SEISMIC REFLECTION STUDY OF THE SUBSURFACE GEOLOGY AND SEISMOGENIC FAULTS IN THE AREA INTERESTED BY THE 2016-2017 EARTHQUAKE SEQUENCE (CENTRAL ITALY)

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Introduction. On 24 August 2016, an earthquake of Mw 6.0 (Tinti *et al.*, 2016) struck a wide area of Central Italy, giving rise to a long seismic sequence, that included 9 earthquakes with Mw≥5 (Fig. 1). The Mw 6.0 earthquake caused heavy damage and resulted in about 300 fatalities and thousands of injured in the area of Amatrice town and surrounding villages (Galli *et al.*, 2016). After two months, on 30 October 2016, a Mw 6.5 earthquake nucleated at 8 km depth close to Norcia (Chiaraluce *et al.*, 2017), associated with impressive co-seismic ruptures along the Mt Vettore fault. The epicentral area affected by this long seismic sequence has a length of 60 km in the NNW-SSE direction (Fig. 1), in agreement with the focal mechanism of the mainshocks, suggesting the activation of complex NNW-SSE oriented normal fault system (Lavecchia *et al.*, 2016; Chiaraluce *et al.*, 2017; Pucci *et al.*, 2017). In particular, the hypocenter distribution allows to recognize three types of seismogenic structures: i) WSW-dipping master faults, also driving the onset and evolution of important Quaternary basins, such as Amatrice and Castelluccio basins; ii) antithetic (i.e. ENE dipping) normal faults, particularly evident in the Norcia-Mt. Vettore sector; and iii) a sub-horizontal (or gently east-dipping) cut-off seismicity layer, located between 10 and 12 km depths.

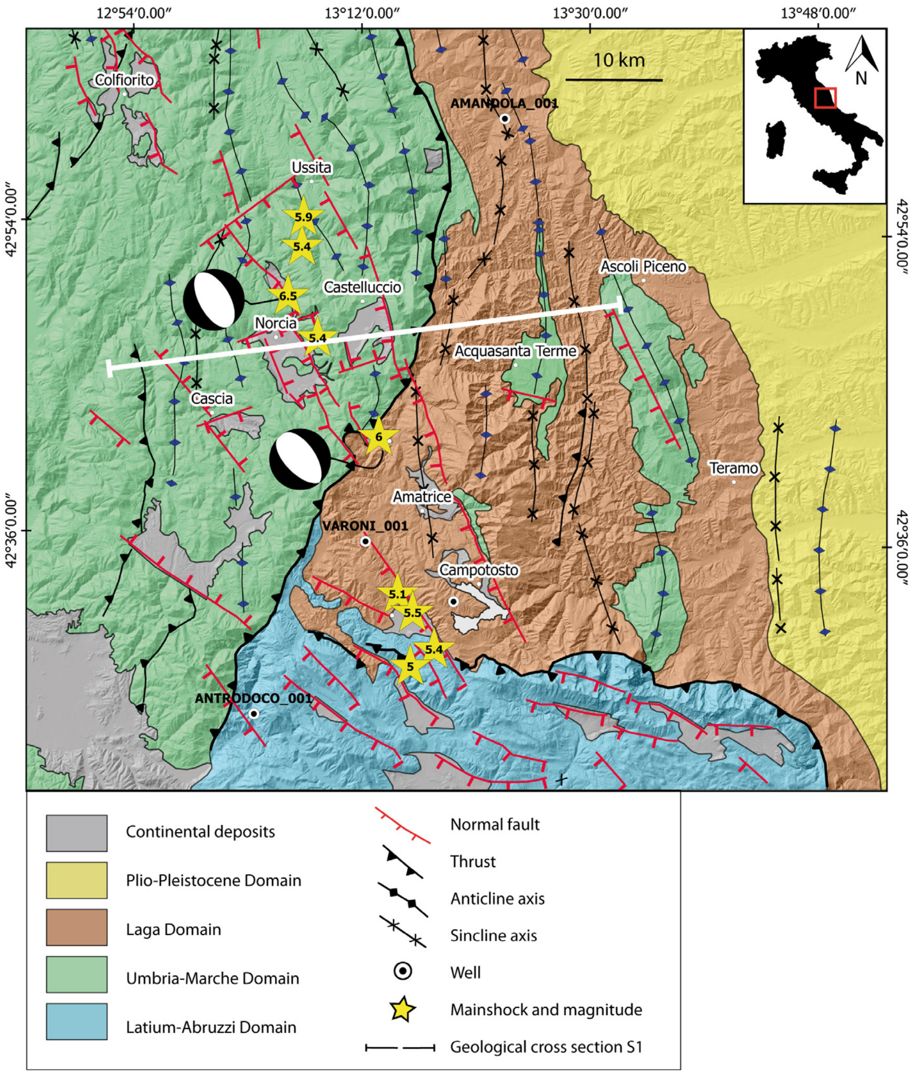

Fig. 1 - Structural sketch of the area affected by the 2016-2017 seismic crisis with the nine main shocks from 24 August 2016 to 30 January 2017 and the two focal mechanisms of the Mw 6.0 (24 August 2016) and Mw 6.5 (30 October 2017) mainshocks.

In this work, we try to clarify some of these aspects by means of geological interpretation of seismic reflection profiles. Though conceived for oil exploration, recent works have demonstrated that the use of seismic reflection profiles can help to unravel the depth geometry of the seismogenic faults as well as the rocks involved in the seismic ruptures. We present a deep geological reconstruction of the area interested by the Mw 6.5 event, along a 54 km long ENE-WSW section crossing the Norcia and Mt. Vettore seismogenic faults and the M. Sibillini thrust (Fig. 1). This section was constructed by means of integration of surface geology and subsurface data. The results of this work propose to give new insights on the subsurface structure of the area affected by the seismic sequence, focusing on:

- the along-dip geometry of the main faults activated during the 2016-2017 sequence;
- their relationships with pre-existing faults (thrusts, normal faults, transfer faults);
- the lithologies where the main shocks are nucleated.

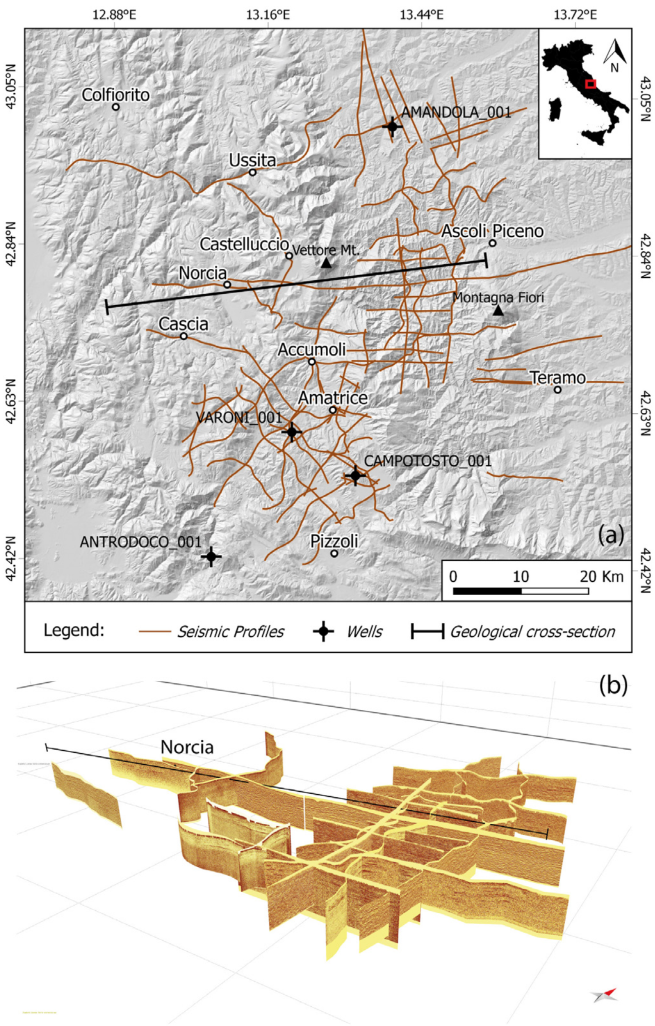

Fig. 2 - a) Location map of the seismic reflection profiles and wells used in this study; b) close-up of the seismic reflection profiles used to construct the geological cross-section (black line), organized into a 3D working project.

Methods and data. Inedited subsurface data are herein presented, consisting of a series of unpublished seismic reflection profiles and wells gathered for the study area. In this work, we use a new dataset of 2D seismic reflection profiles kindly provided by ENI s.p.a. The entire study area is therefore covered by integration of 97 seismic reflection profiles and 4 boreholes (Varoni, Campotosto, Antrodoco, Amandola) (Fig. 2a). The dataset encompasses a heterogeneous amount of stack and time-migrated seismic reflection lines characterized by a variable quality, due to several factors. We loaded and interpreted the entire dataset by using the Midland software MoveTM, accurately accounting for crooked paths and for datum time-shifts. Finally, we also included additional data encompassing geological sections and maps, a Digital Terrain Model (DTM) of the area and earthquakes hypocenters distribution from Chiaraluce *et al.* (2017) covering the period of interest (24 August 2016 - 30 December 2016). Such workflow enabled us to build an integrated pseudo-three-dimensional project of the study area (Fig. 2b), providing a novel and multidisciplinary working environment for the imaging of the geologic subsurface structures. In this work, we show a portion of the entire dataset, presenting a 2D subsurface model built up along one representative geological transect (Fig. 2b), intercepting the area struck by the mainshock Mw 6.5. The seismic profiles belonging to this ENE-WSW transect show subsurface structures down to a maximum depth of 5 s (twt), corresponding to 10–12 km, reconstructing a novel geological model across the Norcia-Mt.Vettore area (Fig. 1).

Results and conclusions. The results of this work provide constraints regarding some critical points discussed in literature for the central Apennines affected by the last 2016-2017 seismic sequence. The main features investigated are: the depth of the basement, the trajectory of the main thrust and normal faults, the role of the inherited structures on the seismogenic faults and the seismogenic layer involved into the seismicity.

The seismic signature of the main thrusts is not evident on the data, but the attitude of the deep reflectors within the tectonic units (top of carbonates and Marne a Fucoidi Fm.) indicates

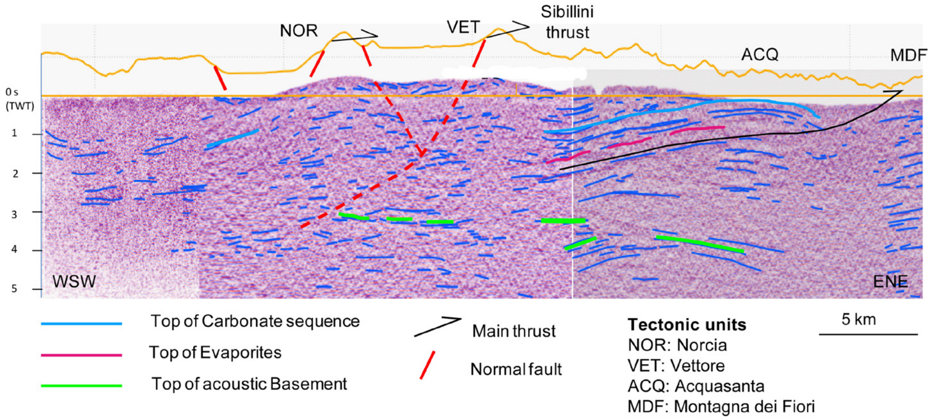

Fig. 3 - Composition of three seismic profiles and its geological interpretation across the S1 section.

that the thrust ramps dip at relatively low angle (<30°) (Fig. 3). The trajectory of the main active seismogenic faults has been reconstructed by combining reflection seismic and surface data: these faults are characterized by prevalent listric geometry, with dip angle of 60°-70° where they crop out (and where the coseismic ruptures were observed) and become progressively less steep at depth, as indicated by the focal mechanisms of the mainshocks and by the distribution of the aftershocks. In general, therefore, our reconstruction suggests that the seismogenic normal faults are significantly steeper than pre-existing thrusts.

In our seismic sections the top of the acoustic basement is marked by reflectors located between 3.2 and 4 s (Fig. 3), corresponding to about 8.5 – 11.5 km of depths. In the region of the 6.5 mainshock, this depth also corresponds to the seismicity cutoff. The correspondence between the top basement and the thickness of the seismogenic layer was already established in adjacent areas of the central Italy extensional seismic belt (Barchi and Mirabella, 2009). The depth and thickness of the seismogenic layer is lithologically controlled, since the seismicity is confined within the sedimentary cover and does not penetrate the underlying basement. The mainshocks are located close to the bottom of the seismogenic layer, within the Triassic evaporites. A sub-horizontal cut-off of seismicity is well recognized at the top of the basement, whereas only a few and low magnitude events are able to penetrate the substrate at depths higher than 12 km.

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