The 2019-2020 repeated small swarms in the Benevento area, Southern Apennines, Italy

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Between November 2019 and November 2020, four seismic swarms occurred 7 km to the SW of the Benevento town in the Sannio region, which is one of the most seismic active areas in the Southern Apennines (Italy). These swarms were nearly collocated with the largest magnitude seismic event occurring on December 16, Mw3.9.

According to the Database Macrosismico Italiano, DBM15 (Locati et al., 2021) the seismic history of Benevento shows strong effects caused by several earthquakes that produced numerous causalities and severe damage, in particular the 1688 and 1702 earthquakes (local Intensity=9) and the 1456 earthquake (local Intensity=8.5). Significant local site effects also contributed to the high seismic hazard and controlled the distribution of the damages and casualties during the 1688 Mw6.7 destructive event (Improta et al., 2005; Di Giulio et al., 2008). Besides, detailed scenarios studies carried out in the framework of a multidisciplinary project coordinated by the National Group for Earthquakes Defence (GNDT; see Traiano Project, 2002) pointed to the very high vulnerability of the building heritage of the town that would experience widespread collapses in case of a future like-1688 earthquake.

In the last decades, the background seismicity of the Sannio area has occurred as sparse events or low magnitude swarms (in Fig. 1 we show the seismicity recorded by the Rete Sismica Nazionale, http://cnt.rm.ingv.it/ before November 2019): considering the recurrence time of large historical earthquakes, this region shows one of the highest seismogenic potentials of the Italian country. Of relevance, no background seismicity was recorded in the area located to the south of Benevento prior to 2019-2020, which therefore represents an evident seismic gap.

The 2019-2020 Benevento seismicity is composed of nearly 150 events with Ml ranging between 0.9 and 3.9 (8 earthquakes with M≥3.0, Tab. 1). We manually picked the first P- and S-wave arrival times, assigning a weighting factor inversely proportional to the uncertainty in the pick.

First, we locate earthquakes using a multi-parameter procedure (Ciaccio et al., 2021): to locate seismic events, we choose the linearized approach by Lahr,1999 (the Hypoellipse code), but exploring the hypocenter solutions space by changing three keys a priori conditions that typically strongly influence the solution convergence in the linearized approach: the starting trial depth, the weight function of arrival times with distance, and the travel time residual cut.

Then we computed relative locations by applying a double-difference technique (HypoDD; Waldhauser and Ellsworth, 2000), that minimizes the residuals between observed and theoretical travel time differences (or double differences) for pairs of earthquakes at each station.

We use a 1-D velocity model specifically defined for the area. The deterministic model is constrained for the first 4 Km by a sonic velocity log from a nearby oil exploration well, and for the deep part from previous tomographic studies (Improta et al., 2014).

The seismicity is distributed in map (Fig. 2-A, Fig. 3, different colors denote different clusters) in a relatively narrow WNW-ESE direction for a near 6 km-long distance and it shows a migration moving towards NW and SE over time. Fig. 2-B shows aftershocks projected onto the N30°-oriented section. The alignment of seismicity delineates a well-defined subvertical plane WNW-ESE oriented, between 7 and 18 km depth, with the strongest earthquakes occurring in the upper part of the section. Such a distribution is consistent with a right-lateral slip on a vertical plane as suggested from the focal mechanisms in Fig. 3, while the stress field in this region is generally ongoing through a NE–SW extension (Mariucci and Montone, 2020).

We estimated the focal mechanisms from the P-wave first-motion polarities using the FPFIT algorithm (Reasemberg and Oppenheimer, 1985). FPFIT is a grid search routine that searches for the double-couple fault plane solution that provides the best fit of a given set of first-motion polarities

observed for an earthquake. We decided to reject the earthquakes with less than six polarity readings and those mechanisms that had multiple solutions.
Based on the analysis of the nearby well and seismic reflection profiles, the 2019-2020 swarms were confined in the thrust-sheets of the Apulia Carbonate Platform and also involved the underlying Apulia crystalline basement. Our study shows the existence in the Benevento area of a WNW-ESE striking fault plane, or shear-zone, with a right-lateral strike-slip kinematics, quite different from the NW–SE-striking active normal faults responsible for moderate to large earthquakes (up to M7) in the Southern Apennines, as the fault systems cropping out in the nearby Matese and Irpinia regions. The fault structure activated during the 2019-2020 swarms measures 6 km along strike (at least) and it therefore represents a potential source of M>5 damaging earthquakes. With its WNW-ESE strike, this fault may represent a transverse strike-slip structure that separates NW-SE trending unknown major normal fault systems and accommodates differential extensional deformation.

N	*Date*	*Lat*	*Lon*	*Depth*	*M*
1	2019/11/25 10:27	41.060	14.749	9.516	3.2 (Ml)
2	2019/11/25 11:15	41.061	14.747	9.504	3.1 (Ml)
3	2019/12/16 08:06	41.061	14.742	11.445	3.6 (Mw)
4	2019/12/16 08:08	41.062	14.739	11.202	3.2 (Ml)
5	2019/12/16 08:52	41.074	14.721	8.046	3.0 (Ml)
6	2019/12/16 08:53	41.064	14.740	12.156	3.4 (Ml)
7	2019/12/16 10:36	41.067	14.740	10.740	3.9 (Mw)
8	2020/11/05 15:43	41.059	14.764	10.176	3.0 (Ml)

Table 1 List of the strongest earthquakes recorded

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Figure captions

Figure 1 Map of the main epicenters of the instrumental seismicity (gray circles) occurred from 1990 with magnitude M≥2.0, recorded before November 2019 (ISIDe Working Group); green squares show historical earthquakes, MCS I ≥ 8.0, from the CPTI (Rovida et al., 2021); orange polylines are surface traces of DISS Composite Seismogenic Sources (DISS Working Group, 2018); black box shows the study area.

Figure 2 A) Map view of Benevento area; the 2019-2020 epicentral locations are colored according to the legend. B) Vertical (N30◦E) cross sections of earthquake locations: hypocenters within ±0.5 km distance from the sections are projected. Stars show M≥3.0 earthquakes.

Figure 3 FPFIT focal mechanism solutions from this study.

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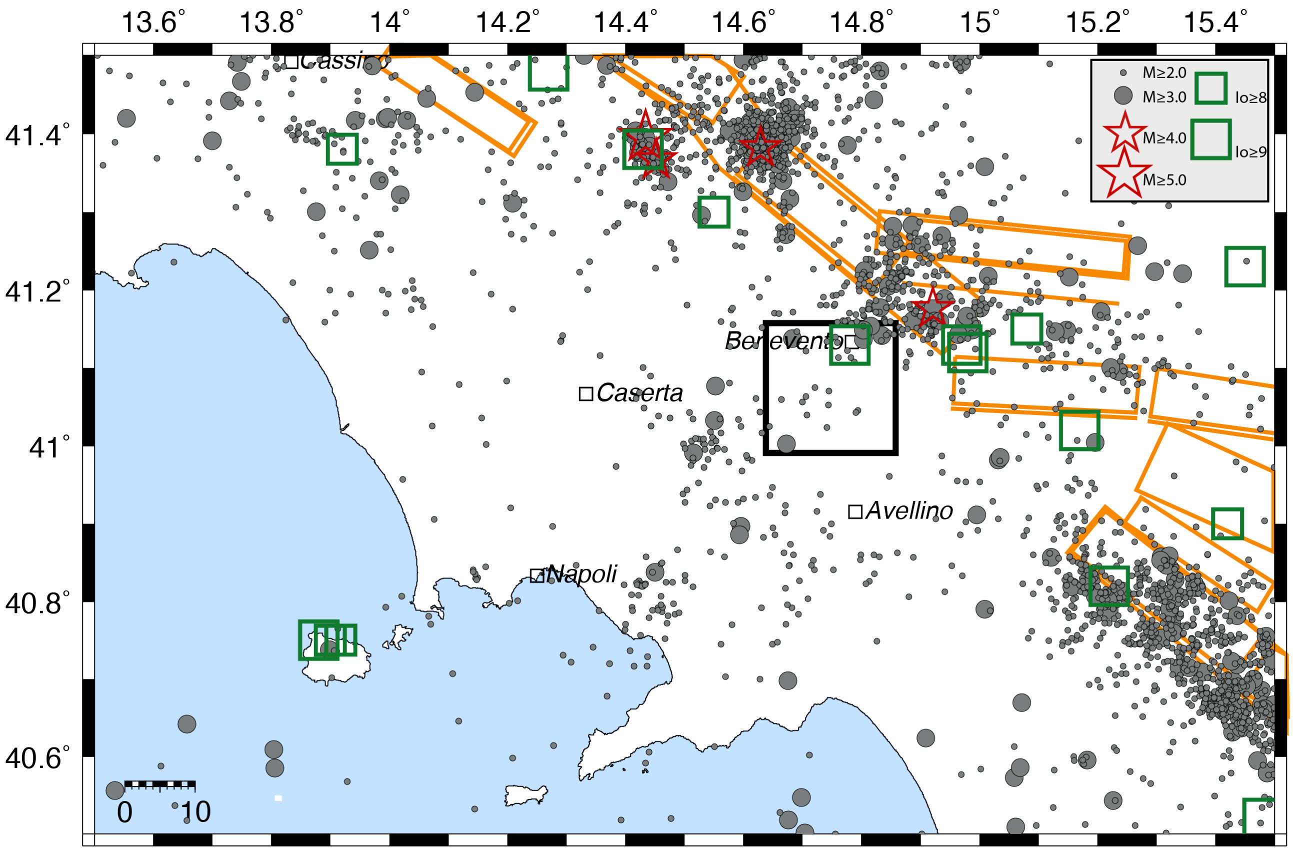


Figure 1

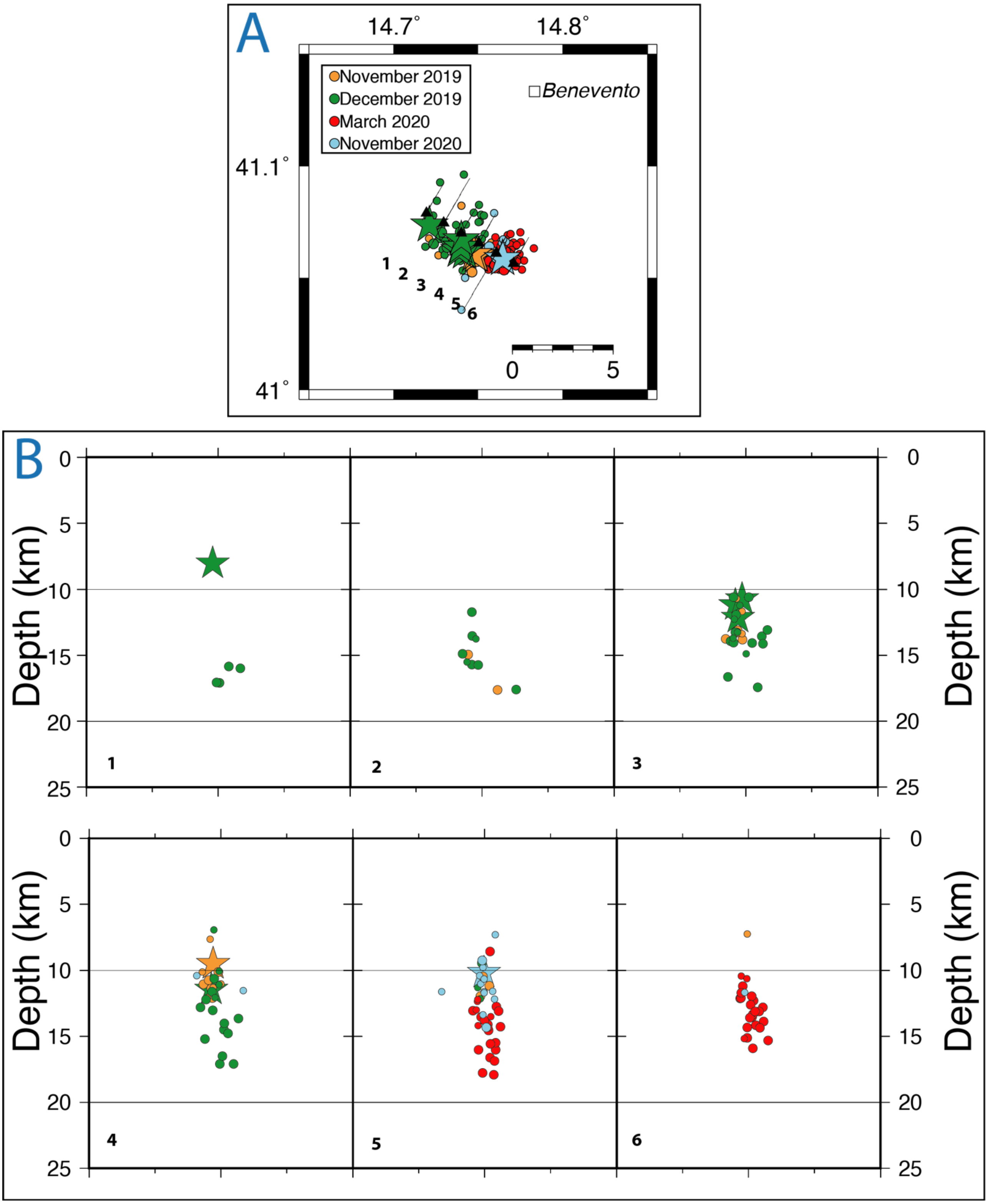
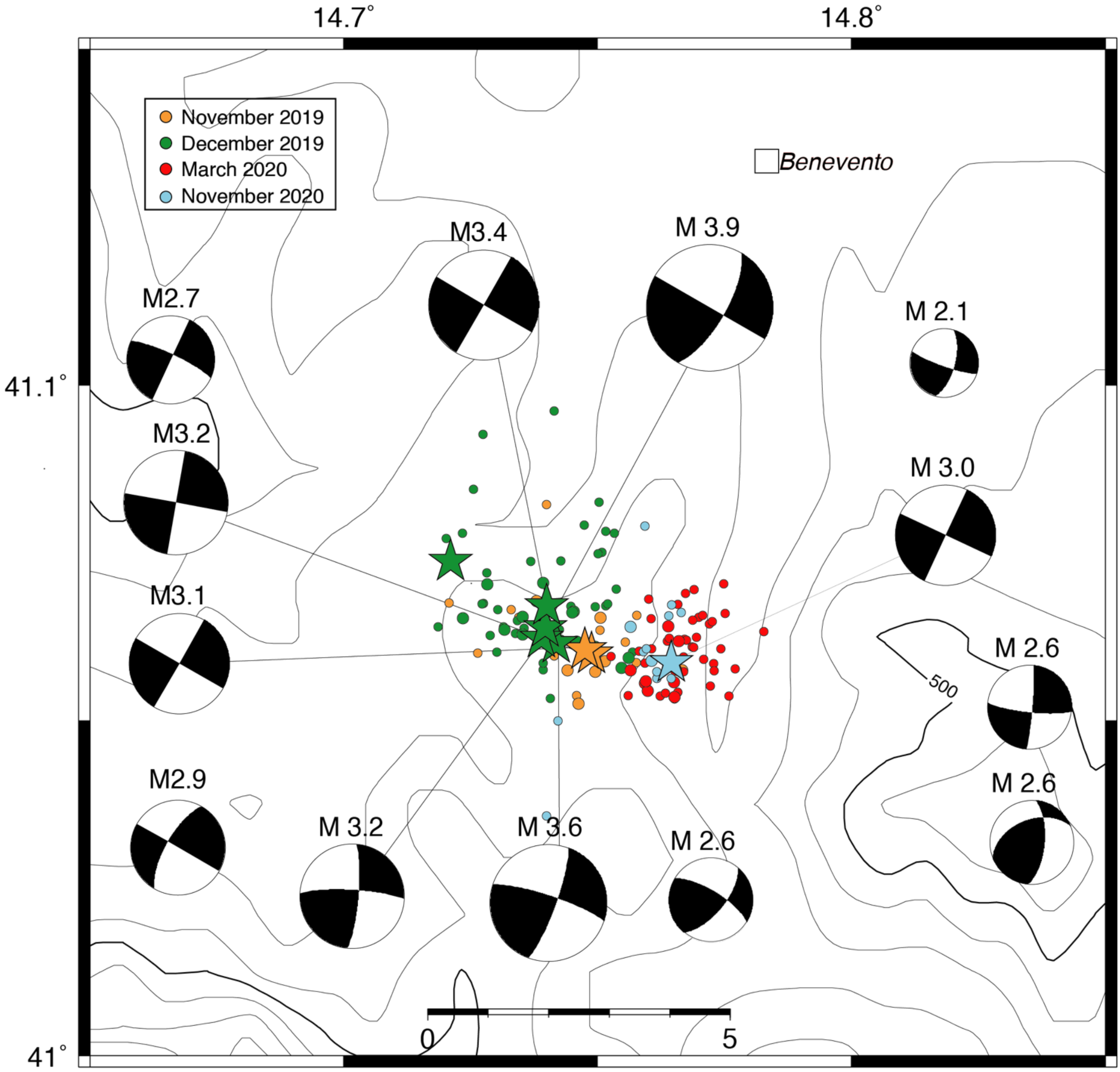

A
14.7°
14.8°
41.1°
41°
November 2019
December 2019
March 2020
November 2020
Benevento
1
2
3
4
5
6
0
5
B
Depth (km)
0
5
10
15
20
25
1
2
3
4
5
6

Figure 2



14.7°
14.8°
41.1°
41°
November 2019
December 2019
March 2020
November 2020
Benevento
M3.4
M 3.9
M2.7
M 2.1
M3.2
M 3.0
M3.1
M 2.6
500
M 2.6
M2.9
M 3.2
M 3.6
M 2.6
0
5

Figure 3