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# KINEMATIC EVOLUTION OF THE MARTANA FAULT (UMBRIA-MARCHE APENNINES, ITALY) DURING PLEISTOCENE-HOLOCENE TIMES

CONTENTS

## ABSTRACT

The Martana Fault exhibits a characteristic "λ"-shape plan view, with the longer fault segment trending N-NNW and the shorter one striking around N100°E. Ongoing activity of this fault is indicated by fresh and prominent fault scarps, interaction of faulting with drainage systems, and displacement of alluvial fan apexes. The structural-geological and geomorphic data indicate a recent polyphase kinematic evolution. After developing as a normal fault in the Early Pleistocene, the N-NNW Martana Fault segment underwent a phase of dextral reactivation that extended from the Early-Middle Pleistocene boundary until around 0.39 Ma. The establishment of a stress field with a NE-ENE-trending $\sigma_3$ axis and NW-NNW $\sigma_1$ axis in the Late Pleistocene-Holocene resulted in a relevant component of sinistral faulting along N-NNW-trending fault segments and almost pure normal faulting on newly formed NW-SE faults, which mostly formed in the Massa Martana area as pull-apart structures in the overlapping area between a pair of N-S-trending transtensional sinistral faults. The active –mainly left-lateral- transtensional kinematic along N-NNW-trending fault segments is also shown by the sinistral offset of the E-W-trending *Decumanus* road at the ruins of the Roman town of *Carsulae*.

KEY WORDS: Polyphase faulting, Middle Pleistocene-Holocene, active faults.

## 1. INTRODUCTION AND GEOLOGICAL SETTING

The Umbria-Marche Apennines fold-and-thrust belt is affected by a complex Quaternary fault pattern composed of NW to N-S-trending fault zones linked by variably trending fault segments. Local historical and present-day seismicity has been mostly referred to two different tectonic models: (1) a pure extensional model relating seismicity to west-dipping faults antithetic to east-dipping low-angle normal faults (Altotiberina Fault System: Boncio *et alii*, 2000), and (2) a strike-slip model relating surface deformation to a roughly NNW-SSE trending sinistral crustal shear zone (Central Apennines Fault System: Cello *et alii*, 1997).

We investigated the regional Martana Fault structure bounding the eastern margin of the south-western branch (the Deruta-Terni sub-basin) of the major Tiber Basin (Fig. 1), which is filled by fluvio-lacustrine sediments ranging from Early-Middle Pliocene to Early Pleistocene. Early to Middle Pleistocene travertine developed at the eastern border of the basin. These sediments are unconformably overlain by slope debris, which are in turn overlain along the N-NNW Martana Fault margin by pyroclastic, surge and fall deposits dated to 0.39±0.01 Ma (Laurenzi *et alii*, 1994; Fig. 2). All the above mentioned sediments are modelled by an erosional surface that is particularly well preserved in the travertine. The inferred age limits of this erosional surface ranges between 390 kyr and 230 kyr (Bonini *et alii*, 2003). Late Pleistocene, generally reddish, slope debris rest unconformably on this erosional surface and are in turn overlain by Late Pleistocene to Holocene alluvial fan deposits.

Geomorphic analysis of fault scarps and offset drainage systems, faulted deposits and erosional surfaces as well as archaeoseismological evidence of surface faulting at the Roman ruins of *Carsulae*, allow the unambiguous identification of the Middle-Late Pleistocene and Holocene activity of this structure.

## 2. THE MARTANA FAULT

The Martana Fault (MF, Figs. 1 and 2) is composed of two main segments: a roughly N-NNW-trending about 28 km long segment and a N100°-trending segment to the south. After its formation as normal fault, indicated by the extensive deposition of the Early Pleistocene travertine, the kinematic of the Martana Fault was characterised by relevant strike-slip components of movement, both dextral and sinistral, as also observed on the nearby Sabina Fault (Alfonsi, 1995; Brozzetti & Lavecchia, 1995; Bonini, 1998; Pierantoni *et alii*, 1995; Fig. 1a). This paper focuses on the dating of these strike-slip events.

### *2.1. The N-NNW-trending Martana fault segment*

In the northern part (Massa Martana-Viepri sector), the MF is mostly characterized by a fault pattern consisting of narrow belts of NW-NNW-trending normal faults interrupted by individual N-S faults (Fig. 2). The most recent deformation is expressed by the NW-NNW-trending fault set offsetting the drainage pattern and clearly affecting the topography of the area (*e.g.* the Viepri Basin, Bonini *et alii*,

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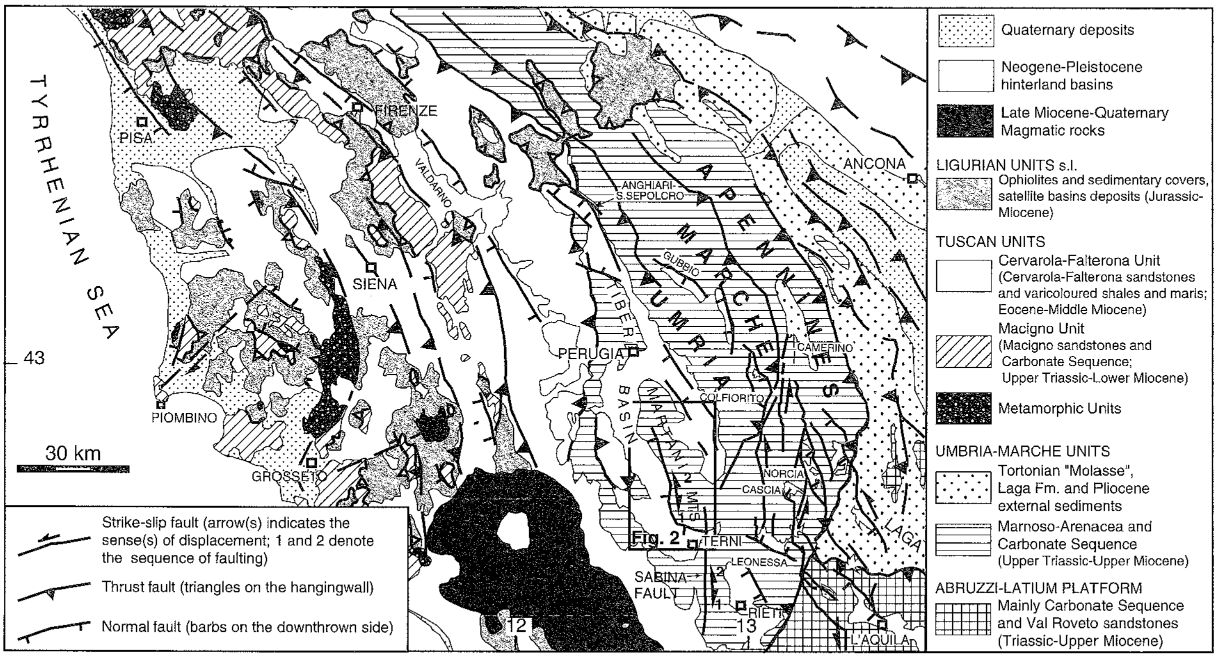

Fig. 1 - Schematic structural-geological map of the Umbria-Marche Apennines. Faults in the Leonessa-Colfiorito area are simplified from Cello *et alii* (1997).

2003; Fig. 2). Likewise, recent activity along the N-S-trending fault is indicated by the sinistral displacement of recent morphological features (the boundary of erosional surfaces and alluvial fan apexes).

Both N-S and NW-NNW-trending fault sets are compatible with the Late Quaternary stress regime in the Apennines characterised by sub-horizontal NW-NNW-trending $\sigma_1$ axis and extension direction ($\sigma_3$ axis) oriented NE-ENE (Cello *et alii*, 1997; Piccardi *et alii*, 1997, 1999; Bonini, 1998). Thus, the NW-NNW-trending normal faults in the Massa Martana-Colle area may represent a sector pulled apart between two left-stepping en-echelon N-S-trending sinistral faults, and the Viepri Basin may have developed as horsetail splay progressively accommodating the sinistral faulting at the tip of the N-S-trending fault (Fig. 2).

Nearly pure sinistral strike-slip faulting has been indeed detected by the analysis of striae along N-S fault planes (Fig. 2). This deformation event is superimposed onto an earlier dextral strike-slip movement along the same fault (Bonini *et alii* 2003).

Southwards, in the Portaria-*Carsulae* area, interpretation of aerial photos reveals a major N-NNW-trending 10 km-long fault segment, referred to as the *Carsulae* Fault, crossing the archaeological ruins of *Carsulae* (Fig. 2). A minor splay of the *Carsulae* Fault appears to offset the *Decumanus* of the ancient town (Figs. 2 and 3a-c; Bonini *et alii*, 2003). The *Decumanus*, traced with E-W direction orthogonal to the N-S oriented *Flaminia Way*, displays a sharp deviation consisting of a roughly N-NNW-trending ~1.8 m sinistral horizontal offset, in correspondence to which the road underwent deformation and consequent restoration (Fig. 3). Because of the lack of historical information, as well as of palaeoseismological and archaeoseismological surveys, we cannot establish whether the observed displacement of the *Decumanus* axis was achieved during a single or multiple (or even aseismic) faulting event(s).

### 2.2. *The N100°-trending Martana fault segment*

The 8 km long, N100°-trending MF segment separates the Martani Mts. Ridge to the south from the Terni depression (Fig. 2). Alignment of numerous Late Pleistocene-Holocene alluvial fans overstepping the Late Pleistocene deposits on the main fault's hangingwall demonstrates the activity at this MF segment. Basinward propagation of MF-related faulting gave rise to the youngest generation of alluvial fans, though the vertical dislocation of Late Pleistocene-Holocene alluvial fan apexes on the main fault demonstrates that activity has been persisting on this fault (Fig. 4; Bonini *et alii*, 2003). Fault-slip data indicate a marked dextral oblique-slip (Fig. 2), in agreement with the results of previous structural investigations (Brozzetti & Lavecchia, 1995).

## 3. KINEMATIC EVOLUTION OF THE MARTANA FAULT

Structural analysis and field mapping allowed the identification of a complex polyphase activity of the Martana Fault, whose N-NNW segment developed as extensional structure during the Early Pleistocene. It was then reactivated consistently by the operating stress field, recording two main deformation events from the Middle Pleistocene onward (Fig. 5).

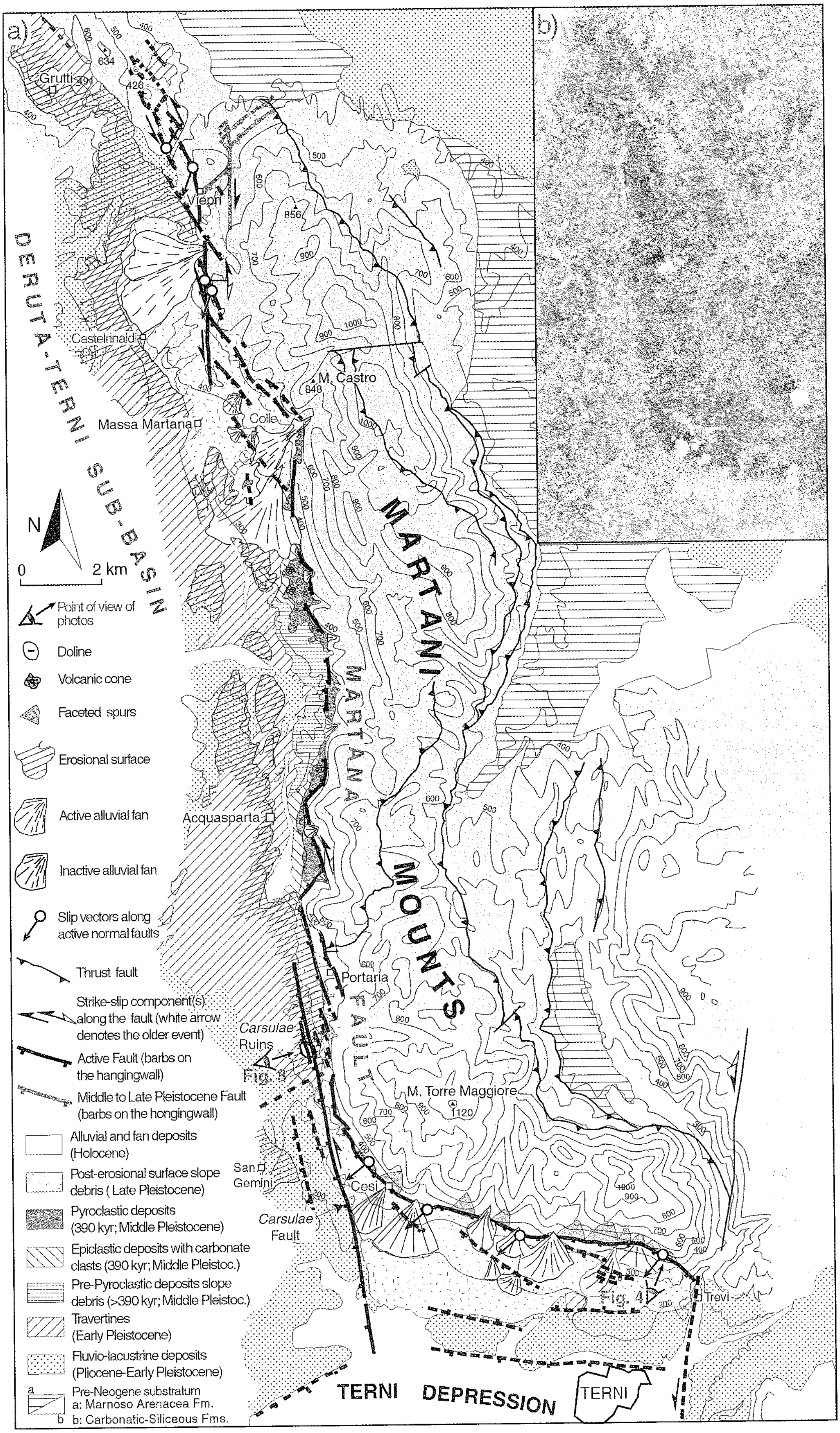

Fig. 2 - (a) Schematic morphostructural map of the Martana Fault (equidistance 100 m) (from Bonini *et alii* 2003); dashed lines indicate blind or inferred faults. (b) SPOT satellite image of the area.

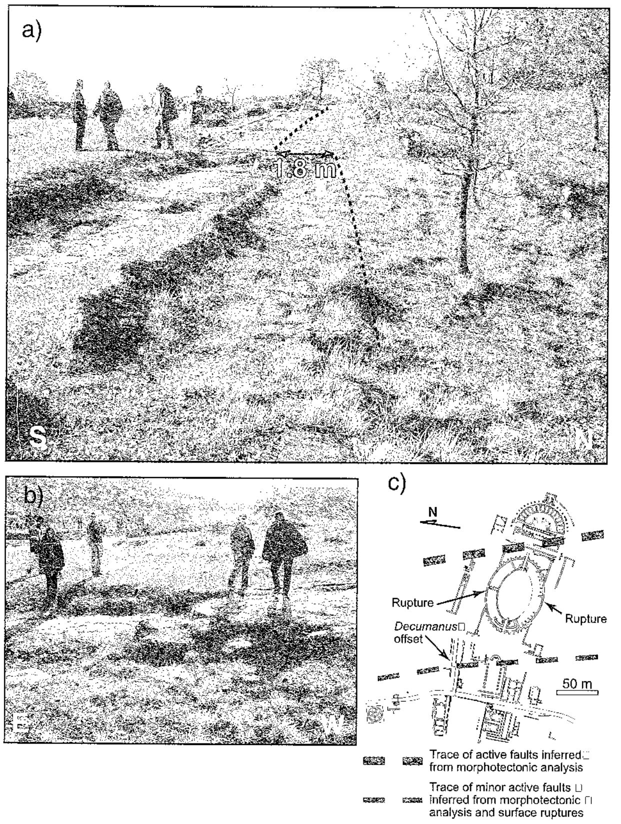

Fig. 3 - (a) View from the east of the N-NNW-striking rupture displacing of about 1.8 m the E-W-trending *Decumanus* at the Roman ruins of *Carsulae*, settled on the smooth erosional surface of the Pleistocene travertine (location in Fig. 2). Original *Decumanus* axis indicated by dashed black line in a). (b) Close-up of the rupture. (c) Topographic map of the *Carsulae* ruins with indication of the ruptures and the trace of the active faults crossing the town.

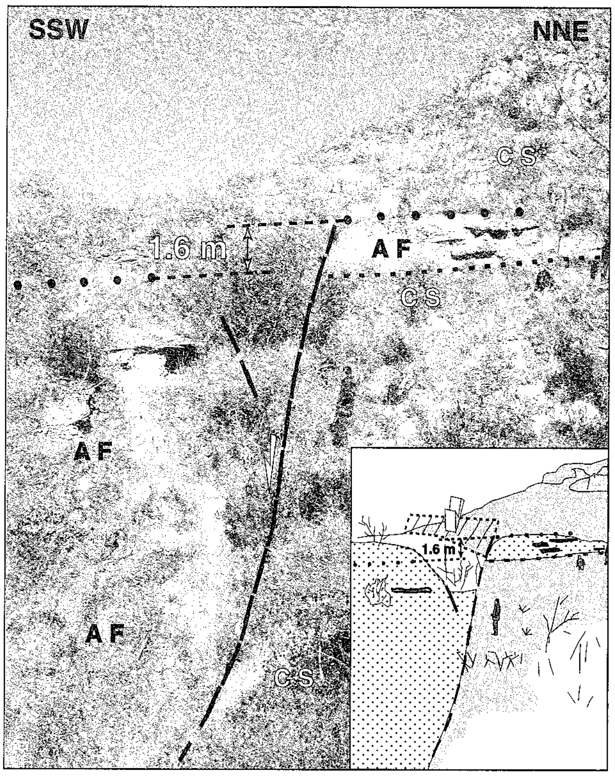

Fig. 4 - Late Pleistocene-Holocene alluvial fan apex faulted of about 1.6 m by the main N100°trending segment of the Martana Fault (location in Fig. 2). The fault strikes ESE, dips SSW and separates the alluvial fan deposits (AF) from the carbonate substratum (CS). Top of the alluvial fan indicated by the black dots. The inset shows an interpretative line-drawing of structures.

### *3.1. The Middle Pleistocene dextral faulting event*

Early dextral component of faulting along the MF has been attributed to the compressional phase with NE-SW-trending shortening, which generated gentle folding in the Tiber Basin around the Early-Middle Pleistocene boundary (0.8-0.7 Ma; Bonini, 1998). Successively, the volcanics erupted along the MF during the Middle Pleistocene (0.39 Ma) were affected by N-S-trending mesoscopic dextral strike-slip faults (Brozzetti & Lavecchia, 1995) (Fig. 5a). The volcanic products may have risen through deep openings pulled apart at releasing right-lateral en-echelon offsets (Fig. 2). In response to these fault kinematics, NE-trending horsetail splays developed at the northern fault termination (*i.e.*, the fault-controlled Montecchio Basin; Figs. 2 and 5a).

### *3.2.The late Pleistocene-Holocene sinistral faulting event*

The following tectonic phase was dominated by a sinistral horizontal kinematics along the N-NNW-trending MF and other subparallel pre-existing faults. This fault kinematics was controlled by the establishment, since the Late Pleistocene, of a regional stress field with a NW-NNW-trending $\sigma_1$ and NE-ENE-trending $\sigma_3$ (Cello *et alii*, 1997; Piccardi *et alii*, 1997, 1999; Bonini, 1998). The lower boundary of this phase is constrained by the absolute age of the magmatic rocks exposed at S. Venanzo (dated at 0.265 Ma; Laurenzi *et alii*, 1994; Fig. 1), deformed consistently with this stress field (Bonini, 1998) (Fig. 5b). This fault kinematic also generated NW-SE-trending normal faults in the pulled area between left-stepping N-S fault segments (Massa Martana area), and horsetail structures at the northern end of the N-S-trending sinistral faults (Viepri Basin), as well as a right-lateral component along the N100° MF segment (Figs. 2 and 5b).

The stress field variation portrayed in Fig. 5 indicates that the relative values among the stress tensors of the system varied in magnitude but not significantly in orientation, configuring a principal axial swapping process. This type of stress field variation has been previously documented across the Apennines, and represents a first-order control resulting from the interactions among plate boundaries in the central Mediterranean (e.g., Piccardi *et alii*, 1997).

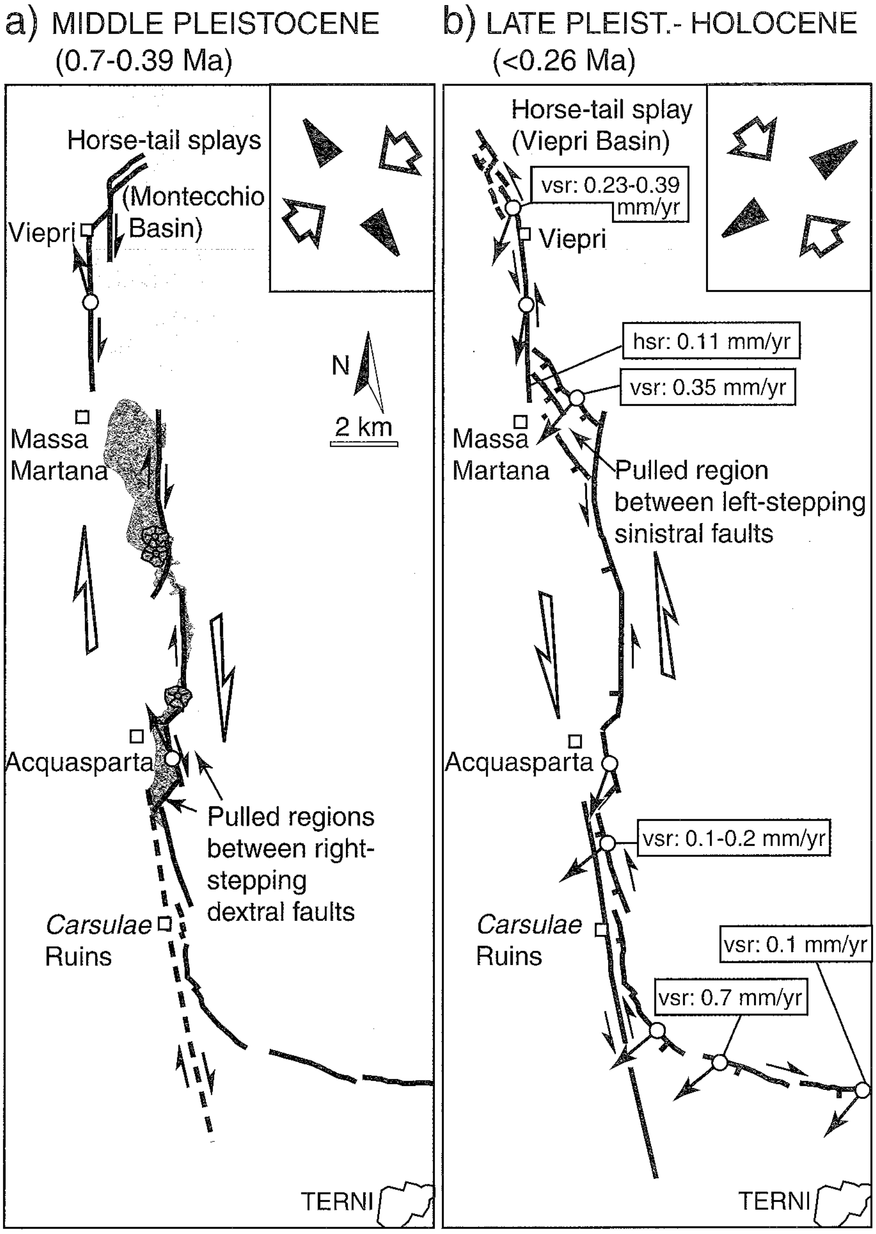

Fig. 5 - Schematic evolutionary tectonic model (from Bonini *et alii* 2003). (a) Middle Pleistocene and (b) Late Pleistocene-Holocene, with slip-vectors and estimated slip-rates (vsr: vertical slip rate; hsr: horizontal slip rate). The large white arrows indicate the regional component of horizontal shear along the MF, whereas the small black arrows indicate the horizontal component of displacement along individual faults. Pliocene-Holocene Tiber Basin sedimentary fill, white; pre-Neogene substratum, grey; Middle Pleistocene pyroclastics, dark grey.

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