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Quaternary tectonic activity of the Murge area (Apulian foreland – Southern Italy)

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Abstract
Integration of structural, stratigraphical, and sedimentological data and instrumental records of some recent low-energy seismic events in the Murge area allow us to suggest a new seismotectonic picture of this region, generally considered an aseismic and stable sector of the Apulian foreland.

Key words *Quaternary tectonics – Apulian foreland – Murge region*

1. Introduction

The seismotectonic evolution of a weakly deformed region may be reconstructed by using and connecting a large amount of data of different analytic sources, as well as by relating the accuracy of field observations and the sensitivity threshold of instrumental measurements to the relatively small size and scarcity of unambiguous tectonic and seismic evidence. For these reasons, the Quaternary tectonics of the Apulian foreland and, particularly, of the Murge area, which is considered an aseismic and stable sector within the foreland, is an issue that has received attention only in the last few years. The integration of structural, stratigraphic, sedimentologic, paleoseismic and seismic data collected in the last ten years allows us to suggest a new seismotectonic picture of the Murge area.

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2. Structural and geological settings

The Apulian region is a sector of the Adria plate characterized by a relatively thick lithosphere (Calcagnile and Panza, 1981) and by a weakly deformed and autochthonous sedimentary cover (Ricchetti, 1980; Ricchetti *et al.*, 1988). This region represents the Plio-Pleistocene foreland of the South-Apennines orogenic system and is called the Apulian foreland («Avampaese Apulo» of Selli, 1962; D'Argenio *et al.*, 1973; Ciaranfi *et al.*, 1983) (figs. 1 and 2).

The Apulian foreland shows a uniform crustal structure with a Variscan crystalline basement and an approximately 6 km thick Mesozoic sedimentary cover (the Apulia carbonate platform – D'Argenio, 1974; Ricchetti, 1975, 1980); this succession is overlain by thin and discontinuous Tertiary and Quaternary deposits (Ricchetti *et al.*, 1988).

Structurally the Apulian foreland corresponds to a wide WNW-ESE trending antiform (Ricchetti and Mongelli, 1980; Biju-Duval *et al.*, 1979; Royden *et al.*, 1987) (fig. 2) which is obliquely oriented with regard to the South-Apennines subduction hinge (Casnedi, 1988; Doglioni *et al.*, 1994; Pieri *et al.*, 1996). Large

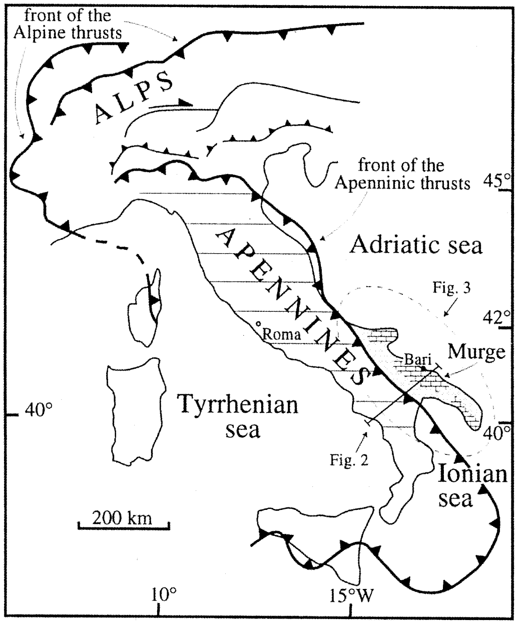

Fig. 1. Schematic structural map of Italy. The coloured area represents the Puglia region (Apulian foreland), which the Murge belongs to.

deformation zones, striking oblique or perpendicular to the main WNW antiform trending, segment the foreland in several large blocks (Doglioni *et al.*, 1994; Gambini and Tozzi, 1996). The outcropping portion of the Apulian foreland, which in practise corresponds to the Puglia region (Southern Italy), is dissected in three main blocks with different degrees of uplift, from the higher Gargano and Murge to the lowland Salento toward the southeast (Ricchetti *et al.*, 1988; Funiciello *et al.*, 1991) (fig. 3).

Normal faults have been documented in all the blocks of the Apulian foreland, be they in the cited outcropping ones (Ciaranfi *et al.*, 1983) or in the submerged ones, represented by the «Rospo High» north of Gargano (André and Doulcet, 1991) and by the «Apulian swell» south of Salento (Rossi and Borsetti, 1974; Auroux *et al.*, 1985). The faults have variable ages, most likely ranging from the Mesozoic to the Pleistocene, and WNW-ESE, NW-SE and E-W main trends. In particular, the Puglia antiform shows down faulted blocks both toward the Bradanic trough to the WSW and toward the Adriatic sea to the ENE (Carissimo *et al.*,

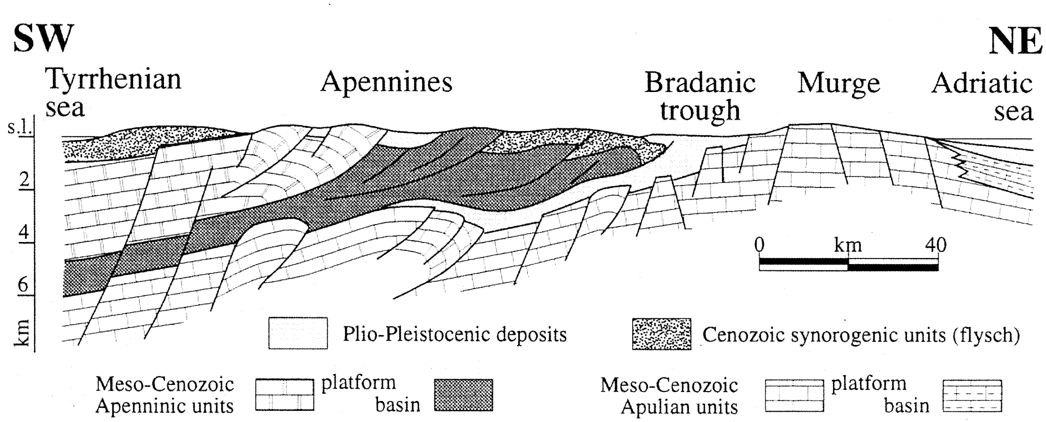

Fig. 2. Geological cross-section showing the main structural features of the Southern Apennines orogenic system (from Sella *et al.* 1988, modified). Note the antiformal structure of the Apulian foreland (Murge). For location see fig. 1.

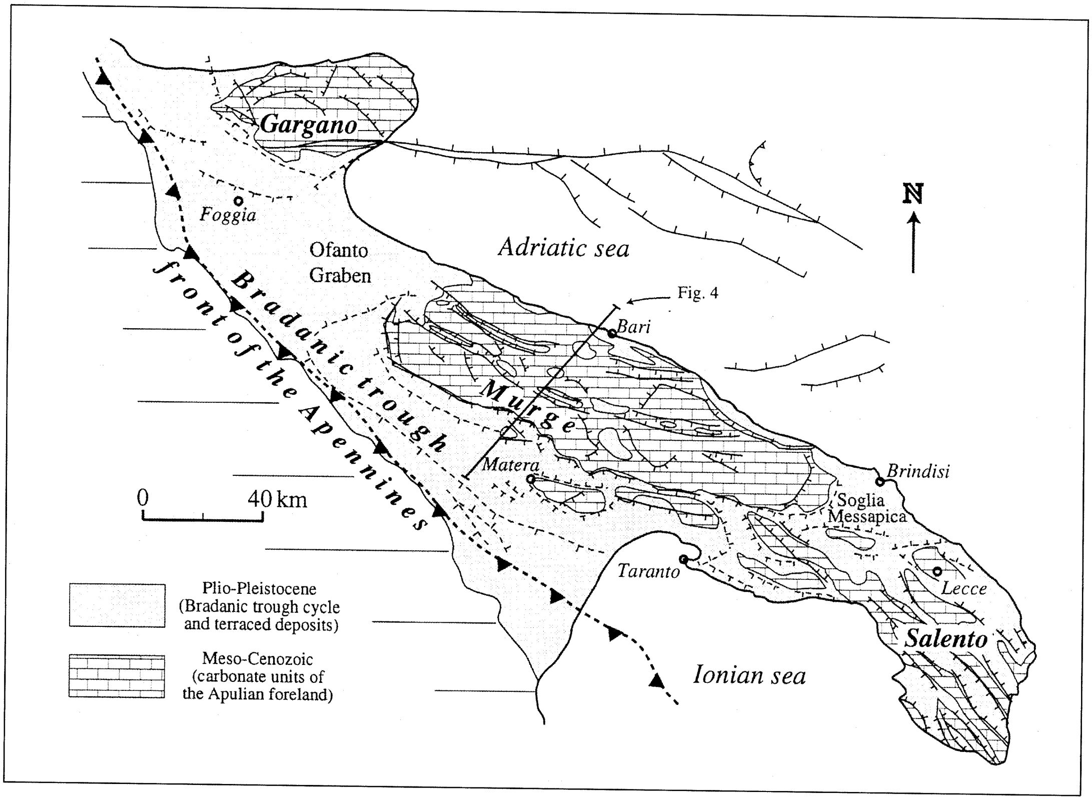

Fig. 3. Schematic geological map of the Puglia region; Gargano, Murge and Salento represent the three structural highs of the Apulian foreland.

1963; Pieri, 1980; Ricchetti, 1980) (fig. 2). These faults were active during the Plio-Pleistocene in the eastern margin of the Bradanic trough (the South-Apennines foredeep – Ciaranfi *et al.*, 1979) as indicated by syn-tectonic deposits west of Murge (Tropeano *et al.*, 1994) and, in the shelf, west of Salento (Tramutoli *et al.*, 1984).

As regards Quaternary tectonic activity inside the outcropping blocks, Gargano is a well-known seismic region of the foreland, being characterized by two main fault zones (Tremiti and Mattinata fault zones, *Auctt.*) which are capable of producing high-energy earthquakes (Postpischl, 1985); Salento presents evidence of Quaternary tectonic activity, documented by several normal faults which clearly cut also Pleistocene deposits (Martinis, 1962; Palmentola and Vignola, 1980; Tozzi, 1993; Moretti, 1996). On the contrary, both the seismicity and/or the Quaternary fault activity are poorly documented in the Murge area since not many historical earthquakes have been reported and it is not clear how the normal faults, which cut the Cretaceous substratum, affect the Quaternary deposits as the latter are very thin and poorly distributed (figs. 3, 4 and 5). For these reasons Murge is generically considered an aseismic and stable sector of the Apulian foreland (De Vivo *et al.*, 1979; Ciaranfi *et al.*, 1981; Boschi *et al.*, 1995). In spite of this deduced stability, during Plio-Pleistocene the Murge, similar to the other outcropping blocks of the foreland, suffered two distinct evolution-

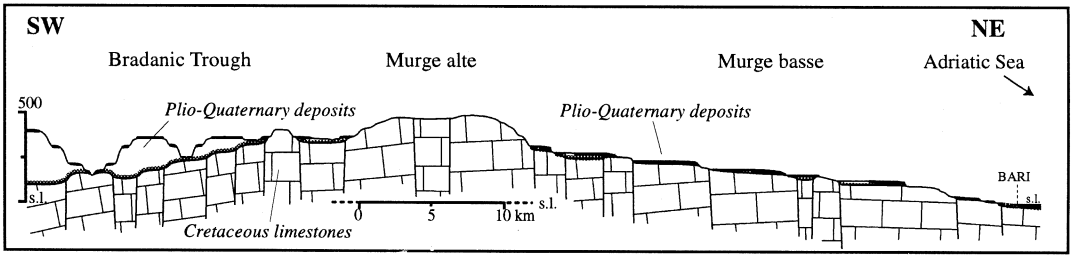

Fig. 4. Schematic geological cross-section of the Murge high (from Doglioni *et al.* 1996, modified).

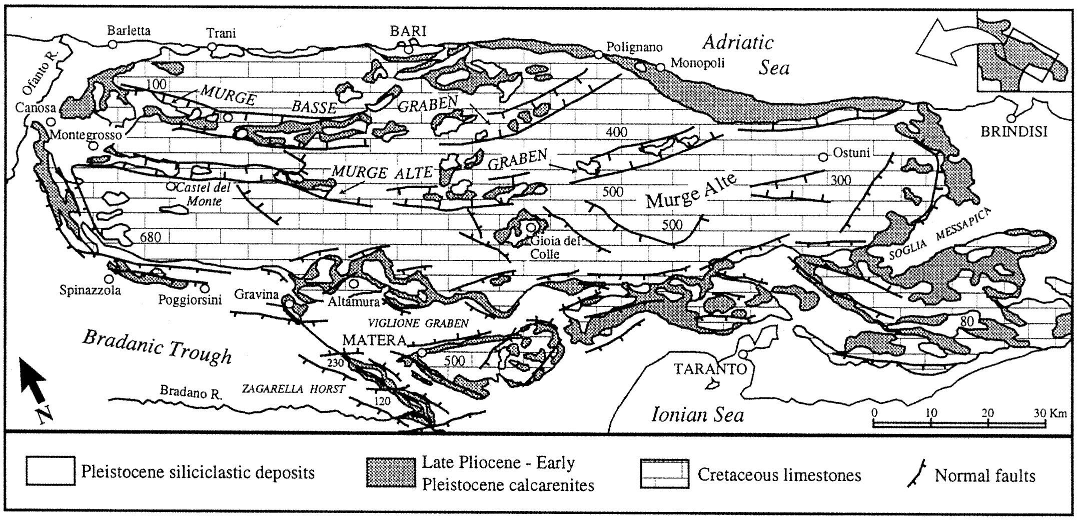

Fig. 5. Geologic map of the Murge area.

ary stages: during the Pliocene and lower part of the early Pleistocene it underwent subsidence; from the upper part of the early Pleistocene it underwent uplift (Ciaranfi *et al.*, 1983).

In particular, middle Pliocene-early Pleistocene subsidence of Murge caused the drowning of Mesozoic rocks, which had uninterruptedly emerged since the upper Cretaceous (Pieri, 1980); transgressive and deepening-upward deposits («Calcarenite di Gravina» and «Argille subappennine» formations) record this subsidence (Iannone and Pieri, 1982). The middle-late Pleistocene uplift of Murge is testified by the presence of 16 orders of uplifted shorelines, recorded by paleocliffs, abrasion platforms, and/or by thin marine terraced deposits («Depositi marini terrazzati»), that overlie the Mesozoic limestones and the late Pliocene-early Pleistocene transgressive units (Ciaranfi *et al.*, 1988). According to late Pleistocene geochronological data, uplift rates are in the order of 0.2-0.3 mm/yr (Cosentino and Gliozzi, 1988; Dai Pra and Hearty, 1988, 1989); however, stratigraphic data suggest uplift rates of at least 0.5 mm/yr (Ciaranfi *et al.*, 1994).

3. Main structural elements with Quaternary activity of the Murge area

Murge is separated from Gargano by the «Ofanto Graben» (*Auctt.*) and from Salento by the «Soglia Messapica» (*Auctt.* – also called «Taranto-Brindisi depression»; Ricchetti *et al.*, 1988) (fig. 3).

The Ofanto Graben is a large structural depression, located North of Murge and with a SW-NE trend, and is filled by a thick Plio-Pleistocene succession (locally more than 1 km in thickness); recently it has been interpreted as a «comb graben» (Doglioni *et al.*, 1994). Main faults are buried, but evidence of tectonic activity during the Plio-Pleistocene have been observed on the Murge side of the graben, near the so called «Ofanto line» (Iannone and Pieri, 1980, 1982). Outcropping faults have SW-NE, N-S and NNW-SSE main trends (Ciaranfi *et al.*, 1983).

The «Soglia Messapica» is a high scarp, mainly oriented E-W, which separates Southern Murge from Salento (Pieri, 1980). The relationship between Murge and Salento is not simple, being due to different rotations of the two main blocks and to strike slip movements along their boundary (Funiciello *et al.*, 1991; Tozzi, 1993; «North-Salento Fault Zone» of Gambini and Tozzi, 1996). In fact, more correctly, Murge and Salento are separated by a large deformation zone, with E-W trend, which corresponds to a large «triangular» depression to the east (filled by a thick succession of Plio-Pleistocene deposits – Ciaranfi *et al.*, 1988; Ricchetti *et al.*, 1988) and to a series of small uplifted blocks and depressions to the west. The latter feature is particularly evident between Matera and Mottola localities, where transpressional and transtensional structures are clearly associated with mainly dextral strike-slip faults; these structures show pre-syn- and post-depositional activities referred to the outcropping late Pliocene-early Pleistocene deposits (Festa, 1996; Tropeano *et al.*, 1997).

The neotectonic studies carried out for the «Progetto Finalizzato Geodinamica – CNR» showed up also the presence of some structural lineaments within Murge, dissecting the region both with WNW-ESE and E-W trends (Ciaranfi *et al.*, 1983; Ambrosetti *et al.*, 1983; Bigi *et al.*, 1988; and references therein) (fig. 5). The main regional structures within the Murge are two narrow grabens («Murge alte» and «Murge basse» Grabens) which mainly formed before the sedimentation of the Plio-Quaternary deposits of the Murge (Iannone and Pieri, 1980, 1982, 1983). These grabens are a few km wide and up to 100 km long; they are approximately parallel each other. Both run from the Ofanto valley toward the Adriatic sea, initially with WNW-ESE and then with E-W trend (fig. 5). The «Murge alte» Graben is located between Montegrosso and Fasano localities; the «Murge basse» Graben between Canosa and Polignano localities. Both grabens are structured by a NE dipping master fault and by a smaller SW dipping synthetic fault. Kinematic indicators show mainly dip-slip movements, but oblique-slip evidence has also been observed. Two morphological depressions correspond to the two grabens, which show fresh cliffed sides and are not completely sutured and/or filled by Plio-Quaternary deposits. Both could be evidence of quaternary activity of the faults.

Middle-late Pleistocene tectonic activity is best recorded in the Northern Murge. In particular, this has been documented in those settings where the marine terraced deposits are relatively thick and widely distributed (fig. 5). Normal faults, with some metres of displacement and with the same main trends of the Murge grabens and of the Ofanto line, have been observed at «Montegrosso», «Canosa» and «Canne della Battaglia» localities (Iannone and Pieri, 1980).

All the above mentioned structures have features similar to the others with the same main elongations recognized in the foreland ramp (Sella *et al.*, 1988), particularly in the sector named «premurge plateau» (Pieri *et al.*, 1994, 1996). Murge and premurge plateau are separated by a SW dipping normal fault which shows also Quaternary activity («faglia della Valle del Bradano» of Martinis, 1961). Other important normal faults, which dissect the foreland ramp, are buried by Plio-Quaternary syntectonic deposits in the Bradano trough («faglie assiali» of Pieri *et al.*, 1994, 1996).

Where the Cretaceous substratum of the pre-murge plateau outcrops, it has been observed that the foreland ramp is characterized by a complex horst and graben system (fig. 5), with structures ranging from kilometric scale (*i.e*, the Zagarella Horst) to metric scale (Pieri and Tropeano, 1994; Tropeano *et al.*, 1994), and by sinistral transtensional faults mainly oriented NW-SE (Festa, 1996). These structures show a pre- syn- and post-depositional activity referred to the late Pliocene-early Pleistocene outcropping formations. Some of the structures grew during the sedimentation of these last deposits, but others completely cut the same deposits, recording at least a middle Pleistocene tectonic activity of the observed normal and transtensional faults (Tropeano *et al.*, 1994, 1997).

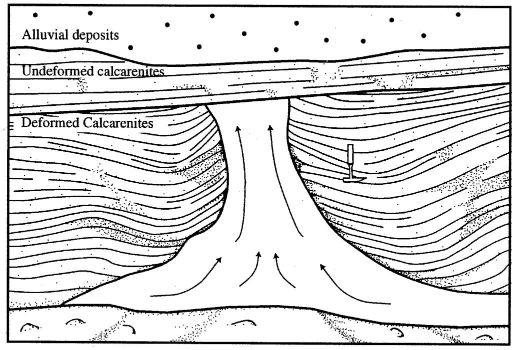

Fig. 6. Sketch of a soft-sediment deformation structure (a sand volcano) induced by seismic liquefaction in the «Depositi marini terrazzati» of Torre S. Gennaro locality.

4. Palaeoseismicity (seismites), historical and instrumental seismicity of Murge

The recognition of soft-sediment deformation structures induced by seismic liquefaction and/or fluidization processes (seismites, *sensu* Seilacher, 1969) represents one of the more innovative tools for palaeoseismological studies (Obermeier, 1996). In particular, seismites are sedimentary fossil records of moderate to high magnitude seismic events ($M \geq 5$, Audemard and de Santis, 1991; Obermeier, 1996) and generally they occur within a range of 40 km from the earthquake epicenter (Galli and Meloni, 1993).

Several soft-sediment deformation structures (*i.e.*, sand volcanoes, load casts, and balls and pillows – fig. 6) have been recognised in the marine terraced deposits of the Murge, and most of them have been attributed to liquefaction induced by earthquakes; younger seismites outcrop near the Adriatic coast of the Murge (near Trani, Bari and Brindisi localities – fig. 7) and also deform Tyrrhenian deposits (Moretti *et al.*, 1994, 1995; Moretti and Tropeano, 1996; Moretti, 1997).

Making use of empirical relationships between magnitude and distances of observed liquefaction phenomena from historical earthquake epicenters in Italy (Galli and Meloni, 1993), the Murge seismites may have been induced only by seismic events of $M \geq 5$ located within the Murge and/or the near Adriatic shelf (Moretti *et al.*, 1995).

As regards the historical seismicity, Baratta (1901) and Kàrnìk (1969) point out some strong earthquakes inside the Murge, but their exact location and true Magnitude are considered uncertain. On the contrary low-energy eartquakes are well known inside the Murge (*i.e*, the 1977 Spinazzola earthquake – Panza and Calcagnile, 1977) and events of maximum intensity of 5° in the MCS scale should be expected (Calcagnile and Del Gaudio, 1990).

Other evidence of recent seismicity and tectonic activity of the Murge have been supplied by Forti and Postpischl (1984) who analysed discontinuities in the growth of stalagmites and displacements of their axes in several caves of the Murge. According to Bruno and Sgobba (1993) the observed evidence is due more probably to slow tectonic displacements rather than to the low-energy earthquakes which seem to characterize the Murge.

More recently, the instrumental record of low-energy earthquakes ($M \leq 3.2$) with epicenters inside the Murge (1988 Poggiorsini; 1988 Altamura-Santeramo; 1991 Castel del Monte – fig. 7) have clearly demonstrated present tectonic activity of some of the above mentioned faults (Del Gaudio *et al.*, 1997).

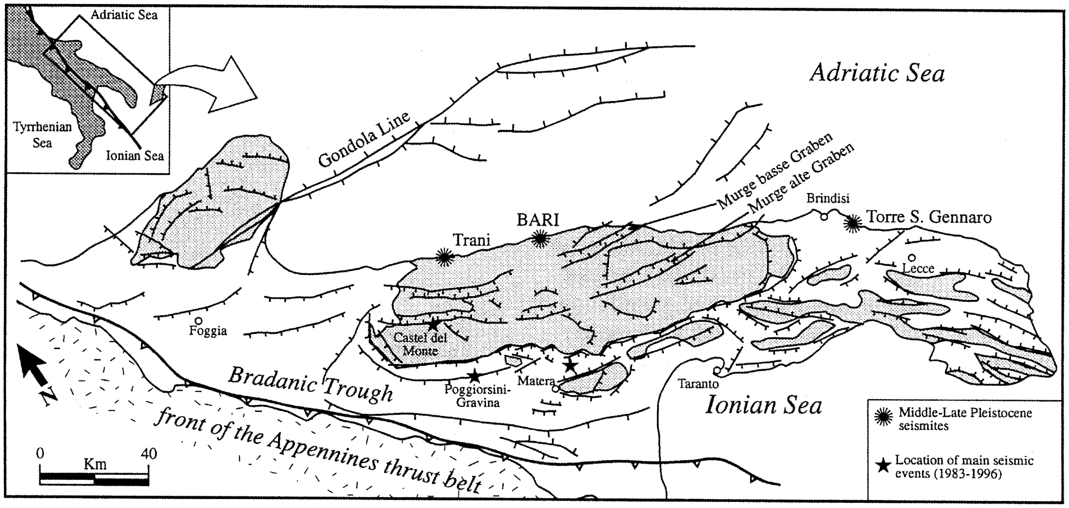

Fig. 7. Structural sketch of the Apulian foreland: localization of seismites and main instrumental seismic shocks. Note the distance of Gondola line from the observed seismites.

5. Discussion and concluding remarks

The above data allow us to suggest a new seismotectonic picture of the Murge area, which is often represented by a «white area» in the seismic zonation and structural maps of the Apulian foreland.

The Apulian foreland is dissected into several blocks because of the oblique interaction of the rigid and thick Apulian ridge with the Apennines and Dinaric orogens (Doglioni *et al.*, 1994, 1996; Gambini and Tozzi, 1996). The antiformal structure assumed by the Apulian ridge, which is also considered a peripheral bulge (*i.e.*, Argnani *et al.*, 1993; de Alteriis, 1995), and its Quaternary high uplift rates have been attributed to a lithospheric buckling due to the slower and shallower penetration rate of the lithospheric slab compared with its eastward rollback rate (Doglioni *et al.*, 1994, 1996) (fig. 8).

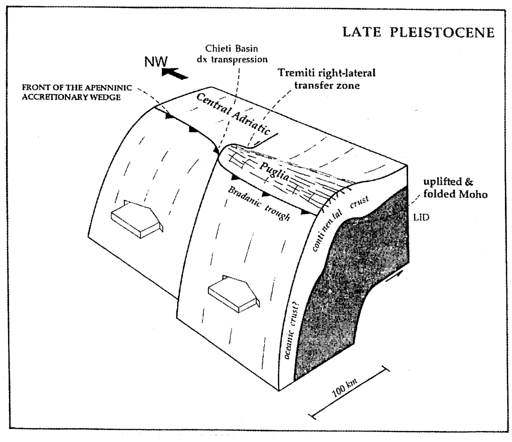

Fig. 8. Block-diagram showing the larger eastward rollback of the Central Adriatic lithosphere relative to the uplifting Puglia, where the lithosphere is thicker (from Doglioni *et al.*, 1994, 1996).

The murge represents one of the outcropping blocks of the Apulian foreland and clearly shows an antiformal structure; it suffered subsidence during middle Pliocene-early Pleistocene and then uplift during middle-late Pleistocene. The Murge is dissected by normal and transtensional faults, activated before the Plio-Pleistocene transgression, being mainly buried by Plio-Pleistocene deposits, but also having grown during subsidence and during the following uplift. Upper Pliocene-early Pleistocene deposits folded or cut by some faults indicate tectonic activity, at least up to the middle Pleistocene; but the recorded earthquakes with epicenters near the main Murge faults prove a present tectonic activity within the region.

The bulk of exposed data proves that, as regards the Murge region, the large bounding deformation zones («Ofanto line» and «Soglia Messapica») and the main horst and graben systems (which are mainly oriented parallel to the axis of foreland buckling) are still slowly developing, and the whole Murge antiformal structure should be considered to be still growing. Uplift of the Murge is marked by the growth of several normal and transtensional faults, which produce low-energy earthquakes instrumentally recorded in the last ten years.

As regards the seismicity of the region, there is an apparent contrast between the palaeoseismic data (both seismites and ancient historical seismic data) and the instrumental recorded earthquakes. The latter indicate low-energy events ($M \leq 3.2$) comparable with the expected maximum intensity of the earthquakes inside the Murge ($I \leq 5°$ MCS). On the contrary, the seismites observed in Tyrrhenian deposits along the Adriatic coast of the Murge indicate «palaeo-events» due to earthquakes of uncertain location but with $M \geq 5$ and able to cause a local PGA of no less than 0.2 g (Moretti *et al.*, 1995; Moretti and Tropeano, 1996; Moretti, 1997).

From macroseismic maps of historical earthquakes of Gargano it is possible to observe that the Adriatic coast of the Murge may be affected by tsunamis and by a local $I = 7°/8°$ MCS (Tinti *et al.*, 1995), higher than that expected by local events. Furthermore, the South Gargano line (Finetti, 1982; Ambrosetti *et al.*, 1983), which runs as the Mattinata fault zone south of the Gargano block and as the Gondola line in the South Adriatic Sea (*Auctt.*), is a high-energy seismogenetic fault on land (*i.e*, Postpischl, 1985), but clearly shows present seismicity (Favali *et al.*, 1990) and present deformation of the sea floor in its offshore prosecution (de Alteriis and Aiello, 1993).

In accordance with Moretti and Tropeano (1996) and Moretti (1997), the Gondola line is the known high-energy seismogenetic line inside the foreland closest to the Adriatic coast of the Murge (it runs up to 50 km offshore Bari) and could be considered the most probable source of high-energy historical and palaeoseismic events recorded inside the Murge.

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