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Topographic expression of active faults in the foothills of the Northern Apennines

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ABSTRACT

Active faults that rupture the earth's surface leave an imprint on the topography that is recognized using a combination of geomorphic and geologic metrics including triangular facets, the shape of mountain fronts, the drainage network, and incised river valleys with inset terraces. We document the presence of a network of active, high-angle extensional faults, collectively embedded in the actively shortening mountain front of the Northern Apennines, that possess unique geomorphic expressions. We measure the strain rate for these structures and find that they have a constant throw-to-length ratio. We demonstrate the necessary and sufficient conditions for triangular facet development in the footwalls of these faults and argue that rock-type exerts the strongest control. The slip rates of these faults range from 0.1 to 0.3 mm/yr, which is similar to the average rate of river incision and mountain front unroofing determined by corollary studies. The faults are a near-surface manifestation of deeper crustal processes that are actively uplifting rocks and growing topography at a rate commensurate with surface processes that are eroding the mountain front to base level.

1. Introduction

Fault distribution may strongly influence landscape evolution in actively deforming areas and are of particular interest for seismic hazard assessment and especially when characterized by high slip rates (McCalpin and Nelson, 1996; Keller and Pinter, 1996). Along tectonically active mountain fronts, high angle normal faults are commonly easily recognized by their sharp relief caused by uplift of the footwall and enhanced subsidence of the hangingwall basin, causing development of exposed escarpments. In contrast, normal faults distal to the active mountain front may less distinct because of burial by sediments washed into the subsiding hangingwall basin, or concealment by surficial processes, such as large-scale mass movements in the footwall block. Nevertheless, high angle normal faults embedded in the hinterland of mountain ranges have clear geodynamic implications for the processes that uplift and deform rocks to make mountains despite their variable slip rates. How those faults interact with surface processes to make topography remains a topic of vigorous discussion (e.g. Roberts and Michetti, 2004).

In this paper, we investigate the foothills of the Northern Apennines, a mountain range characterized by rapid Pliocene and Pleistocene uplift and exhumation (Balestrieri et al., 2003; Bartolini, 2003). The Apennines mountain front and its adjoining foothills are riddled with geologic and geomorphic evidence of active tectonics such as growing folds and faults that collectively represent the near-surface structural response of ongoing Adria-Europe convergence (Bertotti et al., 1997; Capozzi and Picotti, 2002; Simoni et al., 2003; Picotti and Pazzaglia, 2008). This mountain front is commonly described as an out-of sequence structure that is backstepping with respect to the tip of the northern Apennines deformed wedge, presently buried below the plain of the Po river (Fig. 1; Picotti and Pazzaglia, 2008, with references). The northeast verging accretionary wedge of the Northern Apennines is considered inactive because it is sealed by almost undeformed alluvial deposits of Middle Pleistocene to Holocene (see Fig. 1b). Locally, in the Emilia foothills and adjacent Po Plain, however, some thrusts appear reactivating the thrust belt in various ways (e.g. Scrocca et al., 2007), but with remarkable differences, such as a northwest vergence (Picotti et al., 2007). Furthermore, the mountain front of the Northern Apeninnes is thought to be the emergence of a thrust cutting through the Quaternary (e.g. Boccaletti et al., 2004). In a recent paper, Picotti and Pazzaglia (2008) documented that the structure, also known as Pede-Apenninic Thrust Front, does not exist as continuous feature in the upper crust, whereas the present-day compression is accounted by a steep blind ramp, located at around 15 to 18 km of depth. In this frame of ongoing subduction and active compression in the middle crust, the normal faults we intend to describe are active in the upper crust only (Fig. 1b) and have been related to two different processes (see Picotti and Pazzaglia, 2008). In the south, toward the water divide, the stretching, documented also by geodetic strain measurements (e.g. GPS data in Serpelloni et al., 2005), is thought to be associate to the retreat of the upper (Tyrrhenian) plate, a process prograding from the Tyrrhenian back-arc basin toward the northeast since the Pliocene time (Elter et al., 1975). To the north, at the foothills close to the mountain front, the normal faults appear associated to the growing ramp anticline as upper crustal expression

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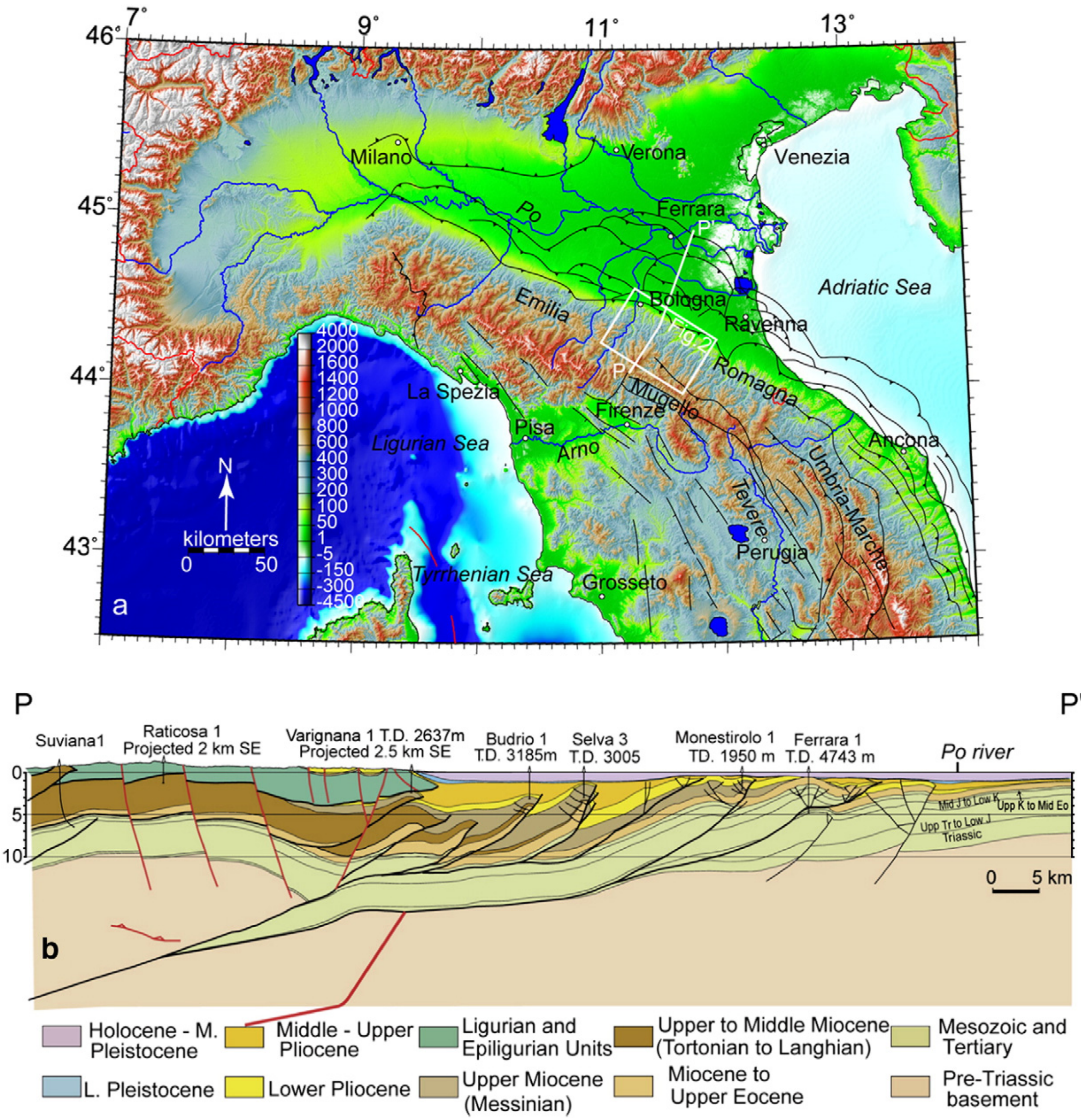

Fig. 1. a) Location of the studied area in the foothills of the Northern Apennines at the boundary between the extensional and the compressional realms. Note the track of the cross section PP′, and the location of Fig. 2 (white box). b) Cross section across the front of the Northern Apennines, showing the structural style of the frontal accretion, already inactive. The red faults represent the active features, normal faults at the surface and compressional structures in the middle crust (modified after Picotti and Pazzaglia, 2008). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

of the middle crustal thrust. The association of normal faulting on the crest of the anticlines is common (e.g. Morley, 2007) and it is due to the inversion of the local stress field in the outer arch of the fold.

Our goal is to provide a representative view of high angle, mostly normal faults in the foothills of the Northern Apennines around Bologna including documentation of their throw, strike lengths, and slip rates. These data are further explored to discuss the role of high angle faulting in shaping the Apennine landscape and the broader, formative underlying tectonic/geodynamic processes.

The most important data applied for our analysis is a geologic map synthesized from our observations and key published maps and reports (see Picotti and Pazzaglia, 2008 and reference therein), supplied with balanced cross sections, regional DEM-based topographic and river course analyses, aerial photography and satellite imagery. Also, offsets of surface of sedimentary recent deposits such as alluvial terraces have been utilized in identifying recent faults. We present a dataset of faults, some of which already known in literature, and discuss the data in terms of their structural development, their interaction with the other landscape-shaping processes such as rock-type resistance to erosion, and some of their implications for seismic hazards. Our data argue for the predominance of high angle normal faults embedded in the carapace of an actively shortening mountain range. Furthermore, we find that footwall blocks tend to have higher rates of watershed-averaged cosmogenically-measured erosion (Cyr and Granger, 2008) than directly adjacent hangingwall blocks.

2. Data

2.1. The S. Luca–Reno fault

The surface trace of the S. Luca–Reno fault develops 7 km with north–south trend. It is a normal fault that dips to the west and defines the eastern flank of the lower reach of the Reno River valley (Figs. 2