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Cretaceous structural features of the Murge area (Apulian Foreland, Southern Italy)

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Key words: Murge, Apulian foreland, Apulian Platform, structural analysis, Cretaceous brittle deformation, normal faults, oblique tranfer faults

ABSTRACT

Structural analysis carried out on the Cretaceous succession of the Apulian Platform allows to propose a new tectonic framework for the Murge area (Puglia, Southern Italy). Regional deformations are represented mainly by faults and secondly by fault-related gentle folds. At the outcrop scale, faults and tectonic stylolite peaks represent the most common mesoscopic-structures. Structurally, the Murge area can be divided into two main zones, a northern and a southeastern one, where two different associations of brittle tectonic structures can be recognized. Regionally, and in map view, faults show an arcuate shape with convexity towards the SW. They trend NW-SE in the northern sector whereas they curve toward an E-W trend in the southeastern one. The kinematic indicators reveal dip-slip movement on the NW-SE trending fault surfaces and dextral transtensional movement on the E-W trending ones. E-W trending faults are interpreted as oblique transfer faults with respect to the NW-SE trending normal ones. The system of normal and transtensional faults in the Aplulian Platform controlled, at least from Late Createceous, the regional dip of the carbonate Cretaceous succession toward SW and the deposition of the "Calcare di Altamura" Fm.

RIASSUNTO

L'analisi strutturale condotta sulla successione cretacica della Piattaforma Apula consente di proporre un nuovo quadro tettonico per l'area delle Murge (Puglia, Italia meridionale). Le deformazioni regionali sono principalmente rappresentate da faglie e subordinatamente da blande pieghe legate a faglie. Alla scala dell'affioramento, faglie e picchi stilolitici di origine tettonica rappresentano le più comuni strutture mesoscopiche. Dal punto di vista strutturale, le Murge possono essere suddivise in due zone principali, una settentrionale e una sud-orientale, in cui due differenti associazioni di strutture tettoniche fragili possono essere riconosciute. Regionalmente, ed in pianta, le faglie mostrano una forma arcuata con una convessità rivolta verso SW. Esse sono allineate in senso NW-SE nel settore settentrionale, mentre assumono una direzione E-W nel settore sud-orientale. Gli indicatori cinematici rivelano un movimento di tipo normale lungo le faglie orientate in senso NW-SE ad un movimento transtensivo destro lungo quelle orientate in senso E-W. Le faglie orientate in senso E-W vengono interpretate come faglie di trasferimento oblique rispetto alle faglie normali con direzione NW-SE. Il sistema di faglie normali e transtensive nella Piattaforma Apula ha controllato, a cominciare almeno dal Cretaceo superiore, sia la regionale immersione verso SW della successione cretacica sia la deposizione della formazione del "Calcare di Altamura".

1. Introduction

Tectonic studies on foreland areas, especially those flanking active mountain belts, may yield important information for tectonic evolution of orogens. In fact, structures of foreland domains involved in orogenesis may control the development of thrust-related structures. In addition, their study may contribute to constrain the pre-compressional deformation observed in several mountain belts (e.g. Tavarnelli 1996 and references therein).

The Apulian foreland (Puglia region, Southern Italy) (Selli 1962) represents the Plio-Pleistocene foreland of both the Apenninic (to the W) and the Dinaric-Hellenic (to the E) orogens (Ricchetti et al. 1988; Funiciello et al. 1991; Argnani et al. 1993) (Fig. 1A). The southern Adriatic sea, to the E, represents the Late Miocene – Quaternary foredeep of the Dinaric orogen (Royden et al. 1987; Argnani et al. 1996); the Bradanic trough, to the W, and the Taranto Gulf represent the Pliocene – Quaternary foredeep of the Apenninic orogen (Crescenti 1975; Pescatore & Senatore 1986; Casnedi 1988; Pieri et al. 1996) (Fig. 1A). The Apulian foreland is characterised by three main structural highs separated by morpho-structural depressions. These main structural highs are represented, from NW to SE, by the Gargano, Murge and Salento areas (Ciaranfi et al. 1983; Ricchetti et al. 1988; Pieri et al. 1997) where Cretaceous carbonates of the Apulian Platform mainly crop out (D'Argenio et al. 1973; Ricchetti et al. 1988) (Fig. 1B). The aim of this work is to point out the Cretaceous tectonics of the

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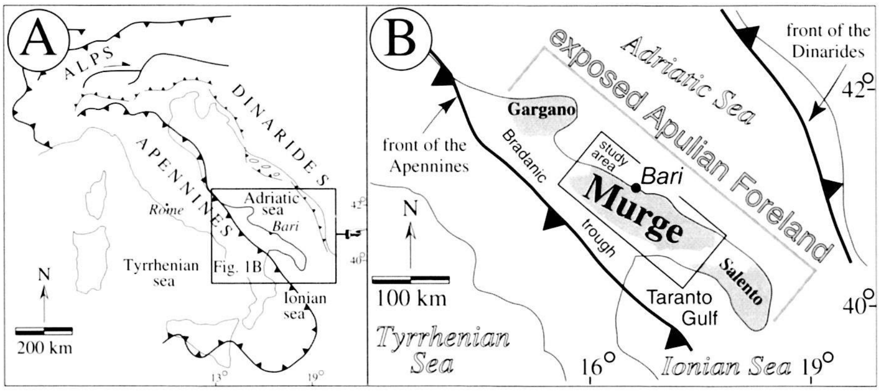

Fig. 1. A & B: Sketch maps illustrating the location of the study area. In Fig. B the grey filled area indicates zones in which the carbonates of the Apulian Platform mainly crop out.

Murge area (Fig. 1B), that up to now has regionally been hypothesized mainly on the basis of stratigraphic data (Ricchetti 1980; Ricchetti et al. 1988; Mindszenty et al. 1995; Luperto Sinni & Borgomano 1989; Pieri & Laviano 1989). Only in the Gargano area, the presence of Cretaceous faults in the Apulian foreland related to the Apulian Platform growth is documented (Winter & Tapponnier 1991; Chilovi et al. 2000). On the contrary, in adjacent sectors of the Apulian Foreland area, such as the central Apennines and Adriatic basin, there is much evidence for Cretaceous extension (e.g. Decandia 1982; Winter & Tapponnier 1991; Del Ben et al. 1994; Tavarnelli 1996).

The structural analysis carried out in the Murge area led to qualitative results about brittle tectonic deformation and to propose a new tectonic framework for this area. Moreover most of the present day observed structural features, both mesoscopic (m- to cm-scale) and macroscopic (km-scale), may be inherited from late Cretaceous deformation, probably connected to the late rifting stage of the Neotethys (e.g. Stampfli 2000).

In order to describe structural features of the Murge area, the terminology proposed by Gibbs (1984) and Peacock & Sanderson (1995) is used in the present contribution.

2. Geological setting of the Murge area

2.1 Stratigraphy.

The Apulian foreland (Selli 1962) is characterised by a uniform crustal structure with a Variscan crystalline basement and a ca. 7 km thick Mesozoic sedimentary cover mainly made up of limestones and dolostones of the Apulian Platform overlain by relatively thin and discontinuous Tertiary and Quaternary deposits (Ricchetti et al. 1988). In particular, the Mesozoic succession consists, from the bottom to the top, of terrigenous and anhydrite deposits (Permian – Trias) and of dolomitic and calcareous rocks of the Apulian Platform (Jurassic – Cretaceous), characterised by restricted platform facies (Fig. 2) (Ricchetti et al. 1988). A 3 Km thick Cretaceous succession crops out in the Murge area showing SW and SSW dip directions (Pieri 1980; Ricchetti 1980; Ciaranfi et al. 1988; Ricchetti et al. 1988). This succession, related to a wide carbonate platform, is mainly characterised by a monotonous well-bedded back-reef facies (Ricchetti 1975; 1980; Pieri 1980; Ciaranfi et al. 1988; Luperto Sinni 1996) and by minor margin and slope facies, only locally exposed (Luperto Sinni & Borgomano 1989; Pieri & Laviano 1989; Laviano et al. 1998). The Cretaceous succession becomes progressively younger from NNE toward SSW (Ciaranfi et al. 1988).

Two main formations were distinguished in the Cretaceous succession of the Murge area: the "Calcare di Bari" Fm., ca. 2000 m thick and cropping out in the northern sector, and the "Calcare di Altamura" Fm., ca. 1000 m thick and cropping out in the southern sector (Valduga 1965; Pieri 1980; Ciaranfi et al. 1988) (Fig 2). Datings based on rudist and/or microfossil (benthic foraminifers) assemblages indicate a Valanginian to late Cenomanian age for the "Calcare di Bari" Fm. and a late Turonian to Maastrichtian age for the "Calcare di Altamura" Fm. (Luperto Sinni 1996 and references therein).

A mild angular, erosional unconformity, trending WNW-ESE and dipping gently toward S and SW, separates the "Calcare di Bari" Fm. from the "Calcare di Altamura" Fm. (Ciaranfi et al. 1988; Luperto Sinni & Reina 1996) (Fig. 2). This stratigtaphic break is marked by bauxites, green clays and/or marly sands (Crescenti & Vighi 1964; Maggiore et al. 1978; Iannone & Laviano 1980). In particular, the base of the "Calcare di Altamura" Fm. is everywhere referred to the late Turonian, while the top of the Calcare di Bari Fm. becomes younger from W (middle Cenomanian) toward E (late Cenomanian) (Luperto Sinni & Reina 1996). Southward, well data indicate a chrono-stratigraphic continuity between the "Calcare di Bari" and "Calcare di Altamura" Fms. (Ricchetti 1975; Luperto Sinni & Reina 1996).

Discontinuous and thin late Pliocene – Quaternary deposits of the southern Apennines foredeep (the Bradanic trough sedimentary cycle) overlie the Cretaceous succession both within and on the flanks of the Murge high. An angular, erosional unconformity bounds the Cretaceous succession

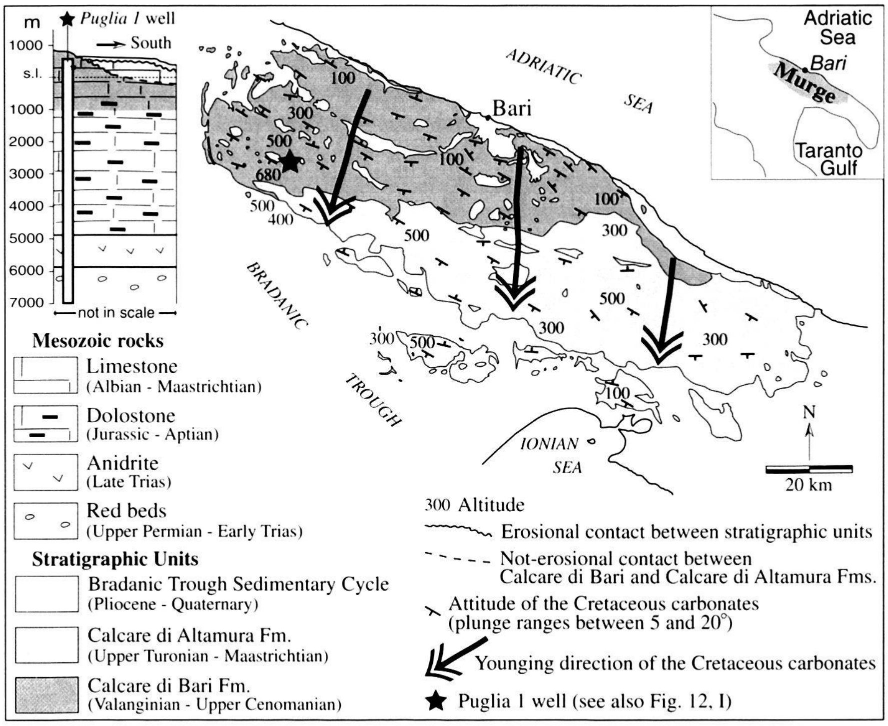

Fig. 2. Main stratigraphic units cropping out in the Murge area and their relationships with drilled ones in the study area (modified after Ciaranfi et al. 1988).

from the "Calcarenite di Gravina" Fm., which represents, with its maximum thickness of about 80 m, the base of the Pliocene-Quaternary Bradanic trough sedimentary cycle (Pieri et al. 1996, Tropeano & Sabato 2000). Datings based on biostratigraphic analysis indicate a middle Pliocene to early Pleistocene age for the "Calcarenite di Gravina Fm. (e.g. Ciaranfi et al. 1988; Tropeano & Sabato 2000 and references therein).

2.2 Tectonics.

Structurally, the Murge area is characterised by brittle deformation, without significant tectonic reflections. The recognised deformational macroscopic structures consist of gentle folds and faults.

Gentle folds have NW-SE, WNW-ESE and WSW-ENE oriented hinge lines (Martinis 1961; Valduga 1965; Pieri 1980; Ciaranfi et al. 1988; Ricchetti 1980; Ricchetti et al. 1988) (Fig. 3A). They were interpreted either as due to intraplate deformations related to Turonian and Eocene-Oligocene Alpine compressional phases (Ricchetti et al. 1988) or as foreland deformations related to the Neogene compressional tectonic regime responsible for building of the adjacent Apennines chain (Pieri 1980; Festa 1999). In particular, folds related to the Apennines contractional events are present mainly in the northwestern Murge area, that represents the immediately adjacent domain of the Apulian foreland nerby to the Apenninic thrust front (Festa 1999). Among the macroscopic folds connected to the Alpine phases, an important structure is the "Monte Acuto" anticline (Martinis 1961). This structure affects the Cretaceous succession in the north-eastern Murge and exposes in its core the oldest rocks of the region (Ricchetti 1969; Campobasso et al. 1972; Luperto Sinni & Masse 1984) (Fig. 3a). Ricchetti (1980) and Ricchetti et al. (1988) recognised another large, gentle anticline with an ESE plunging hinge line trending close to the Adriatic coast line of the

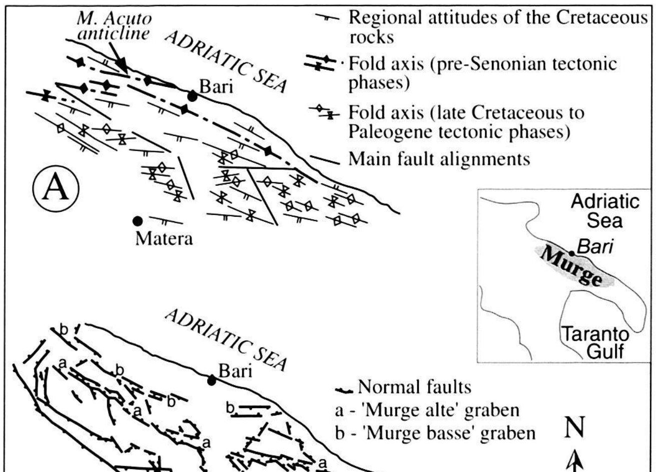

Fig. 3. A: structural map of the Murge area modified after Ricchetti (1969) and Ricchetti et al. (1988). B: neotectonic map of the Murge area (Iannone & Pieri 1982).

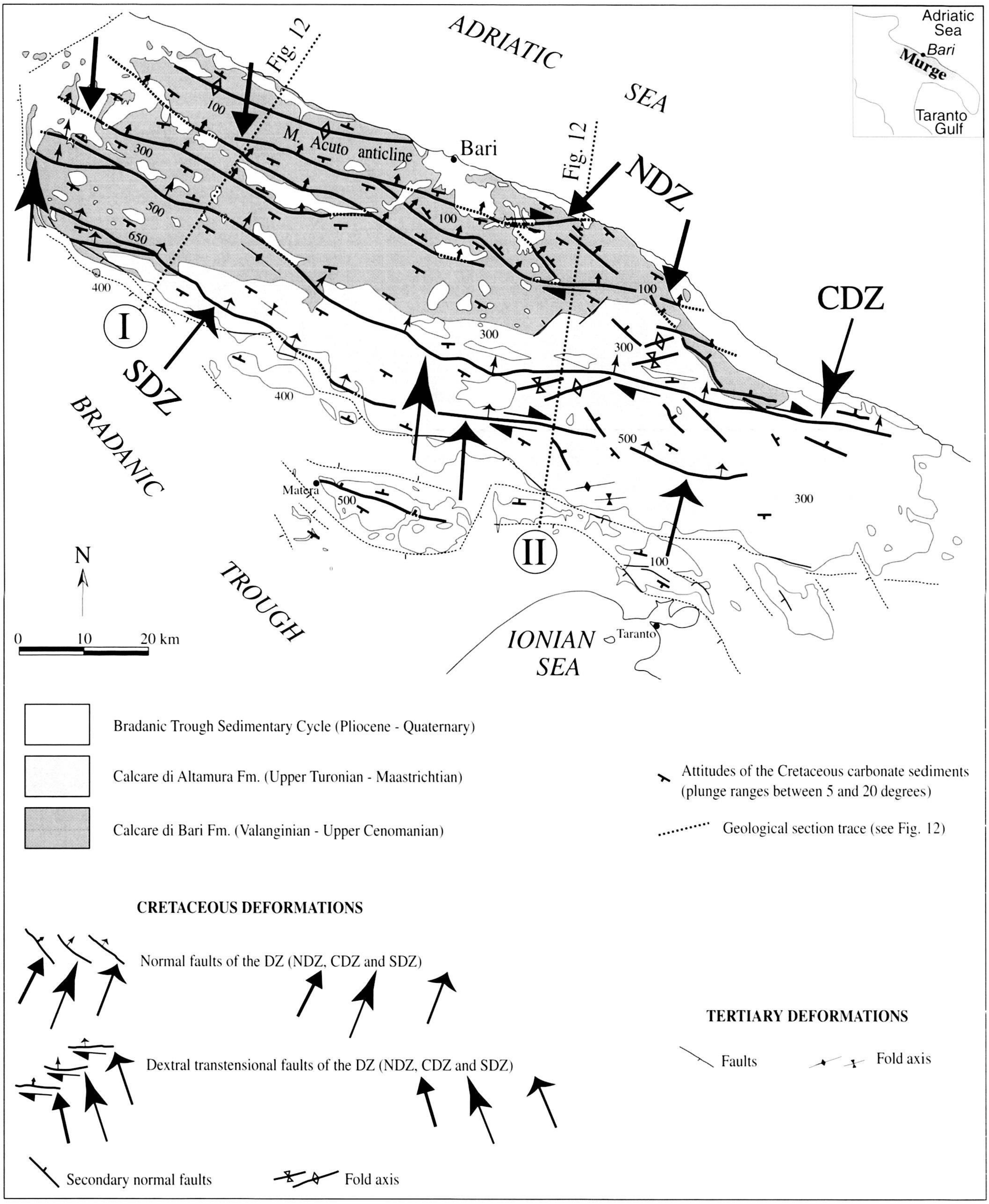

Fig. 4. Structural map of the Murge area. In particular, different styles of arrows are used to discriminate the NDZ (Northern Deformation Zone), the CDZ (Central Deformation Zone) and the SDZ (Southern Deformation Zone).

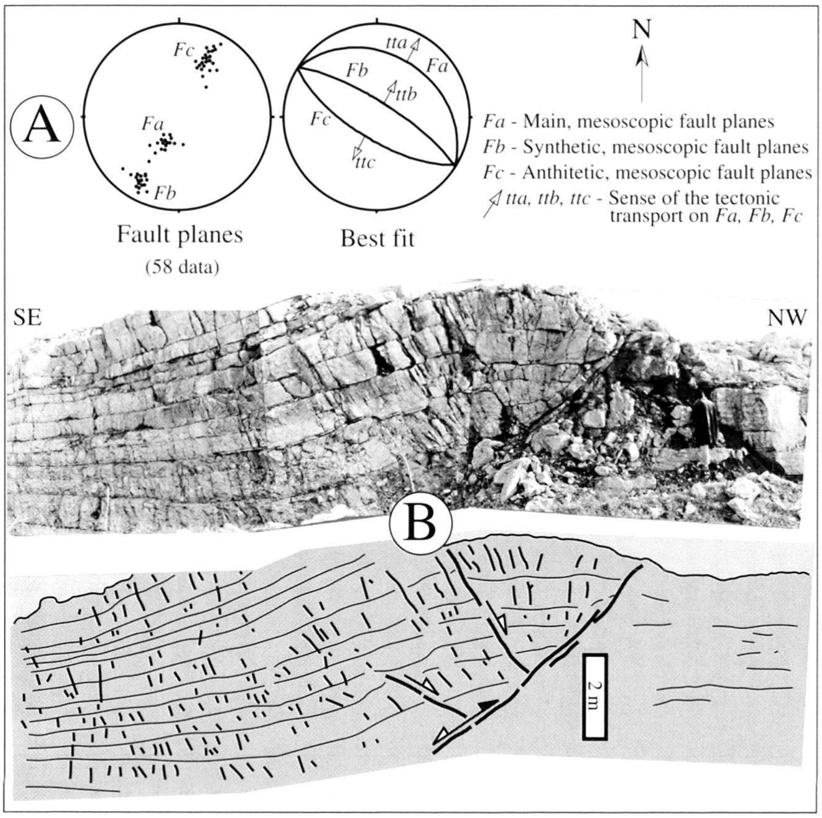

Fig. 5. A: Lower hemisphere equal area projections of NW-SE oriented extensional mesoscopic faults cropping out near NW-SE striking segments of the DZ (northern Murge) and active at least from late Cretaceous. B (photograph and interpretation): NW-SE striking normal synsedimentary fault in Cenomanian rocks (northern Murge); the extensional movement is indicated by the empty arrow. Note the preservation of a greater thickness of sediment on the hanginwall and the following reactivation as reverse fault; the reverse movement is indicated by the filled arrow.

Murge area. SW and SSW-dip directions of the Cretaceous succession stratal surfaces were ascribed to the southern limb of this large-scale fold (Fig. 3a). Moreover, an intraplate compressional E-W trending regional fold, that determined an infra-Cretaceous bulge, was hypothesised to account for the unconformity between the two Cretaceous formations on its southern limb (Mindszenty et al. 1995).

The main recognised faults trend N-S, NW-SE, WNW-ESE, NE-SW and E-W (Fig. 3b). The main regional faults bound the Murge high from the adjacent morpho-structural depressions and divide it into different blocks (Martinis 1961; Ricchetti 1980; Iannone & Pieri 1982; Gambini & Tozzi 1996; Pieri et al. 1997). Among these regional faults, the "Murge alte graben" and the "Murge basse graben" represent large structural fault associations within the considered area (Iannone & Pieri. 1982; Pieri et al. 1997) (Fig. 3b). All these faults are mainly considered as due to Pliocene and Pleistocene mild deformations (Iannone & Pieri 1982; Ciaranfi et al 1983; Tropeano et al. 1994; Pieri et al. 1997), but their activity since Miocene time cannot be ruled out (Pieri 1980; Iannone & Pieri 1982; Ciaranfi et al. 1983; Funiciello et al. 1991; Gambini & Tozzi 1996). Faults are interpreted as the effects of the extensional, transtensional and transcurrent deformations mainly related to the tectonic evolution of the Apulian foreland – Apennines chain system (Pieri et al. 1997 and references therein). The presence of older Upper Cretaceous faults was hypotesised only on the basis of stratigraphic evidence (Luperto Sinni & Borgomano 1989; Pieri & Laviano, 1989), even though no structural data have so far been provided to test this hypothesis.

3. Structural analysis

A new structural analysis was carried out in the Murge area and was performed at both map- and outcrop-scales. At the map scale, mainly faults and related folds represent large, brittle tectonic deformations of the Cretaceous succession of the Apulian Platform. At the outcrop scale the analysed mesoscopic-structural elements are tectonic stylolite peaks and faults. The latter produce diplacements of marker beds up to 2 m.

At the map scale, the Cretaceous succession shows three Deformation Zones (hereafter indicated as DZ). Each DZ is characterised by the presence of regional faults that affect both the "Calcare di Bari" Fm. and the "Calcare di Altamura" Fm. (Fig. 4). The DZ trend NW-SE to WNW-ESE and show an arcuate shape convex towards the southwest. They are few hundreds of metres wide and up to 100 km long. In the northwestern sector of the Murge area, the DZ strike NW-SE, whereas in the southeastern sector they are deflected toward an E-W

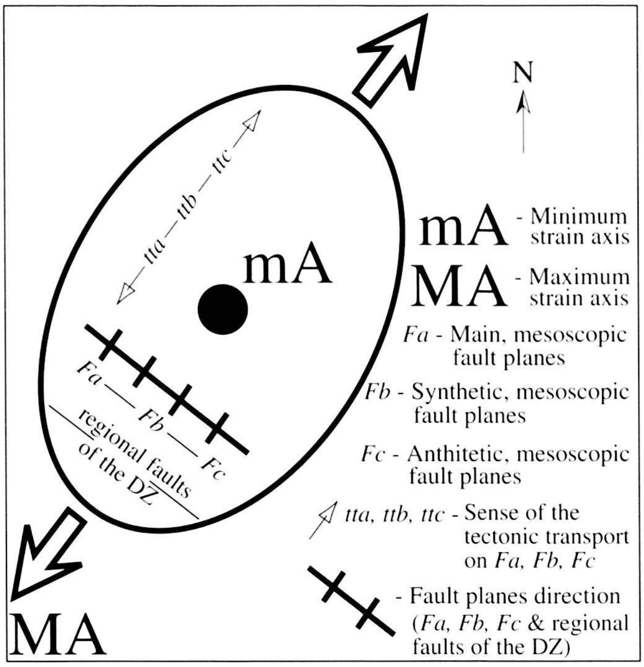

Fig. 6. Qualitative deformational strain ellipse for the northern Murge during Late Cretaceous.

strike. In detail, an array of anastomosed faults affects the Northern Deformation Zone (hereafter indicated as NDZ); a single, large fault charaterises the Central Deformation Zone (CDZ); a single fault, with discontinuities towards its southeastern termination, charaterises the Southern Deformation Zone (SDZ). Regional faults of the three DZ mainly dip toward N and northeastward, with dip angles ranging between 70° and 50°; northeastward-dipping fault surfaces are common in the NW-SE oriented segments of the DZ, whereas northward dipping surfaces characterise the E-W striking segments. The calculated dip-slip displacement toward NE for each regional fault ranges approximately between 150 m and 400 m. The zones located between the E-W striking segments of the DZ are affected by secondary, macroscopic normal faults striking NNW-SSE. These structures dip towards ENE and define, in map view, an en-échelon array with respect to the E-W oriented segments of the host DZ. This en-échelon pattern is particularly evident in the southeastern Murge area, between the NDZ and the CDZ. Normal faults are accompanied by development of mild folds. The most important fold structure is represented by the "Monte Acuto" anticline (Fig. 4), a large symmetrical, gentle anticline with a 10° SE-plunging axis that intersects the topography in the northeastern Murge. The axial plane trace of this anticline extends for about 30 Km near the Adriatic coastline of the northeastern Murge area. In map view, similarly to the three DZ, its axial plane trace shows an arcuate shape with a gentle convexity towards the southwest (Fig. 4). Northwards, it strikes NW-SE whereas southwards it curves towards an E-W trend. Other minor folds are present near E-W trending segments of the DZ. They are macroscopic, symmetrical open folds showing ENE-WSW oriented axial planes. When seen in map view, these structures define an en-échelon array with the E-W oriented portions of the DZ. This fold pattern is particularly evident in the southeastern Murge area, near the CDZ and in the zone between the NDZ and the CDZ.

The mesoscopic structural analysis was carried out along regional faults of the DZ, where tectonic stylolite peaks and faults were examined. The measured kinematic indicators suggest dip-slip movements on mesoscopic faults near the NW-SE striking segments of the DZ. Extensional mesoscopic faults, consisting of NW-SE trending planar surfaces, define extensional systems of synthetic and anthitetic faults. These extensional mesoscopic faults dip both northeastward and southwestward. The main mesoscopic faults dip about 45°, while associated synthetic and antithetic faults dip 50° – 70° (Fig. 5A & Fig. 5B). Gentle to open drag folds represent the hanging-wall deformation effects related to the extensional slip along the mesoscopic normal fault surfaces. Often these extensional mesoscopic faults exhibit the features of growth structures. The preservation of a greater thickness of carbonates on the hanginwall with respect to the footwall is evidence for a synsedimentary tectonic activity at least during Upper Cretaceous time (Fig. 5B). Nevertheless, in some cases this faults were reactivated during subsequent tectonic phases (Fig. 5B).

Macroscopic and mesoscopic structural data collected near NW-SE striking segments of the DZ and in the zones between them are consistent with a qualitative strain ellipse characterised by a vertical minimum strain axis (mA) and a horizontal maximum one (MA). The maximum inferred strain axis is oriented NE-SW in the present geographic coordinates. This strain ellipse can be related to NE-SW directed extension that was active at least from Late Cretaceous. This inference is consistent with the NW-SE trending extensional growth mesoscopic faults (Fig. 6).

The domains between E-W striking segments of the DZ are affected by either transtensional or extensional mesoscopic faults. The transtensional faults consist of E-W oriented surfaces dipping ca. 70° towards north (Fig. 7A & Fig. 7B). They show kinematic indicators, basically represented by pull aparts and P fractures, suggesting dextral-oblique slip (Fig. 7C). The extensional faults consist of NNW-SSE trending planar surfaces making up systems of linked synthetic and antithetic faults. Extensional mesoscopic faults dip toward either ENE or WSW. The main faults dip ca. 50°, whereas synthetic and antithetic associated faults have dip angles ranging from ca. 50° to 70° (Fig. 8A & Fig. 8B). In several cases right transtensional and extensional mesoscopic faults are growth structures. A synsedimentary tectonic activity is recorded in the hangingwalls of these right transtensional and extensional structures, where Upper Cretaceous carbonates show: (i) the preservation of a greater stratigraphic thickness with respect to the footwall,

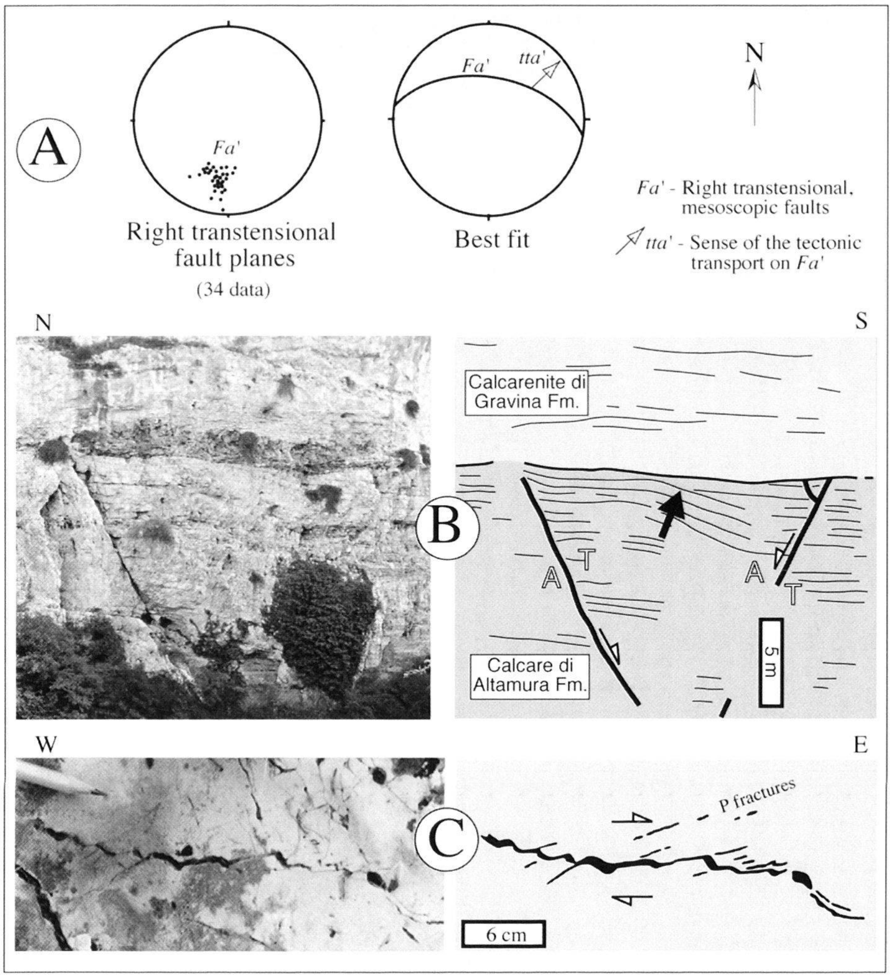

Fig. 7. A: Lower hemisphere equal area projections of the right transtensional mesoscopic faults E-W striking, cropping out near E-W striking segments of the DZ (southern Murge) and active at least from late Creaceous. B (photograph and interpretation): System of E-W striking, right transtensional faults. Note the intra-Senonian synsedimentary stratal discontinuity (indicated by black filled arrow) in the hanginwall, with younger carbonates onlapping deformed ancient ones. C (photograph and interpretation): System of pull-aparts and P fractures indicating the destral component of the movement on a E-W striking mesoscopic fault.

(ii) the progressive decrease of stratal surface dip from bottom to top and (iii) the presence of synsedimentary stratal discontinuities (Fig. 7B & Fig. 8B). Several Upper Cretaceous growth mesoscopic structures, observed along regional faults of the DZ, are sutured by the Plio-Pleistocenic sediments of the "Calcarenite di Gravina" Fm., as shown in Fig. 8B. Nevertheless, in some cases these faults also offset the "Calcarenite di Gravina" Fm., indicating reactivation during the Pliocene – Present time interval. Compressional mesoscopic structures are mainly localized along the nearby W-E striking segments of the DZ. They consist of sub-horizontal tectonic stylolite peaks striking NW-SE (Fig. 9).

Mesoscopic and macroscopic structural data near the E-W oriented segments of the DZ and in zones between them, are consistent with a qualitative strain ellipse characterised by a horizontal NNW-SSE directed minimum strain axis (m'A) and a horizontal ENE-WSW directed maximum one (M'A), in the present geographic coordinates. This strain ellipse can be associated with the E-W directed strike-slip component of movement that is present in right transtensional E-W trending faults (Fig. 10). Moreover, the associated deformation took place at least since Late Cretaceous time, as indicated by growth structures represented by right transtensional and extensional mesoscopic faults, that trend E-W and NNW-SSE, respectively.

4. Discussion

Structurally, the Murge area can be divided into two main zones, a northern zone and a southeastern zone, where the Cretaceous succession, represented by both the "Calcare di Bari" Fm. and the "Calcare di Altamura" Fm., was affected by two different associations of tectonic structures (Fig 11). In the northern zone, the NW-SE trending normal macroscopic and mesoscoic faults suggest a qualitative strain ellipse with vertical compressional and horizontal NW-SE oriented extensional strain axes, in the present geographic coordinates. The mesoscopic and macroscopic structures in the southeastern zone of the Murge area are represented by: NNW-SSE trending normal faults, E-W trending right trantensional mesoscopic faults,

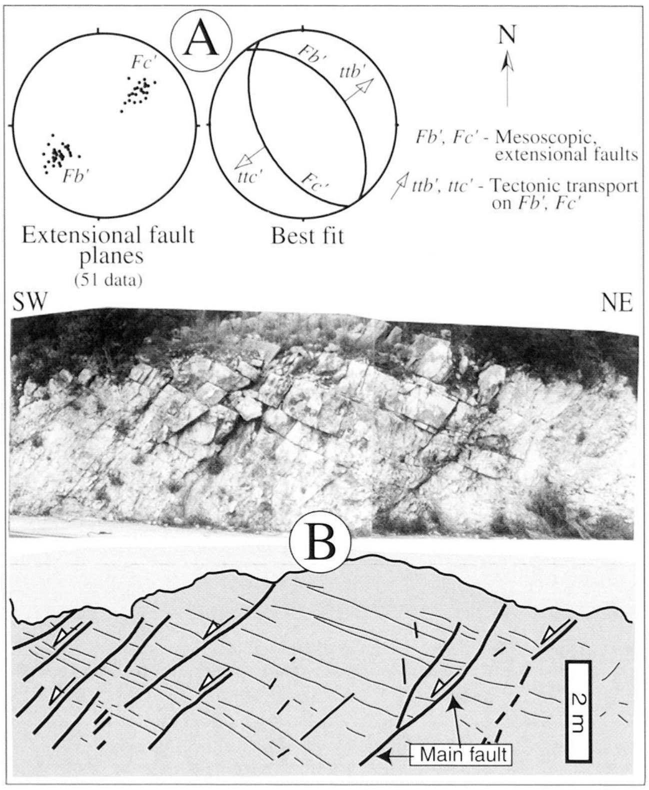

Fig. 8. A: Lower hemisphere equal area projections of the NNW-SSE striking extensional mesoscopic faults cropping out near E-W striking segments of the DZ (southern Murge) and active at least from late Creaceous. B (photograph and interpretation): NNW-SSE striking syn-sedimentary normal faults in Santonian rocks (southern Murge). Note both (i) the preservation of a greater thickness of sediments and (ii) the progressive decrease of stratal surfaces plunge from bottom to top in the hanginwall of the main fault.

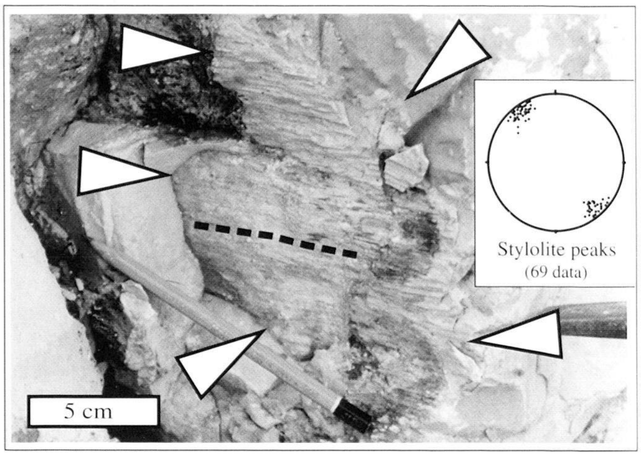

Fig. 9. Horizontal stylolite peaks in Santonian limestones on a oblique stylolite surface (indicated by the empty arrows) near E-W striking segments of the DZ (southern Murge). The dashed line indicates the direction of stylolite peaks. In the right part, their lower hemisphere equal area projection.

ENE-WSW trending sub-vertical axial plane traces of macroscopic open folds and sub-horizontal NW-SE directed tectonic stylolite peaks. The combination of these tectonic structures suggests a qualitative strain ellipse characterised by horizontal compressional and extensional strain axes, oriented NNW-SSE and ENE-WSW respectively, in the present geographic coordinates. This strain ellipse can be associated with the right transtensional E-W trending faults. The synsedimentary character of mesoscopic faults suggests that deformation of the Apulian Platform was active, in the study area, at least since Late Cretaceous time. In this tectonic context the Cretaceous succession appears deformed by the DZ, each one characterised by the occurrence of regional faults. Fig. 12 shows two regional cross-sections (I & II) at high angle with respect to both NW-SE (I) and E-W (II) striking segments of the DZ. The main structures are represented by regional faults of DZ that dip both northeastward (I) and northward (II). These structures are postulated as planar or listric faults. Unfortunately, the controls on the deep fault geometry and the depth of the detachments are very difficult to evaluate owing to the absence of deep stratigraphic data below the Mesozoic sequence. Nevertheless, some important considerations can be done on the deep geometry of faults in the Mesozoic succession. In fact, the stratigraphy of the Murge area is well known and probably controlled the deep trajectory of some regional faults.

The blocks between regional faults are compartmentalized by smaller faults that are either synthetic (northeastward dipping) or antithetic (southwestward dipping) with respect to the NW-SE trending faults of DZ. In the Murge area, the present-day regional southwestward dip of the outcropping Apulian Platform carbonate succession (Pieri 1980; Ricchetti 1980; Ciaranfi et al. 1988; Ricchetti et al. 1988) can be interpreted as a late Cretaceous heritage generated by the southwestward rotation of fault-bounded blocks while the system of normal faults and related transfer faults of the DZ was active. This inherited regional dip is confirmed by the Plio-Pleistoce sediments of the "Calcarenite di Gravina" Fm. that seal Upper Cretaceous growth mesoscopic structures. Within DZ, E-W trending faults may represent oblique transfer faults of the NW-SE trending normal faults to define a linked extensional fault system (Fig. 4 & Fig. 11). The weak Pliocene-Quaternary activity of faults in the Murge area (Pieri et al. 1997 and references therein) can be related to the reactivation of some Cretaceous faults during the tectonic evolution of the Apulian foreland – Bradanic trough – Apennine chain system. This reactivation is confirmed by the good correspondance between the CDZ and the "Murge alte" graben and between the NDZ and the "Murge basse" graben. The occurrence of E-W trending Cretaceous faults in the Apulian Platform and their reactivation after the Apulian foreland – Bradanic trough – Apennine chain interaction was observed by Chilovi et al. (2000) only in the Gargano area. Fault reactivation represents a common feature in the evolution of orogenic systems (Holdsworth et al. 1997). In the structural context of the Apulian foreland,

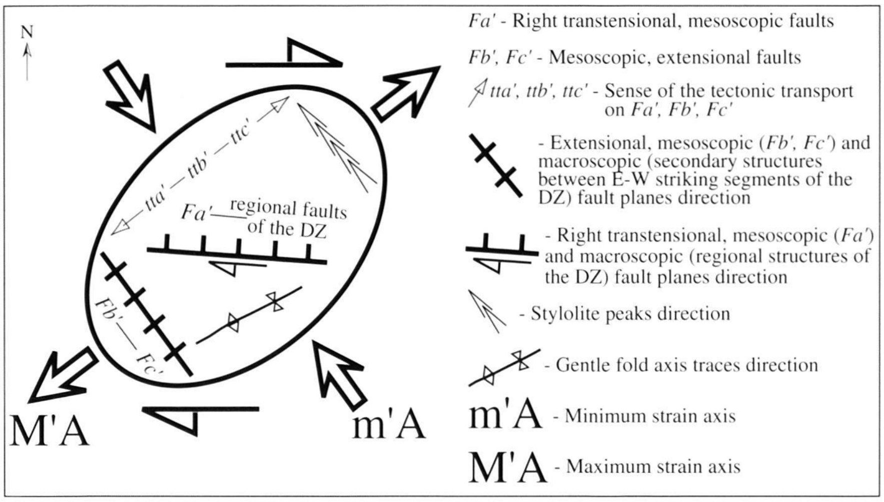

Fig 10. Qualitative deformational strain ellipse for the southern Murge during late Cretaceous.

reactivation of Cretaceous faults during Neogene time is of critical importance. In fact, it is not generally recognised that tectonic inheritance may affect areas devoid of orogenic deformations.

Open folds observed in the Cretaceous succession basically show NW-SE, WNW-ESE and WSW-ENE oriented axial plane traces. Several authors ascribed the origin of open folds to the intraplate deformation to the Late Cretaceous and Eocene Alpine tectonic phases (Ricchetti, 1980; Ciaranfi et al. 1988; Ricchetti et al. 1988). However, the folds in the northwestern sector of Murge area, seem best explained by tectonic

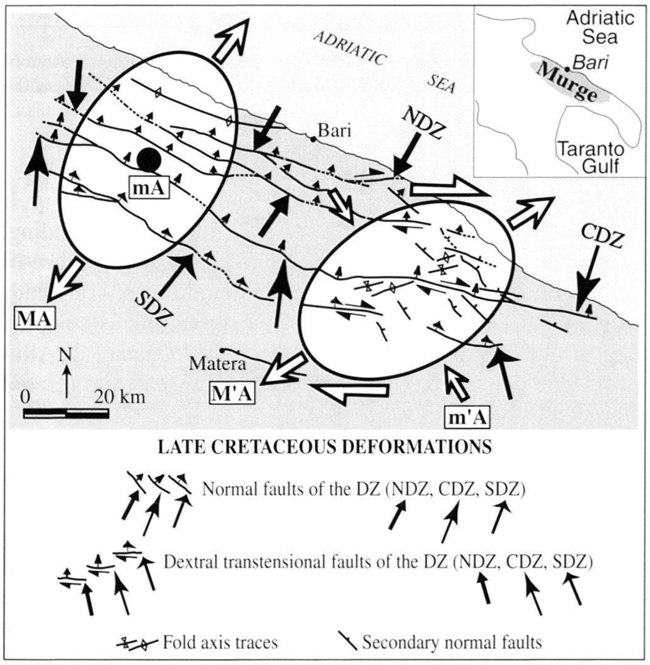

Fig 11. Comprehensive view of the late Cretaceous strain ellipse (see also Fig. 6 & Fig. 10) and deformations (see also Fig. 4) in the Murge area.

contraction related to building of the Apennine chain (Festa 1999). The regional open fold structures described in this paper can be interpreted as (i) hanging-wall deformations linked to extensional fault surface geometries and (ii) drag folds along regional faults present in the DZ (Fig. 12, I & II). In particular, the "Monte Acuto" anticline can be interpreted as a broad, roll-over anticline located in the hanging-wall of a postulated, listric normal fault of the NDZ and produced above footwall ramps connected by a flat (Fig. 12, I). In fact, in map wiew the axial plane trace of the "Monte Acuto" anticline and the NDZ are parallel (Fig. 4), suggesting a kinematic link between faulting and hanging-wall folding. The occurrence of the flat in the fault trajectory may be reasonably controlled by the presence of the weak anhydrite horizon at the base of the Apulian Platform succession.

For what concerns the gentle angular unconformity between the "Calcare di Bari" Fm. and the "Calcare di Altamura" Fm., the occurrence of an infra-Cretaceous lithospheric bending, as hypothesised by Mindszenty et al. (1995), cannot be ruled out. The culmination of this regional bending may be located in corrispondance of the "Monte Acuto" anticline, that grew at least from late Cretaceous. The "Calcare di Altamura" Fm. deposited on the subsident southern limb of the lithospheric bending when the system of normal and related oblique transfer faults was active (Fig 4 & Fig. 12). The attempt to explain the occurrence of the infra-Cretaceous unconformity and the deposition of the "Calcare di Altamura" Fm. allows to locate the Murge sector of the Apulian Platform in the subsident "B zone" of the basin formation model of Wernicke (1985).

5. Conclusions

A new tectonic framework is proposed for the Murge area. It is recorded by structures recognised on a variety of scales, from regional to mesoscopic. Large-scale structures are mainly represented by dextral oblique transfer regional faults connected to normal faults and, secondly, by open fault-related

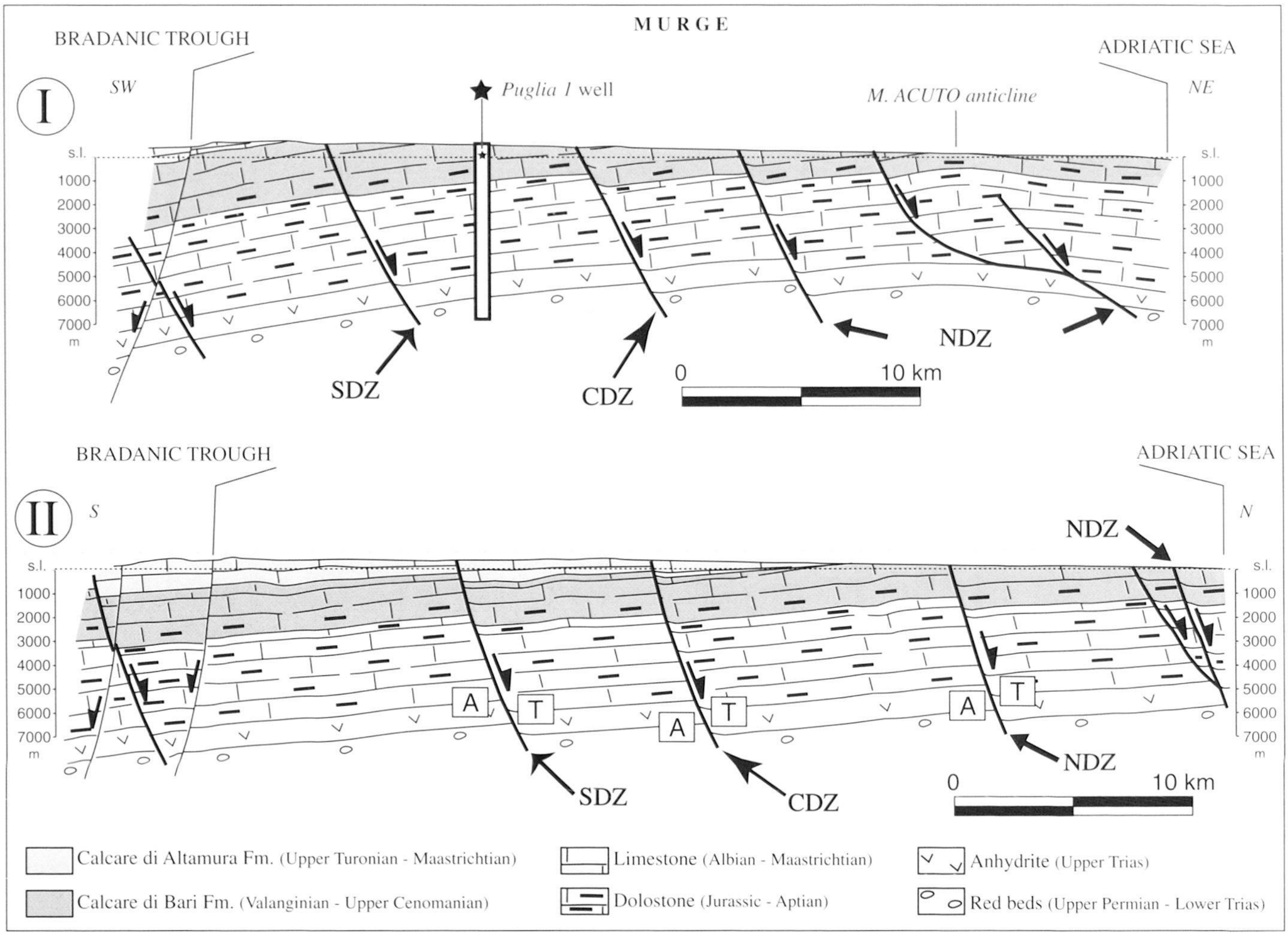

Fig. 12. Geological cross-sections across the Murge (see traces in Fig. 4). Large-scale faults of the DZ affect the Cretaceous succession to form a system of normal faults (I) and related oblique transfer faults (II) (see also Fig. 4). Note that the "Monte Acuto" anticline is related to the deep geometry of faults of the NDZ (I).

folds. Mesoscopic structures are represented by faults and stylolite peaks. Field evidence and structural analysis indicate that these structures were all active at least since Late Cretaceous time.

Regional normal faults strike NW-SE, dip toward NE and characterise the northern Murge area; regional dextral oblique transfer faults strike E-W, dip toward N and characterise the southern Murge area. Some of the Cretaceous faults were probalbly reactivated during the Neogene – Quaternary tectonic evolution of the Apulian foreland – Bradano foredeep – Apennines chain system. Regional open fold structures resulted from: (i) the hanging-wall deformation related to regional extensional fault geometries; (ii) drag folds along regional faults; (iii) the local deformation related to the dextral strike-slip component of the movement on oblique transfer faults.

The system of normal faults determined, in the Murge area, the present-day regional southwestward dip of the outcropping Apulian Platform carbonate succession. Moreover, it affected the southern limb of a regional lithospheric bending, whose culmination was probably located in corrispondance of the "Monte Acuto" anticline. The regional lithospheric bending grew at least from Late Cretaceous during the extensional regime. On its subsident southern limb the "Calcare di Altamura" Fm. deposited while the system of normal and related oblique transfer faults was active.

The Upper Cretaceous extensional tectonic phase recorded in the Murge area can be likely transferred in other sectors of the Apulian Platform and can be reasonably connected to the late rifting stages of the Neotethys. The inferred NE direction of the Cretaceous exstension for the Murge area is similar to that inferred, in the present geographic coordinates, for the Gargano area of the Apulian Foreland (Winter & Tapponnier 1991; Chilovi et al. 2000) and for the Cretaceous domains of the adjacent central Apennine belt (Winter & Tapponnier 1991; Tavarnelli 1996).

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