carbonates overlain by pelagic sediments. This transition from platform to basin sediments never occurred in the near-coast well Jolly. Interestingly, the major depocentre of Mesozoic pelagic sediments occurs in the well Gondola that is located right on the top of the SGDB. These sediments have been relatively uplifted with respect to the adjacent coeval sediments. Tertiary sediments are noticeably absent over the SGDB while they occur in two depocentres on either side of the structure. Paleocene and Eocene sediments have never been encountered in any well of this area. Tectonic subsidence curves (fig. 6b)) show Late Triassic-Early Jurassic rifting and ensuing smooth thermal subsidence interrupted, between 35 and 15 Ma, by slight uplift followed by a subsidence pulse centred at about 20 Ma. Another subsidence acceleration occurs around 5

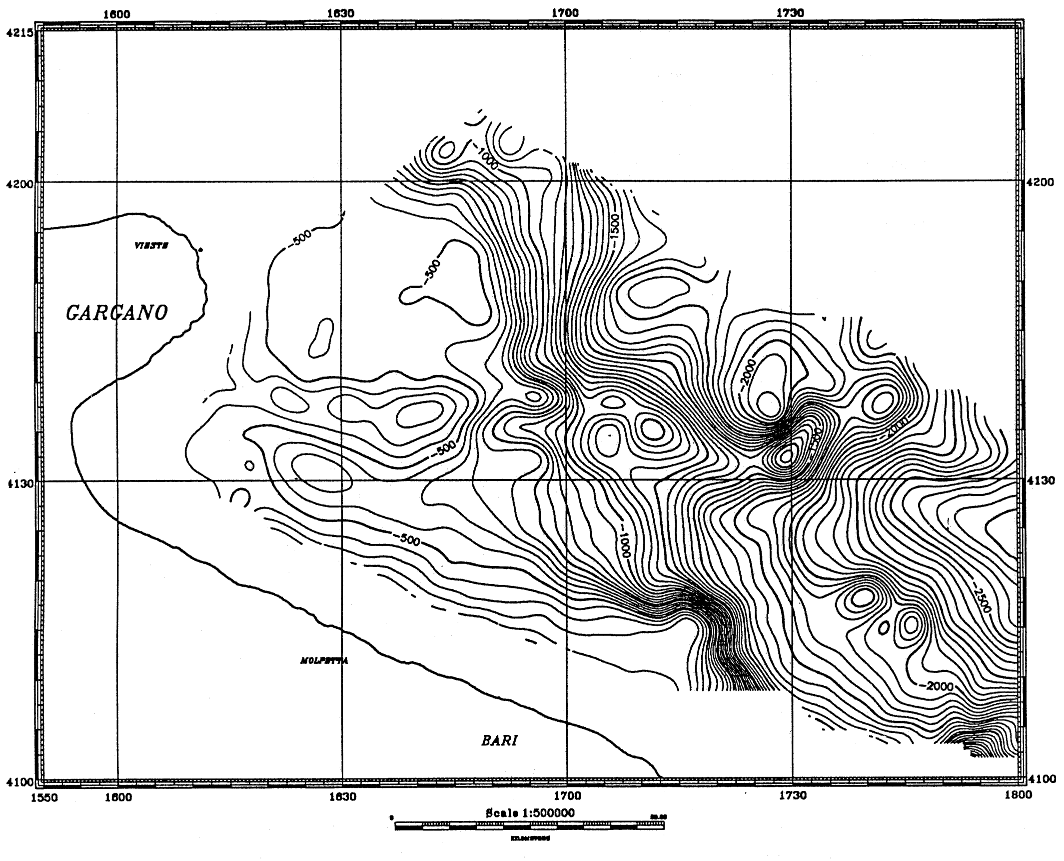


Fig. 8. Base Pliocene isochron map of the sector south of the Gargano Promontory. The SGDB can be followed from close to the Gargano Promontory, eastwards, where it changes direction and shows up more markedly. Deepening towards the north-east reflects the proximity of the foredeep related to the southern Dinarides thrust belt.

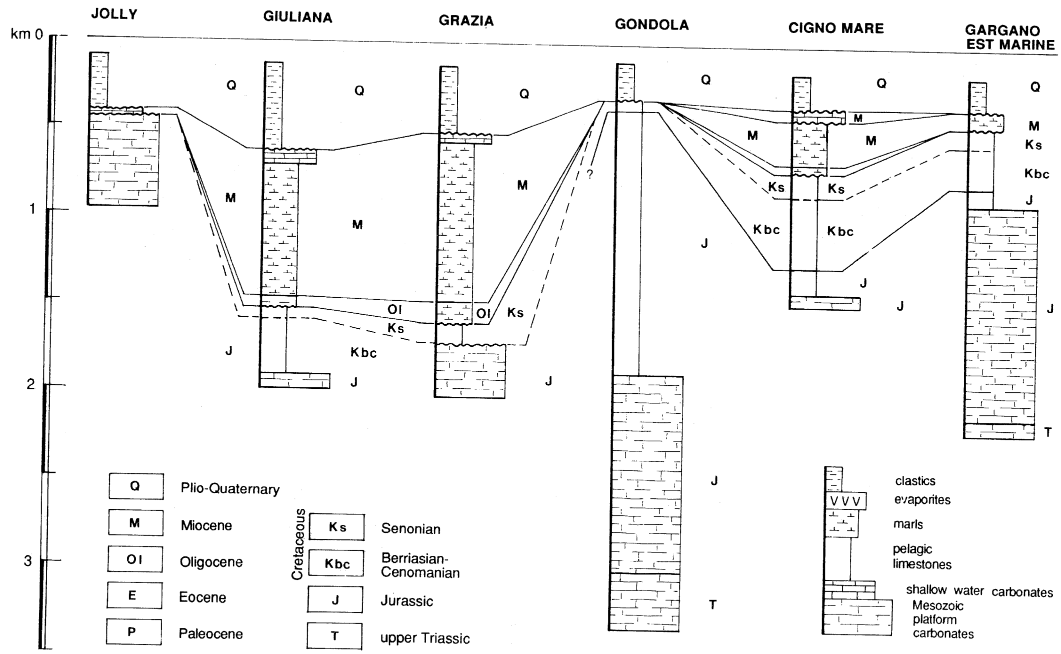


Fig. 9. Summary stratigraphy along a N-S transect south of the Gargano Promontory. Note that Gondola, located on the SGDB, shows the most expanded Mesozoic pelagic sequence, notwithstanding the probable erosion of further section since Plio-Quaternary clastics rest directly onto lower Cretaceous pelagic limestones (about 110 Ma of missing section).

Ma and is related to the south Dinarides foredeep.

Of the three lines in fig. 10 two (D-436 and PG-22) cross the SGDB, while the third one (F-8) is located on the easternmost continuation of this belt where its trend changes substantially. Line D-436 crosses the structure where it is about to die out westward. The SGDB is very narrow and to the south of it there is a wedge-shaped unit with onlapping reflections at its base. The lower part of this unit represents Mesozoic pelagic sediments onlapping the tilted top of platform carbonates, while the upper part, bounded on top by the «M» reflector and onlapping at its base, is thought to represent the Oligo-Miocene sequence. In reality, as all of the wells are located onto relative structural highs, it is not given to know if the lack of Paleocene and Eocene is real all over the area or if it represents a biased picture. In Line PG-22 the SGDB is wider and is better developed. The well Gondola is located a few km to the east of this line but, unfortunately, the internal geometry of the structure is not resolved on the seismics and its relationship with the thick Mesozoic pelagic succession reported in the well is not clear. However, on the southern flank of this broad asymmetric fold a seismic unit with parallel reflections onlapping at its base and truncated at its top by the «M» unconformity is well displayed. Such a unit likely represents the Oligo-Miocene sequence and rests on the Mesozoic pelagic sediments.

The onlap of the Plio-Quaternary sediments onto the «M» reflection is remarkable and is in agreement with what observed in the previous profile. Moving eastward, the SGDB changes its trend (fig. 8). Work in this sector is still in progress, but there is good evidence of contraction as indicated by the fault-bend-fold geometry displayed in Line F-8 where the folded «M» horizon is onlapped by Plio-Quaternary sediments.

Also in this area, as in the north Gargano one, Mesozoic rifting favoured the accumulation of great thicknesses of shallow-water carbonates and led, eventually, to the breakdown of carbo-

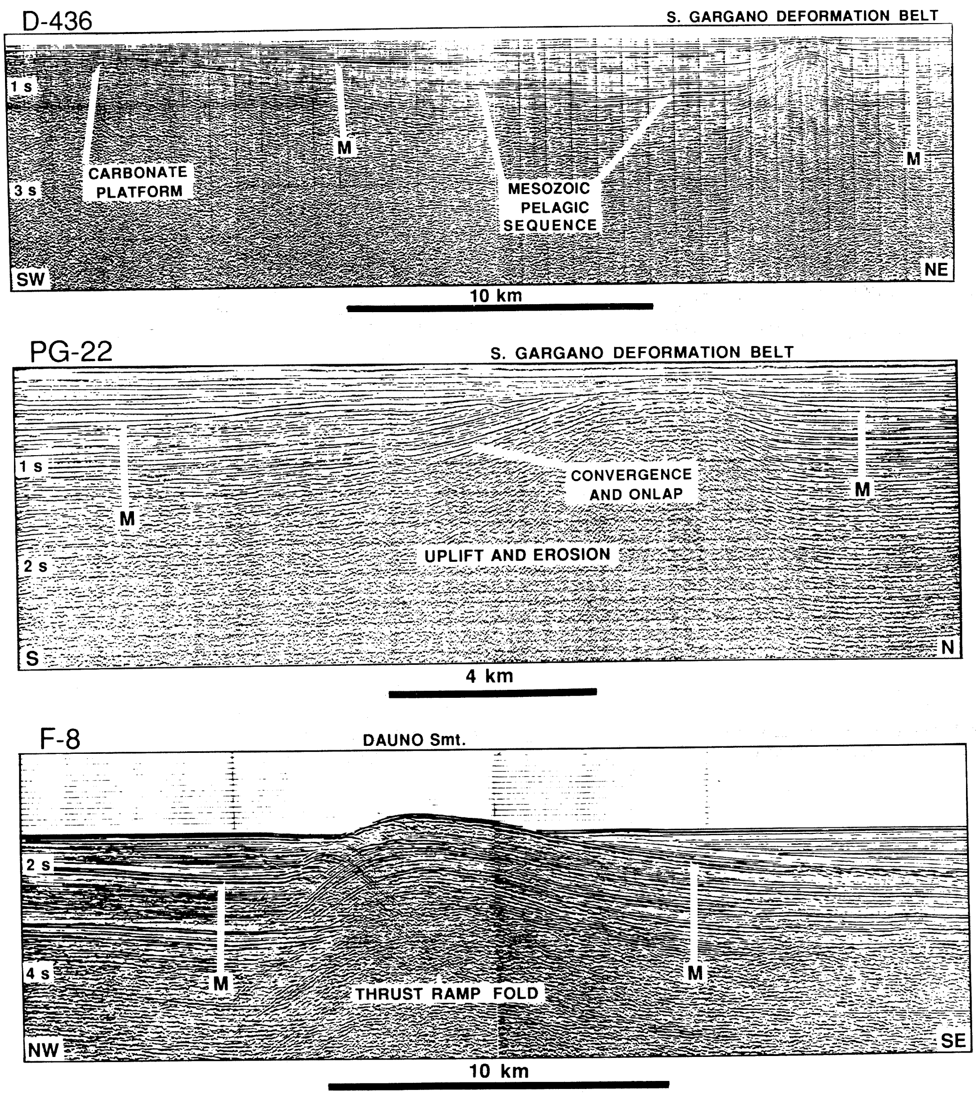


Fig. 10. Seismic sections showing the structural characters of the SGDB passing from west (Line D-436) to east (Lines PG-22 and F-8). For discussion, see text.

nate platforms and to the deposition of pelagic sediments within half-grabens. Paleocene and Eocene sediments are not reported in exploration wells although they may occur in undrilled structural lows. The observed onlap of the Oligo-Miocene sediments onto the tilted Mesozoic units indicates that some tectonic activity occurred sometime during Paleocene and Eocene. This tectonic episode originated the SGDB which was later reactived in Messinian time, as documented by the tilted Oligo-Miocene sediments and by the onlapping Plio-Quaternary strata. Unlike the TDB, where most of the deformation took place during the Plio-Quaternary, the SGDB apparently was not active in that time interval. The broadly folded reflectors of the

SGDB, its position above a Mesozoic extensional fault (D-436) and the presence at its core of a depocentre of Mesozoic pelagic sediments (well Gondola) suggest that this structure might be related to tectonic inversion of a previous extensional fault.

5.3. *Summary*

Two major deformation belts occur offshore the Gargano Promontory with different trends and different geologic evolution. The TDB, to the north, has a marked bathymetric expression and a NE-SW trend. The development of this structure occurred essentially during the Plio-Quaternary and its activity lasted until very recent. The E-W–trending SGDB, on the other hand, lacks bathymetric expression. The onset of this structure is difficult to constrain, although it occurred sometime within the Paleocene-Eocene time span. Assuming that this structure is due to inversion tectonics, an Eocene onset is more likely because it would be coeval with a major tectonic pulse in the Dinarides. A second activation of the SGDB occurred during the Messinian. This seems to be the main event responsible for the deformation of the easternmost part of the structure whose trend swings from E-W to NE-SW.

6. Discussion

Although the Gargano Promontory and its surroundings area are sites of seismicity both historical and recent, the geology of this region has not been properly addressed and understood. Only a few papers have been devoted to this task and the results are sometime controversial; for example, the South Gargano fault is interpreted as strike-slip dextral in the offshore (Finetti, 1984; Colantoni *et al.*, 1990) and as strike-slip sinistral in the onshore (Funiciello *et al.*, 1988). Our study, that concerns only the offshore, allows one to define the timing of activity of the two major deformation belts present to the north and to the south of the Gargano Promontory. A summary of the deformational events occurred in these two zones, and described in greater length above, is illustrated in fig. 11. Is is worth to point out that the two deformation belts show a different time of activity. The main deformational episode affected the TDB during Plio-Quaternary while in the SGDB it occurred about the Eocene. Given the position of the two deformation belts, it appears reasonable to link these episodes to the evolution of the adjacent chains. In particular, the SGDB seems to have recorded the onset of the Dinaric foredeep, while the deformation in TDB appears to be related to the evolution of the

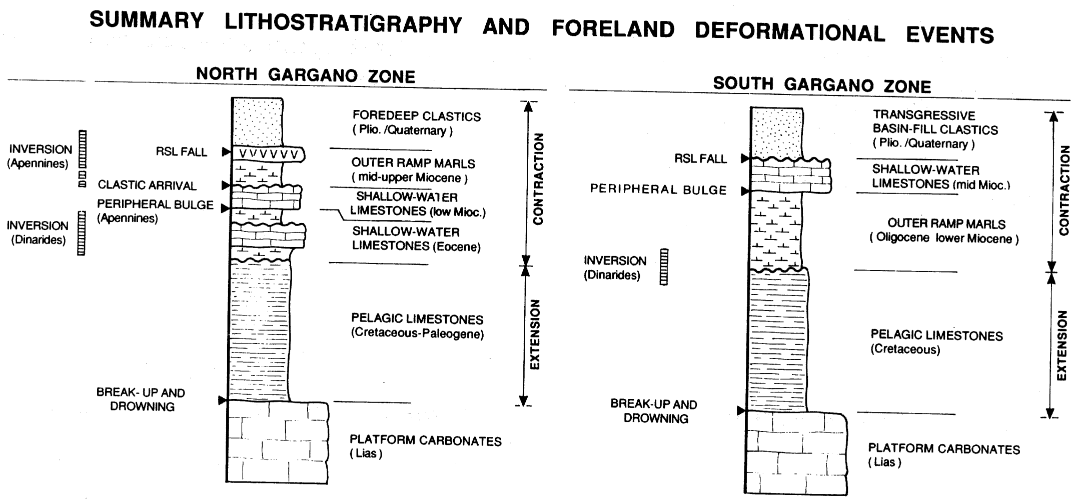


Fig. 11. Summary stratigraphic logs, based on the studied wells and subsidence curves, for the northern and southern sectors showing the proposed correlation between deformational events and litho-stratigraphy.

Plio-Quaternary Apenninic foredeep. It is likely that the Eocene episode was recorded, to a minor extent, also in the northern zone where indications of tectonic activity have been observed. In our opinion, this Eocene event marks the transition from an evolution controlled by extensional tectonics to one where contraction is the dominant motif.

As far as the structural style is concerned, the two belts show similar characters. They both appear as broad and unfaulted folds when looking at the upper sedimentary units. As pointed out above, stratigraphic and structural data suggest that these folds may have originated by tectonic inversion of Mesozoic extensional faults. Although other Authors (Finetti, 1984; Colantoni *et al.*, 1990) interpret the TDB and the SGDB essentially as strike-slip features, we believe that there is no need to call upon transcurrent motion to explain the structures observed. While the arguments used to support strike-slip tectonics (great length of the SGDB and one change in the sense of separation; Colantoni *et al.*, 1990) are not unambiguous, we fail to recognize other characters considered typical of strike-slip tectonics. For example, *en-echelon* structures related to the main fault zone are absent, and, although the SGDB is rather curvilinear (fig. 8), no evidence of structures connected to restraining and releasing bend has been observed. However, a strike-slip component of motion cannot be ruled out after this, still preliminary, interpretation.

A moderate seismic activity offshore Gargano has been recorded in the last few years and mostly in connection with the TDB. Small earthquakes occurred also south of Gargano, but their magnitude is too small to allow a reliable location. Data concerning historical earthquakes indicate that seismic activity occurred both north and south of Gargano and, therefore, both areas can be considered at present seismically active. The link with the structures observed on seismic profile is neverthelesses far from clear. In fact, although the TDB has been actively deformed until recent time, the SGDB ended its activity by the early Pliocene. It is worth to point out that the seismicity of the Adriatic Promontory occurs in a portion of this continental block where a great deal of structural deformation is also observed. It seems therefore that the Gargano Promontory and its offshore represent an area of foreland where deformation preferentially concentrated since the emplacement of the surrounding fold-and-thrust belts. The large gravimetric anomaly present above the Gargano Promontory and roughly elongated E-W (fig. 2) appears to be related to a perturbing mass located at a depth of about $(35 \div 40)$ km, *i.e.* within the lithospheric mantle. The horizontal component of the gravity field of a rotating Earth acting on this mass anomaly can increase the local stress field (Gasperini *et al.*, in preparation) and this may also contribute to the recent seismicity.

Looking at the whole of the Adriatic block (fig. 12), it appears that the foredeep system is asymmetric and that the axis of the peripheral bulge presents a major kink. The Gargano Promontory is located within this zone of distorsion where the stress propagating from the surrounding chains is likely to be amplified. This fact, coupled with the occurrence of inherited Mesozoic weakness zones, may have favoured the tectonic inversion that we envisage as the main deformational feature of the area.

7. Conclusions

The area offshore the Gargano Promontory has been investigated using multichannel seismic reflection profiles and exploration wells. Two major deformation belts have been observed north and south Gargano, the NE-SW–trending TDB and the E-W–trending SGDB, respectively.

Although these zones were known already in the literature, our study points out that their evolution was more complex than previously mentioned. The TDB is essentially of Plio-Quaternary age, while the deformation of the SGDB began during the Eocene and was completed by the early Pliocene. Despite previous interpretations regarding these structures as due to strike-slip faulting, we propose that tectonic inversion of Mesozoic extensional faults can equally explain the observed geologic features and also fits the regional geologic setting of a foreland surrounded by fold-and-thrust belts. The stress propagating from the adjacent mountain chains is believed to have caused the tectonic inversion:

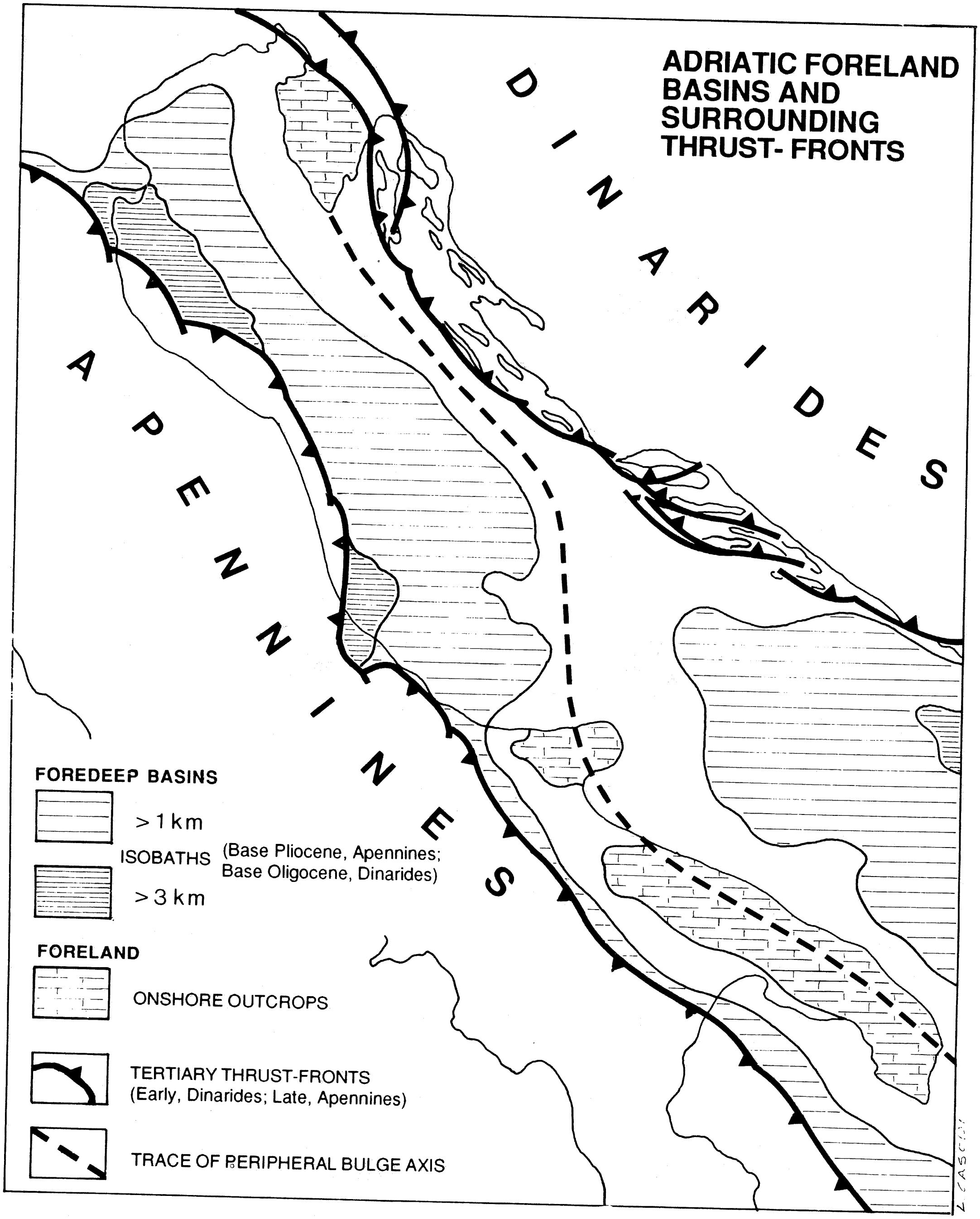


Fig. 12. Sketch map of the Adriatic foreland with an outline of the flexural bulge resulting from the double load of the Apennines and Dinarides fold and thrust belts.

the timings of deformation in the chains and in the Garganic area are, in fact, almost coincidental.

The area is at present seismically active suggesting that it still represents a preferential site of deformation within the Adriatic continental block.

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