



Latest Pleistocene to Holocene thrust faulting paleoearthquakes at Monte Netto (Brescia, Italy): lessons learned from the Middle Ages seismic events in the Po Plain

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The seismicity of the Po Plain in Northern Italy is characterized by two strong Middle Ages earthquakes, the 1117, I° X MCS Verona, and the December 25, 1222, I° IX-X Brescia, events. Historical reports from these events describe relevant coseismic environmental effects, such as drainage changes, ground rupture and landslides. Due to the difficult interpretation of intensity data from such old seismic events, considerable uncertainty exists about their source parameters, and therefore about their causative tectonic structures. In a recent review, Stucchi et al. (2008) concluded that “the historical data do not significantly help to constrain the assessment of the seismogenic potential of the area, which remains one of the most unknown, although potentially dangerous, seismic areas of the Italian region”. This issue needs therefore to be addressed by using the archaeological and geological evidence of past earthquakes, that is, archeoseismology and paleoseismology. Earthquake damage to archaeological sites in the study area has been the subject of several recent papers. Here we focus on new paleoseismological evidence, and in particular on the first observation of Holocene paleoseismic surface faulting in the Po Plain identified at the Monte Netto site, located ca. 10 km S of Brescia, in the area where the highest damage from the Christmas 1222 earthquake have been recorded. Monte Netto is a small hill, ca. 30 m higher than the surrounding piedmont plain, which represent the top of a growing fault-related fold belonging to the Quaternary frontal sector of the Southern Alps; the causative deep structure is a N-verging back thrust, well imaged in the industrial seismic reflection profiles kindly made available by ENI E&P.

New trenching investigations have been conducted at the Cava Danesi of Monte Netto in October 2009, focused on the 1:10 scale analysis of the upper part of the 7 m high mid-Pleistocene to Holocene stratigraphic section exposed along the quarry walls. In particular, we excavated a 3 m deep trench across the graben that affects the crest of a decametric anticline due to paleoseismic bending-moment faulting; evidence of paleoseismicity is also provided by the observation of paleoliquefaction features near the graben. The trench walls allowed to identify 3 discrete events of graben reactivation, interpreted as generated by 3 strong paleoearthquakes. These paleoearthquakes occurred between ca. 45 kyr BP and ca. 5.5 kyr BP, based on OSL and AMS dating of stratigraphic units sampled on the main quarry walls, and mapped also in the October 2009 trench. The post 5.5 kyr BP stratigraphy is missing at the trench site, due to plowing and reworking.

The paleoseismic deformation observed at Monte Netto is suitable to constrain the magnitude of the causative earthquakes. At a local scale, the November 24, 2004, MI 5.2 Salò, earthquake, occurred ca. 40 km NE of Monte Netto, produced rockfalls and fractures in the Lake Garda shores, but no fault displacement at the surface. The only well known surface faulting earthquakes in the Southern Alps is the May 6, 1976, Ms 6.5 Friuli event; secondary surface ruptures were observed for a length of few km and with maximum offset of 20 cm. Using the global database of surface faulting events, the smallest thrust faulting earthquake known to be associated with secondary tectonic ruptures at the ground surface is the October 29, 1989, Mw 6.0 Mount Chenoua, Algeria, event. On the other hand, shallow crustal compressional earthquakes with $M > 7.0$ such as the 1980 El Asnam, 1988 Spitak, and 1999 Taiwan events are invariably associated with tens of km of primary tectonic scarps, with maximum surface

displacement of several meters. In the Monte Netto area there is no cumulative geomorphic evidence for repeated surface faulting events of this size.

Therefore, our best estimate of the Monte Netto paleoseismic magnitudes is in the range of M6.0 to 6.8, in good agreement with the macroseismically estimated magnitude of the Christmas 1222 event.

If this seismogenic potential is confirmed in the Brescia area, similar earthquake hazard should be associated to several Quaternary thrust and backthrust that have been mapped in the Lombardia and Ticino Southern Alps. In particular, Holocene reverse displacement recently observed near Como along the Gonfolite backthrust strongly suggests that tectonic structures capable of producing M6 to 6.8 earthquake may exist also in the region between Lake Como and Lake Maggiore.