We analysed the seismic sequence that affects the Umbria-Marche Apennine (central Italy) since the August 2016, focusing on the \( M_w 6.5 \) Norcia earthquake, nucleated along the Mt. Vettore extensional fault on October 30, 2017. We investigate the ground deformation pattern and the source geometry responsible of the 2016 central Italy seismic sequence by joint exploiting the multisensors and multiorbits satellite measurements (i.e. ALOS 2; e.g. Cheloni et al., 2017) and their integration with the available geological/structural and seismological data. Starting from DInSAR (i.e. ALOS 2) and seismological data (i.e. hypocentral distribution and
available focal mechanisms), we computed the rock volumes involved during the earthquake nucleation process and delimited between the Mt. Vettore main fault and by an antithetic fault, as suggested by earthquakes hypocentral distribution. In particular, in this work we estimated both the collapsed rock volume and the consecutive uplifted rock volume. In fact, DInSAR results highlight two different ground deformation within the hangingwall block: a larger zone and a smaller area affected by significant subsidence phenomena and by uplift processes, respectively. The Amatrice-Norcia seismogenic area is inserted in the tectonic setting of the Umbria-Marche Apennine. The seismic sequence began with the $M_w$ 6.0 Amatrice earthquake, nucleated on August 24, 2016 along the Mt. Gorzano extensional fault (e.g., Lavecchia et al., 2016). Then, on October 26, two seismic events, occurred with $M_w$ 5.4 and $M_w$ 5.9 respectively, nucleated nearby Ussita and Visso (Chiaraluce et al., 2017), activating another major fault called the Mt. Vettore Fault System. Finally, on October 30 (at 06:40 UTC) the largest event of the sequence, with $M_w$ 6.5, occurred near the town of Norcia along the Mt. Vettore Fault System. At the moment, the seismic sequence is still active. The Mt. Gorzano Fault and the Mt. Vettore Fault System can be considered as the main seismically active extensional faults in the area and are associated to numerous historical and instrumental earthquakes which occurred in this area in the previous centuries (e.g., Galadini and Galli, 2003; Galli et al., 2008). The Mt. Gorzano Fault is a ~30 km long SW-dipping (~60-70°) active extensional fault (e.g., Galadini and Galli, 2003; Smeraglia et al., 2017) exposed in the Amatrice area along the foothills of Mt. Gorzano. The Mt. Vettore Fault System is a ~18 km long active fault system consisting of a series of SW-dipping (34-75°) extensional faults exposed on the flanks and along the foothills of Mt. Vettore, Mt. Porche, and Mt. Bove (e.g., Galadini and Galli, 2003).

Fig. 1 - a) Deformation map of the Norcia area, extracted by multi-temporal InSAR processing, showing both subsiding and uplifting areas. Associated cross-sections across the subsiding area showing ground subsidence pattern. b) Deformation map of the Norcia area, extracted by multi-temporal InSAR processing, showing both subsiding and uplifting areas. Associated cross-sections across the uplifting area showing ground uplift pattern.
To estimate the volumes involved in the earthquake processes and starting from the obtained interferograms, we created 104 for the subsidenced area (Fig. 1a) and 74 profiles for the uplifted zone (Fig. 1b). Applying the Cavalieri-Simpson method, we calculated the involved volumes. The subsidence and the uplift volumes are equal to $0.067 \text{ km}^3$ and $0.020 \text{ km}^3$, respectively. Therefore, our results highlight a mass deficit within the crustal volume involved during the earthquake.

We suggest that the volume loss at the surface (i.e., the subsidence) reflects a volume loss within the crustal volume at depth. In particular, deformation processes that can promote volume loss and inelastic (i.e., permanent) deformation within a rock mass are diffusion mass transfer (i.e., pressure solution) and/or plastic deformation (i.e., mineral recrystallization, grain boundary sliding) processes. These processes develop during deformation at low strain rates (i.e., during the interseismic phase) as shown by field evidence (e.g., Gratier et al., 2013) and laboratory simulations (e.g., Tesei et al., 2014). However, in our case, we observe a sudden volume loss in response to a high strain rate deformation (i.e., during the earthquake nucleation). Therefore, we propose that high strain rate inelastic processes must have occurred at depth to allow such volume loss. In particular, we suggest that the sudden closure of previously open fractures at depth can account for the observed volume loss (Fig. 2). These fractures could be localized within a fractured and dilated zone located antithetically respect to the main fault, as previously suggested by Doglioni et al. (2015) and Petricca et al. (2015) for the 2009 L’Aquila earthquake. In particular, according to the model proposed by Doglioni et al. (2015), when the stresses related to gravitational energy exceed the strength of the fractured and dilated zone the rock volume collapses slipping along the main fault and generating the earthquake.

References