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RECENT AND ACTIVE EXTENSIONAL TECTONICS IN THE SOUTHERN UMBRO-MARCHEAN APENNINES (CENTRAL ITALY)

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ABSTRACT

Recent and active extensional faults in the Umbro-Marchean Apennines Ridge (U-M. A.R.) are analyzed. Normal faults are arranged in fault zones ranging in lenght up to 30-40 km and trending NNW-SSE, oblique to Neogene thrusts oriented N-S. Within various thrust-sheets, fault zones display different patterns. Major faults generally stop close to the main thrust planes. Other minor faults exhibit morphotectonic evidences (fault scarps), and displace the main thrust planes. For Quaternary faults, these relationships suggest a listric geometry on different thrust planes which have consequently been inverted. For active faults, seismological data suggest a high-angle geometry up to 10-12 km at depth; this data and structural data constrain the proposed faulting model (seismotectonic model).

KEY WORDS: *Recent and active extensional faults. Umbro-Marchean Apennines.*

RIASSUNTO

Nella Catena umbro-marchigiana faglie attive e/o recenti dislocano, soprattutto nel settore sud-occidentale, pieghe e sovrascorrimenti di età neogenica. Nella Dorsale appenninica umbro-marchigiana le strutture compressive descrivono una forma arcuata mostrando una direzione NW-SE a nord e circa N-S a sud; per quanto riguarda le faglie attive e/o recenti, presenti soprattutto nella porzione più meridionale, esse hanno una direzione media N140°-150°, e quindi obliqua a quella delle pieghe e dei sovrascorrimenti. Tali faglie sono organizzate in «fasci» che mostrano uno sviluppo longitudinale fino a 30-40 km ed una distribuzione areale differente nei diversi *thrust-sheets*. Le singole faglie, generalmente immergenti ad WSW, sono disposte *en échelon* e/o raccordate da minori segmenti di trasferimento.

I rigetti massimi (900-1200 m) sono realizzati dalle faglie che generalmente si interrompono sui fronti dei sovrascorrimenti. L'inizio della loro attività è riferito dagli Autori al Pleistocene inferiore-medio.

Sulla base di elementi morfostrutturali e della diffusa attività sismica dell'area, alcune faglie possono essere considerate attive. Queste, in genere, hanno un rigetto intorno ai 250-300 m e sono caratterizzate da una evidente scarpata di faglia. La caratterizzazione geometrica ha evidenziato per i suddetti fasci direzioni più frequenti N140°-150° e subordinatamente N-S±10° e N100°±10°, l'inclinazione è in genere compresa tra 60° e 70°. I piani ad andamento N140°-150° hanno un carattere principalmente normale, mentre quelli N-S±10° e N100±10° sono rispettivamente transtensivi sinistri e destri. Su questi ultimi è stato misurato anche un movimento *dip-slip*. Tali caratteri cinematici consentono di determinare una direzione di estensione principale N50°-60°E ed una subordinata N10°-20°E.

L'estensione calcolata nell'area analizzata è di 2 km, pari circa al 10%. Considerando che il fagliamento è iniziato nel Pleistocene inferiore-medio (1-0.8 Ma), si calcola un tasso medio di estensione di 2 mm/anno. Inoltre si ottiene uno *slip-rate* medio intorno a 1.5 mm/anno per i fasci a maggior rigetto (1.5 km).

Il carattere geometrico delle faglie studiate, i loro rapporti con i piani di sovrascorrimento, l'analisi dei dati sismologici, nonché la presenza di anticlinali di «*roll-over*» (es.: la blanda anticlinale di M. Careschio-Castelsantangelo, ubicata tra Visso e M. Bove), consentono di ipotizzare una loro geometria listrica su livelli di scollamento ubicati a diverse profondità. Questi sono rappresentati dai piani di sovrascorrimento, che vengono quindi invertiti (*detachment faults*).

Il modello di fagliamento quaternario proposto, per l'area studiata, prevede l'attivazione di *detachment faults* via via più esterne in relazione alla migrazione verso est del «fronte estensionale». Inoltre, è ipotizzabile anche una contemporaneità del fagliamento estensionale nei diversi *thrust-sheets*. Ciò suggerisce che i preesistenti piani di accavallamento e le evaporiti triassiche possono aver consentito tra un *thrust-sheet* e l'altro un fagliamento estensionale indipendente (*decoupling*).

Tale modello comporta alcune considerazoni: a) via via che il fronte estensionale migra verso est, le *detachment faults* più interne si disattivano e così anche le faglie ad alto angolo ad esse relative. Tuttavia non si esclude una loro riattivazione soprattutto durante momenti di forte incremento dell'estensione; b) le faglie ad alto angolo che si raccordano sulle *detachment faults* più in superficie possono non essere importanti da un punto di vista sismogenetico. Infatti la presenza di rocce cataclastiche foliate e/o tettoniti *S/C* suggeriscono, per queste strutture, un regime di scorrimento più stabile rispet-

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to alle faglie che si raccordano su *detachment faults* più in profondità (10-12 km), caratterizzate da brecce di frizione, brecce di faglia e *gouge*, che ne indicano uno scorrimento frizionale di tipo sismico.

INTRODUCTION

In the northern Apennines, active extensional tectonics overprint the Upper Oligocene-Pleistocene compressive tectonics from west to east, leading to thrust inversion and tectonic basin development (Elter et al., 1975; Lavecchia et al., 1984; Boccaletti et al., 1986; Lavecchia, 1988).

In the Umbro-Marchean Apennines Ridge (U-M. A.R.), Neogene structures (folds and thrusts) have been displaced and/or inverted by NNW-SSE trending extensional faults since the lower-middle Pleistocene (Calamita et al., 1979; Calamita et al., 1982; Coltorti et al., 1989). Based on widespread seismic activity within this area, some normal faults are still considered active (Deiana et al., 1980; Gasparini et al., 1985; Pizzi, 1992). In this paper we describe the surface pattern of structures related to recent and active extensional tectonics in the U-M. A.R. and the geometrical relationships with respect to these structures. Moreover, we provide a reconstruction for strain fields on Quaternary faults, and propose a faulting mechanism (seismotectonic model). Finally, we apply this model in a geological cross-section to extrapolate surface data at depth.

QUATERNARY FAULT PATTERNS AND STRUCTURAL FEATURES

In the U-M. A.R. (hanging-wall of the Mts. Sibillini thrust), Neogene thrust strikes and fold axes describe an arcuate shape with eastward convexity (NW-SE trending in the north and N-S trending in the south (fig. 1). Active and/or recent faults oblique to compressive structures are also recognized in this area and trend N140°-150° on average (Centamore et al., 1980). Generally, these normal faults are arranged in fault zones ranging in length up to 30-40 km and are spaced 10-15 km apart, and show dissimilar arrangements between individual thrust-sheets (fig. 2). Within each individual fault zone, faults have on average a WSW dip-direction and are arranged en-échelon or linked by minor transfer faults (Calamita et al., 1992a; Pizzi, 1992). The maximum throw for an individual fault zone, is about 1500 m (Calamita et al., 1992a). Individual normal faults with maximum downthrows of 900-1200 m generally stop close to the main thrust planes (e.g., the Mt. Cavallo fault and the Mt. Vettore fault; Scarsella, 1941, and Cooper & Burbi, 1988); others assume a trend nearly parallel to the thrust traces (e.g., the Norcia fault). For normal faults, this suggests a listric geometry on the thrust planes which have, therefore, been inverted. Surface ruptures, minor faults affecting recent continental deposits (Coltorti et al., 1989; Blumetti et al., 1990; Pizzi, 1992), and major faults in the bedrock showing evident and continuous fault scarps (sometimes marked by a «white stripe» of unweathered bedrock), point to very recent activity for some normal faults (e.g., the Cordone del Vettore fault: Calamita et al., 1992a, 1992b; the Mt. Alvagnano-Ocricchio fault, Pizzi, 1992). These structures offset the M. Sibillini thrust plane with a downthrow of 250-300 m (Calamita et al., 1992b) and hence are probably linked to a deeper decollement level.

With regard to the Norcia fault zone, Coltorti et al. (1989) established K/Ar ages up to 0.23 Ma for the main activity of these Pleistocene master normal faults. Consistent with this dating, we favour an age older than 0.23 Ma for faults associated with deeper decollment levels and, according to Slemmons (1990) definition, we consider these faults active. This is in agreement with seismic activity in the area, where the 19.09.79 ($M_s = 5.8$: Gasparini et al., 1985) Norcia earthquake represents the latest important event. Pizzi (1992) links the Norcia earthquake to the Mt. Alvagnano-Ocricchio fault on the basis of geological and seismological data.

Structural analysis of these normal faults indicates mainly WSW dip-directions and 60°-70° dipping planes. Faults striking N-S and E-W are recognized as well. Faults trending N140°-150° generally exhibit normal dip-slip accompanied rarely with a left-lateral component and very rarely with a right-lateral component. N-S and E-W trending faults have a transtensive character with left-lateral or right-lateral strike-slip components respectively. Rarely, they exhibit a prevalent strike-slip character. E-W trending faults also show a normal dip-slip sense of movement.

The main extension direction is N50°-60°E; the NNE-SSW trend is clearly subordinate. The strike-slip component of the N-S and E-W trending normal faults suggests a stress field (i.e., σ_1 vertical; σ_2 and σ_3 horizontal and oriented N140°-150° and N50°-60°E, respectively) characterized by stages where the value of the σ_2 modulus is very close to σ_1 (Calamita et al., 1992a, 1992b; Pizzi, 1992). The NNE-SSW extension is generally younger than the N50°-60°E extension (Pizzi, 1992). Analogous extension directions (with the same relative chronology) have been documented for Plio-

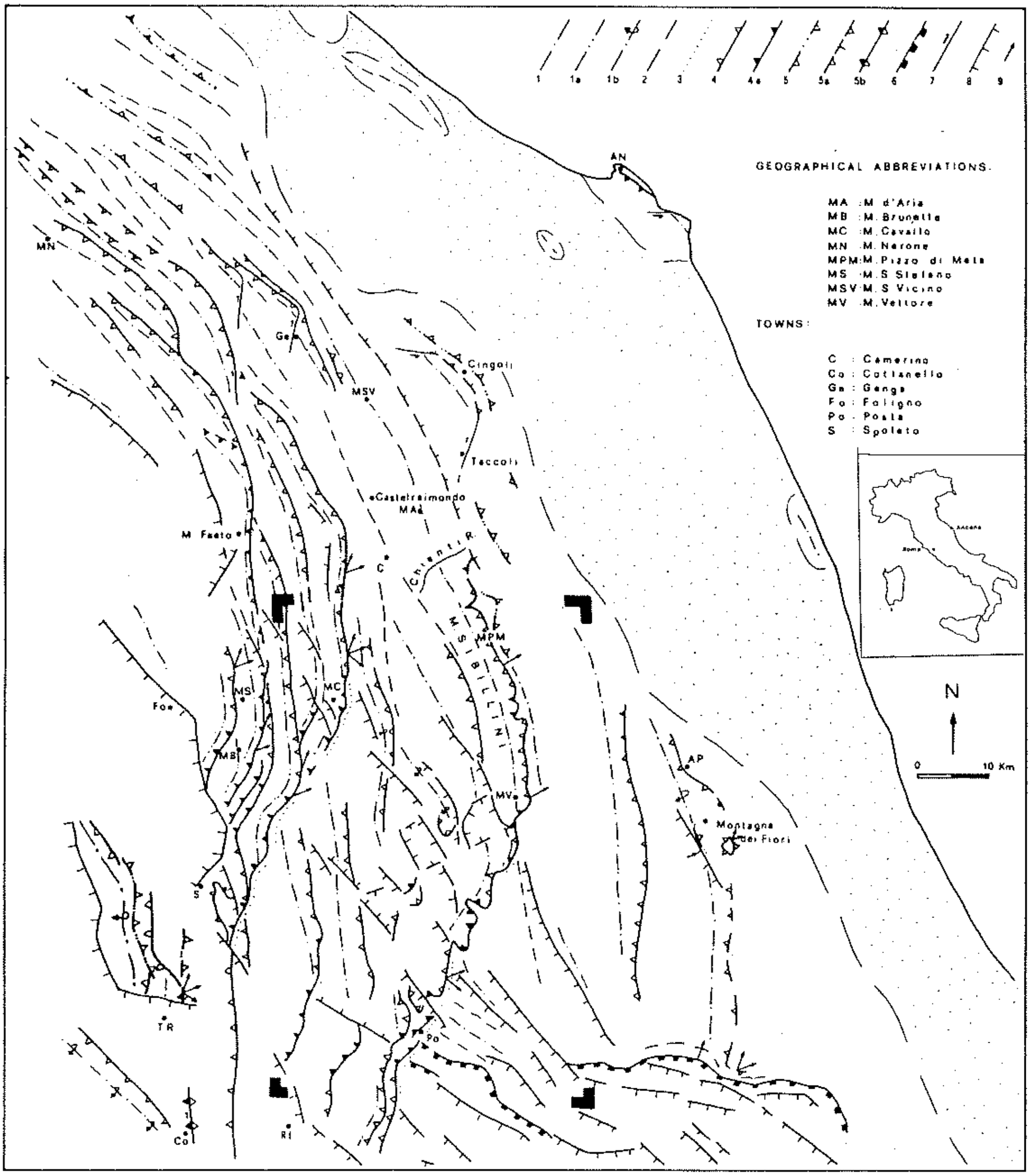

Fig. 1 – Structural map of the Umbro-Marchean mountain belt: 1 – macroanticline (1a – macroanticline with intensively tectonized forelimb; 1b – macroanticline with markedly overturned forelimb); 2 – syncline; 3 – axial trend of minor folds near the thrust fronts; 4 – thrust (4a – transpressive thrust and/or lateral or very oblique ramp); 5 – back-thrust (5a – pre-existing normal fault (probably Messinian age) inverted by back-thrusting in the hanging-wall of an inferred thrust (Cingoli structure) and buried under the Lower Pliocene sequence; inversion was probably Messinian-Early Pliocene in age because the Lower Pliocene deposits (*Globorotalia punticulata* zone) lie unconformably on the older sequence of Messinian-Early Pliocene age; 5b – back-thrust in a triangular zone); 6 – thrust front of the Lazio-Abruzzi Platform; 7 – transpressive tear fault; 8 – Quaternary normal fault; 9 – slip-vector on the thrust plane. Farther east, the chain is buried under the sandy and clayey Middle Pliocene-lower Pleistocene post-transgressive sequence (dotted area); from Calamita (1990).

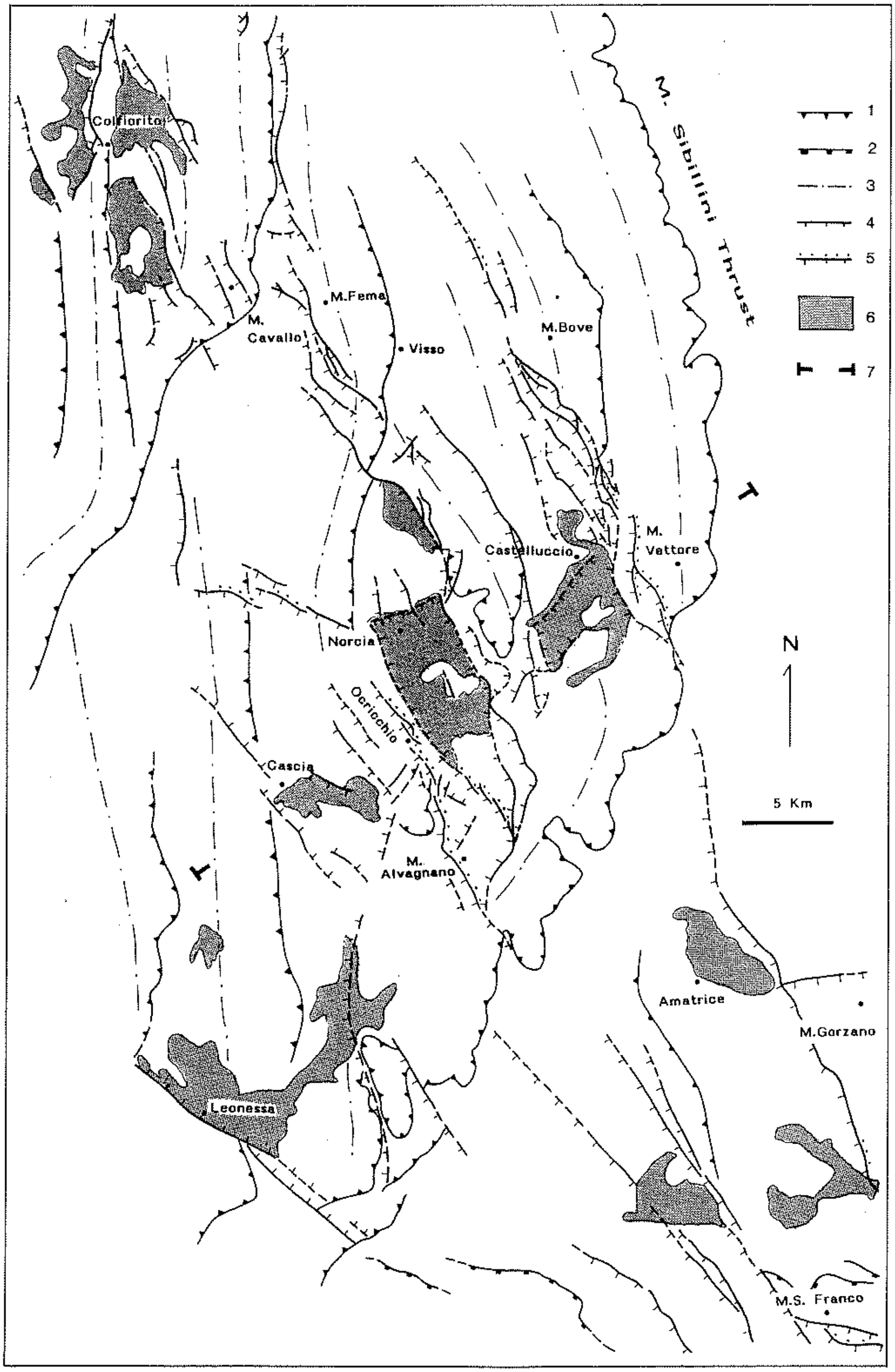

Fig. 2 – Structural sketch of the southern Umbro-Marchean Apennines Ridge: 1 – thrust; 2 – thrust in the Lazio-Abruzzi Domain; 3 – macroanticline; 4 – Quaternary normal fault; 5 – active normal fault; 6 – continental Quaternary basin; 7 – trace of the cross-section (see fig. 4).

Pleistocene extensional tectonics in the Umbrian area (Barchi et al., 1991). Marsili & Tozzi (1991) describe two extensional events for the Mt. Gorzano fault, one oriented NNE-SSW and the other oriented NE-SW.

Quaternary basins associated with the analyzed fault zones are developed very locally within the downthrown blocks. They occur in tectonic depressions and consequently are controlled by: listric fault geometry, en-échelon fault arrangement, the presence of antithetic structures, pre-existing discontinuities and two different maximum extension directions (Calamita et al., 1992a; Pizzi, 1992; Calamita & Pizzi, in press).

DISCUSSION AND CONCLUSIONS

In the Umbro-Marchean Apennines Ridge (U-M. A.R.), normal faults are organized in fault zones trending N140°-150°. Since lower-middle Pleistocene, they have offset Neogene N-S oriented structures of a fold and thrust belt. We argue for the listric geometry of normal faults on decollement levels seated at different depths based on: a) dissimilar fault zone arrangements between individual thrust-sheets; b) geometrical relationships with respect to the thrust surfaces; c) the presence of roll-over anticlines (a roll-over anticline has been interpreted for the very open Mt. Careschio-Castelsantangelo fold: Calamita et al., 1992a, in press, between Visso and Mt. Bove – see fig. 2); and d) focal depths from earthquake records and their distribution along a high-angle band (e.g., 19.9.79 Norcia event; Deiana et al., 1980). Thrust planes seated at different depths throughout the structural belt and the duplication of Triassic evaporites could provide the decollement levels for normal faulting.

Therefore, in this portion of the Umbro-Marchean Apeninnes Quaternary extensional tectonics has been recognized in the brittle upper crust (10-15 km thick. According to Menichetti & Minelli, 1991, «the transition between unstable frictional faulting and quasi-plastic shear-floweage is about 12 km.») for west-dipping detachment faults

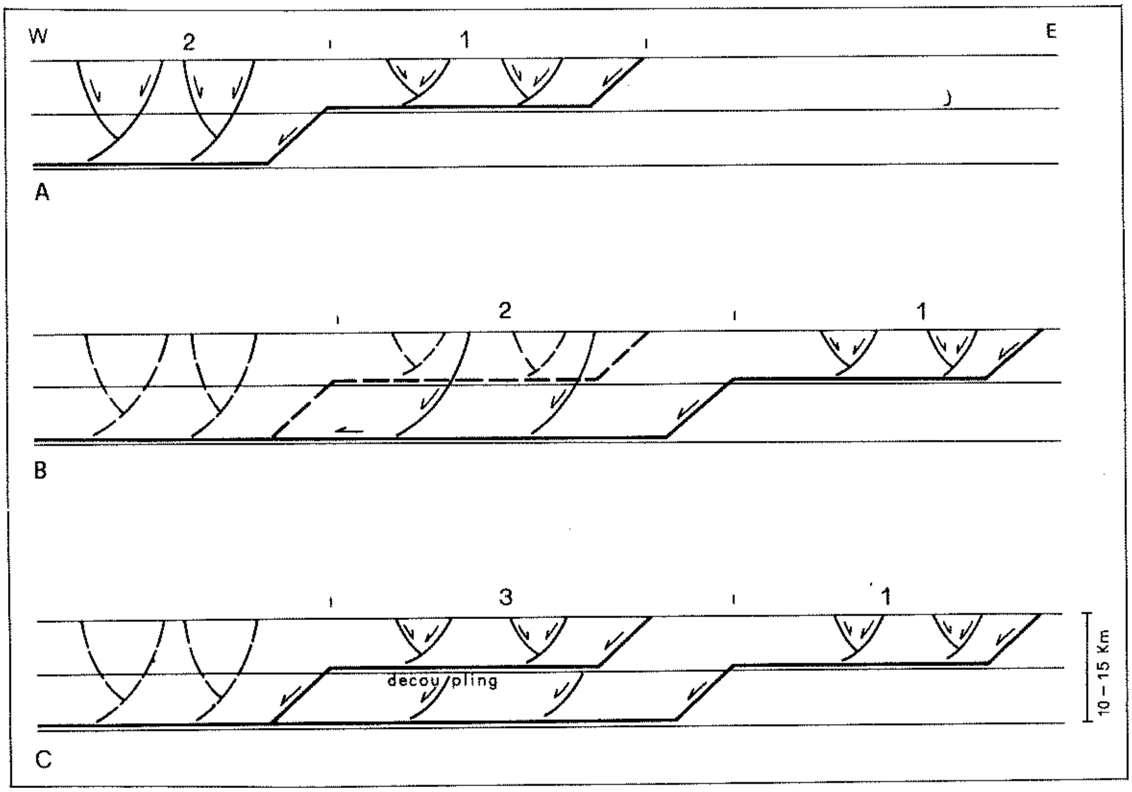

Fig. 3 – Sketch showing the proposed mode for Quaternary extensional faulting. Dashed lines represent structures becoming progressively inactive as a consequence of an eastward migrating extensional front (further explanations in the text: A, B, C, 1, 2, 3).

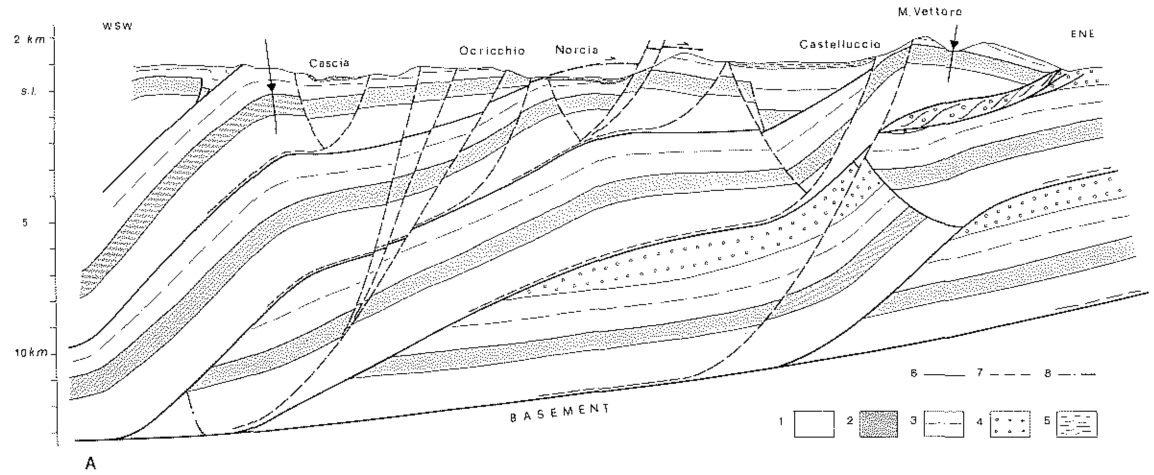

Fig. 4 – Geological cross-section: 1 – Triassic evaporites (Anidriti di Burano); 2 – Calcare massiccio (Upper-Triassic-Lower Lias); 3 – Pelagic and hemipelagic sequence (Middle Lias-Lower/Middle Miocene); 4 – Siliciclastic turbidite deposit (Upper Miocene); 5 – Quaternary continental deposit; 6 – Thrust; 7 – Quaternary normal fault; 8 – Jurassic normal fault. No vertical exaggeration.

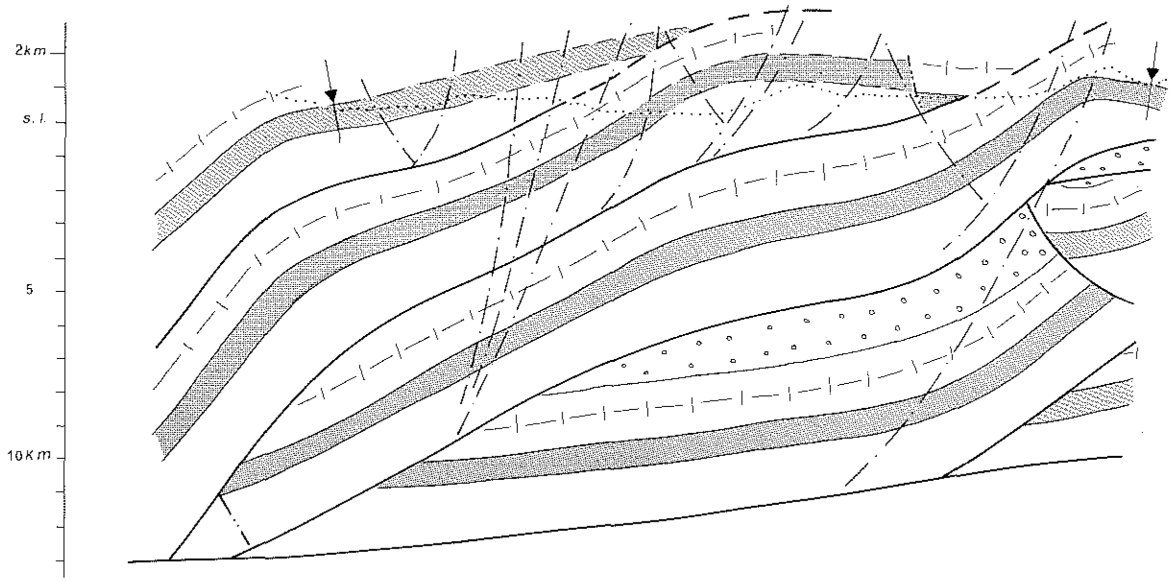

Fig. 5 – Geological cross-section of figure 4 with restored Quaternary normal faults.

(which are inverted thrust planes) and the related high-angle normal faults. The progressive activation of outer detachment faults and related high-angle faults (constistent with a simple-shear extensional model; see Wernicke & Burchfiel, 1982; Lavecchia, 1988) is a consequence of an eastward migrating extensional front (fig. 3 A and B).

Thus, as the extensional front migrates toward the east, the inner detachment faults as well as the related high-angle faults become inactive (fig. 3 B). Their reactivation, however, cannot be ruled out because of periods of increased rates of extension. High-angle faults linked to the upper detachments may not be important from a seismogenetic point of view (zone 1 in fig. 3). The occurrence of foliated cataclasites and/or *S/C* tectonites (Pizzi, 1992) suggests a stable sliding regime for these structures. High-angle faults linked to deep detachments (zone

2 in fig. 3) are characterized by crush- and fault-breccia and gouge (Calamita, 1991; Pizzi, 1992) thus implying a frictional stick-slip behaviour (sensu Sibson, 1989).

Synchronous high-angle normal faults may be active between individual thrust-sheets (Cascia faults, Norcia faults, etc.), thus suggesting their appartenance to different detachments. In other words, such detachments may have worked contemporaneously within decoupling levels (*sensu* Reston, 1990), which provided independent normal faulting within each thrust-sheet (zone 3 in fig. 3 C).

In the geological cross-section of figure 4, surface data have been extrapolated at depth based on: a) a thin-skinned tectonic style for the belt on a sole thrust lying at about 12 km (using magnetic basement data; Arisi Rota & Fichera, 1985); b) the above-discussed faulting model concerning active and/or recent faults linked to different decollement levels, based on geometrical relationships between normal faults and thrust planes; and c) focal parameters from the 19.09.1979 Norcia earthquake (associated with the Mt. Alvagnano-Ocricchio fault by Pizzi, 1992).

The extension of this area (between Cascia and Mt. Vettore) is about 2 km, corresponding to 10% (figs. 4 and 5). The average rate of extension is about 2 mm/yr, and the average slip-rate for these normal faults is 1.5 mm/yr.

According to the proposed model, the area represented in the cross-section of figure 4 may correspond to zone 2 in figure 3B.

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