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STRESS FIELD EVOLUTION IN CENTRAL ITALY DURING MIDDLE-LATE PLEISTOCENE: NEW INFORMATION FROM SOUTHERN LATIUM

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RIASSUNTO - *Evoluzione del campo di* stress *in Italia centrale durante il Pleistocene medio-superiore: nuove indicazioni nel Lazio meridionale* - Il Quaternario *Italian Journal of Quaternary Sciences*, **10**(2), 1997, 631-636 - I risultati che vengono presentati in questo lavoro sono il frutto di una sintesi di studi effettuati nell'area di Roccamonfina (Italia centrale) e di nuovi elementi identificati tramite correlazioni stratigrafiche tra depositi continentali e vulcanici (Pleistocene medio-superiore) ed analisi dei tassi di deformazione lungo le strutture principali. L'evoluzione del settore durante l'intervallo cronologico considerato indica un valore costante (in modulo) del campo di *stress,* confrontabile con quello riscontrato in altri settori dell'Appennino centro-meridionale. La riscontrata alternanza della direzione di estensione da NW-SE a NE-SW in periodi di 100-200 ka suggerisce valori molto simili di σ_2 ed σ_3 con un valore molto più elevato per l'asse verticale σ_1.

Key words: Campo di *stress,* Pleistocene, Lazio meridionale, Italia centrale
Parole chiave: Stress field, Pleistocene, southern Latium, Central Italy

1. INTRODUCTION

A strong alkali-potassic volcanism (Roman Magmatic Province, RMP), related mainly to a NE-SW extensional tectonic activity, developed along the Tyrrhenian margin of Latium-Campania (Fig. 1) starting from Lower Pleistocene. Many of the RMP volcanic complexes are located in correspondence of NE- and NW-trending fault zones. The NE-SW extension is at present still active along South-central Apennines, as seismological observations (Dziewonski *et al.*, 1983 and following; Gasparini *et al.*, 1985) and *in-situ* stress measurements (Montone *et al.*, 1995) indicate. On the contrary, detailed structural and volcanological studies on several RMP volcanic complexes and surrounding areas (Bosi 1995; Faccenna *et al.*, 1994; De Rita & Giordano, 1996) show that local relationships between tectonics and volcanic activity are much more complicated, with NE-SW striking structures that display a northwest-southeastwards extension. In particular, the Roccamonfina volcanic area (Fig. 1) was recently studied from both the structural and volcanological viewpoints (De Rita & Giordano, 1996, and references therein); these studies can be considered as the starting point of our research.

This paper presents: i) new data obtained from the structural analysis (geometry, kinematics and slip rate along major faults) of Middle-Late Pleistocene deposits; ii) correlations between major unconformities of volcanic and continental depositional sequences; iii) relations to major changes in the local stress field orientation; iv) style of volcanism. On this basis specific topics — such as a) stress field orientation and its possible rapid change (~100-200 ky) during Middle-Late Pleistocene; b) stress field influence on the development and style of volcanism and interaction between NE- and NW direction of extension — are discussed.

2. GEOLOGICAL DATASET

The geomorphic and structural setting of the area are described in terms of three main macrostructural features (Fig. 2).

2.1 The NW-trending South Marsica Fault Zone (SMFZ)

The NW-trending SMFZ and related structures are characterised by a polyphasic tectonic activity with a prevalent left-lateral motion (transpressive) before Lower Pliocene (Cavinato & Sirna, 1988) and the occurrence of normal faulting with a NE-SW direction of extension (minimum slip-rate 0.4 mm/year; Bosi, 1995 and references therein) during Middle-Upper Pleistocene. A further activity during Holocene with minimum slip-rate of 0.7 mm/year was hypothesised by Bosi (1997).

The NE-trending faults, which characterise the footwall block, are interrupped by the SMFZ. Structural and geomorphic observations indicate a possible in-time progressive southward migration of the activity of the NE-trending faults until about 400 ky ago. Northwards, this activity — testified by fault systems in the Mountains of Venafro, which originated small NE-trending intramontane basins — occurred before the sedimentation of lacustrine deposits in the Liri Valley (which are not displaced by NE-trending faults).

The stratigraphy of continental deposits in the Liri Valley can be seen in the light of the relationship between erosional phases and tectonic activity along SMFZ. Breccia deposits were emplaced during the SMFZ most important episodes of activity, being related to the increased rate of erosion due to the uplifting of basement blocks (BC, Lower-Middle Pleistocene; BPI, Upper Pleistocene; BMA, 19±2 ky BP, O.S.L. dating). The stratigraphic correlations shown in Figure 3, indicate that 1st order uncon-

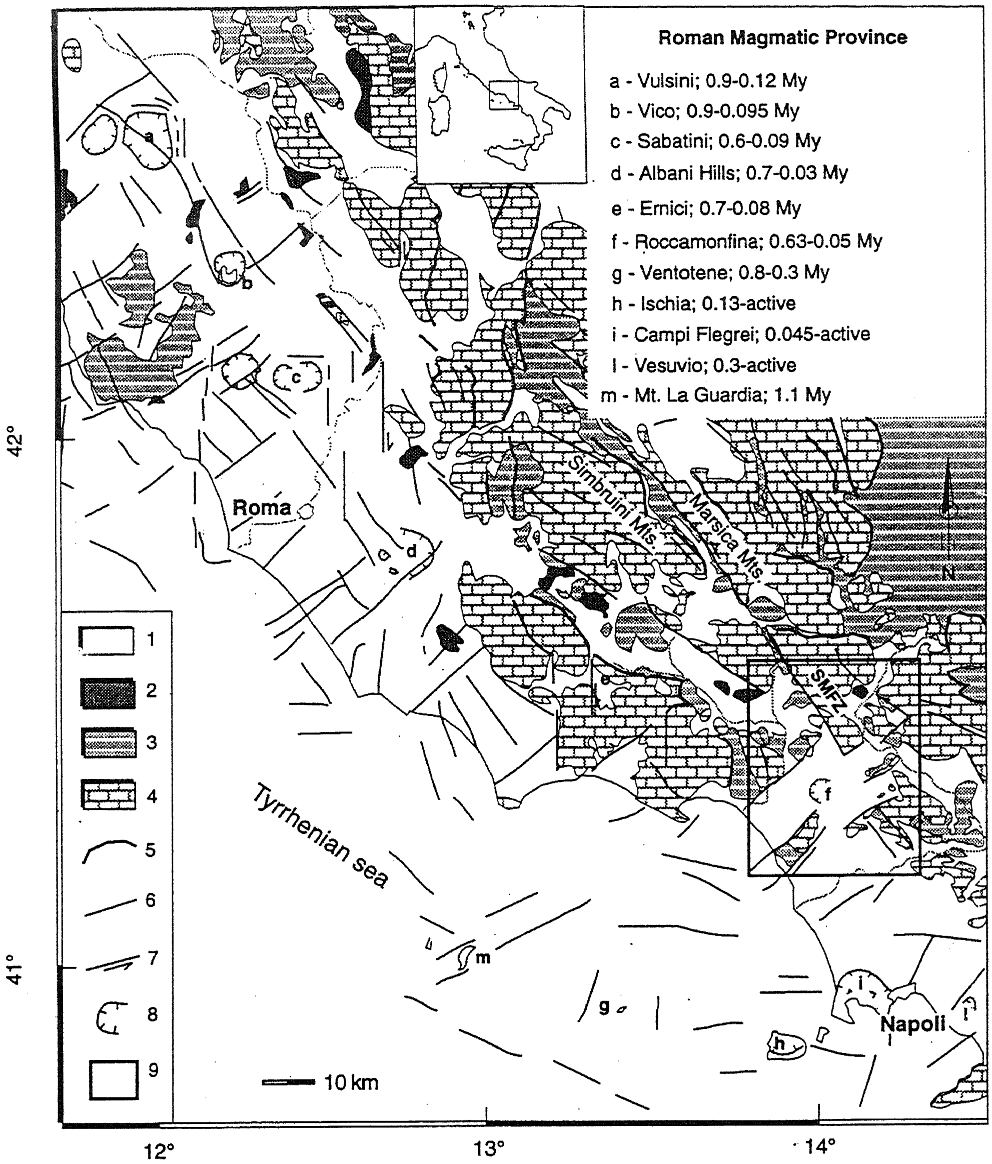

Fig. 1 - Geological sketch map with tectonic elements of the Central Italy Tyrrhenian margin. Legend: 1) Volcanic and sedimentary deposits (Pliocene-Quaternary); 2) Travertines (Quaternary); 3) Terrigenous sequences (Middle-Upper Miocene); 4) Carbonate sequences (Trias-Miocene); 5) main thrusts; 6) main normal faults; 7) main transcurrent faults; 8) calderas; 9) study area. SMFZ indicates the Southern Marsica Fault Zone (see text).

Carta geologica schematica con elementi tettonici del margine tirrenico dell'Italia centrale. Legenda: 1) Depositi vulcanici e sedimentari del Pliocene-Quaternario; 2) Travertini (Quaternario); 3) Successioni terrigene (Miocene medio-superiore); 4) Successioni carbonatiche (Trias-Miocene); 5) scorrimenti principali; 6) faglie dirette principali; 7) principali faglie trascorrenti; 8) caldere; 9) area studiata; SMFZ indica la Zona della Faglia della Marsica meridionale (vedi il testo).

formities in the different environments are strictly connected with the tectonic evolution of the area.

2.2 Roccamonfina volcano

The activity evolution of the Roccamonfina volcano (from 630 to 50 ky BP) can be summarized as follows (De Rita & Giordano, 1996 and references therein):

– Epoch 1 (630-385 ky BP): An initial stage of diffused magma intrusion (dykes and small centres cover an area of about 1000 km^2), was followed by the growth of a stratovolcano, characterised by an open-conduit effusive style. The gravitational collapse of the summit about 385 ky ago and the high effusion rate (about 100 km^3 of mainly undersaturated lavas over 230 ky) have been interpreted as the response to the high deformation rate along the NE-trending faults of the Garigliano graben.

– Epoch 2 (385-230 ky BP): the style of volcanic activity changed to explosive. Five major time-spaced small- to intermediate-volume explosive eruptions of saturated magma emplaced a total magma volume of about 8.5-11 km^3.

– Epoch 3 (230-54 ky BP) represents the ending of eruptive activity at Roccamonfina. Phreatomagmatic products, lava domes, and scoria cones emplaced a total magma volume of about 1-2 km^3. Volcanic centres were aligned along a system of N-trending *en échelon* right stepping lineaments, each of them 5 to 7 km long, which cut the volcano apparatus.

2.3 Ring basins

A system of NE-striking tectonic basins (Garigliano, Formicola and Riardo basin (Fig. 2), which underwent a high and rapid subsidence during Pleistocene surround the volcano. In the Garigliano graben downthrows during Pliocene were of about 1000 m and of at least 700 m starting from the Lower Pleistocene (Giordano *et al.*, 1995). The Riardo rectangular basin developed in the Middle Pleistocene (Giordano., 1995) (Fig. 2), and is bounded by NE- to ENE-trending and NW-trending fault systems with an apparent perpendicular direction of

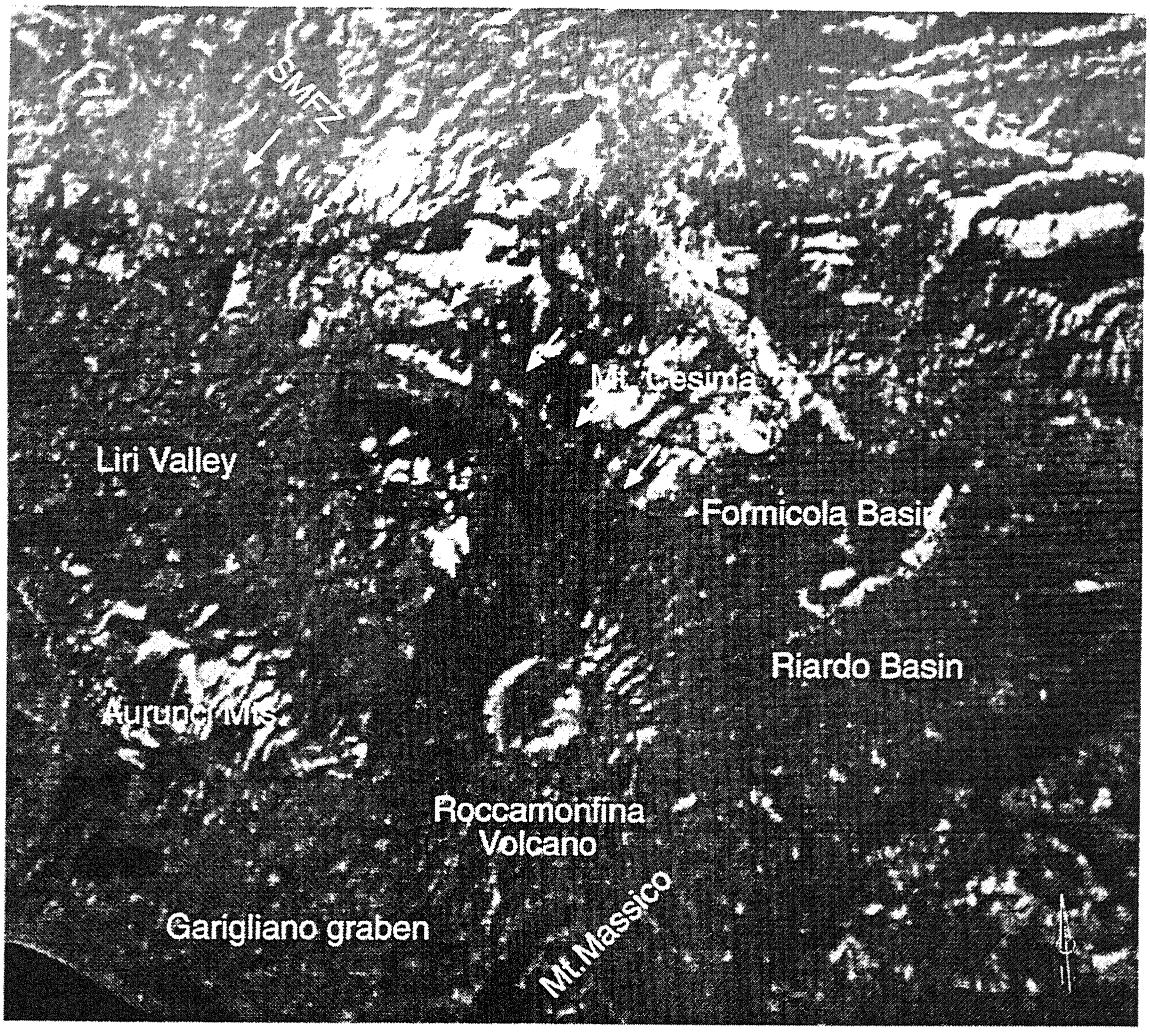

Fig. 2 - Satellite image of the Roccamonfina area. By courtesy of Stefano Salvi, ING, Roma.
Immagine da satellite della zona circostante il Vulcano di Roccamonfina (per gentile concessione di Stefano Salvi, ING, Roma).

extension (NE-SW and NW-SE). Along the NE-trending faults bounding the basin, the total normal downthrow is in the order of 350-370 m, of which about 100 m developed after 385 ky BP (Giordano *et al.*, 1995). The waning of tectonic activity along these fault systems is evidenced by both structural and volcanologic data (Bosi, 1995; De Rita & Giordano, 1996 and references therein).

The main factors controlling stratigraphy and facies geometry of the volcaniclastic apron sequences are: style of volcanism and tectonics (especially rates of subsidence *vs* rate of volcanic debris production; Smith, 1991). The fluvial and reworked stratigraphic series of the ring plains are interpreted to be subdived into the following stages:

(1) Stratovolcano growth and high-rate of subsidence of the ring plains. The dominant emplacement of erosion-resistent lavas and subordinate strombolian pyroclastic products during Epoch 1 has a two-fold consequence: a) the amount of available debris was scarce and generally limited to coarse- to sand-grained material in comparison to the volume of emplaced volcanic products; b) at that time, the volcano morphological profile should be unstably convex and periodically subject to short periods of major degradation. During Epoch 1, owing to the high subsidence rate, the surrounding plains were largely filled by coarse- to sand-grained volcaniclastic deposits (Fig. 3). Facies geometry can be related to type 2b of Smith (1991). By the end of Epoch 1, the gravitative collapse of the volcano summit caused the diversion of drainage network toward the Formicola and Riardo basins. A subsequent reduction of both eruption- and subsidence-rates led the erosional processes to overcome the depositional ones along the volcano entire slopes. This is testified by a percent increase in coarse-grained material on top of Epoch 1 sediments in the surrounding plains. During Epoch 2, despite the decrease in magma output-rate, the occurrence of mainly explosive eruptions produced a huge amount (at least 30 km^3) of loose debris. Volcaniclastic sequences on the plains surrounding the volcano are dominated by the rapid aggradation of sand- to silt-grained fluvial-lacustrine deposits. Facies geometry can be correlated to type 1 of Smith (1987). At the end of Epoch 2, the production of primary volcanic debris quickly waned. The major unconformity at the base of Epoch 3

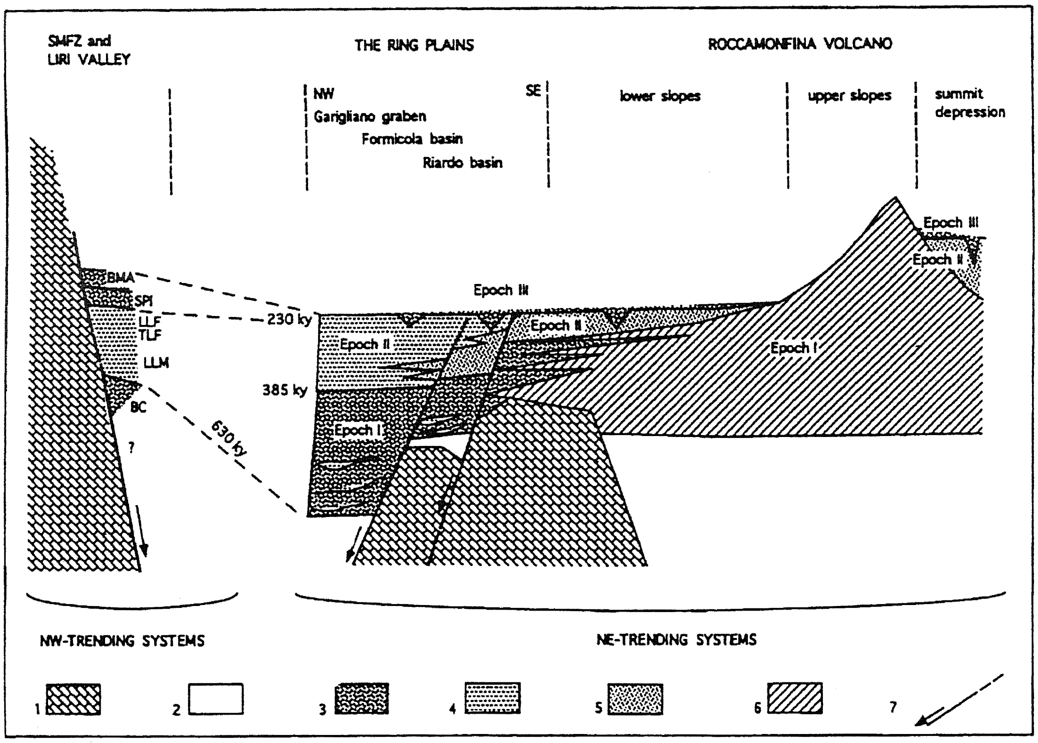

Fig. 3 - Schematic section showing the tectonic-statigraphic correlation among SMFZ, rings plains and the Roccamonfina volcano. Epoch 1, 2 and 3 refer to the three main rock-sequences (Supersyntems), each of which related to a distinct style of volcanic activity acc. to De Rita & Giordano (1996): i) Supersynthem of Roccamonfina (Epoch 1; 630-385 ka BP; ii) Supersynthem of the Riardo Basin (Epoch 2; 385-230 ka BP); iii) Supersynthem of Vezzara (Epoch 3; 230-54 ka BP). LLM, TLF and LLF are the three stratigraphic units defined by Devoto (1965).

Rappresentazione schematica delle correlazioni tettono-stratigrafiche fra la SMFZ, le pianure che circondano il (cont.) *vulcano di Roccamonfina ed il vulcano stesso. Le tre successioni litologiche principali sono indicate con Epoca 1, 2 e 3 (supersintemi) ciascuna delle quali relativa ad un distinto stile di attività vulcanica secondo De Rita & Giordano (1996): i) Supersintema di Roccamonfina (Epoca 1, 630-385 ka BP); ii) Supersintema del bacino di Riardo (Epoca 2, 385-230 ka BP); iii) Supersintema di Vezzara (Epoca 3, 230-54 ka BP). LLM, TLF e LLF sono le tre unità stratigrafiche di Devoto (1965).*

deposits represents in fact the re-establishment of a definite fluvial network. Deeply-incised gullies characterise the present-day topography of the Roccamonfina landscape, which indicates the waning of volcanic activity and of extensional tectonic activity along the NE-trending faults bounding the plains around the volcano

3. KINEMATIC MODEL

Geological data indicate that the NE-trending fault systems played a major role in controlling the volcanic system, being the upwelling of magmas mainly driven by such fault systems. The Middle Pleistocene to Recent evolution of the studied region can be summarised as follows (Fig. 4):

– At the beginning of Middle Pleistocene extensional processes, which had acted since Lower Pleistocene (Garigliano Graben), produced the uprising of magma into a wide area. The Roccamonfina volcano edifice developed in the time interval from 630 to 385 ky BP, while an extensional tectonic activity was occurring mainly through the action of NE-trending faults causing the Garigliano Graben to deepen and the Formicola and Riardo basins to develop. Major NW-trending faults were quiescent and would have been cut by NE-trending systems (SMFZ was cut by the Formicola and Riardo basin).

– After 385 ky BP extension began to be accommodated by NW-trending normal faults and N-trending left transtensional faults, which displaced all the previous structures. NE-trending faults were reactivated as transfer faults.

– Slip-rates along the NE-trending faults are positively correlated with magma output-rates and style of volcanism at Roccamonfina, which changed from an effusive open-conduit volcano with high slip- and magma output rates, to time-spaced explosive volcano with lower slip- and magma output rates.

– The minimum deformation rate (about 1 mm/year) calculated along the NE-trending faults for the time period from 630 to 385 ky is comparable to that calculated for the NW-trending faults during the last 100 ky (0.7 mm/year) (Fig. 5) and it is consistent with the rates obtained by recent paleoseismological investigations along NW-trending active faults in the Southern Apennines (1 mm/year; Pantosti *et al.*, 1993 and references therein). It is worth noting that the value of 0.7 mm/year does not indicate the deformation rate of the area for the entire Late Pleistocene, because deformation occurred also along the N-S left lateral trending fault systems. The lower total values attained during Epoch 2 might be related to a transitional tectonic episode. By assuming deformation rates as reasonable indicators of the regional extension, it can be concluded that the regional extension rate did not change

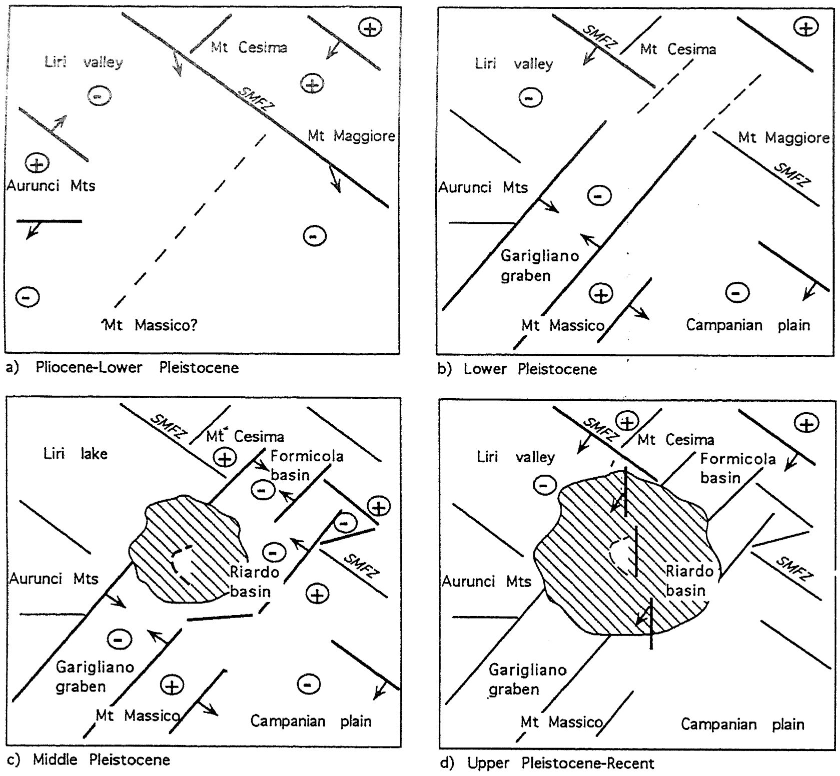

Fig. 4 - Schematic model of the evolution and timing of activity for each structure, from Pliocene time to the Recent. Kinematic indicators as in Bosi & Giordano (in prep). a), b) and c) refer to Epoch 1, 2 and 3depositional successions, respectively.

Modello schematico dell'evoluzione e della sequenza temporale dell'attività delle varie strutture dal Pliocene al Recente. Per gli indicatori cinematici vedi Bosi & Giordano (in prep.). a), b) e c) si riferiscono rispettivamente alle sequenze deposizionali delle Epoche 1, 2 e 3.

in time because it accommodate to various fault systems.

– The acting of this extensional tectonic regime as in-time flipping orthogonal pure normal fault systems suggests higher rate values for the vertical (gravitative) component (σ_1) with respect to the other components of stress tensor (σ_2, σ_3). In this case, the activation of various fault systems does not imply dynamic causes, but it can be the expression of the discrete kinematic response of different structures to a basically vertical tectonism ($\sigma_1 >> \sigma_2, \sigma_3$).

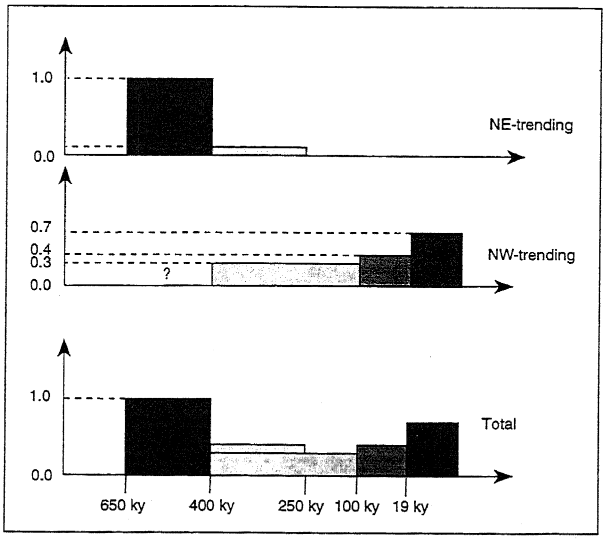

Fig. 5 - Total slip *vs* time for the NE- and NW-trending fault systems. The comparison between slip rates indicates a constant extension rate in the area (see text).

Spostamento totale nel tempo lungo i sistemi di faglie a direzione NE e NW. Il confronto tra velocità di spostamento indica per l'area una velocità costante di distensione.

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