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Late Quaternary tectonics in the inner Northern Apennines (Siena Basin, southern Tuscany, Italy) and their seismotectonic implication

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ABSTRACT

Defining the most recent Quaternary tectonics represents a challenging task for neotectonic, palaeoseismological and seismotectonic studies. This paper focuses on an integrated approach to reconstructing the latest Quaternary deformation affecting the northern part of the Siena Basin (inner Northern Apennines, i.e., southern Tuscany, Italy) near the town of Siena, and to discuss the seismological implications. Field work and structural and stratigraphic analyses, coupled with the interpretation of reflection seismic lines, have been combined to define the geometry, kinematics and age of mesoscopic to map-scale faults which have affected the mainly Quaternary continental and Pliocene marine deposits. The resulting dataset describes a tectonic setting characterized by coeval SW- and NW-trending transtensional and normal faults, respectively, dissecting alluvial sediments younger than 23.9 ± 0.23 ka. Seismic interpretation sheds light on the geometrical setting of the faults at deeper levels, down to 1–2 km, and provides support for the presence of a wide brittle shear zone defined by conjugated fault segments, locally giving rise to an asymmetrical negative flower-like structure. Faults and their damage zones have controlled (and still control) the discharge of gas vents (mainly CO_2 and H_2S) and hydrothermal circulation (which deposits travertine) since at least 23.216 ± 0.124 ka. The resulting complete data set provides support for our description of the Neogene–Quaternary tectonics which were active until the late Quaternary, providing additional information about the seismotectonic framework of an area characterized by low seismicity and generally low-magnitude earthquakes ($M < 4$), but having experienced significant seismic events over the last few centuries.

1. Introduction

Reconstructing the effects of the most recent Quaternary tectonics in a region represents a challenging task for geologists dealing with neotectonics, palaeoseismology and seismotectonics. Faults active during the Quaternary are primary structures to be analyzed in order to constrain the seismotectonic context and contribute to the evaluation of the geological and seismic hazard of a region. Indeed, it has been documented that in favourable tectonic contexts, strong earthquakes having large recurring time intervals, up to several thousand years (Davis, 1983; Galli et al., 2008; Kagan et al., 2005; Min et al., 2000), may occur even in areas characterized by low seismicity, and thus where data on earthquake occurrence rates are lacking. Regions characterized by significant seismogenic potential and insufficient earthquake records for their seismic assessment are classified as 'seismic gaps'. In seismic gap areas, the effects of earthquakes may be particularly dangerous because their records exceed the historical memory, leading to the local population having an inaccurate perception of the real seismic risk. In this view, neotectonic studies represent a powerful tool, providing fundamental contributions to the reconstruction of palaeoseismic events through time.

Differently from the outer zones of the Northern Apennines collisional belt (e.g., the Marche–Abruzzo Region and the Adriatic Sea), where earthquakes with magnitudes usually less than 6 (but occasionally reaching 6.8: Avezzano earthquake, 1915, where around 32,000 people died) have been recorded during the last centuries (Alessandrini et al., 2001; Chiarabba et al., 2005; Console et al., 1993; De Luca et al., 1999; Faenza and Pierdominici, 2007; Galadini and Galli, 2000; INGV-CNT Seismic Bulletin, 2008; Pace et al., 2006), southern Tuscany (i.e., the inner Northern Apennines, Fig. 1a) is characterized by low seismicity. In this area, seismic events are mainly confined to the shallow crust, at depths between 3 and 10 km (Batini et al., 1995a, 1995b; Cameli et al., 1993; Di

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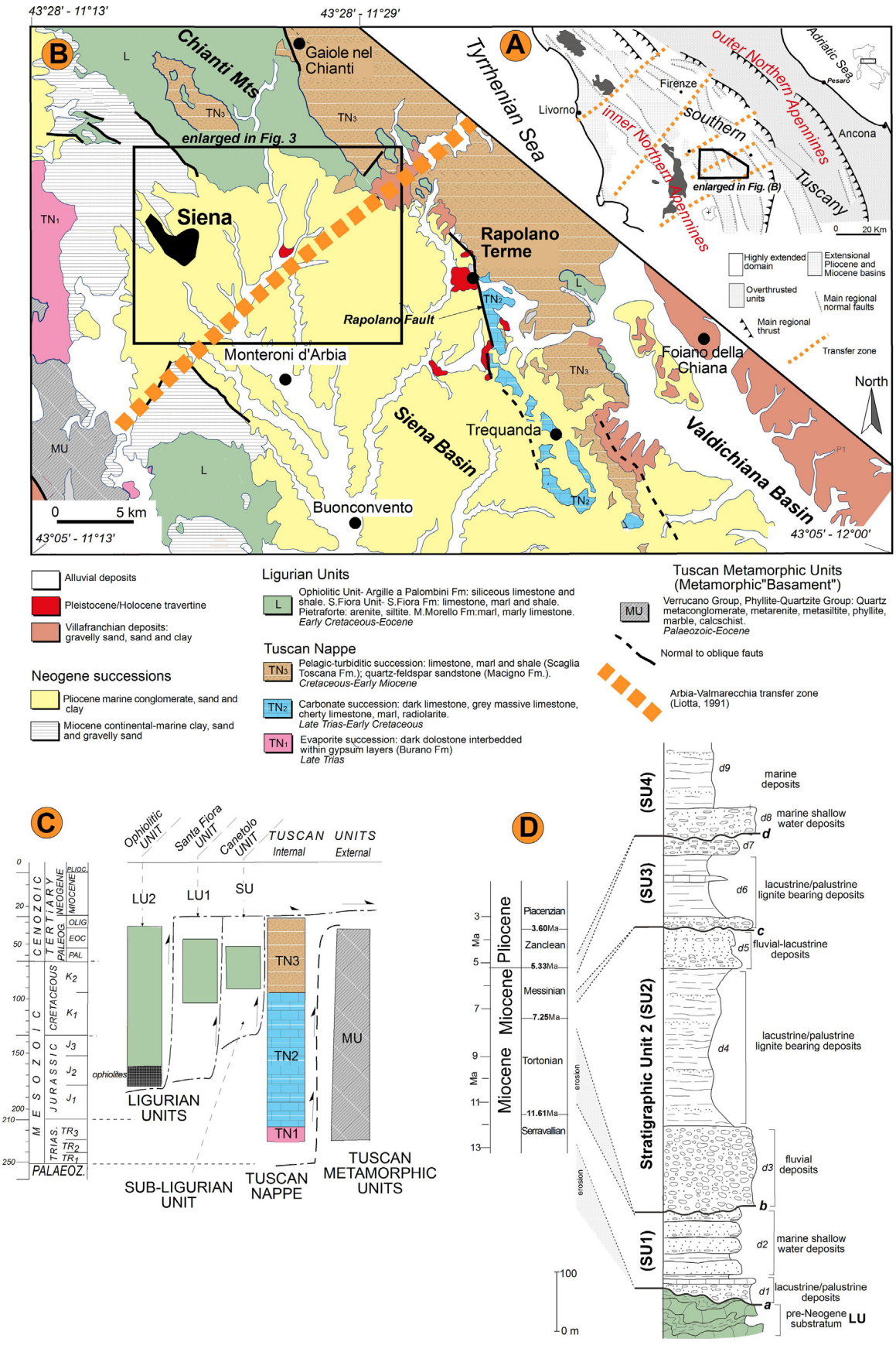

Fig. 1. (A) Tectonic sketch of the inner Northern Apennines with the main structural elements; (B) geological map of the northern Siena Basin where the study area is located; (C) relationships between the different tectonic units of the Northern Apennines exposed in the northern Siena basin and surroundings. Symbols: LU—Ligurian Units: LU1—Ophiolitic Unit; LU2—S. Fiora Unit; SU—Subligurian Unit: Canetolo Unit; TN—Tuscan Nappe; TN1—Late Triassic evaporites; TN2—Late Triassic–Cretaceous carbonate and siliceous succession; TN3—Late Cretaceous–Oligocene clayey (Scaglia Toscana) succession; Oligocene–Early Miocene arenaceous (Macigno) succession;